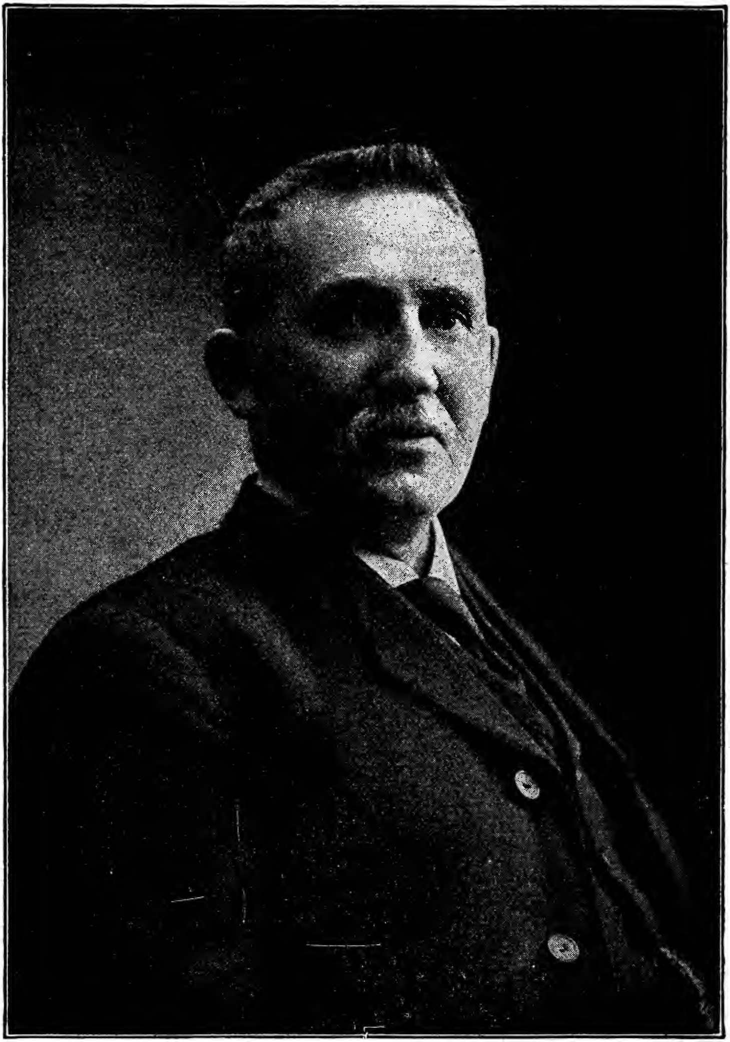

Yours Fraternally
Calvin F Swingle

TWENTIETH CENTURY HAND-BOOK
FOR
STEAM ENGINEERS AND ELECTRICIANS

WITH QUESTIONS AND ANSWERS

A PRACTICAL NONTECHNICAL TREATISE

On the Care and Management of Steam Engines, Boilers and Electric Machinery. With full instructions in Regard to the Intelligent Management of all Classes of Steam Engines, Steam Turbines, Gas Engines, Air Compressors and Elevators, both Electric and Hydraulic. ¶ The section on Electricity is of especial importance to all engineers. : : : : :

By CALVIN F. SWINGLE, M. E.

Author of "Encyclopedia of Engineering," "Examfnation Questions and Answers for Marine and Stationary Engineers," "Modern Locomotive Engineering," and "Modern Steam Boilers."

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INTRODUCTION.

Owing to the very generous reception accorded the first, and second editions of the 20th Century Hand Book for Steam Engineers; there having been over one hundred thousand copies sold, the author was urged to revise, and greatly enlarge the present edition, thus making it in a sense an encyclopedia of practical information, covering each department of work in which the stationary engineer is likely to be called upon to engage in the pursuit of his calling. In order to obtain a practical working knowledge of steam engineering it is absolutely necessary that the young man who desires to become a successful engineer should start in the boiler-room, that he should thoroughly familiarize himself with all of the details of boiler management, and while his hands and eyes are thus gradually being trained to the practical part of the work he should at the same time be training his mind in the theoretical part by reading and studying technical books and journals relative to steam engineering.

Without a doubt the most successful operating engineers are those who combine practice with theory, but the engineer in charge of a steam plant should, in addition to his other accomplishments, have at least sufficient technical knowledge to enable him to ascertain, by measurements and calculations, such very important points as the safe working pressure of his boiler, the most economical point of cut off for his engine, whether engine and boiler are properly proportioned for the work to be performed, and many other details requiring his attention.

In the following pages the author proposes to deal mai with the operation of steam engines, boilers, feed pumps, and all the necessary adjuncts of a steam plant, while at the same time considerable space will be devoted to the design, construction, and erection of steam machinery, Gas engines, Air compressors, and Elevators, both electric and hydraulic. In the compilation of the section on Electricity for engineers, special efforts have been put forth to adapt the discussion of this important subject to the needs of engineers, and electricians in charge of central stations; or isolated plants of smaller capacity. Within the past ten years there has been introduced a comparatively new prime mover, in the shape of the steam Turbine, and judging from present indications it has come to stay. Therefore it behooves engineers to make themselves acquainted with it, and the sooner they do so the more will they be benefited by the advent of this stranger. In these pages the author presents to his readers a plain practical description of each of the leading types of steam Turbines now in use, including an explanation of the principles controlling their action, together with rules and instructions for guidance in their operation. In order to facilitate the study of the different subjects treated upon, a series of practical questions and answers will follow the close of each section. And now with the hope that a study of the following pages may prove to be a help to all into whose hands this book may come, the author respectfully dedicates it to his fellow craftsmen, the engineers of America.

Calvin F. Swingle.

The Boiler

Stationary boilers may be divided into four different classes. The first and most simple type, and the one from which the others have gradually evolved, is the plain cylinder boiler in which the heated gases merely pass under the boiler, coming in contact only with the lower half of the shell and then pass to the stack. These boilers are generally of small diameter (about 30 in.) and great length (30 ft.).

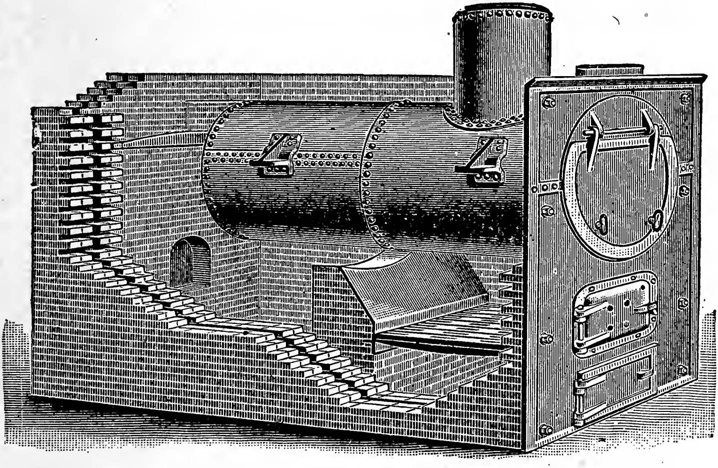


Fig. 1

RETURN TUBULAR BOILER—SHOWING SETTING

Next comes the flue cylindrical boiler, which is somewhat larger in diameter than the former, generally 40 in. diameter and 20 to 30 ft. long, with two large flues 12 to 14 in. diameter extending through it. The return tubular boiler,

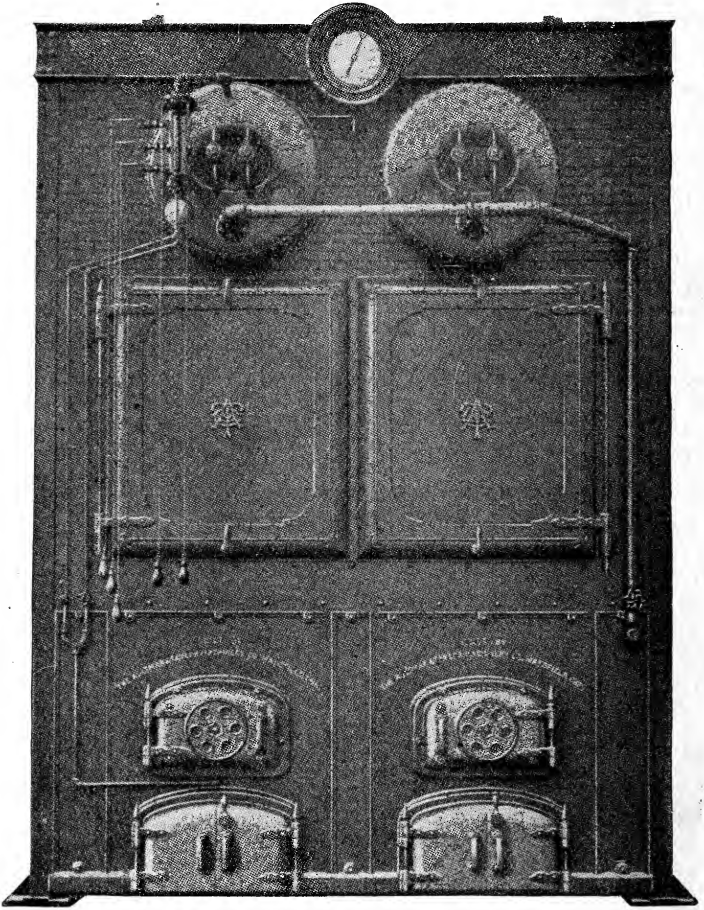


Fig. 2

FRONT VIEW OF 250 H. P. CAHALL HORIZONTAL BOILER

consisting of a shell with tubes of small diameter (2 to 4 in.) extending from head to head through which the hot gases from the furnace pass on their way to the stack. This boiler, which comes in the third class, is probably more extensively used in the United States for stationary service than any other type. The fourth class comprises the water tube boilers, in which the water is carried in tubes 3 to 4 in. in diameter, sometimes vertical and sometimes inclined, and connected at the top to one end of a steam drum, and having the lower ends of the tubes connected to a mud drum, which is also connected to the opposite end of the steam drum, thus providing for a free circulation of the water. Of the latter type there have been many different kinds evolved during the last one hundred years, the majority of them having had but a brief existence, being compelled to obey the inexorable law of the survival of the fittest, and to-day there are a few excellent types of water tube boilers which have become standard and are being extensively used. The margin of safety as regards disastrous explosions appears to be in favor of the water tube boiler. It is not contended that they are entirely exempt from the danger of explosion. On the contrary, the percentage of explosions of water tube boilers in proportion to the number in use is probably as large, if not larger, than it is with boilers of the shell or return tubular type, but the results are seldom so destructive of life or property, for the reason that if one or more of the tubes give way the pressure is released and the danger is past.

THE CAHALL WATER TUBE BOILER.

Figures 2 and 3 show, respectively, front and side views of the Cahall horizontal water tube boiler. These boilers are built in sizes of from 125 horsepower up to 850 horsepower, in single units. The boilers are built for working pressures of from 160 pounds per sq. in. up to 500 pounds per sq. in. The steam drums are made of the best open hearth flange steel, the heads for the drums being of the same material, hydraulically flanged. All the sheets are beveled on the edges, bent into shape, and the rivet holes drilled after bending. This insures absolutely round holes, without crystallization, and allows calking of all seams, both inside and outside. In boilers, the working pressure of which is not to exceed 160 lbs. to the sq. in., the longitudinal seams in the drums are double riveted. In those of higher working pressures, that is, from 160 to 500 lbs. per sq. in., all of the horizontal seams are butt and double strapped joints, with six rows of rivets. Each drum is provided at both ends with the Cahall patent swinging man-head. The

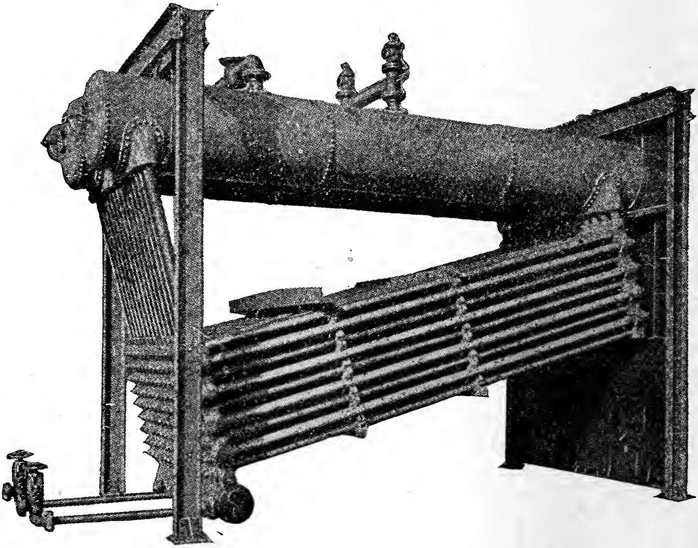


FIG. 3

SIDE VIEW OF 250 H. P. CAHALL HORIZONTAL BOILER SUSPENDED READY FOR BRICK WORK action of this man-head is as follows: By loosening the nuts, a slight push swings the head in similar to a door, and when it is desired to again close it, it is pulled back to its place, and, owing to its being hinged, the seats come together in exactly the same place every time, thus insuring a tight joint. The flanges on the steam drums for the steam and safety valve openings are all drop forged, from flanged steel plates. Referring to Figure 3, it will be noticed that each section of tubes is connected by nipples to saddles on the steam drums. These saddles or cross boxes are made from open hearth steel, which is melted and run into molds. This steel, after cooling and annealing, presents all the chemical and physical properties of regular boiler plate steel, physical tests on a large number of coupons from these forms showing an elongation of over 25 per cent, a reduction in area of over 50 per cent, with a tensile strength of over 60,000 lbs. to the square inch.

It can be seen from the side view of the boiler (Fig. 3) that it stands on wrought iron supports and cross beams, independent of the brickwork, so that the entire structure is free to contract and expand without any strains occurring either on the setting or on the boiler itself. In this method of suspension, the entire framework is outside of the brickwork, thereby avoiding the possibility of its burning away or weakening through over-heating, as has frequently happened in the case of other designs.

The fronts for the boiler are what is known as the wrought iron style—that is, the entire general framework of the front is made up of wrought iron or steel beams, channels and girders, and only the panels containing the door frames are cast. This permits of a very light but rigid structure, which it is impossible to crack from the application of in-

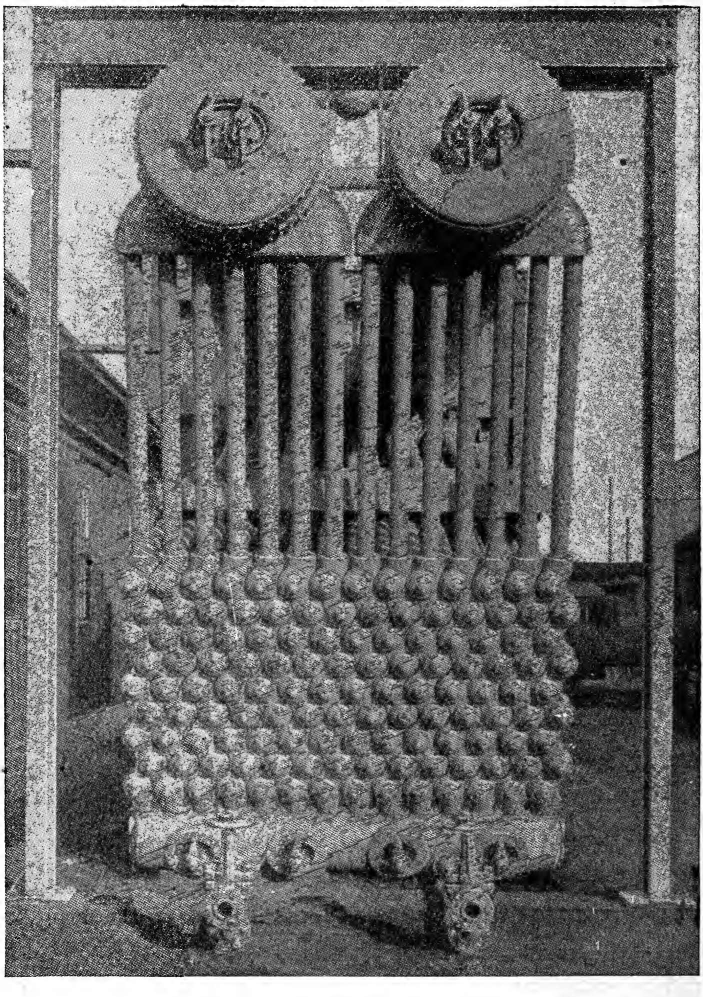


FIG. 4

REAR VIEW OF 250 H. P. CAHALL HORIZONTAL BOILER SUSPENDED READY FOR BRICK WORK ternal heat, which has been heretofore one of the greatest faults found with this type of boiler.

All the tubes used in this boiler are made of the best knobbled charcoal iron, which though very much more expensive than the standard iron boiler tube, yet repays the customer in future years for the additional investment in first cost. The general fittings and trimmings of the boiler are of the highest grade purchasable, the safety valves being of the solid nickel seated type. The water column used is either the Reliance or Pittsburg High and Low Water Alarm. The blow-off valves are specially made under patents owned by the Aultman & Taylor Machinery Co., and are so designed that the discs are renewable at any time, and both the disc and valve seat can be cleaned without taking the valve apart.

It will be noticed in the illustration (Fig. 4) giving the rear view of the boiler that these valves have two wheels, one directly above the other, the upper one being smaller than the lower. The larger wheel forces the disc down on its seat, the smaller wheel revolves the spindle carrying the disc. By revolving the larger wheel until the disc rests lightly on its seat and then revolving the smaller wheel, the disc is rotated on its seat, effectually clearing it of any obstructions that may have accumulated thereon.

The side cleaning doors for the boiler are of a new design, which permits the use of only one door instead of two, and when the door is opened it is thrown back entirely from the slot into which it fits, leaving a full, free opening for the introduction of the steam hose, and when the door is closed, wedge-shaped fire-brick tile, which line the door, are pushed forward in a straight line into the opening, making a perfectly smooth wall on the inside and an absolutely tight joint against the leakage of air into the setting.

Where very high pressures are to be used, say in excess of 225 pounds to the square inch, the headers or manifolds for the reception of the tubes are made of the same material used in the cross-boxes on the drums, viz., special "flowed" steel.

THE HEINE SAFETY BOILER.

Figure 5 shows a general view of the Heine water tube boiler.

The boiler is composed of the best lap welded wrought iron tubes, extending between and connecting the inside faces of two "water legs," which form the end connections between these tubes and a combined steam and water drum or "shell," placed above and parallel with them. (Boilers over 200 horsepower have two such shells.) These end chambers are of approximately rectangular shape, drawn in at top to fit the curvature of the shells. Each is composed of a *head plate* and a *tube sheet,* flanged all around and joined at bottom and sides by a butt strap of same material, strongly riveted to both. The water legs are further stayed by *hollow stay bolts* of hydraulic tubing, of large diameter, so placed that two stays support each tube, and hand hole and are subjected to only very slight strain. Being made of heavy metal, they form the strongest parts of the boiler and its natural supports. The WATER LEGS are joined to the shell by *flanged and riveted joints* and the drum is cut away at these two points to make connection with inside of water leg, the opening thus made being strengthened by bridges and special stays, so as to preserve the original strength.

THE SHELLS are cylinders with *heads dished* to form parts of a *true sphere.* The sphere is everywhere as strong as the circle seam of the cylinder which is well known to be twice as strong as its side seam. Therefore these heads require no stays. Both the cylinder and its spherical heads are therefore *free to follow* their *natural lines of expansion* when put under pressure. Where flat heads have to be braced to the sides of the shell, both suffer local distortions where the feet of the braces are riveted to them, making the calculations of their strength fallacious. To

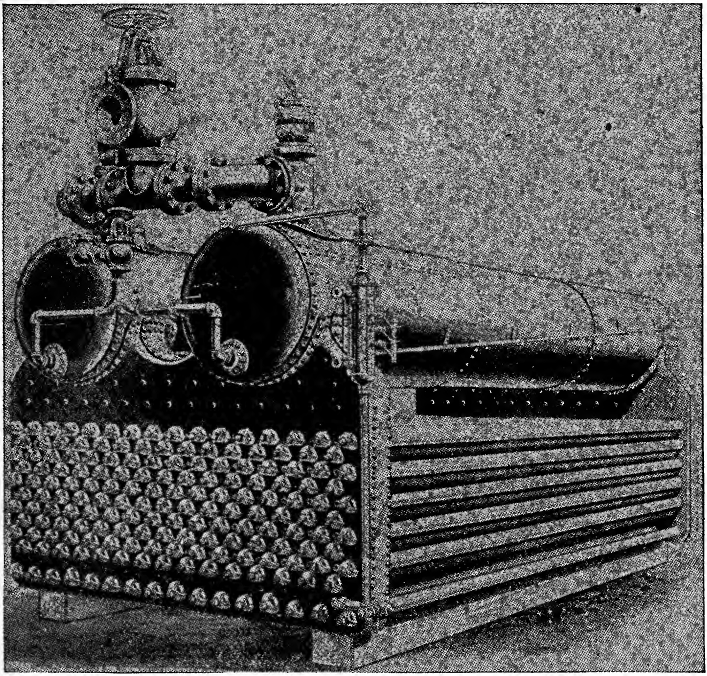


FIG. 5

375 H. P. HEINE BOILER

the bottom of the front head a flange is riveted into which the feed pipe is screwed. This pipe is shown in the cut with *angle valve* and *check valve* attached.

On top of shell near the front end is riveted a *steam nozzle* or saddle, to which is bolted a tee. This tee carries the *steam valve* on its branch, which is made to look either to front, rear, right or left; on its top the *safety valve* is placed. The saddle has an area equal to that of stop valve and safety valve combined. The rear head carries a *blow-off flange* of about the same size as the feed flange, and a *manhead* curved to fit the head, the manhole supported by a strengthening ring outside. On each side of the shell a square bar, the *tile-bar,* rests loosely in flat hooks riveted to the shell. This bar supports the *side tiles* whose other ends rest on the *side walls,* thus closing in the furnace or flue on top. The top of the tile bar is two inches below *low water line.* The bars rise from front to rear at the rate of one inch in twelve. When the boiler is set, they must be exactly level, the whole boiler being then on an incline, i. e., with a fall of one inch in twelve from front to rear.

It will be noted that this makes the height of the *steam space* in front about *two-thirds* the diameter of the shell, while at the rear the *water* occupies *two-thirds* of the shell, the whole contents of the drum being equally divided between steam and water.

THE TUBES extend through the tube sheets into which they are expanded with roller expanders; opposite the end of each and in the head plates is placed a hand hole of slightly larger diameter than the tube, and through which it may be withdrawn. These hand holes are closed by small cast iron hand hole plates, which can be easily removed for the purpose of cleaning or inspecting a tube. Figure

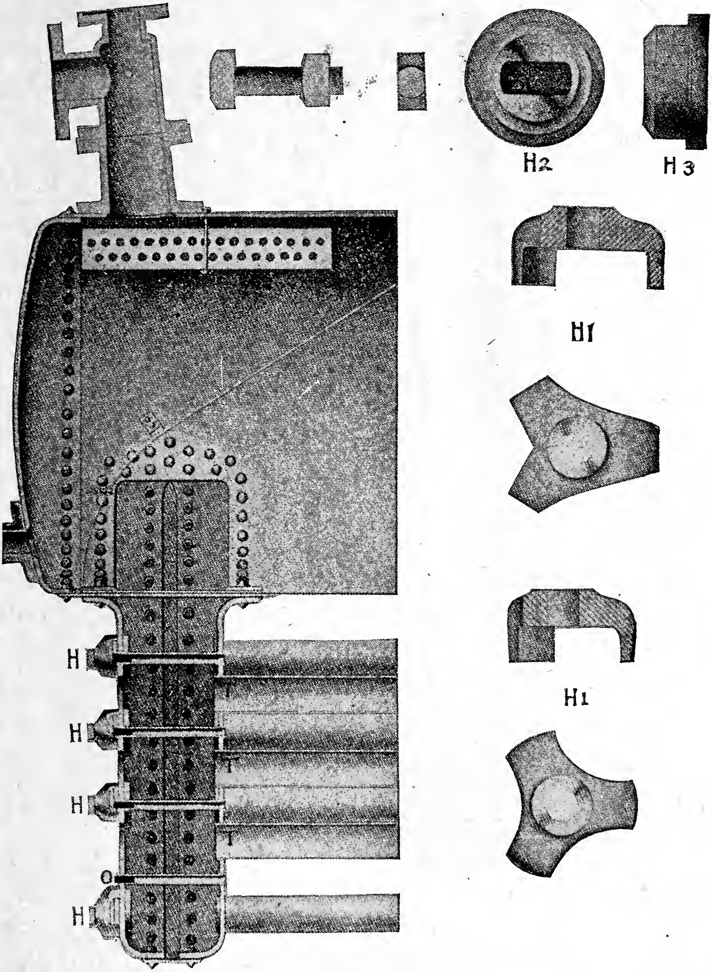


Fig. 6

DETAIL OF WATER-LEG, HAND HOLE PLATES AND YOKES, ETC., OF HEINE BOILERS

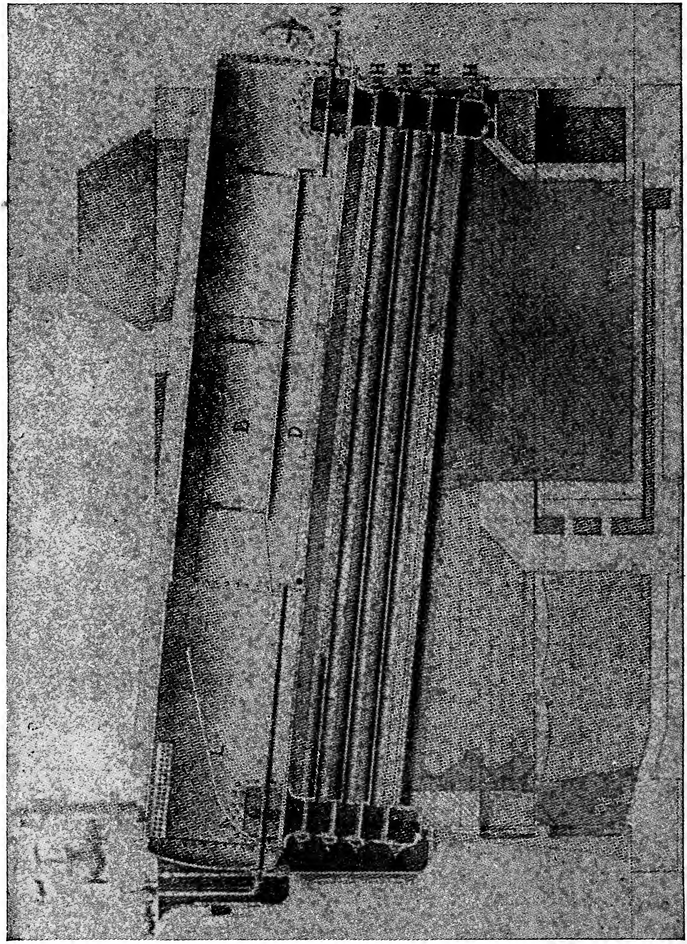


Fig. 7

SIDE SECTIONAL VIEW OF HEINE BOILER

6 shows these hand hole plates, marked H. In the upper corner one is shown in detail, H^2 being the top view, and

H^3 a side view, while H^1 is the yoke or crab placed outside to support the bolt and nut. Figure 7 is a longitudinal section showing inside construction. The mud drum D is located well below the water line, parallel to and three inches above the bottom of the shell. It is of oval section, slightly smaller than the manhole. It is entirely enclosed, except about eighteen inches of its upper portion at the front end, which is cut away nearly parallel with the water line. The mud drum D is made of strong sheet iron, with cast iron heads, and its action is as follows:

The feed water enters it through the pipe F about one-half inch above its bottom; even if it has previously passed the best heaters it is colder than the water in the boiler. Hence it drops to the bottom, and, impelled by the pump or injector, passes at a *greatly reduced speed* to the rear of the mud drum. As it is gradually heated to near boiler temperature it rises and flows slowly in reverse direction to the open front of the mud drum; here it passes over in *a thin sheet* and is immediately swept backward into the main body of water by the swift circulation, thus becoming *thoroughly mixed* with it before it reaches the tubes. During this process the mud, lime, salts, and other precipitates are deposited as a sort of semi-fluid "sludge" near the rear end of the mud drum, whence it is blown off at frequent intervals through the blow-off valve N. As the speed in the mud drum is only about one-fiftieth of that in the feed water pipe, plenty of time is given for this action. Any precipitates which may escape the mud drum at first, will of course form a scale on the inside of the tubes, etc. But the action of expansion and contraction cracks off scale on the *inside* of a tube *much faster* than on the *outside,* and then the circulation sweeps the small chips, like broken egg-shells, upward, and as they pass over the mouth of the mud drum *they drop in the eddy,* lose velocity in this slow current and fall to the bottom, and, being pushed by the feed current to the rear end, are blown off from the mud drum with other refuse. On opening a Heine boiler after some months' service, such bits of scale, whose shape identifies them, are always found in the mud of the mud drum. *Very little loose scale* is found on the bottom of the water legs; the current through the lower tubes, always the swiftest, brushes too near the bottom to allow much to lodge there.

This explanation of the action of the mud drum shows how *the inside of the tubes may be kept clean.* To keep the *outside clear of soot and ashes* which deposit on, and sometimes even bake fast to the tubes, each boiler is provided with two special nozzles, with both side and front outlets, a short one for the rear, a long one for the front. They are of three-eighth inch gas pipe and each is supplied with steam by a one-half inch steam hose. The nozzle is passed through each stay bolt in turn, and thus delivers its side jets on the three or four tubes adjacent, with the full force of the steam, at the short range of two inches, *knocking the soot and ashes* off completely, while the end jet carries them into the main draft current, to lodge at points in breeching or chimney base convenient for their ultimate removal. An inspection of the cuts will show that the stay bolts are so located that the nozzle can in turn be brought to bear on all sides of the tubes. As soon as the nozzle is withdrawn from the stay bolt this is closed airtight by a plain wooden plug.

In cleaning a boiler it is only necessary to *remove every fourth or fifth handhole plate* in the front water leg; the water hose, supplied with a short nozzle, can be entered in all the adjacent tubes, owing to the ample dimensions of the water leg. In the rear water leg only one or two handholes in the lower row need be opened to let the water and debris escape. The others in rear water leg are frequently *left untouched for years.* A lamp or candle hung on a wire through the manhead may be held opposite each tube so that it can be perfectly inspected from the front.

The feed pipe F enters the mud drum through a loose joint in front, and the blow-off pipe N is screwed tightly into its rear head, passing by a steam-tight joint through the rear head of the shell. Just under the steam nozzle is placed a dry pipe A. L is a deflection plate, extending from the front of the shell, and inclined upwards, beyond the mouth of the front water leg. The throat or mouth of each water leg is large, to equal in area the total tube area, and where it joins the shell it increases gradually in width by double the radius of the flange. In the setting, the front water leg is placed firmly on a set of strong cast iron columns, bolted and braced together by the door frames, dead plate, etc., forming the fire front. This is the fixed end. The rear water leg rests on rollers, free to move on cast iron plates set in the lower masonry of the rear wall. The brick work does not close in entirely to the boiler, the space between being filled with tow or waste saturated with fire clay or other refractory, but pliable material, thus leaving the boiler and its walls each free to move separately during expansion or contraction, without disturbing any joints in the masonry. On the lower, and between the upper tubes, are placed light fire brick tiles. The lower tier extends from the front water leg to within a few feet of the rear one, leaving there an upward passage across the rear ends of the tubes for the flame and gases. The upper tier closes into the rear water leg, and extends forward to within a few feet of the front one, thus leaving an opening for the gases in front. The side tiles extend from the side walls to tile bars, and close up to the front water leg, and front wall, and leave open the final uptake for the waste gases over the back part of the shell, which is here covered above the water line with a row of lock fire brick, resting on the tile bars. The rear wall, and one parallel to it, are arched over the shell a few feet forward, and form the uptakes.

THE BABCOCK & WILCOX WATER TUBE BOILER.

Description. Figure 8 presents a side view of the Babcock & Wilcox boiler, and Figure 9 a partial section.

This boiler is composed of lap-welded wrought iron tubes, placed in an inclined position and connected with each other, and with a horizontal steam and water drum, by vertical passages at each end, while a mud-drum is connected to the rear and lowest point in the boiler.

The end connections are in one piece for each vertical row of tubes, and are of such form that the tubes are "staggered" (or so placed that each row comes over the spaces in the previous row). The holes are accurately sized, made tapering, and the tubes fixed therein by an expander. The sections thus formed are connected with the drum, and with the mud-drum also by short tubes expanded into bored holes, doing away with all bolts, and leaving a clear passageway between the several parts. The openings for cleaning opposite the end of each tube are closed by handhole plates, the joints of which are made in the most thorough manner, by milling the surfaces to accurate metallic

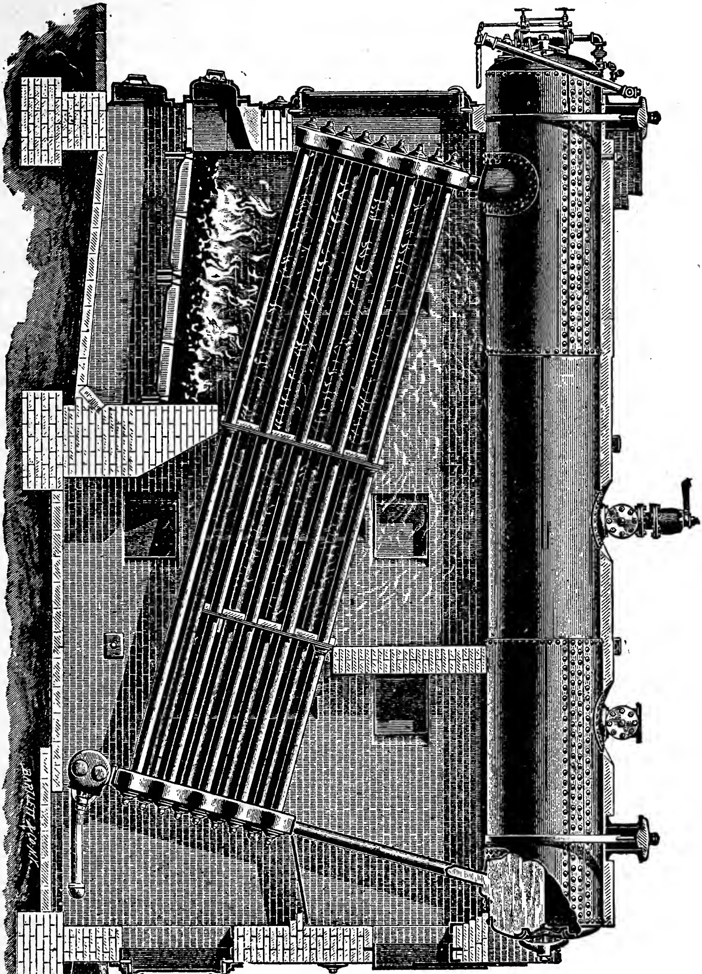


Fig. 8

SIDE VIEW OF BABCOCK & WILCOX BOILER OF WROUGHT STEEL CONSTRUCTION contact, and are held in place by wrought-iron forged clamps and bolts. They are tested and made tight under a hydrostatic pressure of 300 pounds per square inch, *iron to iron, and without rubber packing or other perishable substances.*

The steam and water drums are made of flange iron or steel, of extra thickness, and double riveted. They can be made for any desired pressure, and are always tested at 50 per cent above the pressure for which they are constructed. The mud-drums are of cast iron, as the best material to withstand corrosion, and are provided with ample means for cleaning.

Erection. In erecting this boiler, it is suspended entirely independent of the brickwork, from wrought iron girders resting on iron columns. This avoids any straining of the boiler from unequal expansion between it and its enclosing walls, and permits the brickwork to be repaired or removed, if necessary, without in any way disturbing the boiler. All the fixtures are extra heavy and of neat designs.

Operation. The fire is made under the front and higher end of the tubes, and the products of the combustion pass up between the tubes into a combustion chamber under the steam and water drum; from thence they pass down between the tubes, then once more up through the spaces between the tubes, and off to the chimney. The water inside the tubes, as it is heated, tends to rise towards the higher end, and as it is converted into steam—the mingled column of steam and water being of less specific gravity than the solid water at the back end of the boiler—rises through the vertical passages into the drum above the tubes, where the steam separates from the water and the latter flows back to the rear and down again through the tubes in a con-

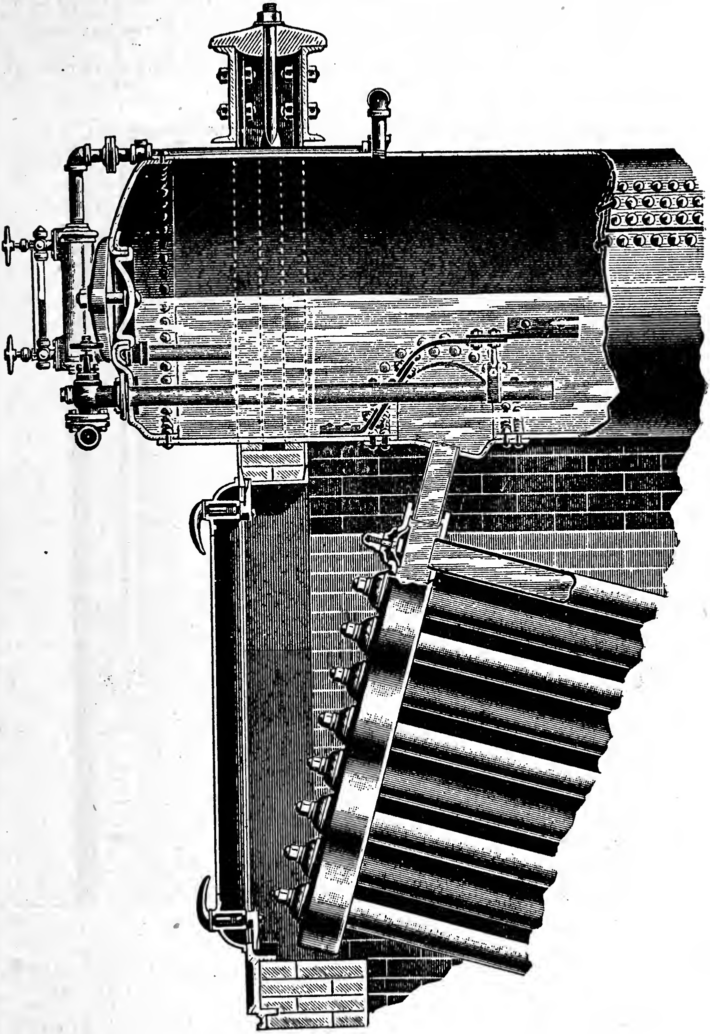


FIG. 9
PARTIAL VERTICAL SECTION BABCOCK & WILCOX BOILER

tinuous circulation. As the passages are all large and free, this circulation is very rapid, sweeping away the steam as fast as formed, and supplying its place with water; absorbing the heat of the fire to the best advantage; causing a thorough commingling of the water throughout the boiler and a consequent equal temperature, and pre-

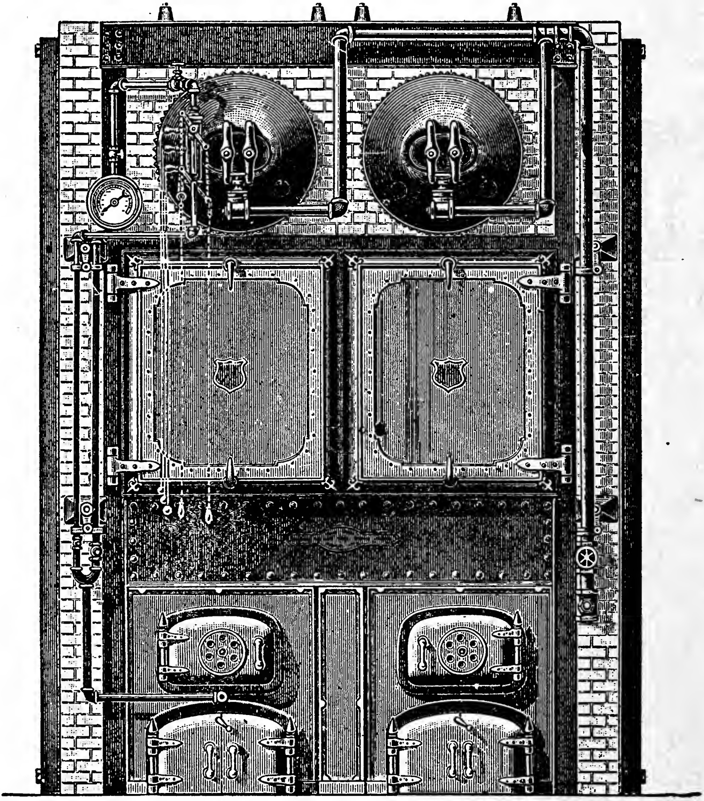


FIG. 10

STANDARD FRONT OF BABCOCK & WILCOX BOILER venting, to a great degree, the formation of deposits or incrustations upon the heating surfaces, sweeping them away and depositing them in the mud-drum, whence they are blown out.

The steam is taken out at the top of the steam-drum near the back end of the boiler after it has thoroughly separated from the water, and to insure dry steam, a perforated dry-pipe is connected to the nozzle inside the drum.

THE STIRLING WATER-TUBE SAFETY BOILER.

The Stirling boiler, Figures 11 and 12, consists of three upper or steam drums, each connected by a number of tubes (called a "bank") to a lower or mud drum. Suitably disposed fire tile baffles between the banks direct the gases into their proper course. Shorter tubes connect the steam spaces of all upper drums, also water spaces of front, and middle drums. The boiler is supported on a structural steel framework, around which is built a brick setting, whose only office is to provide furnace space, and serve as a housing to confine the heat. The entire front is of metal of appropriate and artistic design. These parts, together with the usual valves and fittings, constitute the completed boiler, which represents the acme of simplicity and eliminates the complication of the older types.

The drums vary from 36 to 54 inches in diameter and are made of the best open hearth flange steel. The plates extend the entire distance between heads, hence there are no *circular seams.* The longitudinal seams—which are double or triple riveted according to the working pressure to be carried—are so placed that they are not exposed to high temperature. The drum heads are hydraulically dished to proper radius; each drum is provided with one manhole, and the manhole plate and arch bars are of wrought steel; four manhole plates, which can be removed in ten minutes, give access to the entire interior of the boiler, and expose every tube end, rivet and joint. The drum interiors are perfectly clear; there are no baffles, stays, tie-rods, mud pipes or other obstructions in them.

The tubes are best lap-welded mild steel. They are slightly curved at the ends to permit them to enter the drums normally and to provide for free expansion of the boiler when at work. The tubes are expanded directly into reamed holes in tube sheets of the drums, hence the annular recess between tubes and the cast headers of some types of boiler is eliminated, and failure of tubes by pitting through corrosion, caused by accumulation of soot in these recesses, is avoided. There are no short nipples and no tube joints in places which can be reached only by jointed handles on the tube expander, rendering it impossible to determine when the tube has been properly expanded. In the Stirling boiler every tube end is visible and accessible. As the entire weight of boiler and contents is supported on the steel frame work, cracking of the setting, due to unequal settlements, is obviated, and no blocking is needed when the brick work has to be repaired. The design of frame work can be modified to suit special conditions. The brick setting is so clearly shown in Figures 11 and 12 that an extended description is unnecessary. No special shapes or other material not found in open market are needed. Any necessary repairs to the brick work can be made without disturbing the boiler connections. In the design of the Stirling furnace it will be seen by reference to Figures 11 and 12, that a fire brick arch is sprung over the grates, and immediately in front of the first bank of tubes. The

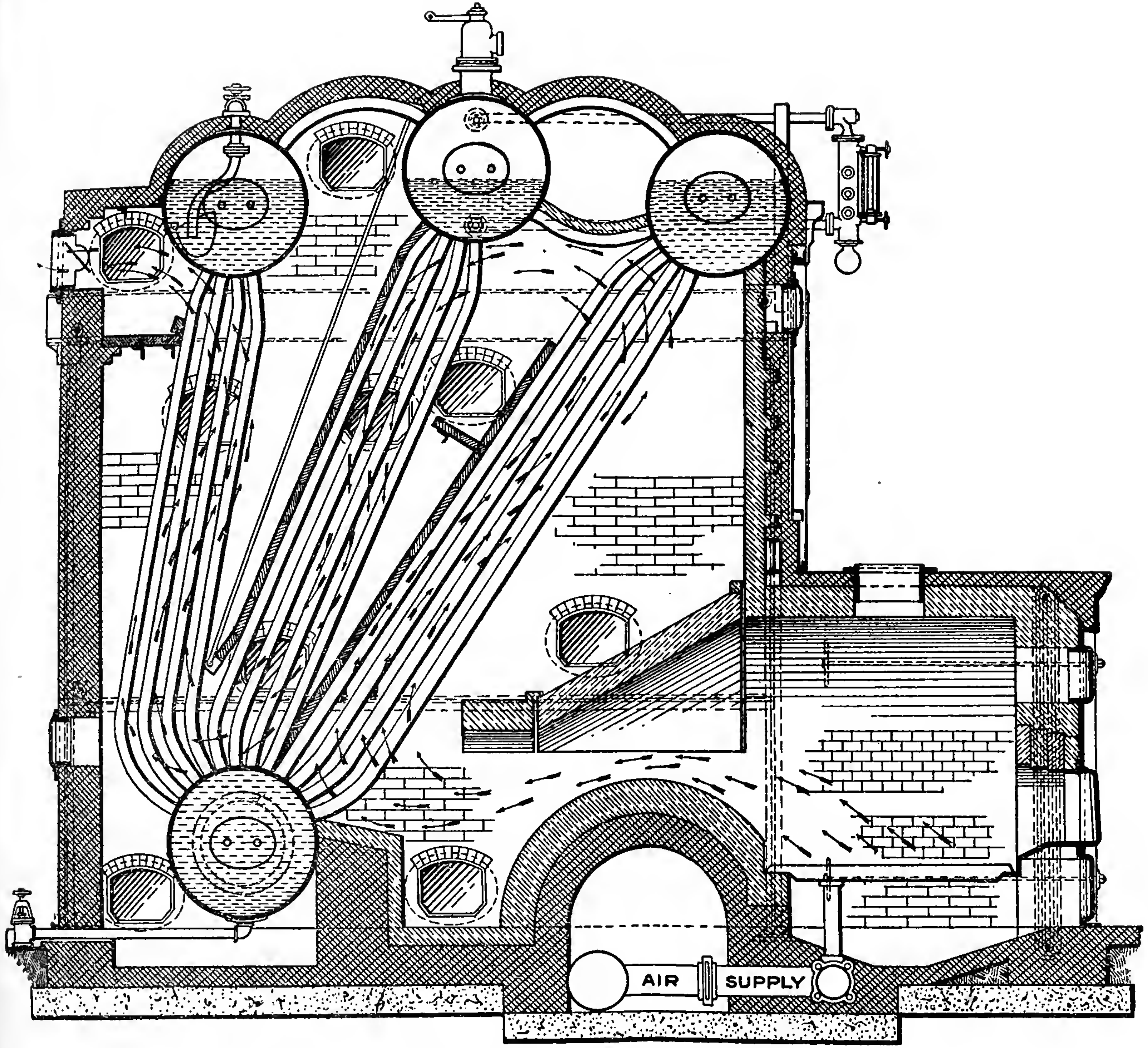


FIG. 11
SECTIONAL SIDE ELEVATION OF THE STIRLING BOILER AND BAGASSE FURNACE.

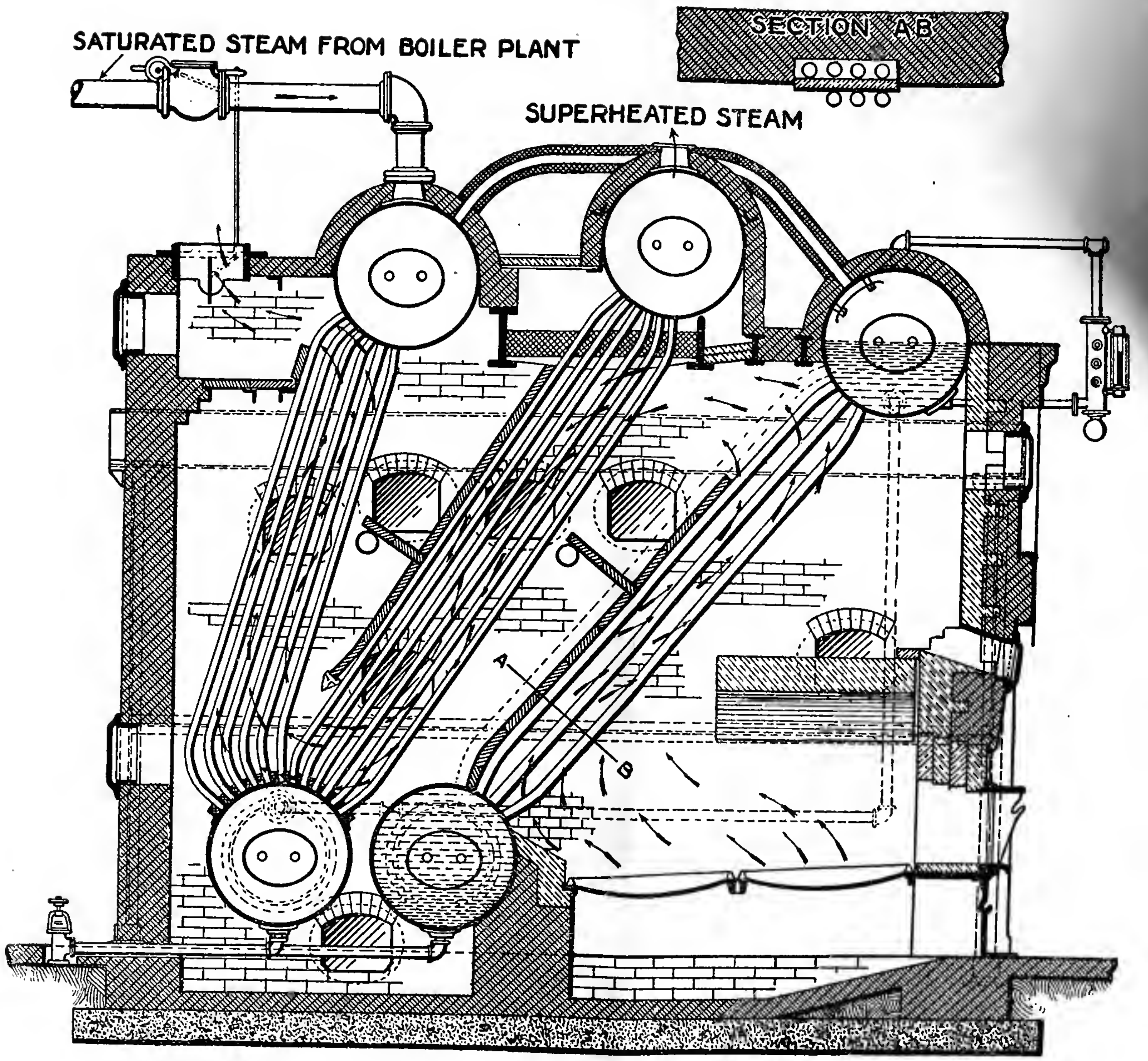


FIG. 12
SECTIONAL SIDE ELEVATION OF THE STIRLING INDEPENDENTLY FIRED SUPERHEATER.

large triangular space between boiler front, tubes and mud drum is available for a combustion chamber, and for installation of sufficient grate surface to meet the requirements of the lowest grades of fuel.

Baffles and Course of Gases. The baffle walls rest directly upon the tubes, and guide the course of the gases up the front bank, down the middle and up the rear bank, thus bringing them into such intimate contact with the boiler surface that the heat is quickly and thoroughly extracted from them. In no other boiler are the gases compelled to travel as far before reaching the stack, and the effect upon economy is evident. The baffles are made of plain rectangular firetile carried in stock by all fire-brick dealers, in contrast to the special formed bricks (obtainable only from the manufacturer) required by many types

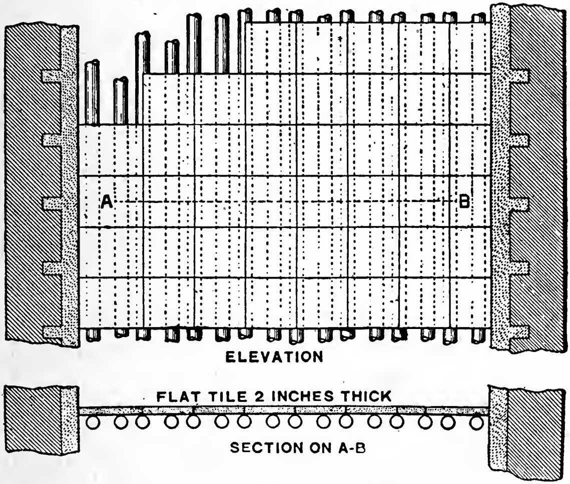


FIG. 13

ELEVATION AND SECTION OF FIRETILE BAFFLES IN STIRLING BOILERS of water-tube boiler. Another marked advantage of the Stirling baffles is that since no tubes pass *between* or through the tiles (see Fig. 13), they are not pried apart and made leaky by distorted tubes; they can be removed and replaced without disturbing a tube. Baffles built across the tubes, as in many boilers, are damaged by pulling a faulty tube through them, and can be repaired in but one way—by removal of every tube necessary to permit a man to crawl in and reach the defective spot.

Simplicity. There are no details of complicated shape; no flat surfaces, tie-rods, water-legs, headers, return-bends, outside circulating pipes to plug up; no multitudinous handhole plates to be removed and packed with gaskets, or to be ground and scraped to a fit whenever boiler is opened; no baffles or mud pipes in the drums; no short nipples, seams exposed to heat, or parts inaccessible for cleaning.

Expansion and Contraction. In the Stirling, the mud drum is not embedded in brickwork, but is suspended on the tubes which connect it with the upper drums.

In consequence of this construction, not only may the mud drum with perfect freedom move an amount representing the resultant expansion of the boiler, but any difference in expansion between the individual tubes, such as caused when one side of the furnace is being cleaned and other side is excessively hot, is taken up by the curve in the tube. The boiler therefore stays tight, and is entirely free from the stresses and frequent leaks caused by unequal expansion of straight tubes rigidly connected at each end to headers, water-legs, or large drums. It will thus be seen that the bent tube performs in the boiler the same function as an expansion loop in a steam line.

Rapid Circulation. The path of the circulation in the Stirling is as follows: The water is fed into upper rear drum, passes down the rear bank of tubes to the lower drum, thence up the front bank to forward steam drum. Here the steam formed during passage up the front bank disengages and passes through the upper row of cross tubes into the middle drum, while the *solid water* passes through the lower cross tubes into middle drum, then down the middle bank to the lower drum, from which it is again drawn up the front bank to retrace its former course until it is finally evaporated. The steam generated in the rear bank passes through cross tubes to the center drum.

The temperature of gases in contact with the tubes will evidently be greatest at the bottom of the front bank, and gradually decreases as the gases proceed along their course to the breeching. Obviously then the velocity of water circulation and quantity of steam generated will be a maximum in the front bank; in the rear bank there is a slow circulation downward equal to the quantity of water evaporated in the other two banks.

Rapid circulation is essential for the following reasons:

(1) To keep all parts of the boiler at practically the same temperature, thus eliminating severe stresses due to unequal expansion.

(2) To permit quick raising of steam and rapid response to sudden demands on the boiler capacity.

(3) To sweep away from the heating surfaces all steam bubbles as fast as formed, and thereby prevent "steam pockets," which quickly burn out the tubes. This is so particularly the case where intense local heating occurs due to use of gas or oil fuel, that some types of boiler fairly well adapted to coal cannot be successfully used with these fuels.

The third requirement is met only indifferently or, not at all in those types of boilers in which tubes often numbering as many as eighteen must discharge their entire content of steam and water through a narrow water-leg, or, worse still, through a single nipple whose cross section is equal to that of but one tube. At 150 pounds' gauge one cubic foot of water, when converted into steam, will have a volume of about 151 cubic feet. In consequence of this great increase in volume, as soon as the boiler is forced, the nipple area becomes insufficient, steam pockets form in the lower tubes, which then become overheated, and buckle and leak, and finally burn out. So inadequate are these nipples and headers that recent experiments of M. Brull have shown that in boilers whose circulation is constricted by nipples or narrow water-legs, the circulation in the upper tubes *reverses,* that is, it goes from the front to rear instead of in the opposite way, as intended. In consequence of this, much matter suspended in the water is swept into the bottom tubes, which fact, in connection with the steam pockets, explains why those tubes so rapidly fail.

In the Stirling boiler there is *no constriction of the circulation,* as each tube discharges directly into the drums, without intervention of headers, nipples or water-legs. The nearly vertical position of the tubes also promotes rapid circulation, hence steam pockets cannot form, and a fruitful cause of interrupted service and tube renewals is thus eliminated.

A most fruitful cause of burnt tubes is a piece of scale which becomes detached and falls on the bottom of the tube, and the spot under it is certain to burn out quickly. The Stirling is free from this source of tube destruction, because while the scale will not form in the hotter tubes unless the boiler is neglected, even if it does form owing to such neglect and a piece becomes detached, it will slide down to the mud drum instead of lodging.

Cleaning the Interior. By removing four manhole plates, which can be done in ten minutes, the entire boiler interior is accessible for cleaning. From the preceding discussion it is evident that the precipitates are settled into the mud drum, whence they are blown off at intervals; the scale is practically confined to the rear bank of tubes, and by reason of escaping the high temperatures it is soft and easily detached. Consequently it happens in most cases that only the rear bank needs cleaning each time the boiler is opened, while the others need only occasional attention. The scale is quickly and cheaply removed by a "turbine cleaner," described and illustrated in the section on Boiler Operation.

Cleaning the Exterior. Ample cleaning doors are provided both in the sides and rear of the setting, so that the exterior of the heating surfaces may be kept clean and all accumulations of soot, ashes, etc., blown off as rapidly as they form, by using a steam blower-pipe which is furnished with every boiler.

Durability. By reason of the elimination of thick plates and riveted joints exposed to the fire; cast metal of all kinds; parts of irregular shape and uncertain strength; stresses due to unequal expansion, multitudes of caps, joints and nipples, and similar objectionable details, the Stirling boiler is free from parts liable to get out of order. The prevention of scale deposits in the hottest tubes; the perfect facilities for keeping the boiler clean; the rapidity of water circulation and impossibility of forming steam pockets, all combine to protect the tubes against burning out. Hence the necessity of repairs to the boiler itself is extremely remote. The setting is simple and substantial and not subject to derangement other than the natural wear of surface lining.

MAXIM WATER-TUBE BOILER.

The Maxim water-tube boiler (Figs. 14 and 15) consists of two drums, one above the other, connected by tubes.

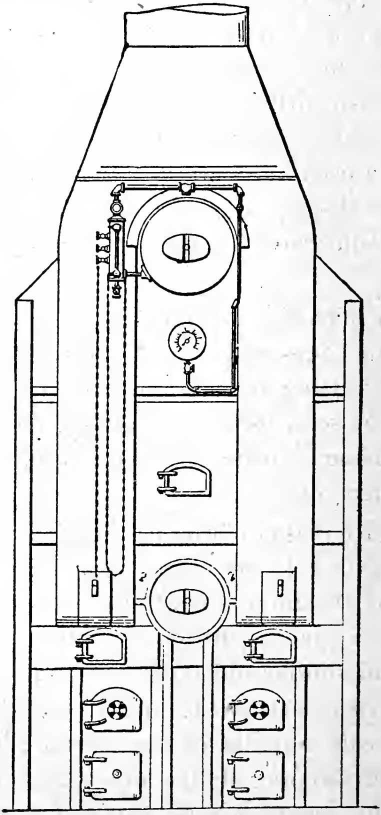


FIG. 14

FRONT ELEVATION MAXIM BOILER

Each tube has two bends, thus providing for unequal expansion and contraction. The space between the tubes is greater than the diameter of the tubes, so that any tube can be passed through the space between. The tubes, which are nearly vertical, are arranged in parallel rows, the lower tube plates being cylindrical, and the bottom end of every tube is opened to the lower drum, thus enabling the flue dust, mud and loose scale to drop away from the heating surface. There are no riveted joints exposed to the flames or fire gases, and there are no cylinders subject to external pressure.

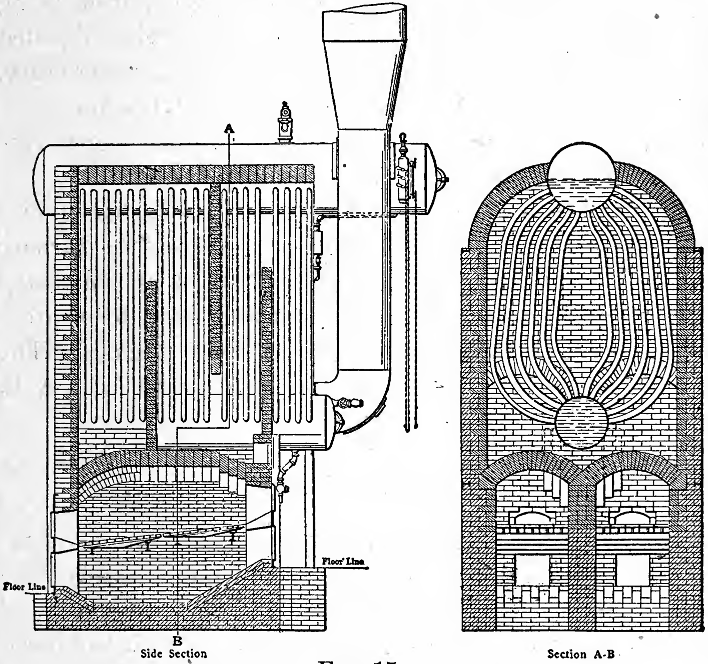


FIG. 15

MAXIM BOILER

The heating surface is arranged so as to break up the current of heated gases, which travels three times the length of the tube, the form and direction of the gas current being changed seven times between the furnace and chimney, to insure a low temperature to the escaping gases.

The circulation is constant, the return circulation being provided for by a third set of tubes, which are subjected to the heat of the gases just before reaching the chimney. As the cold feed water meets the gases as they leave the boiler, the front section of the tube, which receives the feed water, acts as an economizer and purifier.

The furnace of this type of boiler is constructed of fire-brick, and is built under the boiler. Between the furnace and each combustion chamber there is a throat contracted to the proper size for drafts, the purpose being to insure a better combustion by an intimate mixture of gases. The illustrations show a side view, sectional view through A B, and a front view.

THE BIGELOW-HORNSBY WATER-TUBE BOILER.

The American rights to manufacture the Hornsby water-tube boiler, which has been on the English market five years, were recently acquired by the Bigelow Company, of New Haven, Conn., hence in this country it will be known as the "Bigelow-Hornsby" boiler. It has been re-designed in a measure, to meet the requirements of American high-pressure practice. A general idea of its construction may be obtained from Fig. 16, which shows a section through the setting. It will be noted that the boiler is supported entirely from the overhead beams, leaving the lower part free to respond to expansion stresses. The front tubes are inclined at an angle of 68 degrees, and the rear units

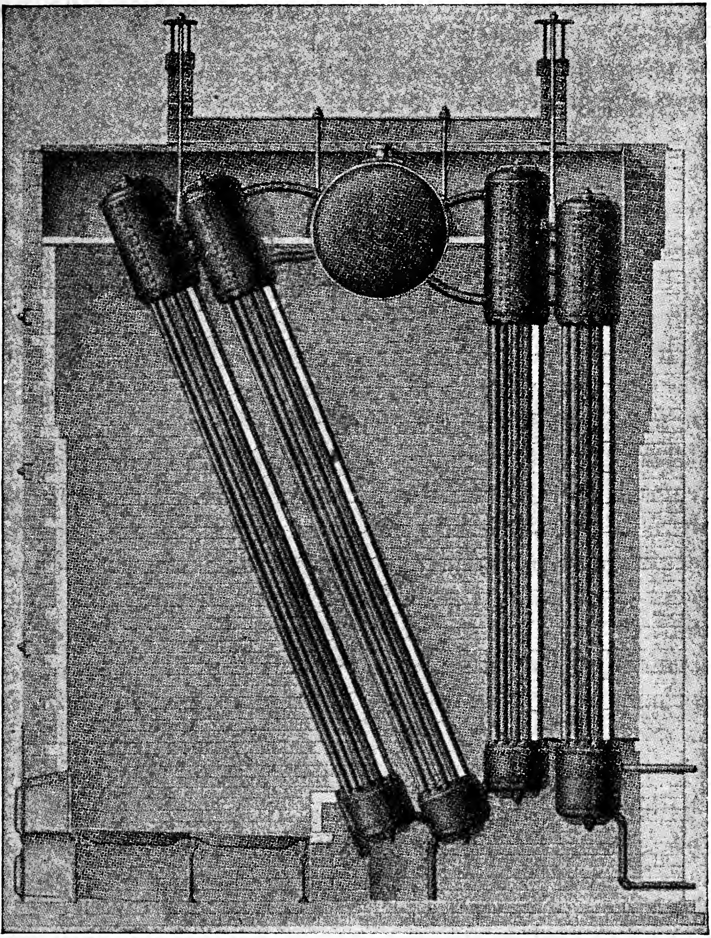


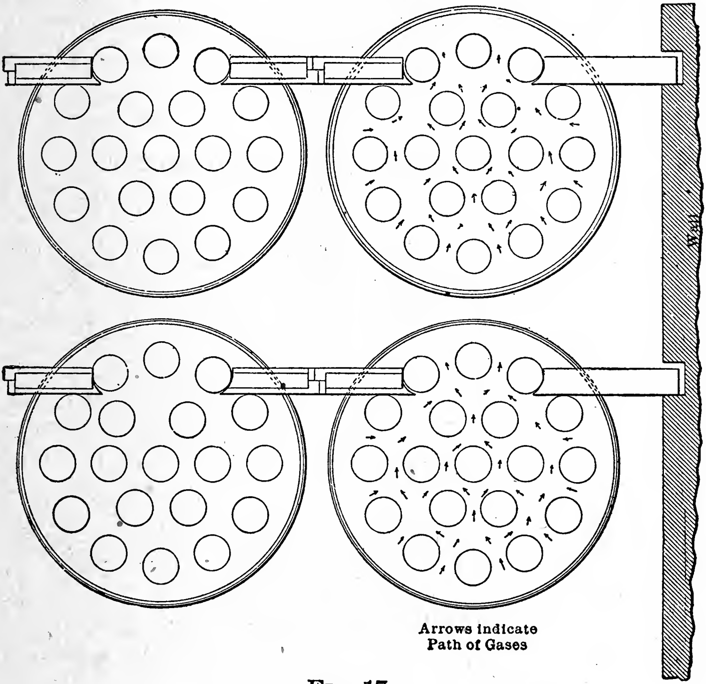
FIG. 16

SECTION THROUGH SETTING OF BIGELOW-HORNSBY BOILER

are vertical, as shown. Only two lengths of tubes are used. Each section is independent of its neighbor, except the nipples connecting with the steam drum and the equalizing nipples which connect the bottom drums of the rear sections. This flexible form of construction permits the building of very large units, even larger than the 2,200-horsepower Hornsby boilers at the Bow Street station of the Charing Cross & London Electricity Works, where four boilers containing 21,700 square feet of heating surface evaporate in regular service 110,000 pounds of water per hour. A large percentage of the heating surface is exposed to the radiant heat of the furnace, and to the first pass of gases, before these have reached any other heating surface. The tubes of the front unit, which are located in front of the baffles, comprise more than 12 per cent of the heating surface of the boiler.

The feed-water is admitted into the bottom drum of the rear unit and is advanced gradually from the coldest to the hottest portion of the boiler, first passing up the entire length of the tubes in the rear unit, then from the top of those tubes to the unit immediately in front, down this unit, and up the two front units and back through the steam drum to the first vertical unit at the rear of the steam drum. There is also, as may be conceived, a rapid local circulation in each of the units while the general circulation is going forward. The speed of the feed-water up the rear unit being regulated by the amount of steam generated, ample time is permitted for sediment and scale-forming matter to be deposited in the bottom drum of this unit. All liberation of steam from the water surfaces takes place in the upper drums and is entirely unrestrained, the full area of the tube openings communicating with the drums. The transfer of steam and water between units occurs through separate nipples, and the water nipples are required merely to care for the general circulation through the boiler.

The arrangement of this boiler is such that it can be baffled so that the products of combustion are carried uniformly over the heating surfaces in thin layers, there being no large unrestricted paths parallel to the heating surfaces through which the gases can flow in their passage to the uptake. Fig. 17, which is a horizontal section through some of the rear units, shows how they are arranged with reference to the gas currents, and how the baffle-plates serve to guide the gases through in substantially uniform passages.



Arrows indicate
Path of Gases

Fig. 17

The smoke flue can be taken off at the back of the boiler at any point between the top and bottom. All the tubes are straight and every tube in each section can be reached for cleaning by the removal of a single manhole cover.

The boiler is built to a factor of safety of five for 200 pounds working pressure, and it is stated that a test section has been subjected to hydrostatic pressure of 1,000 pounds without rupture. The ratio of grate surface to heating can be made as low as 1 to 26.

WICKES VERTICAL WATER-TUBE BOILER.

This boiler (see Fig. 18) consists primarily of two cylinders joined together by straight tubes, which are divided by a fire brick tile passing through their center into two compartments. The whole is then erected in a vertical position and surrounded by brickwork.

Drum. The two cylinders are duplicates in their diameter and general construction, but differ in height and arrangement of convexed heads. The top cylinder, designated hereafter, from its use, as the steam drum, is the longer, the length and diameter being varied in accordance with the size of boiler desired and local requirements.

The bottom cylinder, designated hereafter, from its use, as the mud drum, is the shorter, and is varied in the dimension as to diameter and length in accordance with the power of boiler required and local conditions. Both drums are closed at one end with the tube sheet, and at the other end with convexed heads.

Tubes. The mud and steam drums are joined together by the tubes, which are perfectly straight in themselves and plumb, in position, when expanded into the two tube sheets. They are arranged in parallel rows, from furnace

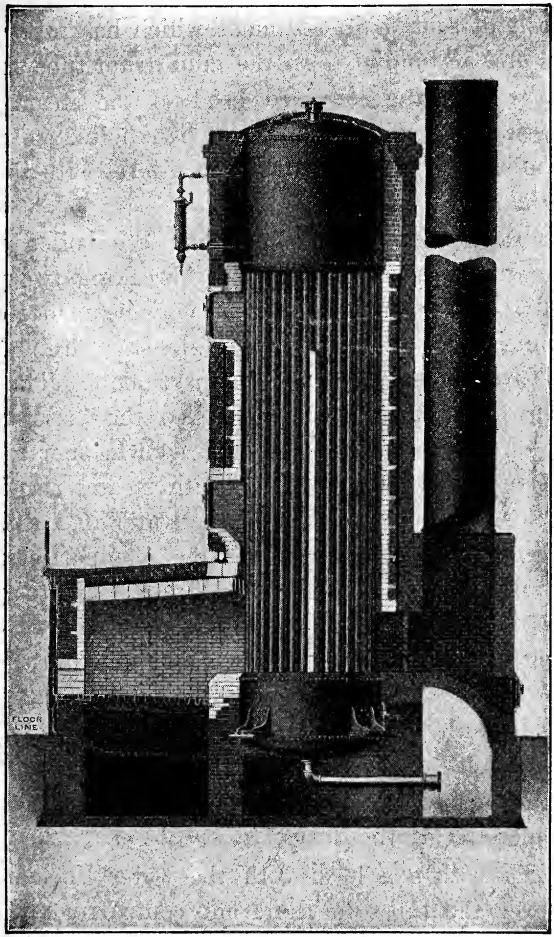


FIG. 18
WICKES VERTICAL WATER TUBE BOILER

to stack, with a clear space between rows sufficient to permit of introducing a small hoe for the purpose of removing any deposit of soot or of sediment which has fallen from the tubes and accumulated on the mud drum tube sheet.

Manholes. In the convexed head of the steam drum one large manhole, and a number of handholes, are placed, and in the shell of the mud drum on a level with the floor another manhole is placed.

This arrangement permits entering the boiler at the highest and lowest points by simply breaking two joints, from which points an examination may be made, or the tubes cleaned. By the introduction of heavy fire clay tile, the tubes are divided into two compartments. The tubes in the forward compartment are called the "risers," and those in the rear compartment the "downcomers," since the heat, and the water, mingled with steam, rise in the forward tubes, and both heat and the water in a solid column descend in those forming the rear compartment, the steam having passed into the upper drum. This gives the heat two complete sweeps through the entire length of the boiler, and the second sweep from above downward. The heat in its double passage surrounds completely and closely the tubes in both compartments.

Water Line. The water line in this boiler is maintained in the steam drum, at a sufficient height to insure the complete submersion of the tubes.

Baffle Plate. On a level with the water line, and extending over the tubes in the front compartment, is the baffle plate, which deflects the water of circulation rising, commingled with its steam, directly to the "downcomers," and without splashing and spraying the steam room directly above with globules or masses of water.

Liberating Surface. Fully two-thirds of the entire area of steam drum is liberating surface, and, as the liberation takes place mainly over the "downcomers," it does so in the quietest manner and in the absence of violent ebullition or turmoil.

Steam Room. The large steam room is therefore entirely free from water, and the steam outlet is the topmost point, which is far away from the water line, in large boilers the distance being from six to seven feet. On the other hand, the blow-off is at the very lowest point, and where all impurities are precipitated by gravity, and by separation due to the flow of the water of circulation.

Feed Water. The feed water may be introduced in the steam drum directly into the "downcomers" and far below the water line, or in the mud drum above the precipitated sediment. The latter method, viz., introducing the feed water into the mud drum is to be preferred.

Setting. The brick work setting of the Wickes boiler is so arranged that it is entirely independent of the weight of the boiler, and is therefore free to expand or contract as its co-efficient may dictate, thus allowing the boiler to expand and contract in accordance with the special laws governing its change of form.

The gases of combustion are closely confined to the tubes, after their generation in the furnace, and on their passage to the stack. The direct flow of the heat is, by virtue of the draft over the tile, and down by the shortest possible route, or path of least resistance; while heat of radiation rises naturally and surrounds the steam drum which, as will be seen by reference to Fig. 18, is surrounded by brick work to its top seam. It is claimed by the manufacturers of this boiler that very dry steam is obtained from it, the upper drum acting as a superheater. A damper, either single or double wing, is placed in the setting at the point of exit of the gases. It is so designed as to allow the quick and easy removal of the wings when cleaning is going on. The foundation is so designed that by means of a door through the circular brickwork, a man can enter underneath the boiler, examine the blow-off pipe and rivets, and see that the bottom of the mud drum is kept well and heavily painted.

ATLAS WATER-TUBE BOILER.

The design and construction of the Atlas water-tube boiler will be easily comprehended by reference to Fig. 19, which presents a full view of this boiler before setting. It consists mainly of three drums, and two water-legs extending crosswise, and the tubes running lengthwise. The rear water-leg is mounted on rollers in setting, in order to allow for expansion, and contraction of the tubes.

An important and original feature in the general design is, that the water-legs are formed by the continuation of the plates of which the shells of the front and rear drums are composed. Thus no flanged plates, or riveted seams whatever are exposed either to the fire or hot gases at any point. The value of this form of construction lies in the fact that it eliminates the possibility of the crystallization of plates and rivets and consequent cracks, and annoying leaks at the seams arising from overheating and unequal expansion and contraction of double metal thickness, due to exposure to flames and furnace gases of high temperature.

Another exclusive and very valuable feature of the design is the arrangement for passing the steam, after leaving the vessels containing water, through a series of superheating tubes, wherein it loses every particle of moisture

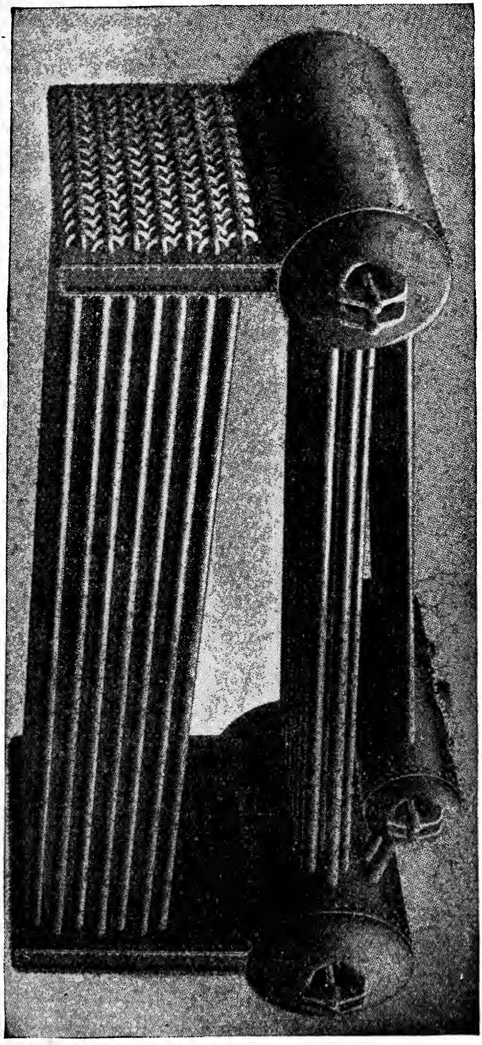


Fig. 19
ATLAS WATER TUBE BOILER

and is heated to a temperature many degrees higher than that normal to its pressure.

Attention is directed to the fact that no matter how large the boiler, there is only one steam drum, consequently the entire product of the boiler can be piped out of a single steam opening. This means a large saving in the cost of piping when compared to the expense incident to installing other types of boilers, which in units of, say, 200 horsepower, or larger, necessarily have two longitudinal drums to be connected together by the purchaser.

All parts of the Atlas boiler and the fixtures furnished are designed for a safe working pressure of 160 pounds per square inch with a safety factor of more than 5.

All materials have been selected with especial reference to their adaptability to the service required. The shells and heads of the drums and water-legs are open hearth homogeneous flange steel, bearing the maker's stamp of 60,000 pounds tensile strength per square inch of section, with not less than 50 per cent of ductility as indicated by contraction of area at point of fracture under test; an elongation of 25 per cent in a length of 8 inches, and guaranteed by the makers to be capable of bending down flat upon itself when cold, red hot or after being heated to a cherry red and quenched in cold water, without sign of fracture. The chemical and physical properties are determined by thorough tests, and all plates must meet the requirements of the best accepted practice.

The tubes are standard American lap welded, thoroughly tested in all particulars before being expanded into place by roller expanders and again after the boiler is assembled. The tube-holes are accurately placed by template, then reamed and neatly chamfered.

Double-refined iron staybolts and braces, having an ultimate tensile strength of 52,000 pounds per square inch of section, an elastic limit of at least half the tensile strength and an elongation of eighteen per cent in a length of 8 inches, are set to bear uniform tension.

The rivets are of mild steel and can be bent over cold till the sides meet, without developing cracks on the outside of the bent portion. All rivet holes are reamed to perfect fairness, and the riveting wherever practicable is done by hydraulic machinery, upsetting the rivet its full length, completely filling the hole and forming a perfect head in line with it. There are no riveted seams in the fire, or in the path of the furnace gases.

All heads are first heated to a uniform bright red and then flanged at a single operation in a hydraulic flanging press. The bends in the plates forming the bottoms of the water-legs are pressed cold under heavy pressure. There is no distortion, either of heads or plates and there is a total absence of marks resulting from frequent and partial heating and hammering into shape.

No cast metals are used in any parts that are subjected to tensile stresses, or furnace heat. The cast iron that is used for handhole and manhole plates and yokes is good, soft, grey iron, free from flaws or imperfections.

The rapid, steady, unimpeded flow of the water in the course natural to expansion by exposure to heating surface, bears important relation to the most economical utilization of the heat units in the furnace gases, and is an essential factor in the achievement of the highest efficiency in the production of steam. Uniform temperature in all parts exposed to furnace heat, which is so necessary to the safety and durability of the boiler, cannot exist with faulty circulation.

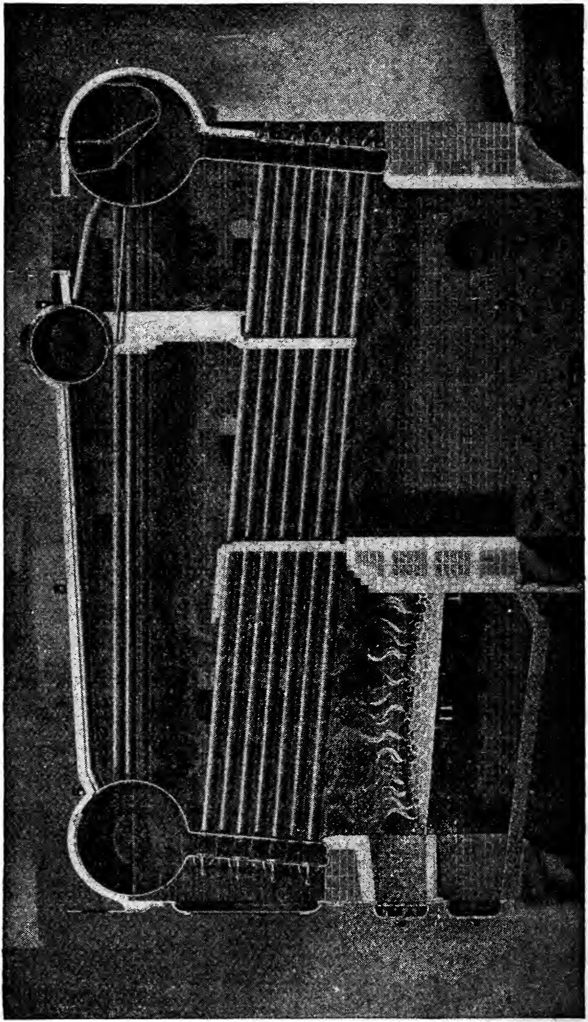


FIG. 20

ATLAS WATER TUBE BOILER—SECTIONAL VIEW

The water is fed into the purifier, whence it overflows into the rear drum and passes down into the rear leg, thence through the inclined tubes to the front leg and upward into the front drum, where the globules of steam generated in the tubes are liberated and carried through the superheating tubes to the steam drum. Meanwhile the water continues its flow through the equalizing tubes to the rear drum, joining the feed current at that point. The regular movement of all the water in the circuit just described, indicates uniform temperature in all the water-tubes, and when an unimpeded circuit has been established in the manner just explained, a maximum supply of dry steam will be delivered. When the circulation is retarded to sluggishness, the water does not so readily absorb the heat, and wet steam and a smaller quantity of it must be expected. It will be noted that while the design of this boiler admits with equal facility the use of either the vertical or the horizontal flame travel, the illustrations herewith show the vertical, it being preferred for several reasons, not the least important of which is that a more uniform distribution of the heat arising from the grates is obtained by first passing the gases upward through the entire nest of tubes between the front end of the furnace, and the first vertical baffle, thence downward between the first and second baffles and finally upward again through the entire nest of tubes between the second baffle, and the rear water-leg. It is not difficult to understand that, aside from all other considerations, the course of the heated gases as described is conducive to a more nearly equal division of the units of heat among all the water-carrying tubes than is possible with the horizontal travel which concentrates by far the greatest degree of heat on the lowest tubes during almost their entire length. Uniform heat distribution means uniform temperature, which logically followed leads to the reasonable belief that the circulation, which increases or decreases as the temperature goes up or down, is of regular direction in all of the tubes, and that each tube is doing its full share of the work.

Superheated steam has of late years been the subject of much thought and experiment, and now the economical utility of steam containing a number of degrees of superheat is quite generally understood. Ordinary steam at 100 pounds gauge pressure has a normal temperature (omitting decimals) of 338° Fahr., and at 160 pounds its normal temperature is 370° Fahr. The temperature in excess of normal for steam of a given pressure is technically designated superheat. Steam that is in contact with the water from which it was generated cannot be heated above the temperature normal to its pressure. The process of superheating must therefore take place subsequent to the passage of the steam from the vessels containing water. Superheat is obtained by exposing the steam to gases of a higher temperature. The number of degrees of superheat obtainable is governed by the temperature of the gases to which the steam is exposed, and the duration of the exposure. It is claimed for the Atlas water-tube boilers that during various tests under actual working conditions they have produced steam containing from 10 to 30 degrees of superheat.

All users of steam are familiar with radiation losses in steam pipes and the wastes in engine cylinders due to the fact that at each stroke the new supply of steam is brought into contact with the face of the piston and the internal surfaces of the cylinder, which have been cooled by the exhaust of the previous stroke. When steam is used at normal temperature, each degree of heat thus lost means condensation and a proportional decrease of pressure. When superheated steam is used there is no loss of pressure until the steam is cooled to the temperature normal to the boiler pressure. Up to within the last few years it was customary to equip each boiler with a mud drum. Two very important facts, however, militated so seriously against the mud drum that it is now eliminated from the best boiler practice. In the first place a dangerously large percentage of the substances in the feed water, which at high temperatures become insoluble, would not gravitate toward and settle within the mud drum according to the plan laid out for them, and in the second place, the mud drum proved in many cases little short of an aggravation by reason of the constant and irremediable leakage of the joints between the drum and the boiler, due to greater expansion and contraction of the boiler, the drum being necessarily situated outside of the current of the hottest gases.

Fig. 20, which is a sectional view of the Atlas water-tube boiler as it appears set in brick work, shows a purifying device which is hung loosely by strap hooks inside the shell of the rear water drum, its depth gradually increasing toward the blow-off end.

The water is fed into the shallow end and, the pan being large and always full of, and surrounded by, hot water and steam, it is raised to from 250° to 275° Fahr. before it overflows into the main portion of the drum.

The overflow takes place entirely at the shallow end of the pan, the top of that head being one inch lower than the other head and the sides. It is a well-known fact that water begins to clear itself when it reaches a temperature of 200° Fahr., and as the liberal dimensions of the pan allow the water to remain in it a considerable time, practically all the scale-forming impurities are precipitated to the bottom of the pan where they remain in a soft sludge-like state pending the opening of the blow-off valve, the frequency of which should be governed by the character of the water and the rapidity of the accumulation.

It will be noted that aside from its open top, which is several inches above the water line in the boiler, the pan is water-tight. It is entirely practicable, therefore, to blow off the sediment as often as desirable while the boiler is under pressure without fear of reducing the water level below the point of safety.

Corrosion is one of the inevitable effects of the accumulation of mud and sediment on metal. Unlike purifiers common to some other boilers, which consist of a pocket-shelf built against the shell or one head of the boiler itself, which, therefore, forms part of the purifier and is exposed to the corrosive action of its contents, the purifier in the Atlas boiler is self-contained and absolutely independent of the boiler-shell or heads. The pan is made in sections and when it finally deteriorates to an unserviceable point, can be removed and replaced through the manhole with little labor and small expense.

It is estimated that an incrustation of $\frac{1}{16}$-inch will cause a loss of 13 per cent of fuel, $\frac{1}{8}$-inch 25 per cent, and so on, and these figures are probably not far from correct. Therefore, the purification of the feed water before it reaches the surfaces exposed to the baking heat of the furnace tends to a more economical use of fuel. It also reduces cleaning labor and the cost of repairs and increases the life of the boiler by avoiding the early disintegration of the metal which results from subjecting it to that intense heat necessary to boil water through the additional thickness due to a coating of scale. An individual hand-hole is located opposite each end of each water tube.

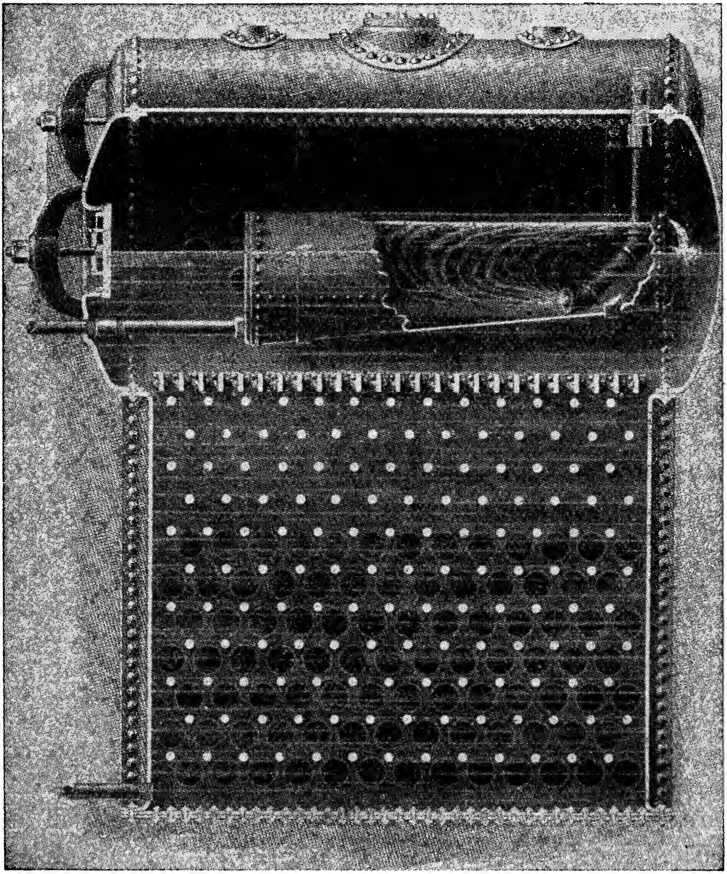


FIG. 21

ATLAS WATER TUBE BOILER

Section through Rear End Showing Water Purifier

These hand-holes are of the diamond-oval shape, having an accurately fitting plate, held in position by a suitable yoke with bolt and nut, the construction being such that the pressure on the inside of the boiler maintains the tightness of the joint. Any one of these plates can be removed and replaced through its own opening without disturbing any of the others. The water tubes in this boiler being absolutely straight, in order to clean them thoroughly on the inside, it is only necessary to remove the front hand-hole plates, insert a scraper and push the sediment back into the rear water-leg, from which it may be easily removed through a few of the hand-holes in the bottom row, or through the blow-off. The internal condition of each water tube may be determined without removing any of the rear hand-hole plates by suspending a light through the full length throat between the rear water-leg and drum, and holding it in turn opposite the rear end of each water tube, while looking through the open hand-holes in front. Or, if the engineer prefers, the top row of rear hand-hole plates may be removed, and the light inserted and suspended, without entering the drum.

The interior of each of the three cross drums of the Atlas boiler is reached through a large manhole in one end. The edge of this manhole forms a deep flange at right angles with the head, is faced true and provided with an accurately fitted plate with yokes, bolts and nuts, all of such proportions that this part of the head is as strong as any other of like area.

MARZOLF WATER-TUBE BOILER.

Another design of water-tube boiler is shown in Fig. 22. The object has been to construct a boiler so that the relative arrangements of the tubes, drum, and heat passages are such as to obtain the most economical distribution of heat. Another object is to facilitate the heating of the water, and increase the circulation by arranging the drums,

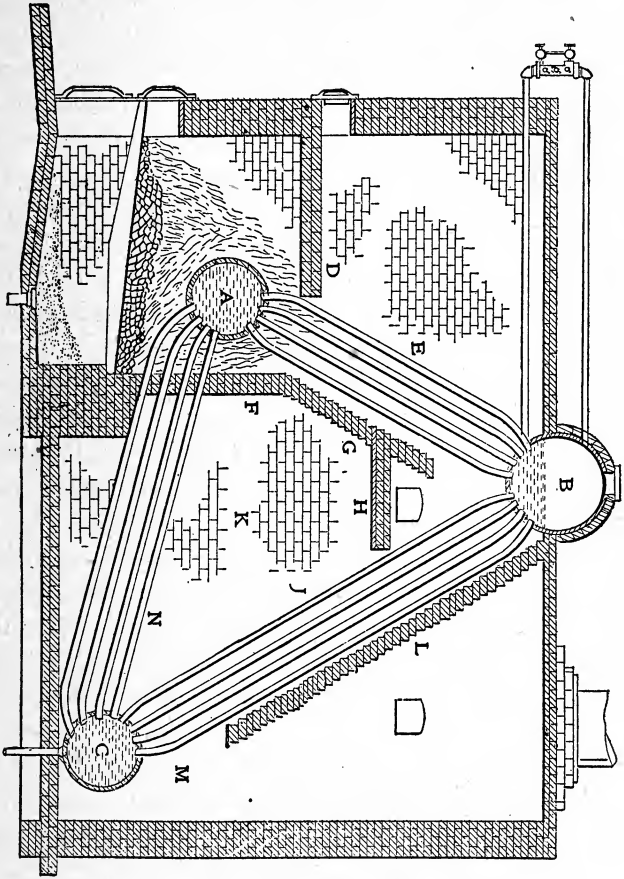


Fig. 22

MARZOLF BOILER—SECTIONAL VIEW

and a series of tubes so as to receive the direct application of the heat from the furnace.

As shown, the drum A is located in the furnace and connected to the drum B by tubes slightly bent at each end, the drums A and B being connected to the drum C by similar tubes. As the flame and hot gases rise from the furnace, they surround the water drum A and, striking the arch or baffle wall D, follow along the inclined tubes E, which receive the direct application of the heat generated by the combustion of the fuel. The extension of the bridge wall is reduced in thickness above the grate, as shown at F, forming a back wall which rises vertically behind the water drum A, to a point close beneath the series of tubes E. This wall is surmounted by a sloping wall G, which stands adjacent to, and parallel with, the tubes E, and extends toward the drum B. Owing to the baffle wall H, the hot gases are forced up along the tubes E, and down through the tubes I to the heating chamber K, the roof of which is found by the baffle wall H. The baffle wall L is inclined downward parallel to and close to the rear of the series of tubes J from a point directly behind the steam drum B, to a point over the mud drum C, whereby the heat and products of combustion are deflected downwards among the tubes N.

The hot gases pass from the heating chamber to the passage M between the lower end of the baffle wall and the mud drum C to a draft passage located between the baffle and the rear wall leading to the stack.

The heat thus not only acts directly upon the water-drum A and upon the portions of the tubes N and E, located within the furnace, but also upon the tubes E above the furnace, upon the steam drum B, the tubes J and the mud drum C. The portion of the tubes N which lies within the heating chamber K also receives heat to some extent, although the heat does not act directly upon them as upon the other tubes.

The feed water supply to this boiler is admitted through the drum C, and circulates through the tubes N, water drum A, tubes E, steam drum B, and tubes J, back to the mud drum, making one continuous circuit. As shown by the illustration, the steam drum B is relatively larger and consequently of much greater capacity than either of the other two drums. It will be noticed that the tubes N are placed on an incline, owing to the mud drum being located on a lower level than the water drum A, a design intended to cause all sediment carried into the boiler to gravitate to the mud drum C, from which it may be readily removed through the usual blow-off.

DUPLEX WATER-TUBE BOILER.

In the Duplex water-tube boiler, Fig. 23, the features which are most strongly emphasized by the designers are: Delivery of steam from the boiler in a superheated condition, without the use of a special superheater; removal of steam from the boiler at a point where there is no ebullition, and elimination of a great many parts of the undulating header type of boiler. The design of the boiler shows absence of stay-bolted surfaces, the drums are not exposed to the direct action of the fire, all seams or rivets are entirely removed from contact with the heat, rigid connections are avoided between parts, and all joints are expanded.

The Duplex boiler consists of two upper steam drums connected by tubes. Short tubes expanded into the bottom

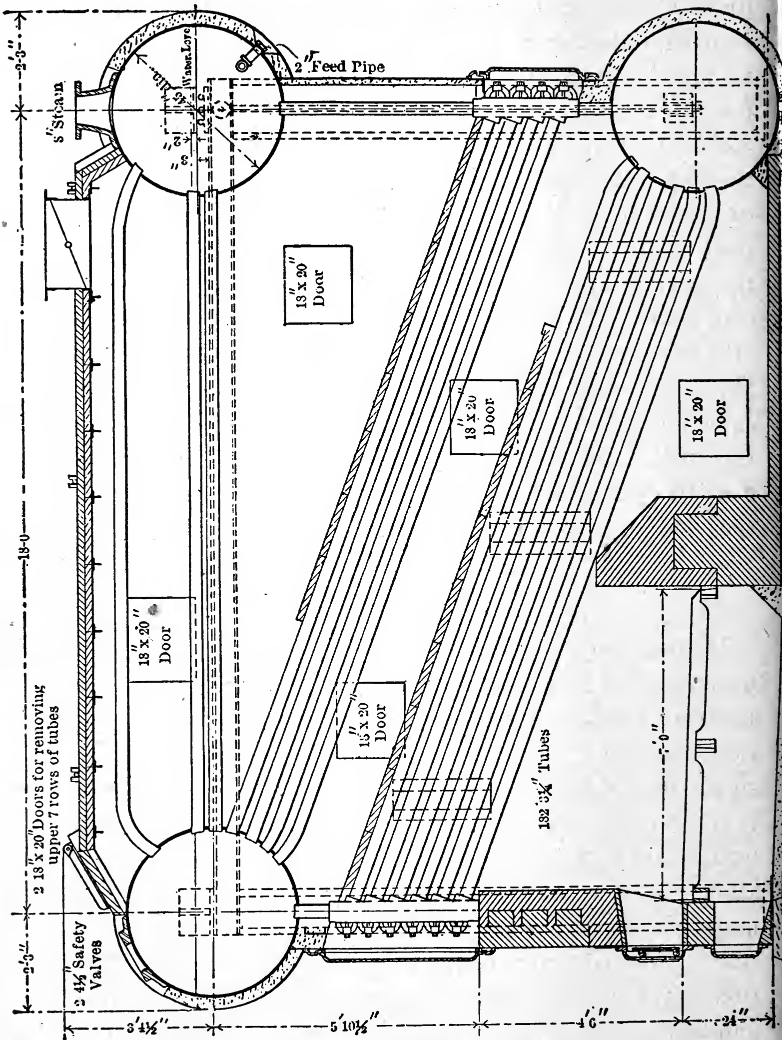


FIG. 23

DUPLEX WATER TUBE BOILER

of the shell of the rear drum form the connection to a set of headers below it, which are connected to the front drum by tubes expanded into the shell of the latter. This comprises the upper generating system. These headers are likewise connected to a drum situated below them by short nipples, and this lower drum is in turn united to a set of headers below, and similarly connected to, the front drum. This comprises the lower generating system. The tubes are inclined 20 degrees to insure rapid and positive circulation.

The drums are made in one sheet with no circular seams except those connecting the heads to the shell. The longitudinal seams are butt-strapped, either double or triple riveted, as the pressure demands, and located on the outside of the shell. A pressed-steel manhole is placed on the circumference of the shell for access to the interior of the drums.

The headers are heavy, made of open-hearth steel, and the section of the header to which the hand-hole plates are secured is designed to be extra heavy, as is that portion where the tubes enter the header, this latter being intended to provide a wide tube seat and obviate the danger of leaky tube joints. The headers are of long box-like form and each header is designed to take in two vertical rows of tubes. An elliptical hand-hole is placed opposite the ends of two tubes through which the tubes are cleaned or removed. This hand-hole is closed by an elliptical cap inside the header held in position by a bolt secured with an outside crab. The joint between the cap seat and the header is made tight with an asbestos gasket to avoid the necessity of remilling the contact surfaces every time a cap is removed and replaced. In this construction the bolt and crab are relieved of the strain of the boiler pressure.

The boiler tubes are 3¼ inches in diameter, of either charcoal-iron, or steel lap-welded, expanded directly into the shell of the drums or into the headers, and the ends are belled over one-quarter of an inch.

A heavy steel framework incased in the brick setting supports the boiler. On the sides and independent of the boiler are built walls of brick about 17 inches in thickness. The rear of the boiler is fitted with a sheet-iron casing protected with asbestos covering, the boiler being roofed over with fire-tile supported by heavy T-irons. The boiler fronts are of steel and doors of ornamental design are provided for access to the headers. The frame-work is so designed as to provide for the free expansion of all the tubes. The two upper drums are set on lugs secured to the heads, the lugs in turn being supported by the steel framework. The rear lugs are first set on rollers which allow for the expansion of the tubes connecting the two drums. The horizontal style of baffling is used. These baffles rest on the tubes, and guide the gases along the lower bank, and the horizontal circulating tubes.

Finally, the gases pass through the smoke outlet, which may be located on the top of the boiler at the rear, or at a point just under the rear drum. The course of the gases is always upward, which is the free and natural passage for them. The baffles are of the common rectangular shape, which any dealer carries in stock. The upper and lower banks of tubes comprise the active heating surface of this boiler. The tubes that form the lower system are connected at their rear ends to a large mud drum, which acts as a reservoir for water to insure an ample supply for the bottom tubes at all times. The upper bank of tubes is arranged in reverse of the lower, the tubes being connected to the front drums at their front ends. All the tubes of the upper system discharge independently into this drum. The header ends of both banks of tubes are connected into headers that are straight and of ample area. The tubes are of easy access for the purpose of scraping off soot that has been baked on in service. The feed water is introduced in the upper rear drum, where any air that it contains may be liberated. It then passes downward through the rear circulating tubes and headers to the lower rear drum, where any impurities present in the feed water may be deposited.

The passage of the water is then upward through the lower bank of tubes, through the front headers to the front drum.

At this point any steam that is generated separates from the water, and passes across the steam tubes to the rear drum, and is believed to be thoroughly dried out, and slightly superheated in the process by coming in contact with the hot gases surrounding these tubes. The water passes across through the circulating, horizontal tubes to the rear drum, thence downward again to the rear headers, and thence up the upper bank of tubes into the front drum again. By this time it is expected that the water will have become heated to a very high temperature and, becoming steam, it passes to the rear drum through the superheating tubes, becoming superheated on the route.

From this rear drum the steam is withdrawn, there being no ebullition at this place, as experiment with a boiler with glass heads on the rear drum has shown. The safety valve is located on the front drum, where its sudden operation cannot throw water into the steam opening. The spaces between the banks of tubes provide access to all parts of the boiler inside the setting through doors in the setting, and other openings in the setting permit the boiler tubes to be cleaned by blowing with steam, or compressed air.

The builders of this boiler, the Robb-Mumford Boiler Company, of South Framingham, Mass., have been carrying on some very satisfactory experimental tests during the past year.

ERIE CITY WATER-TUBE BOILER.

The Erie City Iron Works, of Erie, Penn., has added to its line of products the boiler shown in the accompanying illustrations, Figs. 24 to 26, the reproduced photographs shown being from the experimental boiler at the Erie shops. It is not claimed that the type is novel, but that the Erie iron works will bring to its manufacture and exploitation refinements and improvement in detail and experience and facilities which should soon make a place for it among the standard types.

Unite the three banks of tubes of a Stirling boiler in a single upper drum, placed with its center directly over the center of the lower one, and you have the type. The furnace is an extension on the Dutch-oven plan, allowing great flexibility in the adjustment of grate to heating surface, and introducing the improved furnace conditions of the reverberatory arch. Additional capacity is gained by increasing the length of the drums and the number of tubes sidewise, carrying with it increased width of fur-

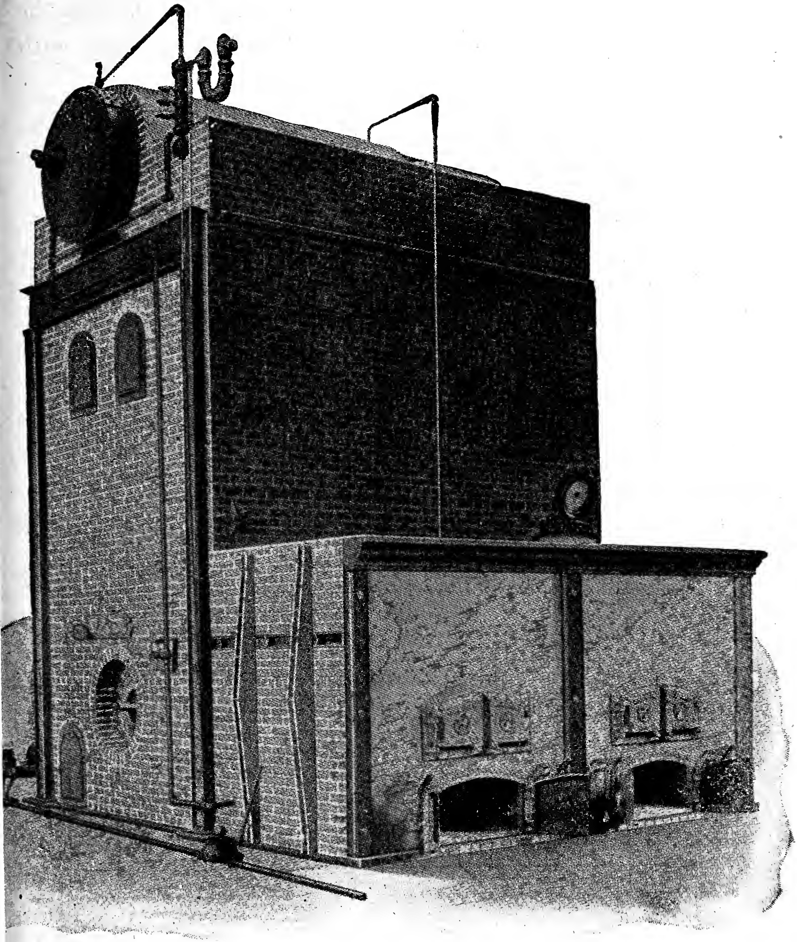


FIG. 24
ERIE CITY WATER TUBE BOILER

nace and proportionate increase of grate surface, while the length of the grate may be made such as to give the desired ratio of grate to heating surface.

The tubes are so spaced that any one of them may be cut out, removed and replaced without interfering with any other. The entire boiler is suspended, as the engravings show, from the upper drum, giving perfect flexibility

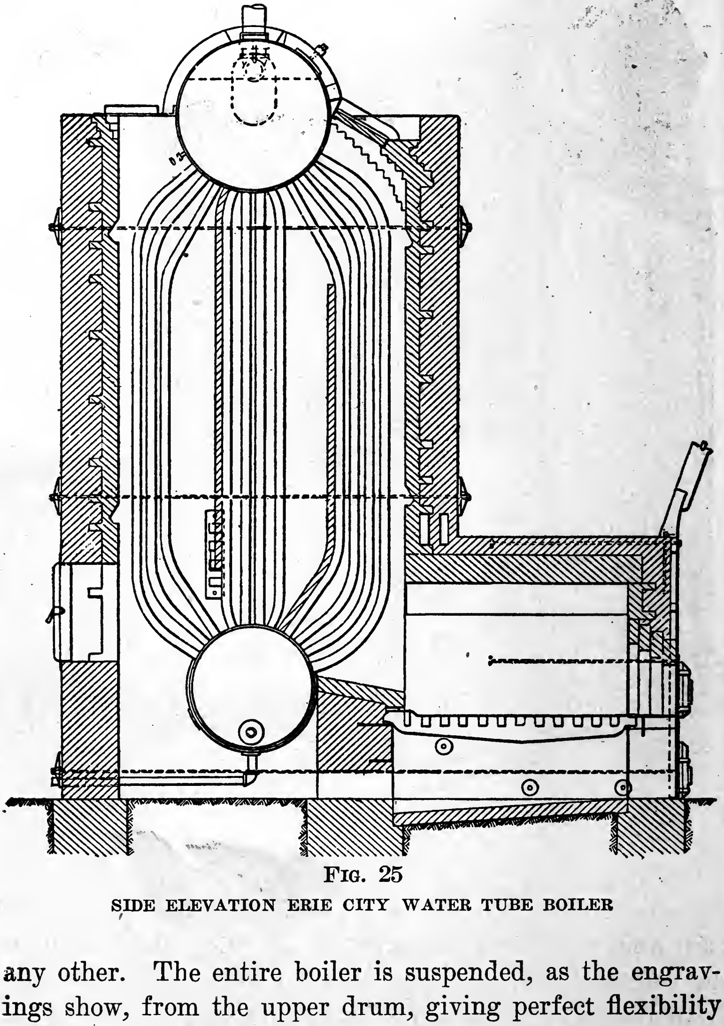


FIG. 25

SIDE ELEVATION ERIE CITY WATER TUBE BOILER and freedom to adjust itself to varying conditions of temperature and stress. The sufficiency of the expanded tube joints in the upper drum to sustain the weight thus brought upon them has not only been tested out thoroughly in

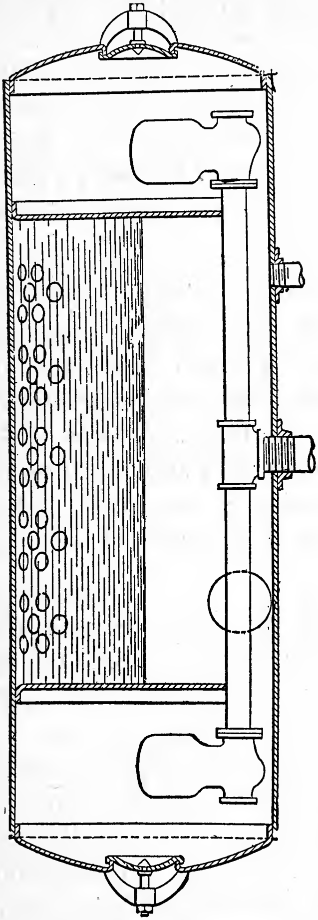


Fig. 26

ENLARGED VIEW SHOWING SEPARATOR IN DRUM OF ERIE CITY BOILER former boilers of this construction, but has been tried in the boiler illustrated by means of hydraulic jacks and found to be entirely adequate.

In this particular boiler the upper drum is 48 and the lower 40 inches in diameter, with 11 rows of connecting 3-inch tubes and, with 22 tubes in each row, furnishing 2,377 square feet of water-heating surface. The front and rear groups contain four rows each, the central group, three rows.

The baffling is arranged to give three passes as shown, the gases passing longitudinally through each group of tubes. This gives a travel of the gas of something like 40 feet in contact with the heating surface, yet with such freedom of passage that there was little drop in draft pressure between the stack and the furnace when the boiler, nominally rated at 238 horsepower, was developing over 500, and burning 36.7 pounds of coal per square foot of grate.

At each end of the upper drum is a dry chamber, as shown in the longitudinal section (Fig. 26), in which is placed a separator upon each end of the steam-outlet pipe, with the inlet facing toward the end of the drum and away from the steam-liberating surface. The boiler appears to be one which will be well adapted to the large units and intensive service demanded by the modern power plant, especially those in which large amounts of power are required for peak periods and where the ability to stand forcing is particularly desirable.

SETTING RETURN TUBULAR BOILERS.

In setting a return tubular boiler the prevailing custom has been to support on cast iron brackets resting upon the side walls, which are liable in course of time to crumble away and cause trouble. A great improvement is made when we suspend such boilers from I-beams supported by cast iron columns. Figures 27 and 28 show the setting of this type of boilers either singly or in double batteries, by means of suspension. In setting an even number of boilers, as six or eight in one setting, it is best to divide them into pairs so that not more than two boilers will be suspended between supports.

The principal reason for this is that when the large sizes, such as from 150 to 250 horsepower, are used, the size I-beam required to safely carry this load between supports is so large that it overbalances the cost of two or more cast-iron columns.

In setting an odd number of boilers, such as three or five, in a battery, columns are usually placed between the boilers with a 2-inch air space all around the column, and an air duct at the bottom of the setting which runs through from the front to the back and connects with each air space around the column. This allows a free circulation of air, thus tending to keep the columns comparatively cool. In setting boilers in this way, the columns and I-beams are set in position first. The boiler is then hoisted to the proper height by means of tackle, which is attached to the I-beams, and when the boiler is brought to the proper height, the U-bolts are slipped into place and fastened by nuts and washers to the I-beams.

This method abolishes the use of blocking and leaves all of the space under the boilers clear for the brick work.

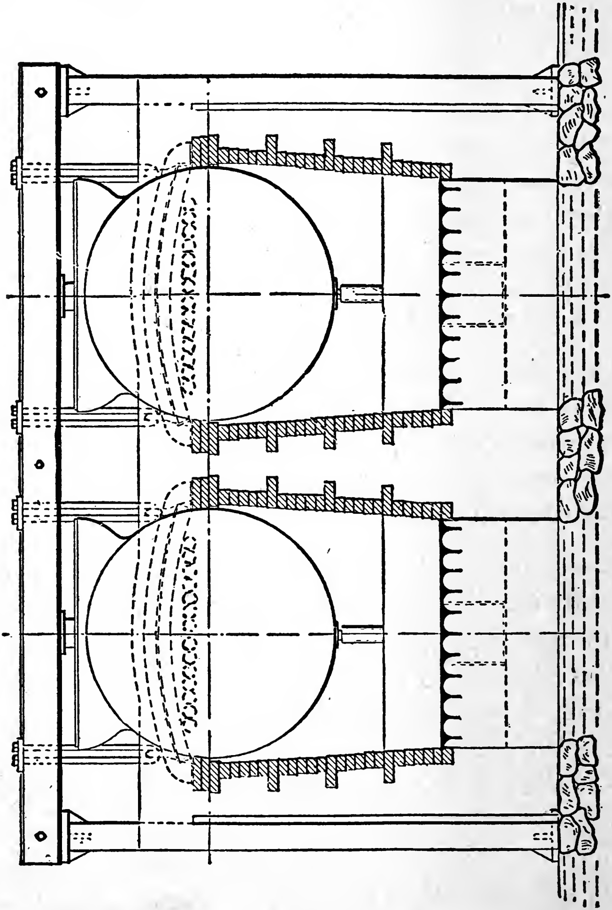


Fig. 27

The expansion is easily taken care of by the U-bolts and hangers, and if the walls are properly set, they will show no cracks as they carry no weight, and are free to go and come. The accompanying table, No. 1, has been carefully worked out with a factor of safety of 5, and gives the different sizes and lengths of I-beams and columns required

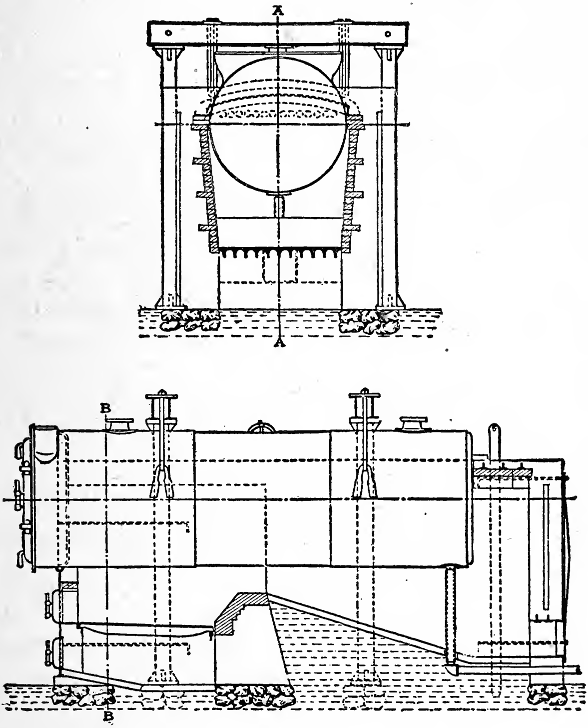


Fig. 28

for boilers of 36 inches in diameter and 8 feet long, to boilers of 90 inches in diameter and 20 feet in length, giving the total weight to be supported and the sizes, weights, and positions of the columns, and I-beams required:

TABLE 1

SIZES AND WEIGHTS OF COLUMNS AND I-BEAMS RE

HORSE POWER	15	20	25	30	35	40	45	50	60
Dia. of boiler in inches	36	36	42	42	44	48	50	54	54
Length of tubes in feet	8	10	10	12	12	12	13	13	15
Length of curtain sheet in inches	11	11	12	12	12	14	14	14	14
Total weight of boiler and water	6500	7500	9400	10500	11500	13300	14200	15300	17800
Rear head to center of hanger	2–0	2–6	2–6	3–0	3–0	3–0	3–3	3–3	3–0
Center to cen. of hang'rs	4–0	5–0	5–0	6–0	6–0	6–0	6–6	6–6	7–6
Front head to center of hanger	2–0	2–6	2–6	3–0	3–0	3–0	3–3	3–3	3–9
Distance between C of supports (1 boiler)..	6–6	6–6	7–0	7–0	7–2	7–6	7–8	8–0	8–0
Distance between C of supports (2 boilers)..	11–8	11–8	12–8	12–8	13–0	13–8	14–0	14–0	14–8
Length of I-beam for 1 boiler	7–3	7–3	7–10	7–10	8–0	8–4	8–6	8–10	8–10
Length of I-beam for 2 boilers	12–6	12–6	13–8	13–8	14–0	14–8	15–0	15–10	15–10
Size of I-beam required for 1 boiler.........	4	4	5	5	5	6	6	6	6
Size of I-beam required for 2 boilers........	6	6	8	8	9	9	9	10	10
Weight per ft. of I-beam for 1 boiler.........	7.5	7.5	9.75	9.75	9.75	12.25	12.25	12.25	12.25
Weight per ft. of I-beam for 2 boilers........	12.25	12.25	18	18	21	21	21	25	25
Length of cast-iron col.	8–0	8–0	8–6	8–6	8–8	9–3	9–5	10–0	10–0
Outside dia. of C. I. col. for 1 boiler.........	4	4	4	4	4	5	5	5	5
Outside dia. of C. I. col. for 2 boilers.........	5	5	5	5	5	6	6	6	6
Size of flange on ends of col. for 1 boiler.....	9½	9½	10	10	10	10½	10½	10½	10½
Size of flange on ends of col. for 2 boilers....	10½	10½	12	12	12½	12½	12½	13½	13½
Thickness of C. I. col. for 1 boiler.........	½	½	½	½	½	½	½	½	½
Thickness of C. I. col. for 2 boilers.........	¾	¾	¾	¾	¾	¾	¾	¾	¾

TABLE 1—CONTINUED.

QUIRED IN SETTING RETURN TUBULAR BOILERS.

70	75	80	90	100	125	150	175	200	200	225	225	250
60	60	60	66	66	72	72	78	78	84	84	90	90
14	15	16	15	16	16	18	18	20	18	20	18	20
16	16	16	17	17	18	18	18	18	20	20	22	22
20800	24800	27200	30300	35000	40000	44000	48000	56000	55000	67000	65000	75000
3–6	3–9	4–0	3–9	4–0	4–0	4–6	4–6	5–0	4–6	5–0	4–6	5–0
7–0	7–6	8–0	7–6	8–0	8–0	9–0	9–0	10–0	9–0	10–0	9–0	10–0
3–6	3–9	4–0	3–9	4–0	4–0	4–6	4–6	5–0	4–6	5–0	4–6	5–0
9–0	9–0	9–0	9–6	9–6	10–0	10–0	10–6	10–6	11–0	11–0	11–6	11–6
16–2	16–2	16–2	17–2	17–2	18–2	18–2	19–2	19–2	20–2	20–2	21–2	21–2
10–0	10–0	10–0	10–6	10–6	11–0	11–0	11–7	11–7	12–0	12–0	12–6	12–8
17–4	17–4	17–4	18–4	18–4	19–5	19–5	20–6	20–6	21–6	21–6	22–6	22–6
7	7	7	7	7	8	8	9	9	9	9	9	10
12	12	12	12	12	15	15	15	15	15	15	15	15
15	15	15	15	15	18	18	21	21	21	21	21	25
31.5	31.5	31.5	40	40	42	42	60	60	60	80	80	80
10–8	10–8	10–8	11–2	11–2	12–0	12–0	12–6	12–6	13–0	13–0	13–10	13–10
5	5	5	6	6	6	6	6	6	6	6	6	6
6	6	6	6	6	8	8	8	8	8	8	8	8
11½	11½	11½	11½	11½	12	12	12½	12½	12½	12½	12½	13½
14	14	14	14½	14½	15	15	16	16	16	17	17	17
¾	¾	¾	¾	¾	¾	¾	1	1	1	1	1	1
¾	¾	¾	1	1	¾	¾	¾	¾	1	1	1	

QUESTIONS AND ANSWERS.

1. What types of boilers are most commonly used for stationary work?

Ans. The horizontal tubular boiler and the water-tube boiler.

2. Describe in general terms the horizontal tubular boiler.

Ans. It consists of a shell having tubes of small diameter, extending from head to head.

These tubes are located in the water space.

3. What is their function?

Ans. To supply a passageway to the stack for the hot gases from the furnace.

4. Does the water in the boiler receive heat from these tubes?

Ans. It certainly does.

5. Describe the route taken by the smoke and hot gases in the operation of a tubular boiler.

Ans. From the furnace, located under the front end of the boiler, the gases pass under and along the sides of the shell, back to the rear end, the upper part of which is arched over. The route is here reversed, and the products of combustion return through the flues towards the front end and thence through the breeching into the stack.

6. Is this type of boiler economical in the burning of fuel?

Ans. It can be made so if properly set and handled in operation.

7. Describe in a general way the water-tube boiler.

Ans. It consists of a set, or sets of tubes 3 to 4 inches in diameter, sometimes vertical, and sometimes inclined, and connected at the top to a steam drum, and at the bottom to a mud drum.

8. What advantages as regards circulation of the water has the water tube boiler?

Ans. It provides for a free circulation.

9. Name another advantage connected with the water tube boiler.

Ans. The margin of safety from dangerous explosions.

10. Why is this?

Ans. Because if one or more tubes give way the pressure is relieved.

11. What precautions should be observed in the design and construction of a boiler?

Ans. The best materials should be used, the boiler should be simple in design, and the workmanship should be perfect.

12. Where should the mud drum be located?

Ans. In a place removed from the action of the fire.

13. What should be the capacity of the boiler relative to its work?

Ans. It should have a steam and water capacity sufficient to prevent any fluctuation in either the steam pressure, or the water level, if properly fed.

14. Why should the water in a boiler circulate freely and constantly?

Ans. In order to maintain all parts at as near the same temperature as possible.

15. What should the strength of a boiler be, relative to the strain it is liable to be subject to?

Ans. It should have a great excess of strength.

16. Is a combustion chamber an advantage to a boiler?

Ans. It is, in order to complete the combustion of the gases before they escape to the chimney.

17. How should a boiler be arranged with regard to cleaning?

Ans. All parts should be easily accessible for cleaning and repairs.

18. What type of boiler is the Cahall?

Ans. It is a water-tube boiler.

19. Is it vertical or horizontal?

Ans. It is built either way.

20. What form of Cahall is generally used in central power stations?

Ans. The horizontal form.

20a. What is the range of pressures that these boilers are built for?

Ans. From 160 to 500 pounds per square inch.

21. Describe the method of constructing the joints.

Ans. The sheets are beveled on the edges, bent into shape, and rivet holes drilled after bending.

22. What is gained by so doing?

Ans. Absolutely round rivet holes and no crystallization.

23. What type of riveted joint is used on the higher pressure boilers?

Ans. Triple riveted, double strapped.

24. How are the tubes connected to the steam drum in the Cahall boiler?

Ans. By nipples connected to saddles on the drum.

25. Does this boiler rest upon the brick work?

Ans. It does not, but is suspended free from the masonry.

26. What advantage is there in this style of setting?

Ans. The entire structure is free to expand or contract without causing any strains on either boiler or brick work.

27. Describe the Heine boiler.

Ans. It consists of one, and sometimes two shells on drums resting upon water legs riveted to each end. These water legs are connected by horizontal tubes. The water fills the tubes, water legs, and partially fills the shell, leaving the upper portion for steam space.

28. In the setting does this boiler occupy a horizontal position?

Ans. No. The shell and tubes have an incline of one inch in twelve from front to rear.

29. What provision is made for cleaning and repairing the tubes?

Ans. Hand-holes are located in the head plates opposite each tube.

30. How are these hand-holes closed?

Ans. In the ordinary way, by plates.

31. Where is the mud drum located in the Heine boiler?

Ans. Inside the shell, near the bottom.

32. How is the Heine boiler supported in the setting?

Ans. The front or fixed end rests upon cast iron columns. The rear water leg upon rollers.

33. Describe in brief the Babcock & Wilcox boiler.

Ans. It is composed of wrought iron tubes, placed in an inclined position, and connected with each other, and with a horizontal steam, and water drum by vertical headers.

34. Where is the mud drum in this boiler?

Ans. In the rear, and connected to the lowest part of the boiler.

35. What provision is made for cleaning the tubes in the Babcock & Wilcox boiler?

Ans. Through hand-holes in the headers, opposite each tube?

36. How is this boiler supported in the setting?

Ans. It is suspended from wrought iron girders, entirely independent of the brick work.

37. Describe in general terms the Stirling boiler.

Ans. It consists of three upper steam drums, each being connected by a number of tubes to a lower or mud drum.

38. How are the steam spaces connected?

Ans. By shorter tubes.

39. How is the boiler supported?

Ans. On a structural steel frame work.

40. What provision is made for expansion and contraction of the tubes?

Ans. They are slightly curved near the ends.

41. How are the hot gases directed in their course from furnace to stack?

Ans. By means of fire brick baffle walls.

42. How is the interior of this boiler cleaned?

Ans. Four manholes are provided in the drums, by which access to the interior of both the drums and tubes is obtained.

43. What type of boiler is the Maxim boiler?

Ans. It is a water-tube boiler consisting of two drums, one above the other, connected by tubes.

44. Describe the tubes.

Ans. Each tube has two bends, thus providing for unequal expansion or contraction.

45. How is the heating surface of the Maxim boiler arranged?

Ans. It is so arranged that the current of heated gases is made to travel three times the length of the tubes, the direction of the current being changed seven times in its route from furnace to stack.

46. What can be said of the Bigelow-Hornsby water-tube boiler?

Ans. Owing to the flexible form of its construction it is possible to build it in very large units, 2,000 horsepower and upwards.

47. What peculiar feature makes this possible?

Ans. Each section is independent of its neighbor, except the nipples connecting with the steam drum, and the equalizing nipples connecting the bottom drums of the rear sections.

48. How is the boiler supported?

Ans. Entirely from overhead beams.

49. What percentage of the heating surface do the tubes of the front unit comprise?

Ans. More than 12 per cent.

50. Where is the feed water first admitted?

Ans. Into the bottom drum of the rear unit.

51. Describe the course of the feed water.

Ans. The feed water is admitted into the bottom drum of the rear unit, and is advanced gradually from the coldest to the hottest portion of the boiler.

52. How is the speed of the feed water up the rear unit regulated?

Ans. By the amount of steam generated, ample time being permitted for scale forming matter to be deposited in the bottom drum of this unit.

53. Where does the liberation of steam take place?

Ans. In the upper drum.

54. What can be said of this boiler regarding the utilization of the heat?

Ans. It is baffled so that the products of combustion are carried uniformly over the heating surfaces in thin layers, the baffle plates serving to guide the gases through in substantially uniform passages.

55. To what factor of safety is the Bigelow-Hornsby boiler built?

Ans. Five for 200 pounds working pressure.

56. Describe in brief the Wickes vertical water-tube boiler.

Ans. It consists of two cylinders joined together endways by straight tubes, and erected in a vertical position.

57. What can be said of the top cylinder?

Ans. It is the longer, and is designated the steam drum.

58. What about the bottom cylinder?

Ans. It is the shorter, and is designated the mud drum. Both cylinders vary in dimensions as to diameter and length, according to the power required of the boiler.

59. Where are the manholes of the Wickes boiler?

Ans. One is placed in the convex head of the steam drum; there are also a number of hand-holes in this head. A manhole is also placed in the lower or mud drum, near the floor, thus permitting access to the top and bottom of the boiler.

60. How are these tubes divided?

Ans. By heavy fire-clay tile these tubes are divided into two compartments. Those tubes in the front compartment are called the "risers" and those in the rear the "downcomers."

61. What can be said of the heat in its double passage?

Ans. It surrounds completely, and closely the tubes in both compartments.

62. Where is the water line in this boiler?

Ans. At a sufficient height in the steam drum to insure the complete submersion of all the tubes.

63. How is the brick work setting of the Wickes water-tube boiler arranged?

Ans. It is independent of the weight of the boiler, and free to expand or contract.

64. Describe briefly the design of the Atlas water-tube boiler.

Ans. It consists mainly of three drums and two water legs extending crosswise, while the tubes extend lengthwise.

65. What is the original feature in the design of the water legs?

Ans. They are formed by the continuation of front and rear shell plates.

66. What other valuable feature is claimed for this boiler?

Ans. After the steam leaves the vessels containing water it is passed through a series of superheating tubes, and is superheated.

67. Describe the course of the feed water.

Ans. It is fed first into the purifier, whence it overflows into the rear drum and down into the rear leg, thence through the inclined tubes to the front leg, thence up into the front drum, where the steam is liberated and carried through superheating tubes to the steam drum.

68. What are the facilities for cleaning the water tubes of this boiler?

Ans. An individual hand-hole is located opposite each end of each water tube.

69. How is the interior of each of the three cross drums reached?

Ans. Through a large manhole in each end.

70. Describe briefly the design and construction of the Marzolf water-tube boiler.

Ans. It consists of three drums connected with each other in triangular form. Drum A directly over the fire is connected by tubes with drum B above it, and with drum C in the rear and slightly below it. Drum C, which is the mud drum, is also connected with drum B. The tubes are each slightly bent. The steam is collected in drum B, which is maintained about one-third full of water.

71. Describe in brief the action of the heat upon this boiler.

Ans. It acts first upon the water in drum A over the furnace, then by means of a baffle wall it is carried along the inclined tubes to drum B, where it is deflected and carried down along other inclined tubes to drum C, thence to the stack.

71. How are the products of combustion caused to act upon the lower bank of tubes?

Ans. By means of baffle walls located in the rear of the furnace.

72. At what point in this boiler is the feed water admitted?

Ans. At the lowest point, viz., the mud drum.

73. What are the principal advantages claimed for the Duplex water-tube boiler?

Ans. Delivery of superheated steam; the removal of steam from the boiler at a point where there is no ebullition; the drums not exposed to the direct action of the fire.

74. Describe in brief the design of this boiler.

Ans. Two upper steam drums connected by tubes, a mud drum at the bottom and rear which is connected to the upper drums by headers and short nipples. The tubes are inclined 20 degrees to insure rapid and positive circulation.

75. How is this boiler supported?

Ans. Upon a heavy steel framework.

76. What is the leading feature in connection with the Erie City water-tube boiler?

Ans. The three banks of tubes are practically vertical, connected to upper, and lower drums, and spaced so that any one of them may be cut out for repairs without interfering with the others.

77. How do the products of combustion act upon this boiler?

Ans. The baffling is arranged to pass three times across the tubes, and at each end of the upper drum is a dry chamber.

78. Describe in brief the best method of supporting horizontal tubular boilers.

Ans. By means of hangers suspended from I beams, supported by cast iron columns. This takes the weight off the side walls.

Boiler Construction

As it is of the highest importance not only to the engineer in charge of the plant, but also to his assistants, and in fact to all persons whose business compels them to be in the vicinity of the boiler-room, that there should be absolutely no doubt as to the safe construction of the boilers, and their ability to withstand the pressures under which they are operated, the author has compiled the following by such eminent authorities as Dr. Thurston, Prof. Wm. Kent, Dr. Peabody, D. K. Clark, Hutton and many other experts have been consulted, and the author has also added data regarding the construction and strength of boilers. The deductions and reports of tests and experiments made

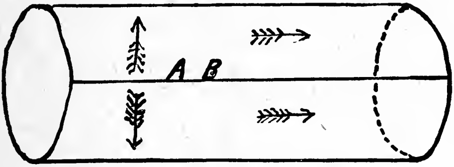


FIG. 29

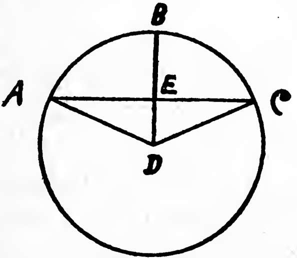


FIG. 30

the results of his own observations, collected during an experience of thirty-five years as a practical engineer.

When steel was first introduced as a material for boiler plate, it was customary to demand a high tensile strength, 70,000 to 74,000 pounds per square inch, but experience and practice demonstrated in course of time that it was much safer to use a material of lower tensile strength. It was found that with steel boiler plate of high tenacity there was great liability of its cracking, and also of certain changes occurring in its physical properties, brought about by the variations in temperature to which it was exposed. Consequently present-day specifications for steel boiler plate call for tensile strengths running from 55,000 to 66,000 pounds, usually 60,000 pounds per square inch. Dr. Thurston gives what he calls "good specifications" for boiler steel as follows: "Sheets to be of uniform thickness, smooth finish, and sheared closely to size ordered." Tensile strength to be 60,000 pounds per square inch for fire box sheets and 55,000 pounds per square inch for shell sheets. Working

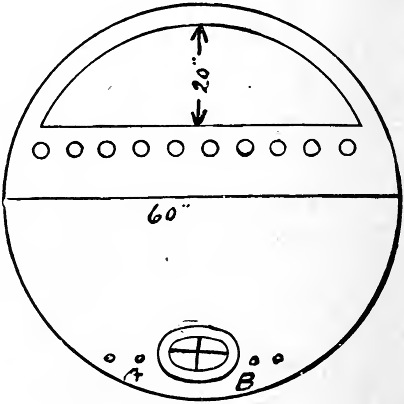


FIG. 31

test: a piece from each sheet to be heated to a dark cherry red, plunged into water at 60° and bent double, cold, under the hammer. Such piece to show no flaw after bending. The U. S. Board of Supervising Inspectors of Steam Vessels prescribes, in Section 3 of General Rules and Regulations, the following method for ascertaining the tensile strength of steel plate for boilers: "There shall be taken from each sheet to be used in shell or other parts of boiler which are subject to tensile strain, a test piece prepared in form according in figure 32. The straight part in center shall be 9 inches in length and 1 inch in width marked with light prick punch marks at distances 1 inch apart, as shown, spaced so as to give 8 inches in length. The sample must show, when tested, an elongation of at least 25 per cent in a length of 2 inches for thickness up to 1/4 inch, inclusive; in a length of 4 inches for over 1/4 inch to $\frac{7}{16}$ inches, inclusive; in a length of 6 inches, for all plates over $\frac{7}{16}$ inches and under 1 3/4 inches in thickness. The samples shall also be capable of being bent to a curve of which the inner radius is not greater than 1 1/2 times the thickness of the plates, after having been heated uniformly to a low cherry red and quenched in water of 82° F.

Punched and Drilled Plates. Much has been written on this subject, and it is still open for discussion. If the material is a good, soft steel, punched sheets are apparently as strong and in some instances stronger than drilled; especially is this the case with regard to the shearing resistance of the rivets, which is greater with punched than with drilled holes.

Concerning rivets and rivet iron and steel, Dr. Thurston has this to say in his "Manual of Steam Boilers": "Rivet iron should have a tenacity in the bar approaching 60,000 pounds per square inch, and should be as ductile as the very best boiler plate when cold. A good ⅝-inch iron rivet can be doubled up and hammered together cold without exhibiting a trace of fracture." The shearing resistance of iron rivets is about 85 per cent and that of steel rivets about 77 per cent of the tenacity of the original bar, as shown by experiments made by Greig and Eyth. The researches made by Wöhler demonstrated that the shearing strength of iron was about four-fifths of the tensile strength.

For the benefit of beginners, the following simple rules are given for finding the percentage of efficiency, or in other words the ratio of the strength of the riveted joint, to the strength of the solid plate. In these calculations the tensile strength of the rivets was assumed to be 38,000 to 40,000 pounds per square inch. The highest efficiency is attained in a riveted joint when the tensile strength of the rods from which the rivets are cut approaches that of the plates, and when the proportions of the joint are such that the tensile strength of the plates, the shearing strength of the rivets, and the crushing resistance of the rivets and plate, for a given section or unit strip, are as nearly equal as it is possible to secure them.

The shell should be made of homogeneous steel of about 60,000 pounds tensile strength. The thickness depending upon the pressure to be carried. The term tensile strength means that it would take a pull of 60,000 pounds in the direction of its length to break a bar of the material one inch square, or two inches wide by one-half inch thick, or three-eighths of an inch thick by 2.67 in. wide.

The heads are generally made ⅛ inch thicker than the shell.

Riveting. Boiler rivets should be of good charcoal iron, or a soft, mild steel of 38,000 pounds to 40,000 pounds, T. S. No boiler is stronger than its weakest part, and it is evident that a riveted joint has not the full strength of the solid plate. In order to ascertain the safe working pressure of a boiler it is necessary to first determine the strength of the riveted seams, and the method of doing this is as follows: Assume the boiler to be of the horizontal tubular type, 60 inches in diameter by 16 feet in length. The plates to be of steel 3/8 in. thick, having a tensile strength of 60,000 pounds per square inch, the longitudinal seams to be double riveted and the girth seams to be single riveted. The pitch of the rivets, that is the distance from the center of one rivet hole to the center of the next one in the same row, to be for the double riveted seams 3¼ inches and for the single riveted seams 2⅜ inches. The diameter of the rivets to be 7/8 inches and diameter of holes to be $\frac{15}{16}$ inches. Assume the rivets to have a T. S. of 38,000 pounds per square inch of sectional area. First, find strength of a section of solid plate 3¼ inches wide, which is the width between centers of rivet holes before punching.

Rule 1 Pitch × thickness × T. S. Thus, 3.25 × .375× 60,000 = 73,125 pounds, strength of solid plate.

Second, find strength of net section of plate, meaning that portion of plate left after deducting the diameter of one hole $\frac{15}{16}$ inches, which expressed in decimals = .9375 inches from the width of plate before punching.

Rule 2. Pitch—diameter of hole × thickness × T. S. Thus, 3.25—.9375×.375×60,000=52,031 pounds, strength of net section of plate.

Third, find strength of rivets. In calculating the strength of rivets in a double riveted seam, the sectional area of two rivets must be considered, taking one-half the area of two rivets in the first row, and the area of another rivet in the second row. The area of a 7/8-inch rivet is .6013 inches, but when in position it is assumed to fill the hole $\frac{15}{16}$ inches. Consequently, its area would then be .69 inches and its strength is found by Rule 3.

Rule 3. Sectional area×T. S. Thus, $.69\times38{,}000=26{,}220$ pounds, strength of one rivet, and multiplying by 2, as there are two rivets, the result is $26{,}220\times2=52{,}440$ pounds, strength of rivets in the seam under consideration. It thus appears that the plate is the weakest portion and the percentage of strength retained is found by multiplying 52,031 by 100 and dividing by 73,125, the strength of solid plate. Thus, $\frac{52{,}031\times100}{73{,}125}=71.1$ per cent.

The query might arise, why is the diameter of one rivet hole deducted from the pitch when figuring the strength of net plate? The answer is, that in punching the holes one-half the diameter of each hole is cut from the section designated, thereby reducing its width by just that amount.

The 71.1 per cent obtained by the calculation represents the strength of the boiler as compared to the strength of the sheet before punching, and should enter into all calculations for the safe working pressure.

It is usual in practice to figure the strength of a double-riveted seam at 70 per cent of the strength of the solid plate. The strength of triple-riveted butt joints may be calculated by taking a section of plate along the first row of rivets and estimate it as a single-riveted joint, then add to this result the strength of rivets in the second and third rows for a section of the same width. In properly designed triple-riveted butt joints the percentage of strength retained is 88, and some recent achievements in designing have shown the remarkable result of quadruple-riveted butt joints retaining as high as 92 to 94 per cent of the strength of the solid plate.

Bursting Pressure. The query might arise, why should the longitudinal or side seams require to be stronger than the girth or round about seams? The answer is, that the force tending to rupture the boiler along the line of the longitudinal seams is proportional to the diameter divided by two, while the stress tending to pull it apart endwise is only one-half that, or proportional to the diameter divided by four.

To illustrate, let Fig. 29 represent the shell of the boiler heretofore referred to, ignoring for the time being the tubes and braces, and consider the boiler simply as a hollow cylinder. Now the total force tending to rupture the boiler along the line of the girth seams or in the direction of the horizontal arrows=area of one head in square inches× pressure in pounds per square inch. It is true that the pressure is exerted against both heads, but the area of one head can only be considered for the reason that the two stresses are exerted against each other just as in the case of two horses pulling against each other, or in opposite direction on the same chain. The stress on the chain will be what one horse (not both) pulls. To further illustrate, suppose one of the horses to be replaced by a permanent post or wall and let one end of the chain be attached thereto. One head or one side of the boiler pulls against the other, and the stress on the seams is the force with which each (not both) pulls. Referring again to Fig. 29, area of one head$=60^2\times.7854=2827.4$ square inches. Suppose there is a pressure of 10 pounds per square inch in the boiler. Then total stress on the girth seams=2827.4×10=28,274 pounds. Opposed to this pull is the entire circumference of the boiler, which is 60×3.1416=188.5 inches. Therefore, dividing total pressure (28,274 pounds) by the circumference in inches (188.5) will give 150 pounds as the stress on each inch of the girth seams. While the stress on each inch of the longitudinal seams or along the line A B, Fig. 29, and which is exerted in the direction of the vertical arrows, is pressure (10 pounds)×one-half the diameter (30 inches)=300 pounds. One-half the diameter is used because the pressure in any direction is effective only on the surface at right angles to that direction.

The formula for finding the bursting pressure of a boiler may be expressed as follows:

$B=\frac{T.S.\times T}{R}$ in which B=bursting pressure.

T.S.=tensile strength.
T=thickness of sheet.
R=radius or one-half the diam.

Example. T.S.=55,000 pounds per square inch.
T=3/8 inches (expressed decimally=.375 inches).
R=30 inches.

Then 55,000×.375÷30=687.5 pounds per square inch, which is the pressure at which rupture would take place provided there were no seams in the boiler and the original strength of the sheet was retained, but, as has been seen, a certain percentage of strength is lost through punching or drilling the necessary rivet holes, and this must be taken into account.

The formula now becomes, for double riveting, $B=\frac{T.S.\times T\times .70}{R}$, in which the letters preserve the same value as in the original formula, but the result is reduced by multiplying by the decimal .70, which represents the percentage of strength retained by double-riveted seams. Consequently B will now$=\frac{55,000\times .375\times .70}{30}=481$ pounds.

In case the seams are all single riveted .56 must be substituted for .70, and with triple-riveted butt joints .88 can safely be used.

Safe Working Pressure. In order to ascertain the safe working pressure of a boiler it is necessary first to calculate the bursting pressure and divide this by another factor called the factor of safety. The one most commonly used for boilers is 5, or in other words the safe working pressure = one-fifth the bursting pressure. In the case of the boiler under consideration, the safe pressure would be $481\div 5=96$ pounds, at which point the safety valve should blow off.

Bracing. Every engineer can easily ascertain for himself whether the boilers under his charge are properly braced or not. The parts that require bracing are: all flat surfaces, such as the sides and top of the fire-box in boilers of the locomotive type, and those portions of the heads above and below the tubes in horizontal tubular boilers, also the top of the dome.

The stress per square inch of sectional area on braces and stays should not exceed 6,000 pounds. It is customary to consider the flange of the head and the top row of tubes as sufficient bracing for a space two inches wide above the tubes and the same distance around the flange. Therefore the part of the head to be braced will be the segment contained within a line drawn two inches above the top row of tubes and two inches inside the flange.

In order to ascertain the number of braces required for a given boiler head, three factors are necessary: first, the area of the segment in square inches; second, the diameter and T. S. of the braces, and third, the pressure to be carried. By the use of Table 2 the areas of segments of boiler heads ranging from 42 to 72 inches in diameter can easily be obtained. Assume the boiler to be 60 inches in diameter, distance from top of tubes to top of shell 24 inches. Deduct 4 inches for surface braced by top row of tubes and flange, leaving the height of segment to be braced 20 inches.

TABLE 2

Diameter of Boiler.	Distance from Tubes to Shell.	Height of Segment.	Constant.
42 in.	15 in.	11 in.	.16314
44 in.	17 in.	13 in.	.1936
48 in.	19 in.	15 in.	.20923
54 in.	21 in.	17 in.	.21201
60 in.	24 in.	20 in.	.22886
66 in.	25 in.	21 in.	.214
72 in.	29 in.	25 in.	.24212

Rule. Multiply the square of the diameter of the boiler by the constant number found in right hand column opposite column headed diameter.

Example. $60 \times 60 \times .22886 = 823.89$ square inches, area of segment to be braced. Find number of braces required. Assume the braces to be 1⅛ inches in diameter and of a T. S. of 38,000 pounds per square inch of section. The area of one brace will be .994 square inches, which × 6,000 pounds gives 5,964 pounds as the stress allowable on each brace. Suppose the pressure to be carried is 100 pounds per square inch. There will be area of segment (823.89 square inches)×pressure (100 pounds)=82,389 pounds, total stress. Dividing this result by 5,964 pounds (the capacity of each brace) gives 13.8 braces as the number needed. In practice there should be fourteen.

Having a T. S. of 38,000 pounds and using 6 as the factor of safety, each brace could safely sustain a pull of 6,295 pounds. Therefore it is evident that the above mentioned load for each brace is well within the limit. For convenience in calculating the areas of segments of circles, other than those mentioned in Table 2, the following rule is given:

Referring to Figure 30 it is desired to find the area of the segment contained within the lines A B C E. It will be necessary first to find the area of the sector bounded by the lines A B C D. This is done by multiplying one-half the length of the arc, A B C, by the radius, D B. Having obtained the area of the sector, the next step is to find the area of the triangle bounded by the lines A E C D and subtract it from the area of the sector. The remainder will be the area of the segment. Having found the area of the surface to be braced, and the number of braces required, it now becomes necessary to consider the spacing of the same.

Rule. Divide area to be braced by the number of braces, and extract the square root of quotient.

Example. 823.89÷14=58.8 square inches to be allotted to each brace. Extract square root of 58.8 and the result is 7.68 inches, which is the length of one side of the square which each brace will be required to sustain.

For internally fired boilers the same rules can be applied except that the surfaces to be braced are generally of rectangular shape and consequently the area is more easily figured than in the case of segments. That part of the head below the tubes also requires to be braced, and two braces are generally sufficient, as at A and B, Fig. 31. In the case of domes it is safe to consider the portion of the head within three inches of the flange as sufficiently braced. Then suppose the dome to be 36 inches in diameter, there will remain a circle 30 inches in diameter to be braced. The circumference of this circle is 94.2 inches and the pitch, or distance from center to center of the braces, being 7.6 inches, the number of braces required is found by dividing 94.2 by 7.6, giving 12 braces. These braces should be located along a line which is one-half the pitch, or 3.8 inches, within the circumference of the 30-inch circle. The space immediately surrounding the hole cut for the steam outlet will be sufficiently re-enforced by the flange riveted on for the reception of the steam pipe. All holes cut in boilers, such as man holes, hand holes, and those for pipe connections, above two inches should be properly re-enforced by riveting either inside or outside a wrought-iron or steel ring or flange of such thickness and width as to contain at least as much material as has been cut from the hole.

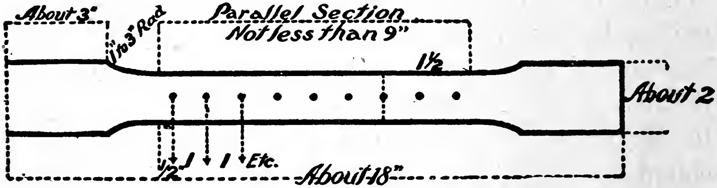


FIG. 32

TEST PIECE

The preceding rules and calculations will serve to give the young student an idea of the need of mathematics in boiler making, and the subject is to be pursued still farther and deeper, thus enabling the engineer in charge of a steam plant to calculate for himself whether or not his boilers are working within the margin of safety.

The tables that follow have been compiled from the highest authorities and show the results of a long and exhaustive series of tests and experiments made in order to ascertain the proportions of riveted joints that will give the highest efficiencies.

The following Table 3 gives the diameters of rivets for various thicknesses of plates and is calculated according to a rule given by Unwin:

TABLE 3

DIAMETERS OF RIVETS.

Thickness of Plate.	Diameter of Rivet.	Thickness of Plate.	Diameter of Rivet.
$\frac{1}{4}$ in.	$\frac{1}{2}$ in	$\frac{9}{16}$ in.	$\frac{7}{8}$ in.
$\frac{5}{16}$ in.	$\frac{9}{16}$ in.	$\frac{5}{8}$ in.	$\frac{15}{16}$ in.
$\frac{3}{8}$ in.	$\frac{11}{16}$ in.	$\frac{3}{4}$ in.	$1\frac{1}{16}$ in.
$\frac{7}{16}$ in.	$\frac{3}{4}$ in.	$\frac{7}{8}$ in.	$1\frac{1}{8}$ in.
$\frac{1}{2}$ in.	$\frac{13}{16}$ in.	1 in.	$1\frac{1}{4}$ in.

The efficiency of the joint is the percentage of the strength of the solid plate that is retained in the joint, and it depends upon the kind of joint and method of construction.

If the thickness of the plate is more than $\frac{1}{2}$ inch, the joint should always be of the double butt type.

The diameters of rivets, rivet holes, pitch and efficiency of joint, as given in the following Table 4, which was published in the "Locomotive" several years ago, were adopted at the time by some of the best establishments in the United States:

Concerning the proportions of double-riveted butt joints, Prof. Kent says: "Practically it may be said that we get a double-riveted butt joint of maximum strength by making the diameter of the rivet about 1.8 times the thickness of the plate, and making the pitch 4.1 times the diameter of the hole."

TABLE 4

PROPORTIONS AND EFFICIENCIES OF RIVETED JOINTS.

	Inch.	Inch.	Inch.	Inch.	Inch.
Thickness of plate	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$
Diameter of rivet	$\frac{5}{8}$	$\frac{11}{16}$	$\frac{3}{4}$	$\frac{13}{16}$	$\frac{7}{8}$
Diameter of rivet-hole...............	$\frac{11}{16}$	$\frac{3}{4}$	$\frac{13}{16}$	$\frac{7}{8}$	$\frac{15}{16}$
Pitch for single riveting............	2	$2\frac{1}{16}$	$2\frac{1}{8}$	$2\frac{3}{16}$	$2\frac{1}{4}$
Pitch for double riveting............	3	$3\frac{1}{8}$	$3\frac{1}{4}$	$3\frac{3}{8}$	$3\frac{1}{2}$
Efficiency, single-riveted joint........	.66	.64	.62	.60	.58
Efficiency, double-riveted joint.......	.77	.76	.75	.74	.73

Table 5 as given below is condensed from the report of a test of double-riveted lap and butt joints. In this test the tensile strength of the plates was 56,000 to 58,000 pounds per square inch, and the shearing resistance of the rivets (steel) was about 50,000 pounds per square inch.

TABLE 5

DIAMETER AND PITCH OF RIVETS—DOUBLE-RIVETED JOINT.

Kind of Joint.	Thickness of Plate.	Diameter of Rivet.	Ratio of Pitch to Diameter.
Lap	$\frac{3}{8}$ inch	0.8 inches	3.6 inches
Butt	$\frac{3}{8}$ inch	0.7 inches	3.9 inches
Butt	$\frac{3}{4}$ inch	1.1 inches	4.0 inches
Butt	1 inch	1.3 inches	3.9 inches

Lloyd's rules, condensed, are as follows:

TABLE 6

LLOYD'S RULES—THICKNESS OF PLATE AND DIAMETER OF RIVETS.

Thickness of Plate.	Diameter of Rivets.	Thickness of Plate.	Diameter of Rivets.
$\frac{3}{8}$ inch	$\frac{5}{8}$ inch	$\frac{3}{4}$ inch	$\frac{7}{8}$ inch
$\frac{7}{16}$ inch	$\frac{5}{8}$ inch	$\frac{13}{16}$ inch	$\frac{7}{8}$ inch
$\frac{1}{2}$ inch	$\frac{3}{4}$ inch	$\frac{7}{8}$ inch	1 inch
$\frac{9}{16}$ inch	$\frac{3}{4}$ inch	$\frac{15}{16}$ inch	1 inch
$\frac{5}{8}$ inch	$\frac{3}{4}$ inch	1 inch	1 inch
$\frac{11}{16}$ inch	$\frac{7}{8}$ inch		

The following Table 7 is condensed from one calculated by Prof. Kent, in which he assumes the shearing strength of the rivets to be four-fifths of the tensile strength of the plate per square inch, and the excess strength of the perforated plate to be 10 per cent.

TABLE 7

Thickness of Plate.	Diameter of Hole.	Pitch: Single Riveting.	Pitch: Double Riveting.	Efficiency: Single Riveting.	Efficiency: Double Riveting.
Inches.	Inches.	Inches.	Inches.	Per Cent.	Per Cent.
$\frac{3}{8}$	$\frac{7}{8}$	2.04	3.20	57.1	72.7
$\frac{7}{16}$	1	2.30	3.61	56.6	72.3
$\frac{1}{2}$	1	2.14	3.28	53.3	70.0
$\frac{1}{2}$	$1\frac{1}{8}$	2.57	4.01	56.2	72.0
$\frac{9}{16}$	1	2.01	3.03	50.4	67.0
$\frac{9}{16}$	$1\frac{1}{8}$	2.41	3.69	53.3	69.5
$\frac{9}{16}$	$1\frac{1}{4}$	2.83	4.42	55.9	71.5
$\frac{5}{8}$	1	1.91	2.82	47.7	64.6
$\frac{5}{8}$	$1\frac{1}{8}$	2.28	3.43	50.7	67.3
$\frac{5}{8}$	$1\frac{1}{4}$	2.67	4.10	53.3	69.5

Another table of joint efficiencies as given by Dr. Thurston is as follows, slightly condensed from the original calculation:

TABLE 8

Single riveting								
Plate thickness	$\frac{5}{16}''$	$\frac{3}{8}''$	$\frac{7}{16}''$	$\frac{1}{2}''$	$\frac{5}{8}''$	$\frac{3}{4}''$	$\frac{7}{8}''$	1″
Efficiency	.55	.55	.53	.52	.48	.47	.45	.43
Double riveting								
Plate thickness	$\frac{3}{8}''$	$\frac{7}{16}''$	$\frac{1}{2}''$	$\frac{3}{4}''$	$\frac{7}{8}''$	1″		
Efficiency	.73	.72	.71	.66	.61	.63		

The author has been at considerable pains to compile Tables 9, 10 and 11, giving proportions and efficiencies of single lap, double lap and butt, and triple-riveted butt joints. The highest authorities have been consulted in the computation of these tables and great care exercised in the calculations:

It will be noticed that in single-riveted lap joints the highest efficiencies are attained when the diameter of the rivet hole is about 2 1/3 times the thickness of the plate, and the pitch of the rivet 2⅜ times the diameter of the hole.

TABLE 9

PROPORTIONS OF SINGLE-RIVETED LAP JOINTS.

Thickness of Plate, Inches.	Diameter of Rivet, Inches.	Pitch of Rivet, Inches.	Efficiency, Per Cent.
5/16	9/16	1.13	50.5
5/16	5/8	1.33	53.3
5/16	11/16	1.55	55.7
3/8	3/4	1.60	53.3
3/8	7/8	2.04	57.1
7/16	7/8	1.87	53.2
7/16	1	2.30	56.6
1/2	1	2.14	53.3
1/2	1⅛	2.57	56.2
9/16	1	2.01	50.4
9/16	1⅛	2.41	53.3
9/16	1¼	2.83	55.9
5/8	1⅛	2.28	50.7
5/8	1¼	2.67	53.3

With the double-riveted joint it appears, according to Table 10, that in order to obtain the highest efficiency, the joint should be designed so that the diameter of the rivet hole will be from 1 4/5 to 2 times the thickness of plate, and the pitch should be from 3 1/3 to 3½ times the diameter of the hole. Concerning the thickness of plates Dr. Thurston has this to say: "Very thin plates cannot be well caulked, and thick plates cannot be safely riveted. The limits are about ¼ of an inch for the lower limit, and ¾ of an inch for the higher limit." The riveting machine, however, overcomes the difficulty with very thick plates.

The triple-riveted butt joint with two welts, one inside and one outside, has two rows of rivets in double shear and one outer row in single shear on each side of the butt, the pitch of rivets in the outer rows being twice the pitch of the inner rows. One of the welts is wide enough for the three rows of rivets each side of the butt, while the other welt takes in only the two close pitch rows.

TABLE 10

PROPORTIONS OF DOUBLE-RIVETED LAP AND BUTT JOINTS.

Thickness of Plate, Inches.	Diameter of Rivet, Inches.	Pitch of Rivet, Inches.	Efficiency, Per Cent.
$\frac{5}{16}$	$\frac{9}{16}$	1.71	67.1
$\frac{5}{16}$	$\frac{5}{8}$	2.05	69.5
$\frac{3}{8}$	$\frac{3}{4}$	2.46	69.5
$\frac{3}{8}$	$\frac{7}{8}$	3.20	72.7
$\frac{7}{16}$	$\frac{3}{4}$	2.21	66.2
$\frac{7}{16}$	$\frac{7}{8}$	2.86	69.4
$\frac{7}{16}$	1	3.61	72.3
$\frac{1}{2}$	1	3.28	70.0
$\frac{1}{2}$	$1\frac{1}{8}$	4.01	72.0
$\frac{9}{16}$	1	3.03	67.0
$\frac{9}{16}$	$1\frac{1}{8}$	3.69	69.5
$\frac{9}{16}$	$1\frac{1}{4}$	4.42	71.5
$\frac{5}{8}$	$1\frac{1}{8}$	3.43	67.3
$\frac{5}{8}$	$1\frac{1}{4}$	4.10	69.5
$\frac{3}{4}$	1	2.50	72.0
$\frac{7}{8}$	$1\frac{1}{8}$	3.94	74.2
1	$1\frac{1}{4}$	4.10	76.1

When properly designed this form of joint has a high efficiency, and is to be relied upon. Table 11 gives proportions and efficiencies, and it will be noted that the highest degree of efficiency is shown when the diameter of rivet hole is from 1¼ to 1½ times the thickness of plate, and the pitch of the rivets is from 3½ to 4 times the diameter of the hole. This, of course, refers to the pitch of the close rows of rivets, and not the two outer rows.

The highest efficiency is attained in a riveted joint when the tensile strength of the rods from which the rivets are cut approaches that of the plates, and when the proportions of the joint are such that the tensile strength of the plates, the shearing strength of the rivets, and the crushing resistance of the rivets and plate, for a given section or unit strip, are as nearly equal as it is possible to secure them.

TABLE 11

PROPORTIONS OF TRIPLE-RIVETED BUTT JOINTS WITH INSIDE AND OUTSIDE WELT.

Thickness of Plate, Inches.	Diameter of Rivet, Inches.	Pitch of Rivet, Inches.	Pitch of Outer Rows, Inches.	Efficiency, Per Cent.
$\frac{3}{8}$	$\frac{13}{16}$	3.25	6.5	84
$\frac{7}{16}$	$\frac{13}{16}$	3.25	6.5	85
$\frac{1}{2}$	$\frac{13}{16}$	3.25	6.5	83
$\frac{9}{16}$	$\frac{7}{8}$	3.50	7.0	84
$\frac{5}{8}$	1	3.50	7.0	86
$\frac{3}{4}$	$1\frac{1}{16}$	3.50	7.0	85
$\frac{7}{8}$	$1\frac{1}{8}$	3.75	7.5	86
1	$1\frac{1}{4}$	3.87	7.7	84

A few examples of calculations for efficiency will be given, taking the three forms of riveted joints in most common use. The following notation will be used throughout:

T. S.=Tensile strength of plate per square inch.
T=Thickness of plate.
C=Crushing resistance of plate and rivets.
A=Sectional area of rivets.
S=Shearing strength of rivets.
D=Diameter of hole (also diameter of rivets when driven).
P=Pitch of rivets.

In the calculations that follow T. S. will be assumed to be 60,000 pounds, S will be taken at 45,000 pounds, and the value of C may be assumed to be 90,000 to 95,000.

DOUBLE-RIVETED LAP AND BUTT JOINTS.

Figure 33 shows a double-riveted lap joint. The style of riveting in this joint is what is known as chain riveting.

In case the rivets are staggered, the same rules for calculating the efficiency will hold as with chain riveting, for the reason that with either style of riveting the unit strip of plate has a width equal to the pitch or distance p. (Fig. 33.)

The dimensions of the joint under consideration are as follows: P=3¼ inches, T=$\frac{7}{16}$ inch, D=1 inch (which is also diameter of driven rivet).

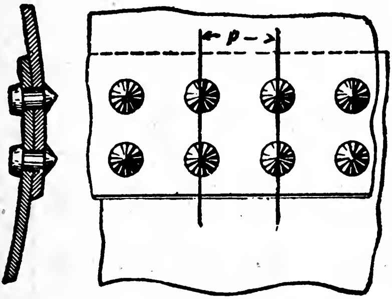


FIG. 33

DOUBLE RIVETED LAP JOINT.

The strength of the unit strip of solid plate is P×T×T. S.=85,312.

The strength of net section of plate after drilling is P—D×T×T.S.=59,062.

The shearing resistance of two rivets is 2A×S=70,686.

The crushing resistance of rivets and plate is D×2×T ×C=78,750.

It thus appears that the weakest part of the joint is the net strip or section of plate, the strength of which is 59,062 and the efficiency=59,062×100÷85,312=69.2 per cent.

A double-riveted butt joint is illustrated by Fig. 34, and the dimensions are as follows:

P, inner row of rivets=2¾ inches.

P′, outer row of rivets=5½ inches.

T of plate and butt straps=$\frac{7}{16}$ inch.

D of hole and driven rivet=1 inch.

Failure may occur in this joint in five distinct ways, which will be taken up in their order.

1. Tearing of the plate at the outer row of rivets. The net strength at this point is $P-D\times T\times T.S.$, which, expressed in plain figures, results as follows: $5.5-1\times.4375\times60{,}000=118{,}125$.

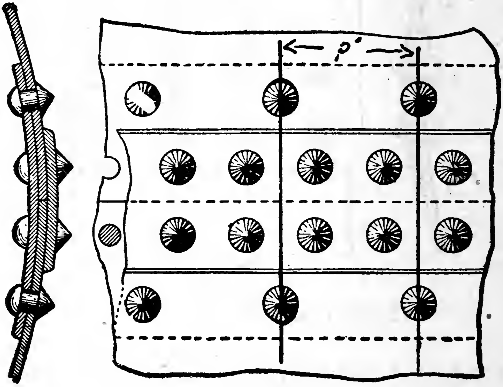


Fig. 34

DOUBLE RIVETED BUTT JOINT

2. Shearing two rivets in double shear and one in single shear. Should this occur, the two rivets in the inner row would be sheared on both sides of the plate, thus being in double shear. Opposed to this strain there are four sections of rivets, two for each rivet. Then at the outer row of rivets in the unit strip there is the area of one rivet in single shear to be added. The total resistance, therefore, is $5A\times S$ as follows: $.7854\times5\times45{,}000=176{,}715$.

3. The plate may tear at the inner row of rivets and shear one rivet in the outer row. The resistance in this case would be $P'-2D\times T\times T.S.+A\times S$ as follows: $5.5-2\times.4375\times60{,}000+.7854\times45{,}000=127{,}218$.

4. Failure may occur by crushing in front of three rivets. Opposed to this is $3D\times T\times C$, or $1\times3\times.4375\times95{,}000=124{,}687$.

5. Failure may occur by crushing in front of two rivets and shearing one. The resistance is represented by $2D \times T \times C + 1A \times S$; expressed in figures, $1 \times 2 \times .4375 \times 95{,}000 + .7854 \times 45{,}000 = 118{,}468$.

The strength of a solid strip of plate 5½ inches wide before drilling is $P' \times T \times T.S.$, or $5.5 \times .4375 \times 60{,}000 = 144{,}375$, and the efficiency of the joint is $118{,}125 \times 100 \div 144{,}375 = 81.1$ per cent.

TRIPLE-RIVETED BUTT JOINT.

A triple-riveted butt joint is shown in Fig. 35, the dimensions of which are as follows:

$T = \frac{7}{16}$ inch, $D = \frac{15}{16}$ inch, $A = .69$ inch, $P = 3\frac{3}{8}$ inches, $P' = 6\frac{3}{4}$ inches.

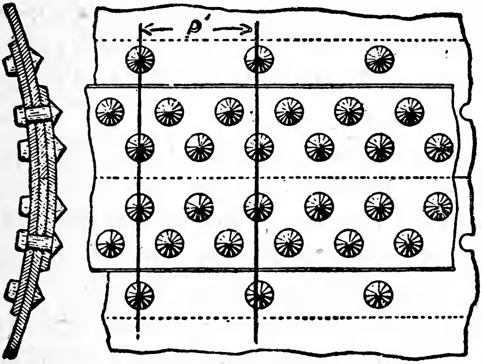


FIG. 35
TRIPLE RIVETED BUTT JOINT

Failure may occur in this joint in either one of five ways.

1. By tearing the plate at the outer row of rivets where the pitch is 6¾ inches. The net strength of the unit strip at this point is $P' - D \times T \times T.S.$, found as follows: $6.75 - .9375 \times .4375 \times 60{,}000 = 152{,}578$.

2. By shearing four rivets in double shear and one in single shear. In this instance, of the four rivets in double shear, each one presents two sections, and the one in single shear presents one, thus making a total of nine sections of rivets to be sheared, and the strength is $9A \times S$, or $.69 \times 9 \times 45{,}000 = 279{,}450$.

3. Rupture of the plate at the middle row of rivets and shearing one rivet. Opposed to this strain the strength is $P' - 2D \times T \times T.S. + 1A \times S$, equivalent to $6.75 - (.9375 \times 2) \times .4375 \times 60{,}000 + .69 \times 90{,}000 = 190{,}068$.

4. Crushing in front of four rivets and shearing one rivet. The resistance in this instance is $4D \times T \times C + 1A \times S$, or $.9375 \times 4 \times .4375 \times 90{,}000 + .69 \times 45{,}000 = 178{,}706$.

5. Failure may be caused by crushing in front of five rivets, four of which pass through both the inside and outside butt straps, while the fifth rivet passes through the inside strap only, and the resistance is $5D \times T \times C$, equivalent to $.9375 \times 5 \times 90{,}000 = 184{,}570$.

The strength of the unit strip of plate before drilling is $P' \times T \times T.S.$, or $6.75 \times .4375 \times 60{,}000 = 177{,}187$, and the efficiency is $152{,}578 \times 100 \div 177{,}187 = 86$ per cent.

With the constantly increasing demand for higher steam pressures, the necessity for higher efficiencies in the riveted joints of boilers becomes more apparent, and of late years quadruple and even quintuple-riveted butt joints have in many instances come into use. The quadruple butt joint when properly designed shows a high efficiency, in some cases as high as 94.6 per cent. Figure 36 illustrates a joint of this kind, and the dimensions are as follows:

$T = \frac{1}{2}$ inch.
$D = \frac{15}{16}$ inch.
$A = .69$ inch.

P, inner rows=3¾ inches.
P′, 1st outer row=7½ inches.
P″, 2d outer row=15 inches.

The two inner rows of rivets extend through the main plate and both the inside and outside cover plates or butt straps.

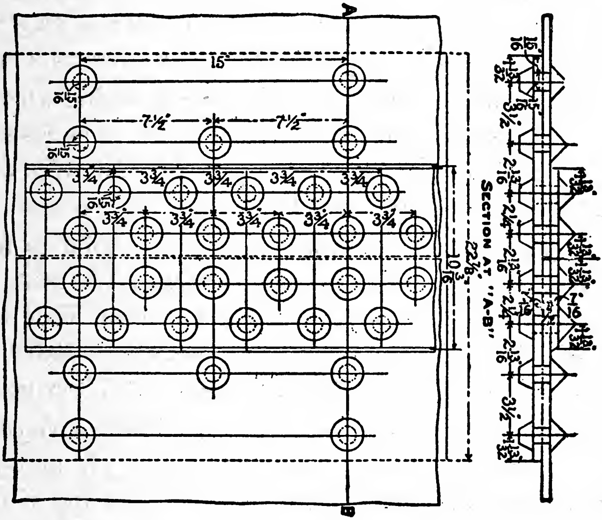


Fig. 36
QUADRUPLE RIVETED BUTT JOINT

The two outer rows reach through the main plate and inside cover plate only, the first outer row having twice the pitch of the inner rows, and the second outer row has twice the pitch of the first.

Taking a strip or section of plate 15 inches wide (pitch of outer row), there are four ways in which this joint may fail.

1. By tearing of the plate at the outer row of rivets. The resistance is $P'' - D \times T \times T.S.$, or $15 - .9375 \times .5 \times 60{,}000 = 421{,}875$.

2. By shearing eight rivets in double shear and three in single shear. The strength in resistance is $19A \times S$, or $.69 \times 19 \times 45{,}000 = 589{,}950$.

3. By tearing at inner rows of rivets and shearing three rivets. The resistance is $P'' - 4D \times T \times T.S. + 3A \times S$, or $15 - (.9375 \times 4) \times .5 \times 60{,}000 + .69 \times 3 \times 45{,}000 = 430{,}650$.

4. By tearing at the first outer row of rivets, where the pitch is 7½ inches, and shearing one rivet. The resistance is $P'' - 2D \times T \times T.S. + A \times S$, or $15 - (.9375 \times 2) \times .5 \times 60{,}000 + .69 \times 45{,}000 = 424{,}800$.

It appears that the weakest part of the joint is at the outer row of rivets, where the net strength is 421,875. The strength of the solid strip of plate 15 inches wide before drilling is $P'' \times T \times T.S.$, or $15 \times .5 \times 60{,}000 = 450{,}000$, and the efficiency is $421{,}875 \times 100 \div 450{,}000 = 93.7$ per cent.

Figure 37 shows another style of quadruple-riveted butt joint. This joint is now used on nearly all high-grade boilers of the horizontal return-tubular type, and it marks about the practical limit of efficiency for riveted joints connecting plates of uniform thickness together. The methods of failure to be considered are practically the same as in the two preceding joints, except that there are more rivets concerned in the calculations:

(1) Pulling apart of the sheets along net section A A.

(2) Pulling apart of the sheet along section D E F G and shearing rivets A, B, C.

(3) Pulling apart of sheet along section D E F G and crushing of rivets A, B, C in the strap.

(4) Shearing rivets A, B, C in single shear and D, E, F, G, H, I, J, K in double shear.

(5) Crushing of rivets D, E, F, G, H, I, J, K in plate and A, B, C in the strap.

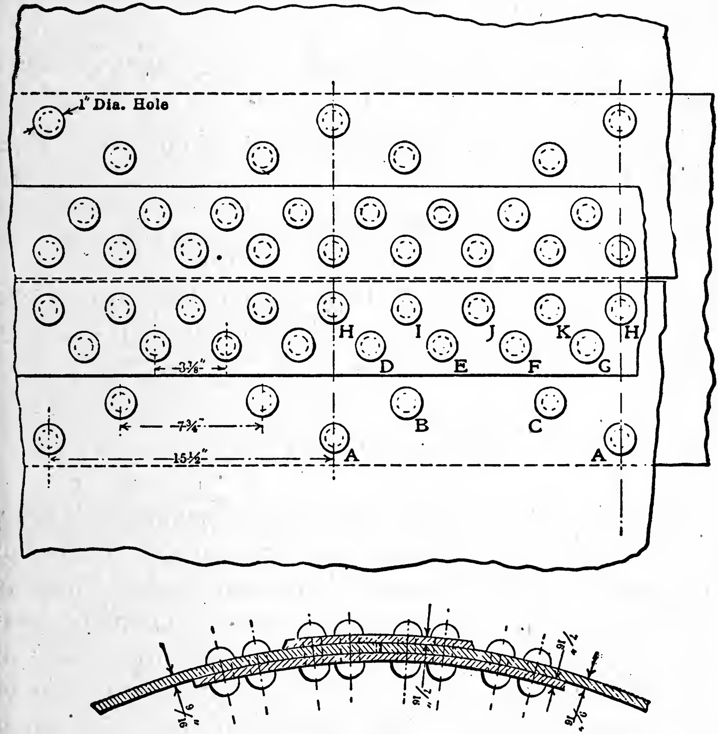


FIG. 37

QUADRUPLE RIVETED BUTT JOINT

(6) Crushing of rivets D, E, F, G, H, I, J, K in the plate and shearing rivets A, B, C.

Using the numerical values previously given:

(1) $(15.5-1)\times 0.5625\times 55{,}000=448{,}580$ pounds.

(2) $[(15.5-4)\times 0.5625\times 55{,}000]+(3\times 42{,}000\times 0.7854)=454{,}739$ pounds.

(3) $[(15.5-4)\times 0.5625\times 55{,}000]+(3\times 0.4375\times 1\times 95{,}000)=480{,}465$ pounds.

(4) $(3\times 42{,}000\times 0.7854)+(8\times 78{,}000\times 0.7854)=589{,}050$ pounds.

(5) $(8\times 0.5625\times 1\times 95{,}000)+(3\times 0.4375\times 1\times 95{,}000)=552{,}187$ pounds.

(6) $(8\times 0.5625\times 1\times 95{,}000)+(3\times 42{,}000\times 0.7854)=526{,}461$ pounds.

The strength of the solid plate is

$$15.5\times 0.5625\times 55{,}000=479{,}528$$

pounds, and the failure of the sheet by pulling apart along the net section A A is the one that determines the efficiency of the joint, which is

$$\frac{448{,}580}{479{,}528}=93.55 \text{ per cent.}$$

Staying Flat Surfaces. The proper staying or bracing of all flat surfaces in steam boilers is a highly important problem, and while there are various methods of bracing resorted to, still, as Dr. Peabody says, "the staying of a flat surface consists essentially in holding it against pressure at a series of isolated points which are arranged in regular or symmetrical pattern." The cylindrical shell of a boiler does not need bracing, for the very simple reason that the internal pressure tends to keep it cylindrical. On the contrary, the internal pressure has a constant tendency to bulge out the flat surface. Rule 2, Section 6, of the rules of the U. S. Supervising Inspectors provides as follows: "No braces or stays hereafter to be employed in the construction of boilers shall be allowed a greater strain than 6,000 pounds per square inch of section."

The method to be employed in staying a boiler depends upon the type of boiler and the pressure to be carried. Formerly when comparatively low pressures were used (60 to 75 pounds per square inch) the diagonal crow foot brace was considered amply sufficient for staying the flat heads of boilers of the cylindrical tubular type, both above and below the tubes, but in the present age, when much higher pressures are demanded, through stay rods are largely employed. These are soft steel or iron rods 1¼ to 2 inches in diameter, extending through from head to head, with a pull at right angles to the plate, thus having a great advantage over the diagonal stay in that the pull on the diagonal stay per square inch of section is more than 5 per cent in excess of what a through stay would have to resist under the same conditions of pressure.

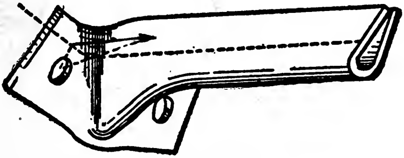


FIG. 38

The weakest portion of the crow foot brace when in position is at the foot end, where it is connected to the head by two rivets. With a correctly designed brace the pull on these rivets is direct, and the tensile strength of the material needs to be considered only, but if the form of the brace is such as to bring the rivet holes above or below the center line of the brace, or if the rivets are pitched too far from the body of the brace, there will be a certain leverage exerted upon the rivets in addition to the direct pull. Figure 38 shows a brace of incorrect design and Figs. 39 and 40 show braces designed along correct lines.

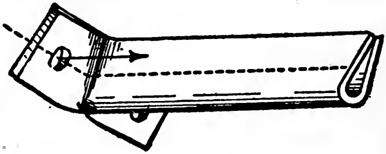


FIG. 39

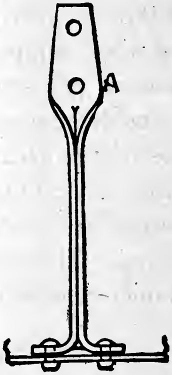


FIG. 40

Other methods of staying, besides the crow foot brace and through stays, consist of gusset stays, and for locomotives, and other fire box boilers screwed stay bolts are employed to tie the fire box to the external shell. The holes for these stay bolts are punched or drilled before the fire box is put in place. After it is in and riveted along the lower edge to the foundation ring, or mud ring as it is sometimes called, a continuous thread is tapped in the holes in both the outside plate and the fire sheet by running a long tap through both plates. The steel stay bolt is then screwed through the plates and allowed to project enough at each end to permit of its being riveted cold. Stay bolts are liable to be broken by the unequal expansion of the fire box and outer shell, and a small hole should be drilled in the center of the bolt, from the outer end nearly through to the inner end. Then in case a bolt breaks, steam or water will blow out through the small hole, and the break will be discovered

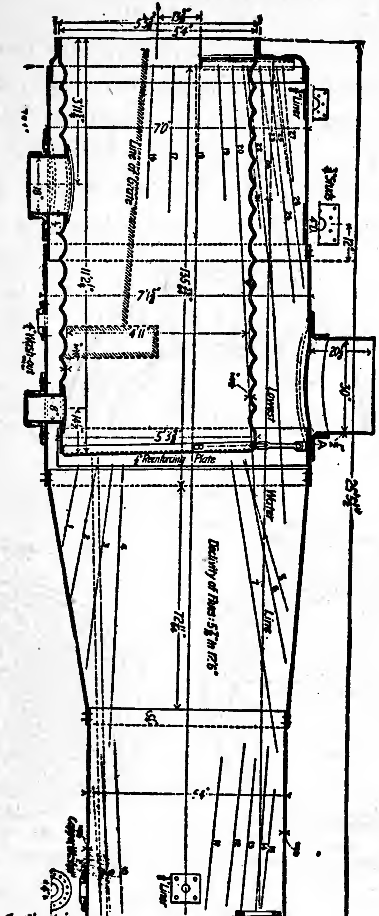
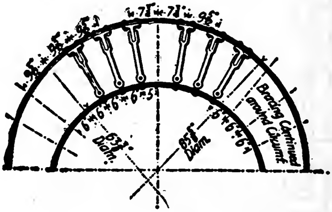

Line of Grate
Lowest
Water
Line
Delivery of Flues
Reenforcing Plate
Wash-out
Liner
Ring
A
B
C
D
35
17
67"
45"
30"
12"
5'4"
7'0"
4'11"
5'3"

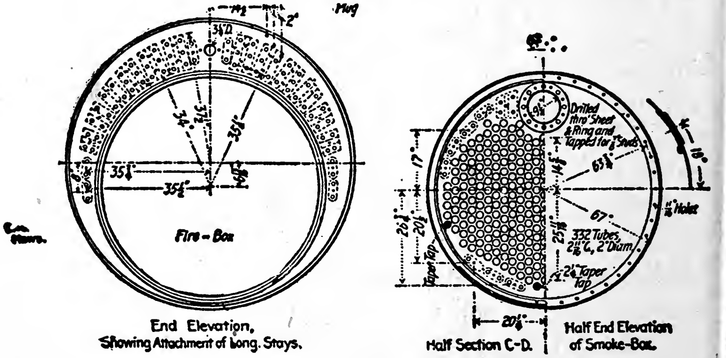
FIG. 41

at once. The problem of properly staying the flat crown sheet of a horizontal fire box boiler, especially a locomotive boiler, is a very difficult one and has taxed the inventive genius of some of the most eminent engineers.

Before the invention of the Belpaire boiler, with its outside, or shell plate flat above the fire box, the only method



Vertical Section A-B.



End Elevation, Showing Attachment of Long. Stays.

Half Section C-D.

Half End Elevation of Smoke-Box.

FIG. 42

of staying the crown sheet was by the use of cumbersome crown bars or double girders extending across the top of the crown sheet, and supported at the ends by special castings that rest on the edges of the side sheets and on the flange of the crown sheet. At intervals of 4 or 5 inches crown bolts are placed, having the head inside the fire box and the nut bearing on a plate on top of the girder. There is also a thimble for each bolt to pass through, between the top of the crown sheet and the girder. These thimbles maintain the proper distance between the crown sheet and girder and allow the water to circulate freely.

The Belpaire fire box dispenses with girders, and permits the use of through stays from the top of the flat outside plate, through the crown sheet and secured at each end by nuts, and copper washers.

For simplicity of construction and great strength the cylindrical form of fire box known as the Morison corrugated furnace has proved to be very successful. This form of fire box was in 1899 applied to a locomotive by Mr. Cornelius Vanderbilt, at the time assistant superintendent of motive power of the New York Central & Hudson River R. R. This furnace was rolled of $\frac{3}{4}$-inch steel, is 59 inches internal diameter and 11 feet $2\frac{1}{4}$ inches in length. It was tested under an external pressure of 500 pounds per square inch before being placed in the boiler. It is carried at the front end by a row of radial sling stays from the outside plate, and supported at the rear by the back head. Figures 41 and 42 show respectively a sectional view, and an end elevation of this boiler. It will be seen at once that the question of stays for a fire box of this type becomes very simple. The boiler has proved to be so satisfactory that the company has since had many more of the same type constructed.

Gusset stays are used mainly in boilers of the Lancashire model, and are triangular-shaped plates sheared to the proper form and having two angle irons riveted to the edges that comes against the shell, and the head. The angle irons are then riveted to the shell and the flat head. This form of brace is simple and solid, but its chief defect is, that it is very rigid, and does not allow for the unequal expansion of the internal furnace flues and the shell. Fig. 43 illustrates a gusset stay and the method of applying it.

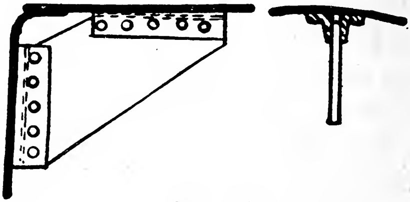


Fig. 43

Coming now to through stay rods, it is safe to say that whenever, and wherever it is possible to apply them they should be used. In all cases they should be placed far enough apart to allow a man to pass between them for the purposes of inspection and washing out of the boiler. Through stay rods are usually spaced 14 inches apart horizontally, and about the same distance vertically. The ends, as far back as the threads run, are swaged larger than the body, so that the diameter at the bottom of the thread is greater than the diameter of the body. There are several methods of applying through stays. One of the most common, especially for land boilers, is to allow the ends of the rod to project through the plates to be stayed, and holding them in place by a nut and copper washer, both inside and outside the plate. Another and still better plan is to rivet 6-inch channel bars across the head, inside above the tubes, the number of bars depending upon the height of the segment to be stayed.

The channel bars are drilled to correspond with the holes that are drilled in the plate to receive the stay rods, which latter are then secured by inside and outside nuts and copper washers. These channel bars act as girders, and serve to greatly strengthen the head or flat plate. Fig. 44 will serve to illustrate this method.

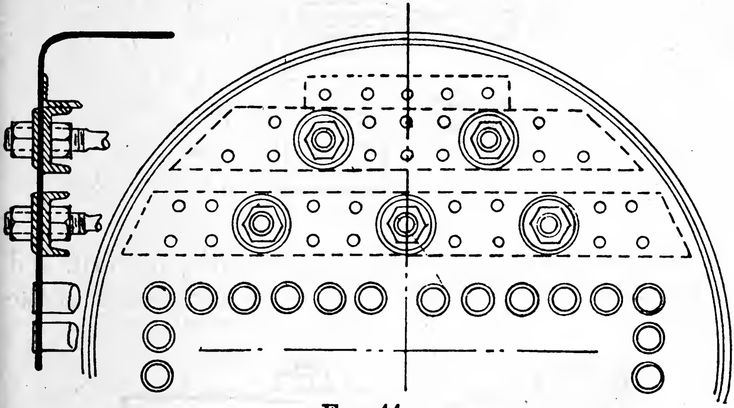


FIG. 44

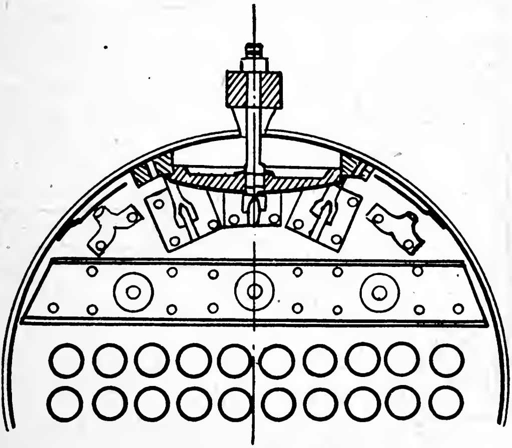


FIG. 45

Sometimes a combination of channel bar and diagonal crow foot braces is used, as shown by Fig. 45.

A good form of diagonal crow foot stay is obtained by using double crow feet, made of pieces of boiler plate bent as shown by Fig. 46 and riveted to the plate by four rivets.

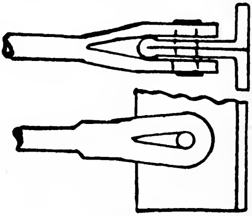


Fig. 46

A hole is drilled through the body of the crow foot, and a bolt passing through this secures the forked end of the stay.

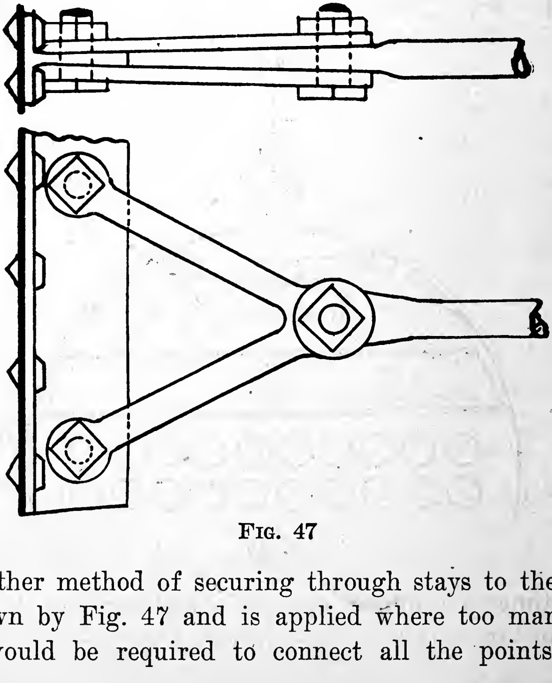


Fig. 47

Another method of securing through stays to the heads is shown by Fig. 47 and is applied where too many stay rods would be required to connect all the points to be stayed. A tie iron is first riveted to the flat plate to be stayed, and two V-shaped forgings are bolted to it as shown. The through stay is then bolted to the forgings, and thus two points in the flat head are supported by one stay. It will readily be seen that this method will reduce the number of through stay rods required.

Calculating the Strength of Stayed Surfaces. In calculations for ascertaining the strength of stayed surfaces, or for finding the number of stays required for any given flat surface in a boiler, the working pressure being known, it must be remembered that each stay is subjected to the pressure on an area bounded by lines drawn midway between it and its neighbors. Therefore the area in square inches, of the surface to be supported by each stay, equals the square of the pitch or distance in inches between centers of the points of connection of the stays to the flat plate. Thus, suppose the stays in a certain boiler are spaced 8 inches apart, the area sustained by each stay$=8\times8=64$ square inches, or assume the stay bolts in a locomotive fire box to be pitched $4\frac{1}{2}$ inches each way, the area supported by each stay bolt$=4\frac{1}{2}\times4\frac{1}{2}=20\frac{1}{4}$ square inches. Again taking through stay rods, suppose, for example, the through stays shown in Fig. 44 to be spaced 15 inches horizontally and 14 inches vertically, the area supported by each stay$=15\times14=210$ square inches.

The minimum factor of safety for stays, stay bolts and braces is 8, and this factor should enter into all computations of the strength of stayed surfaces.

The pitch for stays depends upon the thickness of the plate to be supported, and the maximum pressure to be carried.

In computing the total area of the stayed surface it is safe to assume that the flange of the plate, where it is riveted to the shell, sufficiently strengthens the plate for a distance of 2 inches from the shell, also that the tubes act as stays for a space of 2 inches above the top row. Therefore the area of that portion of the flat head or plate bounded by an imaginary line drawn at a distance of 2 inches from the shell and the same distance from the last row of tubes is the area to be stayed. This surface may be in the form of a segment of a circle, as with a horizontal cylindrical boiler, or it may be rectangular in shape, as in the case of a locomotive, or other fire box boiler. Other forms of stayed surfaces are often encountered, but in general the rules applicable to segments or rectangular figures will suffice for ascertaining the areas.

The method of finding the area of the segmental portion of the head above the tubes is as follows, using Table 12. The diameter of the circle and the rise or height of the segment being known, the area of the segment may be found by the following rule:

Rule. Divide the height of the segment by the diameter of the circle. Then find the decimal opposite this ratio in the column headed "Area." Multiply this area by the square of the diameter. The result is the required area.

Example. Diameter of circle=72 inches. Height of segment=25 inches. 25÷72=.347, which will be found in the column headed "Ratio," and the area opposite this is .24212. Then .24212×72×72=1,255 square inches, area of segment.

The following examples of calculating the number of braces, and the spacing of the same will serve to make the matter plain.

A boiler is 66 inches in diameter, the working pressure is 100 pounds per square inch. The distance from the top row of tubes to the shell is 25 inches. Required, the num-

TABLE 12

AREAS OF SEGMENTS OF A CIRCLE.

Ratio	Area	Ratio	Area	Ratio	Area	Ratio	Area
.2	.11182	.243	.14751	.286	.18542	.329	.22509
.201	.11262	.244	.14837	.287	.18633	.33	.22603
.202	.11343	.245	.14923	.288	.18723	.331	.22697
.203	.11423	.246	.15009	.289	.18814	.332	.22792
.204	.11504	.247	.15095	.29	.18905	.333	.22886
.205	.11584	.248	.15182	.291	.18996	.334	.22980
.206	.11665	.249	.15268	.292	.19086	.335	.23074
.207	.11746	.25	.15355	.293	.19177	.336	.23169
.208	.11827	.251	.15441	.294	.19268	.337	.23263
.209	.11908	.252	.15528	.295	.19360	.338	.23358
.21	.11990	.253	.15615	.296	.19451	.339	.23453
.211	.12071	.254	.15702	.297	.19542	.34	.23547
.212	.12153	.255	.15789	.298	.19634	.341	.23642
.213	.12235	.256	.15876	.299	.19725	.342	.23737
.214	.12317	.257	.15964	.3	.19817	.343	.23832
.215	.12399	.258	.16051	.301	.19908	.344	.23927
.216	.12481	.259	.16139	.302	.20000	.345	.24022
.217	.12563	.26	.16226	.303	.20092	.346	.24117
.218	.12646	.261	.16314	.304	.20184	.347	.24212
.219	.12729	.262	.16402	.305	.20276	.348	.24307
.22	.12811	.263	.16490	.306	.20368	.349	.24403
.221	.12894	.264	.16578	.307	.20460	.35	.24498
.222	.12977	.265	.16666	.308	.20553	.351	.24593
.223	.13060	.266	.16755	.309	.20645	.352	.24689
.224	.13144	.267	.16843	.31	.20738	.353	.24784
.225	.13227	.268	.16932	.311	.20830	.354	.24880
.226	.13311	.269	.17020	.312	.20923	.355	.24976
.227	.13395	.27	.17109	.313	.21015	.356	.25071
.228	.13478	.271	.17198	.314	.21108	.357	.25167
.229	.13562	.272	.17287	.315	.21201	.358	.25263
.23	.13646	.273	.17376	.316	.21294	.359	.25359
.231	.13731	.274	.17465	.317	.21387	.36	.25455
.232	.13815	.275	.17554	.318	.21480	.361	.25551
.233	.13900	.276	.17644	.319	.21573	.362	.25647
.234	.13984	.277	.17733	.32	.21667	.363	.25743
.235	.14069	.278	.17823	.321	.21760	.364	.25839
.236	.14154	.279	.17912	.322	.21853	.365	.25936
.237	.14239	.280	.18002	.323	.21947	.366	.26032
.238	.14324	.281	.18092	.324	.22040	.367	.26128
.239	.14409	.282	.18182	.325	.22134	.368	.26225
.24	.14494	.283	.18272	.326	.22228	.369	.26321
.241	.14580	.284	.18362	.327	.22322	.37	.26418
.242	.14666	.285	.18452	.328	.22415	.371	.26514

TABLE 12—CONTINUED.

Ratio	Area	Ratio	Area	Ratio	Area	Ratio	Area
.372	.26611	.405	.29827	.438	.33086	.471	.36373
.373	.26708	.406	.29926	.439	.33185	.472	.36471
.374	.26805	.407	.30024	.44	.33284	.473	.36571
.375	.26901	.408	.30122	.441	.33384	.474	.36671
.376	.26998	.409	.30220	.442	.33483	.475	.36771
.377	.27095	.41	.30319	.443	.33582	.476	.36871
.378	.27192	.411	.30417	.444	.33682	.477	.36971
.379	.27289	.412	.30516	.445	.33781	.478	.37071
.38	.27386	.413	.30614	.446	.33880	.479	.37171
.381	.27483	.414	.30712	.447	.33980	.48	.37270
.382	.27580	.415	.30811	.448	.34079	.481	.37370
.383	.27678	.416	.30910	.449	.34179	.482	.37470
.384	.27775	.417	.31008	.45	.34278	.483	.37570
.385	.27872	.418	.31107	.451	.34378	.484	.37670
.386	.27969	.419	.31205	.452	.34477	.485	.37770
.387	.28067	.42	.31304	.453	.34577	.486	.37870
.388	.28164	.421	.31403	.454	.34676	.487	.37970
.389	.28262	.422	.31502	.455	.34776	.488	.38070
.39	.28359	.423	.31600	.456	.34876	.489	.38170
.391	.28457	.424	.31699	.457	.34975	.49	.38270
.392	.28554	.425	.31798	.458	.35075	.491	.38370
.393	.28652	.426	.31897	.459	.35175	.492	.38470
.394	.28750	.427	.31996	.46	.35274	.493	.38570
.395	.28848	.428	.32095	.461	.35374	.494	.38670
.396	.28945	.429	.32194	.462	.35474	.495	.38770
.397	.29043	.43	.32293	.463	.35573	.496	.38870
.398	.29141	.431	.32392	.464	.35673	.497	.38970
.399	.29239	.432	.32941	.465	.35773	.498	.39070
.4	.29337	.433	.32590	.466	.35873	.499	.39170
.401	.29435	.434	.32689	.467	.35972	.5	.39270
.402	.29533	.435	.32788	.468	.36072		
.403	.29631	.436	.32887	.469	.36172		
.404	.29729	.437	.32987	.47	.36272		

ber of diagonal crow foot braces that will be needed to support the heads above the tubes, also the sectional area of each brace. The thickness of the head is ⅝ inch and the T.S.=55,000 pounds per square inch.

Assume the head to be sufficiently strengthened by the flange for a distance of 2 inches from the shell, the diameter of the circle of which the segment above the tubes requires to be stayed is reduced by 2+2=4 inches and will therefore be 66—4=62 inches. The rise or height of the segment above the tubes is 25—4=21 inches. Required, the area. 21÷62=.338. Looking down the column headed "Ratio" in Table 12, area opposite .338 is .23358. Area of segment=.23358×62×62=897.88 square inches. The total pressure on this area will be 897.88×100=89,788 pounds.

Assume the braces to be made of 1⅛ inch round steel, having a T.S. of 50,000 pounds per square inch and to be designed in such a manner as to allow for loss of material in drilling the rivet holes in the crow feet. Each brace will have a sectional area of .994 square inches, and using 8 as a factor of safety, the strength or safe holding power of each stay may be found as follows: .994×50,000÷8=6,212 pounds, and the number of stays required=89,788 pounds (total pressure) divided by 6,212 pounds (strength of each stay)=14.5, or in round numbers 15. If the stays are made of flat bars of steel the sectional area should equal that of the round stays, and the dimensions of the crow feet of all stays should be such as to retain the full sectional area of the body after the rivet holes are drilled.

Each stay is connected to the plate by two ⅞-inch rivets, having a T.S. of 55,000 pounds per square inch and a shearing strength of 45,000 pounds per square inch. These rivets are capable of resisting a direct pull of 10,818 pounds, using 5 as a factor of safety; ascertained as follows: 2A ×45,000÷5=10,818=strength of two rivets. They are also subjected to a crushing strain, and the resistance to this is D×C÷5, which expressed in figures is .875×90,000 ÷5=15,750 pounds.

The proper spacing comes next, and is arrived at in the following manner:

Area to be stayed=897.88 square inches.

Number of stays=15.

Area supported by each stay=897.88÷15=59.8 square inches.

The square root of 59.8=7.75 nearly, which is the distance in inches each way that the stays should be spaced, center to center.

If through stay rods are used in place of diagonal braces for staying the boiler under consideration, the number and diameter of the rods may be ascertained by the following method:

Assuming the heads to be supported by channel bars, as previously described, and that the stays are pitched 14 inches apart horizontally and 13 inches vertically, each stay would be required to support an area of 14×13=182 square inches, and the number of stays would be 897.88÷182=4.9, in round numbers 5. See Fig. 44. The pressure being 100 pounds per square inch, the total stress on each stay=182×100=18,200 pounds. Assume the stay rods to be of soft steel having a T.S. of 50,000 pounds per square inch, and using a factor of safety of 8, the sectional area required for each stay will be found as follows: 18,200×8÷50,000=2.9 square inches, and the diameter will be found as follows: 2.9÷.7854=3.69, which is the square of the diameter, and the square root of 3.69=1.9 inches, or practically 2 inches. The same methods of calculation are applicable to the staying of the heads below the tubes, also for stay bolts in fire box boilers.

Strength of Unstayed Surfaces. A simple rule for finding the bursting pressure of unstayed flat surfaces is that of Mr. Nichols, published in the "Locomotive," February, 1890, and quoted by Prof. Kent in his "Pocket-book." The rule is as follows: "Multiply the thickness of the plate in inches by ten times the tensile strength of the material used, and divide the product by the area of the head in square inches." Thus,

Diameter of head=66 inches.
Thickness of head=$\frac{5}{8}$ inch.
Tensile strength=55,000 pounds.
Area of head=3,421 square inches.

$\frac{5}{8}\times55{,}000\times10\div3{,}421=100$, which is the number of pounds pressure per square inch under which the unstayed head would bulge.

If we use a factor of safety of 8, the safe working pressure would be $100\div8=12.5$ pounds per square inch, but as the strength of the unstayed head is at best an uncertain quantity it has not been considered in the foregoing calculations for bracing, except as regards that portion of it that is strengthened by the flange.

In all calculations for the strength of stayed surfaces, and especially where diagonal crow foot stays are used, the strength of the rivets connecting the stay to the flat plate must be carefully considered. A large factor of safety, never less than 8, should be used, and the cross section of that portion of the foot of the stay through which the rivet holes are drilled should be large enough, after deducting the diameter of the hole, to equal the sectional area of the body of the stay.

Dished Heads. In boiler work where it is possible to use dished, or "bumped up" heads as they are sometimes called, this type of head is rapidly coming into use. Dished heads may be used in the construction of steam drums, also in many cases for dome-covers, thus obviating the necessity of bracing. The maximum depth of dish, as adopted by steel plate manufacturers April 4, 1901, is $\frac{1}{8}$ of the diameter of the head when flanged, and if the tensile strength and quality of the plate from which the heads are made are the same as those of the shell plate, the dished head becomes as strong as the shell, provided the head has the same thickness, or is slightly thicker than the shell plate.

Welded Seams. A few boiler manufacturers have succeeded in making welded seams, thus dispensing with the time-honored custom of riveting the plates together. A good welded joint approaches more nearly to the full strength of the material than can possibly be attained by rivets, no matter how correctly designed the riveted joint may be. The weld also dispenses with the necessity of caulking, and a boiler having a perfectly smooth surface inside, such as would be afforded by welded seams, would certainly be much less liable to collect scale and sediment than would one with riveted joints. But in order to make a success of welded seams the material used must be of the best possible quality, and great care and skill are required in the work.

The Continental Iron Works of Brooklyn, New York, exhibited at the St. Louis World's Fair in 1904, a welded steel plate soda pulp digester without a single riveted joint. The dimensions of this vessel, which may be likened to a cylinder boiler without flues, were as follows: Thickness of plate, ¾ inch; diameter, 9 feet; length, 43 feet. The heads were dished to the standard depth. The safe working pressure was 125 pounds per square inch. It appears not only possible, but probable, that the process of welding boiler joints may in time supplant the older custom of riveting.

QUESTIONS AND ANSWERS.

79. What three principles should govern the design and construction of steam boilers?

Ans. First: They should be absolutely safe. Second:

They should be economical in the consumption of fuel. Third: They should be capable of furnishing dry steam.

80. What is meant by the term tensile strength as applied to boiler material?

Ans. The number of pounds of pull that would be required to break a bar of the material in the direction of its length.

81. What is liable to occur in case the tensile strength is too high?

Ans. Cracking of the sheets, also certain changes in the physical properties of the metal.

82. Which are the stronger, punched or drilled plates?

Ans. If the material is good soft steel, punched plates show a greater shearing resistance.

83. What should be the tensile strength of rivet iron?

Ans. About 60,000 pounds per square inch.

84. What is a good test for a 5/8-inch rivet?

Ans. It should stand being doubled up and hammered together cold without being fractured.

85. What is the shearing resistance of iron rivets?

Ans. About 85 per cent of the original bar.

86. What is the shearing resistance of steel rivets?

Ans. 77 per cent of the original bar.

87. What is meant by efficiency of the joint?

Ans. The percentage of strength of the solid plate, that is retained in the joint.

88. What should be the style of joint with sheets thicker than 1/2 inch?

Ans. It should be a double butt joint.

89. What should be the ratio of diameter of rivet to thickness of plate for double butt joints?

Ans. The diameter of the rivet should be about 1.8 times the thickness of sheet.

90. What should be the pitch of rivets?

Ans. Three and one-half to four times the diameter of the hole.

91. Describe the triple riveted butt joint.

Ans. It has two welts or straps, one inside, and one outside.

92. Is this a good form of joint?

Ans. It is.

93. What type of joint gives the highest efficiency?

Ans. A joint in which the tensile strength of the rods from which the rivets are cut approaches that of the plates, and when the proportions of the joint are such, that the tensile strength of the rivets, and the crushing resistance of the rivets and plate, for a given, or unit strip, are as nearly equal as it is possible to make them.

94. In how many ways may failure occur in a double riveted butt joint?

Ans. In five distinct ways.

95. Name the first manner of failure.

Ans. Tearing of the plate at outer row of rivets.

96. What is the second?

Ans. Shearing two rivets in double shear, and one in single shear.

97. What is the third manner of failure?

Ans. Tearing of the plate at inner row of rivets, and shearing one rivet in the outer row.

98. Describe the fourth method of failure.

Ans. Crushing in front of three rivets.

99. What is the fifth manner of failure?

Ans. Crushing in front of two rivets, and shearing one.

100. How may a triple riveted butt joint fail?

Ans. First: By tearing the plate at the outer row of rivets. Second: By shearing four rivets in double shear, and one in single shear. Third: Rupture of the plate at the middle row of rivets, and shearing one rivet. Fourth: Crushing in front of four rivets, and shearing one rivet.

101. What is the efficiency of the quadruple riveted butt joint?

Ans. In some cases as high as 94 per cent.

102. In what four ways may failure occur in this type of joint?

Ans. First: By tearing the plate at the outer row of rivets. Second: By shearing eight rivets in double shear, and three in single shear. Third: By tearing at inner row of rivets, and shearing three rivets. Fourth: By tearing at first outer row of rivets where the pitch is 7½ inches.

103. What is implied in the staying of a flat surface?

Ans. Holding it against pressure at a series of isolated points, which are arranged in symmetrical order.

104. Does the cylindrical shell of a boiler need bracing?

Ans. No.

105. Why is this?

Ans. Because the internal pressure tends to keep it cylindrical.

106. How are the heads sometimes stayed?

Ans. By through stay rods of soft steel, or iron 1¼ or 2 inches in diameter extending through from head to head.

107. What advantage has this form of stays?

Ans. The pull is at right angles to the plate.

108. What other methods of bracing the heads of high pressure boilers are used?

Ans. Gusset stays, and dished heads.

109. What is the minimum factor of safety for stays, and braces?

Ans. Eight.

110. Give a simple rule for finding the bursting pressure of unstayed flat surfaces.

Ans. Multiply the thickness of the plate in inches by ten times the tensile strength and divide the product by the area of the surface in square inches.

Boiler Setting and Equipment

Setting. In the following remarks concerning boiler setting, reference is had chiefly to the horizontal tubular boiler. Owing to the many and varied styles of water-tube boilers no prescribed set of rules is applicable, each builder of this type of boiler having a set plan of his own for the brick work, and these plans have already been illustrated and described in the section on water-tube boilers. In the case of internally fired boilers the matter of setting resolves itself into the simple point of securing a sufficiently solid foundation, either of stone or brick laid in cement, for the boiler to rest upon.

In the case of the horizontal tubular boiler, there are two methods of support, one by suspension from I-beams and girders, which has already been fully described; the other by supporting the boiler upon brackets riveted to the side sheets, and resting upon the side walls, and in such settings particular attention should be paid to securing a good foundation for the walls and great care exercised in building them in such manner that the expansion of the inner wall or lining will not seriously affect the outer walls. This can be done by leaving an air space of two inches in the rear and side walls, beginning at or near the level of the grate bars and extending as high as the fire line, or about the center line of the boiler. Above this height the wall should be solid. Fig. 48 shows a plan and an end elevation illustrating this idea. The ends of some of the bricks should be allowed to project at intervals from the outer walls across the air space, so as to come in touch with the inner walls.

Where boilers are set in batteries of two or more, the middle or party walls should be built up solid from the foundation. All parts of the walls with which the fire comes in contact should be lined with fire brick, every fifth course being a header to tie the lining to the main wall.

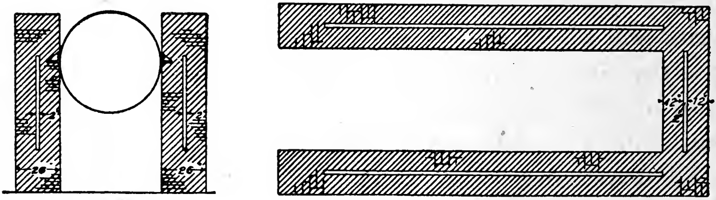


FIG. 48

Bridge walls should be built straight across from wall to wall of the setting, and should not be curved to conform to the circle of the boiler shell. The proper distance from the top of the bridge wall to the bottom of the boiler varies from eight to ten inches, depending upon the size of the boiler. The space back of the bridge wall, called the combustion chamber, can be filled in with earth or sand, and should slope gradually downward from the back of the bridge wall to the floor level at the rear wall, and should be paved with hard burned brick. The ashes and soot can then be easily cleaned out by means of a long-handled hoe or scraper inserted through the cleaning out door, which should always be placed in the back wall of every boiler setting.

Back Arches. A good and durable arch can be made for the back connection, extending from the back wall to the boiler head, by taking flat bars of iron 5/8 x 4 inches, cutting them to the proper length and bending them in the shape of an arch, turning 4 inches of each end back

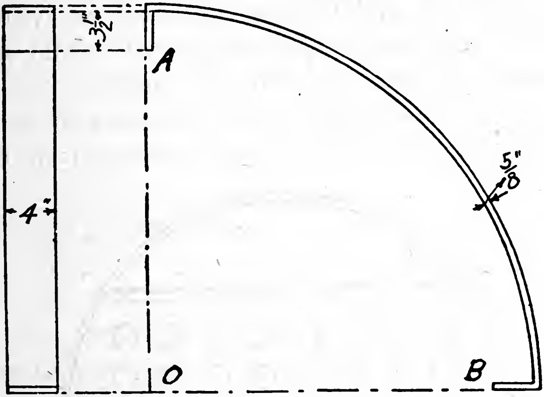


FIG. 49

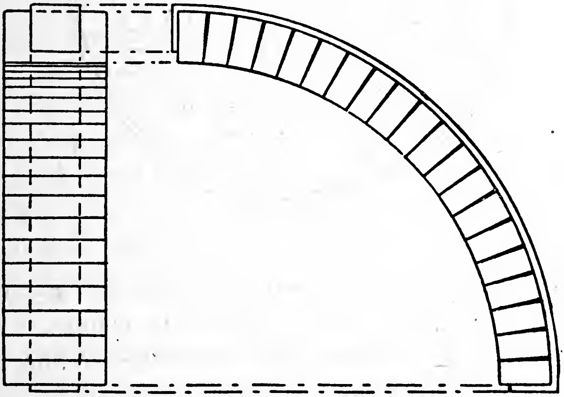


FIG. 50

at right angles, as shown in Fig. 49. The distance O-B should equal that from the rear wall to the boiler head, and the height, O-A, should be about equal to O-B, and should bring the point A about two inches above the top row of tubes. The clamp thus formed is filled with a course of side arch fire brick, Fig. 50, and will form a complete and self-sustaining arch, the bottom, B, resting on the back wall, and the top, A, supported by an angle iron riveted across the boiler head about three inches above the top row of tubes. See Figs. 51 and 52.

Enough of these arches should be made so that when laid side by side they will cover the distance from one side wall to the other across the rear end of the boiler. A fifty-four-inch boiler would thus require six clamps, a sixty-inch boiler seven clamps, and a seventy-two-inch boiler would require eight clamps; the length of a fire brick being about nine inches. In case of needed repairs to the back end of the boiler the sections can be lifted off, thus giving free access to all parts, and when the repairs are completed the arches can be reset with very little trouble and much less expense than the building of a solid arch would neces-

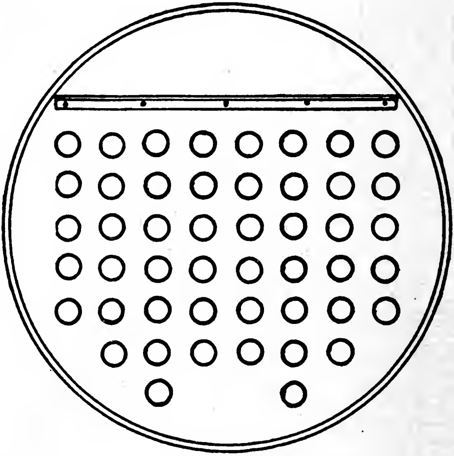


FIG. 51

sitate. This form of segmental arch allows ample freedom for expansion of the boiler, in the direction of its length, without leaving an opening when the boiler contracts.

The crosswise construction of arch bars, while affording equal facility in repair work, is necessarily more expensive than the form here described, and is also open to the objection that it cannot follow the contracting boiler and maintain a tight joint or connection between the back arch and the rear head above the tubes.

Boiler walls should always be well secured in both directions by tie rods extending throughout the entire length and breadth of the setting, whether there be one boiler or a battery of several. The bottom rods should be laid in place at the floor level when starting the brick work, and the top rods extending transversely across the boilers can be laid on top of the boilers. The top rods extending from front to back can be laid in the side walls, or rest on top of them. All tie rods should be at least one inch in diameter, and for batteries of several boilers they should be larger. The rods should extend three or four inches beyond the brick work, with good threads and nuts on each end to receive the buck stays. In laying down the transverse tie rods they should be located so as to allow the buck stays to bind the brick work where the greatest concentration of heat occurs.

Horizontal boilers should always be set at least one inch lower at the back end than at the front, to make sure that the rear ends of the tubes will be covered with water so long as any appears in the gauge glass, provided of course that the lower end of the glass is properly located with reference to the top row of tubes, which will be discussed later on. Upon the brick work and immediately under each lug of the boiler there should be laid in mortar a wrought or cast iron plate several inches larger in dimension than the bearing surface of the lug and not less than one inch in thickness. Upon each of these plates there should be placed two rollers made of round iron 1 or 1⅛ in. in diameter, and as long as the width of the lug. These rollers should be placed at right angles to the length of the boiler, in such a position that the lug will bear equally upon them. The object of the rollers is to prevent disturbance of the brick work by the endwise expansion and contraction of the boiler.

It will be found very convenient when making tests to have an opening into the combustion chamber back of the bridge-wall, also in the back wall opposite the tubes, to insert a pyrometer, or to connect a draft gage or gas sampler. This can be accomplished by inserting a 1¼-inch pipe in the wall flush with each side, and screwing a cap on the outside. The inner end can be packed with asbestos fiber. A ¾-inch hole drilled in the delivery pipe between the valve and the nozzle will save drilling one by hand when it is desired to insert a calorimeter.

Grate Surface. The number of square feet of grate surface required depends upon the size of the boiler. A good rule and one easy to remember is to make the length of the grates equal to the diameter of the boiler. The width, of course, will depend upon the construction of the furnace. If the fire brick lining is built perpendicular, the width of grate will be about equal to the diameter of the boiler. On the other hand, if the lining is given a batter of three inches, starting at the level of the grate, then the width will be reduced six inches. It is customary to allow one square foot of grate surface to every 36 sq. ft. of heating surface. The distance of the grate-bars from the shell of the boiler varies from 24 to 28 in., according to the dimensions of the boiler.

Insulation All boilers should be well protected from the cooling influence of outside air, if economy of fuel is any object. The tops of horizontal boilers should be covered with some kind of heat insulating material, or arched over with common brick, leaving a space of two inches, starting at the level of the grate, then the width saving in fuel will far more than compensate for the extra expense in a very short time. All cracks in the side and rear walls should be carefully pointed up with mortar or fire clay. One source of heat loss in return flue boilers is short circuiting from the furnace to the breeching, caused by the arches over the fire doors becoming loose and shaky, and allowing considerable of the heat to escape directly to the stack instead of passing under the boiler and through the tubes. Another bad air leak often occurs at the back connection when the arch rests wholly upon iron bars imbedded in the side walls. This leak, as has already been noted, is caused by the expansion of the boiler, which gradually pushes the arch away from the back head until, in the course of time, there will be a space of 5/8 inch and sometimes 3/4 inch between the head and the arch. The obvious remedy for this is an arch that will go, and come with the movement of the boiler, and such an arch can be secured by building it in sections, as illustrated by Fig. 52, and then riveting a piece of angle iron to the boiler head, above the top row of tubes for the upper ends of the sections to rest upon, as already described. It will be seen that within all possible range of boiler movement in either direction the arch will, with this construction, always remain close to the head.

Water Columns. Water columns should be so located as to bring the lower end of the gauge glass exactly on a level with the top of the upper row of tubes, thus always affording a perfect guide as to the depth of water over the tubes. Many gauge glasses are placed too low, and water tenders and firemen are often deceived by them, unless their positions with relation to the tubes are carefully noted.

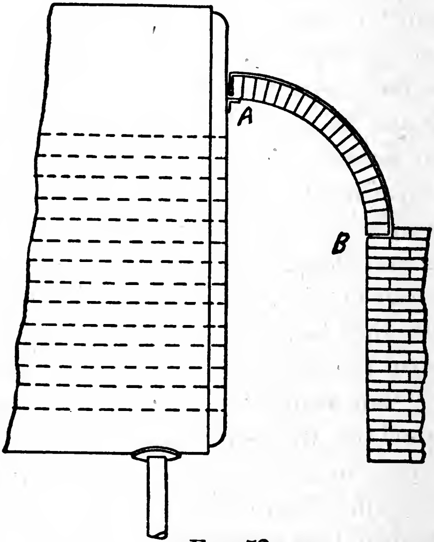


Fig. 52

The only safe plan for an engineer to pursue in taking charge of a steam plant is to seize the first opportunity for noting this relation. When he has washed out his boilers he may leave the top man-hole plates out while refilling them, and when the water stands at about four inches over the top row of tubes, the depth of water in the glass should be measured. He should do this with every boiler in the plant, and make a memorandum for each boiler. He will then know his bearings with regard to the safe height of water to be carried in the several gauge glasses. If he finds any of them are too low, he should lose no time in having them altered to conform to the requirements of safety. The position of the lower gauge cock should be three inches above the top row of tubes.

In making connections for the water column plugged crosses should always be used in place of ells. Brass plugs are to be preferred if they can be obtained; but whether of brass or iron, they should always be well coated with a paste made of graphite and cylinder oil before they are screwed in. They can then be easily removed when washing out the boiler, so as to allow the scale, which is sure to form in the lower connection, to be cleaned out. The best point at which to connect the lower pipe with the boiler is in the lower part of the head just below the bottom row of tubes, and near the side of the boiler on which the water column is to stand; 1¼ or 1½ in. pipe should be used in all cases. The top connection can be made either in the head near the top, or in the shell. A ¾ or 1 in. drain pipe should be led into the ash pit, fitted with a good reliable valve which should be opened at frequent intervals to allow the mud and dirt to blow out of the water column and its connections. This is a very important point, and great care should be taken to keep the water column and all its connections thoroughly clean at all times.

One of the best indications that some portion of the connections between the water glass and the boiler is choked or plugged with scale, is when there is no perceptible movement of the water in the glass. When the connections are free and the boiler is being fired, there is always a slight movement of the water up and down in the glass, and when there is no perceptible movement it is time to look for the cause at once. Many instances of burned tubes have occurred, and even explosions caused by low water in boilers while the gauge glass showed the water to be at a safe height. But owing to the connections having become plugged with scale, the water in the glass had no connection whatever with that in the boiler, and the water column was therefore worse than useless.

The above remarks apply particularly to horizontal return tubular boilers. In the case of water tube boilers the location of the gauge glass as regards height is governed by the desired level of the water in steam drum, or drums.

Steam Gauges. As water columns are made at present the steam gauge is usually connected at the top of the column. This makes a handsome and convenient connection, although theoretically the proper method would be to connect the steam gauge directly with the dome, or the steam space of the shell. There should always be a trap or siphon in the gauge pipe in order to retain the water of condensation, so as to prevent the hot steam from coming in contact with the spring.

If at any time the water is drained from the siphon, care should be exercised in turning on the steam again by allowing it to flow in very slowly at first until the siphon is again filled with water.

There are different types of steam gauges in use, but the one most commonly used, and which no doubt is the most reliable, is known as the Bourdon spring gauge (see Fig. 53). This gauge consists of a thin, curved, flattened metallic tube, closed at both ends and connected to the steam space of the boiler by a small pipe, bent at some portion of its length into a curve or circle that becomes filled with water of condensation, and thus prevents the hot live steam from coming directly in contact with the spring, while at the time the full pressure of steam in the boiler acts upon

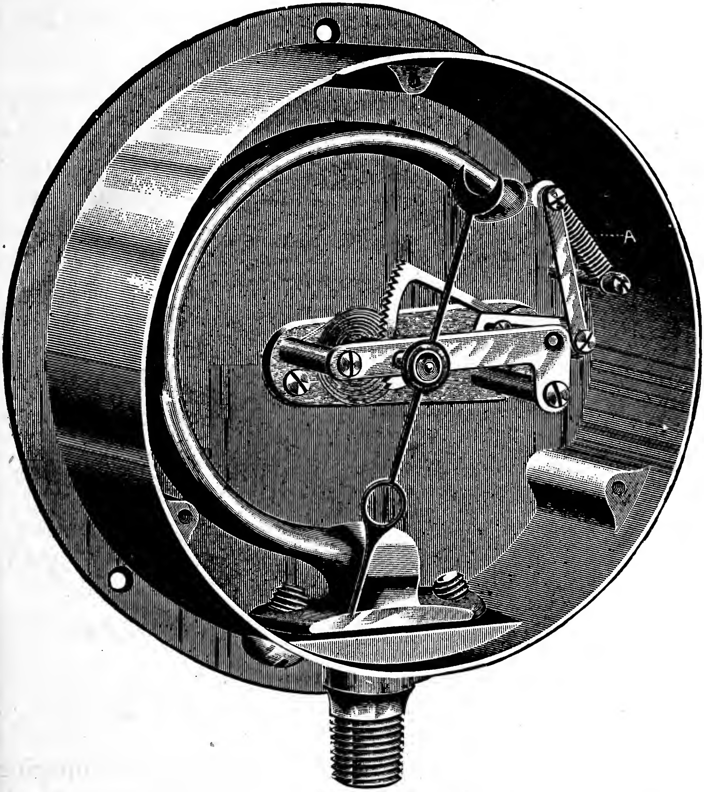


FIG. 53
AUXILIARY SPRING PRESSURE GAUGE, SECTIONAL VIEW

the spring, tending to straighten it. The end or ends of the spring being free to move, and connected by suitable geared rack and pinion with the pointer of the gauge, this hand or pointer is caused to move across the dial, thus indicating the pressure of steam per square inch in the boiler. When there is no pressure in the boiler the hand should point to 0.

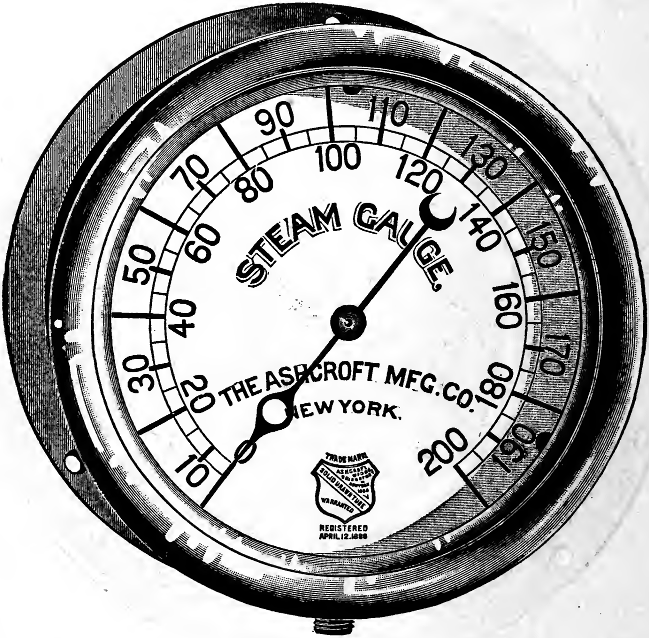


FIG. 54

AUXILIARY SPRING PRESSURE GAUGE

Steam gauges should be tested frequently by comparing them with a test gauge that has been tested against a column of mercury.

The steam gauge and the safety valve should be compared frequently by raising the steam pressure high enough to cause the valve to open at the point for which it is set to blow.

Safety Valves. The modern pop valve is generally reliable, but, like everything else, if it is allowed to stand idle too long it is likely to become rusty and stick. Therefore it should be allowed to blow off at least once or twice a week in order to keep it in good condition.

Most pop valves for stationary boilers are provided with a short lever, and if at any time the valve does not pop when the steam gauge shows the pressure to be high enough, it can generally be started by a light blow on the lever with a hammer.

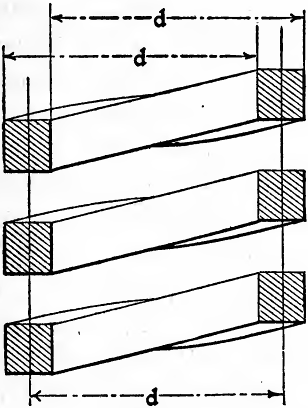


FIG. 55

The ratio of safety valve area to that of grate surface is, for the old style lever and weight valve, 1 sq. in. of valve area for each 2 sq. ft. of grate surface, and for pop valves 1 sq. in. of valve area for each 3 sq. ft. of grate surface.

Each boiler in a battery should have its own safety valve, and, in fact, be entirely independent of its mates as regards safety appliances.

One example of safety valve computation will be given. Suppose the grate surface of a boiler is $5 \times 6 = 30$ sq. ft., what should be the diameter of the lever safety valve? The required area of the valve is 30÷2=15 sq. in. Then 15÷.7854=19, which is the square of the diameter of the valve. Extracting the square root of 19 gives 4.35 in. diameter of valve. In actual practice one 5 in. or two 3 in. lever safety valves would be required. If a pop valve is to be used the required area is 30÷3=10 sq. in. Then 10÷.7854=12.73=square of diameter of valve. Extract the square root of 12.73 and the result is 3.6 in.=diameter of valve. In practice a 4-in. valve would be required.

Regarding the pressure at which a spring-loaded, or pop safety valve will blow off, it is first necessary to ascertain by experiment the force required to compress the spring. The pressure at which a spring will yield depends not only upon the shape and size of the material of which it is made, the diameter, number and pitch of the coils, all of which are measurable and determinable, but upon the nature and condition of the material itself.

For instance, a spring of brass will compress with less pressure than one of steel, similar in every other respect, and there is such a wide difference in steels that there will be a great deal of difference in the action of steel springs according to the kind of metal, degree of temper, etc.

The following rule may be used in calculations of this character:

RULE.

Multiply the compression in inches by the fourth power of the thickness of the steel in sixteenths of an inch, and by 22 for round or 30 for square steel. Product I.

Multiply the cube of the diameter of the spring, measured from center to center of the coil (as on the line d, in Fig. 55) in inches, by the number of free coils in the *spring, and by the area of the valve in square inches. Product II.*

Divide Product I by Product II and the quotient will be the pressure per square inch at which the valve will blow off.

With a dead weight or a lever-loaded valve the force required to lift it remains the same, no matter how high the valve lifts. The weights weigh no more if they are raised an inch or two, and the leverage does not change, but with the spring-loaded valve, the more the valve lifts the more the spring is compressed, and the more force is required to compress or hold it. It follows then that if an ordinary valve were loaded with a spring it would simply crack open and commence to sizzle when the pressure equaled the force at which the spring was set, and that if this were not enough to relieve the boiler the pressure would have to increase, opening the valve more and more until the steam blew off as fast as it was made.

But the ideal valve should stay on its seat until the pressure reaches the desired limit, then open wide and discharge the excess. This result is accomplished by the construction shown in Fig. 56. With the first opening of the valve the steam passes into the little "huddling chamber" made by the cavity near the overhanging edge of the valve, and a similar cavity surrounding the seat. The pressure which accumulates here, acting on the additional area of the valve, raises it sharply with the "pop" which gives the valve its name, and it is sustained by the impact and reaction of the issuing steam, until the pressure has subsided sufficiently to allow the spring to overcome these actions.

A short space will be devoted to the consideration of the lever safety valve also, as it may be of interest to some students.

The U. S. marine rule for lever valves is here repeated: "Lever safety valves to be attached to marine boilers shall have an area of not less than one square inch to every two square feet of grate surface in the boiler, and the seats of all such safety valves shall have an angle of inclination of 45° to the center line of their axis."

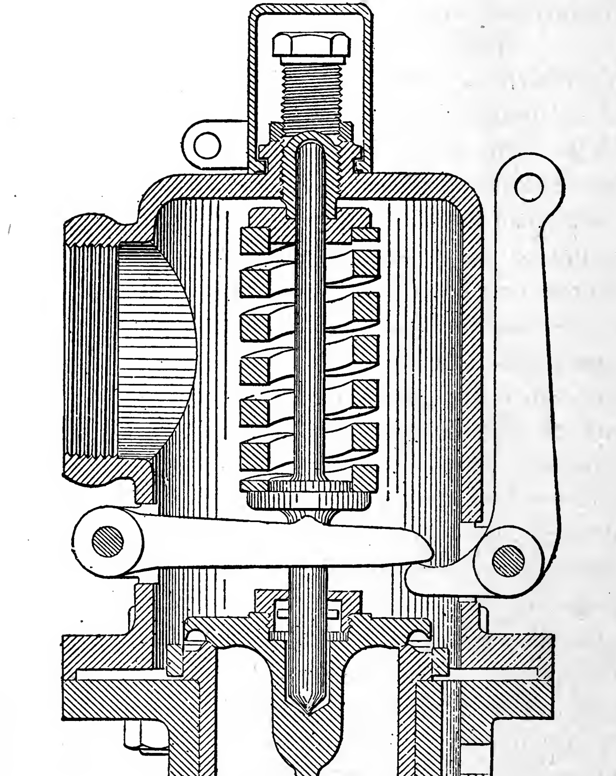


Fig. 56

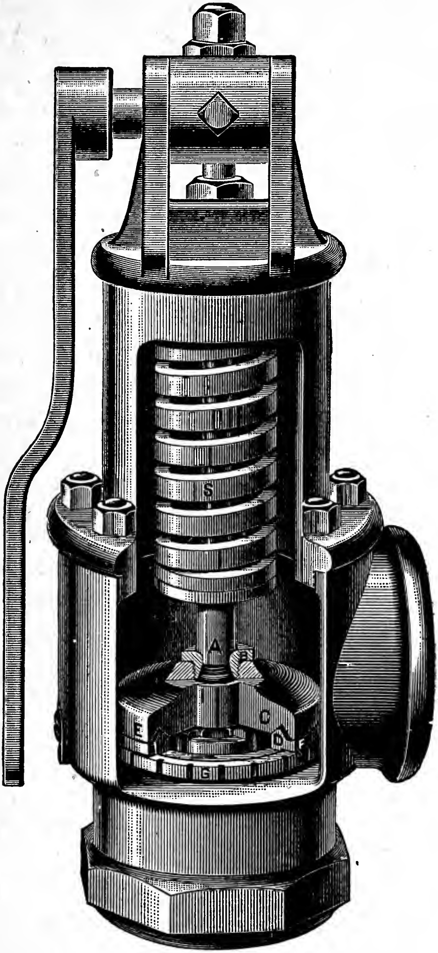


FIG. 57

INSIDE VIEW OF A POP SAFETY VALVE

In order to arrive at accurate results in lever safety valve calculations it is necessary to know first the number of pounds pressure exerted upon the stem of the valve by the lever itself, irrespective of the weight, also the weight of the valve and stem, as all these weights, together with the weight of the ball suspended upon the lever tend to hold the valve down against the pressure of the steam. The effective weight of the lever can be ascertained by leaving it in its position attached to the fulcrum, and connecting a spring balance scale to it at a point where it rests on the valve stem. The weight of the valve and stem can also be found by means of the scale. When the above weights are known, together with the weight at the end of the lever and its distance from the fulcrum, also the area of the valve and its distance from the fulcrum, the pressure at which the valve will blow can be found by the following rules:

Rule 1. Multiply the weight by its distance from the fulcrum. Multiply the weight of the valve and lever by the distance of the stem from the fulcrum and add this to the former product. Divide the sum of the two products by the product of the area of the valve multiplied by the distance of its stem from the fulcrum. The result will be pressure in pounds per square inch required to lift the valve.

Example. Diameter of valve, 3 in.

Distance of stem from fulcrum, 3 in.

Effective weight of lever, valve and stem, 20 lbs.

Weight of ball, 50 lbs.

Distance of ball from fulcrum, 30 in.

Required pressure at which the valve will blow off, $50 \times 30 + 20 \times 3 = 1560$.

Area of valve, $7.0686 \times 3 = 21.2058$.

$1560 \div 21.2058 = 73.57$ pounds pressure.

When the pressure at which it is desired the valve should blow off is known, together with the weights of all the parts, the proper distance from the fulcrum at which to place the weight is ascertained by Rule 2.

Rule 2. Multiply the area of the valve by the pressure, and from the product subtract the effective weight of the valve and lever. Multiply the remainder by the distance of the stem from the fulcrum, and divide by the weight of the ball. The quotient will be the required distance.

Example. Area of valve, 7.07 square inches.
To blow off at 75 pounds.
Effective weight of lever and valve, 20 pounds.
Weight of ball, 50 pounds.
Distance of valve stem from fulcrum, 3 inches.
$7.07 \times 75 - 20 = 510.25$.
$510.25 \times 3 \div 50 = 30.6$ inches, distance from fulcrum at which to place the ball.

When the pressure is known, together with the distance of the weight from the fulcrum, the weight of the ball is obtained by Rule 3.

Rule 3. Multiply the area of the valve by the pressure, and from the product subtract the effective weight of the lever and valve. Multiply the remainder by the distance of the stem from the fulcrum, and divide by the distance of the ball from the fulcrum. The quotient will be the required weight.

Example. Area of valve, 7.07 square inches.
Pressure in pounds per square inch, 80 pounds.
Effective weight of lever and valve, 20 pounds.
Distance of stem from fulcrum, 3 inches.
Distance of weight from fulcrum, 30 inches.
$7.07 \times 80 - 20 = 545.6$.
$545.6 \times 3 \div 30 = 54.56$ pounds, weight of ball.

Safety valves, especially those of the lever type, are liable to become corroded and stick to their seats if allowed to go any great length of time without blowing. Therefore it is good practice to raise the steam pressure to the blowing off point at least two or three times a week, or oftener, for the purpose of testing the valve. If it opens and releases the steam at the proper point all is well, but if it does not, it should be looked after forthwith. Generally the mere raising of the lever by hand, or a few taps with a hammer if it be a pop valve, will free it and cause it to work all right again; but if this treatment has to be resorted to very often the valve should be taken down and overhauled. In too many steam plants not enough importance is attached to the safety valve. The fact is, it is one of the most useful and important adjuncts of a boiler, and if neglected serious results are sure to follow.

Fusible Plugs. A fusible plug should be inserted in that part of the heating surface of a boiler which is first liable to be overheated from lack of water.

In a horizontal tubular, or return flue boiler the proper location for the fusible plug is in the back head about 1½ or 2 inches above the top row of tubes. In fire-box boilers the plug can be put into the crown sheet directly over the fire. These plugs should be made of brass with hexagon heads and standard pipe threads, in sizes ½, ¾, 1 inch, or even larger if desired. A hole drilled axially through the center, and countersunk in the end that enters the boiler is filled with an alloy of such composition that it will melt and run out at the temperature of the dry steam at the pressure carried in the boiler. Thus, if the water should get below the plug the dry steam, coming in contact with the fusible alloy, melts it and, escaping through the hole in the plug, gives the alarm, and in case of fire-box or internally fired boilers the steam will generally extinguish the fire also. The hole is countersunk on the inner end of the plug so as to retain the fusible metal against the boiler pressure. These plugs should be looked after each time the boilers are washed out, and all dirt and scale should be cleaned off in order that the fusible metal may be exposed to the heat.

Another type of fusible plug consists of a small brass cylinder into one end of which is screwed a plug filled with a metal which will fuse at the temperature of dry steam at the pressure which is to be carried in the boiler. The other end of the cylinder is reduced and fitted with a small stop valve and threaded to screw into a brass bushing inserted into the top of the boiler shell. This bushing also receives at its lower end a piece of ½ or ¾-inch pipe which extends downwards to within 2 inches of the top row of tubes, or the crown sheet, if the boiler is internally fired. The principle of the device is that in case the water falls below the lower end of the pipe, steam will enter, fuse the metal in the plug, and be free to blow and give warning of danger. Some of these appliances are fitted with whistles which are sounded in case the steam gets access to them. But even with such devices, no engineer can afford to relax his own vigilance and depend entirely upon the safety appliances to prevent accidents from low water.

Domes and Mud Drums. As a general proposition, both mud drums and domes are useless appendages to steam boilers. There are, no doubt, instances where they may serve a purpose, but as a rule their use is of no advantage to a boiler. Neither are the so-called circulating systems, sometimes attached to return tubular boilers, of any real value. These consist of one or more 4 to 6-inch pipes extending under the boiler from front to back through the furnace, and the combustion chamber and connected to each end of the boiler.

Blow Off Pipes. Blow off pipes should always be connected with the lowest part of the water space of a boiler. If there is a mud drum, then of course the blow off should be connected with it; but if there is no mud drum, the blow off should connect with the bottom of the shell, near the back head, extend downwards to the floor of the combustion chamber, and thence horizontally out through the back wall, where the blow off cock can be located.

The best blow off cocks are the asbestos packed, iron-body plug cocks, which are durable and safe. A globe valve should never be used in a blow off pipe, because the scale and dirt will lodge in it and prevent its being closed tightly. A straight way, or gate valve is not so bad, but an asbestos packed plug cock is undoubtedly the best and safest.

In order to protect the blow off pipe from the intense heat, a shield consisting of a piece of larger pipe can be slipped over the vertical part before it is connected.

Blow off cocks should be opened for a few seconds once or twice a day, to allow the scale and mud to be blown out. If neglected too long they are liable to become filled with scale and burn out. A plan which is said to give good results is to connect a tee in the horizontal part of the pipe, and from this tee run a 1 inch pipe to a point in the back head at the water level. It is claimed that this will cause a circulation of water in the pipe, and prevent the formation of scale.

A surface blow off is a great advantage, especially if the water is muddy or liable to foam. By having the surface blow off connected on a level with the water line a large amount of mud, and other matter which is kept on the surface by the constant ebullition can be blown out.

A combination surface blow off, bottom blow off, and circulating system can be arranged by a connection such as illustrated in Fig. 58. By closing cock A and opening cocks B and C the bottom blow off is put in operation; by closing B and opening A and C the surface blow off is started, and by closing C and leaving A and B open the device will act as a circulating system. The pipe should be of the same size throughout. Blow off pipes should be of ample size, never less than 1¼ inch, and from that to 2½ inch, depending upon the size of the boiler.

Feed Pipes. Authorities differ in regard to the proper location of the inlet for the feed pipe, but upon one point all are agreed, namely, that the feed water, which is always at a lower temperature than the water in the boiler, should not be allowed to come directly in contact with the hot boiler sheets until its temperature has been raised to within a few degrees of the temperature of the water in the boiler. Certainly one of the most fruitful sources of leaks in the seams, and around the rivets, is the practice of introducing the feed water into the bottom either at the back or front ends of boilers, as is too often the case. The cool water coming directly in contact with the hot sheets causes alternate contraction and expansion, and results in leaks, and very often in small cracks in the sheet, the cracks extending radially from the rivet holes. It would appear that the proper method is to connect the feed pipe either into the front head just above the tubes, or into the top of the shell. The nipple entering the boiler should have a long thread cut on the end which screws into the sheet, and to this end, inside the boiler there should be connected another pipe which shall extend horizontally at least two-thirds of the length of the boiler, resting on top of the tubes, and then discharge. Or, what is till better, allow the internal pipe to extend from the entering nipple at the front end to within a few inches of the back head, then at right angles across the top of the tubes to the other side, and from there discharge downward. By this method the feed water is heated to nearly, if not quite, the temperature of the water in the boiler before it is discharged. One of the objections to this system is the liability of the pipe inside

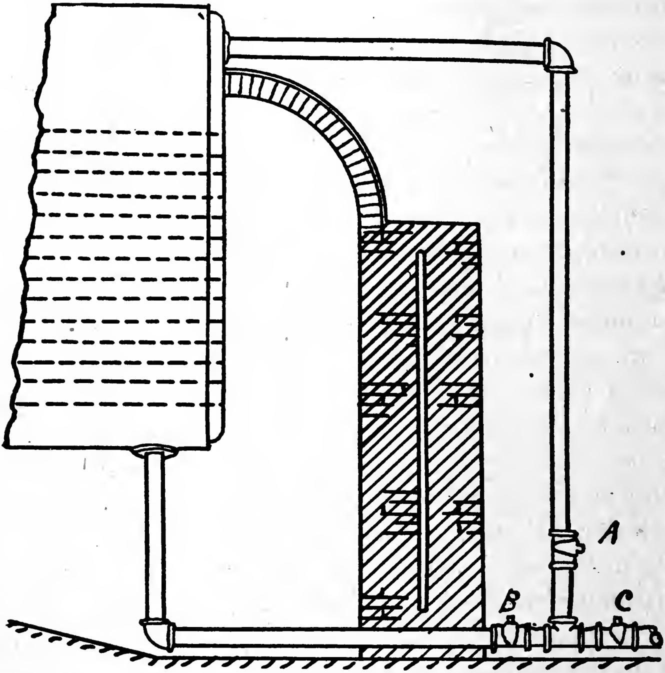


Fig. 58

the boiler to become filled with scale and finally plugged entirely. In such cases the only remedy is to replace it with new pipe. But the great advantage of having the water thoroughly heated before being discharged into the boiler will much more than compensate for the extra expense of piping, and the general idea of introducing the feed water at the top, instead of at the bottom of the boiler is therefore recommended as being the best.

The diameters of feed pipes range from 1 inch for small sized boilers, up to 1½ and 2 inches for boilers of 54 to 72 inches in diameter. It is not good policy to have the feed pipe larger than necessary for the capacity of the boiler; because it then acts as a sort of cooling reservoir for the feed water, and may cause considerable loss of heat.

For batteries of two or more boilers it is necessary to run a main feed header, with branch pipes leading to each boiler. The header should be large enough to supply all the boilers at the same time, should it ever become necessary to do so. The header can be run along the front of the boilers just above the fire doors, with the branch pipes running up on either side, clear of the flue doors and entering the front connection, or smoke arch, and the boiler head at a point two inches above the tubes. There should always be a valve in each branch pipe, between the check valve and the header for the purpose of regulating the supply of water to each boiler, and also for shutting off the pump pressure in case of needed repairs to the check valve. Another valve should be placed between the check valve and the boiler. By this arrangement it is always possible to get at the check valve when it is out of order.

FEED PUMPS.

Feed Pumps and Injectors. The belt driven power pump is the most economical boiler feeder, but is not the most convenient nor the safest. When the engine stops, the pump stops also, and sometimes it happens that the belt gives way, and the pump stops at just the time when the boiler is being worked the hardest.

The modern double acting steam pump, of which there are many different makes to choose from, is without doubt the most reliable boiler feeding appliance and the one best adapted to all circumstances and conditions, although it is not economical in the use of steam, since the principle of expansion cannot be carried out with the pump as with the engine.

In selecting a feed pump care should be exercised to see that it is of the proper size and capacity to supply the maximum quantity of water that the boiler can evaporate. This may be ascertained by taking into consideration the amount of heating surface and the required consumption of coal per square foot of grate surface per hour. First, take the coal consumption. Assume the boiler to have 30 square feet of grate surface, and that it is desired to burn 15 pounds of coal per square foot of grate per hour, which is a good average with the ordinary hand fired furnace using bituminous coal. Suppose the boiler is capable of evaporating 8 pounds of water per pound of coal consumed. Then $30 \times 15 \times 8 = 3{,}600$ pounds of water evaporated per hour. Dividing 3,600 by 62.4 (the weight of a cubic foot of water in pounds) gives 57.6 cubic feet per hour, which, divided by 60, gives 0.96 cubic feet per minute. This multiplied by 1,728 (number of cubic inches in a cubic foot) gives 1,659 cubic inches per minute which the pump is required to supply. Suppose the pump is to make forty strokes per minute, and the length of stroke is five inches. Then 1,659÷40=41.47 cubic inches per stroke, which, divided by 5 (length of stroke in inches) gives 8.294 square inches as the required area of water piston. 8.294÷.7854= 10.56, which is the square of the corresponding diameter, and the square root of 10.56=3.25. So, theoretically, the size of the water end of the pump would be 3¼ inches in diameter by 5 inches stroke; but as it is always safer to have a reserve of pumping capacity, the proper size of the pump would be 3½ inches in diameter, by 5 inches stroke, with a steam cylinder of 6 or 7 inches in diameter.

There is another rule for ascertaining the size of the feed pump, viz., by taking the number of square feet of heating surface in the boiler and allow a pump capacity of 1 cubic foot per hour for each 15 square feet of heating surface. Thus, let the total heating surface of the boiler be 786 square feet. Dividing this by 15 gives 52.4 as the number of cubic feet of water required per hour, from which the pump dimensions may be found in the same way as in the preceding case.

In figuring on the capacity of a feed pump for a battery of two or more boilers, the total quantity of water required by all the boilers must be taken into consideration. All boiler-rooms should be supplied with at least two feed pumps, so that if one breaks down there may always be another one available.

Hard rubber valves are, all things considered, the best for a boiler feed pump, as they are not affected by hot water and do not hammer the seats like metallic composition valves do. Every boiler feed pump should be fitted with a good sight-feed lubricator for cylinder oil. The steam valve mechanism of a steam pump is very sensitive and delicate, and requires good lubrication in order to do good work. In too many cases feed pumps are fitted with an old style cylinder oil cup and there is generally more oil on the outside of the valve chest than there is inside, while the valve is bulldozed into working by frequent blows from a convenient club.

The steam valves of all steam pumps are adjusted before they are sent out from the factory, and most of them are arranged so that the stroke may be shortened or lengthened as the engineer desires. It is best, as a rule, to allow a pump to make as long a stroke as it will without striking the heads, because then the parts are worn evenly.

Sometimes an engineer is called upon to set the valves of a duplex pump which have become disarranged. In such a case he should proceed as follows: Place both pistons exactly at mid-stroke. This may be done in two ways. First, by dropping a plummet line alongside the levers connecting the rock shafts with the spools on the piston rods. Then bring the rods to the position where the centers of the spools will be in a vertical line with the centers of the rock shafts.

The second method is to move the piston to the extreme end of the stroke until it comes in contact with the cylinder head. Then mark the rod at the face of the stuffing box gland. Next move the piston to the other end of the stroke and mark the rod at the opposite gland. Now make a mark on the rod exactly half way between the two outside marks and move the piston back until the middle mark is at the face of the gland and the piston will be at mid-stroke. Having placed both pistons at mid-stroke, remove the valve chest covers, and adjust the valves in their central position, viz., so that they cover the steam ports. The valve rod being in position, and connected to the rocker arms by means of the short link, the nut or nuts securing the valve to the rod should be so adjusted as to be equidistant from the lugs on the valve, say $\frac{3}{32}$ or $\frac{1}{8}$ of an inch, according to the amount of lost motion desired, which latter factor governs the length of stroke in some makes of duplex pumps, while in others it is controlled by tappets on the valve rod outside of the valve chest. Care should be taken while making these adjustments that the valve be retained exactly in its central position.

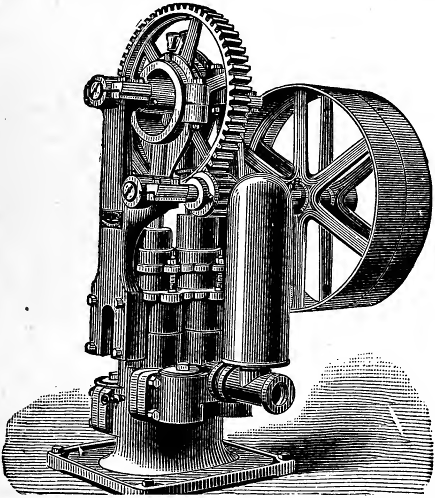


FIG. 59

DAVIS BELT DRIVEN FEED PUMP

Having set the valves correctly, move one of the pistons far enough from mid-stroke to get a small opening of the steam port on the opposite side, then replace the valve chest covers and the pump will be ready to run. As these valves are generally made without any outside lap, a slight movement of one of the pistons in either direction from its central position will suffice to uncover one of the ports on the other cylinder sufficiently to start the pump.

Sometimes duplex pumps "work lame," that is, one piston will make a quick full stroke, while the other piston will move very slowly, and just far enough to work the steam valve of the opposite side. In the majority of cases this irregular action is due to unequal friction in the packing of the rods, or the packing rings on one of the pistons may be worn out.

If one side of a duplex pump becomes disabled from any cause, as breaking of piston rod in the water cylinder, for instance, which is liable to happen, the pump may still be operated in the following manner until duplicate parts to replace the broken ones have been secured: Loosen the nuts or tappets on the valve stem of the broken side and place them far enough apart, so that the steam valve will be moved through only a small portion of its stroke, thereby admitting only steam enough to move the empty steam piston and rod, and thus work the steam valve of the remaining side. The packing on the broken rod should be screwed up tight, so as to create as much friction as possible; there being no resistance in the water end. In this way the pump may be operated for several days or weeks and thus prevent a shut down.

Large Boiler Feed Pumps. The plan of using one large pump for feeding the boilers has recently been tried in several large power stations. For instance, in the Ashley Street Power House of the Union Electric Light and Power Company of St. Louis, there was recently installed one large Prescott steam pump to take the place of four smaller ones which had been in use for feeding the boilers.

This pump is of the duplex compound condensing type, having high-pressure steam cylinders 18 inches in diameter, low-pressure steam cylinders 34 inches in diameter and water plungers 17 inches in diameter, with 24-inch stroke in each instance. The normal capacity of the pump is 1,800 gallons per minute, or 900,000 pounds of water per hour, which is equal to 45,000 kilowatts at 20 pounds per kilowatt-hour. The present capacity of the Ashley street power station is 36,000 kilowatts.

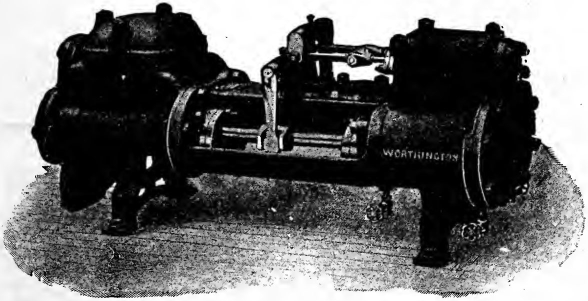


FIG. 60

WORTHINGTON DUPLEX BOILER FEED PUMP

The novel departure of installing a boiler feed-pump in one large unit for this work will arouse the interest of engineers, because it is customary to install several small units for boiler-feed purposes in power plants of this size. But as a matter of fact, this large pump is the consummation of a process of evolution in this plant, which was at first equipped with several small feed-pumps.

To produce the most economical results, the low-pressure cylinders and their heads are steam-jacketed; the steam valves are of the rotative type, there being one steam valve for the high-pressure cylinders, and two each for the low-pressure cylinders. The arrangement of two steam valves in the low-pressure steam cylinders reduces the clearance to the lowest possible amount. The water end is of the pot-form type, having four suction and discharge valves, 5¾ inches in diameter, in each quarter of the suction and discharge. The water plungers are of cast bronze of the outside end-packed type.

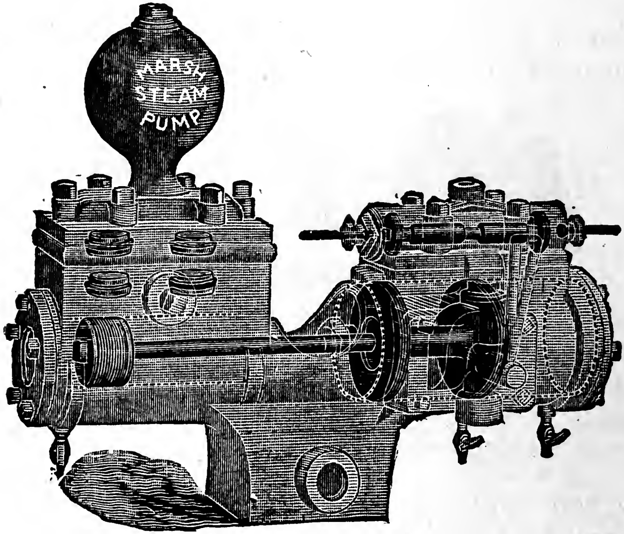


FIG. 61

PHANTOM VIEW OF MARSH INDEPENDENT STEAM PUMP

The boiler pressure carried is 175 pounds per square inch. The pump operates against a pressure of 225 pounds per square inch in the feed-water pipe system to the boilers. This feed-water system is provided with a relief valve, and the pump is controlled by a pressure governor. The boilers are provided with thermostat valves, which allow the water to flow into the boilers and maintain the proper level. All of the automatic apparatus may be controlled by hand, when desirable, for all the boilers, or for each boiler separately. Such occasions are very rare, however, as the pump responds readily to changes in station load, and is under perfect control of the automatic devices for controlling and delivering the proper amount of feed-water to each boiler.

The feed-pipe system, in effect, is simply a system of water mains, in which the number of valves and fittings liable to leak are reduced to a minimum.

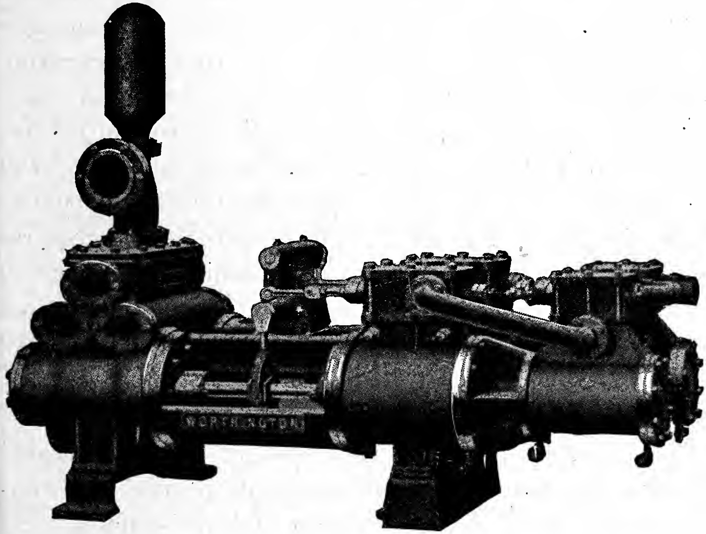


FIG. 62

THE WORTHINGTON COMPOUND STEAM PUMP

Piston Pattern, for General Service—For 150 Pounds Water Pressure

Figures 62 and 63 show views of the Worthington boiler feed pump, adaptable to large steam plants. In the arrangement of steam cylinders shown in figure 62, the steam is used expansively, thereby effecting a great saving.

Figure 64 illustrates a type of pump which is rapidly coming into favor for feeding boilers against high pressure. The steam pressures of from 150 to 200 pounds, which are in common use, require a more substantial construction of feed-pump than the lower pressures of a few years ago. These machines are designed for high pressure and for handling either hot or cold water. The steam ends are made extra heavy and provided with extra strong bolting for all joints, making them suitable for constant operation under steam pressures up to 200 pounds per square inch. The water ends are of the piston pattern, pot-valve type, are of ample strength for working pressures up to 200 pounds and will easily stand test pressure of 300 pounds per square inch. The piston-pattern construction requires less room than the outside-packed machine of either the center-packed, or end-packed type, and, furthermore, does away with the large outside stuffing-boxes and excessive amounts of drip. The pistons are fibrous-packed and are readily accessible on removal of the cylinder-heads.

The valves are in special valve chambers or pots, located above the cylinders. This arrangement provides for constant submergence of the pistons, and the reliability of action of the machine consequent to such submergence. Each pot contains one suction and one discharge valve, each valve having an individual cover easily removable for inspection. Valves are of composition of the wing-guided type, with bevel seats, and are of ample area for the requirements of the service. A manifold connects the suction openings of the various pots to a common suction inlet and another manifold provides a common discharge outlet.

While designed primarily for boiler-feed purposes, these pumps are very desirable machines for general service against pressures not exceeding 200 pounds per square inch.

A good engineer will always take a pride in keeping his feed pump in good condition, and if he has two or more of them, which every steam plant of any consequence should have, he will have an opportunity to keep his pumps in good shape. The water pistons of most boiler feed pumps are fitted to receive rings of fibrous packing. The best packing for this purpose and one that will stand both hot and cold water service is made of pure canvas cut in strips of the required width, ½, ⅝, ¾ inches, etc., and laid together with a water proof cement having the edges for the wearing surface. This packing is called square canvas packing, and can be purchased in any size required for the pump. The size is easily ascertained by placing the water

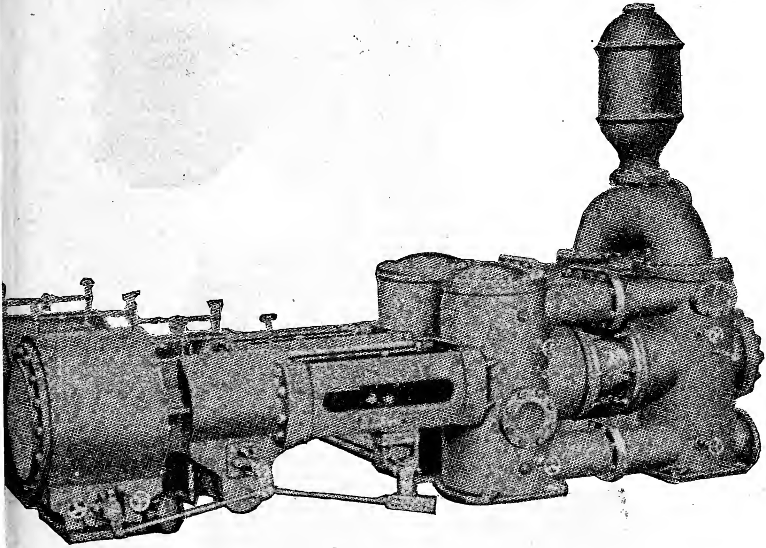


Fig. 63

THE WORTHINGTON PACKED-PLUNGER PUMP
Scranton Pattern—For 250 Pounds Water Pressure

piston, minus the follower plate, centrally in the water cylinder and measuring the space between the piston and cylinder walls. This packing should not be allowed to run for too long a time before renewing, for the reason that pieces of it are liable to become loose, and be forced

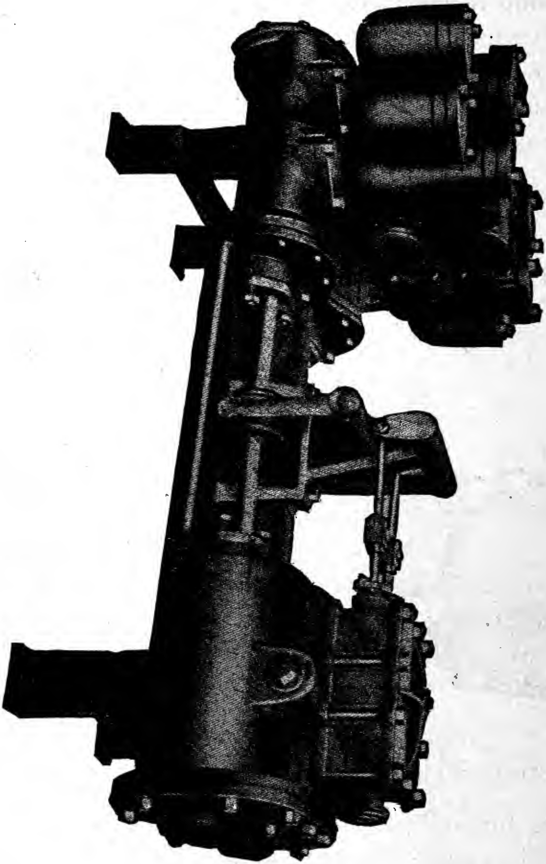


Fig. 64

DEANE PISTON-PATTERN POT-VALVE-TYPE BOILER FEED-PUMP along with the feed water on its way to the boiler and lodge under the check valve, holding it open and causing no end of trouble. If the feed pump has to handle hot water, or has to lift the water several feet by suction, the packing rings should be looked after at least once a month.

Provisions for Testing. While considering feed pipes and other apparatus necessarily appertaining to the feeding of boilers, it is well to devote a short space also to the fittings, and other devices required for successfully conducting tests of the boiler and furnace. This subject is mentioned here for the reason that the author considers that the necessary fittings and appliances for making evaporative tests properly belong to, and in fact are a part of, the feed piping, and can be put in while the plant is being erected at much less cost and trouble than if the matter is postponed until after the plant is in operation.

Beginning then at the check valve, there should be a tee located in the horizontal section of the feed pipe, as near to the check valve as practicable, and between it and the feed pump; or a tee can be used in place of an ell to connect the vertical and horizontal sections of the branch pipe where it rises in front of the boiler. One opening of this tee is reduced to 3/8 or 1/2 inch to permit the attachment of a hot water thermometer. (See Fig. 65). These thermometers are also made angle-shaped at the shank, so that if desired they can be screwed into a tee placed in vertical pipe, and still allow the scale to stand vertically. The thermometer is for the purpose of showing at what temperature the feed water enters the boiler during the test, and therefore should be as near the boiler as possible. After the test is completed the thermometer may be taken out and a plug inserted in its place.

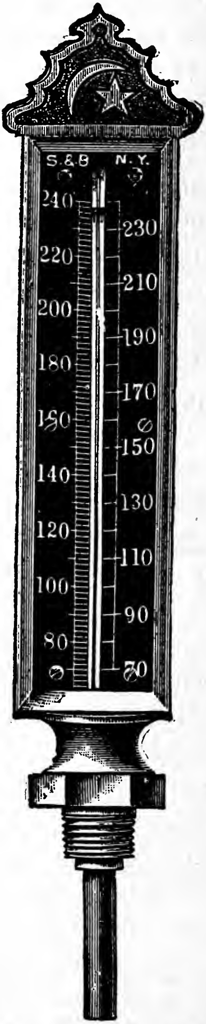


Fig. 65
HOT WATER THERMOMETER

The next requirement will be a device of some kind for ascertaining the weight of water pumped into the boiler during the test. In some well ordered plants each boiler is fitted with a hot water meter in the feed pipe, but as this arrangement is hardly within the reach of all, a substitute equally as accurate can be made by placing two small water tanks, each having a capacity of eight or ten cubic feet, in the vicinity of the feed pump. These tanks can be made of light tank iron, and each should be fitted with a nipple and valve near the bottom for connection with the suction side of the pump. The tops of the tanks may be left open. If an open heater is used, and it is possible to place the tanks low enough to allow a portion of the water from the heater to be led into them by gravity, it will be desirable to do so. A pipe leading from the main water supply, with a branch to each tank, is also needed for filling them. One of the feed pumps, of which there should always be at least two, as already stated, is fitted with a tee in the suction pipe near the pump to receive the pipe leading from the tanks. During the test the main suction leading to this pump from the general supply should be kept closed, so that only the water that passes through the tanks is used for feeding the boiler. If the plant be a small one, with but one or two boilers and only a single feed pump, the latter can be made to do duty as a testing pump, because during the test there will be no other boilers to feed besides the ones under test.

If metal tanks are considered too expensive, two good water-tight barrels can be substituted. Figure 66 will give the reader a general idea of what is needed for obtaining the weight of the water by the method just described. If a closed heater is used and no other boilers are in service during the test, the cold water can be measured in the tanks and pumped directly through the heater, but if it is necessary to feed other boilers besides those under test, then either a separate feed pipe must be run to the test boilers, or else hot water meters will have to be put into the branch pipes.

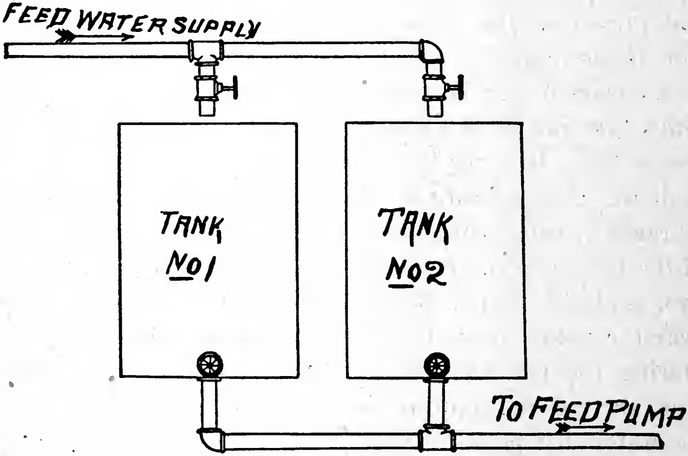


FIG. 66

In cases where a separate feed pipe must be put in for the test boiler, and the water which is used for testing cannot be passed through a heater, there should be a ¾ or 1 inch pipe connected to the feed main, or header and leading to the testing tanks, in order to allow a portion of the hot feed water to run into and mix with the cold water in the tanks as they are being filled, thus partially warming the water before it goes to the boiler.

THE INJECTOR.

The Injector. Although the injector is not generally used for feeding stationary boilers, still a short study of the philosophy of its action may prove interesting, and useful to engineers and water tenders. Consequently a space will be devoted to this useful device for boiler feeding.

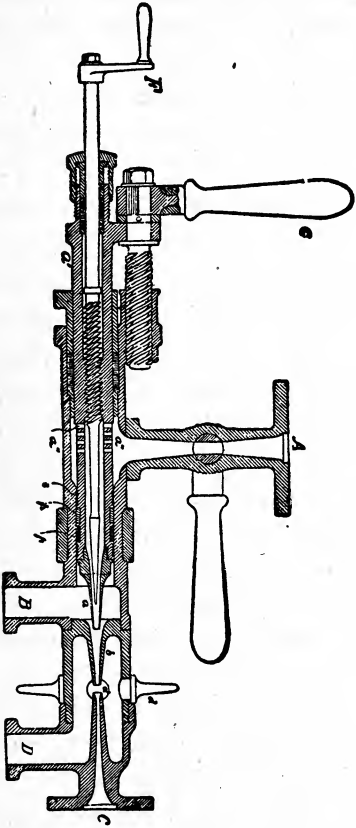


FIG. 67

ORIGINAL FORM OF THE GIFFORD INJECTOR

Ever since the time of the invention of the injector in 1858 by that eminent French engineer Henri Giffard, and its introduction into this country in 1860 by Wm. Sellers & Co., of Philadelphia, it has been constantly improved upon, and developed by various inventors and manufacturers.

How an Injector Works. How can an injector lift and force large volumes of water into the boiler, against the same or even higher pressure than that of the steam?

An injector works because the steam imparts sufficient velocity to the water to overcome the pressure of the boiler.

This is a statement of fact; to explain the action, we will take up the important parts of the question separately.

Why should an injector work? Let us assume that the boiler pressure is 180 pounds—that is to say, every square inch of the sheets, top and bottom, receives an internal pressure of 180 pounds. If the thermometer is placed inside, it is found that both the water and the steam are at the same temperature, 379°. But the steam contains more heat than the water, because after water is heated, more coal must be burned to break up the drops of water to change them into steam; this heat is stored in the steam and represents work done by the burning of the coal. Steam not only exerts a pressure of 180 pounds per square inch, but also can expand eight, to twenty-six times its original volume, depending upon whether it exhausts into the air or into a partial vacuum; water under the same pressure would be discharged in a solid jet, and without expansion. Either steam, or water can be used in the cylinder of an engine, or to drive the vanes of a steam or water turbine, but one pound of steam is capable of much more work than one pound-weight of water, on account of the heat which has been used to change it into steam. This is easily seen by comparing the velocities of discharge from a steam nozzle and a water nozzle under 180 pounds pressure; steam would expand while issuing, reaching at the end of the nozzle a velocity of about 3,600 feet per second, while the water, having no expansion, would have a velocity of only 164 feet per second, about 1/22 of that of the steam. The same weight of steam discharged per second would therefore have vastly more power for doing work than the water jet.

If a steam or water jet comes in contact with a body in front of it, the tendency is to drive the body forward. The force which tends to move the body is called "momentum," and is equal to the weight of water or steam discharged by the jet in one second, multiplied by its velocity per second. If 1 pound of both the water and the steam are discharged per second, the "momentum" of the steam jet is 3,600; because 1 multiplied by 3,600=3,600; the momentum of the water jet is 164. If the water jet discharged about 22 pounds per second, its momentum would be the same as that of the steam, because 22 multiplied by 164 is nearly 3,600. The two jets are discharged under the same pressure, but the steam has 22 times as much "momentum" or force as the water jet; it could, therefore, easily enter a boiler at 180 pounds pressure if we could reduce it to the size of the hole of the water nozzle.

How ought an injector to work? Here a practical difficulty is reached. A steam jet 6 inches from the nozzle is much larger than at the opening, and it would appear almost impossible to make it enter a smaller tube. Even at the narrowest part of the nozzle it is more than sixteen times larger in diameter than a water jet discharging the same weight per second; therefore, if the steam is changed to water without reducing its velocity, it would pass through a hole one-sixteenth the diameter of the "steam nozzle" at a velocity of 3,600 feet per second. The simplest and best way to reduce its size is to condense it, and to use water for this purpose, especially as water is needed in the boiler. To condense the steam and utilize its velocity, the water must be brought into close contact with it, without interfering with the direct line of discharge; a funnel, or "combining tube" suitably placed will compel water to enter evenly all around the steam jet. The mouth of this funnel must not be too large, or too much water will enter and swamp the jet; if too small, insufficient water will enter to condense the steam. The effect of condensing the steam is to reduce the diameter of the jet; therefore the funnel or combining tube must be a smooth, converging taper, to lead the combined jet of water and condensed steam into the smaller hole of the delivery tube. The effect of the impact of the steam is to give the water its momentum, so that a solid stream shall issue from the lower end of the tube. Each little drop of entering water is driven ahead faster and faster by the vast number of little atoms of steam moving hundreds of times as rapidly, until the steam and water thoroughly combine into one swiftly-moving jet of water and condensed steam, which contracts sufficiently in diameter to enter the smaller delivery tube.

Why does the jet enter the boiler? The combined jet now passes from the end of the combining tube into the delivery tube; why does it enter the boiler?

If a pipe shaped like a fire-hose nozzle or a "delivery tube" is connected to a tank or boiler carrying 180 pounds, the water will issue in a solid jet with a velocity of about

164 feet per second; or, if we could force water into the tube at a speed of 164 feet per second at the same part of the tube, this water would enter and fill up the boiler, or tank against 180 pounds pressure. Therefore to enter the boiler the combined jet of water and steam issuing from the combining tube must have a velocity of at least 164 feet per second.

Now, what is the velocity of the combined jet at the lower end of the combining tube? If the steam nozzle discharges one pound per second at 3,600 feet velocity, the momentum of the steam is 1 multiplied by 3,600, or 3,600. If the vacuum caused by the condensation of the steam lifts and draws into the combining tube ten pounds of water per second at a velocity of forty feet, its momentum is 400; and that of the combined jet is 3,600 added to 400, or 4,000. The weight of the combined jet is eleven pounds, and at the time of entering the delivery tube its velocity ought to be equal to 4,000 divided by 11, or 366 feet per second; but as the water and the steam do not meet in precisely the line of discharge there is a loss of momentum, and the velocity in the delivery tube is only 198 feet per second. But the jet only needs a velocity of 164 feet to enter the boiler, or tank carrying 180 pounds pressure, therefore the actual jet in the delivery tube is able to overcome a pressure of 206 pounds per square inch, or 26 pounds above that of the steam, because the velocity of a jet of water under a head or pressure of 206 pounds would be 198 feet per second. This excess is more than sufficient to overcome the friction of the delivery piping and the resistance of the main check valve. Therefore:

The action of the injector is due to the high velocity with which a jet of steam strikes the water entering the combining tube, imparting to it its momentum, and forming with it during condensation a continuous jet of smaller diameter, having sufficient velocity to overcome the pressure of the boiler.

The Sellers Improved Self-acting Injector. Description. This injector is simply constructed and contains few operating parts. The lever is used in starting only, and the water valve for regulation of the delivery. It is self-adjusting, with fixed nozzle, and restarts automatically. All the valve seats that may need refacing can be removed; the body is not subject to wear and will last a lifetime.

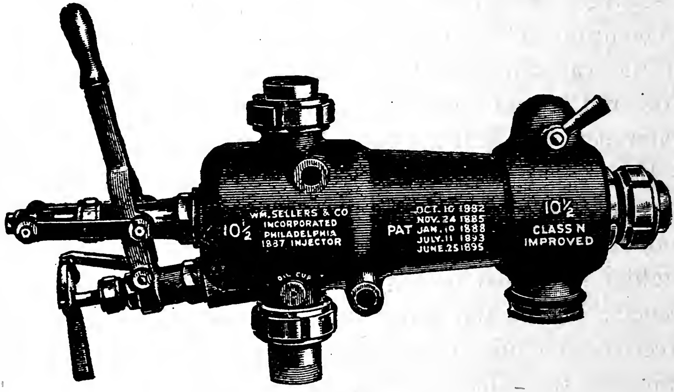


FIG. 68

THE SELF-ACTING INJECTOR, CLASS N IMPROVED

The action is as follows (referring to Fig. 69): Steam from the boiler is admitted to the lifting nozzle by drawing the starting lever (33) about one inch, without withdrawing the plug on the end of the spindle (7) from the central part of the steam nozzle (3). Steam then passes through the small diagonal-drilled holes and discharges by the outside nozzle, through the upper part of the combining tube

(2) and into the overflow chamber, lifts the overflow valve (30), and issues from the waste pipe (29). When water is lifted the starting lever (33) is drawn back, opening the forcing steam nozzle (3), and the full supply of steam discharges into the combining tube, forcing the water through the delivery tube into the boiler pipe.

At high steam pressure there is a tendency in all injectors having an overflow to produce a vacuum in the chamber (25). In the Improved Self-Acting Injector this is utilized to draw an additional supply of water into the combining tube by opening the inlet valve (42); the water is forced by the jet into the boiler, increasing the capacity about 20 per cent.

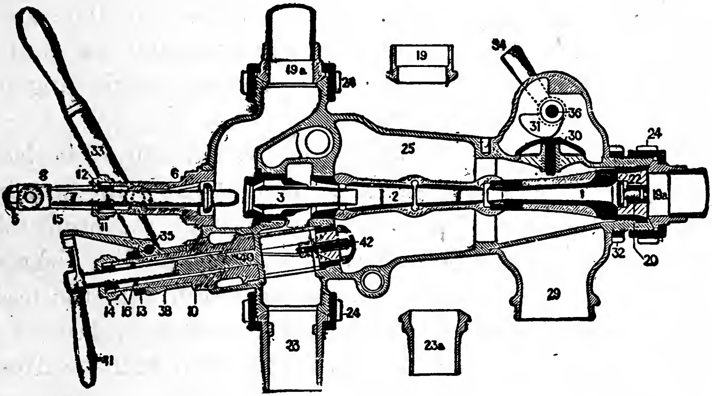


Fig. 69

THE SELF-ACTING INJECTOR, CLASS N IMPROVED

Sellers Standard Form

The water-regulating valve (40) is used only to adjust the capacity to suit the needs of the boiler. The range is unusually large.

The cam lever (34) is turned toward the steam pipe to prevent the opening of the overflow valve when it is desired to use the injector as a heater, or to clean the strainer. The joint between the body (25) and the waste-pipe (29) is not subject to other pressure than that due to the discharging steam and water during starting; the metal faces should be kept clean and the retaining nut (32) screwed up tight.

To tighten up the gland of the steam spindle, push in the starting lever (33) to end of stroke, remove the little nut (5) and draw back the lever (33). This frees the cross-head (8) and links (15), which can be swung out of the way, and the follower (12) tightened on the packing to make the gland steam-tight.

The injector is a reliable boiler feeder, and is in fact more economical than the steam pump, because the heat in the steam used is all returned to the boiler, excepting the losses by radiation. But the disadvantage attending the use of the injector is that it will not work well with the feed water at a temperature very much in excess of 100° F., while a good steam pump, fitted with hard rubber valves, will handle water at a temperature as high as 200° or 208° F., when the water flows to the pump by gravity from a heater, or it will raise water from a receiving tank on a short suction lift at a temperature of 150° or 160° F.

STEAM HEADERS AND CONNECTIONS.

The design, size and location of the main steam header, and the connections between it and the boilers is a very important problem, and should receive close attention.

If it was merely a case of uniting all boiler outlets into a common pipe or header, regardless of the strains of expansion, and ease of pipe fitting, the difficulties would be few.

The header should not only be a main for uniting all the boilers, but it should also be of sufficient capacity to act as a receiver-reservoir to counteract the effects of any momentarily heavy demand for steam which would otherwise tend to lift some of the water out of the boilers. The size of the header may be determined by the following rule, viz., let sectional area of main header equal, or slightly exceed the sum of the areas of all boiler outlets connected with it. Take for example a battery of four 72-inch by 18 feet horizontal tubular boilers, each having 6-inch outlets. By reference to the table of areas and circumferences of circles it will be seen that the area of a circle 6 inches in diameter equals 28.274. Therefore the combined areas of the four outlets is $28.274 \times 4 = 113$ square inches, and reference to the table again will show that a 12-inch pipe will be required for the header. It is best to have the header of a uniform diameter throughout its length, as it will then have the greatest storage capacity possible, and the supply to the largest engine or steam user should be taken from as near the middle of the header as possible.

The location of the header must be determined by local conditions, and by the relative positions of the boilers to the engine room, but the header should be so located that all valves, joints and connections are easily accessible, and so that the valves can be conveniently operated from a fixed platform, or from the top of the boilers. It should not be necessary to use a movable ladder to control any steam valve on the header, as the chances are that the ladder would not be in its place in time of emergency or accident. Locating the header in front of the boilers over the firing space should be avoided if possible, as any leakage would be liable to discomfort the firemen. A good location is along the top of the boilers near the rear, the header being supported by brick piers built upon the boiler-setting walls.

All boiler connections should enter the header at the top and the outlets should also be taken from the top to insure that any water in the header will not be carried over to engine, but will be drained off at the proper place. It is not necessary to pitch the header for draining, provided that the drain connection is made close to the point where the heaviest draft of steam is taken. If the header is level, the movement of the steam toward the heaviest outlet will naturally cause the water in the bottom of the header to flow in the same direction. A good arrangement for draining a header is to use a cross at the heaviest outlet, with the outlet connection taken from the top opening, and the lower opening fitted with a blind flange tapped for drainage, but the use of a good high-pressure trap attached to the drain opening of the header, and discharging into a return tank, hot-well, or open heater is the most reliable method of drainage.

Valves. The question of valves is next in order. The day of the single valve in each boiler connection is passing. Many cities by ordinance now require two valves in each connection, and many engineers know only too well what it means to crawl into a boiler with a leaky valve on top of them. This condition can be eliminated by the use of two valves. Globe valves should be avoided on account of the turns in the steam path, gate and angle valves being preferable. One of the neatest, and most efficient arrangements is to use two angle valves, one on top of the header and the other on top of the boiler.

Automatic stop and check-valves are daily finding favor, and are coming into general use. These valves which are adaptations of the ordinary check-valve, are generally made in the angle type to set over the boiler outlet. The disk falls to its seat when the flow of steam reverses, so that if a tube should blow out the automatic stop and check, or non-return valve would close because of the unbalanced pressure, thereby isolating the disabled boiler from the others. The advantages of such an arrangement are fully apparent. The check disk in these valves is not attached to the valve-stem, but the valve can be used as an ordinary stop-valve by screwing the stem down until it holds the disk securely on its seat. It is impossible to open this type of valve when the boiler is out of commission, and this in itself is a safety item to be considered by those who have to enter boilers for cleaning or repairs. The non-return valve will also close if the boiler becomes sluggish in generating steam, and will not open until the pressure equals that in the header. The valve should be equipped with an outside lever, or indicating device which will clearly show whether it is open or closed.

There are a few types of non-return valve which have an added feature of closing if the velocity should increase in the regular direction beyond the normal rate, which might easily be caused by the bursting of a pipe or joint in the piping system. The location of the automatic stop and check-valves should be as near as possible to the boiler outlets. Where the ordinary angle or gate valves are used, they should preferably have rising stems to readily indicate whether the valve is open or closed.

Superheaters. The location of the superheater in the boiler setting is a very important point, but there are certain rules and reasons that help to determine where it should be placed in a particular type of boiler. The temperature of superheated steam at 150 pounds pressure superheated 200 degrees is 566 degrees, and if it were desired to place a superheater in a boiler to meet such conditions, it is evident that if the temperature of the escaping gases were 500 degrees it would be impossible to place the superheater near the uptake. It would be necessary to place the superheater at some point in the setting where there would be a sufficient temperature drop between the gases and the superheating surface to cause the necessary heat transfer. The nearer the furnace, the greater will be the temperature drop from the gases to the steam, and a greater heat transfer per square foot of heating surface per hour. Therefore, for a given degree of superheat the superheater that is placed closest to the furnace will require the least heating surface per horse-power, and for a given design the superheater having the least heating surface is the cheapest to build.

If the superheater is placed at such a point in the setting that the gases exceed 1,000 degrees, it is necessary to provide for flooding with water whenever the flow of steam through the superheater is stopped or during the raising of steam. Except in certain special cases flooding is objectionable, and the superheater should be placed just beyond the point where the average temperature of the gases has reached 1,000 degrees. In the average water-tube boiler having a furnace temperature of 2,500 degrees, and an uptake temperature of 500 degrees, 75 per cent of the total amount of steam has been generated when the gases have passed over 40 per cent of the heating surface and have dropped to a little less than 1,000 degrees.

Besides the above there are other considerations, such as adaptability to the design of the boiler, and accessibility for cleaning and repairs.

The superheater contained within the boiler setting is the most efficient type for degrees of superheat not exceeding 200. It has the added advantage that it does not require any additional space for its installation, except in some cases an increase in the height of the boiler. It can be installed without any additional piping over that required for a simple boiler. If properly located it will deliver a fairly uniform temperature of steam, and will automatically follow the fluctuations in the boiler load. Whenever it is necessary to cut out a superheater, only one unit is lost and the other units will take care of the loss by carrying an overload, thus preventing any wide temperature change in the piping system, or an appreciable loss in economy.

In the boiler-setting type, the superheater is forced whenever the boiler is forced, but the temperature of the escaping steam may fluctuate on account of leaving the fire doors open too long, or firing too heavily or irregularly. Where there are a number of boilers in a battery the temperature of the steam at the engines should not vary, as the fluctuations in temperature do not occur at the same time in all the boilers, and therefore the average of all the boilers should be nearly constant. Superheaters of this type can be designed so that they will compound on overload; that is, the degree of superheat will increase with the load up to a certain amount.

The freedom of expansion of each of the elements of heating surface is very important and should be given careful consideration. The U-bend provides absolute freedom, and cannot produce any strain on the joints, provided its movement is not restrained by hangers, or clamps. In designs where straight or slightly curved tubes are expanded at each end into manifolds, considerable trouble is experienced with leaky joints due to the difference in expansion of the tubes and the rigidity of the manifolds.

In properly designed all-steel superheaters very few repairs will be required, but just as careful provisions should be made for such repairs as if they were of frequent occurrence. All the expanded joints, and all the manifold cover-plates should be easily accessible for inspection and repairs.

HYDRAULICS FOR ENGINEERS.

Among the many difficult problems that are continually coming up for engineers to solve, there is none more perplexing than the correct calculation of the quantity of water which will be discharged in a given time from pipes of various sizes, and under the many different heads or pressures. Problems in hydraulics, as given by the majority of writers on engineering, are usually in elaborate algebraic equations, which, to the ordinary working engineer, are very perplexing, at least the author has found them to be so in his experience. Therefore with a view of assisting his brother engineers in the solution of problems along this line which they may be called upon to solve, the author has spent considerable time and labor in searching for and compiling a few rules and examples for hydraulic calculations in plain arithmetic, which he hopes may be of benefit.

First, to find velocity of flow in the pump, or in other words, piston speed.

Rule. Multiply number of strokes per minute by length of stroke in feet, or fractions thereof.

Second, the velocity of flow in the discharge pipe is in inverse ratio to the squares of the diameters of the pipe, and the water cylinder of pump.

Thus, a pump cylinder is 6 inches in diameter, and the piston speed is 100 feet per minute; the discharge pipe being 3 inches in diameter. What is the velocity of flow in the pipe?

Example. $\frac{6\times6}{3\times3}=4$. In this case the velocity in the pipe is four times that in the pump, and 100×4=400 feet per minute, velocity for water in the discharge pipe.

Third, to find velocity in feet per minute necessary to discharge a given quantity of water in a given time.

Rule. Multiply the number of cubic feet to be discharged by 144 and divide by area of pipe in inches.

Fourth, to find area of pipe when the volume and velocity of water to be discharged are known.

Rule. Multiply volume in cubic feet by 144 and divide by the velocity in feet per minute.

Fifth, one of the first requisites in making correct calculations of the quantity of water discharged from any sized pipe is to obtain the velocity of flow per second. There are several rules for doing this, among which the following appear to be the plainest and most simple:

Rule 1. Multiply the square root of the head in inches by the constant 27.8. For instance, assume the head to be 100 feet=1,200 inches. The square root of 1,200 is 35 nearly, then 35×27.8=973 inches=81 feet per second velocity.

Rule 2. Multiply the square root of the head in feet by the constant 8, as follows: The square of 100=10 and 10×8=80 feet velocity per second.

Rule 3. Multiply twice the acceleration of gravity by the head in feet, and extract the square root of product. The acceleration of gravity may be considered the constant number 32, neglecting decimals, 32×2×100=6,400. Square root of 6,400=80 feet per second.

In many instances it is more convenient to use the pressure in pounds per square inch as shown by gauge, instead of the height or head, and we can then apply Rule 4.

Rule 4. Multiply the square root of the pressure in pounds per square inch by the constant number 12.16 as follows: Pressure due to 100-foot head=44 pounds, nearly. Square root of 44=6.6, which multiplied by 12.16=80.2 feet velocity per second.

Having ascertained the velocity of flow, we may now proceed to calculate the weight of water in pounds per second discharged from any size of pipe, neglecting for the time being the loss in pressure caused by friction from elbows and bends in the pipe and also the peculiar shape assumed by a stream of water flowing through pipes, or conduits when there is no resistance except the pressure of the atmosphere, and friction caused by long distance transmission.

We will take for our calculation a four-inch pipe from which the water has a free flow under a head of 100 feet, which gives a velocity of 80 feet per second.

Rule 5. Divide the velocity in feet per second by the constant 2.3, and multiply the quotient by the area of discharge pipe in square inches. 80÷2.3=34.7. Now the area of a four-inch pipe is 12.57 square inches, and 34.7 ×12.57=436 pounds discharge per second.

In order to get the matter clearly before us, let us assume that we have a section of four-inch pipe just 80 feet in length and that it lies in a horizontal position and is filled solidly full of water. It will contain area, 12.57 square inches×length, 960 inches=12,067.2 cubic inches of water, and as one pound of water occupies a space of 27.7 cubic inches, we therefore have 12,067.2÷27.7=436 pounds of water, and at a velocity of 80 feet per second our pipe will be emptied and refilled continuously each second. We have also Rule 6 to find the number of cubic feet discharged per minute when the velocity per minute is known.

Rule 6. Multiply the area of pipe in square inches by the velocity in feet per minute and divide by the constant 144.

Example. Area of 4-inch pipe=12.57 square inches. Velocity of flow=80 feet per second=4,800 feet per minute.

Then $\frac{12.57 \times 4,800}{144}$=419 cubic feet per minute=6.99 cubic feet per second, which multiplied by 62.3 pounds (weight of 1 cubic foot)=435.4 pounds per second.

As stated before, no allowance is made by the above rules for friction or other retarding influences, but for ordinary purposes in connection with a steam plant a deduction of 25 per cent is probably sufficient. Of course if the water is being discharged into an elevated tank, or against direct pressure of any kind, the resistance in pounds per square inch or, the height in feet must be deducted from the impelling pressure or head. Let us assume, for instance, that our 4 inch pipe is discharging water into a tank at an elevation of 75 feet above the level of the pump, and that to reach the tank requires 100 feet of pipe with two 90° ells and one straight-way valve. We wish to discharge 500 gallons per minute into the tank, and will therefore require a velocity of about 13 feet per second, which will necessitate a pressure of a little more than 1 pound per square inch to be maintained at the pump over and above all resistance. Now the resistance to be overcome in this case will be:

Pressure per square inch due to 75-foot head....	32.5 lbs.
Friction loss due to length of pipe and velocity...	7.43 lbs.
Friction loss due to two 90° ells..............	2.16 lbs.
Friction loss due to straight-way valve..........	.2 lbs.
Total	42.29 lbs.

Requiring a pressure of say 43 pounds per square inch, or about the equivalent of 100 feet head at the pump.

Again, suppose that in place of the elevated tank we have 1,000 feet of 8-inch horizontal pipe with a 4-inch delivery at the end farthest from the pump, and three branch pipes each 100 feet long and 4 inches in diameter with one 90° ell, one straightway valve, connected at intervals to the 8-inch main, and it is required to discharge in all 1,000 gallons per minute, or at the rate of 250 gallons per minute for each 4-inch delivery. The friction loss for each 100 feet in length of 8-inch pipe at a velocity of 13 feet per second is .94 pounds, and for each 100 feet of 4-inch pipe it is 1.89 pounds. Likewise the friction loss for each 90° ell is 1.08 pounds, and for a straight-way valve .2 pounds, at the above velocity. The total resistance therefore to be overcome is as follows:

For 1,000 feet of 8-inch pipe....	.94 lbs. × 10 =	9.4 lbs.
For 300 feet of 4-inch pipe......	1.89 lbs. × 3 =	5.67 lbs.
For four 90° ells..............	1.08 lbs. × 4 =	4.32 lbs.
For four straight-way valves....	.2 lbs. × 4 =	.8 lbs.
Total		20.19 lbs.

Consequently the pressure required at the pump will be about 22 pounds per square inch, equal to a head of 50 feet.

TABLE 13

PRESSURE OF WATER.

The pressure of water in pounds per square inch for every foot in height to 260 feet; and then by intervals to 3,000 feet head. By this table, from the pounds pressure per square inch, the feet head is readily obtained; and vice versa.

Feet Head.	Pressure per sq. in.	Feet Head.	Pressure per sq. in.	Feet Head.	Pressure per sq. in.	Feet Head.	Pressure per sq. in.	Feet Head.	Pressure per sq. in.
1	0.43	64	27.72	127	55.01	190	82.30	253	109.59
2	0.86	65	28.15	128	55.54	191	82.63	254	110.03
3	1.30	66	28.58	129	55.88	192	83.17	255	110.46
4	1.73	67	29.02	130	56.31	193	83.60	256	110.89
5	2.16	68	29.45	131	56.74	194	84.03	257	111.32
6	2.59	69	29.88	132	57.18	195	84.46	258	111.76
7	3.03	70	30.32	133	57.61	196	84.80	259	112.19
8	3.46	71	30.75	134	58.04	197	85.33	260	112.62
9	3.89	72	31.18	135	58.48	198	85.76	261	113.06
10	4.33	73	31.62	136	58.91	199	86.20	262	113.49
11	4.76	74	32.05	137	59.34	200	86.63	270	116.96
12	5.20	75	32.48	138	59.77	201	87.07	275	119.12
13	5.63	76	32.92	139	60.21	202	87.50	280	121.29
14	6.06	77	33.35	140	60.64	203	87.93	285	123.45
15	6.49	78	33.78	141	61.07	204	88.36	290	125.62
16	6.93	79	34.21	142	61.51	205	88.80	295	127.78
17	7.36	80	34.65	143	61.94	206	89.21	300	129.95
18	7.79	81	35.08	144	62.37	207	89.66	305	132.12
19	8.22	82	35.52	145	62.81	208	90.10	310	134.28
20	8.66	83	35.95	146	63.24	209	90.53	315	136.46
21	9.09	84	36.39	147	63.67	210	90.96	320	138.62
22	9.53	85	36.82	148	64.10	211	91.39	325	140.79
23	9.96	86	37.25	149	64.54	212	91.83	330	142.95
24	10.39	87	37.68	150	64.97	213	92.20	335	145.12
25	10.82	88	38.12	151	65.40	214	92.69	340	147.28
26	11.20	89	38.55	152	65.84	215	93.13	345	149.45
27	11.69	90	38.98	153	66.27	216	93.56	350	151.61
28	12.12	91	39.42	154	66.70	217	93.99	355	153.78
29	12.55	92	39.85	155	67.14	218	94.43	360	155.94
30	12.99	93	40.28	156	67.57	219	94.86	365	158.10
31	13.42	94	40.72	157	68.00	220	95.30	370	160.27
32	13.86	95	41.15	158	68.43	221	95.73	375	162.45
33	14.29	96	41.58	159	68.89	222	96.16	380	164.61
34	14.72	97	42.01	160	69.31	223	96.60	385	166.78
35	15.16	98	42.45	161	69.74	224	97.03	390	168.94
36	15.59	99	42.88	162	70.17	225	97.46	395	171.11
37	16.02	100	43.31	163	70.61	226	97.90	400	173.27
38	16.45	101	43.75	164	71.04	227	98.33	425	184.10
39	16.89	102	44.18	165	71.47	228	98.76	450	195.00
40	17.32	103	44.61	166	71.91	229	99.20	475	205.77
41	17.75	104	45.05	167	72.34	230	99.63	500	216.58
42	18.19	105	45.48	168	72.77	231	100.00	525	227.42
43	18.62	106	45.91	169	73.20	232	100.49	550	238.25
44	19.05	107	46.34	170	73.64	233	100.93	575	249.09
45	19.49	108	46.78	171	74.07	234	101.39	600	259.90
46	19.92	109	47.21	172	74.50	235	101.79	625	270.73
47	20.35	110	47.64	173	74.94	236	102.23	650	281.56

TABLE 13—CONTINUED.

Feet Head.	Pressure per sq. in.	Feet Head.	Pressure per sq. in.	Feet Head.	Pressure per sq. in.	Feet Head.	Pressure per sq. in.	Feet Head.	Pressure per sq. in.
48	20.79	111	48.08	174	75.37	237	102.66	675	292.40
49	21.22	112	48.51	175	75.80	238	103.09	700	303.22
50	21.65	113	48.94	176	76.23	239	103.53	725	314.05
51	22.09	114	49.38	177	76.67	240	103.96	750	324.88
52	22.52	115	49.81	178	77.10	241	104.39	775	335.72
53	22.95	116	50.24	179	77.53	242	104.83	800	346.54
54	23.39	117	50.68	180	77.97	243	105.26	825	357.37
55	23.82	118	51.11	181	78.40	244	105.96	850	368.20
56	24.26	119	51.54	182	78.84	245	106.13	875	379.03
57	24.69	120	51.98	183	79.27	246	106.56	900	389.86
58	25.12	121	52.41	184	79.70	247	106.99	925	400.70
59	25.55	122	52.84	185	80.14	248	107.43	950	411.54
60	25.99	123	53.28	186	80.57	249	107.85	975	422.35
61	26.42	124	53.71	187	81.00	250	108.20	1000	433.18
62	26.85	125	54.15	188	81.43	251	108.73	1500	649.70
63	27.29	126	54.58	189	81.87	252	109.16	2000	866.30
								3000	1,299.50

QUESTIONS AND ANSWERS.

111. What two methods of support are generally used in the setting of horizontal tubular boilers?

Ans. First: By suspension from I beams and girders, and secondly by means of brackets riveted to the side sheets, and resting upon the side walls.

112. How are water tube boilers usually supported in the setting?

Ans. By suspension.

113. What important details should be looked after concerning the brick work?

Ans. The foundations should be good, and the walls built in such manner as to take care of the expansion and contraction.

114. How is this accomplished?

Ans. By leaving an air space of two inches in the side and rear walls beginning at the level of the grate bars, and extending up to about the center line of the boiler.

115. What kind of brick should be used for inside lining?

Ans. Fire brick of good quality.

116. How should bridge walls be built for horizontal tubular boilers?

Ans. Straight across from wall to wall.

117. About what distance from the bottom of the boiler should this wall be?

Ans. Eight to ten inches.

118. Where is the combustion chamber?

Ans. It is the space back of the bridge wall.

119. How should boiler walls be secured?

Ans. By means of tie rods extending the entire length, and breadth of the setting.

120. What are the buck stays?

Ans. They are strong cast-iron, or wrought-iron bars placed vertically upon the outside of the walls, and secured to the tie rods.

121. Should horizontal tubular boilers be set perfectly level lengthwise?

Ans. It is better that they be set about one inch lower at the back end, than at the front end.

122. Give one of the main reasons for this style of setting.

Ans. When washing out the boiler, the mud and water will more easily drain towards the blow off pipe.

123. What is the usual ratio of grate surface to heating surface?

Ans. One square foot of grate surface to each 36 square feet of heating surface.

124. At what point should the glass water-gauge be located?

Ans. In such a position as to bring the lowest visible portion of the gauge glass exactly on a level with the top of the upper row of tubes of a horizontal tubular boiler. With other types of boilers the lowest end of the gauge glass should always be on a level with the danger point.

125. Why should the above rules be observed in locating a water column?

Ans. Because when the water level in the glass begins to draw near to the lower end of glass the engineer or water tender will have an infallible guide to warn him to get busy.

126. What is a good indication that the connections of the water glass are choked or plugged with scale?

Ans. When there is no movement of the water in the glass.

127. Why should there be a trap, or siphon in the pipe connecting the steam gauge to the boiler?

Ans. To prevent the hot steam from coming into contact with the spring of the gauge.

128. How may the steam gauge, and safety valve be tested in comparison with each other?

Ans. By occasionally raising the steam pressure high enough to cause the valve to open at the point for which it is set to blow.

129. Is the pop valve reliable as a safety valve?

Ans. It is, if not allowed to stand idle too long and become rusty.

130. How often should it be allowed to blow off?

Ans. At least twice a week.

131. Are lever safety valves used to any extent?

Ans. They are still in use to some extent, but are rapidly being superseded by pop valves.

132. What is the function of a fusible plug?

Ans. The fusible alloy of which it is composed will melt when it comes in contact with dry steam, and allow the steam to blow a warning.

133. Where is the fusible plug located?

Ans. In that portion of the heating surface of a boiler which is first liable to be overheated from lack of water.

134. Are Domes and Mud drums necessary parts of boilers?

Ans. They are not as a rule.

135. Where should the blow off pipe always be connected?

Ans. With the lowest part of the water space.

136. Should the blow off cock be opened while the boiler is under pressure?

Ans. Yes, for a few seconds, once, or twice each day.

137. Is a surface blow off any advantage?

Ans. It is, especially if the water is muddy.

138. What precautions should be observed with regard to inlet for feed water?

Ans. The feed water should not be allowed to come directly in contact with the hot boiler sheets until its temperature is equal to, or near that of the water within the boiler.

139. How may this be brought about?

Ans. By means of feed water heaters, and internal coils of pipe through which the feed water is caused to pass.

140. What is the most economical style of feed pump?

Ans. The belt-driven power pump.

141. Is it the most reliable, or safest?

Ans. It is not.

142. What is the most reliable boiler feeding device, for all conditions of stationary practice?

Ans. The double acting steam pump.

143. What precautions should be observed in figuring on the capacity of a feed pump for a battery of two or more boilers?

Ans. To take into account the total quantity of water required by all of the boilers; and let the capacity of the pump be equal to it.

144. In connection with feed apparatus for boilers, what other fittings and devices should be installed?

Ans. There should be a tee located in the horizontal section of the feed pipe near the check valve, and between it and the feed pump. One opening of this tee is to be reduced to 3/8 or 1/2 inch to receive a hot water thermometer for testing the temperature of the feed water when making evaporative tests, etc.

145. What other provisions along this line should be made?

Ans. Tanks for weighing the feed water—also a separate feed pipe to the boiler under test, also means for weighing the coal burned during test.

146. Is the injector an efficient boiler feeder?

Ans. It is in locations where there is not very much exhaust steam available for heating the feed water.

147. When, and by whom was the injector invented?

Ans. In the year 1858, by Henri Giffard.

148. Why does an injector force water into a boiler that is under steam pressure?

Ans. Because the steam passing through the injector imparts sufficient velocity to the water to overcome the boiler pressure.

149. Why does an injector lift water from a lower level?

Ans. Because the condensation of the steam in the combining tube creates a vacuum there, and in the suction pipe connected with it.

150. How may the size of the steam header for a battery of boilers be determined?

Ans. The sectional area of the header should equal or slightly exceed the sum of the areas of all the boiler outlets to be connected with it.

151. Where should all connections except for drainage, enter, and leave the main header?

Ans. At the top.

152. How many valves should there be in each boiler connection leading to the header?

Ans. Never less than two.

153. What kind of valves are best for this purpose?

Ans. Automatic stop, and check valves.

154. What is the most efficient type of superheater for practical purposes?

Ans. The one that is contained within the boiler setting.

155. How is the velocity of flow, or piston speed per minute of a pump ascertained?

Ans. Multiply number of strokes per minute by length of stroke in feet, or fractions thereof.

156. The piston speed being known, how is the velocity of flow in the discharge pipe found?

Ans. The velocity of flow in the discharge pipe is in inverse ratio to the squares of the diameters of the pipe and the water cylinder of pump.

157. When it is required to discharge a certain quantity of water from a given size of pipe in a given time, how may the velocity of flow in feet per minute be found?

Ans. Multiply the number of cubic feet to be discharged by 144 and divide by area of pipe in inches.

158. When the volume of water to be discharged and the velocity of flow are known, how is the area of the pipe obtained?

Ans. Multiply volume in cubic feet by 144, and divide by velocity in feet per minute.

159. What is meant by "acceleration of gravity," and what constant number represents it in connection with hydraulics?

Ans. Acceleration of gravity is the increase in velocity caused by the actual weight of the water, and is represented by the constant 32.

160. What per cent of allowance is ordinarily made for friction in water pipes?

Ans. A deduction of 25 per cent is sufficient.

Feed Water Heaters

Feed Water Heaters. One great source of economy in fuel is the utilization of all the available exhaust steam for heating the feed water before it enters the boiler. Of course if the main engines are condensing, the exhaust from

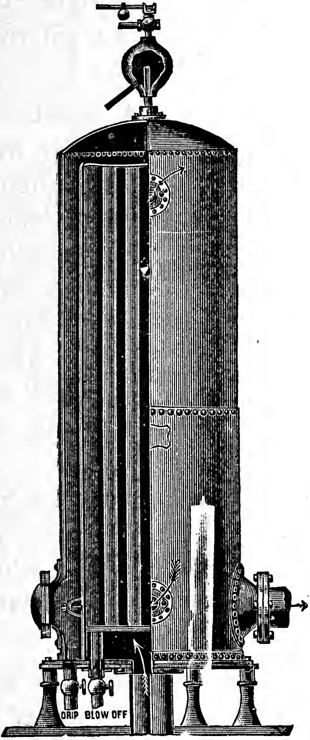


FIG. 70

BARAGWANATH STEAM JACKET FEED WATER HEATER

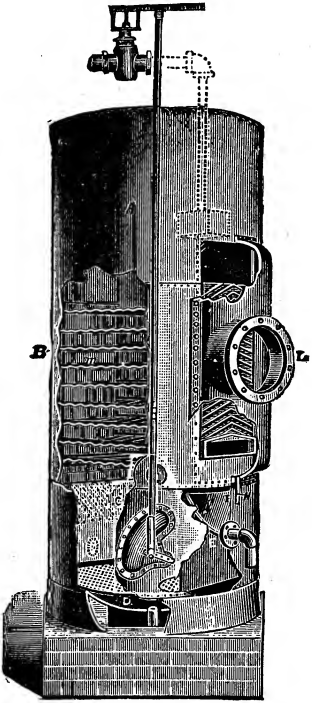


FIG. 71

INTERIOR VIEW OF OPEN HEATER

that source is not directly available, except by interposing a closed heater between the cylinder and the condenser, or by using the water of condensation for feeding the boilers. This can be done with safety, provided a surface condenser is used, but with a jet condenser or an open heater in which the exhaust mingles with the water, it is advisable to have an oil separator to prevent the oil from getting into the boilers.

Exhaust heaters are of two kinds, open and closed. In the open heater the exhaust steam mingles directly with the water, and a portion of it is condensed. A well-designed open exhaust heater will raise the temperature of the water to very nearly the boiling point, 212° F. These heaters should be set so that the water will flow by gravity from them to the feed pump. In the closed type of exhaust heaters the exhaust steam and the water are kept separate. In some styles the steam passes through tubes, which are surrounded by water, while in others the water fills the tubes, which are in turn surrounded by the steam. In either case the water in the closed heater is under the full boiler pressure, while the feed pump is in operation, because the heater is between the pump and the boiler, while with the open heater the pump is between the heater and the boiler.

The saving effected by heating the feed water with exhaust steam can be easily ascertained by the use of a thermometer, a steam table, and a simple arithmetical calculation. First, find by thermometer the temperature of the water before entering the heater; find its temperature as it leaves the heater. Next ascertain by table 17 the number of heat units above 32° F. in the water at each of the two temperatures. Subtract the less from the greater,

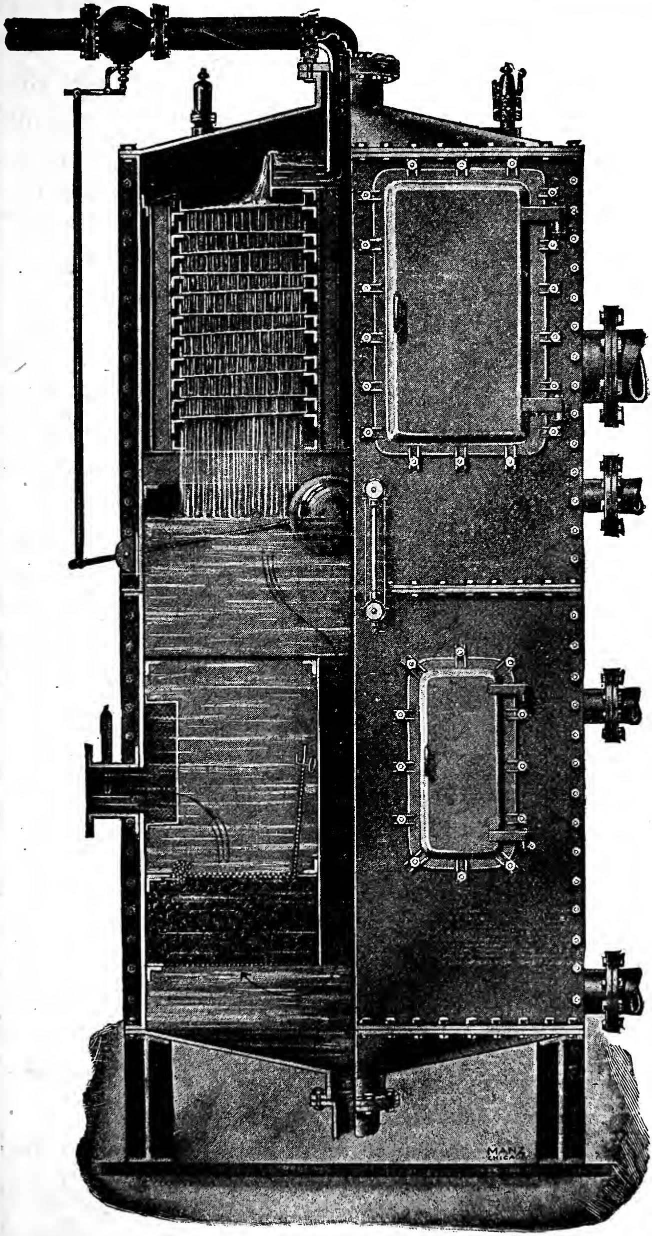


FIG. 72

and the remainder will be the number of heat units added to the water by the heater. Next find by table 17 the number of heat units above 32°F. in the steam at the pressure ordinarily carried in the boiler, and subtract from this the number of heat units in the water before it enters the heater. The result will be the number of heat units that would be required to convert the water into steam of the required pressure, provided no heater were used. Then to find the percentage of saving effected by the heater, multiply the number of heat units added to the water by the heater by 100, and divide by the number of heat units required to convert the unheated water into steam, from the initial temperature at which it enters the heater.

Example. Assume the boiler to be carrying 100 pounds gauge pressure. Suppose the temperature of the water before entering the heater is 60° F., and that after leaving the heater its temperature is 202° F., what is the percentage of saving due to the heater? The solution of the problem is as follows:

Boiler pressure by gauge=100 pounds.

Initial temperature of feed water=60° F.

Heated temperature of feed water=202° F.

From Table 17 it is found that

Heat units in water at 202° F.=170.7.

Heat unit in water at 60° F.=28.01.

Heat units added to water by heater=170.7—28.01=142.69.

Heat units in steam at 100 pounds gauge pressure=1185.0.

Heat units to be added to water at 60° F. to make steam of 100 pounds gauge pressure=1185.0—28.01=1156.99.

Percentage of saving effected by the use of the heater

$$=\frac{142.69\times100}{1156.99}=12.33 \text{ per cent.}$$

Suppose the coal consumed under this boiler amounts to two tons per day at a cost of $3.00 per ton, or a fuel cost of $6.00 per day. Then the saving in dollars and cents due to the heater in the foregoing example would be 12.33 per cent of $6.00, or $0.7398 (74 cents) per day.

Hoppes Class R Heater. Figure 74 is a side sectional elevation of a Hoppes class R open feed-water heater, Fig. 75 being an end sectional view of the same. Although this heater has been on the market several years, it has recently been improved, and embodies features not hertofore shown. The shell of the heater is cylindrical and the heads are "bumped," a design calculated to resist pressure, and also to prevent pulsations due to the impulses of the exhaust. The interior of the heater is provided with layers of trough-shaped pans arranged in tiers and designed to afford a large amount of heating surface. To avoid corrosion the pans are of cast-iron, as are also the bottom of the shell, the lower ends of the center posts, and all other parts with which the water comes in contact. The shell may be entirely cast-iron, however, if desired. In the back end of the heater is located a large oil catcher, through which the exhaust passes. See Fig. 74.

The principle of operation is, to provide that the flow of water from the cast-iron troughs at the top be so gradual that the water will be distributed over the edges of the pans in a thin film, and over the sides and ends so gently that it will follow the bottom contour of each pan to the lowest point before dropping off into the pan beneath.

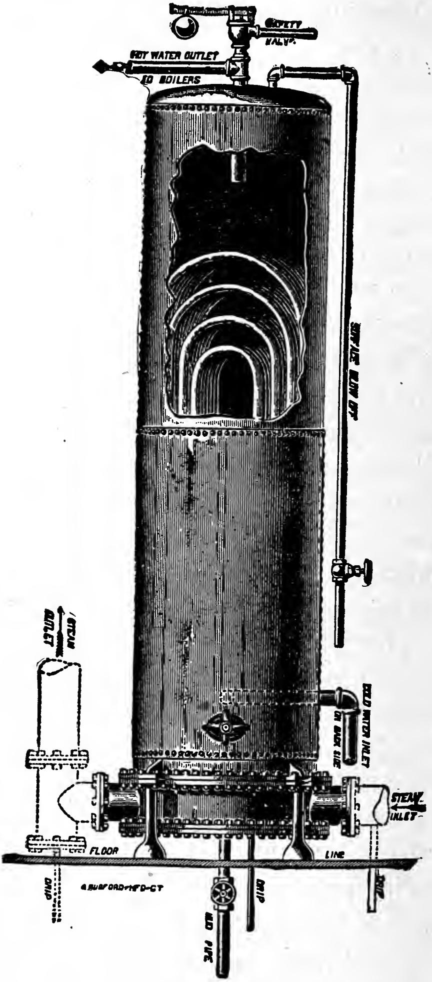


FIG. 73

CLOSED FEED WATER HEATER

While the water is following the under side of the pans, the exhaust steam will come in direct contact with, and heat it to the temperature of the exhaust. Lime and other solids which may be held in solution in the water will, when liberated by the heat, form mostly on the under side of the pans and hence will not detract from the efficiency of the process, as the same direct action of the exhaust on the water will continue as when the pans are clean.

In open heaters of large size the regulation and distribution of water so as to obtain the best results are important. In the Hoppes apparatus the water is regulated to the heater by a float in a separate float-chamber operating a double-disk balanced valve of the company's manufacture. Branch pipes from the main feed-pipe are connected to the shell at the top, and these branches have extensions inside the heater to which are attached flanged tees. To the flanges of these tees are bolted flanged inverted L-shaped pipes, the long arms of which extend below the water level of the feed troughs in the top of the heater.

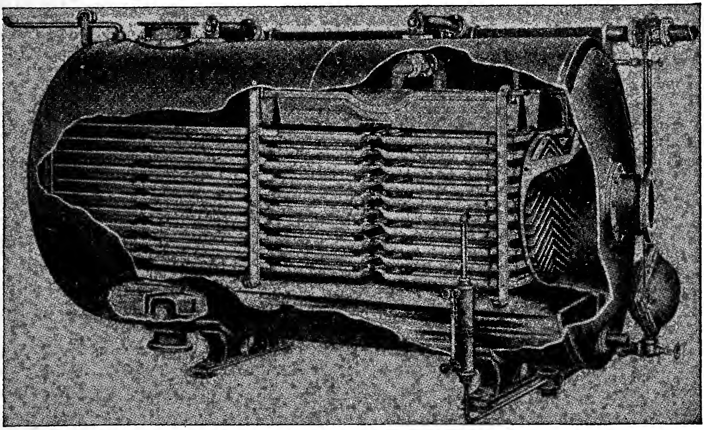


FIG. 74

SECTIONAL ELEVATION OF HOPPES CLASS R FEED-WATER HEATER

Disks with orifices of proper and equal size are placed between the flanges of the L-shaped feed-pipes and the tees, and by this means the water is equally distributed into the various tiers of pans.

When it is desired to feed two or more heaters in multiple, an equal distribution of water is given to all the heaters by using a single regulating valve on the main water inlet, and branching the same to the heaters to be supplied.

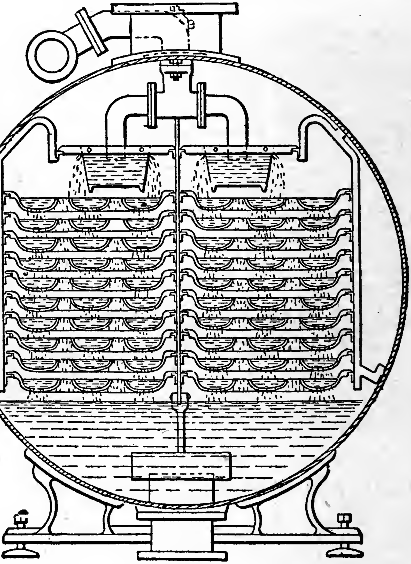


Fig. 75

END SECTIONAL VIEW OF HOPPES CLASS R HEATER

A feature recently added is an overflow dam, at the rear end of the heater, which is intended to act as a skimmer and also to add to the capacity of the overflow pipe by increasing the head on the outlet without causing the water to rise higher in the heater. The drip from the oil separator is piped into the chamber formed by the dam, but this may have a separate connection, if preferred. Filters are provided on request, but it is believed that the large amount of lime-catching surfaces obviates the necessity for their use in most cases.

These heaters are built in sizes ranging from 50 to 30,000 horse-power.

Heaters, especially those of the closed type, should have capacity sufficient to supply the boiler for fifteen or twenty minutes. There would then be a body of water continually in the heater in direct contact with the heating surface, and as it passes slowly through it will receive much more heat than if rushed through a heater that is too small. All heaters and feed pipes should be well protected by some good insulating covering to prevent loss of heat by radiation. In some cases the exhaust steam, or a portion of it at least, can be used to advantage in an exhaust injector. This device, where it can be used at all, is economical in that it not only feeds the boiler, but also heats the water without the use of live steam. But it will not force the water against a pressure much above 75 pounds to the square inch, and if the initial temperature of the water is much above 75° F. the exhaust injector will not handle it. Heaters which use live steam direct from the boilers heat the feed water to a much higher temperature, so that they act as purifiers by removing a large portion of the scale-forming impurities before the water enters the boiler. Live steam heaters, however, are not to be considered as economizers of heat.

MECHANICAL STOKERS.

The principles governing the operation of mechanical or automatic stokers are in the main correct, viz., that the supply of coal and air is continuous, and that provision is

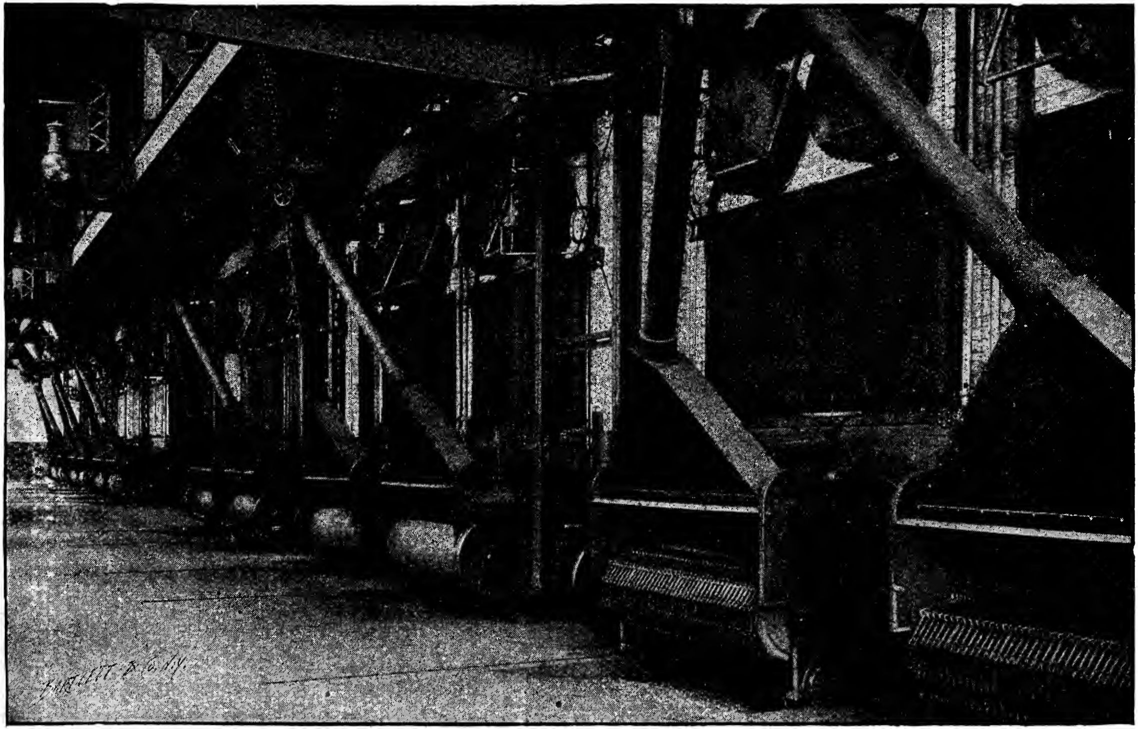


Fig. 76

made for the regulation of the supply of fuel according to the demand upon the boiler for steam; also that the intermittent opening and closing of the furnace doors, as in hand firing, thereby admitting a large volume of cold air directly into the furnace on top of the fire, is avoided.

Mechanical stokers have within the last twelve years been largely adopted in the United States, especially in sections where bituminous coal is the principal fuel. The disadvantages attending their use are:

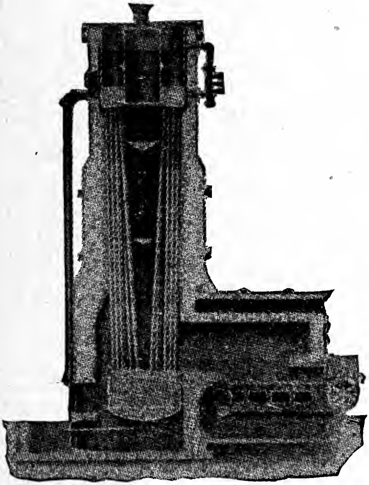


FIG. 77

CAHALL VERTICA BOILER WITH CHAIN GRATE STOKER ATTACHED

First, that the cost of properly installing them is so great that their use is practically prohibited to the small manufacturer.

Second, that in case of a sudden demand upon the boilers for more steam the automatic stoker cannot respond as promptly as in hand firing, although this objection could no doubt be met by skillful handling.

Third, the extra cost for power to operate them, although this is probably offset by the diminished expense for labor required, as compared to hand firing.

There are many different types of mechanical stokers, and automatic furnaces, but they may for convenience be grouped into four general classes. In class one, the grate consists of an endless chain of short bars that travel in a horizontal direction over sprocket wheels, operated either by a small auxiliary engine or by power derived from an overhead line of shafting in front of the boilers.

In class two may be included stokers having grate bars somewhat after the ordinary type as to length and size, but having a continuous motion up and down or forward and back. This motion, though slight, serves to keep the fuel stirred and loosened, thus preventing the firing from becoming sluggish. The grate bars in this class of stokers are either horizontal, or inclined at a slight angle, and their constant motion tends to gradually advance the coal from the front to the back end of the furnace.

Class three includes stokers having the grate bars steeply inclined. Slow motion is imparted to the grates, the coal being fed onto the upper end, and forced forward as fast as required.

Class four includes an entirely different type of stoker, in that the fresh coal is supplied underneath the grates, and is pushed up through an opening left for the purpose midway of the furnace. The gases, on being distilled, immediately come in contact with the hot bed of coke on top, and the result is good combustion. In this type of stoker, steam is the active agent used for forcing the coal up into the furnace, either by means of a long, slowly revolving screw, as in the American stoker, or a steam ram, as with the Jones under-feed stoker. A forced draft is employed, and the air is blown into the furnace through tuyeres.

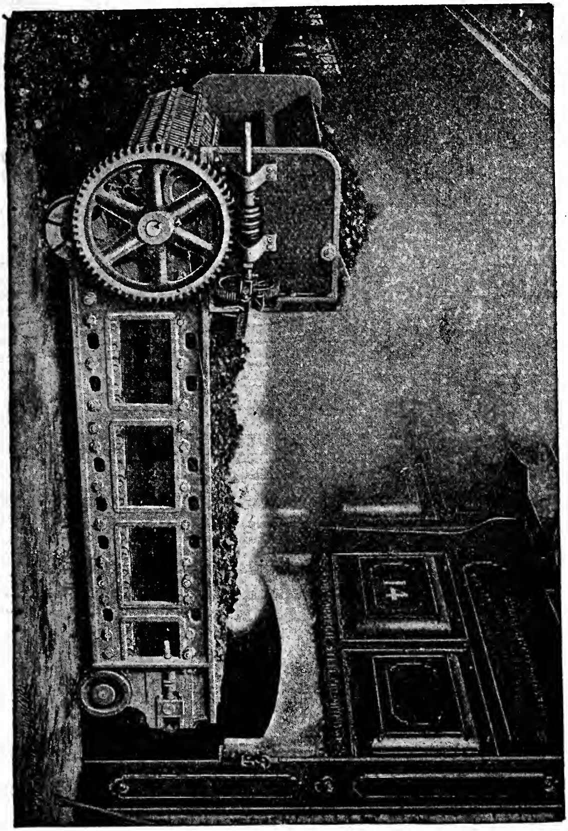


FIG. 78

MANSFIELD CHAIN GRATE STOKER

Showing How it Can Be Withdrawn from under Boiler

When these stokers are intelligently handled they give good results, especially with cheap bituminous coal. The clinker formed on the grate bars or dead plates is easily removed.

The coal is supplied to mechanical stokers, either by being shoveled by hand into hoppers in front of, and above the grates, or, as is the case in most of the large plants using them, it is elevated by machinery and deposited in chutes, through which it is fed to each boiler by gravity. Stokers of the chain grate variety are usually constructed so that they may be withdrawn from underneath the boiler in case repairs are necessary. The coal, either nut or screenings, is fed into a hopper in front of and above the level of the grate, and is slowly carried along towards the rear end. The ash drops from the grate as it passes over the sprocket wheel at the rear.

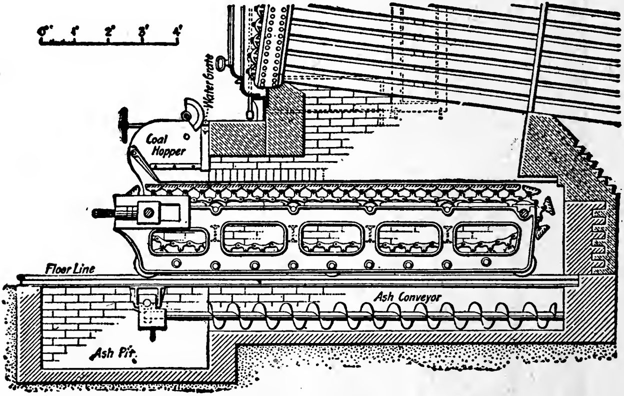


FIG. 79
PLAYFORD STOKER

Fig. 76 shows a battery of Babcock & Wilcox water-tube boilers fitted with chain grate stokers. The buckets for elevating the coal to bins overhead, from whence it is fed by gravity to the stokers, are not shown. These buckets or carriers may also be utilized for conveying the ashes from the boiler-room.

Fig. 77 is a sectional view of a vertical Cahall boiler with a *Mansfield* chain grate stoker, and Fig. 78 shows the same stoker withdrawn from the boiler.

The *Coxe* mechanical stoker operates upon the same general principles as do those previously described, being of the chain grate type, but it has in addition a series of air chambers just underneath the upper traveling grate. These air chambers are made of sheet iron, and are open at the top and provided with dampers for regulating the air pressure for different sections of the grate. The air blast is sup-

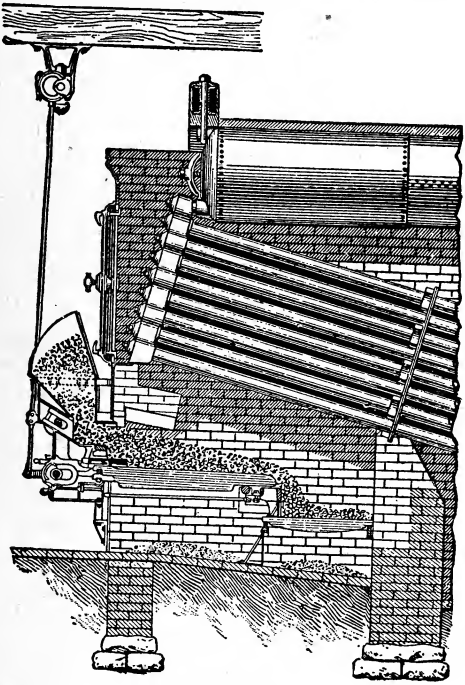


Fig. 80

VICARS MECHANICAL STOKER

plied by a fan. Another feature of this stoker is a water chamber for the bottom section of the grate to travel through on its return.

The *Playford* stoker has wrought iron T bars extending across the furnace and attached to the traveling chains. These T bars carry the small cast iron sections composing the grate. A screw conveyor is also placed in the ash pit for the purpose of carrying the ashes from the rear to the front of the pit. Fig. 79 is a sectional view of the Playford stoker attached to a water-tube boiler.

In class two may be included stokers having the grates inclined more or less. In some varieties the grates incline from front to rear, while in others they are made to incline from the side walls toward the center line of the furnace.

In the *Vicars* mechanical stoker the grate bars are somewhat of the shape of the ordinary grate, and lie in two tiers in a horizontal position. The lower or back tier next the bridge wall is stationary, and is placed there for the purpose of catching what coal is carried over the ends of the upper or moving grate bars. These have a slow reciprocating motion which gradually moves the hot coke back towards the bridge wall. The coal is fed from a hopper into two compartments, from which it is pushed by reciprocating plungers onto a coking plate and from thence it passes to the grate bars. The motion of these bars has several intermediate variations, from a state of rest to a movement of 3½ inches. They have a simultaneous movement forward by which the fuel is advanced, but on the return movement the bars act at separate intervals. In this manner the fuel remains undisturbed by the return motion of the grates. Fig. 80 illustrates this stoker.

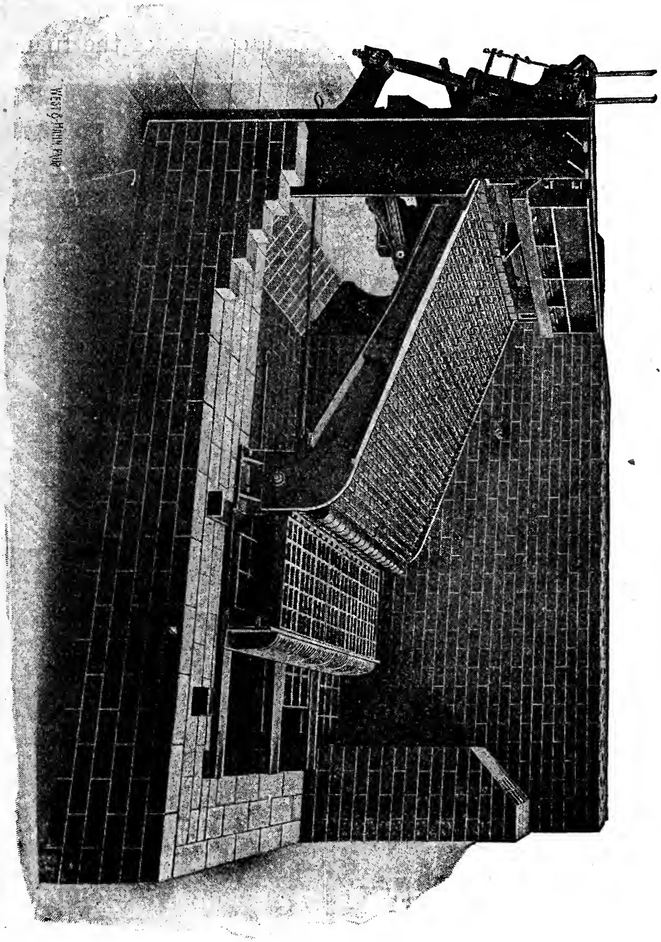


FIG. 81

FURNACE VIEW, WILKINSON STOKER

In the *Wilkinson* stoker, Fig. 81, the grate bars are hollow and are set at an angle of 20°, the inclination being from front to back. Each bar is stepped along its fire surface, and on the rise is perforated with a long, narrow slot. A steam pipe extends along the front of the furnace, and from this pipe small branch pipes lead into the ends of the grate bars, which latter are in fact a series of hollow trunks with their front ends open. When in operation a

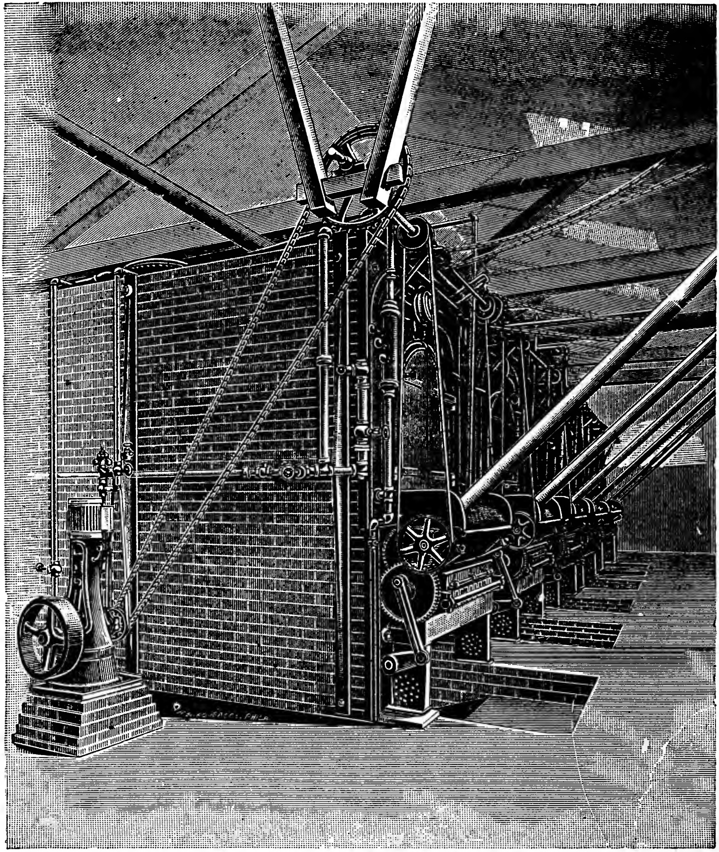


FIG. 82
WILKINSON STOKER

steam blast is admitted to each of the several trunk grate bars through the small branch pipes, and this blast induces an air current of more or less pressure, which finds an outlet through the narrow slots in the stepped fire surface of the grates, and directly into and through the burning mass of fuel. A slow reciprocating motion is imparted to the grates by means of cranks and links operated from an overhead shaft; see Fig. 82. These cranks are set alternately at 90° with each other, thus giving a forward movement to one-half of the grate bars, while at the same time the other half is moving backward. In this manner the fuel is kept slowly moving down the inclined grates.

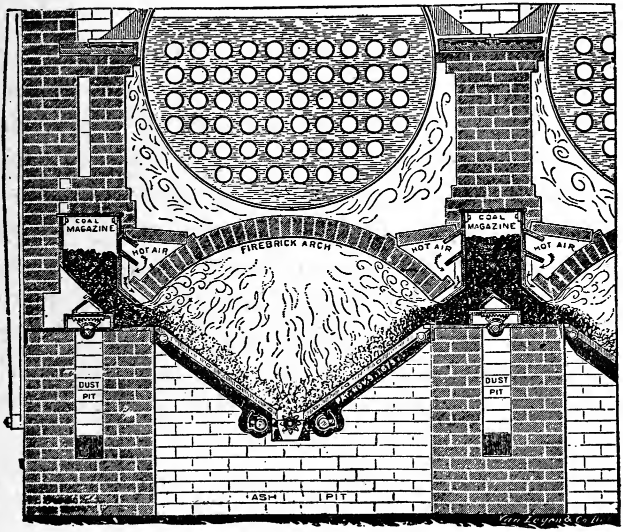


FIG. 83

THE MURPHY AUTOMATIC FURNACE

The *Murphy Automatic Furnace,* a sectional view of which is shown in Fig. 83, has the grates inclined inwards from the side walls, while a fire brick arch is sprung from side to side to cover the entire length of the grate. The coal is shoveled or fed by carrier into the coal magazines, one on each side, as shown in the cut. If the furnace is placed directly under the boiler it necessitates putting these coal magazines within the side walls, but as the Murphy furnace is usually constructed at the present day as an outside furnace, the coal magazines are independent of the boiler walls.

The bottom of each magazine is used as a coking plate, against which the upper ends of the inclined grates rest. On the central part of this plate is an inverted open box. This is termed the "stoker box," and it is moved back and forth across the face of the coking plate by means of a shaft with pinions that mesh into racks under each end of the box. By means of this motion of the stoker boxes the coal is pushed forward to the edge of the coking plate and from thence it slowly passes down over the inclined grates toward the center of the furnace. At this point the slowly rotating clinker breaker grinds the clinker and other refuse and deposits them in the ash pit.

Above the coking plates are the "arch plates," upon which the bases of the fire brick arch rest. These plates are ribbed, the ribs being an inch apart, and, the arch resting upon these ribs, there is thus provided a series of air ducts by means of which the air, already heated by having been admitted in front and passed through the flues over the arch, is conducted into the furnace above the grates and comes directly in contact with the gases rising from the coking fuel. Air is also admitted under the coking plate and, passing up through the grates, serves to keep them cool and also furnishes the needed supply to the burning coke as it slowly moves down toward the center.

The fuel is aided in its downward movement by the constant motion of the grates, one grate of each pair being moved up and down by a rocker at the lower end.

Motion is imparted to the various moving parts of this furnace by means of a reciprocating bar extending across the outside of the entire front, and to which all the working parts are attached by links and levers. This bar is operated by a small engine at one side of the setting, the power required being about one horsepower per furnace.

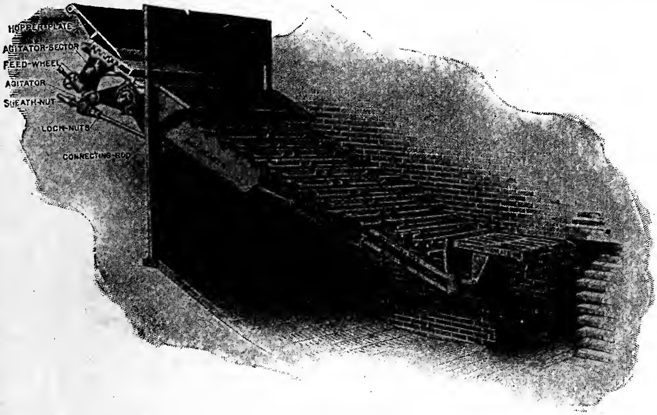


FIG. 84

SECTIONAL PERSPECTIVE OF THE RONEY MECHANICAL STOKER

The *Roney* stoker consists of a set of rocking stepped grate bars, inclined from the front toward the bridge wall. The angle of inclination is 37°. A dumping grate operated by hand is at the bottom of the incline for the purpose of receiving and discharging the clinker and ash. This dumping grate is divided into sections for convenience in handling.

The coal is fed onto the inclined grates from a hopper in front. The grate bars rock through an arc of 30°, assuming alternately the stepped, and the inclined positions. Fig. 84 is a sectional perspective view of this stoker and illustrates the working parts.

The grate bars receive their motion through the medium of a rocker bar and connecting rod. A shaft extending across the front of the stoker under the coal hopper carries an eccentric that gives motion to the connecting rod and also to the pusher in the coal hopper. This pusher, working back and forth, feeds the coal over the dead plates onto the grates, and its range of motion is regulated by a feed wheel from no stroke, to full stroke, according to the demand for coal. The motion of the grate bars may also be regulated by a sheath nut working on a long thread on the connecting rod. Each grate bar consists of two parts, viz., a cast iron web fitted with trunnions on each end that rest in seats in the side bearer, and a fuel plate having the under side ribbed to allow a free circulation of air.

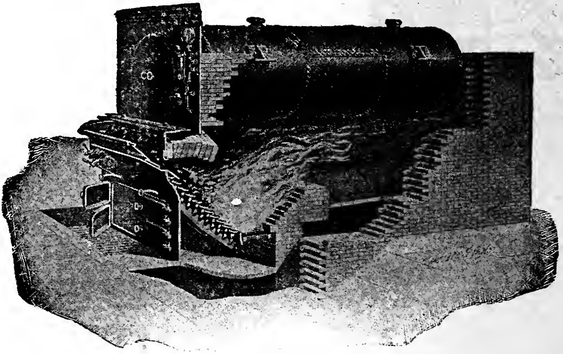


FIG. 85

The fuel plate is bolted to the web and carries the fuel. The grates lie in a horizontal position across the furnace in the form of steps, and ample provision is made for the admission of air through the slotted webs. A fire brick arch is also sprung across the furnace, covering the upper portion of the grate.

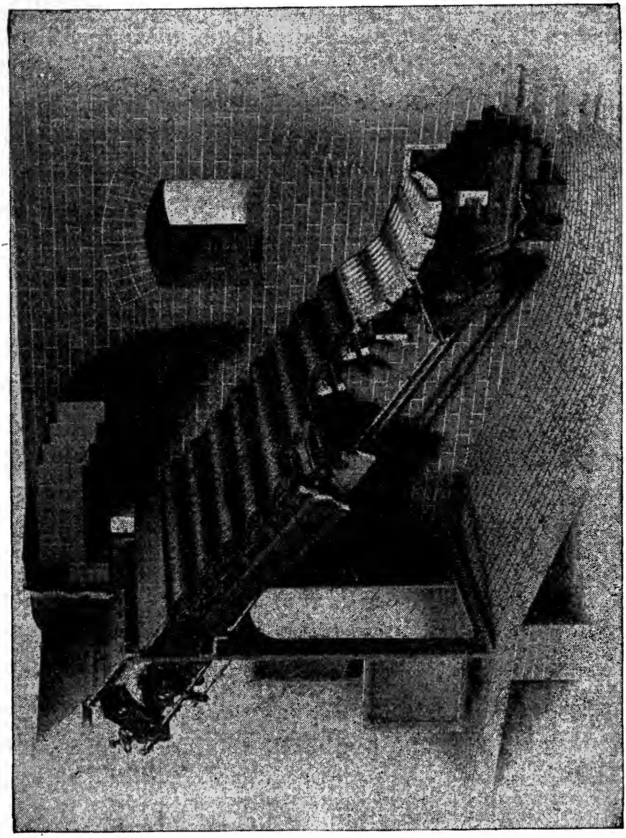


Fig. 86

NEW RONEY STOKER AS IT APPEARS IN FURNACE

This arch, being heated to a high temperature, serves in a measure to partly coke the coal as it passes under it. Air is also admitted on top of the coal at the front. This air is heated by its passage through a perforated tile over the dead plate and adjoining the fire brick arch. Fig. 85 shows the location of the arch and tile.

The Westinghouse Machine Company has recently designed an improved model of the Roney mechanical stoker. Some of the most important features in connection with its design is, that the number of complete grate bars has been reduced one-half over that used with the old type of stoker. The tops, webs, guards and dumping grates are interchangeable. The grate bars automatically center themselves in the side bearings by their own weight; they may also be re-distributed so as to equalize wear over all parts of the furnace. The guard and dumping grates are interchangeable without disturbing the side or center bearings. Fig. 86 shows the stoker as it appears in a furnace setting.

For the upper four grates a non-sifting type of top is used, provided with abutting, horizontal ledges to prevent the fine fuel from sifting through the bars, and at the same time permit a free entrance of the air. For each square foot of grate exposed to the fire, 7.4 square feet of surface is cooled by the air, giving 7.4 times the cooling effect of the flat-top grate bar.

As will be seen from Fig. 87, the grate proper consists of a number of thin plates set on edge in V-grooves. These hook over a trussed web, and are held in place by a key-rod slipped in from the end. They are, therefore, easily removed. One of the principal advantages of the sectional grate-bar tops is, that it reduces the amount of scrap when they have been sufficiently worn to be discarded. In this stoker no bolts are used, and any part can be removed without disturbing the other.

FIG. 87
BONEY STOKER
Showing Construction of Grate

The new type of guard prevents the fire from sliding into the ash-pit when the dumping grate is operated. As the lower end of the guard is now raised, instead of cutting through the fire, as formerly, it not only makes it possible to dislodge from the fire all clinker formed at the bottom, but also provides an unobstructed descent for the ash and clinker separately. When dropped to its normal position, it permits the lower edge of the fire to settle quietly without a tendency to slide.

The new dumping grate is hinged about one-third forward, dumping both front and rear. Being nearly balanced, it is very easily operated. The upward motion of the dumping grate breaks up any clinker bridge tending to form between the grates and bridge-wall.

In mechanical stokers of the under-feed type the air is supplied by forced draft.

The *American* stoker consists of a horizontal conveyor pipe into which the coal is fed from a hopper. The diameter of this pipe depends upon the quantity of coal to be burned, and varies from 4½ inches for the smaller sizes up to 9 and 10 inches for the larger sized stokers. The length of the conveyor pipe for the standard 10-inch stoker is 72 inches. Attached to the outer end of this conveyor pipe, and forming a part of it, is an iron box containing a reciprocating steam motor, which, through the medium of a rocker arm, and pawl and ratchet wheel, drives a screw conveyor shaft that slowly revolves within the pipe, thus forcing the coal forward and up through another box or trough, which latter is wholly within the furnace. Extending around the top edges of this box, and on a level with the grate bars, there is a series of tuveres through which the air is forced.

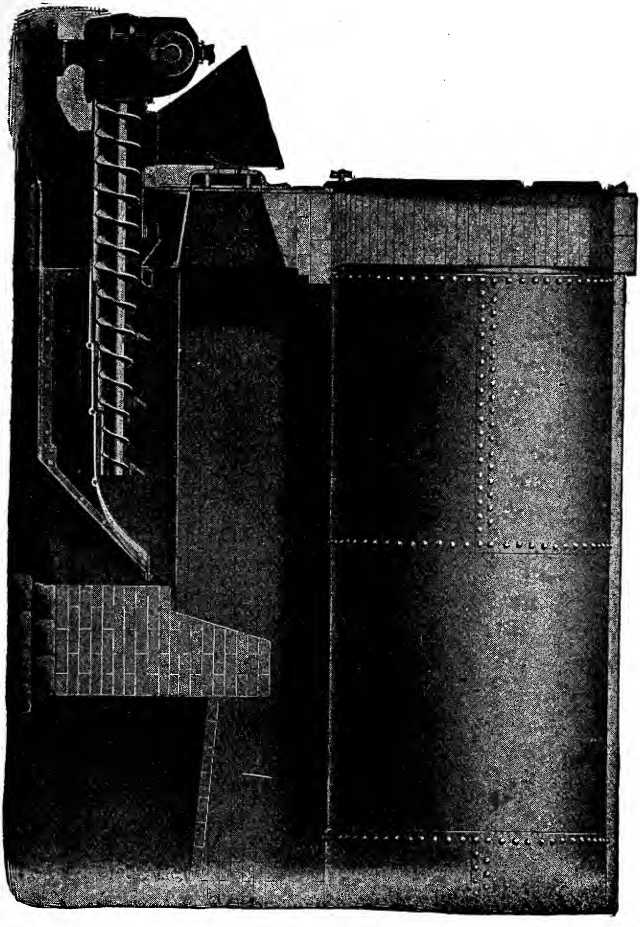


FIG. 88

TYPICAL SETTING OF AMERICAN STOKER UNDER A RETURN TUBULAR BOILER

These tuyeres, being at a high temperature, serve to heat the air in its passage through them, thus greatly aiding combustion. Fig. 88 is a longitudinal sectional view of this stoker.

The speed of the screw conveyor is regulated by the hand throttle of the motor, according to the demand for coal. With the 9-inch standard stoker from 350 to 1,200 pounds of coal per hour may be burned. Fig. 89 is a view of the American stoker before being placed in position in the furnace.

The air jets, passing out from the tuyeres in a horizontal direction, and from opposite sides, cut through the rounded bed of coal and the gases are thus ignited and consumed immediately after being distilled from the coal, while the pressure of the coal rising from underneath forces the already coked fuel over the edges of the trough or box onto the grates which occupy the space between the side walls and the coal trough. The air is first delivered from the fan into the air box that surrounds the coal trough on three sides and from thence it passes to the tuyeres. If this stoker is properly handled very good results may be obtained by its use, but, like all other devices for burning coal under boilers, it is bad policy to endeavor to force it beyond its capacity.

In the *Jones* under-feed stoker the coal is pushed forward and up into the furnace through a cast iron retort or trough. The impelling force is a steam ram connected to the outer end of the retort, and the speed of the ram is regulated automatically by the steam pressure, or by hand as desired. The coal is supplied to the ram through a cast iron hopper having a capacity of 125 to 140 pounds.

Force draft is also employed in this stoker, the air being conducted from the fan or blower through galvanized iron pipes into the closed ash pit, which really forms an air box, as the space on either side of the retort that is usually occupied by grate bars is in this case covered by solid cast

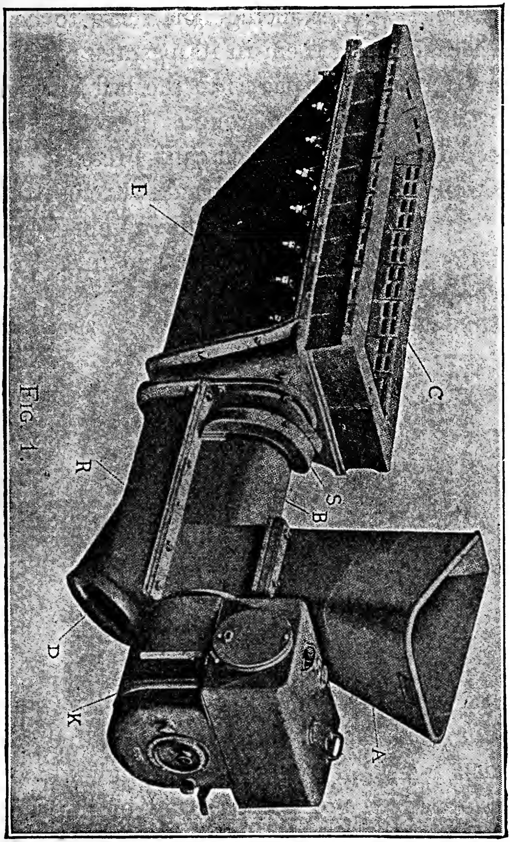


FIG. 89

STANDARD 8 AND 9 INCH AMERICAN STOKERS

A—Coal hopper; B—Conveyor pipe; C—Tuyeres for introducing air to the fuel; D—Opening to wind-box for air connections; E—Wind-box for supplying air to tuyeres; K—Automatic steam motor for driving conveyor; R—Air pipe to wind-box; S—Gas ducts for returning volatile products from entering coal to furnace.

iron dead plates, upon which the coked fuel lies until it is consumed. These plates, being hot, serve to heat the air coming in contact with them in its passage to the cast iron tuyeres through which it passes to the bed of burning fuel in the retort. Air entirely surrounds the retort on the sides and back end, and is at a constant pressure in the ash pit, but can only pass into the furnace through the tuyeres, the jets of air cutting through the rounded heap of incandescent fuel from opposite sides, and in a direction inclined upwards.

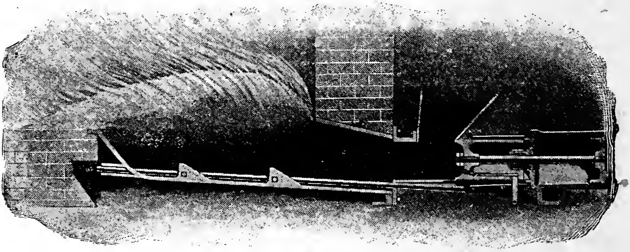


FIG. 90

Coal is supplied to the hopper either by hand, or by mechanical means where the plant is fitted with coal-handling machinery. The opening through which it passes from the hopper to a position in front of the ram is 8x10 inches in size. Each charge of the steam ram carries forward 15 to 20 pounds of coal. Connected to the ram, and moving in conjunction with it is a long rod extending through the retort near the bottom. Upon this rod are carried shoes that act as auxiliary plungers and facilitate the movement of the coal.

Fig. 90 is a sectional view of the Jones stoker, showing the machine full of coal, with the ram ready to make a charge. Fig. 91 shows the stoker complete before being placed in the furnace.

It is claimed by the builders of under-feed stokers, and the claim appears to have good foundation, that by pushing the green coal up, so as to meet the upper crust of glowing fuel the gases on being distilled immediately come in contact with, and are consumed by the burning mass, and the formation of smoke is thus prevented. Both the Jones under-feed, and the American stokers have proved to be very successful in the burning of the cheaper bituminous coals of the West. One feature tending to commend them is the fact that practically all of the coal is utilized, there being no waste caused by the slack coal or fine screenings dropped through the grate bars into the ash pit unconsumed.

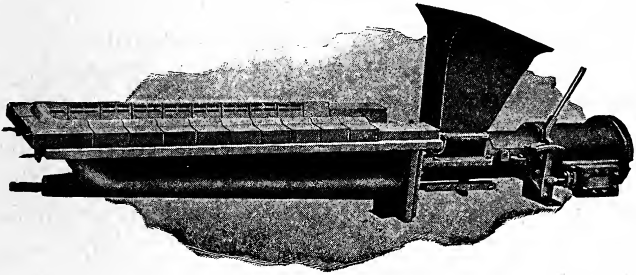


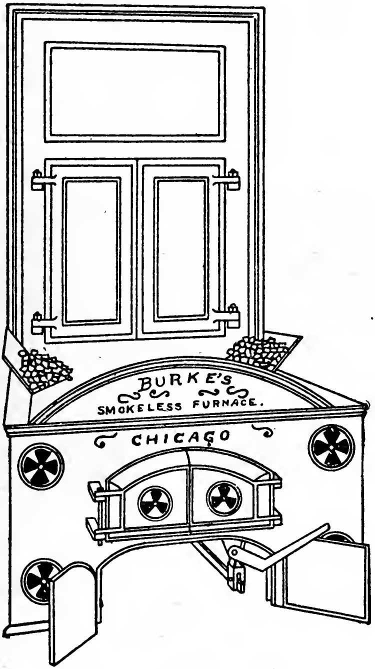
FIG. 91

A good substitute for the mechanical stoker is an outside furnace, by which is meant a boiler installation having the furnace in front of, instead of underneath the boiler. One of the principal hindrances to good combustion in the ordinary type of boiler furnace is the fact that the temperature of the boiler shell or water tubes with which the gaseous products of combustion come in contact can never be higher than the temperature of the water contained within the boiler. This temperature ranges from 297° for steam at 50 pounds gauge pressure, up to 407° for 255 pounds pressure, while the temperature of the furnace, according to Dr. Thurston and other high authorities, ranges from 2,010° to 2,550°.

It is evident that perfect combustion does not take place until these high temperatures are reached. Each time the furnace is charged with fresh coal, especially if the boiler be hand-fired, a large volume of volatile gases is liberated, but not consumed. If these gases are allowed to immediately come in contact with a comparatively cool surface, as for instance the heating surface of the boiler, the result is a cooling of the gases, incomplete combustion and the formation of smoke and soot. If, on the other hand, the furnace is so constructed that these gaseous products first impinge against hot surfaces, such as fire brick arches or bafflers that have a temperature corresponding to that of the furnace, good combustion is assured. This condition is in a large degree attained by the use of outside furnaces, that permit the construction of a fire brick arch to cover the entire grate surface.

The *Burke* furnace, patented by James V. Burke of Chicago, is a notable example of this type of furnace. It is applicable to any type of stationary boiler. Fig. 92 shows this furnace as applied to tubular boilers. It consists of a fire brick arch extending from 6 to 8 feet outwards from the boiler front, and of a width to correspond to the diameter of the boiler. The arch rests securely upon brick work inclosed in a well ventilated iron casing. There is practically no heat radiated from this furnace, all the heat generated by it passing to the boiler. The central portion of the grate bars consists of shaking grates, while the side bars are stationary and inclined.

Fig. 93 is a sectional view and will serve to illustrate the construction of this furnace. The coal is fed through pockets on top on each side of the arch, the larger furnaces having two pockets on each side and the smaller sizes one.



Front View.

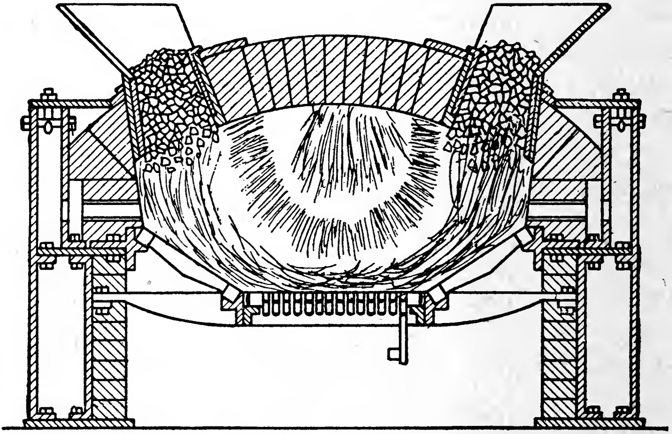
Fig. 92

BURKE FURNACE

The doors in front are only opened for the purpose of cleaning fires, or when first starting fires. The air is supplied by way of the ash pit, passing up through the grate bars. A portion of the air supply is also drawn through the ventilators and passes to the upper part of the furnace.

The arch extends under the front end of the boiler 6 or 8 inches, and there is a bridge wall about 4 feet back from the front, against which the gases from the furnace impinge.

There are 42 square feet of grate surface in the larger sizes, and 22 square feet in the smaller size. Good combustion is attained in this furnace, owing to the fact that the gases as they are distilled from the coal come immediately in contact with the highly heated surface of the arch directly over the fire.



CROSS SECTION.

FIG. 93

BURKE FURNACE

Stoker selection and stoker installation furnish problems requiring a high order of mechanical skill, knowledge of many details and freedom from bias and prejudice. Each installation must be studied individually, and the size and type of stoker and subsidiary details of grate, draft, furnace, etc., determined only after an exhaustive consideration of all points. Thus and only thus may the highest economy be realized, for it is economy primarily that must be sought and secured in this day of keen competition, with a smokeless stack as a secondary consideration.

It is a fact, well recognized by all students of boiler furnace combustion, that smoke suppression does not necessarily mean fuel economy, while it is universally recognized that when combustion is complete with fuel economy at its highest, there can be no smoke.

The very considerable initial cost of installing mechanical stokers may no longer be regarded as a species of speculation, but as a sound investment that returns a truly marvelous annual dividend. It is not overstating the facts, as well recognized by progressive and studious engineers that there is no other single piece of power plant equipment that will pay a richer dividend on its cost than a properly constructed, properly selected, properly installed mechanical stoker.

It is totally impossible to duplicate the condition of a stoker-fired furnace with one in which the coal is fed by hand through the firedoor.

MECHANICAL DRAFT.

Application of mechanical draft assumes three general forms: First, induced draft by the installation of fans to serve as a chimney. Second, forced draft by applying fans to force air beneath boiler grates. Third, the combination of induced and forced draft, obtained by fans applied to serve both purposes, or by separate fans for each. Many large plants are now installed where this combination is employed, the combined forced and induced draft system being brought about on account of equipping the boilers with any make of stokers, outside of the chain type or those having the open ash pit. Air, under a pressure of one and one-fourth to two ounces, is delivered to the stokers by a forced draft fan, the separate induced draft fan, or fans being connected in the ordinary manner, with the boiler breeching, with or without economizer in connection, and discharge the gases through a steel stack into the atmosphere. Under this class may also be included the method of burning powdered fuel in suspension. The practicability of the system has been thoroughly demonstrated by tests extending over a number of months, but, while the system has shown a marked degree of efficiency, it has seldom been made use of in practice. The selection of the proper type to render the highest economy, primarily depends upon the fuel to be consumed, and the various conditions of the steam plant to be outfitted. It is readily seen that no single one of these three applications of mechanical draft will give the best results in all cases, but that every boiler plant must be carefully treated individually.

Mechanical Induced Draft is by no means a new idea, yet it is only within a few years that the same draft has been much used or installed on a large scale. Previously it had been used, with a few exceptions, for the purpose of improving poor draft by helping out an insufficient or an overloaded chimney. The largest and most successful applications of mechanically induced draft have been made in connection with feed water heaters designed to utilize the waste heat of the flue gases, and known as fuel economizers. This form of feed-water heaters has been manufactured in England for over fifty years. They have, however, been imported for many years, as their value as a fuel saving device is well established. Their successful operation is so dependent upon good draft that no well-informed engineer would think of installing an economizer without making provision for much better draft than the boilers would require without it. On account of the reducing effect on the draft, caused by lowering the temperature of the gases and retarding their flow by the mechanical interference of the pipes, it cannot be considered good engineering to attach an economizer to a chimney less than 200 feet in height. The best working economizers in connection with chimneys are those where the chimney is considerably over 200 feet high.

Forced Draft has been used for years, the original installations being principally for burning refuse materials, and for assisting boiler draft of natural low efficiency. The advancement to popular favor has been of healthy but gradual growth. In the early stage it was commonly supposed that what would now be called in mechanical draft a high air pressure was absolutely essential to best results. As this type of mechanical draft has developed, it is noticeable that in succeeding representative plants, the velocity of air has gradually decreased, until now it is generally recognized that forced draft outfits show the best results where a sufficient air volume is used at the lowest pressure which secures complete combustion. Practice has established the fact that this is more economical than using the same quantity of air at double the velocity, because of less liability to blow holes, less unconsumed particles carried up to the stack, and less horse power consumed by the fan.

As is at once understood, the term "forced draft" used in connection with a steam plant refers to the forcing of the air under the grates. The favorite point of introduction into most boilers is through the bridge wall at the rear end of the grates. Where this arrangement is not feasible, however, quite as efficient results are obtained through side walls, or further in front, using properly arranged dampers with convenient accessories for manipulation.

Occasionally objections to forced draft are urged, on the ground that with its use there is an outward leakage of gases, and blow holes through boiler fires at different grate intervals. Such results only occur with poor applications and installation details, or with improper firing. The method of introduction of the air to the grates, and the appliances therefor, figure conspicuously in the securing of maximum economy and efficiency.

Where the air supplied to the fan is taken from an air chamber built around, or through the smoke breeching—and herein is embodied an important saving—the temperature of the air supply, and consequently the temperature of the furnace is raised while the temperature of the gases in the breeching is reduced. With natural draft this would tend to reduce the velocity in the stack. It is highly desirable that the fan be driven by an individual engine, with the valve controlling the steam supply thereto equipped with the special arrangement for governing the speed of the engine, according to the draft requirements. In brief, the principle of this consists of automatically supplying more steam to the engine when the boiler pressure lowers, and less steam when the steam pressure increases. This has been brought to so fine a point that practically a constant pressure is maintained on the boilers with proper firing.

Direct advantages exist in favor of forced draft where certain conditions exist. The chimney of a given steam plant may be capable of handling the boilers, excepting un-

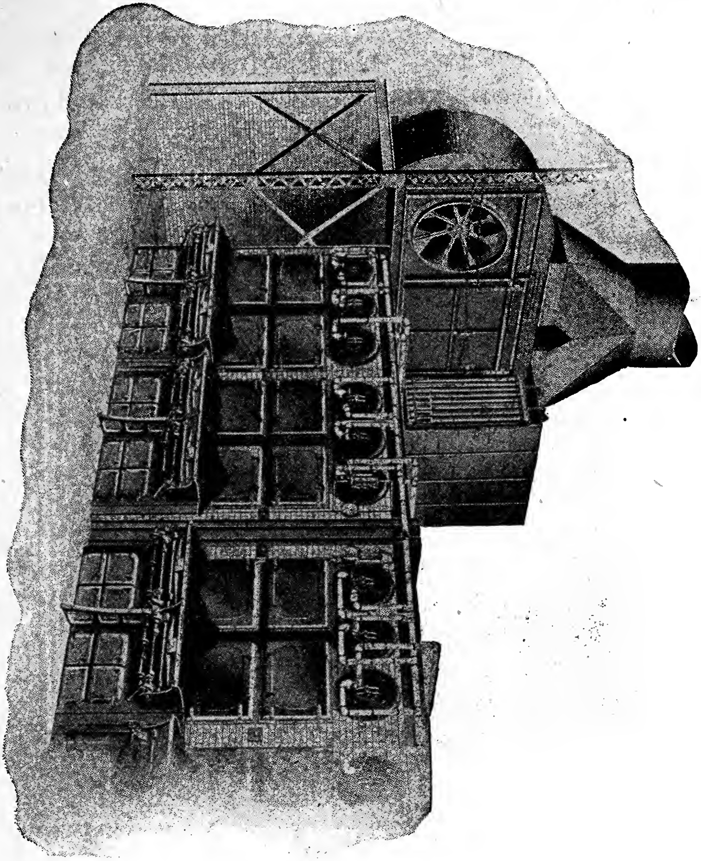


Fig. 94

BUFFALO MECHANICAL DRAFT APPARATUS

Horizontal Tandem Fans—Casing and Economizer Partly Removed to Show Damper

der adverse conditions of weather, when a blower properly applied needs only to be started and run during such periods. While the capacity of a chimney, either with forced or natural draft, is limited, the natural efficiency may be materially increased, so that if more boilers have been added than the chimney will properly handle without some assistance, this may be afforded by the proper application of a blower to force air into the ash-pit.

Fig. 94 shows part of a large steam plant equipped with an induced draft apparatus supplied by the Buffalo Forge Co., Buffalo, N. Y. A portion of the casing is removed in order to show the location of the economizer.

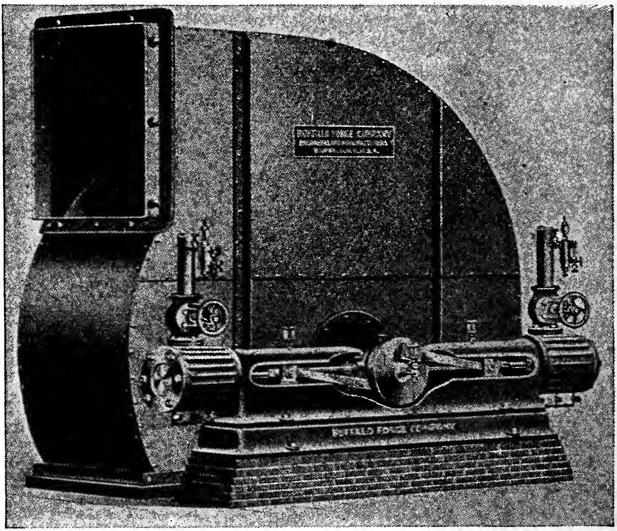


Fig. 95

THREE-QUARTER HOUSING STEEL PLATE FAN WITH DOUBLE HORIZONTAL ENGINE

Fig. 95 shows another style of fan having double horizontal engines, one on each side of the crank shaft, which is extended into the fan, and forms a direct-attached machine by reason of the fan wheel being placed on the opposite end of the shaft. But one of the engines is intended for use at a time, the other rod being disconnected and held in reserve in case of an accident, although the design is such that both may be operated simultaneously, if desired. In the construction of this engine, the desirable point of being able to quickly change from the right to the left-hand engine, or the reverse, at the same time keeping a perfect balance, has been embodied. This feature is accomplished in the following manner: The disc is made sufficiently heavy on the side on which the pin is placed to counterbalance the crank and connections when the left-hand engine connected to the crank is in use. Then when the left-hand engine is disconnected and the right-hand engine is connected up, the pocket provided in the disc on the opposite side from the pin is filled with shot, and the balance re-established for the right-hand engine, when the left-hand engine is held in reserve. The pocket in which the shot is placed is stopped with a threaded plug inserted with a screw-driver and makes a neat finish. It may be filled or emptied in a few seconds' time. The crank shaft is of forged steel, of ample proportions, which is a distinguishing feature of Buffalo Steam Fans. Sufficient space is left between the crank and the disc for the eccentric, and a bearing of ample wearing proportions. The valves employed are of the piston type, carefully fitted up with cages, and snap ring packing. They are attached to the valve stem by a simple, efficient method, which permits of the removal of the valve with the greatest ease. Other general construction details are similar to those found in the Buffalo center-crank engines.

The illustration shows a large fan in three-quarter steel plate housing, the lower portion of the scroll being brickwork, and is used for blowing a battery of stationary boiler fires.

Combined induced and forced draft applied to a battery of boilers is somewhat unusual, but the Buffalo Special Steel Plate Fans have been thus employed with excellent results. The combined system being employed because of equipping the boilers with stokers, requiring a closed ash pit. Certain special boilers are designed particularly for induced and forced draft, and to these have applications been made, with the result of obtaining more than a regular amount of steaming capacity within a given space. Ordinary boilers have also been thus outfitted with considerably increased capacity.

The combination may be installed in two ways, as follows: First, with two separate fans, one an induction, and the other an eduction fan. Second, with a single fan of special construction, having a web or divided wheel and two inlets, one to receive the intake of gases from the boiler stack, and the other to receive fresh air, the amount handled being regulated by an oscillating damper. The former arrangement is necessitated for the special boiler construction alluded to, and is also applicable to large steam plants with ordinary, water-tube, or tubular boilers with or without equipments of economizers, and burning fuel of low grades. The fan for forcing air under the grates is usually somewhat the smaller of the two.

The more simple plants of combined induced and forced draft employ the one fan arrangement, which is built with two inlets and takes in unheated air on one side. Connection, by means of a suitable pipe, is made with the chimney flue or smoke breeching of the boiler to the other side of the fan, thereby taking in the larger part of the flue gases. These are mixed with the fresh air taken in from the other side of the fan as it leaves the outlet and is being delivered to the ash-pit of the furnaces. From thence the air is forced through the grates to the fuel bed. Dampers are used on each side to regulate the proportion of air and flue gases admitted to the fan. Recently published tests of such apparatus using Buffalo Special Steel Plate Fans, show an average temperature of the air discharged under the grates of 235 degrees, and naturally a great gain in efficiency over the same boilers without the device.

The importance of good draft, either natural or artificial, for supplying sufficient oxygen for the economical combustion of fuel has long been recognized by intelligent engineers. The gain, both in efficiency and capacity, obtained by the rapid and energetic combustion of fuel, and the resulting high furnace temperatures is well established. Its importance has been generally conceded only within a few years. To obtain this high furnace temperature requires draft sufficiently strong to deliver an abundant supply of oxygen to the furnace.

CHIMNEYS.

Chimneys are required for two purposes—first, to carry off obnoxious gases; second, to produce a draft, and so facilitate combustion. The first requires size, the second height.

The weight of gas to be carried off by a chimney in a given time depends upon three things—size of chimney, velocity of flow, and density of gas. But as the density decreases directly as the absolute temperature, while the velocity increases, with a given height, nearly as the square root of the temperature, it follows that there is a temperature at which the weight of gas delivered is a maximum. This is about 550° above the surrounding air. Temperature, however, makes so little difference, that at 550° above, the quantity is *only four per cent* greater than at 300°. Therefore, height and area are the only elements necessary to consider in an ordinary chimney.

The intensity of draft is, however, independent of the size, and depends upon the difference in weight of the outside and inside columns of air, which varies nearly as the product of the height into the difference of temperature. This is usually stated in an equivalent column of water, and may vary from 0 to possibly 2 inches.

After a height has been reached to product draft of sufficient intensity to burn fine, hard coal, provided the area of the chimney is large enough, there seems no good mechanical reason for adding further to the height, whatever the size of the chimney required. Where cost is no consideration, there is no objection to building as high as one pleases; but for the purely utilitarian purposes of steam making, equally good results might be attained with a shorter chimney at much less cost.

The intensity of draft required varies with the kind and condition of the fuel, and the thickness of the fires. Wood requires the least, and anthracite screenings the most. The strong draft required for burning the smaller sizes of anthracite coal necessitates a very tall chimney, unless forced blast is used.

Generally a much less height than 100 feet cannot be recommended for a boiler, as the lower grades of fuel cannot be burned as they should be with a shorter chimney.

A round chimney is better than square, and a straight flue better than a tapering, though it may be either larger or smaller at the top without detriment.

The effective area of a chimney for a given power varies inversely as the square root of the height. The actual area, in practice, should be greater, because of retardation of velocity due to friction against the walls. On the basis that this is equal to a layer of air two inches thick over the whole interior surface, and that a commercial horsepower requires the consumption on an average of 5 pounds of coal per hour, we have the following formulas:

$$E=\frac{0.3\,H}{\sqrt{h}}=A-0.6\ \sqrt{A}\ \dots\dots\dots\dots\dots\dots\ 1$$

$$H=3.33\ E\ \sqrt{h}\ \dots\dots\dots\dots\dots\dots\ 2$$

$$S=12\ \sqrt{E}+4\ \dots\dots\dots\dots\dots\dots\ 3$$

$$D=13.54\ \sqrt{E}+4\ \dots\dots\dots\dots\dots\dots\ 4$$

$$h=\left(\frac{0.3\ H^2}{E}\right)\ \dots\dots\dots\dots\dots\dots\ 5$$

in which H=horsepower; h=height of chimney in feet; E=effective area, and A=actual area in square feet; S=side of square chimney, and D=dia. of round chimney in inches. Table 15 is calculated by means of these formulas.

To find the draft of a given chimney in inches of water: *Divide 7.6 by the absolute temperature of the external air* ($\tau_a=t+460$)*; divide 7.9 by the absolute temperature of the gases in the chimney* ($\tau_c=t'+460$)*; subtract the latter from the former, and multiply the remainder by the height of the chimney in feet.* This rule, expressed in a formula, would be:

$$d=h\left(\frac{7.6}{\tau_a}-\frac{7.9}{\tau_c}\right).$$

To find the height of a chimney, to give a specific draft power, expressed in inches of water: *Proceed as above, through the first two steps, then divide the given draft power by the remainder,* the result is the height in feet. Or, by formula:

$$h = \frac{d}{\left(\frac{7.6}{\tau_a} - \frac{7.9}{\tau_c}\right)}$$

To find the maximum efficient draft for any given chimney, the heated column being 600° F., and the external air 62°: *Multiply the height above grate in feet by .007, and the product is the draft power in inches of water.*

The diagram, Fig. 96, shows the draft, in inches, of water for a chimney 100 feet high, under different temperatures, from 50° to 800° above external atmosphere, which is assumed at 60°. The vertical scale is full size, and each division is 1/20 of an inch. It also shows the relative quantity, in pounds of air, which would be delivered, in the same time, by a chimney under the same differences of temperature. It will be seen that practically nothing can be gained by carrying the temperature of the chimney more than 350° above the external air at 60°.

To determine the quantity of air, in pounds, a given chimney will deliver per hour, multiply the distance in inches, at given temperature, on the diagram, Fig. 96, by 1,000 times the effective area in square feet, and by the square root of the height in feet. This gives a maximum. Friction in flues and furnace may reduce it greatly.

The external diameter of a brick chimney at the base should be one-tenth the height, unless it be supported by some other structure. The "batter" or taper of a chimney should be from $\frac{1}{16}$ to ¼ inch to the foot on each side.

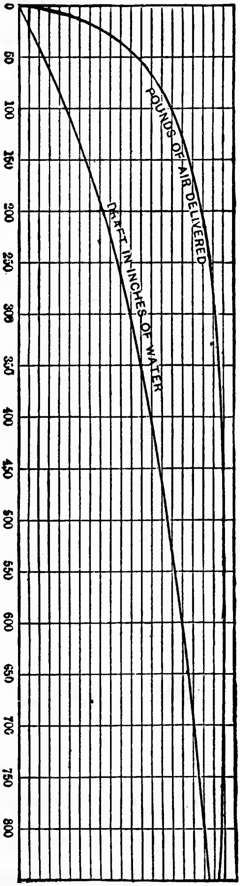


Fig. 96

Thickness of brick work: one brick (8 or 9 inches) for 25 feet from the top, increasing ½ brick (4 or 4½ inches) for each 25 feet from the top downwards.

If the inside diameter exceed 5 feet the top length should be 1½ bricks, and if under 3 feet it may be ½ brick for ten feet.

TABLE 14

THEORETICAL DRAFT PRESSURE IN INCHES OF WATER IN A CHIMNEY 100 FEET HIGH.

(For other heights the draft varies directly as the height.)

Temp. in Chimney Fahr.	TEMP. OF EXTERNAL AIR. (BAROMETER 30 INCHES.)										
	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°
200°	.453	.419	.384	.353	.321	.292	.263	.234	.209	.182	.157
220	.488	.453	.419	.388	.355	.326	.298	.269	.244	.217	.192
240	.520	.488	.451	.421	.388	.359	.330	.301	.276	.250	.225
260	.555	.528	.484	.453	.420	.392	.363	.334	.309	.282	.257
280	.584	.549	.515	.482	.451	.422	.394	.365	.340	.313	.288
300	.611	.576	.541	.511	.478	.449	.420	.392	.367	.340	.315
320	.637	.603	.568	.538	.505	.476	.447	.419	.394	.367	.342
340	.662	.638	.593	.563	.530	.501	.472	.443	.419	.392	.367
360	.687	.653	.618	.588	.555	.526	.497	.468	.444	.417	.392
380	.710	.676	.641	.611	.578	.549	.520	.492	.467	.440	.415
400	.732	.697	.662	.632	.598	.570	.541	.513	.488	.461	.436
420	.753	.718	.684	.653	.620	.591	.563	.534	.509	.482	.457
440	.774	.739	.705	.674	.641	.612	.584	.555	.530	.503	.478
460	.793	.758	.724	.694	.660	.632	.603	.574	.549	.522	.497
480	.810	.776	.741	.710	.678	.649	.620	.591	.566	.540	.515
500	.829	.791	.760	.730	.697	.669	.639	.610	.586	.559	.534

The available draft will be the tabular values, less the amount consumed by friction in the stack. In stacks whose diameter is determined by the formulæ, the *net* draft will be 80% of the tabular values. Hence to obtain from the table the height of stack necessary to produce a net draft of say 0.6 inches, the theoretical draft will be 0.6×1.25=0.75 inches, which can be got with a stack 100 feet high with flue-gas temperature of 420° F., and air temperature of 0° F., or a stack 125 feet high when the air temperature is 60° F.

TABLE 15

SIZES OF CHIMNEYS WITH APPROPRIATE HORSEPOWER OF BOILERS.

Diameter in Inches.	HEIGHT OF CHIMNEYS AND COMMERCIAL HORSEPOWER.											Side of Square Inches.	Effective Area Square Feet.	Actual Area Square Feet.
	50 ft.	60 ft.	70 ft.	80 ft.	90 ft.	100 ft.	110 ft.	125 ft.	150 ft.	175 ft.	200 ft.			
18	23	25	27	...	...	....	....	....	....	....	....	16	0.97	1.77
21	35	38	41	...	...	....	....	....	....	....	....	19	1.47	2.41
24	49	54	58	62	...	....	....	....	....	....	....	22	2.08	3.14
27	65	72	78	83	...	....	....	....	....	....	....	24	2.78	3.98
30	84	92	100	107	113	....	....	....	....	....	....	27	3.58	4.91
33	..	115	125	133	141	....	....	....	....	....	....	30	4.48	5.94
36	..	141	152	163	173	182	....	....	....	....	....	32	5.47	7.07
39	..	...	183	196	208	219	....	....	....	....	....	35	6.57	8.30
42	..	...	216	231	245	258	271	....	....	....	....	38	7.76	9.62
48	..	...	...	311	330	348	365	389	....	....	....	43	10.44	12.57
54	..	...	...	363	427	449	472	503	551	....	....	48	13.51	15.90
60	..	...	...	505	536	565	593	632	692	748	....	54	16.98	19.64
66	..	...	...	...	658	694	728	776	849	918	981	59	20.83	23.76
72	..	...	...	...	792	835	876	934	1023	1105	1181	64	25.08	28.27
78	..	...	...	...	...	995	1038	1107	1212	1310	1400	70	29.73	33.18
84	..	...	...	...	...	1163	1214	1294	1418	1531	1637	75	34.76	38.48
90	..	...	...	...	...	1344	1415	1496	1639	1770	1893	80	40.19	44.18
96	..	...	...	...	...	1537	1616	1720	1876	2027	2167	86	46.01	50.27
102	..	...	...	...	...	....	....	1946	2133	2303	2462	90	52.23	56.75
108	..	...	...	...	...	....	....	2192	2402	2594	2773	96	58.83	63.62
114	..	...	...	...	...	....	....	2459	2687	2903	3003	101	65.83	70.88
120	..	...	...	...	...	....	....	....	2990	3230	3452	106	73.22	78.54
126	..	...	...	...	...	....	....	....	3308	3573	3820	112	81.00	86.59
132	..	...	...	...	...	....	....	....	3642	3935	4205	117	89.19	95.03
138	..	...	...	...	...	....	....	....	3991	4311	4608	122	97.75	103.86
144	..	...	...	...	...	....	....	....	4357	4707	5031	127	106.72	113.10

Iron Chimneys. In many places iron stacks are preferred to brick chimneys. Iron stacks require to be kept well painted to prevent rust, and generally, where not bolted down, they need to be braced by rods or wires to surrounding objects. With four such braces attached to an angle iron ring at 2/3 the height of stack, and spreading laterally at least an equal distance, each brace should have an area in square inches equal to .001 the exposed area of stack (diam. × height) in feet.

Stability, or power to withstand the overturning force of the highest winds, requires a proportionate relation between the weight, height, breadth of base, and exposed area of the chimney. This relation is expressed in the equation

$$C\frac{d\,h^2}{b}=W,$$

in which d=the average breadth of the shaft; h=its height; b=the breadth of base,—all in feet; W=weight of chimney in pounds, and C=a co-efficient of wind pressure per square foot of area. This varies with the cross-section of the chimney, and=56 for a square, 35 for an octagon, and 28 for a round chimney. Thus a square chimney of average breadth of 8 feet, 10 feet wide at base and 100 feet high, would require to weigh $56\times8\times100\times10=448{,}000$ pounds to withstand any gale likely to be experienced. Brickwork weighs from 100 to 130 pounds per cubic foot, hence such a chimney must average 13 inches thick to be safe. A round stack could weigh half as much, or have less base.

Pure Air is a mixture of oxygen and nitrogen in following proportions: by volume 20.91 parts oxygen to 79.09 parts nitrogen; by weight 23.15 parts oxygen to 76.85 parts nitrogen. Air in nature always contains other constituents such as dust, carbon dioxide, ammonia, ozone and water vapor.

Air being perfectly elastic, the density of the atmosphere decreases in geometrical ratio with the altitude. This fact has an important bearing on proportions of furnaces and stacks located in high altitudes, as will later appear. The atmospheric pressure for different altitudes is given in Table 23.

WEIGHT AND VOLUME OF AIR.

A cubic foot of air at 60° and under average atmospheric pressure, at sea level, weighs 536 grains, and 13.06 cubic feet weigh one pound. Air expands or contracts an equal amount with each degree of variation in temperature. Its weight and volume at any temperature under 30 inches of barometer may be found within less than one-half of one per cent by the following formula, in which W=weight in pounds of one cubic foot, V=volume in cubic feet, per pound, and τ=absolute temperature, or 460° added to that by the thermometer, $=t+460$.

$$W=\frac{40}{\tau} \qquad V=\frac{\tau}{40}$$

For any condition of pressure and temperature the following formulas are very nearly exact:

$$W=2.71\frac{p}{\tau} \qquad V=\frac{\tau}{2.71p} \qquad t=2.71Vp-460$$

in which p is pressure above absolute vacuum. The same formulæ answer for any other gas by changing the coefficient.

TABLE 16

VOLUME AND WEIGHT OF AIR AT VARIOUS TEMPERATURES, AND ATMOSPHERIC PRESSURE.

Temperature in Degrees Fahr.	Volume of one Pound Cu. Ft.	Weight of one Cu. Ft. in Lbs.
50	12.840	.077884
55	12.964	.077133
60	13.090	.076400
65	13.216	.075667
70	13.342	.074950
75	13.467	.074260
80	13.593	.073565
85	13.718	.072894
90	13.845	.072230
95	13.970	.071580
100	14.096	.070942
110	14.346	.069698
120	14.598	.068500
130	14.849	.067342
140	15.100	.066221
150	15.352	.065140
160	15.603	.064088
170	15.854	.063072
180	16.106	.062090
190	16.357	.061134
200	16.606	.060210
210	16.860	.059313
212	16.910	.059135
220	17.111	.058442
230	17.362	.057596
240	17.612	.056774
250	17.865	.055975
260	18.116	.055200
270	18.367	.054444
280	18.621	.053710
290	18.870	.052994
300	19.121	.052297
320	19.624	.050959
340	20.126	.049686
360	20.630	.048476
380	21.131	.047323
400	21.634	.046223
425	22.262	.044920
450	22.890	.043686
475	23.518	.042520
500	24.146	.041414
525	24.775	.040364
550	25.403	.039365
575	26.031	.038415
600	26.659	.037510
650	27.913	.035822
700	29.172	.034280
750	30.428	.032865

QUESTIONS AND ANSWERS.

161. Is a feed water heater an economical factor in the equipment of a boiler plant?

Ans. It certainly is, provided exhaust steam is used for heating.

162. How many kinds of exhaust heaters are there?

Ans. Two, viz.: Open, and closed.

163. Describe in brief terms the action of a so-called open heater.

Ans. The exhaust steam mingles directly with the water, and a portion of it is condensed.

164. Describe the operation of a closed heater.

Ans. The exhaust steam and the water are kept separate. In some cases the steam passes through tubes that are surrounded by water, and in other types the water fills the tubes that are surrounded by steam.

165. What difference exists between the two kinds of heater?

Ans. The closed heater is under full boiler pressure when the feed pump is working, while the open heater is not because the feed pump is between it and the boiler.

166. What per cent of saving in fuel may be effected by the use of a heater?

Ans. From 12 to 15 per cent.

167. Of what capacity should a feed water heater be, relative to the boilers?

Ans. It should have capacity sufficient to supply the boilers for 15 or 20 minutes.

168. Can the exhaust injector be used for feeding boilers.

Ans. It can if the boiler pressure does not exceed 75 pounds.

169. What advantages are gained by the use of mechanical stokers?

Ans. Regulation of the supply of fuel to meet the demand for steam; also the opening and closing of furnace doors is avoided.

170. What are the disadvantages attending the use of mechanical stokers?

Ans. First, cost of installation. Second, in case of a sudden demand for steam the mechanical stoker cannot respond as quickly as in hand firing. Third, extra cost for power to operate them.

171. Into how many classes are mechanical stokers grouped?

Ans. Four.

172. Enumerate, and briefly describe.

Ans. Class one—An endless chain of short grate bars that travel horizontally over sprocket wheels.

Class two—Grate bars similar to the ordinary type having a continuous motion up and down, or forward and back, the bars being either horizontal or slightly inclined.

Class three—Grate bars steeply inclined and having a slow motion.

Class four—Under feed stoker in which the coal is pushed up onto the grate by means of a revolving screw, or steam ram.

173. In what three forms is mechanical draft used for boiler.

Ans. First—Induced draft.

Second—Forced draft, in which fans force air beneath the grates.

Third—A combination of induced and forced draft.

174. Is a good draft necessary for the efficient operation of steam boilers?

Ans. It certainly is. The economical combustion of fuel cannot be accomplished without a good draft.

175. For what two purposes are chimneys required?

Ans. First, to carry off obnoxious gases. Second, to create sufficient draft for the combustion of the fuel.

176. What factor governs the intensity of the draft, independent of the dimensions of the chimney?

Ans. The difference in weight of the outside and inside columns of air.

177. What is the best shape of chimney?

Ans. Round, with a straight flue.

178. What is the weight, and volume of air at a temperature of 60°, and under average atmospheric pressure at sea level?

Ans. One cubic foot weighs 536 grains, and 13.06 cubic feet weigh one pound.

Care and Operation of Boilers

Duties. The first act of the engineer on entering his boiler-room when he goes on duty should be to ascertain the exact height of the water in his boilers. This he can do by opening the valve in the drain pipe of the water column, allowing it to blow out freely for a few seconds, then close it tight and allow the water to settle back in the glass. This should be done with each boiler under steam, not only once, but several times during the day. No engineer should be satisfied with a general squint along the line of gauge glasses, but he should either go himself, or else instruct his fireman, or water tender to make the rounds of each boiler and be sure that the water is all right.

The instructions regarding the cleaning of fires, and firing, refer particularly to hand fired boilers. Mechanical stokers will be taken up in their regular order.

The next thing to be looked after is the fire. If the plant is run continuously day and night it is the duty of the firemen coming off watch to have the fires clean, the ash pits all cleaned out, a good supply of coal on the floor, and everything in good order for the oncoming force. A good fireman will take pride in always leaving things in neat shape for the man who is to relieve him.

Cleaning Fires. With some varieties of coal this is a comparatively easy task, especially if the boilers are fitted with shaking grates. With a coal that does not form a clinker on the grate bars, the fires can be kept in good condition by cleaning them twice or three times in twenty-four hours, as the larger part of the loose ashes and noncombustible can be gotten rid of by shaking the grates and using the slice bar at intervals more or less frequent; but such coals are generally considered too expensive to use in the ordinary manufacturing plant, and cheaper grades are substituted.

Fire Tools. For cleaning fires successfully and quickly, the following tools should be provided; a slice bar, a fire hook, a heavy iron or steel hoe, and a light hoe for cleaning the ash-pit. It is unnecessary to describe these tools, as they are familiar to all engineers. A suggestion as to the kind of handles with which they should be fitted may be of benefit. The working ends of the aforesaid tools having been made and each welded to a bar of 1 or 1⅛ inch round iron and 10 or 12 inches long, take pieces of 1 or 1¼ inch iron pipe cut to the length desired for the handles and weld the shanks of the tools to them. To the other end of the pipe weld a handle made of round iron somewhat smaller than the shank. By using pipe handles the weight of the tools is considerably lessened, and they will still be sufficiently strong. The labor of cleaning the fire will thus be greatly lightened. When a fire shows signs of being foul and choked with clinker, preparations should be made at once for cleaning it by allowing one side to burn down as low as possible, putting fresh coal on the other side alone. When the first side has burned as low as it can without danger of letting the steam pressure fall too much, take the slice bar and run it in along the side of the furnace on top of the clinker and back to near the bridge wall, then using the door jamb as a fulcrum, give it a quick strong sweep across the fire and the greater part of the live coals will be pushed over to the other side. What remains of the coal not yet consumed can be pulled out upon the floor with the light hoe and shoveled to one side, to be thrown back into the furnace after the clinker is taken out. Having now disposed of the live coal, take the slice bar and run it along on top of the grates, loosening and breaking up the clinker thoroughly, after which take the heavy hoe and pull it all out on the floor. A helper should be ready with a pail of water, or, what is still better, a small rubber hose connected to a cold water pipe running along the boiler fronts for this purpose, and put on just enough water to quench the intense heat of the red hot clinker as it lies on the floor. When the grates are cleaned, close the door, and with the slice bar in the other side push all the live coal over to the side just cleaned, where it should be leveled off and fresh coal added. After this has become ignited, treat the other side in the same way. An expert fireman will thus clean a fire with very little loss in steam pressure, and practically no waste of coal.

Disposal of the Ashes. The problem of disposing of the ashes in large power plants is quite a serious one, and any device that tends to lessen the cost of labor, and shorten the time consumed in conveying the ashes from the boiler room certainly merits the attention of chief engineers.

The suction conveyor system of the Darley Engineering Company, Chicago, a general view of which is shown in Fig. 97, consists essentially of four parts, as follows:

1. Conveyor Pipe.
2. Separator.
3. Exhauster.
4. Water Jet.

The conveyor pipe line is made in three sizes and capacities, namely, 6″, 8″ and 10″, of iron or steel pipe. The

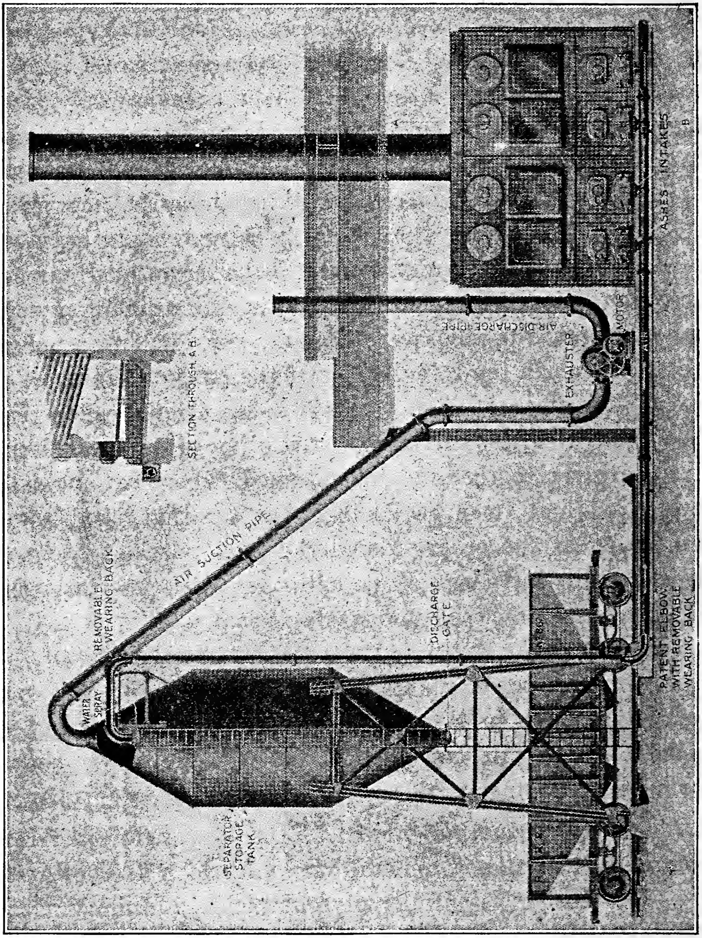


Fig. 97

DIAGRAM SHOWING A COMPLETE SUCTION CONVEYOR SYSTEM AS APPLIED TO HANDLING ASHES FROM BOILERS

conveyor pipe, as far as possible, is run in straight lines. It is generally placed beneath the surface, but can be elevated or run anywhere to suit conditions.

The separator, which is in reality an expansion chamber, also serves as a storage tank for storing the conveyed material. This separator is always placed at the end of the conveyor run. It serves to catch the material conveyed and hold it until it can be drawn (by gravity through an under-cut gate) into cars, carts or barges. This separator is located in the most convenient position for the purpose. The separator can be made any size, to hold any predetermined amount of material, or for a time run of the conveyor of any fixed duration. These separators can also be mounted over bins or bunkers of large or small size, if such addi-

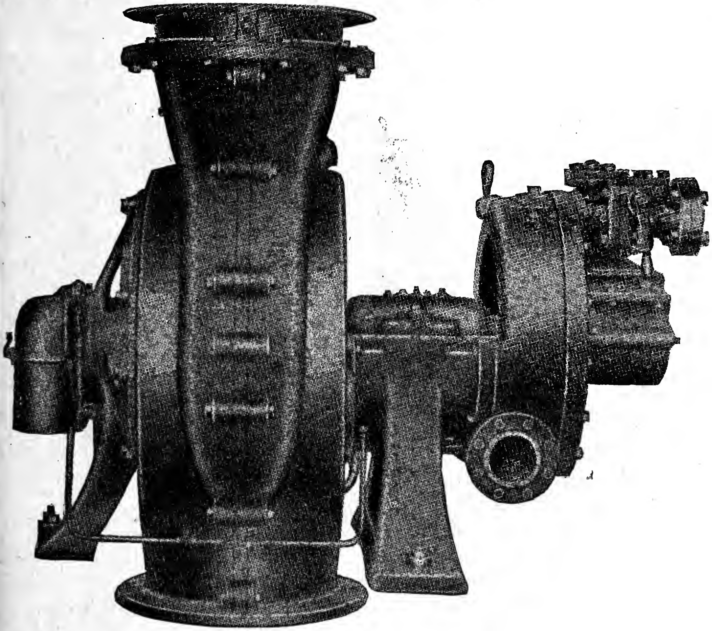


FIG. 98

ASH CONVEYOR—EXHAUSTER SET DRIVEN BY STEAM TURBINE tional bin storage capacity is required. Separators are generally built of cylindrical form and of steel plate construction with a cone top and bottom. For certain work and on small sized plants, they can be made rectangular, or of an irregular shape. They can also be made of concrete, either square or round, with small cone top of steel plate. They are always made water tight.

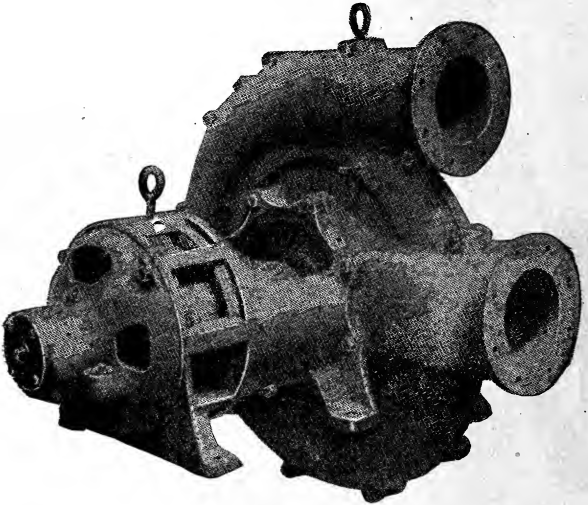


FIG. 99

ASH CONVEYOR—EXHAUSTER SET DRIVEN BY INDUCTION MOTOR

The Exhauster (Figs. 98 and 99) consists essentially of a rotating impeller, surrounded by a suitable case, with an intake air opening at the center, and a discharge opening at the circumference. In appearance, it is similar to the centrifugal pump. The efficiency depends largely upon the design of the impeller and casing, and on the proper shaping of these parts. In actual practice some conditions call for other types. For instance, for a small, simple lay-out, an ordinary exhaust fan can be used, whereas for certain complicated and extensive work, a cycloidal blower is best adapted for the purpose. It can be either steam, or motor driven for alternating or direct current. These machines are very strong in construction, and will operate under adverse conditions with a very low cost for maintenance, and are especially suitable for this class of work.

Just before entering the separator, the conveyed material passes through a water jet, located in the conveyor pipe. This jet is composed of ⅛″ holes, spaced 1″ centers, and serves two purposes, viz., it takes the heat out of the hot material, such as ashes, etc., and eliminates all dust when the material is dusty. In this way all dust is kept out of the exhauster.

In the case of an ashes conveyor, the intakes are placed in front of the ash pits of the boilers, or at any other desired place, and the ashes are hoed or shoveled from the ash pits into these intakes, whence they disappear through the pipe line at a higher velocity. The conveyor pipe line will take them away as fast as they are fed to the intakes. When not in use, a cast iron cover is placed over these intakes. These covers are lifted off when material is to be fed to the conveyor.

The size of the intake opening is slightly smaller in diameter than that of the pipe line, so that any piece of material that passes the intake opening will be conveyed freely through the conveyor pipe.

As the hardest wear comes on the elbows, a patented split elbow is used, having an interchangeable wearing back, about 3″ thick, made of hard iron. These wearing backs will last from 10 to 18 months, and are quickly replaced when worn out, and can be replaced without interfering with the working of the conveyor, and at trifling cost. Patented fittings with interchangeable wearing back are also used when required.

Owing to the higher velocity of the air in the central portion of the pipe, the tendency is to convey the material in suspension in the center of the pipe. That this is a fact can be readily seen on looking into a conveyor pipe in operation.

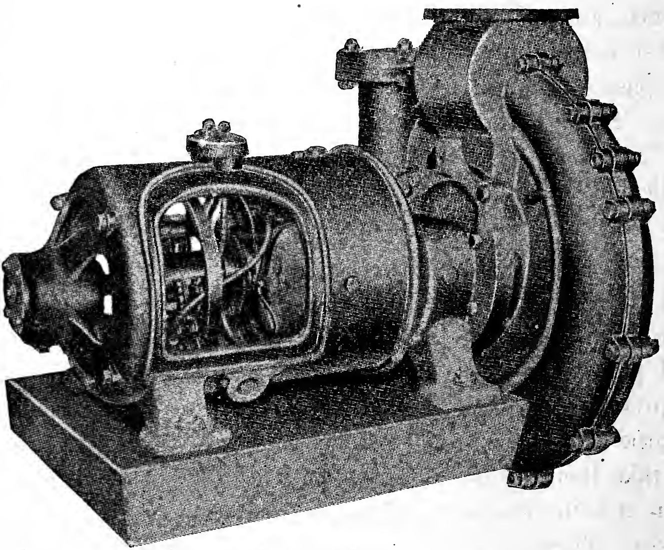


FIG. 100

EXHAUSTER SET DRIVEN BY DIRECT CURRENT MOTOR

This fact prevents serious wear on the pipe, and from observation of plants in use up to two and one-half years, shows that an ordinary steel pipe, handling ashes, will last for years.

No material comes in contact with any moving part of this conveyor, and it is dustless in operation. These facts should appeal to engineers, especially those who have had experience with mechanical conveyors in handling ashes.

There is absolutely no corrosion of the conveyor pipe, as the great rush of air through the pipe keeps same perfectly dry under all conditions.

The following table gives capacities, etc.:
with convenient accessories for manipulation.

Size of Conveyor.	Capacity per minute.
6″	200 lbs.
8″	300 lbs.
10″	500 lbs.

Firing. No definite set of rules for hand firing can be laid down that will be suitable for all steam plants, or for the many different kinds of coal used. Some kinds of coal need very little stirring or slicing, while others that have a tendency to coke, and form a crust on top of the fire need to be sliced quite often.

Every engineer, if he is at all observant, should be able to judge for himself as to the best method of treating the coal he is using, so as to get the most economical results. A few general maxims may be laid down. First, keep a clean fire; second, see that every square inch of grate surface is covered with a good live fire; third, keep a level fire, don't allow hills and valleys, and yawning chasms to form in the furnace, but keep the fire level; fourth, when cleaning the fire always be sure to clean all the clinkers and dead ashes away from the back end of the grates at the bridge wall, in order that the air may have a free passage through the grate bars, because this is one of the best points in the furnace for securing good combustion, provided the bridge wall is kept clean from the grates up.

By keeping the back ends of the grate bars and the face of the bridge wall clean, the air is permitted to come in contact with the hot fire brick, and thus one of the greatest aids to good combustion is utilized. Don't allow the fire to become so deep and heavy that the air cannot pass up through it, because without a good supply of air good combustion is impossible. When the chimney draft is good the quality of cold air admitted underneath the grate bars may be easily regulated by leaving the ash-pit doors partly open.

The amount of opening required can be ascertained by a little experimenting and depends upon the intensity of the draft, and the condition of the fire. With a clean, light fire, and the air spaces in the gates free from dead ashes, a slight opening of the ash-pit doors will suffice to admit all the air required beneath the grates. But if the fire is heavy and the grates are clogged, a larger opening will be necessary. In firing bituminous coal containing a large percentage of volatile (light or gaseous matter), the best results can be obtained by leaving the fire doors slightly open for a few seconds immediately after throwing in a fresh fire. The reason for doing this is that the volatile matter in the coal flashes into flame the instant it comes in contact with the heat of the furnace, and if a sufficient supply of oxygen is not present just at this particular time the combustion will be imperfect, and the result will be the formation of carbon monoxide or carbonic oxide gas, and the loss of about two-thirds of the heat units contained in the coal. This loss can be guarded against in a great measure by a sufficient volume of air, either through the fire doors directly after putting in a fresh fire, or what is still better, providing air ducts through the bridge wall or side walls which will bring the air in on top of the fire.

Each pound of coal requires for its complete combustion 12 pounds, or about 150 cubic feet of air, and the largest volume of air is needed just after fresh coal has been added to the fire.

Cleanliness. In order to get the best results, great care should be taken that the tubes be kept clean and free from soot. Especially does this apply to horizontal return tubular boilers, for the reason that when the tubes become clogged with soot the efficiency of the draft is destroyed, and the steaming capacity of the boiler is greatly reduced. Soot not only stops the draft, but it is a non-conductor of heat. In some batteries of boilers where an inferior grade of coal is used and the draft is poor, it is absolutely necessary to scrape or blow the tubes at least once a day in order to enable the boilers to generate sufficient steam.

As to the process of cleaning there are various devices on the market, both for blowing the soot out by means of a steam jet and also for scraping the inside of the tubes. The steam jet, if properly made and used with a high pressure and dry steam, does very satisfactory work, but is should not be depended upon exclusively to keep the tubes clean, because in process of time a scale will form inside the tubes that nothing but a good scraper will remove. For that reason it is good practice to use the scraper two or three times a week at least. When the boiler is cooled down for washing out, the bottom of the shell should be cleaned of all accumulations of dust and ashes, the combustion chamber, back of the bridge wall cleaned out, and the back flue sheet or head swept off and examined, and if there is a fusible plug in the back head the scale should be scraped from it, both inside and outside the boiler, because if it is covered with scale, neither the water, nor the heat can come in contact with it, and it will be non-effective.

Washing Out. The length of time that a boiler can be run safely and economically after having been washed out depends upon the nature of the feed water. If the water is impregnated to a considerable extent with scale forming matter, the boiler should be washed out every two weeks at the least, and in some cases of particularly bad water it becomes necessary to shorten the time to one week. To prepare a boiler for washing the fire should be allowed to burn as low as possible and then be pulled out of the furnace, the furnace doors left slightly ajar, and the damper left wide open in order that the walls may gradually cool. It is as bad a practice to cool a boiler off too suddenly as it is to fire it up too quick, because the sudden change of temperature either way has an injurious effect on the seams, contracting or expanding the plates, according as it is cooled or warmed, and thus creating leaks and very often small cracks radiating from the rivet holes, and becoming larger with each change of temperature, until finally the strength of the steam is destroyed and rupture takes place. After the boiler has become comparatively cool and there is no pressure indicated by the steam gauge the blow off cock may be opened and the water allowed to run out. The gauge cocks, and also the drip to the water column should be left open to allow the air to enter and displace the water. Otherwise there will be a partial vacuum formed in the boiler and the water will not run out freely.

A boiler should not be blown out, that is, emptied of water while under pressure. The sudden change of temperature is sure to have a bad effect upon the sheets and seams. Suppose for instance that all the water is blown out of a boiler under a pressure of 20 pounds by the steam gauge. The temperature of steam at 20 pounds is 260° F., and it may be assumed that the metal of the boiler is at or near that temperature also. Assume the temperature of the atmosphere in the boiler-room to be 60° F. There will then be a range of 260°—60°=200° temperature for the boiler to pass through within a short time, which will certainly have a bad effect, and besides this the boiler shell will be so hot that the loose mud and sediment left after the water has run out is liable to be baked upon the sheets, making it much harder to remove.

While inside the boiler the boiler washer should closely examine all the braces and stays, and if any are found loose or broken they should be repaired at once before the boiler is used again. The soundness of braces, rivets, etc., can be ascertained by tapping them with a light hammer.

Renewing Tubes. As it is practically impossible to prevent scale from forming on the outside of the tubes of horizontal tubular boilers unless the feed water is expectionally good, and as the tubes will in course of time become leaky where they are expanded into the heads, the engineer if he has a battery of two or more, should take advantage of the first opportunity that presents itself to take out of service the boiler that shows the most signs of deterioration and take out the tubes, and after cleaning them of scale by scraping and hammering or rolling in a tumbling cylinder, he should select those that are still in good condition and have them pieced out at the ends, making them almost as good as new.

All tube failures reduce to four classes:

(1) Pitting, which causes pin holes to be formed.

(2) Defective welds, which cause the tube to open, as in A, Fig. 101.

(3) An initial bagging resulting in a rupture, as in B.

(4) Scabbing and blistering, as in C.

In the first case the tube is not enlarged, and may be drawn through a tube sheet, without disturbing other tubes, though usually with difficulty, owing to deposits on the outer surface.

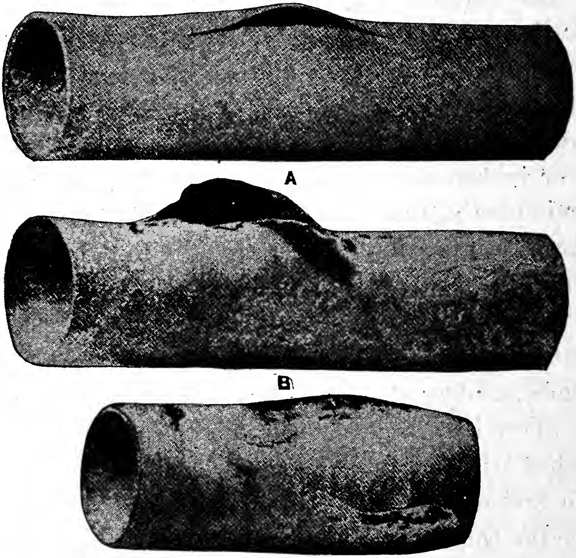


FIG. 101

PHOTOGRAPHS SHOWING DISTENTION OF TUBES AT POINT OF RUPTURE

In the other cases, the tubes become larger than their original size, hence they cannot be drawn through the tube sheet, water-leg or header, unless they are split and collapsed inch by inch for their entire length beyond the point of failure, and if they also pass through cross baffles the enlargement will pull out the bricks and destroy the baffle.

To remove a tube in this way is the work of days, and in consequence the actual method used is to cut out all tubes —numbering at times half a dozen below the defective one —and to avoid destroying the baffles these tubes are cut into several pieces.

In case the tubes are all taken out of the boiler for repairs the boiler washer will have a good opportunity to thoroughly clean the inside of the boiler, and if there are any loose rivets they should be replaced and leaky or suspicious looking seams chipped and caulked. If there are indications of corrosion or pitting, a stiff paste or putty made of plumbago mixed with a small proportion of cylinder oil may be applied to the affected parts with good results.

Feed Water. There is no steam plant of any consequence that does not have more or less exhaust steam, or returns from a steam heating system, which can be utilized for heating the feed water before it enters the boiler. Cold water should never be pumped into a boiler that is under steam when it is possible to prevent it.

In feeding a boiler the speed of the feed pump should be so gauged as to supply the water just as fast as it is evaporated. The firing can then be even and regular.

If the supply of feed water should suddenly be cut off, owing to breakage of the pump or bursting of a water main, and no other source of supply was available, the dampers should be immediately closed, or if there should be no damper in the breeching, the draft may be stopped by opening the flue doors. The fires should then be deadened by shoveling wet or damp ashes in on top of them, or if the ashes cannot be readily procured, bank the fires over with green coal broken into fine bits. This, with the draft all shut off, will deaden the fires, while the engine still running will gradually use up the extra steam. If the water should get dangerously low in the boilers the fires may be pulled, provided they have become deadened sufficiently, but they should never be pulled while they are burning lively, because the stirring will only serve to increase the heat, and the danger will be aggravated.

Connecting a Recently Fired Up Boiler. After a boiler has been washed out, filled with water, and fired up, the next move is to connect it with the main battery. The steam in the boiler to be connected having been raised to the same pressure as that in the battery, the connecting valve should be opened slightly, just enough to permit a small jet of steam to pass through, which can be heard by placing the ear near the body of the valve. This jet of steam may be passing from the battery into the newly connected boiler, or *vice versa.* Whichever way it passes, the valve should not be opened any farther until the flow of steam stops, which will indicate that the pressure has been equalized. It will then be found that the valve will move much easier, and it may be gradually opened until it is wide open.

Foaming. Water carried with the steam from the boiler to the engine, even if in small quantities, is very detrimental to the successful operation of the engine, as it washes the oil from the walls of the cylinder, thereby increasing the friction, and unless a plentiful supply of oil is entering the cylinder, cutting of the piston rings will take place. There is also danger of breaking a cylinder head, or of bending the piston rod if the water comes in too large quantities.

There are certain kinds of water which have a natural tendency to foam, especially such as contain considerable organic matter, and the more severe the service to which the boiler is put the more will the water foam, until it is practically impossible to locate the true level of the water in the boilers, and the only recourse the water tender has is to keep his feed pump running at such a speed as will, in his judgment supply the water as fast as it goes out of the boilers. It is a dangerous condition to say the least, and the only remedy for it is either a change to a different kind of water, or if this is not possible, then an increase in the number of boilers, which would make it possible to supply sufficient steam for the engine without being compelled to fire the boilers so hard.

Priming. By which is meant the carrying over of water in the form of fine spray mingled with the steam, is not so dangerous as foaming and yet it causes much loss in the efficiency of a boiler or engine. It can be prevented to a large extent by placing a baffle plate in the steam space of the boiler directly under the dome or outlet to the connection with the steam main.

The following rules are compiled from those issued by various boiler insurance companies in this country and Europe—they apply to all boilers except as otherwise noted:

1. *Safety Valves.* Great care should be exercised to see that these valves are ample in size and in working order. *Overloading,* or *neglect* frequently leads to the most disastrous results. Safety valves should be tried at least once every day to see that they will act freely.

2. *Pressure Gauge.* The steam gauge should stand at zero when the pressure is off, and it should show the same pressure as the safety valve when that is blowing off. If

not, then one is wrong, and the gauge should be tested by one known to be correct.

3. *Water Level.* The first duty of an engineer before starting, or at the beginning of his watch, is to see that the water is at the proper height. Do not rely on glass gauges, floats or water alarms, but try the gauge cocks. If they do not agree with water gauge, learn the cause and correct it. Water level in Babcock & Wilcox boilers should be at center of drum, which is usually at middle gauge. It should not be carried above.

4. *Gauge Cocks and Water Gauges* must be kept clean. Water gauge should be blown out frequently, and the glasses, and passages to gauge kept clean. The Manchester, England, Boiler Association attributes more accidents to inattention to water gauges than to all other causes put together.

5. *Feed Pump, or Injector.* These should be kept in perfect order, and be of ample size. No make of pump can be expected to be continuously reliable without regular and careful attention. It is always safe to have two means of feeding a boiler. Check valves, and self-acting feed valves should be frequently examined and cleaned. Satisfy yourself that the valve is acting when the feed pump is at work.

6. *Low Water.* In case of low water, immediately cover the fire with ashes (wet if possible) or any earth that may be at hand. If nothing else is handy use fresh coal. Draw fire as soon as it can be done without increasing the heat. Neither turn on the feed, start or stop engine, nor lift safety valve until fires are out, and the boiler cooled down.

7. *Blisters and Cracks.* These are liable to occur in the best plate iron. When the first indication appears there must be no delay in having it carefully examined and properly cared for.

8. *Fusible Plugs,* when used, must be examined when the boiler is cleaned, and carefully scraped clean on both the water and fire sides, or they are liable not to act.

9. *Firing.* Fire evenly and regularly, a little at a time. Moderately thick fires are most economical, but thin firing must be used where the draught is poor. Take care to keep grates evenly covered, and allow no air-holes in the fire. Do not "clean" fires oftener than necessary. With bituminous coal, a "coking fire," i. e., firing in front, and shoving back when coked, gives best results, if properly managed.

10. *Cleaning.* All heating surfaces must be kept clean outside and in, or there will be a serious waste of fuel. The frequency of cleaning will depend on the nature of fuel and water. As a rule, never allow over $\frac{1}{16}$ inch scale or soot to collect on surfaces between cleanings. Hand-holes should be frequently removed, and surfaces examined, particularly in case of a new boiler, until proper intervals have been established by experience.

Water tube boilers are provided with extra facilities for cleaning, and with a little care can be kept up to their maximum efficiency, where tubulars, or locomotive boilers would be quickly destroyed. For inspection, remove the hand-holes at both ends of the tubes, and by holding a lamp at one end and looking in at the other, the condition of the surface can be fully seen. Push the scraper through the tube to remove sediment, or if the scale is hard use the chipping scraper made for that purpose. Water through a hose will facilitate the operation. In replacing hand-hole caps, clean the surfaces without scratching or bruising, smear with oil, and screw up tight. Examine mud-drum and remove the sediment therefrom.

The *exterior* of tubes can be kept clean by the use of blowing pipe and hose through openings provided for that purpose. In using smoky fuel, it is best to occasionally brush the surfaces when steam is off.

11. *Hot Feed-Water.* Cold water should never be fed into any boiler when it can be avoided, but when necessary it should be caused to mix with the heated water before coming in contact with any portion of the boiler.

12. *Foaming.* When foaming occurs in a boiler, checking the outflow of steam will usually stop it. If caused by dirty water, blowing down and pumping up will generally cure it. In cases of violent foaming, check the draft and fires.

13. *Air Leaks.* Be sure that all openings for admission of air to boiler or flues, except through the fire, are carefully stopped. This is frequently an unsuspected cause of serious waste.

14. *Blowing Off.* If feed-water is muddy or salt, blow off a portion frequently, according to condition of water. Empty the boiler every week or two, and fill up afresh. When surface blow-cocks are used, they should be often opened for a few minutes at a time. Make sure no water is escaping from the blow-off cock when it is supposed to be closed. Blow-off cocks, and check-valves should be examined every time the boiler is cleaned.

15. *Leaks.* When leaks are discovered, they should be repaired as soon as possible.

16. *Blowing Off for Washing.* Never empty the boiler while the brickwork is hot.

17. *Filling Up.* Never pump cold water into a hot boiler. Many times leaks, and, in shell boilers, serious weaknesses, and sometimes explosions are the result of such an action.

18. *Dampness.* Take care that no water comes in contact with the exterior of the boiler from any cause, as it tends to corrode and weaken the boiler. Beware of all dampness in seatings or coverings.

19. *Galvanic Action.* Examine frequently parts in contact with copper or brass, where water is present, for signs of corrosion. If water is salt or acid, some metallic zinc placed in the boiler will usually prevent corrosion, but it will need attention and renewal from time to time.

20. *Rapid Firing.* In boilers with thick plates, or seams exposed to the fire, steam should be raised slowly, and rapid or intense firing avoided. With thin water tubes, however, and adequate water circulation, no damage can come from that cause.

21. *Standing Unused.* If a boiler is not required for some time, empty and dry it thoroughly. If this is impracticable, fill it quite full of water, and put in a quantity of common washing soda. External parts exposed to dampness should receive a coating of linseed oil.

22. *General Cleanliness.* All things about the boiler room should be kept clean and in good order. Negligence tends to waste and decay.

Miscellaneous. In burning coal under a boiler, it should be remembered that the object is to transfer as many as possible of the total heat units contained in the coal to the water in the boiler, and that any failure to do this shows a lack of engineering ability.

No leak or waste is too small to deserve attention and unceasing viligance is the price of economy. The grates, if hand-fired, should be of standard shaking pattern, and the fire kept thin enough so that it can be kept clean and bright without too much overhead slicing. Every time that the furnace door is opened for the introduction of coal or for cleaning the fire in any way, there is a distinct loss of efficiency on account of the inrush of cold air. Most boiler-room fires suffer from too much meddling. It is undoubtedly better in all plants of any size to install mechanical stokers, there being the double advantage of a uniform feed of fuel, and a definite air supply, just sufficient to maintain combustion.

HEATING SURFACE.

For a fire-box boiler of the vertical type, the area of the flue sheets minus the sectional area of the flues, plus the area of the fire-box plus the inside area of the flues constitutes the heating surface. If the boiler is a horizontal internally fired boiler, the heating surface will consist of, first, area of three sides of the fire-box; second, area of the crown sheet; third, area of flue sheets minus sectional area of flues; fourth, inside area of the flues.

In estimating the area of the fire-box, the area of the fire door should be subtracted therefrom. If the fire-box be circular, as in the case of a vertical boiler, the area may be obtained by first finding by measurements the diameter, which multiplied by 3.1416 will give the circumference. Then multiply this result by the height or the distance between the grate bars and the flue sheet. In the case of water tube boilers the outside area of the tubes must be taken. Two examples will be given illustrating methods of calculating heating surface:

First, take a horizontal tubular boiler, diameter 72 in., length 18 ft., having sixty-two 4½ in, flues; find area of lower half of shell.

Circumference=diameter×3.1416=18.8496 ft.

One-half of the circumference multiplied by the length =required area. Thus, 18.8496÷2×18=169.64 sq. ft.

Next find heating surface of back head below the water line. Total area=72^2×.7854=4071.5 sq. in. Assume two-thirds of this area to be exposed to the heat, 2/3 of 4071.5=2714.3 sq. in. From this must be deducted the sectional area of the tubes. In giving the size of boiler tubes the outside diameter is taken. The tubes being 4½ in.; the area of a circle 4½ in. in diameter is 15.9 sq. in. Number of flues, 62×15.9=985.8 sq. in.=sectional area of tubes. The heating surface of the back head therefore= 2714.3—985.8=1728.5 sq. in. Dividing this by 144, to reduce to feet, we have 12 sq. ft.

Next find inside area of tubes. The standard thickness of a 4½ in. tube=.134 in. The inside diameter therefore will be 4.5—(2×.134)=4.23 in., and the circumference will be 4.23×3.1416=13.29 in., and the inside area will be 13.29×length, 18 ft.,=216 in. Thus 216×13.29÷144= 19.93 sq. ft., inside area of one flue. There being 62 flues, the total heating surface of tubes is 19.93×62=1235.66 sq. ft. The heating surface of the front head is found in the same manner as that of the back head, with the exception that the whole area should be figured instead of two-thirds, for the reason that the entire surface is exposed to the heat, although that portion above the water line may be considered as superheating surface. The heating surface of front head would be: area 4071.5—sectional area of tubes 985.8=3085.7 sq. in.=21.43 sq. ft.

The total heating surface of the boiler is thus found to be 1438.73 sq. ft., divided up as follows:

Lower half of shell,	169.64 sq. ft.
Back head,	12.00 sq. ft.
Tubes,	1235.66 sq. ft.
Front head,	21.43 sq. ft.
	1438.73 sq. ft.

Next taking a vertical fire-box boiler of the following dimensions: diameter of flue sheet, and also of fire-box, 50 in.; height of fire-box above grate bars, 30 in.; number of flues, 200; size of flues, 2 in.; length of flues, 7 ft.

First, find heating surface in flue sheet.

Area of circle, 50 in. in diameter=1,963.5 sq. in.

Sectional area of 2 in. flue=3.14 sq. in., which multiplied by 200=628 sq. in., total sectional area of tubes. The heating surface of one flue sheet therefore will be 1,963.5—628÷144=9 sq. ft.

Assuming that the tops of the flues are submerged, the area of the top flue sheet will also be 9 sq. ft. Then heating surface of flue sheets=9×2=18 sq. ft.

Second, find heating surface of tubes. The standard thickness of a 2 in. flue is .095 in. The inside diameter will consequently be 2—(.095×2)=1.8 in., and the circumference will be 1.8×3.1416=5.66 in. The length of the flue being 7 ft., or 84 in., the inside area will be 5.66×84÷144=3.3 sq. ft., and multiplying this result by 200 we have 200×3.3=660 sq. ft. as the heating surface of the flues.

Third, find heating surface of the fire-box. Diameter of fire-box=50 in., which multiplied by 3.1416=157.08, which is the circumference. The height being 30 in., the total area will be 157.08×30÷144=32.7 sq. ft. Allowing 1 sq. ft. as the area of the fire door, will leave 31.7 sq. ft. heating surface of fire-box. The heating surface of the boiler will be:

For the flue sheets,	18 sq. ft.
For the flues,	660 sq. ft.
For the fire-box,	31.7 sq. ft.
Total,	709.7 sq. ft.

The above methods may be applied in estimating the heating surface of any boiler, provided in the case of water tube boilers that the outside in place of the inside area of the tubes be figured.

Reducing Loss in Handling Coal. In large coal-handling systems used in power plants of considerable capacity, there is often a chance to save a few dollars in operation if the station staff is on the alert to cut down wastes. In a good sized plant there are frequently several hundred conveyer buckets to be driven, and a twenty or twenty-five horse-power engine, or motor may be needed to operate the system at its full capacity. With the most careful lubrication and skilled attention, the friction load of the conveyer system may amonnt to forty or fifty per cent of the power required when operating with the buckets full. If care is not taken to shut down the conveyer promptly after the delivery of coal to the bunkers or when the collection of ashes has ceased, the power loss may be felt in the year's operating expense of the auxiliaries.

The operation of the endless conveyer chain, empty, once or twice a week for purposes of oiling or greasing may cost perhaps ten dollars a year for the extra power used, compared with lubricating when the conveyer is handling fuel. In larger conveyer installations two men are often needed to apply the oil or grease as each bucket passes by, a third man being on hand to fill the cans. If this work can be arranged to be done when the conveyer is delivering coal, a desirable gain will be made, since there are always points in the travel of the conveyer belt or buckets where they are empty and thus readily inspected in detail, or oiled in any part.

Two other frequent sources of waste in the handling of a coal-conveyor system are, in the pocket lights, and the steam lines which may be in use. Current is wasted through failure to cut off the incandescents as soon as they are not needed in the recesses of the pocket, and when several steam-pipe branch lines are used in connection with hoisting engines, if a main valve is not installed at the entrance of the pocket or tower, leakages in the separate valves are liable to prove expensive.

QUESTIONS AND ANSWERS.

179. What is one of the most important duties of the engineer when he goes on watch?

Ans. To ascertain the exact height of the water in his boilers.

180. Describe the correct method of doing this.

Ans. Open the valve in the drain pipe of the water column, and allow the water to blow out freely for a few seconds, then close the valve and note the level of the water when it settles back in the gauge glass.

181. What is the next important step in beginning the day's work?

Ans. To see that the fires are cleaned, and in good condition.

182. In firing boilers by hand, what is the first and most important rule to be observed?

Ans. Keep a clean fire.

183. What is the second rule?

Ans. See that every square inch of grate surface is covered with a good live fire.

184. Give the third rule regarding firing by hand.

Ans. Keep a level fire.

185. What is the fourth rule?

Ans. When cleaning the fire, always clean all clinkers and dead ashes away from the back end of the grates and the bridge wall.

186. Why should this be done?

Ans. In order to allow a free passage of the air through the grate bars, so as to promote combustion.

187. If the plant runs continuously, day and night, what is one of the important duties of the fireman coming off watch?

Ans. To leave clean fires, clean ash pits, and a good supply of coal ready for the oncoming force.

188. How long a time should the fires be allowed to burn before cleaning?

Ans. This depends upon the quality of the coal. With a coal that does not clinker on the grate bars, an interval of 7 or 8 hours may elapse between cleanings, but with the average soft coal the fires should not be allowed to burn longer than 4 or 5 hours without cleaning.

189. What is one of the greatest aids to good combustion in a hand-fed furnace?

Ans. A clean bridge wall, kept as hot as possible.

190. What precautions should be observed regarding the depth of the fire?

Ans. It should not be allowed to become so deep and heavy as to prevent the air from passing up through it freely

191. How should the position of the ash-pit doors be regulated?

Ans. With a clean, light fire, a slight opening will be sufficient, but with a heavy fire, and the grates clogged with ashes, a larger opening is necessary.

192. How can the best results be secured in firing bituminous coal?

Ans. By leaving the fire doors slightly open for a few seconds immediately after throwing in a fire.

193. What reason is there for doing this?

Ans. Because the volatile matter in the coal flashes into flame the instant it comes in contact with the heat of the furnace, and unless there is sufficient supply of oxygen present just then, the combustion will be imperfect.

194. What is the result of this imperfect combustion?

Ans. The formation of carbonic oxide gas, and the consequent loss of about two-thirds of the heat units contained in the coal.

195. How may this loss be prevented in a great measure?

Ans. By admitting a sufficient volume of air, either through the fire doors, directly after throwing in a fresh fire, or, better still, providing air ducts through the bridge wall, or side walls, which will direct the air in on top of the fire.

196. How much air is required for the complete combustion of one pound of coal?

Ans. By weight 12 pounds—by volume 150 cubic feet.

197. What precaution is necessary regarding the tubes of a boiler in order to get the best results from the fuel?

Ans. The tubes should be kept clean and free from soot and scale.

198. Should the steam jet cleaner be depended upon alone for cleaning the tubes?

Ans. No. The scraper should also be used.

199. How should safety valves be looked after?

Ans. They should be ample in size, never overloaded, and should be tested at least once a day to see that they act freely.

200. At what point should the steam gauge pointer stand when the pressure is off?

Ans. It should stand at zero.

201. What should be done in case of low water in a boiler?

Ans. The fire should be covered immediately with ashes, earth, or if neither is available use fresh coal. Draw the fire as soon as it can be done without increasing the heat.

202. Should the rate of feeding the water be increased, in case of extremely low water in the boiler?

Ans. It should not, neither should the engine be stopped or the safety valve lifted, until the fires are out, and the boiler cooled down.

203. In case of indications of cracks or blisters appearing on the boiler sheets, what should be done?

Ans. There should be no delay in making repairs.

204. What should be done with fusible plugs when used?

Ans. They should be cleaned and carefully scraped on both water and fire sides at each washing out.

205. How may the most economical. results regarding fuel be attained with a steam boiler?

Ans. By keeping the heating surfaces clean, both inside and outside, also careful firing, a little at a time, but keeping the grates covered.

206. Should cold water ever be fed into a boiler when it is under pressure?

Ans. Not when it can be avoided.

207. How may foaming usually be stopped?

Ans. By checking the outflow of steam, by blowing down and pumping up, or by checking the draft and fires.

208. Should air be allowed to pass to the boiler or tubes, except through the furnace?

Ans. It should not, as it will cause a waste of fuel.

209. What should be done with leaks when discovered?

Ans. They should be repaired as soon as possible.

210. What precautions should be observed when preparing to empty a boiler for washing out, or other purposes?

Ans. Allow it to cool down until there is no steam pressure, and until the brick work is cool also.

211. When firing up a boiler what course should be pursued?

Ans. Steam should be raised very slowly, and rapid firing avoided.

212. What bad results follow too rapid firing up of a boiler?

Ans. Straining of the joints and seams caused by unequal expansion.

213. What should be done with a boiler that is to stand idle for any length of time?

Ans. It should be emptied, and thoroughly dried. In case this is impracticable, fill it full of water, and put in a quantity of washing soda.

214. How long a time may a boiler be safely operated between dates of washing out?

Ans. This depends upon the nature of the feed water. The time should never be longer than two weeks, and with very bad water, the boiler should be washed out once a week.

215. Besides cleaning the boiler inside, what other very important work should the boiler washer perform while inside the boiler?

Ans. He should closely examine all braces, stays, and rivets by tapping them with a hammer. Any loose or defective parts can usually be detected in this way.

216. Describe four ways in which tube failures may occur.

Ans. 1. Pitting. 2. Defective welds. 3. Bagging. 4. Scabbing and blistering.

217. How may a great saving in fuel be effected with regard to the feed water?

Ans. By heating it with the exhaust steam from engines and pumps before passing it to the boilers.

218. Describe the available heating surface of a stationary boiler, of either type, return tubular or water tube.

Ans. The lower half of the shell, and heads, and the combined cross sectional area of all the tubes.

219. What should be the location of the water gauge glass, relative to the water level in the boiler?

Ans. It should be located at such a height as to bring the lower end of the glass tube on a level with the danger point for low water in the boiler.

220. Where should the lower gauge cock be located relative to the danger point?

Ans. About three inches above.

222. Should an engineer or water tender depend entirely upon the water gauge glasses?

Ans. He should not, but should frequently open and try the gauge cocks.

223. What should be done with the entire water column several times a day?

Ans. It should be blown out thoroughly.

224. What should be done with the safety valves in order to make them reliable?

Ans. They should be allowed to blow off at least twice a week.

225. Why is this necessary?

Ans. Because the valves are liable to become corroded, and stick to their seats if not attended to properly.

226. What is the rule for finding the bursting pressure of boilers?

Ans. Multiply the tensile strength by the thickness and divide by one-half the diameter of the shell.

227. How may the safe working pressure of a boiler be ascertained?

Ans. By dividing the bursting pressure by five.

228. What is the rule for ascertaining the velocity of flow in a pump?

Ans. Multiply the number of strokes per minute by length of stroke in feet. This will give piston speed.

229. How may velocity of flow in the discharge pipe of a pump be found?

Ans. Divide square of diameter of water piston by the square of the diameter of pipe, and multiply by piston speed per minute.

230. What is the rule for finding velocity in feet per minute required to discharge a given quantity of water in a given time?

Ans. Multiply number of cubic feet to be discharged by 144 and divide by area of pipe in inches.

231. When the volume and velocity of water to be discharged are known, how may the area of the pipe be ascertained?

Ans. Multiply volume in cubic feet by 144 and divide by velocity in feet per minute.

232. What is one of the main requisites in the successful burning of coal in a boiler furnace?

Ans. A good draft.

233. What is a common cause of lost economy in the operation of boilers?

Ans. Air leaks in the brick settings.

234. Mention another source of loss in connection with mechanical stokers.

Ans. The dead area of grate that is covered with a thin layer of clinker, and ash.

235. What is meant by the expression "priming?"

Ans. Carrying over into the cylinder of water in the form of fine spray mingled with the steam.

236. How may this be prevented to a large extent?

Ans. By placing a baffle plate in the steam space of the boiler, directly under the dome. Steam separators may also be employed for this purpose.

237. What should be the principal object in view in burning coal under a boiler?

Ans. To transfer as many as possible of the total heat units in the coal, to the water in the boiler.

Table 17

PROPERTIES OF SATURATED STEAM.

Vacuum Inches of Mercury	Absolute Pressure Lbs. per Sq. In.	Temp. Degrees F.	Total Heat above 32° F.		Latent Heat H-h Heat-units	Relative Volume	Cubic Feet in 1 Lb. Wt. of Steam	Wt. of 1 Cubic Foot of Steam, Lbs.
			In the Water h Heat-units	In the Steam H Heat-units				
29.74	.089	32.	0.	1091.7	1091.7	208.080	3333.3	.0003
29.67	.122	40.	8.	1094.1	1086.1	154,330	2472.2	.0004
29.56	.176	50.	18.	1097.2	1079.2	107,630	1724.1	.0006
29.40	.254	60.	28.01	1100.2	1072.2	76,370	1223.4	.0008
29.19	.359	70.	38.02	1103.3	1065.3	54,660	875.61	.0011
28.90	.502	80.	48.04	1106.3	1058.3	39,690	635.80	.0016
28.51	.692	90.	58.06	1109.4	1051.3	29,290	469.20	.0021
28.00	.943	100.	68.08	1112.4	1044.4	21,830	349.70	.0028
27.88	1.	102.1	70.09	1113.1	1043.0	20,623	334.23	.0030
25.85	2.	126.3	94.44	1120.5	1026.0	10,730	173.23	.0058
23.83	3.	141.6	109.9	1125.1	1015.3	7,325	118.00	.0085
21.78	4.	153.1	121.4	1128.6	1007.2	5,588	89.80	.0111
19.74	5.	162.3	130.7	1131.4	1000.7	4,530	72.50	.0137
17.70	6.	170.1	138.6	1133.8	995.2	3,816	61.10	.0163
15.67	7.	176.9	145.4	1135.9	990.5	3,302	53.00	.0189
13.63	8.	182.9	151.5	1137.7	986.2	2,912	46.60	.0214
11.60	9.	188.3	156.9	1139.4	982.4	2,607	41.82	.0239
9.56	10.	193.2	161.9	1140.9	979.0	2,361	37.80	.0264
7.52	11.	197.8	166.5	1142.3	975.8	2,159	34.61	.0289
5.49	12.	202.0	170.7	1143.5	972.8	1,990	31.90	.0314
3.45	13.	205.9	174.7	1144.7	970.0	1,846	29.60	.0338
1.41	14.	209.6	178.4	1145.9	967.4	1,721	27.50	.0363
0.00	14.7	212.0	180.9	1146.6	963.7	1,646	26.36	.0379

TABLE 17—CONTINUED

Gauge Pressure Lbs. per Sq. In.	Absolute Pressure Lbs. per Sq. In.	Temp. Degrees F.	Total Heat above 32° F.		Latent Heat H-h Heat-units	Relative Volume	Cubic Feet in 1 Lb. Wt. of Steam	Wt. of 1 Cubic Foot of Steam, Lbs.
			In the Water h Heat-units	In the Steam H Heat-units				
0.3	15	213.3	181.9	1146.9	965.0	1,614	25.90	.0387
1.3	16	216.3	185.3	1147.9	962.7	1,519	24.33	.0411
2.3	17	219.4	188.4	1148.9	960.5	1,434	23.00	.0435
3.3	18	222.4	191.4	1149.8	958.3	1,359	21.80	.0459
4.3	19	225.2	194.3	1150.6	956.3	1,292	20.70	.0483
5.3	20	227.9	197.0	1151.5	954.4	1,231	19.72	.0507
6.3	21	230.5	199.7	1152.2	952.6	1,176	18.84	.0531
7.3	22	233.0	202.2	1153.0	950.8	1,126	18.03	.0555
8.3	23	235.4	204.7	1153.7	949.1	1,080	17.30	.0578
9.3	24	237.8	207.0	1154.5	947.4	1,038	16.62	.0602
10.3	25	240.0	209.3	1155.1	945.8	998	16.00	.0625
11.3	26	242.2	211.5	1155.8	944.3	962	15.42	.0649
12.3	27	244.3	213.7	1156.4	942.8	929	14.90	.0672
13.3	28	246.3	215.7	1157.1	941.3	898	14.40	.0696
14.3	29	248.3	217.8	1157.7	939.9	869	13.91	.0719
15.3	30	250.2	219.7	1158.3	938.9	841	13.50	.0742
16.3	31	252.1	221.6	1158.8	937.2	816	13.07	.0765
17.3	32	254.0	223.5	1159.4	935.9	792	12.68	.0788
18.3	33	255.7	225.3	1159.9	934.6	769	12.32	.0812
19.3	34	257.5	227.1	1160.5	933.4	748	12.00	.0835
20.3	35	259.2	228.8	1161.0	932.2	728	11.66	.0858
21.3	36	260.8	230.5	1161.5	931.0	709	11.36	.0880
22.3	37	262.5	232.1	1162.0	929.8	691	11.07	.0903
23.3	38	264.0	233.8	1162.5	928.7	674	10.80	.0926
24.3	39	265.6	235.4	1162.9	927.6	658	10.53	.0949
25.3	40	267.1	236.9	1163.4	926.5	642	10.28	.0972
26.3	41	268.6	238.5	1163.9	925.4	627	10.05	.0995
27.3	42	270.1	240.0	1164.3	924.4	613	9.83	.1018
28.3	43	271.5	241.4	1164.7	923.3	600	9.61	.1040
29.3	44	272.9	242.9	1165.2	922.3	587	9.41	.1063
30.3	45	274.3	244.3	1165.6	921.3	575	9.21	.1086
31.3	46	275.7	245.7	1166.0	920.4	563	9.02	.1108
32.3	47	277.0	247.0	1166.4	919.4	552	8.84	.1131
33.3	48	278.3	248.4	1166.8	918.5	541	8.67	.1153
34.3	49	279.6	249.7	1167.2	917.5	531	8.50	.1176
35.3	50	280.9	251.0	1167.6	916.6	520	8.34	.1198
36.3	51	282.1	252.2	1168.0	915.7	511	8.19	.1221
37.3	52	283.3	253.5	1168.4	914.9	502	8.04	.1243
38.3	53	284.5	254.7	1168.7	914.0	492	7.90	.1266
39.3	54	285.7	256.0	1169.1	913.1	484	7.76	.1288
40.3	55	286.9	257.2	1169.4	912.3	476	7.63	.1311
41.3	56	288.1	258.3	1169.8	911.5	468	7.50	.1333
42.3	57	289.1	259.5	1170.1	910.6	460	7.38	.1355
43.3	58	290.3	260.7	1170.5	909.8	453	7.26	.1377
44.3	59	291.4	261.8	1170.8	909.0	446	7.14	.1400
45.3	60	292.5	262.9	1171.2	908.2	439	7.03	.1422
46.3	61	293.6	264.0	1171.5	907.5	432	6.92	.1444
47.3	62	294.7	265.1	1171.8	906.7	425	6.82	.1466
48.3	63	295.7	266.2	1172.1	905.9	419	6.72	.1488

TABLE 17—CONTINUED

Gauge Pressure Lbs. per Sq. In.	Absolute Pressure Lbs. per Sq. In.	Temp. Degrees F.	Total Heat above 32° F.		Latent Heat H-h Heat-units	Relative Volume	Cubic Feet in 1 Lb. Wt. of Steam	Wt. of 1 Cubic Foot of Steam, Lbs.
			In the Water h Heat-units	In the Steam H Heat-units				
49.3	64	296.8	267.2	1172.4	905.2	413	6.62	.1511
50.3	65	297.8	268.3	1172.8	904.5	407	6.53	.1533
51.3	66	298.8	269.3	1173.1	903.7	401	6.43	.1555
52.3	67	299.8	270.4	1173.4	903.0	395	6.34	.1577
53.3	68	300.8	271.4	1173.7	902.3	390	6.25	.1599
54.3	69	301.8	272.4	1174.0	901.6	384	6.17	.1621
55.3	70	302.7	273.4	1174.3	900.9	379	6.09	.1643
56.3	71	303.7	274.4	1174.6	900.2	374	6.01	.1665
57.3	72	304.6	275.3	1174.8	899.5	369	5.93	.1687
58.3	73	305.6	276.3	1175.1	898.9	365	5.85	.1709
59.3	74	306.5	277.2	1175.4	898.2	360	5.78	.1731
60.3	75	307.4	278.2	1175.7	897.5	356	5.71	.1753
61.3	76	308.3	279.1	1176.0	896.9	351	5.63	.1775
62.3	77	309.2	280.0	1176.2	896.2	347	5.57	.1797
63.3	78	310.1	280.9	1176.5	895.6	343	5.50	.1819
64.3	79	310.9	281.8	1176.8	895.0	339	5.43	.1840
65.3	80	311.8	282.7	1177.0	894.3	334	5.37	.1862
66.3	81	312.7	283.6	1177.3	893.7	331	5.31	.1884
67.3	82	313.5	284.5	1177.6	893.1	327	5.25	.1906
68.3	83	314.4	285.3	1177.8	892.5	323	5.18	.1928
69.3	84	315.2	286.2	1178.1	891.9	320	5.13	.1950
70.3	85	316.0	287.0	1178.3	891.3	316	5.07	.1971
71.3	86	316.8	287.9	1178.6	890.7	313	5.02	.1993
72.3	87	317.7	288.7	1178.8	890.1	309	4.96	.2015
73.3	88	318.5	289.5	1179.1	889.5	306	4.91	.2036
74.3	89	319.3	290.4	1179.3	888.9	303	4.86	.2058
75.3	90	320.0	291.2	1179.6	888.4	299	4.81	.2080
76.3	91	320.8	292.0	1179.8	887.8	296	4.76	.2102
77.3	92	321.6	292.8	1180.0	887.2	293	4.71	.2123
78.3	93	322.4	293.6	1180.3	886.7	290	4.66	.2145
79.3	94	323.1	294.4	1180.5	886.1	287	4.62	.2166
80.3	95	323.9	295.1	1180.7	885.6	285	4.57	.2188
81.3	96	324.6	295.9	1181.0	885.0	282	4.53	.2210
82.3	97	325.4	296.7	1181.2	884.5	279	4.48	.2231
83.3	98	326.1	297.4	1181.4	884.0	276	4.44	.2253
84.3	99	326.8	298.2	1181.6	883.4	274	4.40	.2274
85.3	100	327.6	298.9	1181.8	882.9	271	4.36	.2296
86.3	101	328.3	299.7	1182.1	882.4	268	4.32	.2317
87.3	102	329.0	300.4	1182.3	881.9	266	4.28	.2339
88.3	103	329.7	301.1	1182.5	881.4	264	4.24	.2360
89.3	104	330.4	301.9	1182.7	880.8	261	4.20	.2382
90.3	105	331.1	302.6	1182.9	880.3	259	4.16	.2403
91.3	106	331.8	303.3	1183.1	879.8	257	4.12	.2425
92.3	107	332.5	304.0	1183.4	879.3	254	4.09	.2446
93.3	108	333.2	304.7	1183.6	878.8	252	4.05	.2467
94.3	109	333.9	305.4	1183.8	878.3	250	4.02	.2489
95.3	110	334.5	306.1	1184.0	877.9	248	3.98	.2510
96.3	111	335.2	306.8	1184.2	877.4	246	3.95	.2531
97.3	112	335.9	307.5	1184.4	876.9	244	3.92	.2553

TABLE 17—CONTINUED.

Gauge Pressure Lbs. per Sq. In.	Absolute Pressure Lbs. per Sq. In.	Temp. Degrees F.	Total Heat above 32° F.		Latent Heat H-h Heat-units	Relative Volume	Cubic Feet in 1 Lb. Wt. of Steam	Wt. of 1 Cubic Foot of Steam, Lbs.
			In the Water h Heat-units	In the Steam H Heat-units				
98.3	113	336.5	308.2	1184.6	876.4	242	3.88	.2574
99.3	114	337.2	308.8	1184.8	875.9	240	3.85	.2596
100.3	115	337.8	309.5	1185.0	875.5	238	3.82	.2617
101.3	116	338.5	310.2	1185.2	875.0	236	3.79	.2638
102.3	117	339.1	310.8	1185.4	874.5	234	3.76	.2660
103.3	118	339.7	311.5	1185.6	874.1	232	3.73	.2681
104.3	119	340.4	312.1	1185.8	873.6	230	3.70	.2703
105.3	120	341.0	312.8	1185.9	873.2	228	3.67	.2764
106.3	121	341.6	313.4	1186.1	872.7	227	3.64	.2745
107.3	122	342.2	314.1	1186.3	872.3	225	3.62	.2766
108.3	123	342.9	314.7	1186.5	871.8	223	3.59	.2788
109.3	124	343.5	315.3	1186.7	871.4	221	3.56	.2809
110.3	125	344.1	316.0	1186.9	870.9	220	3.53	.2830
111.3	126	344.7	316.6	1187.1	870.5	218	3.51	.2851
112.3	127	345.3	317.2	1187.3	870.0	216	3.48	.2872
113.3	128	345.9	317.8	1187.4	869.6	215	3.46	.2894
114.3	129	346.5	318.4	1187.6	869.2	213	3.43	.2915
115.3	130	347.1	319.1	1187.8	868.7	212	3.41	.2936
116.3	131	347.6	319.7	1188.0	868.3	210	3.38	.2957
117.3	132	348.2	320.3	1188.2	867.9	209	3.36	.2978
118.3	133	348.8	320.8	1188.3	867.5	207	3.33	.3000
119.3	134	349.4	321.5	1188.5	867.0	206	3.31	.3021
120.3	135	350.0	322.1	1188.7	866.6	204	3.29	.3042
121.3	136	350.5	322.6	1188.9	866.2	203	3.27	.3063
122.3	137	351.1	323.2	1189.0	865.8	201	3.24	.3084
123.3	138	351.8	323.8	1189.2	865.4	200	3.22	.3105
124.3	139	352.2	324.4	1189.4	865.0	199	3.20	.3126
125.3	140	352.8	325.0	1189.5	864.6	197	3.18	.3147
126.3	141	353.3	325.5	1189.7	864.2	196	3.16	.3169
127.3	142	353.9	326.1	1189.9	863.8	195	3.14	.3190
128.3	143	354.4	326.7	1190.0	863.4	193	3.11	.3211
129.3	144	355.0	327.2	1190.2	863.0	192	3.09	.3232
130.3	145	355.5	327.8	1190.4	862.6	191	3.07	.3253
131.3	146	356.0	328.4	1190.5	862.2	190	3.05	.3274
133.3	148	357.1	329.5	1190.9	861.4	187	3.02	.3316
135.3	150	358.2	330.6	1191.2	860.6	185	2.98	.3358
140.3	155	360.7	333.2	1192.0	858.7	179	2.89	.3463
145.3	160	363.3	335.9	1192.7	856.9	174	2.80	.3567
150.3	165	365.7	338.4	1193.5	855.1	169	2.72	.3671
155.3	170	368.2	340.9	1194.2	853.3	164	2.65	.3775
160.3	175	370.5	343.4	1194.9	851.6	160	2.58	.3879
165.3	180	372.8	345.8	1195.7	849.9	156	2.51	.3983
170.3	185	375.1	348.1	1196.3	848.2	152	2.45	.4087
175.3	190	377.3	350.4	1197.0	846.6	148	2.39	.4191
180.3	195	379.5	352.7	1197.7	845.0	144	2.33	.4296
185.3	200	381.6	354.9	1198.3	843.4	141	2.27	.4400
190.3	205	383.7	357.1	1199.0	841.9	138	2.22	.4503
195.3	210	385.7	359.2	1199.6	840.4	135	2.17	.4605
200.3	215	387.7	361.3	1200.2	838.9	132	2.12	.4707

TABLE 17—CONTINUED

Gauge Pressure Lbs. per Sq. In.	Absolute Pressure Lbs. per Sq. In.	Temp. Degrees F.	Total Heat above 32° F.		Latent Heat H-h Heat-units	Relative Volume	Cubic Feet in 1 Lb. Wt. of Steam	Wt. of 1 Cubic Foot of Steam, Lbs.
			In the Water h Heat-units	In the Steam H Heat-units				
205.3	220	389.7	362.2	1200.8	838.6	129	2.06	.4852
245.3	260	404.4	377.4	1205.3	827.9	110	1.76	.5686
285.3	300	417.4	390.9	1209.2	818.3	96	1.53	.6515
485.3	500	467.4	443.5	1224.5	781.0	59	.94	1.062
685.3	700	504.1	482.4	1235.7	753.3	42	.68	1.470
985.3	1000	546.8	528.3	1248.7	720.3	30	.48	2.082

Combustion

Combustion, as the term is used in steam engineering, is the rapid chemical combination of oxygen with carbon, hydrogen, and sulphur, with the accompaniment of heat and light. The substance which combines with the oxygen is the *combustible.* The combustion is *perfect* when the combustible is oxidized to the highest possible degree; thus, conversion of carbon into carbon dioxide (CO_2) represents perfect combustion, while its conversion to monoxide (CO) is imperfect combustion, since the monoxide can be further burned and finally converted into CO_2.

Kindling Point. As in many other chemical processes, a certain degree of heat is necessary to cause the union of the oxygen and combustible; the temperatures necessary to cause this union are the kindling temperatures, and are approximately as given in the following table by Stromeyer:

TABLE 18

KINDLING TEMPERATURES.

Lignite Dust	300° F
Sulphur	470
Dried Peat	435
Anthracite Dust	570
Coal	600
Cokes	Red Heat
Anthracite	Red Heat 750
Carbon Monoxide	Red Heat 1211
Hydrogen	1030 or 1290

The Oxygen necessary for combustion is supplied from the air. Its density is 1.10521 (Air=1); its weight 0.088843 pounds per cubic foot at 32° F., and atmospheric pressure; its atomic weight is 16; a pound of air contains

0.2315 pounds of oxygen, and 1 pound of oxygen is contained in 4.32 pounds of air.

Carbon (C), the most abundant combustible, has atomic weight of 12, and reaches the boiler furnace as a constituent of oil, gas, coal, charcoal, wood, etc.

Hydrogen (H) occurs free in small quantity in some fuels, but is usually in combination with the carbon. Its atomic weight is 1; its density is 0.0692 (Air=1); and its weight per cubic foot at 32° F. and atmospheric pressure is 0.00559 pounds. The heating value of 1 pound of pure carbon is rated at 14,500 heat units, while 1 pound of hydrogen gas contains 62,000 heat units.

Coal. Analysis of coal shows that it contains moisture, fixed carbon, volatile matter, ash and sulphur in various proportions according to the quality of the coal. Table 19 deduced from a few of the many valuable tables of analysis of the coals of the United States will show the composition of the principal bituminous coals in use in this country for

TABLE 19

COMPOSITION OF VARIOUS COALS.

State	Kind of Coal	Moisture	Volatile Matter	Fixed Carbon	Ash	Sulphur
Pennsylvania	Youghiogheny	1.03	36.49	59.05	2.61	0.81
Pennsylvania	Connellsville	1.26	30.10	59.61	8.23	0.78
West Virginia	Quinimont	0.76	18.65	79.26	1.11	0.23
West Virginia	Fire Creek	0.61	22.34	75.02	1.47	0.56
E. Kentucky	Peach Orchard	4.60	35.70	53.28	6.42	1.08
E. Kentucky	Pike County	1.80	26.80	67.60	3.80	0.97
Alabama	Cahaba	1.66	33.28	63.04	2.02	0.53
Alabama	Pratt Co.'s	1.47	32.29	59.50	6.73	1.22
Ohio	Hocking Valley	6.59	35.77	49.64	8.00	1.59
Ohio	Muskingum Valley	3.47	37.88	53.30	5.35	2.24
Indiana	Block	8.50	31.00	57.50	3.00	
Indiana	Block	2.50	44.75	51.25	1.50	
W. Kentucky	Nolin River	4.70	33.24	54.94	11.70	2.54
W. Kentucky	Ohio County	3.70	30.70	45.00	3.16	1.24
Illinois	Big Muddy	6.40	30.60	54.60	8.30	1.50
Illinois	Wilmington	15.50	32.80	39.90	11.80	
Illinois	“ screenings	14.00	28.00	34.20	23.80	
Illinois	Duquoin	8.90	23.50	60.60	7.00	

steam purposes. Two samples are selected from each of the great coal producing states, with the exception of Illinois, from which four were taken.

The process of combustion of fuel consists in the union of the carbon and hydrogen of the fuel with the oxygen of the air. Each atom of carbon combines with two atoms of oxygen, and the energetic vibration set up by their combination is heat. Bituminous coal contains a large percentage of volatile matter which is released and flashes into flame when the coal is thrown into the furnace, and unless air is supplied in large amounts at this stage of the combustion there will be an excess of smoke, and consequent loss of carbon. On the other hand there is a loss in admitting too much air because the surplus is heated to the temperature of the furnace without aiding the combustion, and will carry off to the chimney just as many heat units as were required to raise it from the temperature at which it entered the furnace, to that at which it enters the uptake. It will therefore be seen that a great advantage will be gained by first allowing the air that is needed above the fire to pass over or through heated bridge walls, or side walls. Some kinds of coal need more air for their combustion than do others, and good judgment and close observation are needed on the part of the fireman to properly regulate the supply.

Sulphur (S, atomic weight 32) is found in most coals and in some oils. It is usually present in a combined form, either as sulphide of iron, or sulphate of lime; in the latter form it has no heating value. Its presence in fuel is objectionable, because the gases formed from its combustion attack the metal of the boiler and cause rapid corrosion, particularly in presence of moisture.

Nitrogen (N) is drawn into the furnace with the air. Its atomic weight is 14; its density is 0.9701 (Air=1); its weight per cubic foot at 32° F. and atmospheric pressure is .07831 pounds; each pound of air at atmospheric pressure contains 0.7685 pounds of nitrogen, and 1 pound of nitrogen is contained in 1.301 pounds of air.

Nitrogen performs no useful office in combustion, and passes through the furnace without change. It dilutes the air, absorbs heat and reduces the temperature of the products of combustion, and is the chief source of heat loss in furnaces.

Combining Weights. When chemical elements unite to form a new compound they do so in definite proportions which are always the same, and the union produces heat, the quantity of which is also invariable. Thus, a pound of carbon, when carbon dioxide is formed, will always unite with 2 2-3 pounds of oxygen, and give off 14,600 B. T. U. As an intermediate step the carbon might unite with 1 1-3 times its weight of oxygen, and produce 4,450 B. T. U., but in its further conversion to CO_2 it would unite with an additional 1 1-3 times its weight of oxygen and evolve the other 10,150 B. T. U., since the heat developed in any chemical combination depends upon the initial, and final states, and not upon any intermediate change.

Carlorific Value of Fuel. The amount of heat liberated per pound of fuel undergoing *perfect combustion* is called the calorific value of the fuel.

Some boilers will make steam more economically by partly closing the ash-pit doors, while others require the same doors to be kept wide open. The quantity of air required for the combustion of one pound of coal is, by volume, about 150 cubic feet; by weight, about 12 pounds.

The temperature of the furnace is usually about 2,500°, in some cases reaching as high as 3,000°. The temperature of the escaping gases should not be much above nor below 400° F. for bituminous coal. The waste heat in the escaping gases can be utilized to great advantage by passing them through what are called economizers before they escape into the chimney. These economizers consist of coils, or stacks of cast iron pipe placed within the flue or breeching leading from the boilers to the chimney and are enveloped in the hot gases, while the feed water is passed through the pipes on its way to the boilers, the result being that considerable heat is thus imparted to the feed water that would otherwise go to waste.

In order to attain the highest economy in the burning of coal in boiler furnaces two factors are indispensable, viz., a constant high furnace temperature, and quick combustion, and these factors can only be secured by supplying the fresh coal constantly just as fast as it is burned, and also by preventing as much as possible the admission of cold air to the furnace. This is why the automatic or mechanical stoker, if it be of the proper design, is more economical and causes less smoke than hand firing. The fireman when he puts in a fire is prone to shovel in a good supply all at once, and this has the tendency to greatly reduce the temperature of the furnace, while at the same time it retards combustion. On the other hand the mechanical stoker supplies the coal continuously only as fast as it is required and no faster, and the furnace doors to not need to be opened at all, by which a large volume of cold air is prevented from entering the furnace and reducing the temperature. The author does not wish to be understood as recommending the adoption and use of mechanical stokers to replace hand firing, but he draws this contrast between the two methods of firing in order that it may be of some benefit to the thousands of honest toilers who earn a livelihood by shoveling coal into boiler furnaces.

The problem of the economical use of coal and the abatement of the smoke nuisance, especially in our large cities, has of late years become so serious that it is to the interest of every engineer, and especially every fireman, to use the utmost diligence, care and good judgment in the use of coal, and to emulate as much as possible the methods of the mechanical stoker.

Heat. All matter, whether solid, liquid or gaseous, consists of molecules, or atoms, which are in a state of continual vibration, and the result of this vibration is heat. The intensity of the heat evolved depends upon the degree of agitation to which the molecules are subject.

Heat Effects. When heat is added to or taken from a body, either the temperature of the body is altered, or its volume is varied, or its state is changed. Thus, if heat be added to water under atmospheric pressure, the temperature of the water increases until it reaches 212° F. If more heat be added and the pressure remains unchanged, the temperature does not further increase, but the water evaporates into steam. Heat thus changes water from a liquid to a gaseous state. If heat be abstracted from water the temperature is reduced until it reaches 32° F., after which any diminution of heat does not further decrease the temperature, until the liquor is converted into a solid, or ice. The quantity of heat passing from one body to another can thus be estimated by the effects produced. Therefore heat is something that can be both transferred and measured.

The general effect of heat on a body is to increase its volume. If heat be abstracted from a body the contrary effect ensues, and the volume is diminished. Hence the general principle, to which, however, there are some exceptions, that heat expands and cold contracts. These effects, arising from a change of temperature, are produced in very different degrees according to the nature of the bodies. They are small in solids, greater in liquids, and greater still in gases.

It is well known that the work expended in friction apparently is lost as regards mechanical work; that heat is developed when friction occurs; that the greater the friction the greater is the amount of heat produced. Experiments have proved that the amount of heat generated by friction is exactly equivalent to the amount of work lost, whence it is shown that heat, like mechanical work is one of the forms of energy.

Thermometers. In consequence of the uniform expansion of mercury and its great sensitiveness to heat, it is the fluid most commonly used in the construction of thermometers. In all thermometers the freezing and the boiling point of water, under mean atmospheric pressure at sea level, are assumed as two fixed points, but the division of the scale between these two points varies in different countries, hence there are in use three thermometers, known as the Fahrenheit, the Centrigrade or Celsius, and the Réaumur. In the Fahrenheit, the space between the two fixed points is divided into 180 parts; the boiling point is marked 212, and the freezing point is marked 32, and zero is a temperature which, at the time this thermometer was invented, was incorrectly imagined to be the lowest temperature attainable. In the Centrigrade and the Réaumur scales the distance between the two fixed points is divided

TABLE 20

COMPARISON OF THERMOMETER SCALES.

	Fahrenheit	Centigrade	Reaumur
Absolute Zero	—460.66	—273.70	—218.96
	0	—17.77	—14.22
	10	—12.23	—9.77
	20	—6.67	—5.33
	30	—1.11	—0.88
Freezing Point	32	0.	0.
Maximum Density of Water	39.1	3.94	3.15
	50	10.	8.
	75	23.89	19.11
	100	37.78	30.22
	200	93.34	74.66
Boiling Point	212	100.	80.
	250	121.11	96.88
	300	148.89	119.11
	350	176.67	141.33

$$F = 9\text{-}5\ C + 32° = 9\text{-}4\ R + 32°$$

$$C = 5\text{-}9\,(F - 32°) = 5\text{-}4\ R.$$

$$R = 4\text{-}5\ C = 4\text{-}9\,(F - 32°).$$

into 100 and 80 parts, respectively. In each of these two scales the freezing point is marked 0, and the boiling point is marked 100 in the Centigrade, and 80 in the Réaumur. Each of the 180, 100, or 80 divisions is termed a degree. Table 20 and the appended formulas are useful for converting one scale to another.

Absolute zero. At 32° F. a perfect gas expands $\frac{1}{492.66}$ part of its volume, if its temperature is increased one degree and its pressure remains constant. This rate of expansion holds good at all temperatures above the freezing point, in the case of the gas, which would double its volume if under a constant pressure its temperature were raised to 32°+492.66=524.66° F., while under a diminution of temperature it would shrink and finally disappear at a temperature of 492.66—32=460.66° below zero F.

Therefore the temperature 460.66°, or for the sake of simplicity, 461° F. is taken as absolute zero.

Until as late as the beginning of the nineteenth century two rival theories in regard to the nature of heat had been advocated by scientists. The older of these theories was that heat was a material substance, a subtle, elastic fluid termed caloric, and that this fluid penetrated matter something like water penetrates a sponge. But this theory was shown to be false by the wonderful researches and experiments of Count Rumford at Munich, Bavaria, in 1798.

By means of the friction between two heavy metallic bodies placed in a wooden trough filled with water, one of the pieces of metal being rotated by machinery driven by horses, Count Rumford succeeded in raising the temperature of the water in two and one-half hours from its original temperature of 60° to 212° F., the boiling point, thus demonstrating that heat is not a material substance, but that it is due to vibration or motion, an internal commotion among the molecules of matter. This theory, known as the Kinetic theory of heat, has since been generally accepted, although it was nearly fifty years after Rumford advocated it in a paper read before the Royal Society of Great Britain in 1798, before scientists generally became converted to this idea of the nature of heat, and the science of thermo-dynamics was placed on a firm basis.

During the period from 1840 to 1849 Dr. Joule made a series of experiments which not only confirmed the truth of Count Rumford's theory that heat was not a material substance, but a form of energy which may be applied to or taken away from bodies, but Joule's experiments also established a method of estimating in mechanical units or foot pounds the amount of that energy. This latter was a most important discovery, because by means of it the exact relation between heat and work can be accurately measured.

The first law of thermo-dynamics is this: Heat and mechanical energy, or work are mutually convertible. That is, a certain amount of work will produce a certain amount of heat, and the heat thus produced is capable of producing by its disappearance a fixed amount of mechanical energy if rightly applied. The mechanical energy in the form of heat which, through the medium of the steam engine, has revolutionized the world, was first stored up by the sun's heat millions of years ago in the coal which in turn, by combustion, is made to release it for purposes of mechanical work.

The general principles of Dr. Joule's device for measuring the amount of work in heat are illustrated in Fig. 102. It consists of a small copper cylinder containing a known quantity of water at a known temperature. Inside the cylinder and extending through the top was a vertical shaft to which were fixed paddles for stirring the water. Stationary vanes were also placed inside the cylinder. Motion was imparted to the shaft through the medium of a cord or small rope coiled around a drum near the top of the shaft and running over a grooved pulley or sheave. To the free end of the cord a known weight was attached. This weight was allowed to fall through a certain distance, and in falling it turned the shaft with its paddles, which in turn agitated the water, thus producing a certain amount of heat. To illustrate, suppose the weight to be 77.8 pounds. and that by means of the crank at the top end of the shaft it has been raised to the zero mark at the top of the scale. (See Fig. 102.) One pound of water at 39.1° F. is poured into the copper cylinder, which is then closed and the weight released. At the moment the weight passes the 10 foot mark on the scale, the thermometer attached to the cylinder will indicate that the temperature of the water has been raised one degree. Then multiplying the number of pounds in the weight by the distance in feet through which it fell

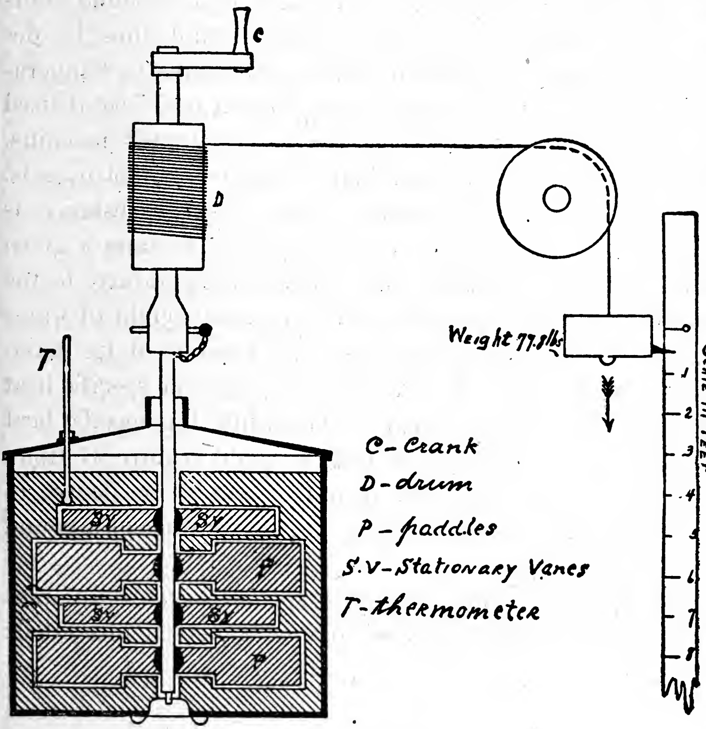


FIG. 102

will give the number of foot pounds of work done. Thus, 77.8 pounds×10 feet=778 foot pounds.

The heat unit or British thermal unit (B. T. U.) is the quantity of heat required to raise the temperature of one pound of water one degree, or from 39° to 40° F., and the amount of mechanical work required to produce a unit of heat is 778 foot pounds. Therefore the mechanical equivalent of heat is the energy required to raise 778 pounds one foot high, or 77.8 pounds 10 feet high, or 1 pound 778 feet high. Or again, suppose a one-pound weight falls through a space of 778 feet or a weight of 778 pounds falls one foot, enough mechanical energy would thus be developed to raise a pound of water one degree in temperature, provided all the energy so developed could be utilized in churning or stirring the water, as in Joule's machine. Hence the mechanical equivalent of heat is 778 foot pounds.

Specific Heat. The specific heat of any substance is the ratio of the quantity of heat required to raise a given weight of that substance one degree in temperature, to the quantity of heat required to raise an equal weight of water one degree in temperature when the water is at its maximum density, 39.1° F. To illustrate, take the specific heat of lead, for instance, which is .031, while the specific heat of water is 1. That means that it would require 31 times as much heat to raise one pound of water one degree in temperature as it would to raise the temperature of a pound of lead one degree.

The following table gives the specific heat of different substances in which engineers are most generally interested:

TABLE 21

SPECIFIC HEAT OF VARIOUS SUBSTANCES.

Water at 39.1° F.	1.000
Ice at 32° F.	.504
Steam at 212° F.	.480
Mercury	.033
Cast iron	.130
Wrought iron	.113
Soft steel	.116
Copper	.095
Lead	.031
Coal	.240
Air	.238
Hydrogen	3.404
Oxygen	.218
Nitrogen	.244

Sensible Heat and Latent Heat. The plainest and most simple definition of these two terms is that given by Sir Wm. Thomson. He says: "Heat given to a body and warming it is sensible heat. Heat given to a body and not warming it is latent heat." Sensible heat in a substance is the heat that can be measured in degrees of a thermometer, while latent heat is the heat in any substance that is not shown by the thermometer.

To illustrate this more fully a brief reference to some experiments made by Professor Black in 1762 will no doubt make the matter plain. It will be remembered that at that early date comparatively little was known of the true nature of heat, hence Professor Black's investigations and discoveries along this line appear all the more wonderful. He procured equal weights of ice at 32° F. and water at the same temperature, that is, just at the freezing point, and placing them in separate glass vessels suspended the vessels in a room in which the uniform temperature was 47° F. He noticed that in one-half hour the water had increased 7° F. in temperature, but that twenty half hours elapsed before all of the ice was melted. Therefore he reasoned that twenty times more heat had entered the ice than had entered the water, because at the end of twenty half hours when the ice was all melted the water in both vessels was of the same temperature. The water having absorbed 7° of heat during the first half hour must have continued to absorb heat at the same rate during the whole of the twenty half hours, although the thermometer did not indicate it. From this he calculated that $7° \times 20 = 140°$ of heat had become latent or hidden in the water.

In another experiment Professor Black placed a lump of melting ice, which he estimated to be at a temperature of 33° F. on the surface, in a vessel containing the same weight of water at 176° F., and he observed that when the whole of the ice had been melted the temperature of the water was 33° F., thus proving that 143° of heat (176°—33°) had been absorbed in melting the ice and was at that moment latent in the water. By these two experiments Professor Black established the theory of the latent heat of water, and his estimate was very near the truth because the results obtained since that time by the greatest experimenters show that the latent heat of water is 142 heat units, or B. T. U.

Black's experiment for ascertaining the latent heat in steam at atmospheric pressure was made in the following simple manner: He placed a flat, open tin dish on a hot plate over a fire and into the dish he put a small quantity of water at 50° F. In four minutes the water began to boil, and in twenty minutes more it had all evaporated. In the first four minutes the temperature had increased $212° - 50° = 162°$, and the temperature remained at 212° throughout the twenty minutes that it required to evaporate all the water, despite the fact that the water had been receiving heat during this period at the same rate as during the first four minutes. He therefore reasoned that in the twenty minutes the water had absorbed five times as much heat as it had in the four minutes, or 160° × 5 = 810°, without any sensible rise in temperature. Therefore the 810° became latent in the steam. Owing to the crude nature of the experiment Professor Black's estimate of the number of degrees of latent heat in steam was incorrect, as it has been proven by many famous experimenters since then that the latent heat of steam at atmospheric pressure is 965.7 B. T. U.

It will thus be perceived that what is meant by the term latent heat is that quantity of heat which becomes hidden, or latent when the state of a body is changed from a solid to a liquid, as in the case of melting ice, or from a liquid to a gaseous state, as with water evaporated into steam. But the heat so disappearing has not been lost, on the contrary it has, while becoming latent, been doing an immense amount of work, as can easily be ascertained by means of a few simple figures. It has been seen that a heat unit is the quantity of heat required to raise one pound of water one degree in temperature and also that the mechanical equivalent of heat, or, in other words, the mechanical energy stored in one heat unit is equal to 778 foot pounds of work.

A horse power equals 33,000 foot pounds of energy in one minute of time, and a heat unit = 778 ÷ 33,000 = .0236, or about 1-43 of a horse-power. The work done by the heat which becomes latent in converting one pound of ice at 32° F. into water at the same temperature = 142 heat units × 778 foot pounds = 110,476 foot pounds, which divided by 33,000 equals 3.34 horse-power. Again, by the evaporation of one pound of water from 32° F. into steam at atmospheric pressure, 965.7 units of heat become latent in the steam and the work done=965.7×778=751,314 foot pounds=22.7 horse-power. It will thus be seen what tremendous energy lies stored in one pound of coal, which contains from 12,000 to 14,500 heat units, provided all the heat could be utilized in an engine.

Total Heat of Evaporation. In order to raise the temperature of one pound of water from the freezing point, 32° F., to the boiling point, 212° F., there must be added to the temperature of the water 212°—32°=180°. This represents the sensible heat. Then to make the water boil at atmospheric pressure, or, in other words, to evaporate it, there must still be added 965.7 B. T. U., thus 180+965.7=1,145.7, or in round numbers 1,146 heat units. This represents what is termed the total heat of evaporation at atmospheric pressure and is the sum of the sensible and latent heat in steam at that pressure. But if a thermometer were held in steam evaporating into the open air, as, for instance, in front of the spout of a tea-kettle, it would indicate but 212° F.

When steam is generated at a higher pressure than 212°, the sensible heat increases and the latent heat decreases slowly, while at the same time the total heat of evaporation slowly increases as the pressure increases, but not in the same ratio. As, for instance, the total heat in steam at atmospheric pressure is 1,146 B. T. U., while the total heat in steam at 100 pounds gauge pressure is 1,185 B. T. U., and the sensible temperature of steam at atmospheric pressure is 212°, while at 100 pounds gauge pressure the temperature is 338 and the latent heat is 876 B. T. U.

WATER.

Water. The elements that enter into the composition of pure water are the two gases, hydrogen and oxygen, in the following proportions:

	Hydrogen	Oxygen
By volume	2	1
By weight	11.1	88.9

Perfectly pure water is not attainable, neither is it desirable nor necessary to the welfare of the human race, because the presence of certain proportions of air and ammonia add greatly to its value as an agent for manufacturing purposes and for generating steam. The nearest approach to pure water is rain water, but even this contains 2.5 volumes of air to each 100 volumes of water. Pure distilled water, such for instance as the return water from steam heating systems, is not desirable for use alone in a boiler, as it will cause corrosion and pitting of the sheets, but if it is mixed with other water before going into the boiler its use is highly beneficial, as it will prevent to a certain degree the formation of scale and incrustation. Nearly all water used for the generation of steam in boilers contains more or less scale-forming matter, such as the carbonates of lime and magnesia, the sulphates of lime and magnesia, oxide of iron, silica and organic matter, which latter tends to cause foaming in boilers.

The carbonates of lime and magnesia are the chief causes of incrustation. The sulphate of lime forms a hard crystalline scale which is extremely difficult to remove when once formed on the sheets and tubes of boilers. Of late years the intelligent application of chemistry to the analyzing of feed waters has been of great benefit to engineers and steam users, in that it has enabled them to properly treat the water with solvents either before it is pumped into the boiler, or by the introduction into the boiler of certain scale preventing compounds made especially for treating the particular kind of water used. Where it is necessary to treat water in this manner great care and watchfulness should be exercised by the engineer in the selection and use of a boiler compound.

From ten to forty grains of mineral matter per gallon are held in solution by the waters of the different rivers, streams and lakes; well and mine water contain still more.

Water contracts and becomes denser in cooling until it reaches a temperature of 39.1° F., its point of greatest density. Below this temperature it expands and at 32° F. it becomes solid or freezes, and in the act of freezing it expands considerably, as every engineer who has had to deal with frozen water pipes can testify.

Water is 815 times heavier than atmospheric air. The weight of a cubic foot of water at 39.1° is approximately 62.5 pounds, although authorities differ on this matter, some of them placing it at 62.379 pounds, and others at 62.425 pounds per cubic foot. As its temperature increases its weight per cubic foot decreases until at 212° F. one cubic foot weighs 59.76 pounds.

The table which follows is compiled from various sources and gives the weight of a cubic foot of water at different temperatures.

TABLE 22

WEIGHT OF CU. FT. OF WATER

Temperature	Weight per Cubic Foot	Temperature	Weight per Cubic Foot	Temperature	Weight per Cubic Foot
32° F.	64.42 lbs.	132° F.	61.52 lbs.	230° F.	59.37 lbs.
42°	62.42	142°	61.34	240°	59.10
52°	62.40	152°	61.14	250°	58.85
62°	62.36	162°	60.94	260°	58.52
72°	62.30	172°	60.73	270°	58.21
82°	62.21	182°	60.50	300°	57.26
92°	62.11	192°	60.27	330°	56.24
102°	62.00	202°	60.02	360°	55.16
112°	61.86	212°	59.76	390°	54.03
122°	61.70	220°	59.64	420°	52.86

The boiling point of water varies according to the pressure to which it is subject. In the open air at sea level the boiling point is 212° F. When confined in a boiler under steam pressure the boiling point of water depends upon the pressure and temperature of the steam, as, for instance, at 100 pounds gauge pressure the temperature of the steam is 338° F., to which temperature the water must be raised before its molecules will separate and be converted into steam. In the absence of any pressure, as in a perfect vacuum, water boils at 32° F. temperature. In a vacuum of 28 inches, corresponding to an absolute pressure of .943 pounds, water will boil at 100°, and in a vacuum of 26 inches, at which the absolute pressure is 2 pounds, the boiling point of water is 127° F. On the tops of high mountains in a rarefied atmosphere, water will boil at a much lower temperature than at sea level, for instance at an altitude of 15,000 feet above sea level water boils at 184° F.

Table 23 gives the boiling point of water at various altitudes above sea level, also the atmospheric pressure in pounds per square inch.

TABLE 23

BOILING POINT OF WATER AT VARIOUS ALTITUDES.

Boiling Point in degrees Fahrenheit.	Altitude above Sea Level. Feet.	Atmospheric Pressure. Pounds per square inch.	Barometer, Inches.
184	15,221	8.19	16.79
185	14,649	8.37	17.16
186	14,075	8.56	17.54
187	13,498	8.75	17.93
188	12,934	8.94	18.32
189	12,367	9.13	18.72
190	11,799	9.33	19.13
191	11,243	9.53	19.54
192	10,685	9.74	19.96
193	10,127	9.95	20.39
194	9,579	10.16	20.82
195	9,031	10.38	21.26
196	8,481	10.60	21.71
197	7,932	10.82	22.17
198	7,381	11.05	22.64
199	6,843	11.28	23.11
200	6,304	11.52	23.59
201	5,764	11.76	24.08
202	5,225	12.01	24.58
203	4,697	12.25	25.08
204	4,169	12.51	25.59
205	3,642	12.77	26.11
206	3,115	13.03	26.64
207	2,589	13.29	27.18
208	2,063	13.57	27.73
209	1,539	13.84	28.29
210	1,025	14.12	28.85
211	512	14.41	29.42
212	Sea-Level	14.70	30.00

STEAM.

Steam. Having discussed to some extent the physical properties of water, it is now in order to devote some time to the study of the nature of steam, which is simply water in its gaseous form, made so by the application of heat.

As has been stated in another portion of this book, matter consists of molecules or atoms inconceivably small in size, yet each having an individuality, and in the case of solids or liquids, each having a mutual cohesion or attraction for the other, and all being in a state of continual vibration, more or less violent according to the temperature of the body.

The law of gravitation which holds the universe together, also exerts its wonderful influence on these atoms, and causes them to hold together with more or less tenacity according to the nature of the substance. Thus it is much more difficult to chip off pieces of iron or granite than it is of wood. But in the case of water and other liquids the atoms, while they adhere to each other to a certain extent, still they are not so hard to separate, in fact, they are to some extent repulsive to each other, and unless confined within certain bounds the atoms will gradually scatter and spread out, and finally either be evaporated or sink out of sight in the earth's surface. Heat applied to any substance tends to accelerate the vibrations of the molecules, and if enough heat is applied it will reduce the hardest substances to a liquid or gaseous state.

The process of the generation of steam from water is simply an increase of the natural vibrations of the molecules of the water, caused by the application of heat until they lose all attraction for each other and become instead entirely repulsive, and unless confined will fly off into space. But being confined they continually strike against the sides of the containing vessel, thus causing the pressure which steam or any other gas exerts when under confinement.

Of course steam, like other gases, when under pressure, is invisible, but the laws governing its action are well known. These laws, especially those relating to the expansion of steam, will be more fully discussed in the section on the Indicator. The temperature of steam in contact with the water from which it is generated, as for instance in the ordinary steam boiler, depends upon the pressure under which it is generated. Thus at atmospheric pressure its temperature is 212° F. If the vessel is closed and the pressure increased the temperature of the steam and also that of the water rises.

Saturated Steam. When steam is taken directly from the boiler to the engine without being superheated, it is termed saturated steam. This does not necessarily imply that it is wet and mixed with spray and moisture.

Superheated Steam. When steam is conducted into or through a vessel or coils of pipe separate from the boiler in which it was generated, and is there heated to a higher temperature than that due to its pressure, it is said to be superheated.

Dry Steam. When steam contains no moisture it is said to be dry. Dry steam may be either saturated or superheated.

Wet Steam. When steam contains mist or spray intermingled it is termed wet steam, although it may have the same temperature as dry saturated steam of the same pressure.

During the further consideration of steam in this book, saturated steam will be mainly under discussion, for the reason that this is the normal condition of steam as used most generally in steam engines.

Total Heat of Steam. The total heat in steam includes the heat required to raise the temperature of the water from 32° F. to the temperature of the steam plus the heat required to evaporate the water at that temperature. This latter heat becomes latent in the steam, and is therefore called the latent heat of steam.

The work done by the heat acting within the mass of water and causing the molecules to rise to the surface is termed by scientists internal work, and the work done in compressing the steam already formed in the boiler, or in pushing it against the superincumbent atmosphere, if the vessel be open, is termed external work. There are, therefore, in reality three elements to be taken into consideration in estimating the total heat of steam, but as the heat expended in doing external work is done within the mass itself it may, for practical purposes, be included in the general term latent heat of steam.

Density of Steam. The expression density of steam means the actual weight in pounds, or fractions of a pound avoirdupois of a given volume of steam. This is a very important point for young engineers especially to remember, so as not to get the two terms, pounds pressure and pounds weight, mixed, as some are prone to do.

Volume of Steam. By this term is meant the volume as expressed by the number of cubic feet in one pound weight of steam.

Relative Volume of Steam. This expression has reference to the number of volumes of steam produced from one volume of water. Thus the steam produced by the evaporation of one cubic foot of water from 39° F. into steam at atmospheric pressure will occupy a space of 1646 cubic feet, but, as the steam is compressed and the pressure allowed to rise, the relative volume of the steam becomes smaller, as for instance at 100 pounds gauge pressure the steam produced from one cubic foot of water will occupy but 237.6 cubic feet, and if the same steam was compressed to 1,000 pounds absolute or 985.3 pounds gauge pressure it would then occupy only 30 cubic feet.

The condition of steam as regards its dryness may be approximately estimated by observing its appearance as it issues from a pet cock or other small opening into the atmosphere. Dry, or nearly dry steam containing about 1 per cent of moisture will be transparent close to the orifice through which it issues, and even if it is of a grayish white color it may be estimated to contain not over 2 per cent of moisture.

Steam in its relation to the engine should be considered in the character of a vehicle for transferring the energy, created by the heat, from the boiler to the engine. For this reason all steam drums, headers and pipes should be thoroughly insulated in order to prevent, as much as possible, the loss of heat or energy by radiation.

There is a wide difference in the value of different substances for protection from radiation, their value varying nearly in the inverse ratio of their conducting power for heat, up to their ability to transmit as much heat as the surface of the pipe will radiate, after which they become detrimental, rather than useful, as covering. This point is reached nearly at baked clay or brick.

Table 24 shows the relative value of various non-conductors of heat, and table 25 gives the loss of heat from steam pipes protected, and unprotected.

Where two values are given in table 24 for the same substance the lower one is for the denser condition.

A smooth or polished surface is of itself a good protection, polished tin or Russia iron having a ratio, for radiation, of 53 to 100 for cast iron. Mere color makes but little difference.

Hair or wool felt, and most of the better non-conductors, have the disadvantage of becoming soon charred from the heat of steam at high pressure, and sometimes of taking fire therefrom.

"Mineral wool," a fibrous material made from blast furnace slag, is the best non-combustible covering, but is quite brittle, and liable to fall to powder where much jarring exists.

Air space alone is one of the poorest of non-conductors, though the best owe their efficiency to the numerous minute air cells in their structure. This is best seen in the value of different forms of carbon, from cork charcoal to anthracite dust, the former being three times as valuable for this purpose, though in chemical constitution they are practically identical.

Any suitable substance used to prevent the escape of steam heat should not be less than one inch thick.

TABLE 24

RELATIVE VALUE OF NON-CONDUCTING MATERIALS.

Substance	Value
*Loose Wool	3.35
*Loose Lampblack	1.12
*Geese Feathers	1.08
*Felt, Hair or Wool	1.
*Carded Cotton	1.
*Charcoal from Cork	.87
Mineral Wool	.68 to .83
Fossil Meal	.66 to .79
*Straw Rope, wound spirally	.77
*Rice Chaff, loose	.76
Carbonate Magnesia	.67 to .76
*Charcoal from Wood	.63 to .75
*Paper	.50 to .74
*Cork	.71
*Sawdust	.61 to .68
Paste of Fossil Meal and Hair	.63
Wood Ashes	.61
*Wood, across grain	.40 to .55
Loam, dry and open	.55
Chalk, ground, Spanish white	.51
Coal Ashes	.35 to .49
Gas-house Carbon	.47
Asbestos Paper	.47
Paste of Fossil Meal and Asbestos	.47
Asbestos, fibrous	.36
Plaster of Paris, dry	.34
Clay, with vegetable fiber	.34
Anthracite Coal, powdered	.29
Coke in lumps	.27
Air Space, undivided	.14 to .22
Sand	.17
Baked Clay, Brick	.07
Glass	.05
Stone	.02

* Combustible, and sometimes dangerous.

The following table gives the loss of heat from steam pipes, naked and clothed with wool or hair felt, of different thickness, the steam pressure being assumed at 75 pounds and the external air at 60°.

TABLE 25

LOSS OF HEAT FROM STEAM PIPES.

Thickness of Covering in inches	OUTSIDE DIAMETER OF PIPE, WITHOUT FELT.														
	2 inch diameter			4 inch diameter			6 inch diameter			8 inch diameter			12 inch diameter		
	Loss in Units per foot run per hour	Ratio of Loss	Feet in Length per H. P. lost	Loss in Units per foot run per hour	Ratio of Loss	Feet in Length per H. P. lost	Loss in Units per foot run per hour	Ratio of Loss	Feet in Length per H. P. lost	Loss in Units per foot run per hour	Ratio of Loss	Feet in Length per H. P. lost	Loss in Units per foot run per hour	Ratio of Loss	Feet in Length per H. P. lost
0	219.0	1.00	152	390.8	1.00	86	624.1	1.000	53	729.8	1.000	46	1077.4	1.000	31
¼	100.7	.46	331	180.9	.46	182	.....	.....	...	.....	.....	...	......	.....	...
½	65.7	.30	507	117.2	.30	284	187.2	.300	.177	219.6	.301	151	301.7	.280	114
1	43.8	.20	761	73.9	.18	451	111.0	.178	300	128.3	.176	259	185.3	.172	179
2	28.4	.13	1173	44.7	.11	745	66.2	.106	504	75.2	.103	443	98.0	.091	340
4	19.8	.09	1683	28.1	.07	1186	44.2	.066	808	46.0	.063	724	60.3	.056	553
6	.....	....	....	23.4	.06	1424	33.7	.054	989	34.3	.047	972	45.2	.042	735

Flow of Steam Through Pipes. The approximate weight of any fluid which will flow in one minute through any given pipe with a given head or pressure may be found by the following formula:

$$W=87\sqrt{\frac{D(p_1-p_2)d^5}{L\left(1+\frac{3.6}{d}\right)}}$$

in which W=weight in pounds avoirdupois, d=diameter in inches, D=density or weight per cubic foot, p_1=the initial pressure, p_2=pressure at end of pipe, and L= the length in feet. Table 26 gives, approximately, the weight of steam per minute which will flow from various initial pressures, with one pound loss of pressure through straight smooth pipes, each having a length of 240 times its own diameter.

For sizes of pipe below 6-inch, the flow is calculated from the *actual* areas of "standard" pipe of such nominal diameters.

For horsepower, multiply the figures in the table by 2. For any other loss of pressure, multiply by the square root of the given loss. For any other length of pipe, *divide 240 by the given length expressed in diameters, and multiply the figures in the table by the square root of this quotient,* which will give the flow for 1 lb. loss of pressure. Conversely, dividing the given length by 240 will give the loss of pressure for the flow given in the table.

The loss of head due to getting up the velocity, to the friction of the steam entering the pipe, and passing elbows and valves, will reduce the flow given in the tables. The resistance at the opening, and that at a globe valve, are each about the same as that for a length of pipe equal to

Table 26

FLOW OF STEAM THROUGH PIPES.

Initial Pressure by Gauge. Pounds per Square Inch.	DIAMETER OF PIPE, IN INCHES. LENGTH OF EACH=240 DIAMETERS.													
	¾	1	1½	2	2½	3	4	5	6	8	10	12	15	18
	Weight of Steam per minute, in pounds, with one pound loss of pressure.													
1	1.12	2.05	5.65	10.15	15.26	25.12	46.27	76.1	111.6	209.1	336.3	495.3	792	1160
10	1.38	2.54	6.98	12.54	18.85	31.03	57.15	93.9	137.9	258.2	415.3	611.8	979	1433
20	1.62	2.97	8.18	14.70	22.09	36.36	66.97	110.1	161.6	302.6	486.7	716.9	1147	1679
30	1.82	3.34	9.21	16.54	24.86	40.92	75.37	123.9	181.8	340.6	547.8	806.9	1291	1889
40	2.01	3.68	10.12	18.18	27.34	44.99	82.87	136.3	199.9	374.5	602.3	887.2	1419	2078
50	2.17	3.98	10.95	19.67	29.57	48.67	89.64	147.4	206.3	404.9	651.5	959.7	1535	2248
60	2.32	4.25	11.71	21.04	31.63	52.06	95.89	157.7	231.3	433.3	696.9	1026.5	1642	2404
70	2.46	4.51	12.42	22.32	33.55	55.22	101.71	167.3	245.4	459.6	739.3	1088.9	1742	2550
80	2.59	4.75	13.09	23.52	35.36	58.19	107.18	176.3	258.6	484.3	778.9	1147.4	1836	2687
90	2.71	4.96	13.66	24.55	36.91	60.74	111.88	183.9	269.9	505.5	811.5	1197.8	1916	2805
100	2.84	5.20	14.32	25.73	38.71	63.66	117.25	192.8	282.9	529.8	852.2	1255.3	2008	2940
120	3.06	5.61	15.44	27.75	41.71	68.64	126.43	207.9	305.1	571.3	918.9	1353.6	2166	3170
150	3.37	6.16	16.97	30.49	45.83	75.42	138.91	228.4	335.2	627.7	1009.6	1487.2	2379	3483

114 diameters divided by a number represented by $1+(3.6 \div \text{diameter})$. For the sizes of pipes given in the table, these corresponding lengths are:

¾	1	1½	2	2½	3	4	5	6	8	10	12	15	18
20	25	34	41	47	52	60	66	71	79	84	88	92	95

The resistance at an elbow is equal to 2/3 that of a globe valve. These equivalents—for opening, for elbows, and for valves—must be added in each instance to the actual length of pipe. Thus a 4 in. pipe, 120 diameter (40 feet) long, with a globe valve and three elbows, would be equivalent to $120+60+60+(3\times40)=360$ diameters long; and $360 \div 240 = 1\frac{1}{2}$. It would therefore have $1\frac{1}{2}$ pounds loss of pressure at the flow given in the table, or deliver $(1 \div \sqrt{1\frac{1}{2}} = .816)$ 81.6 per cent of the steam with the same (1 pound) loss of pressure.

Flow of Steam From a Given Orifice. Steam of any pressure flowing through an opening into any other pressure, less than three-fifths of the initial, has practically a constant velocity, 888 feet per second, or a little over ten miles per minute; hence the amount discharged in pounds is proportionate to the weight or density of the steam. To ascertain the pounds, avoirdupois, discharged per minute, *multiply the area of opening in inches, by 370 times the weight per cubic foot of the steam.* (See Table 17.)

Or the quantity discharged per minute may be approximately found by Rankine's formula:

$$W = 6\,a\,p \div 7$$

in which W=weight in pounds, a=area in square inches, and p=absolute pressure. The theoretical flow requires to be multiplied by $k=0.93$, for a short pipe, or 0.63 for a thin opening, as in a plate, or a safety valve.

Where the steam flows into a pressure more than 2/3 the pressure in the boiler:

$$W=1.9\ a\ k\sqrt{(p-8)8}$$

in which 8=difference in pressure between the two sides, in pounds per square inch, and *a, p,* and *k* as above.

To reduce to horsepower, multiply by 2.

Where a given horsepower is required to flow through a given opening, to determine the necessary difference in pressure:

$$8=\frac{p}{2}-\sqrt{\frac{p^2}{4}-\frac{\text{H.P.}^2}{14a^2k}}$$

QUESTIONS AND ANSWERS.

238. What is meant by the term combustion as used in steam engineering?

Ans. It is the rapid chemical combination of oxygen with the carbon, hydrogen and sulphur in the fuel with the accompaniment of heat and light.

239. What is meant by the symbol CO_2?

Ans. CO_2 represents perfect combustion, viz., the creation of carbon dioxide.

240. What is the most abundant combustible in nature?

Ans. Carbon.

241. How many heat units are contained in one pound of pure carbon?

Ans. 14,500.

242. What is the heating value of one pound of hydrogen gas?

Ans. 62,000.

243. Give the composition of coal.

Ans. Fixed carbon, volatile matter, ash and sulphur in various proportions, depending upon the quality of the coal.

244. Is sulphur desirable as a constituent of coal?

Ans. It is not. The gases formed from its combustion attack the metal of the boiler, causing corrosion.

245. What office does nitrogen perform in combustion?

Ans. No useful office. Rather it is a detriment, and in fact is the chief source of loss in furnaces. It is drawn in with the air.

246. What is meant by the term calorific value of fuel?

Ans. The amount of heat liberated per pound of fuel undergoing perfect combustion.

248. What are economizers in connection with a boiler plant?

Ans. Coils or stacks of cast iron pipe placed within the smoke flue, or breeching and surrounded by the hot gases while the water is passed through the pipes on its way to the boilers, thus receiving an additional amount of heat.

249. What two factors are necessary in order to attain economy in the burning of coal?

Ans. A constant high furnace temperature and quick combustion.

250. Define the term heat.

Ans. Heat is the result of the vibration of the molecules or atoms composing matter.

251. Upon what does the intensity of heat depend?

Ans. Upon the rapidity of the agitation to which the molecules are subject.

252. What are the general effects of heat?

Ans. When heat is added to, or taken away from a body the temperature of the body is altered and its volume is varied.

253. What is absolute zero?

Ans. It is that degree of temperature at which, owing to the intense cold, a perfect gas would disappear. Absolute zero is 461° below the zero of the Fahrenheit thermometer.

254. What is a heat unit (B. T. U.)?

Ans. It is the quantity of heat required to raise the temperature of one pound of water one degree, or from 39° to 40° F.

255. What is the mechanical equivalent of heat?

Ans. 778 foot pounds; in other words, 778 pounds raised one foot high.

256. What is the specific heat of any substance?

Ans. The ratio of the quantity of heat required to raise a given weight of that substance one degree in temperature, to the quantity of heat required to raise an equal weight of water one degree when the water is at its maximum density, viz., 39.1° F.

257. What is latent heat?

Ans. Heat given to a body and not warming it.

258. What is sensible heat?

Ans. Heat given to a body and warming it.

259. Of what is pure water composed?

Ans. By volume—Hydrogen 2 parts, oxygen 1.
By weight—Hydrogen 11.1 parts, oxygen 88.9.

260. Is perfectly pure water desirable for use in a steam boiler?

Ans. It is not, as it will cause corrosion and pitting of the sheets.

261. What two ingredients in water are the chief causes of incrustation in boilers?

Ans. The carbonates of lime and magnesia.

262. What is steam?

Ans. Steam is the vapor of water generated by an increase of the natural vibrations of molecules of the water through the application of heat.

263. What is saturated steam?

Ans. Steam taken directly from the boiler to the engine without being superheated.

264. What is superheated steam?

Ans. Steam that has been heated to a higher temperature than that due to its pressure.

265. What should be done with all pipes through which live steam is conducted for purposes of heating, or power?

Ans. They should be well protected by a covering, in order to prevent loss of heat by radiation.

266. In what respect should steam be considered in its relation to the engine?

Ans. As a vehicle for transferring the heat energy from the boiler to the engine.

Evaporation Tests

Evaporation Tests. The object of making evaporation tests of steam boilers is primarily to ascertain how many pounds of water the boilers are evaporating per pound of coal burned; but these tests can and should be made to determine several other important points with reference to the operation of the boilers, as for instance: 1. The efficiency of the boiler and furnace as an apparatus for the consumption of fuel and the evaporation of water; whether this apparatus is performing its guaranteed duty in this respect, and how it compares with a known standard. 2. To determine the relative economy of different varieties of coal, also to determine the relative value of fuels other than coal, such as oil, gas, etc. 3. To ascertain whether or not the boilers as they are operated under ordinary every day conditions are being run as economically as they should be. 4. In case the boilers, owing to an increased demand for steam, fail to supply a sufficient quantity without forcing the fires, whether or not additional boilers are needed, or whether the trouble could be overcome by a change of conditions in operating them.

Tests for the last three purposes named can be made by the regular engineering force of the plant, but in case a controversy should arise between the maker of the boiler and the purchaser regarding the first mentioned point, viz., the guaranteed efficiency of the boiler or the furnace, the services of experts in boiler testing may be resorted to.

Preparing for a Test. All testing apparatus should be kept in such shape that it will not take three or four days to get it ready for making a test. On the contrary, it can be and should be always kept in condition ready for use, so that the preparations for making a test will occupy but a short time. A small platform scale sufficiently large for weighing a wheel-barrow load of coal should also be provided in addition to the apparatus heretofore described.

The capacity of each of the two tanks illustrated in Fig. 66, can be determined in two ways, either by measuring the cubical contents of each or by placing them one at a time on the scales, filling them with water to within a few inches of the top, and note the weight. Also make a permanent mark on the inside at the water level. The water should then be permitted to run out until within an inch or so of the outlet pipe near the bottom, where another plain mark should be made, after which the empty tank should be again weighed, then by subtracting the last weight from the first the exact number of pounds of water that the tank will contain between the top and bottom marks can be determined and a note made of it.

It is much more convenient to have each tank contain the same quantity of water, although not absolutely necessary. The tanks should also be numbered 1 and 2 respectively in order to prevent confusion in keeping a record of the number of tanks full of water used during the test. Care should be exercised to have the water with which the tanks are filled while on the scale, at or near the same temperature as that at which it is to be fed into the boiler during the test. Otherwise there is liability of error owing to the variation in the weight of water at different temperatures. In order to guard against this, the capacity in cubic feet of each tank between the top and bottom marks should be ascertained by measuring the distance between the marks, also the diameter, or, if the tanks be square, the length of one side, after which the cubical contents can be easily figured and noted down. By knowing the capacity in cubic feet of each tank all possibility of error in the weight of feed water will be eliminated.

The scales for weighing the coal can be fitted with a temporary wooden platform large enough to accommodate a wheel-barrow, and after it has been balanced with the empty barrow on it, the record of weight of coal burned during the test can be easily kept.

The same barrow should be used throughout the test, and to save complications in estimating the weight, the same number of pounds of coal should be filled in the barrow each load. The coal passer will learn in a short time to fill the barrow to within a few pounds of the same weight each load by counting the shovelsful and the difference can easily be adjusted by having a small box of coal near the scale from which to take a few lumps to balance the load, or if there is too much coal in the barrow some of it can be thrown into the box.

At least two separate tally sheets should be provided, marked respectively coal and water, and the one for coal placed near the scale, and care should be taken that each load is tallied as soon as it is weighed. The tally sheet for water should be near the measuring tanks and as soon as a tank is emptied it should be tallied. The temperature of the feed water should be taken at least every thirty minutes, or oftener if possible, from a thermometer placed in the feed pipe near the check valve. The readings should be noted and, at the expiration of the test, the average taken.

To Find the Cubic Contents of a Barrel. To find the cubic contents of a barrel, square the largest diameter, then multiply by 2, then add the square of the head diameter;

multiply this sum by the length of the cask and that product by 0.2618. For example, a barrel whose largest diameter is 21 inches, head diameter 18 inches and height 33 inches: $21\times21\times2=882$; $18\times18=324$; $324+882=1206$; $1206\times33=39{,}798$; $39{,}798\times0.2618=10{,}419.11$ cubic inches. Dividing by 231 for gallons gives 45.10 gallons.

If the object of the test is to ascertain the efficiency of the boiler and furnace it is absolutely necessary that the boiler and all its appurtenances be put in good condition, by cleaning the heating surface both inside the boiler and outside, scraping and blowing the soot out of the tubes, if it be a return tubular boiler, and blowing the soot and ashes from between the tubes if it is a water tube boiler. All dust, soot and ashes should be removed from the outside of the shell and also from the combustion chamber and smoke connections. The grate bars and sides of the furnace should be cleared of all clinker, and all air leaks made as close as possible. The boiler and all its water connections should be free from leaks, especially the blow-off valve or cock. If any doubt exists as to the latter it should be plugged or a blind flange put on it. It is very essential that there should be no way for the water to leak out of the boiler, neither should any water be allowed to get into the boiler during the test except that which is measured by passing through the tanks.

In making an efficiency test it is essential that the boiler should be run at its fullest capacity from the beginning to the end of the test. Therefore arrangements should be made to dispose of the steam as fast as it is generated. If the boiler is in a battery connected with a common header, its mates can be fired lighter during the test, but if there is but the one boiler in use a waste steam pipe should be temporarily connected through which the surplus steam, if there is any, can be discharged into the open air through a valve regulated as required. Before starting the test the boiler should be thoroughly heated by having been run several hours at the ordinary rate. The fire should then be cleaned and put in good condition to receive fresh coal.

At the time of beginning the test the water level should be at or near the height ordinarily carried, and its position marked by tying a cord around one of the guard rods of the gauge glass, and, to prevent all possibility of error, the height of the water in the glass should be measured and a note made of it. Note also the time that the first lot of weighed coal is fed to the furnace, and record it as the starting time. The steam pressure should be noted at the beginning of the test, and at regular intervals during the progress of the test in order that the average pressure may be obtained.

At the close of the test all of the above conditions should be as nearly as possible the same as at the beginning; the quantity, and condition of the fire should be the same, also the steam pressure and water level. This can be accomplished only by careful work towards the close of the test.

During the progress of the test care should be exercised to prevent any waste of coal, especially in cleaning the fire. The ash made during the test must not be wet down until after it is weighed, as in all calculations for combustible and non-combustible matter in the coal the ash should be dry.

The duration of the test should be at least ten hours if it is possible to continue it for that length of time. The feed pump should be kept running at such speed as will supply the water to the boiler as fast as it is evaporated, and no faster. If at the close of the test a portion of water is left in the last tank tallied it can be measured, and deducted from the total. And if any weighed coal is left on the floor it should be weighed back and deducted from the total weight. If the boiler is fed by an injector instead of a pump during the test, the injector should receive steam directly from the boiler under test through a well protected pipe. Also, the temperature of the feed water should be taken from the measuring tanks, or at least from the suction side of the injector, for the reason that the water in passing through the injector receives a large quantity of heat imparted to it by live steam directly from the boiler. Therefore the temperature of the water after it leaves the injector would not be a true factor for figuring the evaporation.

Determination of the Percentage of Moisture in the Steam. This is an important point in estimating the results of an evaporation test for the reason that each pound weight of moisture in the steam as it leaves the boiler represents a pound of water that has not been evaporated into steam, and should therefore be deducted from the total weight of water fed into the boiler during the test.

The steam should be tested for moisture by taking samples of it from the steam pipe or header as near the boiler as possible in order to guard against additional moisture caused by condensation.

Practically all saturated steam contains water, varying in amount from a fraction of one per cent when the steam is generated in a properly designed boiler fed with good water, to five per cent or even more when the feed water is bad, or the boilers are of defective design. Not only is the heat absorbed by raising this water from the boiler feed temperature to the steam temperature practically wasted, but the water causes further loss by increasing the initial condensation in the engine cylinder; it also interferes with proper cylinder lubrication, causes knocking in the engine, and water hammer in the steam pipe.

Quality of Steam. The percentage weight of steam, in a mixture of steam and water, is called the quality of the steam. Thus steam of quality 99.5 contains one-half of one per cent by weight of moisture.

Calorimeters. The apparatus used to determine the moisture in steam is called a calorimeter, though the name is inapt, since the instrument is in no sense a measurer of heat. The first form used was the "barrel calorimeter." In this apparatus liability of error is so great that its use is practically abandoned. Modern calorimeters are usually of either the throttling or separator type.

Throttling Calorimeter. Figure 103 shows a section through a typical form of the instrument. Steam is drawn from the vertical pipe by a nipple arranged as later described, passes around the first thermometer cup as shown, then through a hole about ⅛-inch diameter in the disk as shown. It next passes around the lower thermometer cup, after which it is permitted to escape. Thermometers are inserted into the cups, which are then filled with cylinder oil, and when the whole apparatus is heated the temperature of the steam before, and after passing through the hole in the disk is noted.

The instrument and pipes leading to it should be thoroughly covered to diminish the radiation loss.

When steam passes from a higher to a lower pressure, as in this case, no work has to be done in overcoming a resistance; hence assuming there is no loss from radiation, the quantity of heat is exactly the same after passing the disk as it was ahead of it. Suppose that the higher steam pressure is 150 pounds by gauge, and the lower pressure that of the atmosphere. The total heat in a pound of dry steam at the former pressure is 1193.5 B. T. U. and at the latter pressure is 1146.6 B. T. U., difference, 46.9 B. T. U.

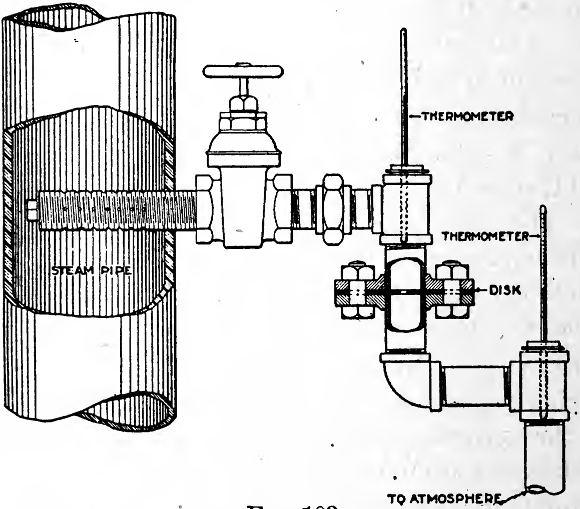


FIG. 103

THROTTLING CALORIMETER AND SAMPLING PIPE

As this heat still exists in the steam of lower pressure, its effect is to *superheat* that steam. Assuming the specific heat of steam to be 0.48, the steam will then be superheated $\frac{46.9}{0.48}=97.7$ degrees. Suppose, however, the steam had contained one per cent. of moisture. Before any superheating could occur, this moisture would have to be evaporated into steam of atmospheric pressure. Since the latent heat of steam at atmospheric pressure is 965.8 B. T. U.

it follows that the one per cent. of moisture would require 9.658 B. T. U. to evaporate it, leaving only 46.9—9.658= 37.242 B. T. U. available for superheating, hence the superheat would be $\frac{37.242}{0.48}=77.6°$ as against 97.7 degrees in the preceding case. In a similar manner the degree of superheat for other amounts of moisture can be determined, and the action of the throttling calorimeter is based on this fact as will now be shown.

Let H=total heat of steam at boiler pressure.
L=latent heat of steam at boiler pressure.
h=total heat of steam at reduced pressure after passing the disk.
t_1=temperature of *saturated* steam at the reduced pressure.
t_2=temperature of steam after expanding through opening in the disk.
0.48=specific heat of saturated steam.
x=proportion of moisture in the steam.

The difference between the B. T. U.'s in a pound of steam at boiler pressure and after passing the disk is the heat which must evaporate the moisture in the steam, and then do the superheating, hence.

$$H-h=xL-0.48\ (t_2-t_1), \text{ therefore}$$

$$x=\frac{H-h-0.48\ (t_2-t_1)}{L} \qquad [6]$$

Almost invariably the lower pressure is taken as that of the atmosphere where $h=1146.6$ and $t_1=212$, hence the formula becomes

$$x=\frac{H-1146.6-0.48\ (t_2-212)}{L} \qquad [7]$$

For practical work it is more convenient to dispense with the upper thermometer in the calorimeter, and substitute an accurate steam gauge whose readings are more easily noted.

Sources of Error. There are two. The first is that the specific heat of superheated steam, while given as 0.48 is far from being certain, and only future investigation can determine the true value. The second source of error is loss of heat by radiation. Evidently from the moment the steam enters the sampling nipple it is losing heat, hence when it passes through the small opening and into the lower pressure the heat available for evaporating moisture, and superheating will be diminished by just the amount lost by radiation, hence the value of t_2 will be lower than it should be. This is sometimes corrected for as follows: A valve in the steam pipe beyond the calorimeter nipple is closed, and the steam left in a quiescent state for about ten minutes, and it is *assumed* that by doing this all the moisture in the steam will settle out, and that a sample of steam drawn from the pipe will be dry. Steam is then allowed to flow through the calorimeter and the temperature of the lower thermometer is noted. Let T denote this temperature. Since the sample of steam was assumed to be dry it follows that if there were no loss from radiation the value of T would be that due to all of the liberated heat being absorbed in superheating the steam of lower temperature. There is, however, a loss of radiation, and the effect of this is to condense some of the steam of lower pressure, and the water thus formed must be evaporated before any superheating can be done. Let x^1 represent the proportion of water thus formed, then evidently

$$x^1 = \frac{H - h - 0.48 \quad (T - t_1)}{L}$$

Now this amount of water was not in the steam originally, but was caused by condensation in the instrument, hence the *true* amount of moisture in the steam, which may be denoted by X, will be

$$X = x - x^1 = \frac{H - h - 0.48\ (t_2 - t_1)}{L} - \frac{H - h - 0.48\ (T - t_1)}{L} = \frac{0.48\ (T - t_2)}{L} \qquad [8]$$

The disadvantages of this method are: (1) It assumes that during the test the boiler pressure will remain the same as it was when T was determined, which is seldom practicable; (2) It assumes that the sample of steam drawn into the instrument when determining T was absolutely dry, although experiment has shown that this assumption is not necessarily true. Notwithstanding these facts, formula [8] is much used by engineers because of its simplicity and convenience, and any error due to its use is of no practical significance.

There are many forms of throttling calorimeter, all of which operate on precisely the same principle as the simple design shown in Fig. 103. An extremely convenient and compact design is shown in Fig. 104. It consists of two concentric cylinders screwed to a cap containing a thermometer cup. The steam pressure is measured by a gauge placed in the supply pipe, or any other convenient place. Steam passes through the opening A, expands to atmospheric pressure, and its temperature at this pressure is measured by a thermometer placed in the cup C. To prevent radiation losses the annular space between the two cylinders is used as a jacket, and is supplied with steam through the hole B.

The limits of the throttling calorimeter at sea level are from about four per cent of moisture at eighty pounds pressure to six per cent at 200 pounds pressure. If there is a greater content of moisture the liberated heat is insufficient to evaporate it, and superheat the steam thus generated.

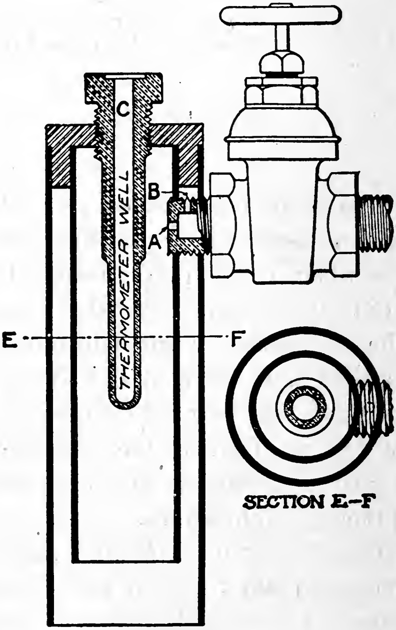


Fig. 104
COMPACT THROTTLING CALORIMETER

Separating Calorimeter. The separating calorimeter (Fig. 105) mechanically separates the entrained water from the steam and collects it in a reservoir, where its amount is either indicated by a gauge glass or determined by draining it off and weighing it. The steam passes out of the calorimeter through an orifice of known size, so

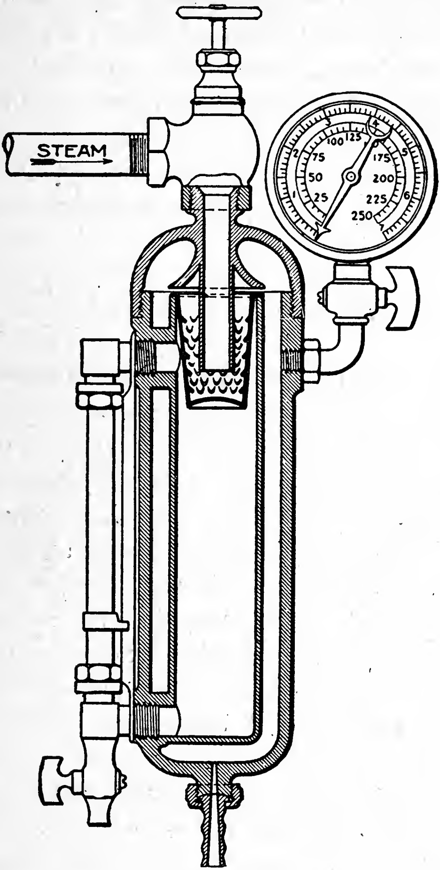


FIG. 105
SEPARATING CALORIMETER

that either its total amount can be calculated, or it can be weighed as later described. To avoid radiation errors, the calorimeter should be well covered with non-conducting material. This instrument is not limited in capacity theoretically, but if the amount of moisture is very large, the readings should be checked by passing the discharged steam through a throttling calorimeter; that is, a small separator should be used between the steam pipe and a throttling calorimeter, and the sum of the percentages obtained from the two instruments be taken as the moisture in the steam.

In the separating calorimeter, the amount of steam passing through the orifice can be determined by Napier's empirical formula,

$$\text{Pounds of steam per second} = \frac{pa}{70}$$

In which p=absolute pressure in pounds per square inch, and a=area of orifice in square inches.

There is liability of considerable error in determining the area of such small orifices, and further, the flow of steam soon wears the orifice larger. A more accurate method of determining the weight of steam passing through is to convey it through a hose into a barrel of water resting on a platform scale. The weight of the barrel and contained water having been noted before and after the steam is run in, the difference is the weight of steam condensed. The moisture caught in the separating calorimeter can be weighed in the same way. If W is the weight of steam condensed, w the weight of moisture from the separating calorimeter, and x the per cent of moisture in the steam, then

$$x = \frac{100w}{W+w} \qquad [9]$$

Location of Sampling Nipple. The principal source of inaccuracy in calorimeter determinations is failure to secure an *average* sample of steam. It is extremely doubtful whether such a sample is ever secured. To diminish the liability of error the instrument should be located as near as possible to the point where the sample is drawn off.

Taking an Observation. Locate the sampling nipple as above directed, attach the instrument as close to it as possible, and cover all exposed parts to prevent radiation. If the throttling calorimeter be used, locate the steam gauge on the pressure side, and the thermometer on the expansion side. To take an observation, note simultaneously the gauge reading and the thermometer reading, and from these the content of moisture may be determined by use of formula [7]. If the separating calorimeter be used, attach to the separator outlet a piece of hose which terminates in a vessel of water on a platform scale graduated to read to 1/100 of a pound. Similarly connect the steam outlet to another vessel of water resting on an equally sensitive scale. Note in each case the weight of each vessel including the water it contains. When ready to take an observation, blow out the instrument thoroughly, so there will be no water in the separator. Then simultaneously close the separator drip, and insert the steam hose into its vessel of water. When the separator has accumulated a sufficient quantity of water, close the valve at the main steam pipe, thus cutting off the supply of steam to the instrument, remove the steam hose from the vessel of water into which it was inserted, and empty the separator water into its vessel on the scale. Note the final weight of each vessel and contents, then the differences between final, and original weights will be respectively, the weight of moisture collected by the separator, and the weight of steam from which the moisture was taken, hence the proportion of moisture can be computed from formula [9].

Before taking any calorimeter observations, steam should be allowed to flow through freely until the instrument is thoroughly heated up.

Moisture in the Coal. This can generally be obtained from the reports of the geologist of the state in which the coal is mined, or from the dealer, although the former is the most reliable. The percentage of moisture must be deducted from the total weight of coal in figuring the weight of combustible.

Measuring the Chimney Draft. A good draft is indispensable for obtaining economical results in an evaporation test. The draft can be easily regulated by a damper to suit the conditions. Chimney draft is ordinarily measured by a draft gauge connected with the smoke flue near the chimney. The usual form of draft gauge is a glass tube bent in the shape of the letter U. (See Fig. 106.) One leg is connected to the flue by a small rubber hose, while the other is open to the atmosphere. The tube is partly filled with water, which will, when there is no draft, stand at the same height in both legs. When connected to the chimney or flue the suction will cause the water in the leg to which the hose is attached to rise, while the level of the water in the other leg will be equally depressed, and the extent of the variation in fractions of an inch is the measure of the draft. Thus the draft is referred to as being .5, .7 or .75 inches. The draft should not be less than .5 inches in any case to insure good results.

The Barrus draft gauge is illustrated in Fig. 107. It consists of a U-tube made of ½-inch glass, surmounted by two larger tubes, or chambers, each having a diameter of 2½-inch. Two different liquids which will not mix, and which are of different color, are used. The movement of the line of demarcation is proportional to the difference in the areas of the chambers and of the U-tube connecting them below. The liquids generally employed are alcohol colored red and a certain grade of lubricating oil. A multiplication varying from eight to ten times is obtained under these circumstances; in other words, with ¼-inch draft the movement of the line of demarcation is some 2 inches. The instrument is calibrated by referring it to the ordinary U-tube gauge.

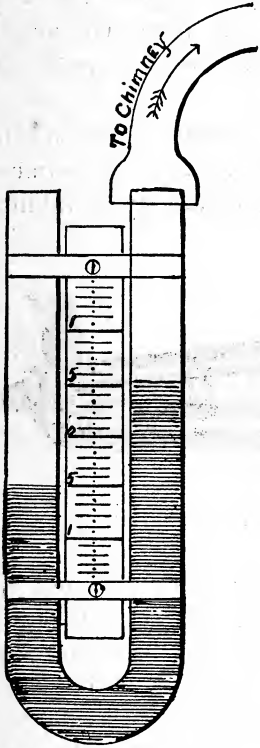


Fig. 106

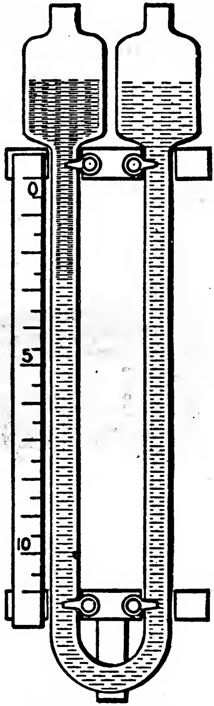


Fig. 107
BARRUS' DRAFT GAUGE

Ellison's Gauge. In this form of gauge the lower portion of the ordinary U-tube has been replaced by a tube slightly inclined to the horizontal, as shown in Fig. 108. By this arrangement any vertical motion in the left hand upright tube causes a very much greater travel of the liquid in the inclined tube, thus permitting extremely small variation in the draft pressure to be read with facility.

The gauge is first leveled by means of the small level attached to it, both legs being open to the atmosphere. The liquid is then adjusted (by adding to or taking from it) until its meniscus rests at the zero point on the right. The left hand leg is then connected to the source of draft by means of a piece of rubber tubing. Under these circumstances, a rise of level of one inch in the left hand vertical tube causes the meniscus in the inclined tube to pass from the point 0 to 1.0. The scale is divided into tenths of an inch, and the subdivisions are hundredths of an inch.

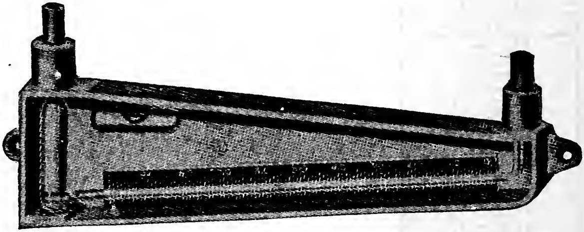


FIG. 108
ELLISON'S DRAFT GAUGE OUTLINE

The right hand leg of the instrument bears two marks. By filling the tube to the lower of these the range of the instrument is increased one-half inch, i. e., it will record draft pressures from 0 to 1½ inches. Similarly, by filling to the upper mark, the range is increased to 2 inches When so used the observed readings in the scale are to be increased by one-half or one-inch, as the case may be.

The makers recommend the use of a non-drying oil for the liquid, usually a 300° test refined petroleum, but water suffices for all practical purposes.

Flue Gas Analysis. The object of the flue-gas analysis is to determine from a sample of the gas the amount of excess air admitted, the degree of completeness of the combustion of the carbon, and the amount and distribution of the heat losses due to the excess air and incomplete combustion. The quantities actually determined by the analysis are the relative proportions of carbon dioxide (CO_2), carbon monoxide (CO), and oxygen (O) in the gases. Although the analysis does not directly determine the amount of nitrogen present in the flue-gases, yet its actual amount, as well as that of the air supply, may readily be ascertained by calculation. When air is drawn through an opening, like an ash-pit door, sometimes an anemometer can be used for ascertaining the velocity through the area, and the air supply be determined by these means.

A pound of carbon requires for complete combustion, 2.67 pounds of oxygen, or a volume of 32 cubic feet at 60° F., and the gaseous product, carbon dioxide (CO_2), when cooled occupies precisely the same volume as the oxygen, viz., 32 cubic feet. If the oxygen is mixed with nitrogen in the same proportion as it is found in air (20.91 O and 79.09 N), the volume of the carbon dioxide (CO_2) after combustion, and also its proportion to nitrogen, is the same as that of the oxygen; hence, for complete combustion of carbon, with no excess of air, the volumetric analysis of the flue gases is,

Carbon dioxide ....CO_2=20.91%
Carbon monoxide ....CO =None
Oxygen ....O =None
Nitrogen ....N =79.09%.

If the supply of air is in excess of that required to supply the oxygen needed, the combined volumes of the carbon dioxide and oxygen are still the same as that of the oxygen before combustion; consequently, *for the complete combustion of pure carbon, the sum of the percentages by volume of the carbon dioxide and oxygen in the flue gases must always be 20.91, no matter what the supply of air may be.*

Carbon monoxide (CO) produced by imperfect combustion of carbon, occupies *twice* the volume of the oxygen entering into its composition, and renders the volume of the flue gases greater than that of the air supply in the proportion of

$$\frac{100}{100-\frac{1}{2}\text{ the \% of CO}}\text{, hence}$$

when pure carbon is the fuel, the sum of the percentages of carbon dioxide, oxygen, and one-half the carbon monoxide must be in the same ratio to the nitrogen as is oxygen in the air, viz. 20.91 to 79.09.

Orsat Apparatus. The analysis of the flue-gases is best made for practical purposes by means of the Orsat apparatus shown in Fig. 109. The operation is as follows: Exactly 100 cc of the gas sample are drawn into the graduated measuring burette, A, and then passed in succession into the U-form absorbing vessels, D, E, F, each time being returned to and measured in A. In passing into the U-shaped vessels, the gas displaces the liquid contained therein, driving it up into the other legs. A portion of the fluids, however, adheres to the glass tubes placed in the vessels for that purpose, and comes in intimate contact with the gas. Each vessel absorbs a different constituent. D is filled with a solution of potassium hydroxide and takes up the carbon dioxide; E contains

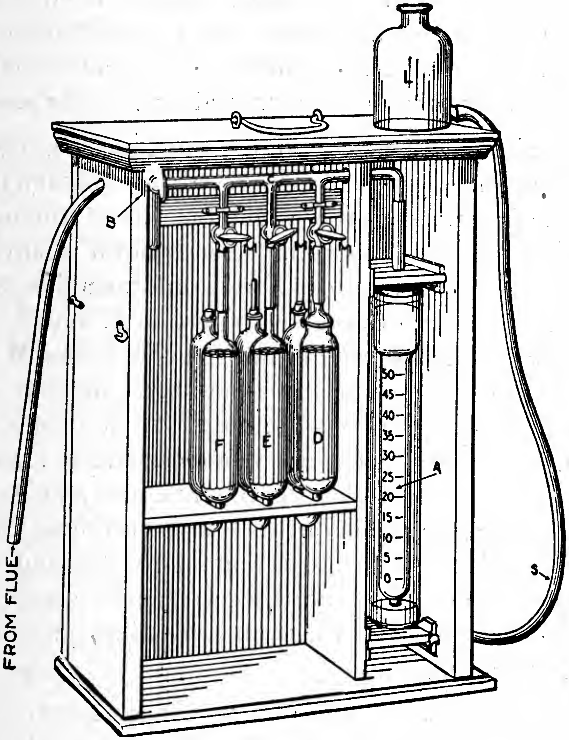


FIG. 109

ORSAT APPARATUS FOR FLUE-GAS ANALYSIS

pyrogallic acid, which removes the oxygen; and F absorbs the carbon monoxide in a solution of cuprous chloride. The reduction in volume measured in A gives the percentage of each constituent gas.

The connections to A are made through the glass stop cocks M, and the capillary tube C. The movement of the gases is produced by lowering or raising the bottle L, which is connected to the lower part of A by the rubber tube S, and is partially filled with water. When a measurement is taken, the level of the water in A and L must be the same, so that all measurements are taken at atmospheric pressure. A constant temperature of the gas in A is maintained by the water in the surrounding cylinder shown.

The sample is drawn into the apparatus through the cock B, which also serves to connect the capillary tube to the atmosphere, the latter connection being through the spindle of the cock; this permits the removal of any excess of gas above 100 cc that may have been drawn into A. Before the sample is drawn, the vessels D, E and F should have their respective liquids raised to the cocks M which can then be closed, and the atmospheric pressure acting through the other leg, which is open, will keep them filled. The burette A and the capillary tubes should be filled with water up to the cock B. All this can easily and quickly be done by raising and lowering L, and opening and closing cocks M and B. The absorption of oxygen and carbon monoxide is very slow, and the gas should be passed back and forth a number of times until a reduction of volume is no longer indicated.

As the pressure of the gases in a flue is less than the atmospheric pressure, they will not, of themselves, flow through the rubber or metal tubing connecting to the analyzing apparatus; but by filling the instrument two or three times and discharging it into the atmosphere through cock B, the air can be removed from the connecting tubing and a sample of the gas be obtained. For rapid work, an aspirator can be used for drawing the gas from the tube in a constant stream. If this is used there is less danger of an admixture of air. It is sometimes desirable to take a sample that represents an average during half an hour, or an hour, and in this case a metal, or glass vessel with a stop-cock at both top and bottom, and filled with water, can be connected through the upper stop-cock to the flue, and the bottom cock then be opened. The water will gradually drip out, drawing the gas into the vessel. The time taken to fill it can be regulated by the lower cock.

The result of a flue-gas analysis depends both on the manner and time of taking the sample, and to get at the average composition of the gas, a number of determinations should be made on samples from different parts of the flue.

The analysis made by the Orsat apparatus is volumetric; if the analysis by weight is required it can be found from the volumetric analysis as follows:

Multiply the percentages by volume by the molecular weight of the gas, and divide by the sum of all the products; the quotient will be the percentage by weight.

The molecular weights are as follows:

Carbon dioxide	44
Carbon monoxide	28
Oxygen	32
Nitrogen	28

Calculations for Efficiency of the Plant. Having thus successfully conducted the test to its close, and being armed with all the data heretofore noted, the engineer is now ready to compute the results.

If the test is made for the purpose of determining the efficiency of the boiler and setting as a whole, including grate, chimney draft, etc., then the result must be based upon the number of pounds of water evaporated per pound of coal. This latter phrase includes not only the purely combustible matter in the coal, but the non-combustible also, as ash, moisture, etc. Some varieties of western coal contain as high as 12 to 14 per cent. of moisture, and the ability of the furnace to extract heat from the mass is to be tested, as well as the ability of the boiler to absorb and transmit that heat to the water. Therefore the efficiency of the boiler and furnace=

$$\frac{\text{Heat absorbed per pound of coal.}}{\text{Heating value of one pound of coal.}}$$

Efficiency of the Boiler. The heating surface of the boiler must transmit heat from the hot furnace gases on one side, to the water on the other. This transmission of heat is very rapid through the metal of the boiler, but the accumulation of scale on the interior, and soot on the exterior surfaces greatly obstructs the flow of heat and renders the heating surface inefficient.

If the test is to determine the efficiency of the boiler itself as an absorber of heat, then the combustible alone must be considered in working out the final result. Thus,

Efficiency of boiler=

$$\frac{\text{Heat absorbed per pound of combustible.}}{\text{Heating value of one pound of combustible.}}$$

When making a series of tests for the purpose of comparing the economical value of different varieties of coal, the conditions should be as nearly uniform as possible; that is, let the tests be made under ordinary working conditions, and with the same boiler or boilers, and if possible with the same fireman.

The following is a record of one of many evaporation tests made by the author, and is introduced here for the purpose of illustrating methods of computing the results to be obtained from the various data. The rather large quantity of coal burned per square foot of grate surface per hour (25 pounds) is owing to the fact that the boiler was run to its full capacity, the coal burning clean, and forming no clinker. The chimney draft also was exceptionally good, giving a large unit of evaporation per square foot of heating surface per hour. The low temperature of the escaping gases is due to the fact that they were returned over the top of the boiler before passing to the chimney.

Date of test..................................

Duration of test, 12 hours.

Boiler, return tubular, 72 in. diameter, 18 ft. long, 62-4½ in. tubes.

Kind of coal, Pocahontas; average steam pressure..........		85	lbs.
Weight of coal consumed..		11,100	lbs.
Weight of water apparently evaporated....................		107,187	lbs.
Weight of dry ash returned..................	8.1 per cent.=	900	lbs.
Moisture in the coal........................	2.0 per cent.=	222	lbs.
Moisture in the steam......................	1.0 per cent.=	1,071	lbs.
Dry coal corrected for moisture...........................		10,878	lbs.
Weight of combustible..		9,978	lbs.
Water corrected for moisture in the steam..................		106,116	lbs.
Water evaporated into dry steam, from and at 212°..........		117,788	lbs.
Water evaporated per lb. of coal, actual conditions..........		9.65	lbs.
Water evaporated per lb. of coal, from and at 212°..........		10.61	lbs.
Water evaporated per lb. of combustible, from and at 212°..		11.81	lbs.
Water evaporated per lb. of dry coal, from and at 212°......		10.82	lbs.
Water evaporated per hr. per sq. ft. of heating surface.......		6.22	lbs.
Coal burned per sq. ft. of grate surface per hour...........		25	lbs.
Horsepower developed by boiler during test................		284.5	
Temperature of feed water, average.......................		141°	
Temperature of chimney gases, average....................		400°	
Square feet of grate surface..............................		36	
Square feet of heating surface...........................		1,576	
Ratio of grate surface to heating surface....................		43.7	

The results obtained will be taken up in their regular order beginning with, first, water evaporated into dry steam from and at 212°. As it may be of benefit to some, a short definition of the meaning of the above expression is here given.

The term "equivalent evaporation," or the evaporation from and at 212°, assumes that the feed water enters the boiler at a temperature of 212° and is evaporated into steam at 212° temperature and at atmospheric pressure. As for instance, if the top man hole plate were left out, or some other large opening in the steam space allowed the steam to escape into the atmosphere as fast as it was generated. Owing to the variation in the temperatures of the feed water used in different tests, and also the variation in the steam pressure, it is absolutely necessary that the results of all tests be brought by computation to the common basis of 212° in order to obtain a just comparison.

The process by which this is done is as follows: Referring to the record of the test it is seen that the steam pressure average was 85 pounds gauge pressure, or 100 pounds absolute, and that the temperature of the feed water was 141°. Referring again to Table 17, physical properties of steam, it will be seen that in a pound of steam at 100 pounds absolute pressure there are 1,181.8 heat units, and in a pound of water at 141° temperature there are 109.9 heat units. It therefore took 1,181.8—109.9= 1,071.9 heat units to convert one pound of feed water at 141° into steam at 85 pounds pressure. To convert a pound of water at 212° into steam at atmospheric pressure, and 212° temperature requires 965.7 heat units, and the 1,071.9 heat units would evaporate 1,071.9÷965.7=1.11 pounds water from and at 212°. The 1.11 is the factor of evaporation for 85 pounds gauge pressure and 141° temperature of feed water, and by multiplying "water corrected for moisture in the steam" (see record of test), 106,116 pounds, by 1.11, the weight of water which could have been evaporated into steam from and at 212° is obtained, which is

117,788 pounds. The factor of evaporation is based upon the steam pressure and the temperature of the feed water in any test and the formula for ascertaining it is as follows: $\text{Factor} = \frac{H - h}{965.7}$, in which H=total heat in the steam and h=total heat in the feed water. It is used in shortening the process of finding the evaporation from and at 212°, and Table 26 gives the factor of evaporation for various pressures and temperatures.

Table 26

FACTORS OF EVAPORATION.

Feed Water Temperature.	Gauge Press. 50 lbs.	Gauge Press. 60 lbs.	Gauge Press. 70 lbs.	Gauge Press. 80 lbs.	Gauge Press. 90 lbs.	Gauge Press. 100 lbs.	Gauge Press. 110 lbs.	Gauge Press. 120 lbs.	Gauge Press. 140 lbs.
212°	1.027	1.030	1.032	1.035	1.037	1.039	1.041	1.043	1.047
200°	1.039	1.042	1.045	1.047	1.050	1.052	1.054	1.056	1.059
191°	1.049	1.052	1.054	1.057	1.059	1.061	1.063	1.065	1.069
182°	1.058	1.061	1.064	1.066	1.069	1.071	1.073	1.075	1.078
173°	1.067	1.070	1.073	1.076	1.078	1.080	1.082	1.084	1.087
164°	1.077	1.080	1.083	1.085	1.087	1.090	1.091	1.093	1.097
152°	1.089	1.092	1.095	1.098	1.100	1.102	1.104	1.106	1.109
143°	1.099	1.102	1.105	1.107	1.109	1.111	1.113	1.115	1.119
134°	1.108	1.111	1.114	1.116	1.119	1.121	1.123	1.125	1.128
125°	1.118	1.121	1.123	1.126	1.128	1.130	1.132	1.134	1.137
113°	1.130	1.133	1.136	1.138	1.140	1.143	1.145	1.146	1.150
104°	1.138	1.142	1.145	1.148	1.150	1.152	1.154	1.156	1.159
95°	1.149	1.152	1.154	1.157	1.159	1.161	1.163	1.165	1.169
86°	1.158	1.161	1.164	1.166	1.169	1.171	1.173	1.174	1.178
77°	1.167	1.170	1.173	1.176	1.178	1.180	1.182	1.184	1.187
65°	1.180	1.183	1.186	1.188	1.190	1.192	1.194	1.196	1.200
56°	1.189	1.192	1.195	1.197	1.200	1.202	1.204	1.206	1.209
47°	1.199	1.201	1.204	1.207	1.209	1.211	1.213	1.215	1.218
38°	1.208	1.211	1.214	1.216	1.218	1.220	1.222	1.224	1.228

Second, water evaporated per pound of coal actual conditions=water apparently evaporated divided by coal consumed=9.65 pounds. No accurate estimate regarding the quality of the coal or the efficiency of the boiler can be made from this figure (9.65 pounds). It can be used, however, in estimating the cost of fuel for generating the steam; as, for instance, if the boiler is supplying steam to an engine that uses 30 pounds of steam per house-power per hour, it will require 30÷9.65=3.1 pounds of coal per horse-power per hour; the "actual conditions" under which the boiler is being operated being the pressure of steam required by the engine and the temperature of the feed water.

Third, water evaporated per pound of coal from and at 212°=water evaporated into dry steam from and at 212° ÷coal consumed=10.61 pounds. This figure is the proper one to use in comparing the relative economic values of different varieties of coal tested with the same boiler or boilers.

Fourth, water evaporated per pound of combustible from and at 212°=water evaporated into dry steam from and at 212°÷weight of combustible=11.81 pounds. This result is the one to be used for ascertaining the efficiency of the boiler, and the percentage of efficiency is found by dividing the heat absorbed by the boiler per pound of combustible by the heat value of one pound of combustible. The average heat value of bituminous and semi-bituminous coals is not far from 15,000 heat units per pound of combustible. In the evaporation of 11.81 pounds of water from and at 212° the heat absorbed was 11.81×965.7= 11,404.9 heat units. The efficiency of the boiler therefore was

$$\frac{11{,}404.9 \times 100}{15{,}000} = 76 \text{ per cent.}$$

In like manner to ascertain the efficiency of the boiler and furnace as a whole, the water evaporated from and at 212° per pound of coal is taken. Thus 10.61×965.7

=10,246 heat units absorbed from each pound of coal. Now assuming that there were 13,500 heat units in each pound of the coal used in the test, the per cent of efficiency of boiler and furnace was

$$\frac{10{,}246 \times 100}{13{,}500} = 75.9.$$

Fifth, water evaporated per pound of dry coal from and at 212°=water evaporated into dry steam from and at 212° divided by coal corrected for moisture. Thus, 117,788÷10.878=10.82 pounds. This result is useful for calculating the results of tests of the same grade of coal, but differing in the degree of moisture in each.

Sixth. Boiler horse-power. The latest decision of the American Society of Mechanical Engineers (than whom there is no better authority) regarding the horse-power of a boiler is as follows: "The unit of commercial horse-power developed by a boiler shall be taken as 34½ units of evaporation per hour. That is, 34½ pounds of water evaporated per hour from a feed temperature of 212° into steam of the same temperature. This standard is equivalent to 33,317 B.T.U. per hour. It is also practically equivalent to an evaporation of 30 pounds of water from a feed water temperature of 100° F. into steam of 70 pounds gauge pressure."

According to this rule the horse-power developed by the boiler during the test under consideration=water evaporated into dry steam from and at 212°, 117,788 pounds ÷12 hours÷34.5=284.5 horse-power.

QUESTIONS AND ANSWERS.

267. What is the primary object of an evaporation test?

Ans. To ascertain how many pounds of water the boilers are evaporating per pound of coal burned.

268. What other important points relative to boiler operation may be determined by these tests?

Ans. There are four. First—To determine the efficiency of the plant as an apparatus for the consumption of fuel, and the evaporation of water. Second—To determine the relative economy of different varieties of coal, and other fuels. Third—To determine whether or not the boilers are being operated as economically as they might be. Fourth—To determine whether the boilers are being over worked.

269. In what condition should the testing apparatus be maintained?

Ans. In first-class condition, ready to be used at any time for making a test.

270. What should be done with the boiler, and all of its appurtenances preparatory to making a test?

Ans. They should be put in good condition, by cleaning, etc.

271. How should the boiler under test be operated during the test?

Ans. At its full capacity.

272. Where should the water level be at the beginning and close of the test?

Ans. At the height ordinarily carried, and its position should be marked by tying a cord around one of the guard rods of the gauge glass.

273. How long should the test last?

Ans. About 10 hours.

274. How is the percentage of moisture in the steam determined?

Ans. By means of the calorimeter.

275. How many, and what kind of calorimeters are used for this purpose?

Ans. Two. The throttling calorimeter, and separating calorimeter.

276. Upon what principle does the throttling calorimeter act?

Ans. Upon the principle of temperatures.

277. How does the separating calorimeter act?

Ans. It mechanically separates the water from a known volume of steam passing through it.

278. In what other manner may the condition of steam regarding its dryness be approximated?

Ans. By observing its appearance as it issues from a pet cock, or other small opening.

279. How will steam containing 1 or 2 per cent of moisture appear under such conditions?

Ans. It will be transparent close to the orifice from which it issues.

280. How is the chimney draft measured?

Ans. By means of a draft gauge.

281. What is the usual form of draft gauge?

Ans. A glass tube bent in the shape of the letter U.

282. Describe the action of a draft gauge.

Ans. One leg of the U tube is connected to the chimney by a small rubber hose. The other leg is open to the atmosphere. The tube is partly filled with water, which when there is no draft will stand at the same height in both legs.

283. When there is a draft and the rubber hose is connected to the chimney how is the water in the U tube affected?

Ans. The draft suction causes the water in the leg to which the hose is connected, to rise while the level of the water in the other leg will be equally depressed.

284. How is the intensity of the draft thus estimated?

Ans. In fractions of an inch, .5, .7 or .75 inches.

285. What is the object of flue gas analysis?

Ans. There are three. First—To determine the amount of excess air admitted to the furnace. Second—To determine the character of the combustion. Third—To ascertain the heat losses.

286. What weight of oxygen is required for the complete combustion of one pound of carbon?

Ans. 2.67 pounds. By volume, 32 cubic feet.

287. What gaseous combination is produced by complete combustion?

Ans. Carbon dioxide (CO_2).

288. What is the result of imperfect combustion?

Ans. Carbon monoxide (CO).

289. How is the efficiency of the boiler and furnace ascertained through an evaporation test?

Ans. By weighing the coal consumed and the water evaporated during a certain number of hours and dividing the number of pounds of water evaporated by the number of pounds of coal consumed. This will give number of pounds water evaporated per pound of coal.

290. What is meant by the term "equivalent evaporation?"

Ans. It assumes that the feed water enters the boiler at a temperature of 212°, and is evaporated into steam at 212° and at atmospheric pressure.

291. Why is this standard necessary in evaporation tests?

Ans. Because of the variations in the temperature of the feed water used in different tests.

292. What is meant by boiler horse-power?

Ans. The evaporation of 34½ pounds water from a feed temperature of 212° into steam of the same temperature; or the evaporation of 30 pounds water from a feed temperature of 100° into steam at 70 pounds gauge pressure.

293. What is meant by the expression "total heat of evaporation?"

Ans. The sum of the sensible heat plus the latent heat, at boiling point.

294. What is steam in its relation to the engine?

Ans. It is merely a vehicle for transferring the heat energy from the boiler to the engine shaft.

Steam Engines

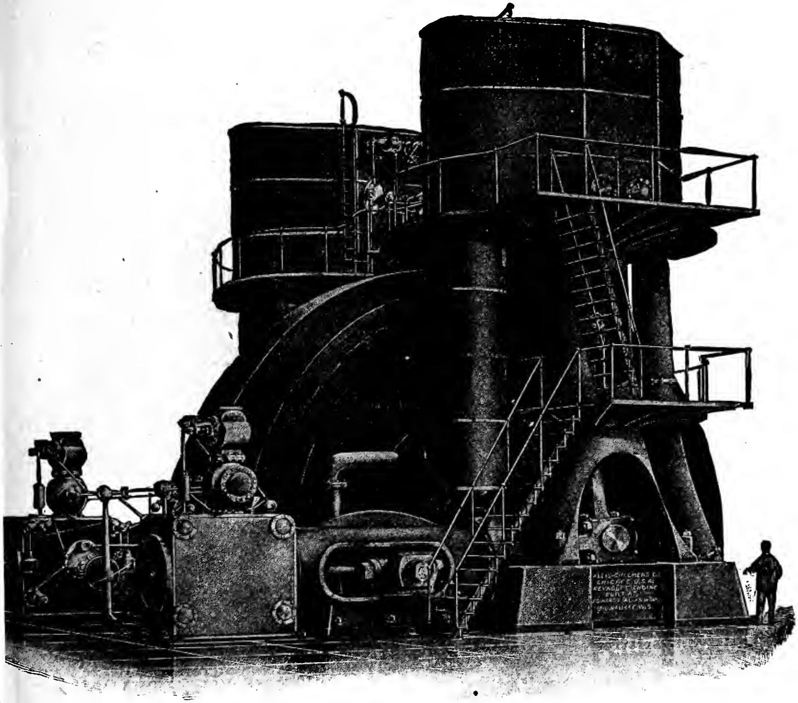


Fig. 110

REYNOLDS COMBINED VERTICAL AND HORIZONTAL ENGINE 12,000 HORSE-POWER CYLINDERS, 44x88x60.

Built by Allis-Chalmers Company

Steam engines may be divided into two general classes, viz., simple and compound.

A *simple* engine may be either condensing or non-condensing, but its leading characteristic is, that the steam is used in but one cylinder, and from thence it is exhausted either into the atmosphere or into a condenser.

A *compound* engine is one in which the steam is made to do work in two or more cylinders before it is allowed to exhaust, and this class of engine may be either condensing or non-condensing.

In a non-condensing engine the pressure of the atmosphere, amounting to 14.7 pounds per square inch at sea level, is constantly in resistance to the motion of the piston. Therefore the exhaust pressure cannot fall below the atmospheric pressure, and is generally from two to five pounds above it, caused by the resistance of bends and turns in the exhaust pipe, or other causes which tend to retard the free passage of the steam.

The advantage, from an economical point of view, of exhausting the steam into a condenser in which a vacuum is maintained, will be fully set forth in the section on Indicator Work.

CONDENSERS.

Condensers are of two classes, viz., jet condensers and surface condensers.

In a jet condenser the steam is exhausted into an air-tight iron vessel of any convenient shape, generally cylindrical and of suitable size, and is there condensed by coming in contact with a jet of cold water, admitted in the form of a spray. The air pump, which also maintains a vacuum in the condenser, draws this water, together with the condensed steam, away from the condenser.

The surface condenser, like the jet condenser, consists of an air-tight iron vessel, either cylindrical or rectangular in shape, but unlike the jet condenser, it is fitted with a large number of brass or copper tubes of small diameter, through which cold water is forced by a pump, called a circulating pump. A vacuum is also maintained in the body of the condenser by the air pump, and the steam exhausting into this is condensed by coming in contact with the cool surface of the tubes. Or, as is often the case, the exhaust steam passes through the tubes in place of around them, and the condensing water is forced into and through the body of the condenser, the vacuum in this case being maintained in the tubes. Owing to the fact that in a surface condenser the steam does not mix with the water, a larger quantity of condensing water is required than in a jet condenser, but on the other hand, an advantage is gained by having the pure water of condensation; in other words, the condensed steam, which may be returned to the boilers along with the regular feed water supply, and will greatly aid in preventing the formation of scale, while the water of condensation as it comes from a jet condenser,

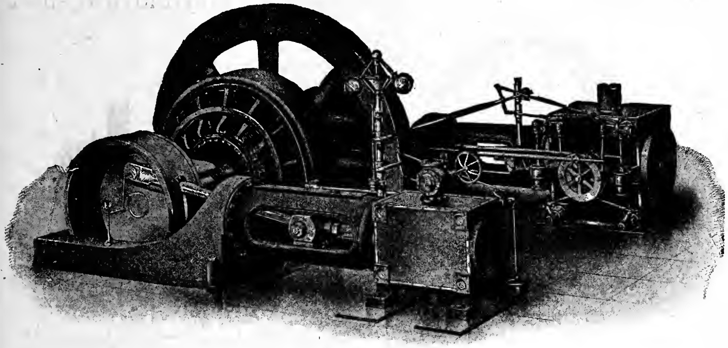


FIG. 111

CROSS COMPOUND DIRECT CONNECTED CORLISS ENGINE, ALLIS-CHALMERS COMPANY being mixed with oil and other impurities, is not, as a rule, suitable to be fed to boilers.

There are many different types of jet condensing apparatus, in some of which no air pump is used; their action being based somewhat upon the principle of the injector used for feeding boilers. In this type of jet condenser the supply of condensing water is drawn from outside pressure, either from an overhead tank or other source, and passing into an annular enlargement of the exhaust pipe, is discharged downwards in the form of a cylindrical sheet of water into a nozzle which gradually contracts. The exhaust steam, entering at the same time, is condensed, and the contracting neck of the cone shaped nozzle gradually brings the water to a solid jet, and it rushes through the nozzle with a velocity sufficient to create a vacuum. This type of condenser can only be used where the discharge pipe has a free outlet.

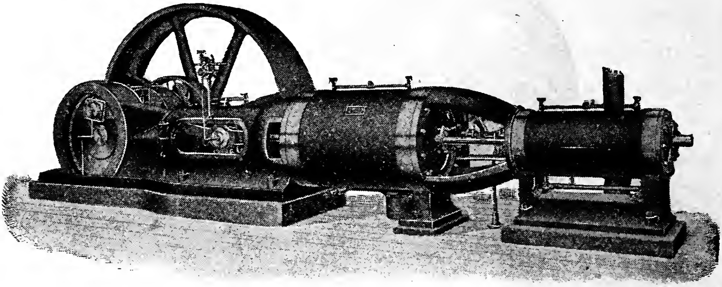


Fig. 112

TANDEM COMPOUND ENGINE, BUCKEYE ENGINE COMPANY

The jet condenser with air pump attached is the most reliable as well as economical for general purposes, for the reason that with this type the supply of condensing water may be drawn from a well or other source lower than the level of the condenser. These condensers are also generally fitted with a "force injection," as it is called, which is simply a connection between the condenser and water main

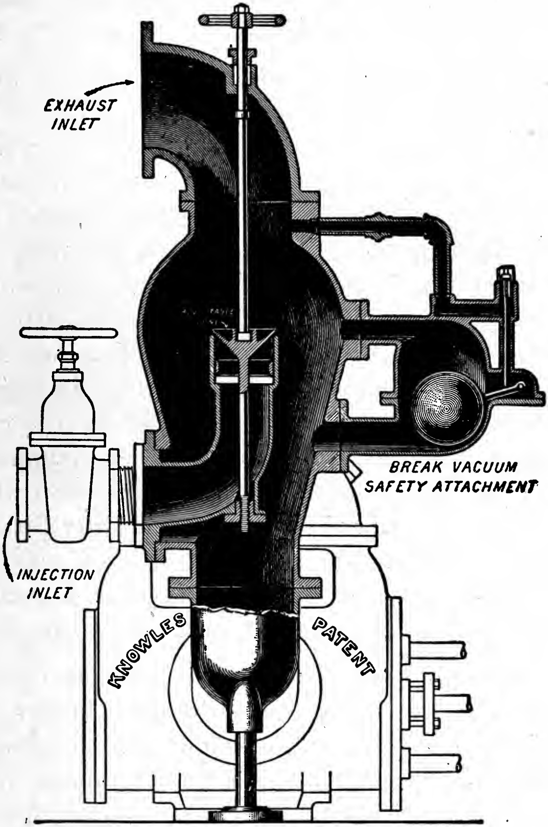


FIG. 113
KNOWLES JET CONDENSER

or tank, for the purpose of letting cold water into the condenser to condense the exhaust steam when starting the engine, and thus aid in forming a vacuum. When a good vacuum has been established and the engine is running up to speed, the force injection may be shut off, and the water will flow into the condenser from the well by suction. The above refers to engines in which the air pump receives its motion directly from the engine.

Another type of jet condensing apparatus is the independent air pump and condenser, which is still better, for the reason that the air pump, which is simply an ordinary double acting steam pump, may be started independently of the engine, and, in fact, before the engine is started, thus creating a vacuum in the condenser, and greatly facilitating the starting of the engine. Another great advantage in the independent condensing apparatus is, that there is not so much danger of the water backing up into the cylinder in case of a sudden shut down of the engine, because the air pump may be kept in operation, thus relieving the condenser of water; whereas, if the air pump gets its motion from the engine, it will of course stop when the engine stops, and unless the injection water is shut off immediately after closing the throttle there is great danger of the cylinder becoming flooded with water, resulting very often in a broken cylinder head, or a bent piston rod.

The quantity of water required to condense the exhaust steam of an engine is determined by three factors: First, the density, temperature and volume of the steam to be condensed in a given time; second, the temperature of the overflow or discharge, and third, the temperature of the injection water. For instance, the temperature of the injection water may be 35° in the winter and 70° in the summer. Or it may be desired to keep the overflow at as high a temperature as possible for the purpose of feeding the boilers. Again, the pressure, and consequently the temperature of the exhaust steam as it enters the condenser, varies with different engines, and often with the same engine, according as the load is light or heavy. Therefore the only accurate method of estimating the amount of condensing water required per minute or per hour, under any and all conditions, is to first ascertain the weight of water required to condense one pound weight of steam at the temperature and pressure at which the steam is being exhausted. In these calculations the total heat in the steam must be considered. This means not only the sensible heat, but the latent heat also.

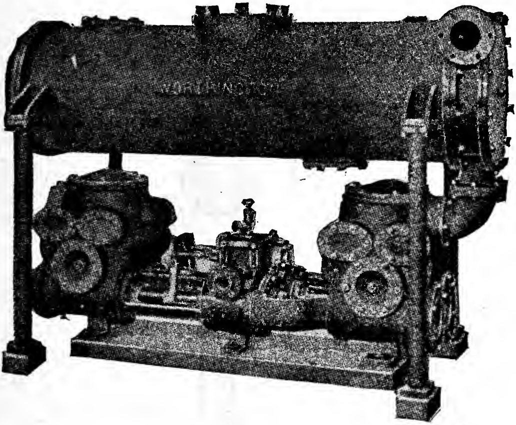


FIG. 114

WORTHINGTON SURFACE CONDENSER, WITH AIR AND CIRCULATING PUMP

The formula for solving the above problem may be expressed as follows: $\frac{H-T}{T-I}=W$, in which

H=total heat in the steam,
T=temperature of the overflow,

I=temperature of the injection water,

W=weight of water required to condense one pound weight of steam.

To illustrate, suppose the absolute pressure of the exhaust, as shown by the indicator diagram, is 7 pounds. Referring to Table 17, it will be seen that the total heat in steam at 7 pounds absolute is 1135.9 heat units. Assume the temperature of the overflow to be 110°, which is as high as is consistent with a good vacuum. Now the total heat to be absorbed from each pound weight of steam in this case would be 1135.9—110=1025.9 B. T. U.

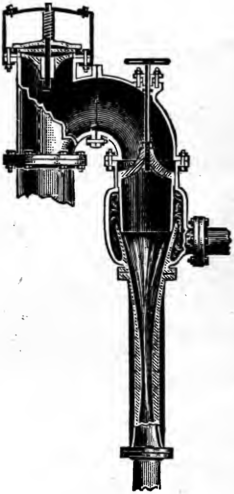


FIG. 115
SIPHON CONDENSER

Suppose the temperature of the condensing water to be 55° and the temperature of the overflow being 110°, there will be 110°—55°=55° of heat absorbed by each pound of water passing into, and through the condenser, and the number of pounds of water required to condense one pound weight of steam under the above conditions will equal the number of times 55 is contained in 1025.9. Expressed in plain figures the calculation is

$$\frac{1135.9-110}{110-55}=18.65 \text{ pounds.}$$

In order to ascertain the quantity of condensing water required per house-power per hour, it is only necessary to know the number of pounds weight of steam consumed by the engine per horse-power per hour, as shown by the indicator diagram, and multiply this by the weight of condensing water required per pound of steam, as found by the above solution.

Thus, suppose the steam consumption of the engine to be 17 pounds per I. H. P. per hour. Then $17\times18.65=317.05$ pounds per hour, which reduced to gallons=38.2 gallons.

Or, if the steam consumption is not known, and the weight only of condensing water required per hour is desired, regardless of the horse-power developed by the engine, it will be necessary, first, to estimate the total volume of steam exhausted per hour and calculate its weight from its known pressure.

Thus, assume the engine to be 24×48 inches, and the R. P. M. to be 80. Then the piston displacement will equal area of piston less one-half area of rod multiplied by length of stroke. Referring to Table 27, the area of a circle 24 inches in diameter=452.39 square inches. Suppose the piston rod to be 4.5 inches in diameter, its area, according to Table 27, is 15.904 square inches, one-half of which=7.952 square inches. The effective area of the piston now becomes $452.39-7.952=444.43$ square inches, and the piston displacement equals $444.43\times48=21332.64$ cubic inches.

Dividing this by 1728 (number of cubic inches in a cubic foot) gives 12.34 cubic feet of piston displacement. The total volume of steam exhausted per minute, therefore, will be 12.34×2×80=1974.4 cubic feet.

The absolute pressure of the exhaust may again be assumed to be 7 pounds per square inch. Referring to Table 17, the weight of one cubic foot of steam at 7 pounds absolute is .0189 pounds, and the total weight of steam exhausted per minute, therefore, would be 1974.4× .0189=37.3 pounds, and if 18.65 pounds water is required to condense one pound of steam, the quantity required per minute would be 37.3×18.65=695.8 pounds, or per hour, 41748 pounds, equal to 5029 gallons. This is at the rate of 8.7 pounds, or a little more than one gallon per revolution for a 24×48 inch, simple condensing engine. Table 28 gives the quantity of injection water required per revolution for different types of condensing engines.

TABLE 27

AREAS AND CIRCUMFERENCES OF CIRCLES.

Diam.	Area	Circum.	Diam.	Area	Circum.
.25	.049	.7854	19	283.529	59.690
.5	.1963	1.5708	19.25	291.039	60.475
1.0	.7854	3.1416	19.5	298.648	61.261
1.25	1.2271	3.9270	20	314.160	62.832
1.5	1.7671	4.7124	20.25	322.063	63.617
2	3.1416	6.2832	20.5	330.064	64.402
2.25	3.9760	7.0686	21	346.361	65.973
2.5	4.9087	7.8540	21.25	354.657	66.759
3	7.0686	9.4248	21.5	363.051	67.544
3.25	8.2957	10.210	22	380.133	69.115
3.5	9.6211	10.995	22.25	388.822	69.900
4	12.566	12.566	22.5	397.608	70.686
4.25	14.186	13.351	23	415.476	72.256
4.5	15.904	14.137	23.25	424.557	73.042
5	19.635	15.708	23.5	433.731	73.827
5.25	21.647	16.493	24	452.390	75.398
5.5	23.758	17.278	24.25	461.864	76.183
6	28.274	18.849	24.5	471.436	76.969
6.25	30.679	19.635	25	490.875	78.540
6.5	33.183	20.420	25.25	500.741	79.325
7	38.484	21.991	25.5	510.706	80.110
7.25	41.282	22.776	26	530.930	81.681
7.5	44.178	23.562	26.25	541.189	82.467
8	50.265	25.132	26.5	551.547	83.252
8.25	53.456	25.918	27	572.556	84.823
8.5	56.745	26.703	27.25	583.208	85.608
9	63.617	28.274	27.5	593.958	86.394
9.25	67.200	29.059	28	615.753	87.964
9.5	70.882	29.845	28.25	626.798	88.750
10	78.540	31.416	28.5	637.941	89.535
10.25	82.516	32.201	29	660.521	91.106
10.5	86.590	32.986	29.25	671.958	91.891
11	95.033	34.557	29.5	683.494	92.677
11.25	99.402	35.343	30	706.860	94.248
11.5	103.869	36.128	30.25	718.690	95.033
12	113.097	37.699	30.5	730.618	95.818
12.25	117.859	38.484	31	754.769	97.389
12.5	122.718	39.270	31.25	766.992	98.175
13	132.732	40.840	31.5	799.313	98.968
13.25	137.886	41.626	32	804.249	100.53
13.5	143.130	42.411	32.25	816.86	101.31
14	153.938	43.982	33	855.30	103.67
14.25	159.485	44.767	33.25	868.30	104.45
14.5	165.130	45.553	33.5	881.41	105.24
15	176.715	47.124	34	907.92	106.81
15.25	182.654	47.909	34.25	921.32	107.60
15.5	188.692	48.694	34.5	934.82	108.38
16	201.062	50.265	35	932.11	109.95
16.25	207.394	51.051	35.25	975.90	110.74
16.5	213.825	51.836	35.5	989.80	111.52
17	226.980	53.407	36	1017.8	113.09
17.25	233.705	54.192	36.25	1032.06	113.88
17.5	240.520	54.978	36.5	1046.35	114.66
18	254.469	56.548	37	1075.21	116.23
18.25	261.587	57.334	37.25	1089.79	117.01
18.5	268.803	58.119	37.5	1104.46	117.81

TABLE 27—CONTINUED

Diam.	Area	Circum.	Diam.	Area	Circum.
38	1134.11	119.38	57	2551.76	179.07
38.25	1149.08	120.16	57.25	2574.19	179.85
38.5	1164.15	120.95	57.5	2596.72	180.64
39	1194.59	122.52	58	2642.08	182.21
39.25	1209.95	123.30	58.25	2664.91	182.99
39.5	1225.42	124.09	58.5	2687.83	183.78
40	1256.64	125.66	59	2733.97	185.35
40.25	1272.39	126.44	59.25	2757.19	186.14
40.5	1288.25	127.23	59.5	2780.51	186.92
41	1320.25	128.80	60	2827.44	188.49
41.25	1336.40	129.59	60.25	2851.05	189.28
41.5	1352.65	130.37	60.5	2874.76	190.06
42	1385.44	131.94	61	2922.47	191.64
42.25	1401.98	132.73	61.25	2946.47	192.42
42.5	1418.62	133.51	61.5	2970.57	193.21
43	1452.20	135.08	62	3019.07	194.78
43.25	1469.13	135.87	62.25	3043.47	195.56
43.5	1486.17	136.65	62.5	3067.96	196.35
44	1520.53	138.23	63	3117.25	197.92
44.25	1537.86	139.01	63.25	3142.04	198.71
44.5	1555.28	139.80	63.5	3166.92	199.50
45	1590.43	141.37	64	3216.99	201.06
45.25	1608.15	142.15	64.25	3242.17	201.85
45.5	1625.97	142.94	64.5	3267.46	202.68
46	1661.90	144.51	65	3318.31	204.20
46.25	1680.01	145.29	65.25	3343.88	204.99
46.5	1698.23	146.08	65.5	3369.56	205.77
47	1734.94	147.65	66	3421.20	207.34
47.25	1753.45	148.44	66.25	3447.16	208.13
47.5	1772.05	149.22	66.5	3473.23	208.91
48	1809.56	150.79	67	3525.66	210.49
48.25	1828.46	151.58	67.25	3552.01	211.27
48.5	1847.45	152.36	67.5	3578.47	212.06
49	1885.74	153.93	68	3631.68	213.63
49.25	1905.03	154.72	68.25	3658.44	214.41
49.5	1924.42	155.50	68.5	3685.29	215.20
50	1963.50	157.08	69	3739.28	216.77
50.25	1983.18	157.86	69.25	3766.43	217.55
50.5	2002.96	158.65	69.5	3793.67	218.34
51	2042.82	160.22	70	3848.46	219.91
51.25	2062.90	161.00	70.25	3875.99	220.70
51.5	2083.07	161.79	70.5	3903.63	221.48
52	2123.72	163.36	71	3959.20	223.05
52.25	2144.19	164.14	71.25	3987.13	223.84
52.5	2164.75	164.19	71.5	4015.16	224.62
53	2206.18	166.50	72	4071.51	226.19
53.25	2227.05	167.29	72.25	4099.83	226.98
53.5	2248.01	168.07	72.5	4128.25	227.75
54	2290.22	169.64	73	4185.39	229.34
54.25	2311.48	170.43	73.25	4214.11	230.12
54.5	2332.83	171.21	73.5	4242.92	230.91
55	2375.83	172.78	74	4300.85	232.48
55.25	2397.48	173.57	74.25	4329.95	233.26
55.5	2419.22	174.35	74.5	4359.16	234.05
56	2463.01	175.92	75	4417.87	235.62
56.25	2485.05	176.71	75.25	4447.37	236.40
56.5	2507.19	177 5	75.5	4476.97	237.19

TABLE 27—CONTINUED

Diam.	Area	Circum.	Diam.	Area	Circum.
76	4536.37	238.76	87.5	6013.21	274.89
76.25	4566.36	239.55	88	6082.13	276.46
76.5	4596.35	240.33	88.5	6151.44	278.03
77	4656.63	241.90	89	6221.15	279.60
77.25	4686.92	242.69	89.5	6291.25	281.17
77.5	4717.30	243.47	90	6371.64	282.74
78	4778.37	245.04	90.5	6432.62	284.31
78.25	4809.05	245.83	91	6503.89	285.88
78.5	4839.83	246.61	91.5	6573.56	287.46
79	4901.68	248.19	92	6647.62	289.03
79.25	4932.75	248.97	92.5	6720.07	290.60
79.5	4963.92	249.76	93	6792.92	292.17
80	5026.56	251.33	93.5	6866.16	293.74
80.5	5089.58	252.90	94	6939.79	295.31
81	5153.00	254.47	94.5	7013.81	296.88
81.5	5216.82	256.04	95	7088.23	298.45
82	5281.02	257.61	95.5	7163.04	300.02
82.5	5345.62	259.18	96	7238.25	301.59
83	5410.62	260.75	96.5	7313.80	303.16
83.5	5476.00	262.32	97	7389.81	304.73
84	5541.78	263.89	97.5	7466.22	306.30
84.5	5607.95	265.46	98	7542.89	307.88
85	5674.51	267.04	98.5	7620.09	309.44
85.5	5741.47	268.60	99	7697.70	311.02
86	5808.81	270.17	99.5	7775.63	312.58
86.5	5876.55	271.75	100	7854.00	314.16
87	5944.66	273.32			

TABLE 28

QUANTITY OF INJECTION WATER FOR JET CONDENSERS.

Injection Temp. 50°. Overflow Temp. 110°.

Low Press. Cylinder.	WATER PER REV.					
	Single Exp. Engines.		Double Exp. Engines.		Triple Exp. Engines.	
	Lbs.	Galls.	Lbs.	Galls.	Lbs.	Galls.
20 in. x 36 in.	4.2	.5	3.9	.47	3.6	.43
22 “ x 36 “	5.1	.61	4.8	.57	4.4	.53
24 “ x 42 “	7.	.84	6.6	.79	6.	.72
26 “ x 42 “	8.3	1.	7.8	.93	7.2	.87
28 “ x 48 “	11.	1.45	10.4	1.24	9.5	1.14
30 “ x 48 “	12.6	1.52	11.7	1.41	10.8	1.3
32 “ x 54 “	16.2	1.95	15.	1.81	13.9	1.68
34 “ x 54 “	18.3	2.2	17.0	2.05	15.8	1.9
36 “ x 60 “	22.8	2.75	21.2	2.55	19.6	2.36
38 “ x 60 “	25.5	3.07	23.7	2.85	21.9	2.64
40 “ x 66 “	31.	3.73	28.8	3.45	26.7	3.2
44 “ x 66 “	37.5	4.51	34.8	4.2	32.2	3.8
48 “ x 72 “	48.5	5.84	45.	5.42	41.7	5.
52 “ x 72 “	57.	6.89	53.1	6.4	49.2	5.9
56 “ x 72 “	66.	7.9	61.5	7.41	57.	6.8
60 “ x 72 “	75.6	9.	70.5	8.5	65.3	7.8
64 “ x 72 “	85.	10.	80.	9.6	74.	8.9

TABLE 29

SIZE OF AIR-PUMPS—SINGLE ACTING.

One Stroke of Pump per Rev. of Engine.

Low-Press. Cylinder.	SIZE OF PUMP.		
	Single Exp. Engines.	Double Exp. Engines.	Triple Exp. Engines.
Dia. Stroke	Dia. Stroke	Dia. Stroke	Dia. Stroke
20 in. x 36 in.	15½ in. x 8 in.	15 in. x 8 in.	14½ in. x 8 in.
22 in. x 36 in.	15¼ in. x 10 in.	16½ in. x 8 in.	16¼ in. x 8 in.
24 in. x 42 in.	17¾ in. x 10 in.	17¼ in. x 10 in.	16½ in. x 10 in.
26 in. x 42 in.	19½ in. x 10 in.	18¾ in. x 10 in.	18 in. x 10 in.
28 in. x 48 in.	22½ in. x 10 in.	21½ in. x 10 in.	20¾ in. x 10 in.
30 in. x 48 in.	21¾ in. x 12 in.	22¾ in. x 10 in.	22 in. x 10 in.
32 in. x 54 in.	24¾ in. x 12 in.	24 in. x 12 in.	23 in. x 12 in.
34 in. x 54 in.	26¼ in. x 12 in.	25½ in. x 12 in.	24½ in. x 12 in.
36 in. x 60 in.	29¼ in. x 12 in.	28¼ in. x 12 in.	27¼ in. x 12 in.
38 in. x 60 in.	31 in. x 12 in.	30 in. x 12 in.	28¾ in. x 12 in.
40 in. x 66 in.	34¾ in. x 12 in.	33 in. x 12 in.	31¾ in. x 12 in.
44 in. x 66 in.	33½ in. x 15 in.	32½ in. x 15 in.	34¾ in. x 12 in.
48 in. x 72 in.	38 in. x 15 in.	37 in. x 15 in.	35½ in. x 15 in.
52 in. x 72 in.	41½ in. x 15 in.	40 in. x 15 in.	38½ in. x 15 in.
56 in. x 72 in.	44½ in. x 15 in.	43 in. x 15 in.	42 in. x 15 in.
60 in. x 72 in.	47¾ in. x 15 in.	46¼ in. x 15 in.	44½ in. x 15 in.
64 in. x 72 in.	51 in. x 15 in.	49½ in. x 15 in.	47 in. x 15 in.

Multiple Cylinder Engines. As has been already explained, a compound engine is one in which the steam is made to do work in two or more cylinders, and the secret of success in this type of engine is due to three factors, viz., (1) a high initial pressure, (2) the expansion of the steam to the greatest extent, and (3) reducing as much as possible the losses caused by cylinder condensation. Prof. Thurston has wisely said that "Maximum expansion, as nearly adiabatic as practicable, is the secret of maximum efficiency."

Horizontal—Vertical. Of the several types of multiple expansion engines, the two cylinder or double expansion engine appears to be best adapted to central power station service, owing to the excessive load variation. Figure 110 shows the horizontal vertical type. It has many advantages, especially in large units. First, the low pressure cylinder can be arranged vertically and thereby avoid the excessive friction due to the weight of so large a piston; second, the cylinders being arranged one vertical and the other horizontal and both acting upon the same crank pin, gives four impulses for each revolution of the crank. The cut represents a pair of such engines with two cranks, the cranks being keyed to one shaft and at right angles to each other make eight impulses for each revolution, a still greater improvement in turning effect. This type of engine is particularly valuable in electric service, with the armature between the engines, and makes a very compact and desirable arrangement.

Cross Compound. A cross compound engine consists of two cylinders, one high pressure, and the other low pressure. Each cylinder has its own connecting rod and crank, the cranks being set at opposite ends of the main engine shaft, and at an angle of 90° to each other. The two cylinders are connected by piping, and there is generally a receiver between them, into which the high pressure cylinder exhausts, and is held in reserve until the opening of the low pressure admission valve. Figure 111 shows a cross compound engine, the receiver being underneath the floor. The power unit shown in figure 110 may be considered as consisting of two cross compound engines.

Tandem Compound. In the tandem compound, the two cylinders are arranged tandem to each other, as shown in Figure 112. The advantage claimed for this type of compound engine is that it gives a much shorter and more direct route for the exhaust steam, in its passage from the high to the low pressure cylinders.

Two Low Pressure Cylinders. Where large units are required, it frequently happens that the low pressure cylinder figures beyond the capacity of the station for handling the work. To meet this limitation, two low pressure cylinders, each of one-half the total area, may be employed; both cylinders being connected with one receiver, three cranks are employed, one in the center and one on each end of same shaft and keyed at 120 degrees to each other.

TABLE 30

NUMBERS, THEIR SQUARE ROOTS AND CUBE ROOTS.

Square Root.	No.	Cube Root.	Square Root.	No.	Cube Root.	Square Root.	No.	Cube Root.	Square Root.	No.	Cube Root.
3.16	10.	2.15	4.24	18.	2.62	5.10	26.	2.96	5.83	34.	3.24
3.19	10.2	2.16	4.26	18.2	2.63	5.12	26.2	2.96	5.84	34.2	3.24
3.22	10.4	2.18	4.28	18.4	2.64	5.14	26.4	2.97	5.86	34.4	3.25
3.25	10.6	2.19	4.30	18.6	2.64	5.16	26.6	2.98	5.87	34.6	3.26
3.28	10.8	2.20	4.33	18.8	2.65	5.18	26.8	2.99	5.89	34.8	3.26
3.31	11.	2.22	4.35	19.	2.66	5.19	27.	3.00	5.91	35.	3.27
3.34	11.2	2.24	4.38	19.2	2.67	5.21	27.2	3.01	5.92	35.2	3.27
3.37	11.4	2.25	4.40	19.4	2.68	5.23	27.4	3.01	5.94	35.4	3.28
3.40	11.6	2.27	4.43	19.6	2.69	5.25	27.6	3.02	5.96	35.6	3.28
3.43	11.8	2.28	4.45	19.8	2.70	5.27	27.8	3.03	5.98	35.8	3.29
3.46	12.	2.29	4.47	20.	2.71	5.29	28.	3.03	6.00	36.	3.30
3.49	12.2	2.30	4.50	20.2	2.72	5.30	28.2	3.04	6.01	36.2	3.30
3.52	12.4	2.32	4.52	20.4	2.72	5.32	28.4	3.04	6.03	36.4	3.31
3.55	12.6	2.33	4.54	20.6	2.73	5.34	28.6	3.05	6.04	36.6	3.32
3.58	12.8	2.34	4.56	20.8	2.74	5.36	28.8	3.06	6.06	36.8	3.32
3.60	13.	2.35	4.58	21.	2.75	5.38	29.	3.07	6.08	37.	3.33
3.63	13.2	2.37	4.60	21.2	2.76	5.39	29.2	3.07	6.09	37.2	3.33
3.66	13.4	2.38	4.63	21.4	2.77	5.41	29.4	3.08	6.11	37.4	3.34
3.69	13.6	2.39	4.65	21.6	2.78	5.43	29.6	3.08	6.12	37.6	3.34
3.71	13.8	2.40	4.67	21.8	2.79	5.45	29.8	3.09	6.14	37.8	3.35
3.74	14.	2.41	4.69	22.	2.80	5.47	30.	3.10	6.16	38.	3.36
3.76	14.2	2.42	4.71	22.2	2.80	5.49	30.2	3.10	6.17	38.2	3.37
3.79	14.4	2.43	4.73	22.4	2.81	5.50	30.4	3.11	6.19	38.4	3.37
3.82	14.6	2.44	4.75	22.6	2.82	5.52	30.6	3.12	6.20	38.6	3.38
3.85	14.8	2.45	4.77	22.8	2.83	5.54	30.8	3.13	6.22	38.8	3.38
3.87	15.	2.46	4.79	23.	2.84	5.56	31.	3.14	6.24	39.	3.39
3.90	15.2	2.48	4.81	23.2	2.84	5.58	31.2	3.14	6.25	39.2	3.39
3.92	15.4	2.49	4.83	23.4	2.85	5.60	31.4	3.15	6.27	39.4	3.40
3.95	15.6	2.50	4.85	23.6	2.86	5.61	31.6	3.16	6.28	39.6	3.41
3.98	15.8	2.51	4.87	23.8	2.87	5.63	31.8	3.17	6.30	39.8	3.41
4.00	16.	2.52	4.89	24.	2.88	5.65	32.	3.17	6.32	40.	3.42
4.03	16.2	2.53	4.90	24.2	2.88	5.67	32.2	3.18	6.33	40.2	3.42
4.05	16.4	2.54	4.92	24.4	2.89	5.68	32.4	3.18	6.35	40.4	3.43
4.08	16.6	2.55	4.95	24.6	2.90	5.70	32.6	3.19	6.36	40.6	3.43
4.10	16.8	2.56	4.97	24.8	2.91	5.72	32.8	3.19	6.38	40.8	3.44
4.12	17.	2.57	5.00	25.	2.92	5.74	33.	3.20	6.40	41.	3.45
4.14	17.2	2.58	5.02	25.2	2.92	5.76	33.2	3.20	6.41	41.2	3.45
4.17	17.4	2.59	5.04	25.4	2.93	5.77	33.4	3.21	5.43	41.4	3.46
4.19	17.6	2.60	5.06	25.6	2.94	5.79	33.6	3.22	6.45	41.6	3.46
4.22	17.8	2.61	5.08	25.8	2.95	5.81	33.8	3.23	6.46	41.8	3.47

Triple Expansion Engine. In the triple expansion engine the steam is expanded successively in three cylinders, each larger in diameter than its predecessor. There is first the high pressure cylinder, second the intermediate cylinder, and third the low pressure cylinder, from which the steam exhausts into the condenser. Very high initial pressure (200 to 225 pounds per square inch) is necessary with this type of engine, as well as the quadruple expansion engine consisting of four cylinders, in order to get good efficiency. The two latter types of multiple expansion engines, viz., the triple and quadruple expansion are best adapted to pumping station work, rather than to the high speeds, and variable loads of the central power station. Owing to present day limitations on boiler pressure, the most desirable number of expansions in each cylinder of the different types of condensing engines should be about as given in Table 31.

Table 31

NUMBER OF EXPANSIONS.

TYPE	Initial Steam Pressure. Pounds Abso.	Total Expansions.	Expansions in Each Cylinder.			
			1st.	2nd.	3rd.	4th.
Single expansions	65	7	7.			
Double expansions	145	22	4.8	4.6		
Triple expansions	185	30	3.2	3.1	3.0	
Quadruple expansions	265	48	2.7	2.65	2.6	2.55

The Steam Jacket. Authorities differ as to the advantages derived from the steam jacket for the low pressure cylinder of a compound engine. There is no doubt that in the case of an engine furnishing power for shop purposes during working hours only, which implies that the service is not continuous, or rather that the engine is in service only ten or twelve hours out of twenty-four, the steam jacket is of great benefit in keeping the cylinder and valve chest warm, and thus preventing the severe strains which would result from the contraction and expansion of the metal. The weight of steam per indicated horse-power per hour that is condensed in the jacket varies from 1.7 pounds to 3.8 pounds, the average being about 2.3 pounds; while the economy of the thoroughly steam-jacketed cylinder over the jacketless one varies from 3 pounds to as high as 7.9 pounds of steam per I. H. P. per hour, or an average of about 4 pounds less steam consumed per H. P. H. by the use of the jacket, after deducting the weight of steam consumed in the jacket. Judging from all the authorities whom the writer has been able to consult, and also from his own practical experience along this line, it seems plain that an actual saving of from 5 to 15 per cent in the consumption of steam can be effected by the judicious use of the steam jacket. In other words, if an engine with unjacketed cylinders consumes steam at the rate of 20 pounds per H. P. H. the same engine with its cylinders jacketed would develop the same amount of power with a consumption of only 16 pounds or 17 pounds per H. P. H. besides the advantage of having the cylinders always warm and ready for operation.

QUESTIONS AND ANSWERS.

295. Into what two general classes are steam engines divided.

Ans. Simple and compound.

296. Describe a simple engine.

Ans. A simple engine may be either condensing or non-condensing, but its leading characteristic is, that the steam is used in but one cylinder.

297. What is a condensing engine?

Ans. One in which the exhaust steam is passed into an air-tight vessel in which a vacuum is maintained, the exhaust steam being there condensed by coming in contact with cold water, or a series of tubes through which cold water is being circulated.

298. Describe a compound engine?

Ans. A compound engine is one in which the steam is made to do work in two or more cylinders before it is allowed to exhaust.

299. How is this accomplished?

Ans. By causing the exhaust steam from the first, or high pressure cylinder, to pass into a second cylinder of larger diameter, and, if the engine be triple or quadruple expansion, from thence into a third or fourth cylinder, the diameters of which increase in regular ratio.

300. What is a non-condensing engine?

Ans. One from which the steam exhausts directly into the atmosphere, or is used for heating purposes before passing out into the open air.

301. What disadvantage does a non-condensing engine constantly labor under?

Ans. The pressure of the atmosphere amounting to 14.7 pounds per square inch is constantly in resistance to the motion of the piston.

302. Mention several other causes that tend to increase the back pressure upon the piston of a non-condensing engine.

Ans. The resistance of bends and turns in the exhaust pipe, also causing the exhaust to pass through feed water heaters or heating coils.

304. What is back pressure?

Ans. Pressure that tends to retard the forward stroke of the piston.

305. What advantage has a condensing engine over a non-condensing engine?

Ans. The atmospheric pressure is removed from in front of the piston to a degree corresponding to the height of the vacuum that is maintained in the condenser.

306. How many classes of condensers are there in general use?

Ans. Two; jet condensers and surface condensers.

307. Describe a jet condenser.

Ans. One in which the steam is exhausted into an air-tight vessel, and is there condensed by coming in contact with a jet or spray of cold water.

308. How is this water removed?

Ans. By means of the air pump, which also maintains a vacuum in the condenser.

309. Describe a surface condenser.

Ans. It is an air-tight vessel, either cylindrical or rectangular in shape, fitted with a large number of brass or copper tubes, of small diameter, through which the cold water is forced by the circulating pump. A vacuum is maintained in the body of the condenser by the air pump, and the steam exhausted into this is condensed by coming in contact with the cool surface of the tubes. In some cases the steam passes through the tubes in place of around them, the condensing water being forced into and through the body of the condenser, and the vacuum being maintained in the tubes.

310. Describe an injector condenser.

Ans. A condenser in which the cold water is forced through an annular enlargement of the exhaust pipe, and passing down into a nozzle which gradually contracts. The exhaust steam entering at the same time is condensed, the water rushing through the nozzle with a velocity sufficient to create a vacuum.

311. About what quantity of water is required per horse-power per hour to condense the exhaust steam from an engine?

Ans. About 38 to 40 gallons, depending upon the temperature of the condensing water.

312. What three factors are necessary to insure good economy with multiple cylinder engines?

Ans. First—A high initial pressure. Second—Expansion of the steam to greatest extent possible. Third—Protecting the surfaces of the cylinders from cooling influences.

313. Describe a cross compound engine.

Ans. An engine consisting of two cylinders, each having its own connecting rod and crank, the cranks being set at opopsite ends of the engine shaft, and at an angle of 90° to each other. The high pressure cylinder exhausts into the low pressure cylinder, usually through a receiver.

314. Describe a tandem compound engine.

Ans. An engine having the two cylinders arranged tandem to each other, with a common piston rod, and connecting rod.

315. What advantage is gained by this design?

Ans. A much shorter and more direct route for the exhaust steam in its passage from the high to the low pressure cylinder.

Valves and Valve Setting

It goes without saying that every man who aspires to be an engineer should endeavor to thoroughly acquaint himself with the principles governing the action of valves, as well as the details of valve adjustment. But it must be remembered that this knowledge cannot be acquired in a day or a week, or even months. True, a man may be able to learn some of the alphabet of valve lore in a comparatively short time, but the more practical experience he has in the work, the more will he realize the supreme need of mastering all the details of the process.

The common D slide valve, simple as it appears, is capable of furnishing problems over which savants have puzzled themselves.

The development of the full amount of power of which the engine is capable, its efficiency and economical use of steam, and its regular and quiet action are, in the largest degree, dependent upon the correct adjustment of its valve, or valves.

There are many different types of valves for controlling the admission and release of steam to and from the cylinders of engines, but the basic principles governing the adjustment of all, whether slide, poppet, rotative, piston, etc., are exemplified in the action of the common D slide valve, viz., the admission of the steam to the cylinder, its cut off and release, and the closure of the exhaust, each and all of which events are to take place at the proper moment during one stroke of the piston.

In order to properly perform these important functions the valve must have lead and lap. The various terms relating to valve action are plainly defined in the section on "Definitions," and it is unnecessary to repeat them here. If the outside lap is increased admission will be later and cut off earlier, and if it be desired to keep the lead the same it will be necessary to move the eccentric forward, which will make the other events, cut off, release and compression, earlier also. If the inside lap is increased the result will be an earlier closing of the exhaust and increased compression.

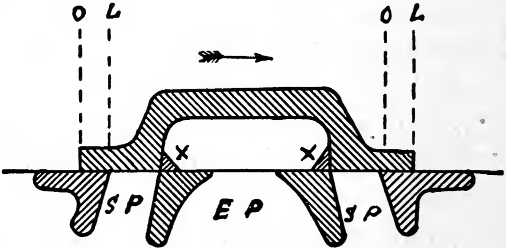


FIG. 116

These propositions refer mainly to engines of the single valve variety in which one valve controls the admission and distribution of the steam for both ends of the cylinder. In engines of the four-valve type, having a separate steam and exhaust valve for each end of the cylinder, each individual valve may be adjusted independently of the others, as will be explained later on, and in the case of engines having separate eccentrics, one for the steam, and one for the exhaust valves, the adjustment becomes still more perfect.

We will first study the action of the D slide valve by referring to Fig. 116, which is a sectional view of a valve, valve seat and ports. The valve is represented at mid travel or in its central position. S. P, S P are the steam ports, and E P is the exhaust port. The projections marked X at each foot of the arch inside the valve represent inside lap, and may be added to or taken from the inside edges of the valve, according as more or less compression is desired. The dotted lines, O L, O L represent outside lap.

Motion is imparted to the valve through the medium of the eccentric. If the valve had neither lap nor lead the position of the eccentric on the crank shaft would be just 90°, or one-quarter of a circle, ahead of the crank, but as more or less lap as well as lead is required, it becomes necessary to move the eccentric still farther ahead of the crank, and this farther advance is termed angular advance, lap angle for lap, and lead angle for lead.

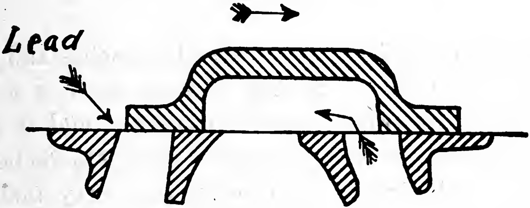


Fig. 117

Assuming the piston to be at the end of the stroke towards the crank, in other words, the engine to be on the dead center, the first function of the valve is lead or admission, illustrated by Fig. 117. Owing to the valve having both lap and lead, the position of the highest point of the eccentric will be assumed in this case to be 120° ahead of the crank, the position of the latter being at 0°.

Exhaust opening has also occurred at the opposite end of the cylinder. The second function is full port opening, Fig. 118, the crank having moved through 60° and the eccentric is now at 180°, the farthest point of its throw in that direction, the valve being at the end of its travel. At this point it might be well to note a matter about which some persons are liable to become confused, simple as it is, viz., that the travel of a slide valve equals twice the port opening plus twice the outside lap. For instance, suppose the width of each steam port to be 1¼ inches and the outside lap to be 1 inch. In Fig. 118 the valve is at the extreme end of its travel towards the right and is about to return. It first covers port number one=1¼ inches. Next it moves to mid travel lap number one=2¼ inches. Its next move is lap number two=3¼ inches, and lastly it uncovers port number two=4½ inches, which is its travel.

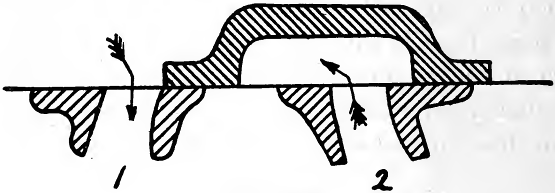


FIG. 118

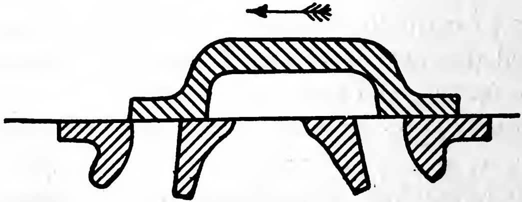


FIG. 119

To return to the third function of the valve or cut off, Fig. 119. The crank has now traversed 120°, and the highest point of the eccentric is at 60° on the return circle, a point equivalent to 240° of the circle described by the crank.

The fourth function is when compression begins at the head end of the cylinder, Fig. 120. The crank is now at 150°, the piston being near the end of the stroke and the eccentric has reached 90° of the return circle, or three-quarters of the crank circle, while the crank has still to travel 30° in order to complete the first one-half of its circle. At this point we can study the effect of inside lap, because if the valve has no inside lap, release on the crank end will begin almost at the same moment that compression takes place at the head end, but by adding inside lap, compression can be caused to take place earlier and release later.

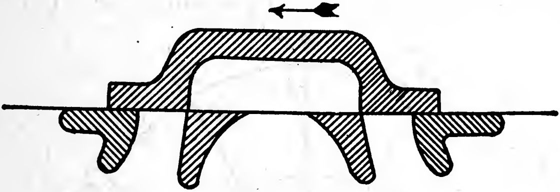


FIG. 120

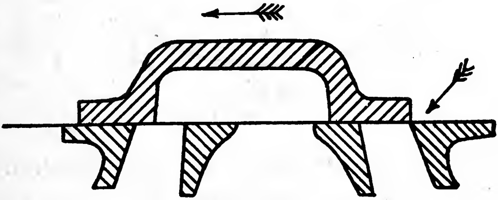


FIG. 121

The next event is admission at the head end of the cylinder, Fig. 121. The crank has now arrived at 180°, having completed one-half of a revolution; the piston is at the end of the stroke, and the eccentric is at 120° on the return path. Fig. 122 serves to better illustrate the relative positions of the crank pin and eccentric during the stroke. The inner circle represents the path described by the high point of the eccentric, and the large circle that of the crank pin. The radius C 2 of the small circle represents the throw of the eccentric, and the distance C L is the lap of the valve plus the lead. The point of intersection of the vertical line, L 1, with the eccentric circle locates the position of the highest point of the eccentric, and the line CB, drawn from the center of the crank shaft through this point, indicates the angular advance which in this case is 30°, represented by the angle A B C. The figures 1, 2, 3, 4, 5 indicate the position of the high point of the eccentric at the moment of each function of the valve. The action of the valve can be more graphically illustrated by means of valve diagrams, of which there are several different kinds, notably the Bilgram and Zeuner. The Zeuner diagram will be made use of in this instance.

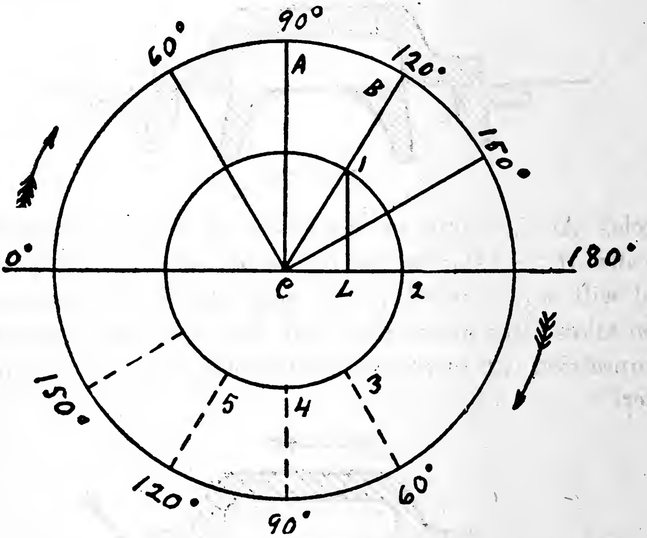


FIG. 122

Figure 123 shows the total movement of the valve, regardless of lap and lead. First draw line C 1 to represent the center line of the engine. Next draw line C 4 perpendicular to the line of centers, with C as the center of the crank shaft. The radius of the semi-circle D, 1, 2, 3, 4, 5,

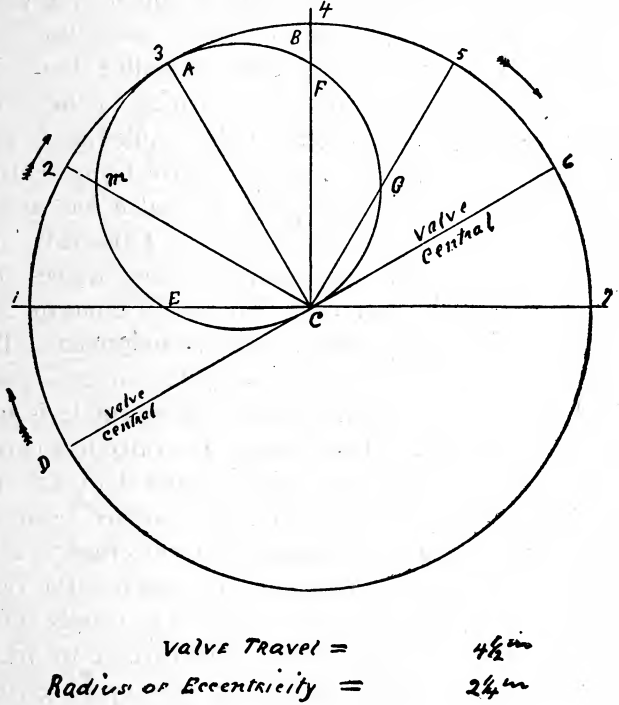


FIG. 123

6 equals the radius of eccentricity. Line C D represents the position of the crank when the valve is at mid travel or in its central position, D being the location of the crank pin. Referring back to Fig. 116, the valve is there shown in its central position, and supposed to be moving in the direction of the arrow in order to admit steam to the crank

end of the cylinder. Again referring to Fig. 123, draw line C A in such a position that the angle A B C will equal the angular advance of the eccentric, which we will assume in this case to be 30°.

This will bring the high point of the eccentric at B while the crank, as before stated, is at D. Next using line C A as the diameter, draw a circle about it called the valve circle. Now suppose the crank to be turning in the direction of the arrows. At position D the crank line is just about to cut into the valve circle, the valve being central. When the crank gets to position 1 the valve has moved the distance C E. When the crank is at 2 the valve has moved the distance C M, and when the crank arrives at 3 the valve has moved to the limit of its travel from its central position, and it now begins the return movement. The motion of the valve is comparatively slow at this point for the reason that the high point of the eccentric is now passing the center at 7. The distance the valve has moved backward while the crank has moved from 3 to 4 is the distance B F, while F C represents its distance from the central position, and G C the same when the crank is at 5. When the crank arrives at 6 and its line has left the valve circle, the valve is again central. Figure 123 merely shows the movement of the valve through one-half of its travel without giving any details regarding port openings, cut off, etc.

In Fig. 124 the influence of outside lap is delineated. According to the dimensions of the valve under consideration the outside lap is one inch. The diagram is drawn precisely as in Fig. 123, and in addition strike an arc representing the outside lap, using C as the center with a radius equal to the outside lap. As before, the crank is at

D and the valve central. When the crank has moved to E and its line cuts the intersection of the outside lap and valve circles, the valve has moved the distance C H, just equal to the outside lap, and the port begins to uncover at this point. Then by the time the crank gets to the center,

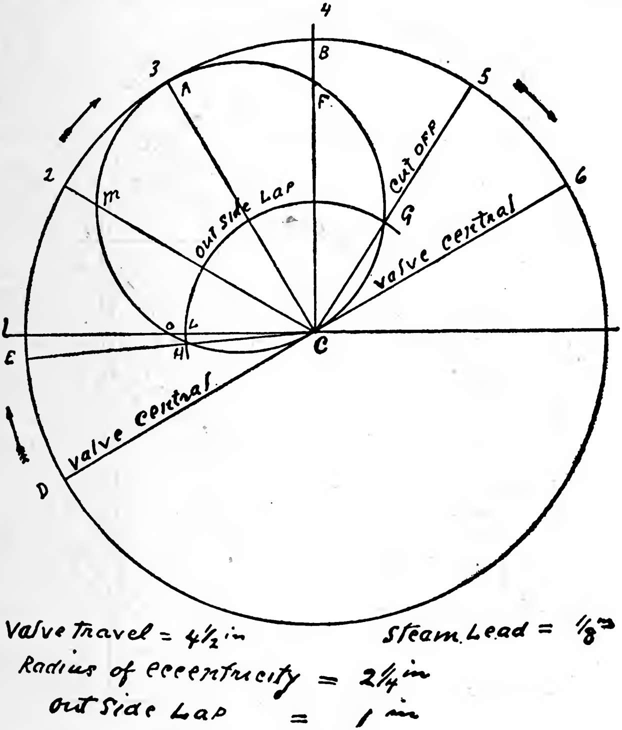


Fig. 124

1, the port is open the distance L O, which is the lead, in this case ⅛-inch. This position of the valve is shown in Fig. 117.

The position of the crank when cut off takes place is ascertained by drawing a line, C G 5, through the intersection of the outside lap and valve circles, where the valve is on its return movement (see Fig. 119). Thus far no account has been taken of release and compression, and in order to determine the position of the crank when these events occur it will be necessary to draw the valve circle

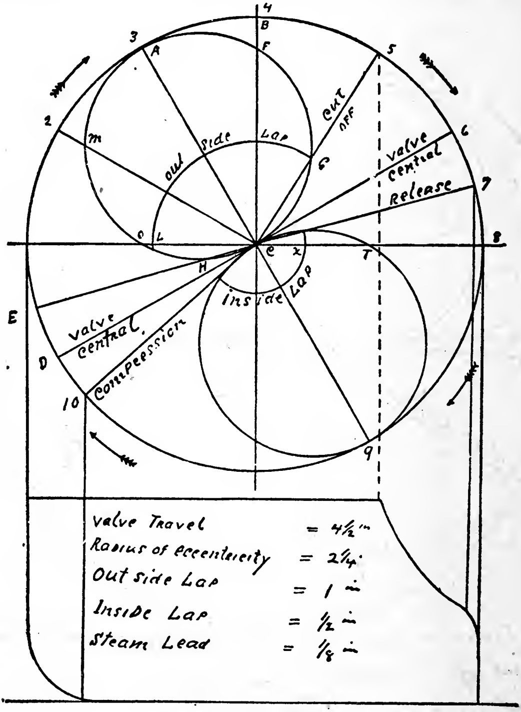


Fig. 125

for the opposite movement of the valve, for be it remembered that the movement of the valve so far considered has been only one-half of its travel; that is, it has moved from its central position towards the head end of the cylinder, and back again. We have seen how it has thus performed the functions of admission, full port opening and cut off for the crank end of the cylinder, and now by referring to Fig. 125 it will be seen at what point of the stroke the remaining events, viz., release and compression, occur.

Draw a second valve circle, Fig. 125, diametrically opposite the first. Also draw an arc with a radius equal to the inside lap, which in this case is assumed to be one-half inch. When the crank gets to the position 7 its center line cuts the intersection of the inside lap and valve circles, and release begins. When the crank arrives on the center 8, the valve has moved the distance C T from central position; but C X of this distance has been occupied by the inside

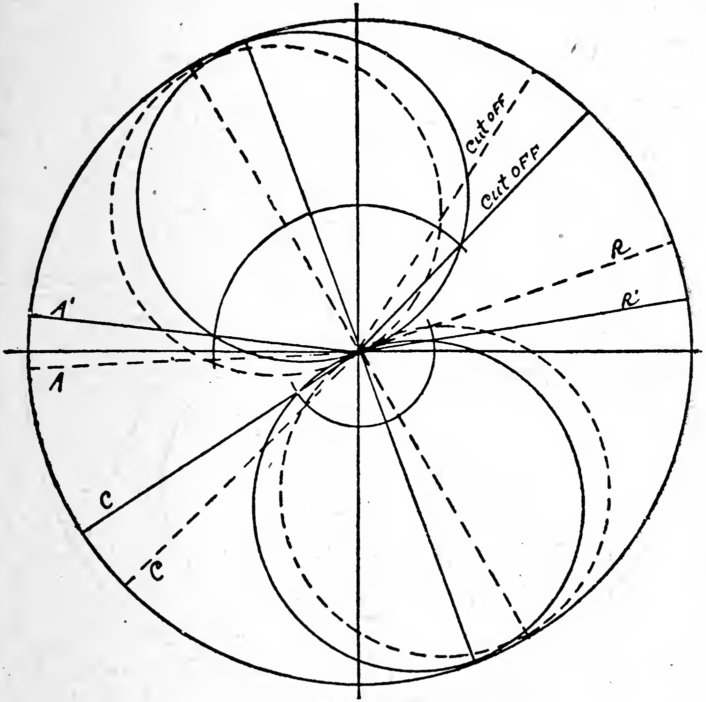


FIG. 126

lap, therefore the lead on the exhaust is represented by the distance X T. When the crank on its return stroke arrives at the position marked 10, its line again cuts the intersection of the inside lap and valve circles and compression takes place, as in Fig. 120. By dropping perpendiculars from the positions of the crank at 1, 5, 7 and 10 an indicator diagram may be drawn showing the performance of an engine with this style of valve.

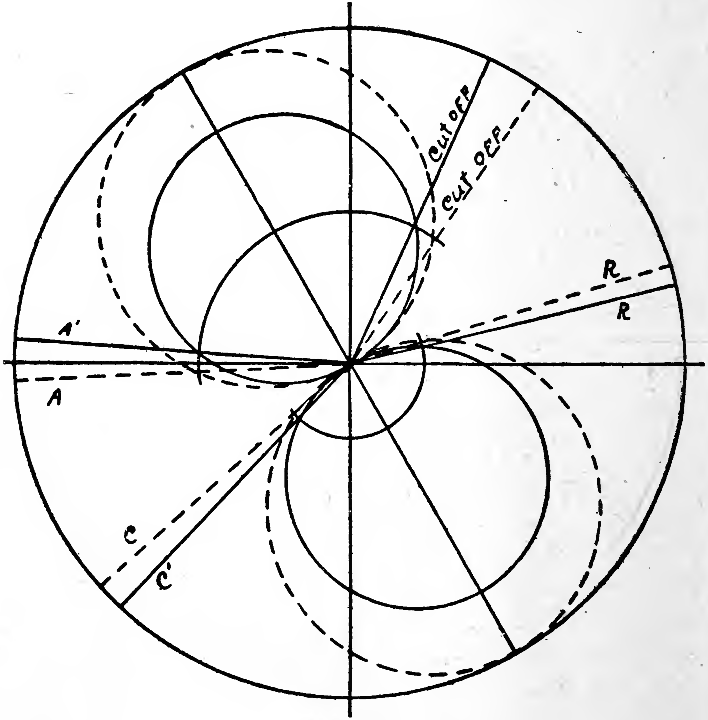


Fig. 127

Figure 126 shows the effect of decreasing the angular advance, that is, setting the eccentric back towards the crank. In this instance the eccentric is set back 10°, thus making the angle of abvance 20° instead of 30°, as before. The full lines represent the new angle, while the dotted circles and lines indicate the valve and its movements as drawn at first. A shows the original point of admission and A′ the position of the crank when admission takes place with the lesser angle of advance. Similarly, R and R′ show the old and new points of release, and C and C′ the compression. The two different points of cut off are also indicated. It will be observed that all of these events occur later and the lead also is diminished.

In locomotives, and also in some types of adjustable cut off engines, the travel of the valve may be varied at will, and the effect of decreasing the valve's travel is illustrated by Fig. 127, the full lines showing the decreased travel and its influence, and the dotted lines showing the original. Admission and release occur later, while cut off and compression take place earlier, and the lead is less. The travel of the valve as indicated in Fig. 127 has been decreased one inch, making it 3½ inches in place of 4½ inches as before.

Figure 128 shows the result of increasing the outside lap. The lap has been increased in this case from 1 inch, as originally drawn, to 1¼ inches, as indicated by the full lines, while the dotted lines show the lap as it was before being changed. The effect of this change is to cause less lead, a later admission and an earlier cut off, but compression and release are not affected for the reason that these latter events are controlled by the inside lap, which has not been changed.

In Fig. 125 the valve is shown as cutting off the steam when the crank has completed 120°, or two-thirds of the half revolution, but the point of cut off on the indicator diagram shows that the piston has traveled 7/9 of the stroke. This discrepancy is due to the obliquity of the connecting rod, as it will be seen by looking at the valve diagram, Fig. 125, that the crank must travel farther to complete the stroke from this point than the piston does. In order to cause the valve to cut off earlier, say at one-half stroke, it will be necessary to do one of two things, either to increase the outside lap, which would have a tendency to cause admission to occur too late, or the angle of advance may be increased sufficient to cause cut off to

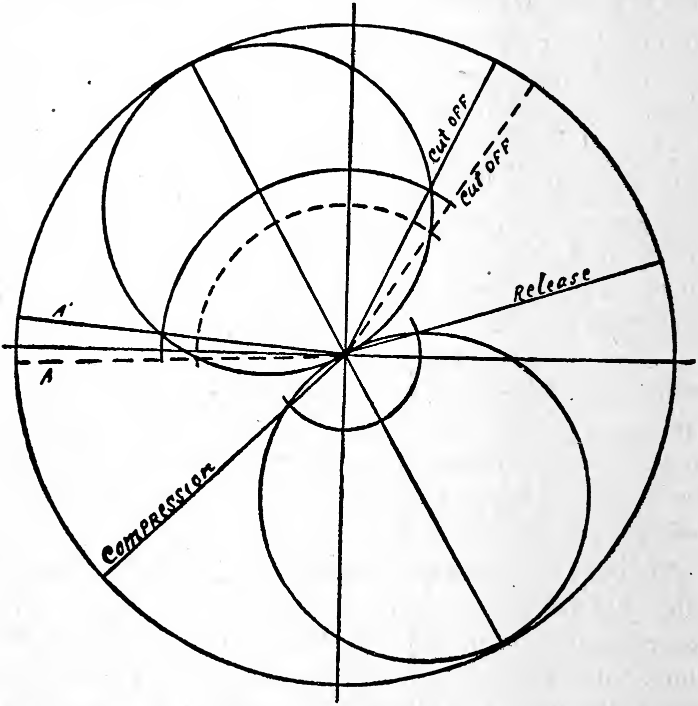


Fig. 128

take place at half stroke, but to do this alone would cause admission to occur too early. Therefore the proper thing to do is to increase both the angle of advance and the outside lap. Figure 129 shows how this can be done without decreasing the travel of the valve. The angle of advance, A B C, is now 50°, where before it was 30°, as in Fig. 125.

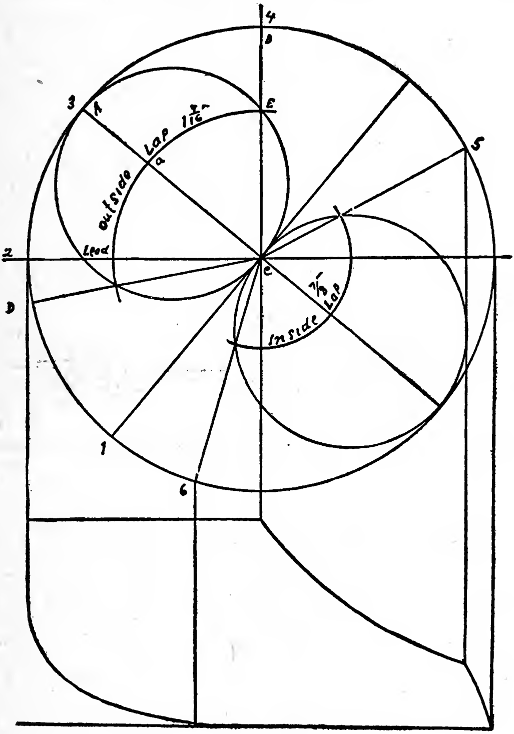


Fig. 129

The valve is central when the crank is at position 1; the high point of the eccentric being at point 4. The outside lap, which before was 1 in., has had 7/16 in. added to it, making it 1 7/16 in. When the crank gets to D the port is just commencing to open, and with the crank on the center at 2, the lead is ¼ in.

It will readily be seen at this point that by increasing the outside lap still more the lead can be diminished, and the point of cut off made still earlier, but this would result in a still further reduction of the power of the engine, which has already been considerably reduced, as shown by the diminished area of the indicator diagram as compared with the one in Fig. 125. When the crank gets to position 3 the valve has reached the limit of its travel, and the port is open the distance A a, which is as far as the outside lap will permit. With the crank at point 4 cut off occurs. But with the increased angular advance and the inside lap remaining as it was before, viz., ½ in., release would occur too early. Therefore it will be necessary to increase the inside lap sufficient to cause release and compression to take place at as near the proper points as possible. In this instance ⅜ in. has been added, making the inside lap ⅞ in., and release takes place with the crank at position 5, while compression begins at 6. These points may also be changed by simply adding to, or decreasing the inside lap.

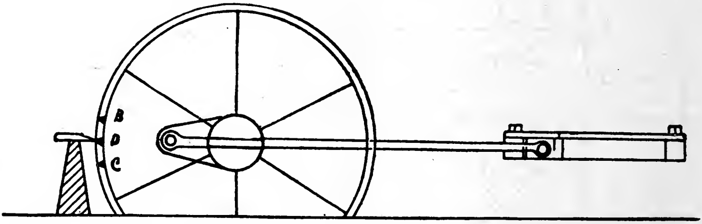


FIG. 130

It should be noted that in the foregoing discussion of valve gear it is understood that the valve stem moves in the same direction as the eccentric rod, that is, the direction of motion is not reversed by a rocker arm interposed between the eccentric and the valve.

The first step in the operation of valve setting is to place the engine on the dead center, which means that the piston is at the end of the stroke, and the centers of the main shaft, crank pin and crosshead pin, or wrist pin, as it is sometimes called, are in line (see Fig. 130). When moving the engine to place it on the center it should always be turned in the direction in which it is to run. This is to guard against any errors which might result from lost motion or looseness in the reciprocating parts. Turn the fly wheel around until the crosshead is almost to the end of the stroke, say within a half inch of it, as at Fig. 131. Then with a steel scriber or penknife mark the location of the crosshead on the guides A, also provide a secure resting place upon the floor of the engine-room for a marker to be placed against the rim of the wheel. This rest should be firmly fastened to the floor in order that its position may not be changed during the operation of valve setting. Place the marker against the wheel, as at B, and mark the point with a center punch or cold chisel. Next turn the engine carefuly until the crosshead completes the stroke and moves back on the return stroke until the mark A is

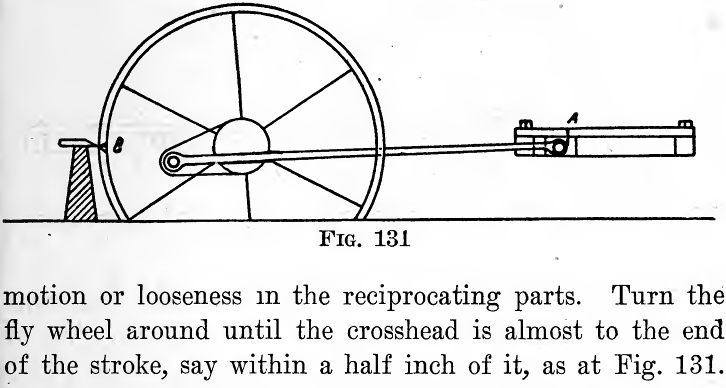


Fig. 131

in line again. Make another mark on the rim of the wheel opposite the marker at C. This position of the engine is shown in Fig. 132, and it will be seen that the crank is now as much above the center as it was below in Fig. 131. Now with a pair of large dividers ascertain the middle or half distance between marks B and C and put another mark D, at this point. Then turn the engine a complete revolution until mark D comes opposite the pointer, Fig. 130, and the engine will be on the true center.

At this point the question may arise, why not simply reverse the motion and back the wheel up until the mark

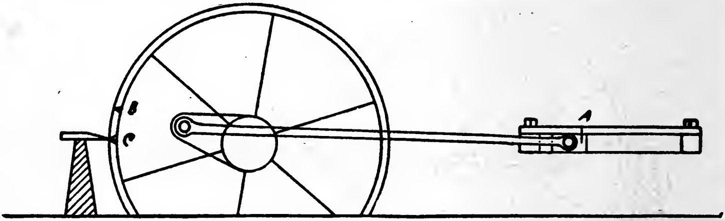


Fig. 132

D is in line with the marker? The answer is, that while this would undoubtedly save considerable labor, yet it would almost certainly result in an error, on account of the lost motion of the moving parts, which would permit of considerable movement of the wheel before any movement of the crosshead would take place if the wheel was turned back. The result would be that when mark D came to be opposite to the pointer, the crank would not be on the true center. The next move is to see that the eccentric rod is adjusted to the proper length. If there is a rocker arm, connect the eccentric rod in its proper place, leaving the valve rod disconnected for the time being. Then adjust the length of the rod so that when the eccentric is turned around on the shaft the rocker arm will vibrate equal distances on each side of a plummet line suspended through the center of the pin upon which the arm turns, as in Fig. 133. Before connecting the valve rod the valve should be put in its central position and marked. To do this it will be necessary to first ascertain the outside lap.

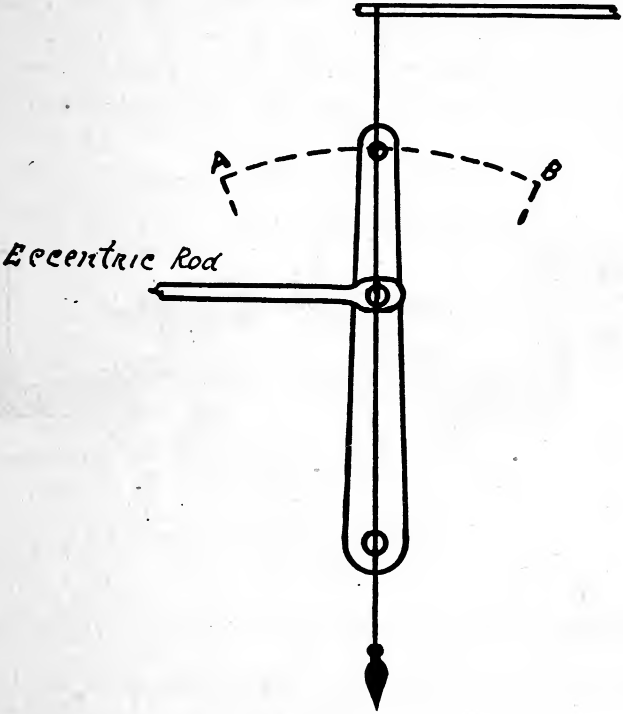


Fig. 133

The most accurate method of doing this is to take the valve out and measure the distances between the outside edges of the steam ports, as at B, Fig. 134. Then measure the width of the valve from edge to edge, as at A. Then

A—B÷2=the outside lap. For instance, A=8.5 in., B=6.5 in. Then 8.5—6.5=2, and 2 divided by 2=1 in., which is the lap. The inside lap should also be measured at this point for convenience, and the measurements preserved for future reference. The inside lap is ascertained by measuring the distance between the inside edges of the ports and the distance across the arch of the valve from one inside edge to the other (see Fig. 134) and dividing the difference by 2. For instance, the distance F is 4 in., and E is 3 in.; then $\frac{4-3}{2}$=.5 in., making the inside lap ½ in.

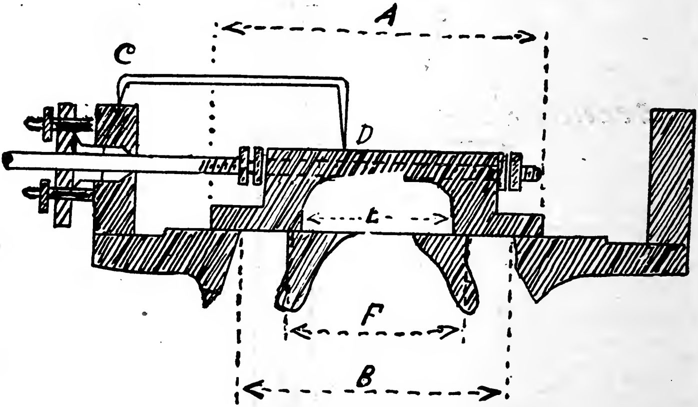


FIG. 134

To place the valve central, measure the width of the outside lap each way from the outside edges of the steam ports and mark the points on the valve seat with a sharp lead pencil. Then place the valve with edges on the marks and it will be central. To insure accuracy, measurements should also be taken from the outside edges of the steam ports to the ends of the seats. Having fixed the valve in its central position, replace the stem and if it is secured in the valve by nuts, as in Fig. 134, care should be taken to leave a little play for the valve between the nuts, otherwise it is liable to become stuck, and held off the seat when it gets hot and expands. Make a center punch mark C, on the edge of the valve chest directly over the valve stem, and placing one leg of a tram or pair of dividers in the mark, with the other leg describe a mark on the top of the valve as at D, thus marking the valve in its central position.

Now with the rocker arm perpendicular, the eccentric rod having been previously adjusted, connect the valve rod to the rocker, and turn the eccentric to the limit of its throw in one direction, and measure the distance the valve has traveled from its central position. Then turn the eccentric around to its extreme throw in the other direction, and if the valve travels the same distance from its central position in the opposite direction the lengths of the rods are correct, but if not correct, the necessary change can usually be made by shifting the nuts on the valve stem, or if the valve is secured to the stem by a yoke the change can be made in the rod.

Having succeeded in getting the correct travel for the valve, the next step is to set the eccentric. With the engine on the dead center, turn the eccentric around on the shaft in the direction in which the engine is to run, so as to take up all the play in the valve stem and other moving parts, and with the tram, or dividers watch the valve until it has moved away from its central position by the amount of its outside lap, plus the lead it is desired to give the valve. For instance, if the valve has one inch outside lap and the lead is to be 1/8 in., the valve should be moved away from its central position 1⅛ in., and also away from the end of the cylinder at which the piston is. The steam port for that end should now be open ⅛ in., and the eccentric should be ahead of the crank one-quarter turn plus the angular advance required for the outside lap and lead, or if as previously explained, the motion of the eccentric is reversed by a rocker arm the eccentric should be behind the crank by the same amount. Tighten the set screws holding the eccentric on to the shaft and turn the engine around until it is on the opposite center. Then if the lead is the same on each center the valve is set correctly. If the lead is not the same, move the valve on the stem toward the end having the most lead, a distance equal to one-half the difference between the two leads. If the lead as equalized is more than is desired move the eccentric back on the shaft until the correct lead opening is secured, then tighten the set screws permanently, and with a sharp cold chisel make a plain mark on the shaft, and opposite to this another mark on the eccentric. This will save considerable trouble in case the eccentric should slip or be accidentally moved from its true position at any time.

Although the common D slide valve as applied to stationary engines usually has its point of cut off fixed, yet there are many types of variable automatic cut off engines with single slide valves of various patterns, such as box valves in which the steam passes through the valve, piston valves, in which the steam either passes through or around the ends of the valve, so-called gridiron valves, and various other types. Such valves are generally applied to high speed engines, and are actuated by eccentrics which are under the control of shaft governors which vary the position of the eccentric with relation to the crank according to the load that is on the engine, thus regulating the point of cut off so as to maintain a constant speed, while the throttle is kept wide open. While the details of setting all the various styles of valves, including the Corliss or four-valve type, differ considerably from those required in setting the D valve, yet the same principles govern the operation, no matter what kind of a valve is to be adjusted.

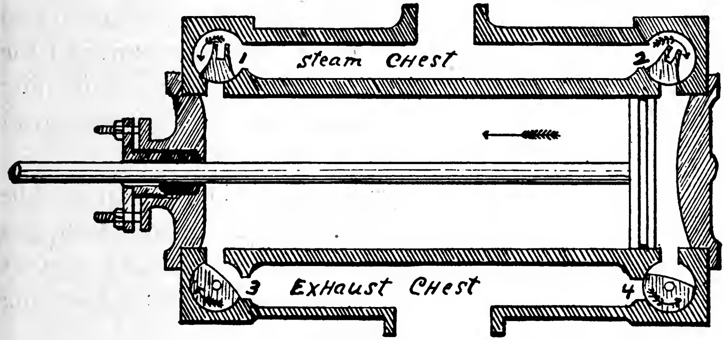


FIG. 135

In all types of reciprocating engines the same factors affecting the distribution of the steam are present, viz., the outside or steam lap affecting admission and cut off, and the inside or exhaust lap affecting release and compression. While the D valve (and other types of single valves) combines these four principal factors within itself (that is, two steam laps and two exhaust laps), it should be noted that in the four-valve type of engine the same factors are distributed among four valves, each valve performing its own particular function in controlling the distribution of the steam for the end of the cylinder to which it is attached. Also each valve may be adjusted to a certain degree independently of the others, and this fact goes far towards explaining why engines of this type, with the disengaging valve gear, are so much more economical in the use of steam than are those with the ordinary fixed cut off. Thus, for instance, the steam valves of a Corliss engine may be adjusted to cut off the steam at any point, from the very beginning up to one-half of the stroke, without in the least affecting the release or compression, because these events are controlled by the exhaust valves.

In some of the modern improved makes of four-valve engines there are two eccentrics, one for the steam and the other for the exhaust valves. This arrangement permits of still greater latitude in adjustments for the economical use of steam.

As the Corliss engine is a prominent and familiar type of the four valve detaching cut off engine, and embodies the main features of nearly all engines belonging to that class, it will be used to illustrate the method of setting the valves on a four valve engine.

Fig. 135 is a sectional view of the cylinder, steam and exhaust chests, and the valve chambers of a Corliss engine. 1 and 2 are the steam valves, and 3 and 4 the exhaust valves. The valves work in cylindrical chambers accurately bored out, the face of the valve being turned off to fit steam tight. They are what is termed rotative valves, that is, they receive a semi-rotary motion from the wrist plate, which in turn is actuated by the eccentric.

In Fig. 135 the piston is shown as just ready to begin the stroke towards the left. Admission is taking place at valve 2 and release at valve 3, valves 1 and 4 being closed. The arrows show the direction in which the valves move. Motion is transmitted from the wrist plate to the valves by means of short connecting rods and cranks attached to the valve stems. These rods are, or at least should be, fitted with right and left hand threads or turn buckles for the purpose of lengthening or shortening the rods while setting the valves.

The valve gear of a Corliss engine with a single eccentric is shown in Fig. 136. The connections of the exhaust valves with the wrist plate are positive, and the travel of these valves is fixed, being a constant quantity, but the connections of the steam valves with the wrist plate are detachable, being under the control of the governor. Various designs of releasing mechanism are in use by different builders, but the same general principles govern the operation of all, viz., that the valve is quickly opened at the commencement of the stroke when the wrist plate has its fastest motion, and that the governor trips the releasing mechanism at that point in the stroke at which it is desired that cut off should take place, and that the valve is then quickly closed by means of a vacuum dash pot or, as

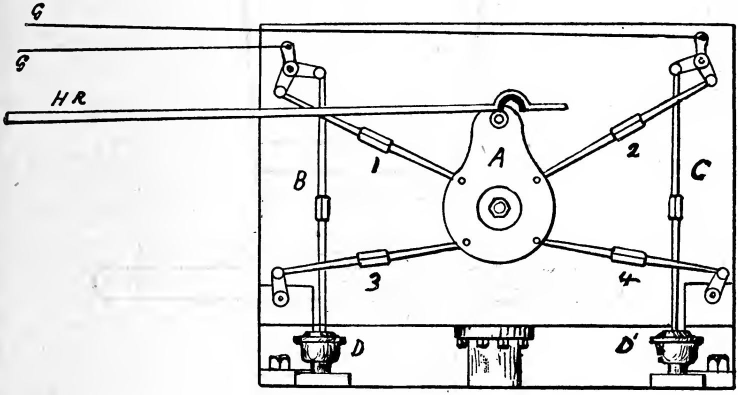


FIG. 136

in some types of engines, by a spring. Connection is made between the wrist plate and rocker arm by means of the hook rod, so-called because it hooks over the wrist plate pin, and can easily be disconnected in case it is desired to work the valves by hand, as in warming up the engine preparatory to starting up.

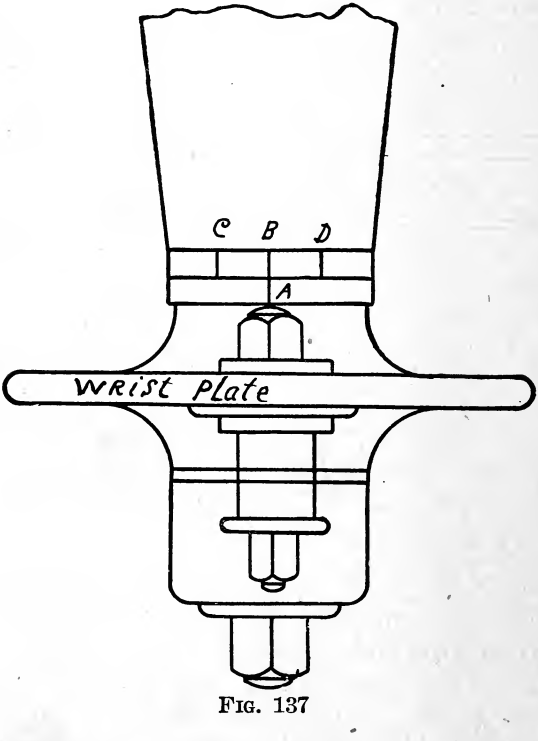


FIG. 137

Referring to Fig. 136, A is the wrist plate, B and C are the dash pot rods, D, D′ the dash pots and H R the hook rod. G and G′ represent the governor rods, and the figures 1, 2, 3 and 4 indicate the valve rods with turn buckles for changing their lengths.

As in setting the slide valve, the first requisite in setting Corliss valves is to put the engine on the center, the method of doing which has been fully described. Next adjust the length of the hook rod, if it is adjustable, if not, then the eccentric rod so that the wrist plate will vibrate equal distances each way from its central position which is marked on top of the hub. (See Fig. 137.) It will be noticed that there are four marks, A, B, C and D. Marks A and B are on the hub of the wrist plate and the stationary flange against which it turns, and when they are in line, indicate that the wrist plate is central. Marks C and D are on the stationary flange at equal distances each way from B, and when the engine is running mark A should travel to the right until it is in line with D and to the left until in line with C, or it may happen that A will travel past C and D or perhaps not quite to them, but which ever it does, it should stop at equal distances from them. This adjustment should be carefully made before setting the valves, because if any change is made in the lengths of the eccentric rod or hook rod after the valves are once set it will seriously affect the action of all the valves.

The method of adjusting the rocker arm so that it will vibrate correctly has been already described and it is very desirable that its travel should be equidistant in either direction from a vertical position, but if it is found that the hook rod is non-adjustable as to length and that the wrist plate still vibrates too far in one direction, then the adjustment must be made on the length of the eccentric rod, which can be screwed into or out of the strap. The vibration of the wrist plate should then be tested by turning the eccentric around on the shaft in the direction the engine is to run. When this is found to be correct the next step is to remove the back bonnets from the valve chambers. Fig. 138 represents one of the steam valves and Fig. 139 one of the exhaust valves, each with back bonnet removed, showing the ends of the valves.

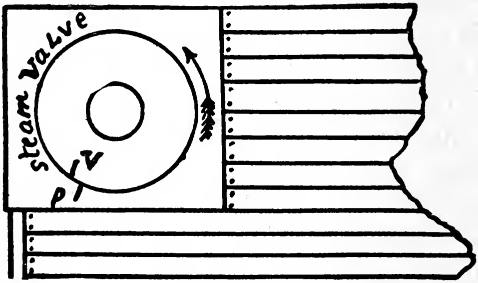


FIG. 138

The working edges of the valve, as well as the ports of a Corliss engine, cannot be seen when the valves are in place, owing to the fact that the circular ends of the valves fill the spaces at the ends of the valve chambers, but certain marks will be found on the ends of the valves, and corresponding marks on the faces of the chambers which serve as a guide in setting the valves. Referring to Fig. 138, mark V on the end of the valve is in line with the edge of

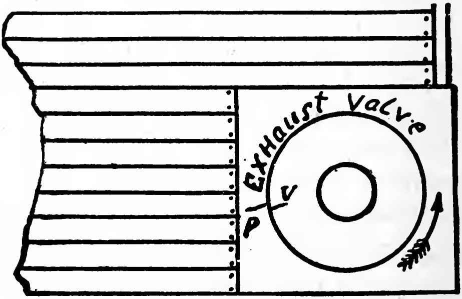


FIG. 139

the valve, and P indicates the edge of the port. The same letters apply to Fig. 139. Having removed the bonnets and found the marks, temporarily secure the wrist plate in its central position by tightening one of the set screws on the eccentric. Then connect the valve rods, adjusting their lengths so that the steam valve will have from $\frac{1}{4}$ to 9/16 in. lap, as in Fig. 138, and the exhaust valves from $\frac{1}{32}$ to $\frac{3}{16}$ in. opening, as in Fig. 139. These figures vary according to the size of the engine, the smaller figures being for small size engines, and the larger figures apply to large sizes.

In adjusting the steam valves be sure and note the direction in which they turn to open. In most Corliss engines the arm of the crank to which the valve rod is connected extends downwards from the valve stem, as in Fig. 136. This will cause the valve to move towards the wrist plate in opening. After the valve rods have been properly adjusted as to length, place the engine on either center by the method previously explained, and move the eccentric around on the shaft in the direction in which the engine is to run until it is far enough ahead of the crank to allow the steam valve the proper amount of lead opening, which will vary according to the size of the engine. Table 32 gives the lap and lead for various sizes of Corliss engines from 12 to 40 in. bore. Having tightened the eccentric set screws, turn the engine around to the opposite center and note whether the lead is the same on each end. If there is a difference it can generally be equalized by slightly altering the length of one of the valve rods. The valves should also be adjusted by means of the indicator at the first opportunity, as that is the only absolutely correct method.

TABLE 32

Size of Engine	Lap of Steam Valve	Lead Opening of Steam Valve	Lead Opening of Exhaust Valve
12 inches	$\frac{1}{4}$ inch	$\frac{1}{32}$ inch	$\frac{1}{32}$ inch
14 inches	$\frac{5}{16}$ inch	$\frac{1}{32}$ inch	$\frac{1}{32}$ inch
16 inches	$\frac{5}{16}$ inch	$\frac{1}{16}$ inch	$\frac{1}{32}$ inch
18 inches	$\frac{3}{8}$ inch	$\frac{1}{16}$ inch	$\frac{1}{16}$ inch
20 inches	$\frac{3}{8}$ inch	$\frac{1}{16}$ inch	$\frac{1}{16}$ inch
22 inches	$\frac{3}{8}$ inch	$\frac{1}{16}$ inch	$\frac{1}{16}$ inch
24 inches	$\frac{7}{16}$ inch	$\frac{3}{32}$ inch	$\frac{3}{32}$ inch
26 inches	$\frac{7}{16}$ inch	$\frac{3}{32}$ inch	$\frac{3}{32}$ inch
28 inches	$\frac{7}{16}$ inch	$\frac{3}{32}$ inch	$\frac{3}{32}$ inch
30 inches	$\frac{1}{2}$ inch	$\frac{3}{32}$ inch	$\frac{1}{8}$ inch
32 inches	$\frac{1}{2}$ inch	$\frac{3}{32}$ inch	$\frac{1}{8}$ inch
34 inches	$\frac{1}{2}$ inch	$\frac{1}{8}$ inch	$\frac{1}{8}$ inch
36 inches	$\frac{1}{2}$ inch	$\frac{1}{8}$ inch	$\frac{1}{8}$ inch
38 inches	$\frac{9}{16}$ inch	$\frac{1}{8}$ inch	$\frac{3}{16}$ inch
40 inches	$\frac{9}{16}$ inch	$\frac{1}{8}$ inch	$\frac{3}{16}$ inch
42 inches	$\frac{9}{16}$ inch	$\frac{1}{8}$ inch	$\frac{3}{16}$ inch

The next point to receive attention is the adjustment of the lengths of the horizontal rods extending from the governor to the releasing mechanism, so that the steam valves will cut off at equal points in the stroke. This is done by raising the hook rod clear of the wrist plate pin, and with the bar provided for the purpose move the wrist plate to either one of its extreme positions as shown by the marks on the hub (see Fig. 137) and holding it in this position adjust the length of the governor rod for the steam valve (which will then be wide open) so that the boss or roller which trips the releasing mechanism is just in contact, or within 1/32 in. of it. Then move the wrist plate to the other extreme of its travel and adjust the length of the other rod in the same manner. To prove the accuracy of the adjustment, raise the governor balls to their medium position, or about where they would be when the engine is running at its normal speed and block them there. Then having again connected the hook rod to the wrist plate, turn the engine around in the direction in which it is to run, and when the valve is released, measure the distance upon the guide that the crosshead has traveled from the end of the stroke. Now continue to turn the engine in the same direction until the other valve is released, and measure the distance that the crosshead has traveled from the opposite end of the stroke, and if the cut off is equalized these two distances will be the same. If there is a difference, lengthen one rod and shorten the other until the point of cut off is the same for both ends.

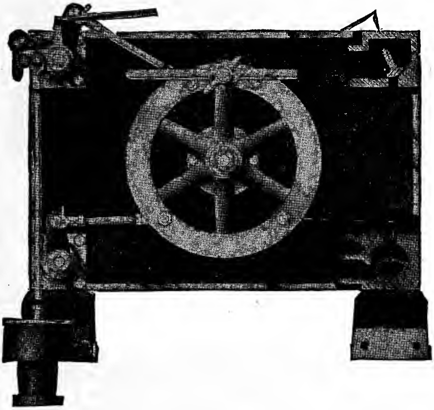


Fig. 140

The lengths of the dash pot rods should also be adjusted so that when the plunger is at the bottom of the dash pot the valve lever will engage the hook.

After all adjustments have been made, tighten the lock nuts on all the rods.

Fig. 140 shows the wrist plate of a Reynolds Corliss engine in its central position ready for adjusting valve connections. The parts broken away show the steam and exhaust valves in their respective positions as regards lap. The valves shown are single ported.

Fig. 141 shows the position of the wrist plate of a Reynolds Corliss engine, when the crank is on the center and the eccentric set so as to give the steam valves the proper amount of lead. The exhaust valves will be correct if they have been set according to table 32—the wrist plate being central.

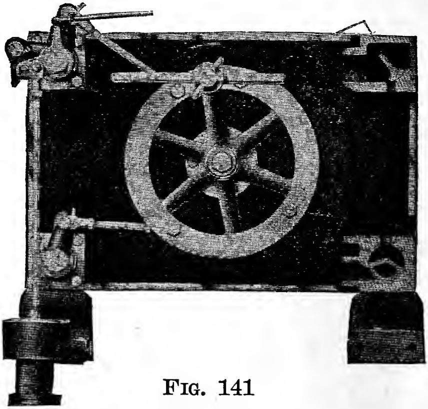


Fig. 141

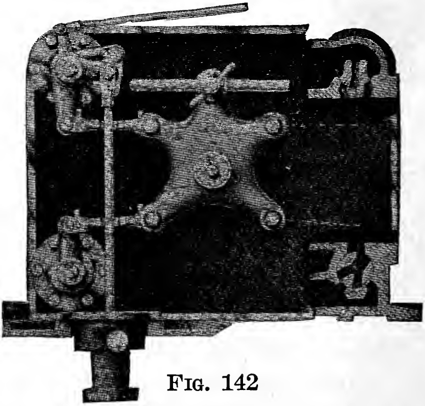


Fig. 142

Fig. 142 shows the wrist plate of a heavy duty or reliance type Reynolds Corliss engine in its central position, ready for adjusting the lengths of the valve rods. The valves in this type of engines are double ported.

Fig. 143 shows the position of the wrist plate of a heavy duty or reliance type Reynolds Corliss engine, when the crank is on the center, and the eccentric set so as to give the steam valves the correct lead. These valves are double ported, and the exhaust valves will be correct if set according to table 32.

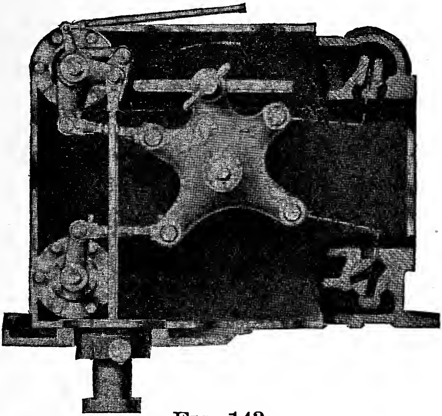


FIG. 143

Reynolds Long Range Cut Off. Fig. 144 shows the valve gear side of an Allis-Chalmers engine equipped with the long range cut off which is designed to give a maximum cut-off for power, and the essential feature of the steam valves is, that they have a negative lap or opening when in mid-position, the cut-off being made entirely by the governor through the knock-off cam.

Referring to Fig. 145, the steam and exhaust valves on one end of the cylinder are shown with the valve-gear removed and the valves and ports in cross-section, while on the other end the valve-cranks have been left in place, and

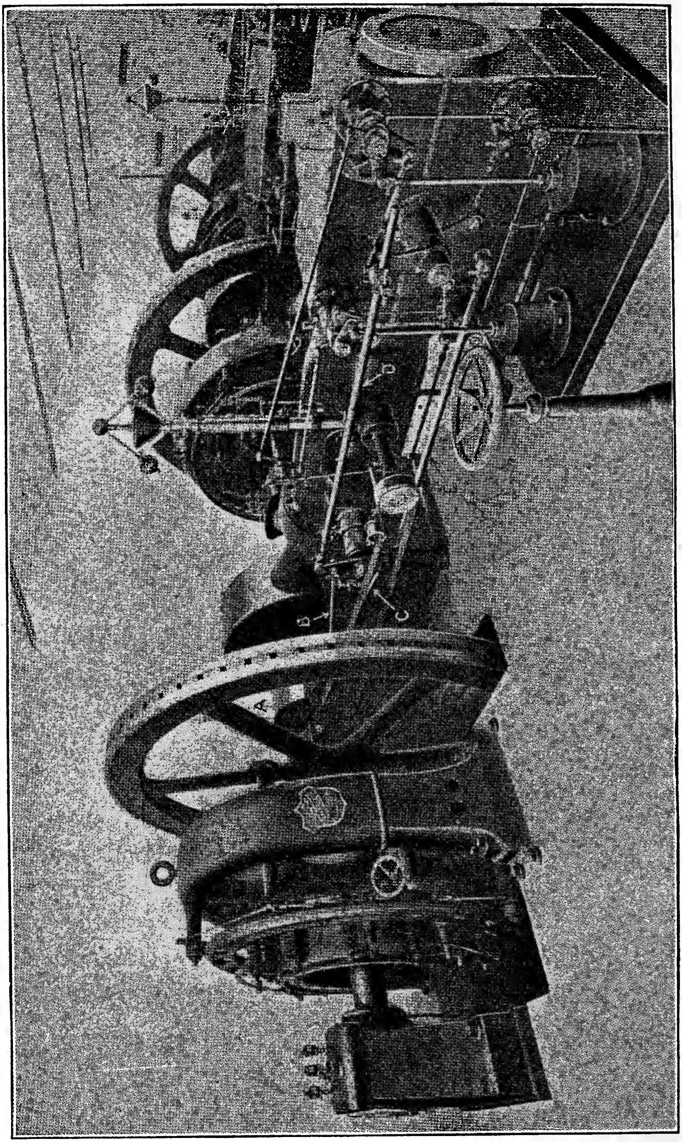


Fig. 144

VALVE-GEAR SIDE OF REYNOLDS LONG-RANGE CUT-OFF ENGINE show their relative position to the valves at the opposite end. The steam and exhaust wrist-plates are shown at A and B, respectively, and above A is shown the travel circle C of the steam eccentric; below is the exhaust circle D. In these circles the crank position is at c and e is the eccentric position. The steam valve-crank is indicated by E, the exhaust valve-crank by F; G is the bell-crank and H the knock-off cam. On the other end of the cylinder where the valves and ports are in cross-section, the dotted lines E′, F′, G′ and H′ denote the center lines of the same parts on that end, and the arcs at the ends of these lines show the respective positions of the pin centers. From each end of these arcs the center lines show the positions of the pins when they reach their respective extremes of travel.

In Fig. 145 the wrist-plates and all connected parts are shown in their central positions, at which the exhaust valves are lapped, as is usual in practice, but the steam valves are open on both ends when they are hooked up. If hooked up and not released the steam valves would be open from the beginning of one stroke up to 75 per cent of the return stroke, but when the knock-off cam-pin center is at a, the cut-off will be carried out to about seven-eights or eleven-twelfths of the stroke, and the cut-off will occur just before the steam valve on the opposite end picks up for lead. When the knock-off cams are in the position represented by the lines H and H′, Fig. 145, the cut-off will occur at about three-eights of the stroke, and when the knock-off pin center is at b the valves will remain lapped, being dropped before they can open. If the regulator is allowed to drop down so the knock-off cam-pin will reach the point c, the valves will not pick up and will remain lapped. This peculiarity must be thoroughly fixed in mind.

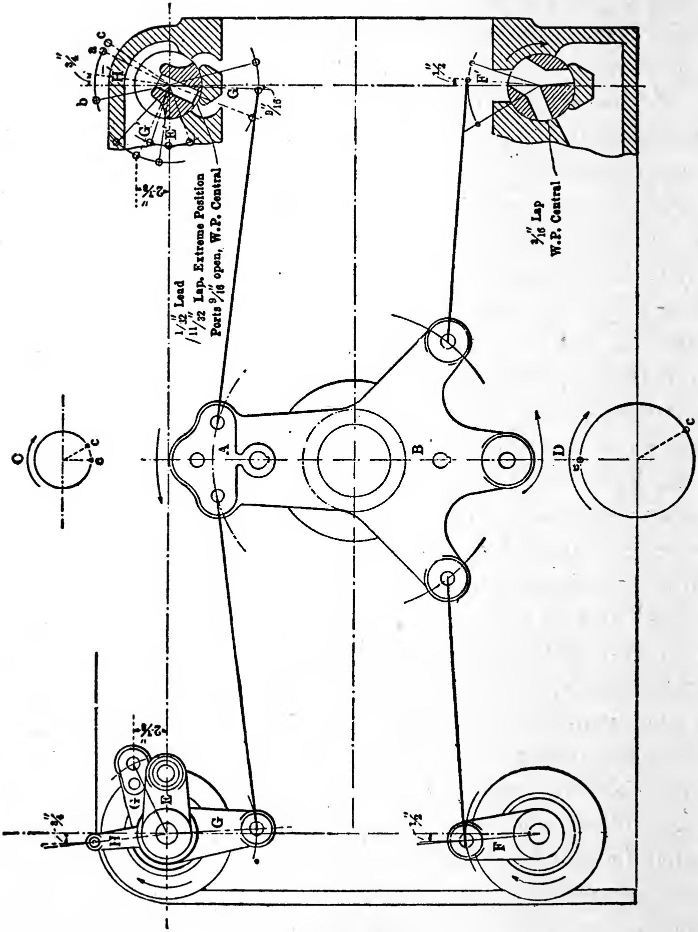


FIG. 145

In Fig. 146 the valve-cranks are in their extreme positions, and the eccentrics likewise, with everything ready to start in the direction of the arrows. On the crank end the steam valve is lapped, and the exhaust valve is open, while

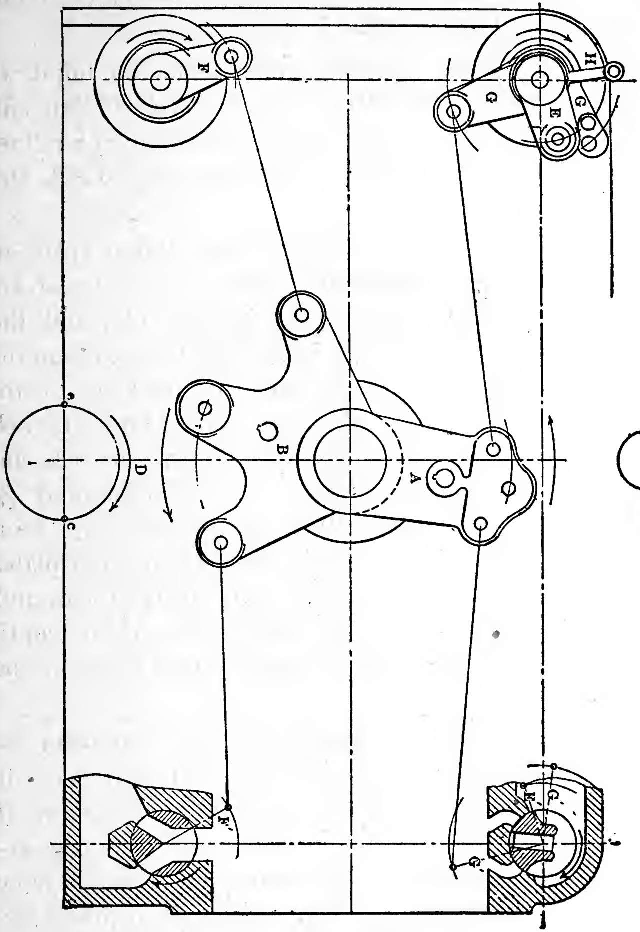


FIG. 146

reverse conditions exist on the head end. On all other types of valve-gear the eccentrics would be advanced 90 degrees when the valves are lapped, but on this engine the steam valve is lapped when the eccentric is on its extreme position. The exhaust valves are the same as on any other double-eccentric Corliss engine.

Setting the Valves. Bearing these points in mind we may proceed to set the valves. The amounts of lap and lead and the positions of the cranks from the center lines given herewith are for engine cylinders of 36, 42, 48, and 60-inch stroke.

First set the wrist-plates central and clamp them in place; then adjust the lengths of the rods so that the steam valves are open $\frac{1}{32}$ inch, as shown in Fig. 145, and the exhaust valves are lapped $\frac{3}{16}$ inch. If the rod lengths are right the center lines of the cranks E and E′ will coincide, the pins of the cranks F and F′ will be one-half inch from the center line, as shown, and the pins on each end of the bell-cranks G and G′ will be $2\frac{7}{8}$ inches and $\frac{9}{16}$ inch from the center lines. When the valves have been set with the wrist-plates central, release the wrist-plates and roll the eccentrics around the shaft to test them, and the reach-rods, and see that they are of the right length to make the wrist-plate travel equally each side of the center line.

Then place the crank on center, and pull the steam eccentric around enough to give $\frac{1}{32}$-inch lead, and make it fast. Next move the engine around in its direction of travel to about 95 degrees of its stroke, and move the exhaust eccentric around until the exhaust valve on the same end is just opening or releasing. Make the exhaust eccentric fast, and move the engine around its full revolution and check off the valves on the other end, and the exhaust closure. Then set the regulator up to its central position and adjust the lengths of the rods from the lever to the knock-off cams, so that the pins of the cams H and

H′ will set ¾ inch of the center line, as in Fig. 145. Let the regulator down and hook up the wrist-plates; then pull the engine around to make sure that the steam valves are released on each stroke alternately, at not later than eleven-twelfths of the stroke, and always before the other valve picks up.

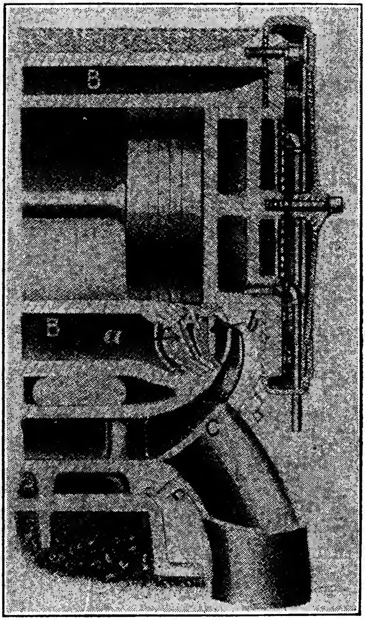


FIG. 147

The Greene Wheelock Engine. In this engine, each cylinder is equipped with four valves of the Hill gridiron type, two steam and two exhaust to each cylinder, and each valve is driven by a separate eccentric. This type of valve and gear gives a large port opening, with a minimum of travel, which in connection with the Greene cut off on the steam, and the toggle motion on the exhaust valves, gives the quickest action at the right time to both. A minimum lap is also obtained with the aid of the gear. It is therefore very important that the movements of the valve and gear be thoroughly understood, and great care be used in adjusting it. The valve plugs contain the valve seats as an integral part of the plug. These are in turn removable for repairs, as are also the valves when in position.

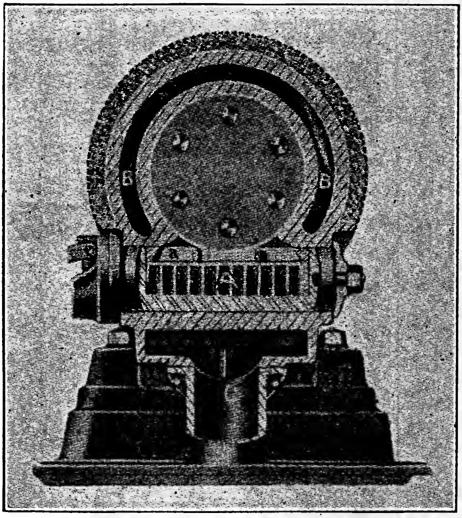


Fig. 148

To the plug is attached the head that holds the working parts of the valve mechanism.

The arrangement of the valves beneath the cylinder as in the Wheelock system, allows short ports, small clearance volume, and a free discharge for the water of condensation through the exhaust. The throttle also is beneath, and admits steam to the steam chest under the cylinder. There are four eccentrics, one for each valve. These eccentrics are of small size and short throw, and receive their motion from the eccentric shaft extending from the back cylinder head, alongside the engine frame to the main crank shaft, from which it receives rotary motion through bevel gear.

An understanding of the valve plugs and their location may be had by reference to Figs. 147, 148, 149. Fig. 147 shows a longitudinal section of the cylinder, and the cross-section of the valve plug at A. This view gives the location of the inlet (steam) valve and seat at a and the outlet (exhaust) valve and seat at b, the steam chest B B forming a jacket for part of the cylinder, as well as admitting the steam through the inlet a into the cylinder. From the cylinder the steam passes out through the outlet b into the exhaust passage C.

Fig. 148 is a cross-section of the cylinder through the clearance space and a longitudinal of the valve plug in that end of the cylinder, showing the back of the inlet valve seat, with the outlet valve cut away.

Fig. 149 is a view of the valve plug with all of the parts assembled. This view shows the inlet or steam valve side of the plug. The inlet valve is at a; the spring which holds it to its seat when not under steam pressure is at b; and c is the pusher crank which actuates the valve by means of a cam at d, which comes in contact with the latch of the valve-stem head e. This is fastened to the inlet valve-stem by clamp bolts. The inlet valve-stem screws into the nut f, so that by loosening the clamp bolts of the head e and turning the rod, an adjustment of the valve setting can be made, as will be shown later.

The inlet valve is opened by the pusher cam pushing it forward, but is released from this cam through the means of a trip cam on the bottom of the valve-plug head,

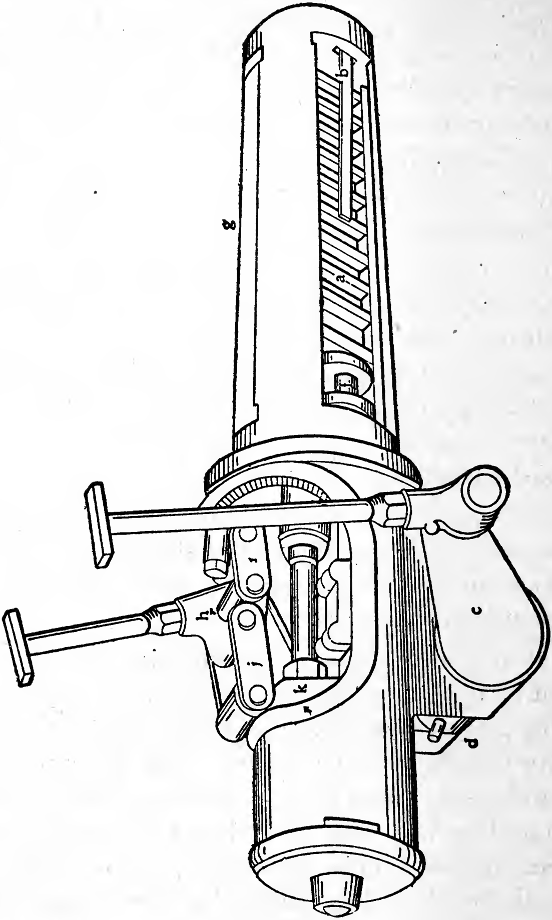


FIG. 149

which is connected to the governor-rods. When released by the trip cam, the valve cuts off by means of the steam pressure on the valve-stem controlled by a dash-pot arrangement in the valve-plug head to which the other end of the rod is attached.

The outlet valve is inside of the valve plug under the strut g. The position of this valve in relation to the inlet can be noted by reference to Fig. 147, where the cross-section of the valves and seats is shown. The outlet valve is actuated by the eccentric acting on the toggle joint h, connected between the two pairs of links, from the point i, where it is fixed, and the joint j, where the link is fastened to the valve-rod head k on the outlet valve-stem.

Instructions For Proper Setting. The following instructions are from the builders of these engines, and if adhered to will give proper setting of the valves. The previous illustrations will aid to a full understanding of these operations.

For reference and a means of checking off the action of the valves it is stated that "A-size" valves have $\frac{5}{32}$-inch lap, with $\frac{3}{4}$-inch travel, and are generally used on cylinders up to and including 16 inches in diameter; "B-size" valves have $\frac{3}{16}$-inch lap, with $1\frac{1}{8}$-inch travel, and are generally used on cylinders from 18 to 26 inches in diameter, inclusive; "C-size" valves have $\frac{1}{4}$-inch lap, with $1\frac{3}{8}$-inch travel, and are used on cylinders from 28 inches in diameter upward.

When starting to adjust the valves, first have all eccentrics loose on the cylinder shaft, and, second, determine the direction the cylinder shaft is to run, and always rotate the eccentrics in the same direction, whether loose on the shaft, or when the shaft and eccentrics turn together.

To Adjust the Travel of the Steam Valves. On the edge of the pusher crank a line is made in the shop, and on the side of the plug head, next to the pusher crank, a corresponding line is made (where the arrow points). When the line on the pusher crank corresponds exactly with the line on the side of the plug head, the pusher plate is vertical: This is its most backward position.

Adjust the eccentric-rod for this valve to such a length that in turning the eccentric around on the shaft the line on the edge of the pusher crank comes back to correspond exactly with the line on the plug head at each revolution. Then, by shimming, adjust the bridge-supporting trip cam, so that the steam valve will travel 3/4 of an inch on "A-size," 1 1/8 inches on "B-size," and 1 3/8 inches on "C-size," but bear in mind that the valve must trip at the end of its travel and the bridge must not be so low that the valve will carry the full stroke without tripping. The roller of the lifter must be in position for full travel.

To Set the Steam Valves. On the steam valve-stem, four scratch lines are made. These lines represent the valve on its lap, the valve just opening, the valve wide open, and the valve pushed in until it strikes the plug. With each valve-gear a steel-wire tram is sent. Just above the valve-stem on the plug-head casting, a prick-punch mark will be found. Loosen up the inlet stem head on the stem, then shove the valve back until it strikes the plug. If the valve is set correctly, the tram with one end in the mark on the plug head casting should with the other end meet the first scratch line on the valve-stem (nearest the outside end of stem). If the point of the tram does not coincide with this line, the valve-stem should be screwed in or out until it does. The valve should then be let back so that the dasher strikes the head, and the inlet stem head be brought back against the pusher plate when the pusher plate is vertical, leaving 1/64 inch clearance between the pusher and latch plates. It will then be found that the point of the tram will correspond with the fourth mark on the stem, with the valve closed.

When the valve is moved forward so that the tram point corresponds with the third line on the stem, the valve is just closing or opening, and when moved farther so that it corresponds with the second line, the valve is wide open. The travel of the valve should be between the second, third and fourth points spoken of, and it should trip just as the tram point corresponds with the second line from the outside end. Then, with the piston on dead center, the eccentric should be revolved on the shaft to bring the steam valve $\frac{1}{32}$ of an inch open on the crank end and 3/64 of an inch on the head end. The eccentric should then be clamped to the shaft, and the valve is set.

To Adjust the Exhaust Valves. On the outside of the plug head are four prick-punch marks. On the outside of the outlet stem head where the tram rests is another prick-punch mark. This is for one point of tram.

To Adjust Valves For Lap. The eccentric rod should be disconnected from the eccentric. Shove the valve back as far as it will go. With the valve in this position, the outside end of the tram should fall into the fourth mark on outside of the plug head nearest the cylinder. If it does not, loosen up the nut holding the outlet stem head, and screw the stem in or out sufficiently to make the tram come into the fourth mark. Then tighten up the nut holding the outlet stem head, connect the eccentric-rod to the eccentric, lengthen or shorten this eccentric rod so that the travel of the valve due to one revolution of the eccentric will move the tram from the first to the third prick-punch mark; and no farther.

The eccentric should then be set so that when the piston is about 5 inches from the end of the return stroke, the exhaust valve should have just closed, and the tram point would fall into the second mark on the plug head.

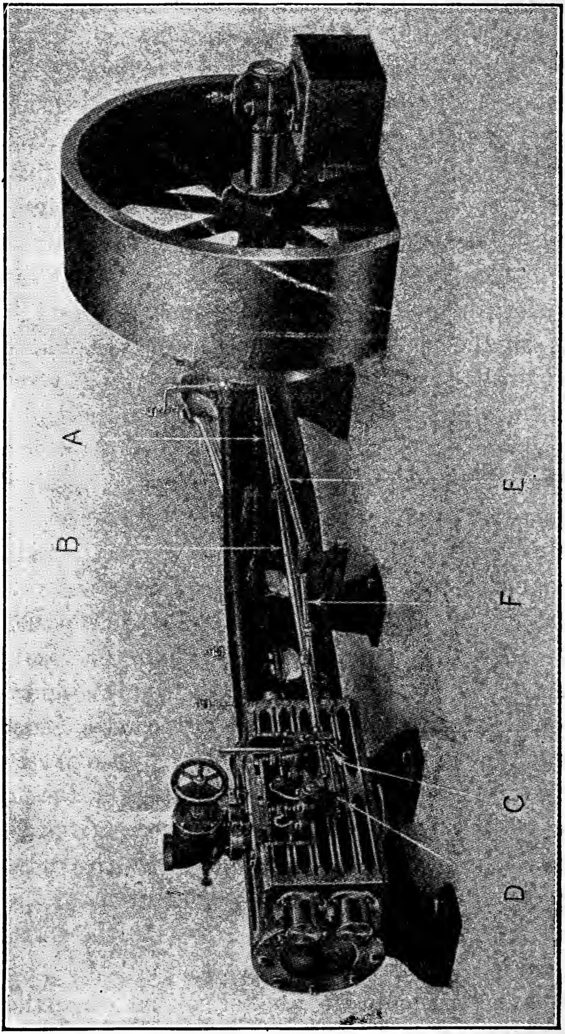


Fig. 150
THE FITCHBURG ENGINE, SHOWING THE VALVE GEAR

As these valves must be set while the valves are out of sight, a strict adherence to these rules of adjustment must be followed, care being taken to be accurate on all points.

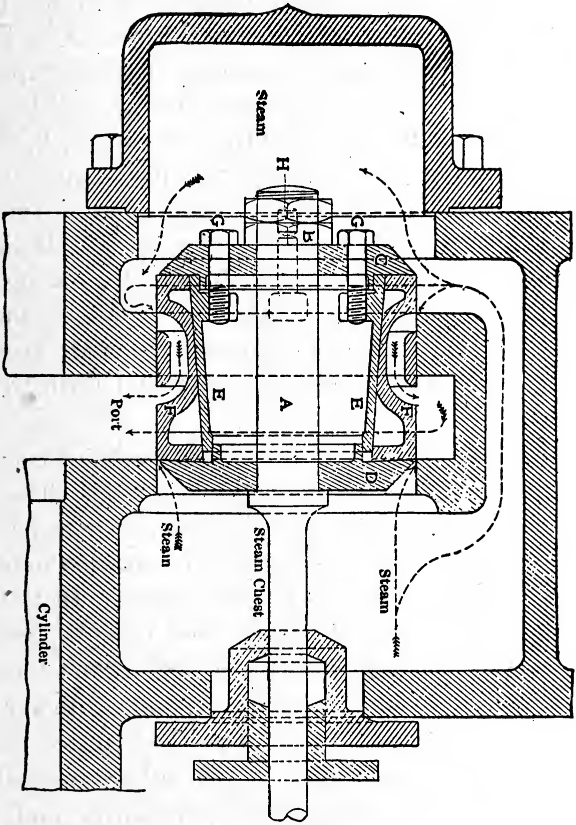


Fig. 151

CROSS SECTION OF STEAM VALVE, FITCHBURG ENGINE

The Fitchburg Engine. This engine is fitted with four valves of the piston type. Motion is imparted to the steam valves by a shaft governor eccentric, acting through rods

A and B, and wrist-cranks C and D, Fig. 150. The exhaust valves have a common stem, and receive their motion from a fixed eccentric through rods F, and E, Fig. 150. The construction of the steam valve is illustrated in Fig. 151. The valve is held in place on the stem A by the nut B. Rings C and D fit into, and bind in place, taper plug E, E, which is used to set out expansible ring F, F. G, G, are adjustment bolts, used for adjusting ring F, F, to wear. To adjust the ring, first slacken nut B just enough to allow ring F freedom to expand or contract, then to expand it slacken the bolts G, G, and run the set-screws H in until the required expansion is accomplished. If too tight, reverse the process by first slackening set screws H, and then tighten bolts G. During the process the valve should be tested for tightness by rocking it back and forth with the starting bar.

Fig. 152 shows the steam and exhaust valves for one end of the cylinder. The exhaust valve A is solid. The steam valve B is double ported, and balanced as shown in Fig. 151. Referring to Fig. 152, the valve motion is on the center of its travel, the valves being lapped. In this position rocker arms C and D should stand vertical, exactly at right angles to the center line of the engine, and the wrist-cranks E and F should be in like position, with the cams G and H as shown, and the valve rod so adjusted that the valves have their proper lap. When all of the rods are properly adjusted as to length, the rocker-arms, and wrist-cranks will travel an equal distance on each side of the center line on which they rest in Fig. 152. Nut J on the steam reach rod has a right-and-left thread in it, and by loosening the lock nuts and turning the center, the length of this rod may be changed so as to bring the wrist-cranks in line. Fig. 151 shows the steam valve just on the point of opening. The arrows indicate the direction of flow of the steam.

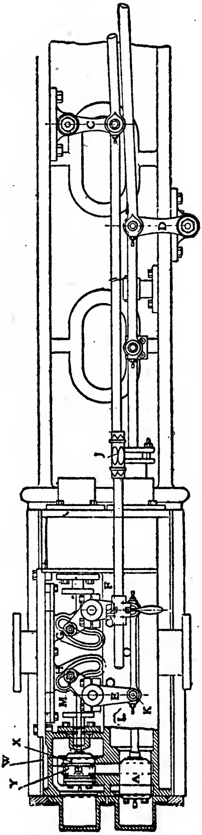


FIG. 152

Fig. 153 shows the same valve at full opening, and the wrist cranks at the extreme position of their travel in that direction. The governor eccentric is also at its maximum throw, and on its center. One steam valve is full open, and the other one is closed. When the positions are reversed, and the eccentric is on the other center, the steam valve here shown will be back in the position shown in Fig. 152, and the crank-end valve will be full open. The ex-

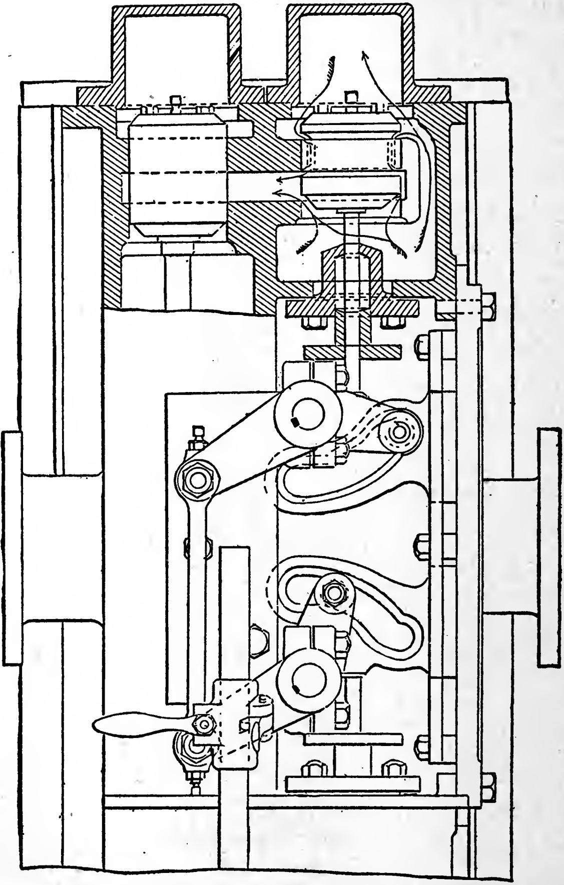


Fig. 153

haust valves should be so adjusted that they will close, and open alternately at about seven-eights of the stroke of the engine. The travel of the steam valves equals the distance W (Fig. 152) or the width of the bridge X, plus the width of the valve port Y. The steam valve is given this travel through the medium of the cams, and herein lies the peculiarity of this valve motion. The largest part of the cam slot is of the same radius that the driving pin and roll on the wrist-crank pass through, so that when the pin is moving down and away from the steam chest and back again to the position shown in Fig. 152, the valve is at rest. This is for a period of one-half the engine revolution. To illustrate this fact, remember that while the wrist-crank is in the position shown in Fig. 152, it is on the center or half of its travel. Supposing the eccentric to move so that the wrist-pin moves from K to L and back again; the engine has completed one-half its revolution. Now while the same wrist-pin is traveling from the position shown in Fig. 152 to that in Fig. 153, the motion of opening is given in one-fourth of the engine revolution, and on moving back to the central position the valve has cut off and lapped in one-fourth of the revolution. To prevent a too sudden action of the valve, the slot is just enough off from the point M to the end to start the cam and valve in motion slightly before the valve opens.

The steam valve is balanced by having the steam pressure on all sides, with the exception of the area of the valve stem on one end. The steam valves admit, and the exhaust valves release steam over their inside ends. The steam valves receive motion indirectly, on account of the wrist-cranks. The exhaust valve motion is direct. The steam and exhaust eccentrics both lead the crank.

Fig. 154 shows the relative position of the crank and steam eccentric at about the point A on the dotted line R X, or it is about 90 degrees plus 37 degrees for lap and lead ahead of the crank, and the exhaust eccentric is approximately at 90 degrees ahead of the crank. This latter fact may be useful to know in the event of a slipped eccentric and the minimum time for adjustment.

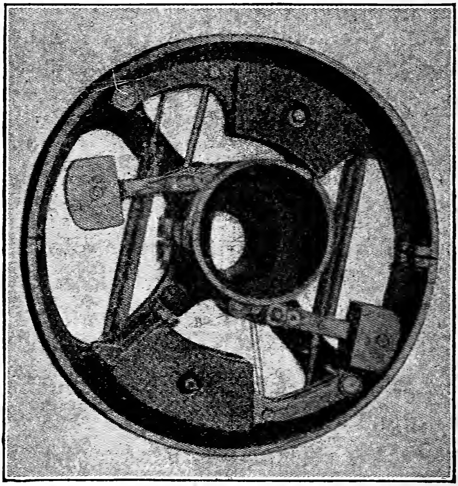


Fig. 154

Fig. 152 shows both eccentrics at 90 degrees, while Fig. 153 shows the lead of the steam valve distorted, for clearness of ilustration, but the wrist-crank is in the same approximate position as when the crank is on the center and the eccentric is, at its greatest throw, advanced to the point shown in Fig. 154. While in this position the steam is cut off at about three-fourths stroke. The angle of advance grows less and less as the eccentric is thrown across the shaft by the action of the governor from higher speed, thus accomplishing the regulation of speed. For a full understanding of this action refer to Fig. 154. The action is as follows: As long as the engine is below speed, the eccentric is kept in its longest throw by the tension of the springs, and steam follows about three-fourths of the stroke, but as soon as the proper speed is reached, centrifugal action causes the weights H to overcome the tension of the springs and to move outward in the direction of the arrow, at the same time lengthening the springs. By means of the connecting rods G G, the outward motion of the weights turns the suspension arms C upon their fulcra and the ears B, the eccentric is carried across the shaft from S toward R, and as the arcs by the centers B B are in opposite curves they compensate each other, and the center S of the eccentric follows a straight line in its movement, preserving a constant lead opening, or otherwise, as desired. This manifestly decreases the eccentricity, and increases the advance of the eccentric, giving an earlier cut-off to the valve until, when the eccentric is swung squarely back of the crank, the valve opens only the lead, there being all points between this and extreme cut-off for variation. Upon the least diminution of speed the springs have more power than the centrifugal force of the weights, and the motion of the parts is arrested and turned in the opposite direction, giving a later cut-off, as more work is performed by the engine.

How to Set and Adjust the Valves. Having now discussed the motion, the idea is to get a working knowledge of how to set the valves and adjust them and the governor for various conditions. The location of the governor case is determined by placing the engine on one dead center, and rolling the case around on the shaft until the off set of the eccentric is on the opposite side of the shaft from the crank pin. Then roll carefully into such position that when (with the springs removed) the eccentric is thrown back and forth across the shaft no end motion is given the valve rod. At this place tighten the governor case firmly upon the shaft, and roll the shaft to the opposite dead center and again move the eccentric back and forth across the shaft, and roll, and if there is at this end any end motion to the valve-rod, change the position of the governor case on the shaft enough to make the motion just half as much, then fasten the governor case firmly in this final position by drilling into the shaft for the point of the set-screw, and then tightening the clamp bolts to place solidly. Put in the springs and tighten them until the proper number of revolutions is obtained, being sure to tighten up the springs that go through the counterbalance which hangs nearest the springs (when the governor is at rest) about three-fourths of an inch more than the springs on the other side.

The travel of the exhaust valves can first be evened up before their eccentric is tightened upon the shaft by rolling the eccentric around the shaft to its extreme throw at each end. It should then be set so that the port is just closed when the crosshead has traveled a little less than seven-eighths of its stroke, and the set screw firmly screwed upon the shaft.

To adjust the steam valves, place the latch of the hook in the center of the half-spiral slot and clamp the hook firmly by its lever, evening up the movement of the wrist-cranks by the right and left nut in the valve-rod, so that in a revolution of the engine shaft they rock evenly each side of a vertical line drawn from the centers of their shafts. Set the engine exactly on one dead center, and move the small valve rod attached to the head end valve in, and out of its cam until the port is opened the proper lead, in usual cases one-sixteenth of an inch, and tighten the set-crew in the neck of the cam upon the rod firmly. Roll the engine to opposite center and set the other valve in the same way. After the valves are thus set as closely as possible, if practicable they should be adjusted by use of the indicator, when the engine is under partial or full load, as no mere measurements can ever set the valves exactly right in any engine. The exhaust valves of the low-pressure cylinder can be set the same as for the high-pressure cylinder.

The shaft governor depends for its action upon the centrifugal power of the two weights nearest the rim, which, through the connecting-rods, move the counterbalancing weights to which the eccentric is attached and thus carry the eccentric across the shaft, altering the throw of the valve-rod and the point of closure of the admission valves. The centrifugal power of the weight arms being exerted against the springs, and the more the weight arms are thrown out toward the rim, the earlier the point of cut-off, it follows that to increase the speed of the engine, tighten the springs or take off some the weight; and to decrease the speed, loosen the springs or add more weight. The springs should not be stretched much over 1½ times the length of the coil when unstretched. The speed of the engine may be changed several revolutions by adjusting the tension of the springs. A small amount of friction should be maintained between the face of the eccentric and the governor case to prevent dancing, and this is secured by the springs and washers on the ends of the pins which carry the counterbalance weights. Once adjusted, they are right for a long time.

Adding to the centrifugal weight arms and increasing the tension of the springs makes the governor more sensitive.

The Governor

The proper regulation of speed is a very important point in the operation of engines, and in order to attain this most desirable object, due attention must be paid to the governor. If the governor is what is known as a throttling governor (see Fig. 155), the principles of which are explained in the section on "definitions," care should be taken to not pack the small valve stem too tight, nor allow the packing to become hard from long usage. The packing nut should be left loose enough to allow a slight leakage of steam past the stem. This will keep it lubricated, and the slightest

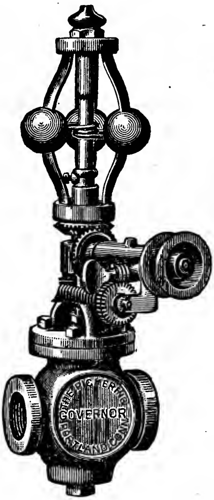


FIG. 155
THROTTLING GOVERNOR

variation of the governor balls will be transmitted to the valve, and the speed will be regular.

If the engine has an automatic cut off mechanism actuated by a fly ball governor, it is obvious that all the moving parts of the governor should work with as little friction as possible. Good oil and enough of it should be used. Particular attention should be paid to the dash pot connected with the governor, the object of which is to regulate the variations of the governor and prevent a jerky movement. It often happens, especially with new engines, that the small piston in the dash pot fits too snug, and the consequence is that it sticks; causing the governor to be slow in responding to changes in the speed of the engine.

It is a good plan sometimes to take the dash pot piston out, and putting it in a lathe, reduce its diameter slightly, and also round off the sharp edges. The oil used in the dash pot should not be allowed to become gummy by being used too long without changing it for fresh oil.

SHAFT GOVERNORS.

Shaft Governors. Many automatic cut off engines, especially those of the high speed type, are fitted with isochronal, or shaft governors. There are various styles of these governors, but all, or nearly all of them control the admission of steam to the cylinder, and consequently the point of cut off by varying the angular advance of the eccentric, which in such engines is free to move across the shaft, being entirely under the control of the governor.

Very close regulation is generally obtained by the use of shaft governors, but particular attention should be given to the lubrication of the steam valve, which, with this class of engines, is generally a slide valve of some description, and although it may be ever so nicely balanced, yet if it does not get sufficient oil, the friction due to dry surfaces rubbing together, will put extra work on the governor, and the speed is liable to be irregular.

The general principle controlling the action of shaft-governors is clearly explained in the section on "definitions," and need not be restated here. A few examples of the various makes of this type of governor will be given. The shaft governor, or "governor eccentric" as it is called, which is attached to the Fitchburg engine is described in connection with that engine. (See Fig. 154.)

Fig. 156 shows the shaft governor of the Russell engine, which is also a four valve high speed engine.

This governor is of the centrifugal type and regulates by advancing the eccentric, or retarding it in its position in relation to the crank, thus hastening or holding the point of cut off without altering the travel, and the lap of valve remaining the same. The weights are pivoted at the ends of the arm by the pins near the rim of the wheel, and their outward motion is resisted by springs. The eccentric is fastened to each weight arm by links, and is counterweighted to offset the weight of the reciprocating parts attached. The governor is very simple, and easily understood.

On a right-hand engine running over, the parts will be mounted as in Fig. 156, with the right-hand weight arm hanging down and the left-hand arm in the position shown. This arrangement also holds good for a left-hand engine running under.

To change from a right-hand engine running over, to a left-hand engine running under, the wheel would be turned around side for side. On a right-hand engine running under or a left-hand engine running over, the weight arm will hang downward on the left, the pin being placed in the vacant hole seen at the top of the spoke. To change from a right-hand engine running under, to a left-hand engine running over, turn the wheel around side for side. In other words the weight must always follow the pivot pin of its arm in the direction of engine travel.

When first working the engine up to speed for the purpose of adjusting the governor, screw up on the springs and keep setting the weights out farther on the arms, until the speed and sensitiveness are about right.

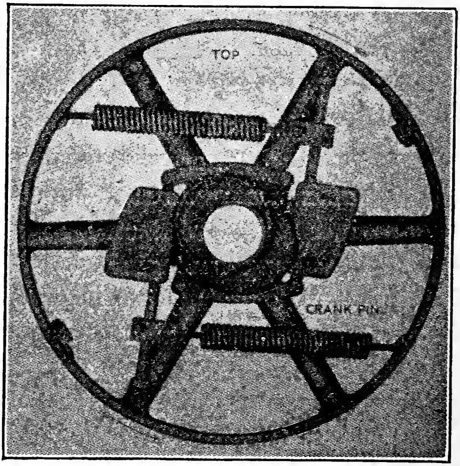


Fig. 156
CENTRIFUGAL GOVERNOR

Then to get more speed, set up on the springs or take off weight.

To get less speed, slacken the springs or add weight.

To make the governor less sensitive, slacken the springs and take off weight.

To make the governor more sensitive, set up on the springs and add weight.

To correct for sluggishness, set up on the springs.

Generally speaking, when the governor regulates closely and a change in speed is desired, the spring tension should not be changed, but the desired speed should be obtained by changing the weights. More weight gives less speed, and less weight more speed. Moving the weights toward the rim of the wheel, or moving the spring clip on the weight arm toward the weight to get more purchase, has the effect of less weight. Moving the weights toward the hub of the wheel, or the spring clip away from the weight, has the effect of more weight.

To move the spring clip too far affects the sensitiveness of the governor as well as the speed, and a radical change should not be made without the advice of the builders. When changes of tension on the spring or in the amount of weight are made in any way, the same amount of change should always be made on each spring or weight, as the case may be. To change the direction of rotation on one of these engines, turn the eccentrics to positions opposite to those for the initial direction, and hang the weight arms according to the directions here given.

Fig. 157 shows the Atlas shaft governor which regulates the supply of steam to the engine by lengthening, or shortening the valve travel, according as the load increases or diminishes.

The movement of the governor parts thus not only controls the speed of the engine under changes of load however wide, but also offers proper conditions for low steam consumption.

The eccentric is pivoted on the same side of the shaft as the crank, and as the eccentric swings across the shaft, decreasing valve travel, the lead is well maintained throughout all working conditions of the engine, insuring prompt opening of the steam ports, with consequent proper steam distribution.

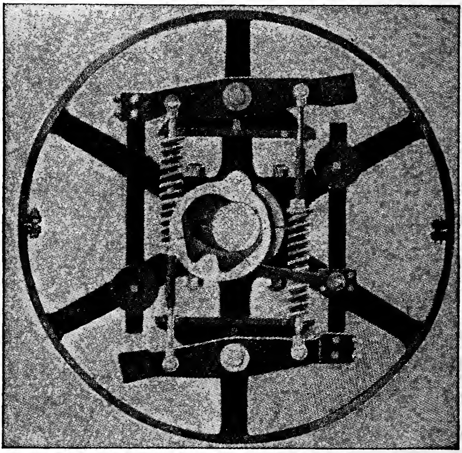


FIG. 157

ATLAS AUTOMATIC SHAFT GOVERNOR

Four-Valve Center Crank Type

The important principle of inertia is made effective in this governor by the manner of weight suspension. This is combined with a very strong centrifugal element, without which no governor is reliable.

The Atlas engine company also supply a so-called inertia, or dead wheel governor for use on their automatic heavy duty (side crank) engines. This governor occupies less space than does the band-wheel type, but is nevertheless a governor of great power, because of the large inertia element stored in the wheel. This wheel is not keyed to the shaft, but is free to turn thereon and by such motion through link connection with the eccentric, combined with the centrifugal action of two weights, the eccentric is shifted across the shaft, changing the angle of advance.

Fig. 158 shows a view of this governor. Both of these governors have spiral springs acting in compression, not in tension.

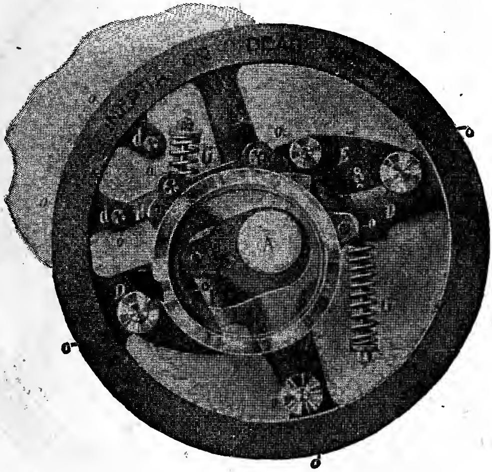


FIG. 158
THE ATLAS AUTOMATIC SHAFT GOVERNOR
Side Crank Type

Figs. 159 and 160 show views of the Armington and Sims shaft governor, which differs in some respects from those already described, notably in that it has two eccentrics, one working inside the other. Referring to Fig. 159 it will be seen that it consists of a wheel which is fixed to the engine shaft, to which are hinged the weights 1, 1; these weights are controlled by springs, one end of the same being seated in a pocked fixed on the spoke of the wheel, or in some cases attached directly to rim of wheel; the inner eccentric, marked C, having ears attached, is placed close to the regulator wheel, and is free to turn upon the shaft; from these ears rods 2, 2 are connected with the weights: on the outside of the inner eccentric and free to turn is placed an eccentric ring D, from which a rod 3 is connected to the toe of one of the weights; on this outer eccentric ring is placed the usual eccentric strap, to which is directly attached the valve rod. To avoid confusion, these are not shown in the cut.

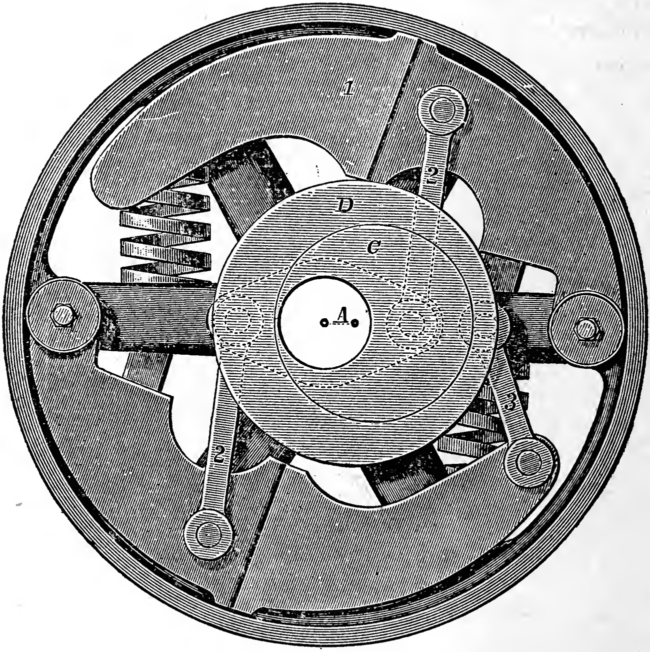


Fig. 159
ARMINGTON AND SIMS SHAFT GOVERNOR

It will be seen that when the engine is running at its greatest velocity the weights, due to the centrifugal force overcoming the springs, will be out, consequently the position of the eccentrics will be as shown in Fig. 159, which gives the valve its least travel and shortest cut-off. The eccentricity of the two combined eccentrics is then the distance shown at A, in the cut.

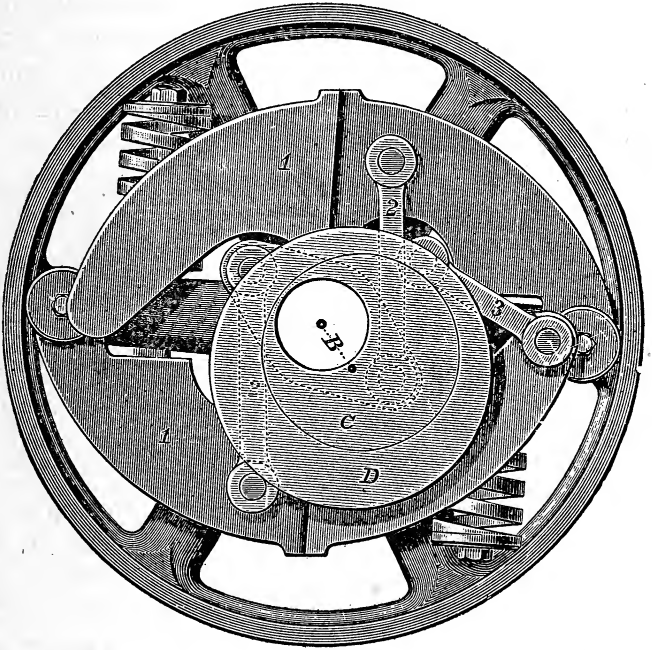


Fig. 160
ARMINGTON AND SIMS SHAFT GOVERNOR

Taking now the other extreme position shown in Fig. 160 when the engine has its heaviest load, requiring later cut off. The position of the weights will then be as shown in the cut, and it will be seen that when the weights are in this position, the inner eccentric has been moved back, and the outer eccentric forward or in the opposite direction, and the eccentricity by this combined movement is increased as shown at B; this is sufficient to allow the steam to follow the piston to about seven-tenths of the stroke. This gives a wide range of valve action, practically from simple lead at A, Fig. 159, to admission during seven-tenths of the stroke, and causes very quick and sensitive action resulting in close regulation. The lead of the valve remains constant at all positions of the eccentrics.

QUESTIONS AND ANSWERS.

316. What inportant features in the operation of an engine are dependent upon a correct adjustment of the valves?

Ans. The efficiency of the engine, the economical use of steam, and the regular and quiet action of the engine.

317. How many different types of valves are there in general use?

Ans. Slide, poppet, rotative, piston, gridiron, etc.

318. What are the basic principles governing the adjustment of the valves of an engine, regardless of the type?

Ans. Admission, cut-off, release, and exhaust closure; each of these functions to occur at the proper moment during one stroke of the piston.

319. Name two important functions of a valve.

Ans. Lap and lead.

320. What is the effect of increasing outside lap?

Ans. Later admission, and an earlier cut off.

321. What results from increasing inside lap?

Ans. Earlier exhaust closure, and an increased conpression.

322. What advantage has an engine of the four valve type over a single valve engine?

Ans. Each individual valve may be adjusted inpendently of the others.

323. If a valve had neither lap nor lead what would be the position of the eccentric relative to the crank?

Ans. 90° ahead of the crank.

324. What is meant by the term "angular advance," and why is it necessary?

Ans. The distance that the high point of the eccentric is set ahead of a line at right angles with the crank. It is necessary in order to give the valve lap, and lead.

325. What is the first function of the valve at the commencement of the stroke?

Ans. Lead, or admission.

326. What is the second function?

Ans. Full port opening.

327. What is the travel of a valve equal to?

Ans. Twice the port opening plus twice the outside lap.

328. What is the third function of the valve?

Ans. Cut off.

329. What is the fourth function?

Ans. Exhaust closure, or compression.

330. What will be the effect if the valve has no inside lap?

Ans. An early release, and no compression.

331. What is meant by "radius of eccentricity?"

Ans. One half the travel of the valve.

332. What is an eccentric?

Ans. A mechanical device for converting rotary into reciprocating motion. Its center of revolution is apart from its center of formation.

333. What is the "throw" of an eccentric?

Ans. The distance from the center of the eccentric to the center of the shaft.

334. What is meant by eccentric position?

Ans. The location of the highest point of the eccentric relative to the center of the crank pin, expressed in degrees.

335. What is valve travel?

Ans. The distance covered by the valve in its movement.

336. What is lap?

Ans. The amount that the ends of the valve project over the edges of the ports when the valve is at mid travel.

337. What is inside lap?

Ans. The lap of the inside, or exhaust edge of the valve over the inside edge of the port.

338. What is outside lap?

Ans. The lap of the outside edge of the valve over the outside edge of the port.

339. What is lead?

Ans. The amount that the port is open when the crank is on the dead center.

340. Why must a valve have outside lap?

Ans. Because admission and cut off are controlled thereby.

341. Why should a valve have inside lap?

Ans. In order that release and compression may be properly controlled.

342. What is the effect of decreasing the angular advance?

Ans. All the important functions of the valve occur later.

343. What results follow from decreasing the travel of the valve

Ans. Less lead, a later admission and release, and an earlier cut off and compression.

344. What is meant by automatic or variable cut off?

Ans. A system in which full boiler pressure is constantly maintained in the valve chest, the speed being regulated by the governor controlling the point of cut off.

345. What is meant by fixed cut off?

Ans. When the point of cut off remains the same, regardless of the load, the speed being regulated by throttling the steam.

346. What three changes must be made in order to cause an earlier cut off on an engine that has a fixed cut off?

Ans. First—Increase the angular advance. Second—Increase the outside lap. Third—Increase the inside lap.

347. What is the first step in valve setting?

Ans. To place the engine on the dead center.

348. What is meant by the dead center?

Ans. When the piston is at the end of the stroke, and the centers of the crank shaft, crank pin, and cross head pin are in line.

349. What rule should be observed in turning an engine to place it on the dead center?

Ans. Always turn it in the direction in which it is to run.

350. Why is this necessary?

Ans. In order to guard against errors which might result from lost motion in the parts.

351. Having placed the engine on the dead center, what is to be done next?

Ans. Adjust the eccentric rod to the proper length?

352. What should be done with the valve before connecting it with the eccentric rod?

Ans. It should be placed at mid travel, and marked.

353. What is necessary before the valve can be placed in its central position?

Ans. The exact amount of outside lap must be known.

354. What amount of lead is usually given to the valve?

Ans. From $\frac{1}{32}$ in. to $\frac{1}{8}$ in. depending upon the size of the engine.

355. What is the function of the governor?

Ans. To properly regulate the speed of the engine.

356. Explain the action of a governor?

Ans. Its action is based upon the principle of the centrifugal, and centripetal forces, which cause the balls or weights attached to the arms, to fly outward or inward as their speed of revolution increases or decreases.

357. In what manner is this movement of the balls caused to regulate the speed?

Ans. In the pendulum or fly ball governor, the motion is transferred by means of levers and rods to the cut off mechanism. In the shaft governor the changes in the position of the weights change the angular advance of the eccentric, thus causing an earlier or later cut off, according as the load is light, or heavy.

358. In what way does the throttling governor regulate the speed of an engine?

Ans. It controls the position of a valve in the steam pipe, opening or closing it according as the engine needs more, or less steam to maintain a regular speed.

359. What is compression?

Ans. If the exhaust port is closed by the valve, just before the piston reaches the end of stroke, a portion of the steam will be entrapped in the cylinder, and being ahead of the piston will be compressed.

360. Is there any advantage in this?

Ans. Yes. The steam thus compressed acts as a cushion for the piston, preventing shock or jar to the moving parts on reaching the end of the stroke.

361. What is an adjustable cut off?

Ans. One in which the point of cut off may be adjusted by a hand wheel attached to the valve stem of a throttling governor.

Definitions

In order to facilitate the study and analysis of indicator diagrams, the following definitions of technical terms, some of which have already been explained in another part of this book, are here given.

Absolute pressure. Pressure reckoned from a perfect vacuum. It equals the boiler pressure plus the atmospheric pressure.

Boiler pressure or gauge pressure. Pressure above the atmospheric pressure as shown by the steam gauge.

Initial pressure. Pressure in the cylinder at the beginning of the stroke.

Terminal pressure (T. P.). The pressure that would exist in the cylinder at the end of the stroke provided the exhaust valve did not open until the stroke was entirely completed. It may be graphically illustrated on the diagram by extending the expansion curve by hand to the end of the stroke. It is found theoretically by dividing the pressure at point of cut off by the ratio of expansion. Thus, absolute pressure at cut off=100 lbs., ratio of expansion=5; then 100÷5=20 lbs., absolute terminal pressure.

Mean effective pressure (M. E. P.). The average pressure acting upon the piston throughout the stroke minus the back pressure.

Back pressure. Pressure which tends to retard the forward stroke of the piston. Indicated on the diagram from a non-condensing engine by the height of the back pressure line above the atmospheric line. In a condensing engine the degree of back pressure is shown by the height of the back pressure line above an imaginary line representing the pressure in the condenser corresponding to the degree of vacuum in inches, as shown by the vacuum gauge.

Total or absolute back pressure, in either a condensing or non-condensing engine, is that indicated on the diagram by the height of the line of back pressure above the line of perfect vacuum.

Ratio of expansion. The proportion that the volume of steam in the cylinder at point of release bears to the volume at cut off. Thus, if the point of cut off is at one-fifth of the stroke, and release does not take place until the end of the stroke, the ratio of expansion, or in other words, the number of expansions, is 5. When the T. P. is known the ratio of expansion may be found by dividing the initial pressure by the T. P.

Wire drawing. When through insufficiency of valve opening, contracted ports, or throttling governor, the steam is prevented from following up the piston at full initial pressure until the point of cut off is reached, it is said to be wire drawn. It is indicated on the diagram by a gradual inclination downwards of the steam line from the admission line to the point of cut off. Too small a steam pipe from boiler to engine will also cause wire drawing, and fall of pressure.

Condenser pressure may be defined as the pressure existing in the condenser of an engine, caused by the lack of a perfect vacuum. As, for instance, with a vacuum of 25 in. there will still remain the pressure due to the 5 in. which is lacking. This will be about 2.5 lbs.

Vacuum. That condition existing within a closed vessel from which all matter, including air, has been expelled. It is measured by inches in a column of mercury contained within a glass tube a little over 30 in. in height, having its lower end open and immersed in a small open vessel filled with mercury. The upper end of the glass tube is connected with the vessel in which the vacuum is to be produced. When no vacuum exists the mercury will leave the tube and fill the lower vessel. When a vacuum is maintained in the condenser, or other vessel, the mercury will rise in the glass tube to a height corresponding to the degree of vacuum. If the mercury rises to the height of 30 in. it indicates a perfect vacuum, which means the absence of all pressure within the vessel, but this condition is never realized in practice; the nearest approach to it being about 28 in.

For purposes of convenience the mercurial vacuum gauge is not generally used, it having been replaced by the Bourdon spring gauge, although the mercury gauge is used for testing.

The vacuum in a condenser is generally maintained by an air pump, although it can be produced and maintained by the mere condensation of the steam as it enters the condenser by allowing a spray of cold water to strike it. The steam when it first enters the condenser drives out the air and the vessel is filled with steam which, when condensed, occupies about 1,600 times less space than it did before being condensed, hence a partial vacuum is produced.

While the vacuum in a condenser cannot be considered as power at all, yet it occupies the anomalous position of increasing, by its presence, the capacity of the engine for doing work. This is owing to the fact that the atmospheric pressure, or resistance which is always ahead of the piston in a non-condensing engine is, in the case of a condensing engine, removed to a degree corresponding to the height of the vacuum, thus making available just so much more of the pressure behind the piston. Thus, if the average steam pressure throughout the stroke is 30 lbs. and there is a vacuum of 26 in. maintained in the condenser, there will be 13 lbs. of resistance per square inch removed from in front of the piston, thus making available 30+13=43 lbs. pressure per square inch.

Absolute zero has been fixed by calculation at 461.2° below the zero of the Fahrenheit scale.

Piston displacement. The space or volume swept through by the piston in a single stroke. Found by multiplying the area of piston by length of stroke.

Piston clearance. The distance between the piston and cylinder head when the piston is at the end of the stroke.

Steam clearance, ordinarily termed clearance. The space between the piston at the end of the stroke and the valve face. It is reckoned in per cent of the total piston displacement.

Horse power (H. P.). 33,000 pounds raised one foot high in one minute of time.

Indicated horse power (I. H. P.). The horse power as shown by the indicator diagram. It is found as follows:

Area of piston in square inches×M. E. P.×piston speed in feet÷33,000.

Piston speed. The distance in feet traveled by the piston in one minute. It is the product of twice the length of stroke expressed in feet, multiplied by the number of revolutions per minute.

R. P. M. Revolutions per minute.

Net horse power. I. H. P. minus the friction of the engine.

Compression. The action of the piston as it nears the end of the stroke, in reducing the volume, and raising the pressure of the steam retained in the cylinder ahead of the piston by the closing of the exhaust valve.

Boyle's or Mariotte's law of expanding gases. "The pressure of a gas at a constant temperature varies inversely as the space it occupies." Thus, if a given volume of gas is confined at a pressure of 50 lbs. per square inch and it is allowed to expand to twice its volume, the pressure will fall to 25 lbs. per square inch.

Adiabatic curve. A curve representing the expansion of a gas which loses no heat while expanding. Sometimes called the curve of no transmission.

Isothermal curve. A curve representing the expansion of a gas having a constant temperature but partially influenced by moisture, causing a variation in pressure according to the degree of moisture or saturation. It is also called the theoretical expansion curve.

Expansion curve. The curve traced upon the diagram by the indicator pencil showing the actual expansion of the steam in the cylinder.

First law of thermodynamics. Heat and mechanical energy are mutually convertible.

Power. The rate of doing work, or the number of foot pounds exerted in a given time.

Unit of work. The foot pound, or the raising of one pound weight one foot high.

First law of motion. All bodies continue either in a state of rest or of uniform motion in a straight line, except in so far as they may be compelled by impressed forces to change that state.

Work. Mechanical force or pressure cannot be considered as work unless it is exerted upon a body and causes that body to move through space. The product of the pressure multiplied by the distance passed through and the time thus occupied is work.

Momentum. Force possessed by bodies in motion, or the product of mass and density.

Dynamics. The science of moving powers or of matter in motion, or of the motion of bodies that mutually act upon each other.

Force. That which alters the motion of a body, or puts in motion a body that was at rest.

Maximum theoretical duty of steam is the product of the mechanical equivalent of heat, viz., 778 ft. lbs. multiplied by the total heat units in a pound of steam. Thus, in one pound of steam at 212° reckoned from 32° the total heat equals 1,146.6 heat units. Then 778×1,146.6 equals 892,054.8 ft. lbs.=maximum duty.

Steam efficiency may be expressed as follows:

$$\frac{\text{Heat converted into useful work}}{\text{Heat expended}}$$

and maximum efficiency can only be attained by using steam at as high an initial pressure as is consistent with safety, and at as large a ratio of expansion as possible. The percentage of efficiency of steam used at atmospheric pressure in a non-expansive engine is very low; as, for instance, the heat expended in the evaporation of one pound of water at 32° into steam at atmospheric pressure=1,146.6 heat units, and the volume of steam so generated=26.36 cu. ft.

One cubic foot of steam at 212° contains energy equal to 144×14.7=2,116.8 ft. lbs., and 26.36 cu. ft.=2,116.8×26.36=55,798.84 ft. lbs., which divided by the mechanical equivalent of heat, viz., 778 ft. lbs.=71.72 heat units, available for useful work. The per cent of efficiency therefore is $\frac{71.72 \times 100}{1,146.6} = 6.2$ per cent. But suppose the initial pressure to have been 200 lbs. absolute, and that the steam is allowed to expand to thirty times its original volume. The heat expended in evaporating a pound of water at 32° into steam at 200 lbs. absolute pressure=1,198.3 heat units, and the volume of steam so generated=2.27 cu. ft. The average pressure during expansion would be 29.34 lbs. per square inch and the volume when expanded thirty times would equal $2.27 \times 30 = 68.1$ cu. ft.

One cubic foot of steam at 29.34 lbs. pressure equals $144 \times 29.34 = 4{,}224.96$ ft. lbs., and 68.1 cu. ft. will equal $4224.96 \times 68.1 = 287{,}719.7$ ft. lbs. of energy, which divided by the equivalent, 778, equals 370.2 heat units, and the per cent of efficiency will be $\frac{370.2 \times 100}{1198.3} = 30.8$ per cent.

Engine efficiency. If the engine is considered merely as a machine for converting into useful work the heat energy in the steam regardless of the cost of fuel, its efficiency may be expressed as follows:

$$\frac{\text{Heat converted into useful work}}{\text{Total heat received in the steam}}$$

Example. Assume an engine to be receiving steam at 95 lbs. absolute pressure, that the consumption of dry steam per horse power per hour equals 20 lbs., that the friction of the engine amounts to 15 per cent, and that the temperature of the feed water is raised from 60° to 170° by utilizing a portion of the exhaust.

In a pound of steam at 95 lbs. absolute there are 1,180.7 heat units, and in a pound of water at 170° there are

138.6 units of heat, but 28.01 of these heat units were in the water at its initial temperature of 60°. Therefore the total heat added to the water by the exhaust steam equals 138.6—28.01=110.59 heat units, and the total heat in each pound of steam to be charged up to the engine is 1,180.7—110.59=1,070.11, and the total for each horse power developed per hour will be 1,070.11×20=21,402.2 heat units.

A horse power equals 33,000 ft. lbs. per minute, or sixty times 33,000=1,980,000 ft. lbs. per hour. From this must be deducted 15 per cent for friction of the engine, leaving 1,683,000 ft. lbs. for useful work. Dividing this by the equivalent, viz., 778 ft. lbs., gives 2,163.2 heat units as the heat converted into one horse power of work in one hour, and the percentage of efficiency of the engine will be

$$\frac{2,163.2\times100}{21,402.2}=10.1 \text{ per cent.}$$

Efficiency of the plant as a whole includes boiler and engine efficiency, and is to be figured upon the basis of

$$\frac{\text{Heat converted into useful work}}{\text{Calorific or heat value of fuel}}$$

Horse power constant of an engine is found by multiplying the area of the piston in square inches by the speed of the piston in feet per minute and dividing the product by 33,000. It is the power the engine would develop with one pound mean effective pressure. To find the horse power of the engine, multiply the M. E. P. of the diagram by this constant.

Logarithms. A series of numbers having a certain relation to the series of natural numbers, by means of which many arithmetical operations are made comparatively easy. The nature of the relation will be understood by considering two simple series, such as the following, one proceeding from unity in geometrical progression and the other from 0 in arithmetical progression:

Geom. series, 1, 2, 4, 8, 16, 32, 64, 128, 256, 512, etc.

Arith. series, 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, etc.

Here the ratio of the geometrical series is 2 and any term in the arithmetical series expresses how often 2 has been multiplied into 1 to produce the corresponding term of the geometrical series. Thus, in proceeding from 1 to 32 there have been 5 steps or multiplications by the ratio 2; in other words, the ratio of 32 to 1 is compounded 5 times of the ratio of 2 to 1. The above is the basic principle upon which common logarithms are computed.

Hyperbolic logarithms. Used in figuring the M. E. P. of a diagram from the ratio of expansion and the initial pressure. Thus, hyperbolic logarithm of ratio of expansion +1 multiplied by absolute initial pressure, and divided by ratio of expansion=mean forward pressure. From this deduct total back pressure and the remainder will be mean effective pressure. The hyperbolic logarithm is found by multiplying the common logarithm by the constant 2.302585. Table 33 gives the hyperbolic logarithms of numbers usually required in calculations of the above nature.

TABLE 33

HYPERBOLIC LOGARITHMS.

No.	Log.	No.	Log.	No.	Log.	No.	Log.	No.	Log.
1.01	0.0099	3.00	1.0986	5.00	1.6094	7.00	1.9459	9.00	2.1972
1.05	0.0487	3.05	1.1151	5.05	1.6194	7.05	1.9530	9.05	2.2028
1.10	0.0953	3.10	1.1341	5.10	1.6292	7.10	1.9600	9.10	2.2083
1.15	0.1397	3.15	1.1474	5.15	1.6390	7.15	1.9671	9.15	2.2137
1.20	0.1823	3.20	1.1631	5.20	1.6486	7.20	1.9740	9.20	2.2192
1.25	0.2231	3.25	1.1786	5.25	1.6582	7.25	1.9810	9.25	2.2246
1.30	0.2623	3.30	1.1939	5.30	1.6677	7.30	1.9879	9.30	2.2310
1.35	0.3001	3.35	1.2090	5.35	1.6771	7.35	1.9947	9.35	2.2354
1.40	0.3364	3.40	1.2238	5.40	1.6864	7.40	2.0015	9.40	2.2407
1.45	0.3715	3.45	1.2384	5.45	1.6956	7.45	2.0018	9.45	2.2460
1.50	0.4054	3.50	1.2527	5.50	1.7047	7.50	2.0149	9.50	2.2513
1.55	0.4382	3.55	1.2669	5.55	1.7138	7.55	2.0215	9.55	2.2565
1.60	0.4700	3.60	1.2809	5.60	1.7228	7.60	2.0281	9.60	2.2618
1.65	0.5007	3.65	1.2947	5.65	1.7316	7.65	2.0347	9.65	2.2670
1.70	0.5306	3.70	1.3083	5.70	1.7405	7.70	2.0412	9.70	2.2721
1.75	0.5596	3.75	1.3217	5.75	1.7491	7.75	2.0477	9.75	2.2773
1.80	0.5877	3.80	1.3350	5.80	1.7578	7.80	2.0541	9.80	2.2824
1.85	0.6151	3.85	1.3480	5.85	1.7664	7.85	2.0605	9.85	2.2875
1.90	0.6418	3.90	1.3610	5.90	1.7750	7.90	2.0668	9.90	2.2925
1.95	0.6678	3.95	1.3737	5.95	1.7834	7.95	2.0731	9.95	2.2976
2.00	0.6931	4.00	1.3863	6.00	1.7918	8.00	2.0794	10.00	2.3026
2.05	0.7178	4.05	1.3987	6.05	1.8000	8.05	2.0857	10.25	2.3273
2.10	0.7419	4.10	1.4010	6.10	1.8083	8.10	2.0918	10.50	2.3514
2.15	0.7654	4.15	1.4231	6.15	1.8164	8.15	2.0988	10.75	2.3749
2.20	0.7885	4.20	1.4351	6.20	1.8245	8.20	2.1041	11.00	2.3979
2.25	0.8110	4.25	1.4469	6.25	1.8326	8.25	2.1102	12.00	2.4849
2.30	0.8329	4.30	1.4586	6.30	1.8405	8.30	2.1162	13.00	2.5626
2.35	0.8544	4.35	1.4701	6.35	1.8484	8.35	2.1222	14.00	2.6390
2.40	0.8755	4.40	1.4816	6.40	1.8563	8.40	2.1282	15.00	2.7103
2.45	0.8961	4.45	1.4929	6.45	1.8640	8.45	2.1342	16.00	2.7751
2.50	0.9163	4.50	1.5040	6.50	1.8718	8.50	2.1400	17.00	2.8332
2.55	0.9361	4.55	1.5151	6.55	1.8795	8.55	2.1459	18.00	2.8903
2.60	0.9555	4.60	1.5260	6.60	1.8870	8.60	2.1518	19.00	2.9444
2.65	0.9746	4.65	1.5369	6.65	1.8946	8.65	2.1576	20.00	2.9957
2.70	0.9932	4.70	1.5475	6.70	1.9021	8.70	2.1633	21.00	3.0445
2.75	1.0116	4.75	1.5581	6.75	1.9095	8.75	2.1690	22.00	3.0910
2.80	1.0296	4.80	1.5686	6.80	1.9169	8.80	2.1747	23.00	3.0355
2.85	1.0473	4.85	1.5790	6.85	1.9242	8.85	2.1804	24.00	3.1780
2.90	1.0647	4.90	1.5892	6.90	1.9315	8.90	2.1860	25.00	3.2189
2.95	1.0818	4.95	1.5994	6.95	1.9387	8.95	2.1916	30.00	3.3782

Steam consumption per horse power per hour. The weight in pounds of steam exhausted into the atmosphere, or into the condenser in one hour, divided by the horse power developed. It is determined from the diagram by selecting a point in the expansion curve just previous to the opening of the exhaust valve, and measuring the absolute pressure at that point. Then the piston displacement up to the point selected, plus the clearance space, expressed in cubic feet, will give the volume of steam in the cylinder, which multiplied by the weight per cubic foot of steam at the pressure as measured will give the weight of steam consumed during one stroke. From this should be deducted the steam saved by compression as shown by the diagram, in order to get a true measure of the economy of the engine. Having thus determined the weight of steam consumed for one stroke, multiply it by twice the number of strokes per minute and by 60, which will give the total weight consumed per hour. This divided by the horse power will give the rate per horse power per hour.

Cylinder condensation and reëvaporation. When the exhaust valve opens to permit the exit of the steam there is a perceptible cooling of the walls of the cylinder, especially in condensing engines when a high vacuum is maintained. This results in more or less condensation of the live steam admitted by the opening of the steam valve; but if the exhaust valve is caused to close at the proper time so as to retain a portion of the steam to be compressed by the piston on the return stroke, a considerable portion of the water caused by condensation will be reëvaporated into steam by the heat and consequent rise in pressure caused by compression.

Ordinates. Parallel lines drawn at equal distances apart across the face of the diagram, and perpendicular to the atmospheric line. They serve as a guide to facilitate the measurement of the average forward pressure throughout the stroke, or the pressure at any point of the stroke if desired.

Eccentric. A mechanical device used in place of a crank for converting rotary into reciprocating motion. An eccentric is in fact a form of crank in which the crank pin, corresponding to the eccentric sheave, embraces the shaft, but owing to the great leverage at which the friction between the sheave and the strap acts, compared with its short turning leverage, it can only be used to advantage for the purpose named above.

Eccentric throw is the distance from the center of the eccentric to the center of the shaft. This definition also applies to the term "radius of eccentricity."

Eccentric position. The location of the highest point of the eccentric relative to the center of the crank pin, measured or expressed in degrees.

Angular advance. The distance that the high point of the eccentric is set ahead of a line at right angles with the crank. In other words, the lap angle plus the lead angle. If a valve had neither lap nor lead, the position of the high point of the eccentric would be on a line at right angles with the crank; as for instance, the crank being at 0° the eccentric would stand at 90°.

Valve travel. The distance covered by the valve in its movement. It equals twice the throw of the eccentric. This refers to engines having a fixed cut off. In the case of an engine with a variable automatic cut off, the travel of the cut off valve is regulated by the governor.

Lap. The amount that the ends of the valve project over the edges of the ports when the valve is at mid travel.

Outside or steam lap. The amount that the end of the valve overlaps or projects over the outside edge of the steam port.

Inside lap. The lap of the inside or exhaust edge of the valve over the inside edge of the port.

Lead. The amount that the port is open when the crank is on the dead center. The object of giving a valve lead is to supply a cushion of live steam which, in conjunction with that already confined in the clearance space by compression, shall serve to bring the moving parts of the engine to rest quietly at the end of the stroke, and also quicken the action of the piston in beginning the return stroke.

Compression. Closing of the exhaust passage before the steam is entirely exhausted from the cylinder. A certain quantity of steam is thus compressed into the clearance space.

Throttling governor. Used to regulate the speed of engines having a fixed cut off. The governor controls the position of a valve in the steam pipe, opening or closing it according as the engine needs more or less steam in order to maintain a regular speed.

Automatic or variable cut off. In engines of this type the full boiler pressure is constantly in the valve chest and the speed of the engine is regulated by the governor controlling the point of cut off, causing it to take place earlier or later, according as the load on the engine is lighter or heavier.

Fixed cut off. This term is applied to engines in which the point of cut off remains the same regardless of the load, the speed being regulated by a throttling governor as explained above.

Isochronal or shaft governor. This device in which the centrifugal and centripetal forces are utilized, as in the fly ball governor, is generally applied to automatic cut off engines having reciprocating or slide valves. It is attached to the crank shaft, and its function is to change the position of the eccentric, which is free to move across the shaft within certain prescribed limits, but is at the same time attached to the governor. The angular advance of the eccentric is thus increased or diminished, in fact is entirely under the control of the governor, and cut off occurs earlier or later according to the demands of the load on the engine.

Adjustable cut off. One in which the point of cut off may be regulated or adjusted by hand by means of a hand wheel and screw attached to the valve stem, the supply of steam being regulated by a throttling governor.

QUESTIONS AND ANSWERS.

362. What is absolute pressure?

Ans. Pressure reckoned from a perfect vacuum.

363. What is gauge pressure?

Ans. Pressure above atmospheric pressure.

364. What is initial pressure?

Ans. Pressure in the cylinder at the beginning of the stroke.

365. What is terminal pressure?

Ans. Pressure in the cylinder at the end of the stroke.

366. What is mean effective pressure (M. E. P.)?

Ans. The average pressure acting upon the piston throughout the stroke.

367. What is back pressure?

Ans. Pressure tending to retard the forward stroke of the piston.

368. What is absolute back pressure?

Ans. Back pressure measured from a perfect vacuum.

369. What is the ratio of expansion?

Ans. The relative volume of steam in the cylinder at point of release, compared to volume at cut off.

370. What is wire drawing of steam?

Ans. Restricted passage of the steam caused by too small a steam pipe.

371. What is condenser pressure?

Ans. Pressure existing in the condenser caused by the lack of vacuum.

372. What is vacuum?

Ans. That condition existing within a closed vessel from which all matter, including air has been expelled.

373. What is absolute zero?

Ans. 461.2° below zero Fahr.

374. What is piston displacement?

Ans. The space swept through by the piston in a single stroke.

375. What is piston clearance?

Ans. The distance between the piston and cylinder head at the end of the stroke.

376. What is steam clearance?

Ans. The distance between the piston at end of stroke, and the valve face.

377. What is a horse power (H. P.)?

Ans. 33,000 lbs. raised one foot in one minute of time.

378. What is indicated horse power (I. H. P.)?

Ans. The horse power as shown by the indicator diagram.

379. What is piston speed?

Ans. The distance in feet traveled by the piston in one minute.

380. Give the rule for figuring the horse power?

Ans. Area of piston in square inches × M. E. P. × piston speed ÷ 33,000.

381. What is net horse power?

Ans. I. H. P. minus engine friction.

382. Define Boyle's law of expanding gases?

Ans. Pressure at constant temperature varies inversely as the space it occupies.

383. What is an adiabatic curve?

Ans. The curve of expanding gas that loses no heat while expanding.

384. What is an isothermal curve?

Ans. The curve of an expanding gas of constant temperature, but influenced by moisture.

385. What is an expansion curve?

Ans. The curve traced upon the diagram by the indicator pencil.

386. Define the first law of thermodynamics.

Ans. Heat and mechanical energy are mutually convertible.

387. What is power?

Ans. The rate of doing work.

388. What is the unit of work?

Ans. The foot pound, viz., the raising of one pound, one foot high.

389. Define the first law of motion?

Ans. All bodies continue either in a state of rest, or of uniform motion in a straight line, unless compelled by impressed forces to change that state.

390. What is work, mechanically considered?

Ans. Pressure × distance passed through × time.

391. What is momentum?

Ans. Mass × density.

392. What is dynamics?

Ans. The science of moving powers.

393. What is force?

Ans. That which alters the motion of a body, or puts in motion a body that was at rest.

394. Define the maximum theoretical duty of steam?

Ans. Mechanical equivalent of heat × total heat units in a pound of steam?

395. How may steam efficiency be expressed?

Ans. Heat converted into useful work÷heat expended.

396. How may engine efficiency be expressed?

Ans. Heat converted into useful work÷total heat received in the steam.

397. How may efficiency of the plant be expressed?

Ans. Heat converted into useful work÷calorific, or heat value of the fuel.

398. What is horse power constant?

Ans. The power the engine would develop with one pound M. E. P.

399. What is meant by steam consumption per H. P. per hour?

Ans. Weight in pounds of steam used÷H. P. developed?

400. What are ordinates as applied to indicator diagrams?

Ans. Parallel lines drawn at equal distances across the face of the diagram, perpendicular to atmospheric line.

The Indicator

One of the greatest aids to the economical operation of the steam engine is the indicator, and it is the privilege of every engineer to have at least an elementary, if not a thorough knowledge of its principles and working. The time devoted to the study of the indicator, and in its application to the engine, is time well spent, and in the end will well repay the student of steam engineering.

Inventor. The indicator was invented, and first applied to the steam engine by James Watt, whose restless genius was not satisfied with a mere outside view of his engine as it was running, but he desired to know more about the action of the steam in the cylinder, its pressure at different portions of the stroke, the laws governing its expansion after being cut off, etc. Watt's indicator, although crude in its design and construction, contained embodied within it all of the principles of the modern instrument.

Principles. These principles are:

First. The pressure of the steam in the engine cylinder throughout an entire revolution, against a small piston in the cylinder of the indicator, which in turn is controlled or resisted in its movement by a spring of known tension, so as to confine the stroke of the indicator piston within a certain small limit.

Second. The stroke of the indicator piston is communicated by a multiplying mechanism of levers and parallel motion to a pencil moving in a straight line. The distance through which the pencil moves being governed by the pressure in the engine cylinder and the tension of the spring.

Third. By the intervention of a reducing mechanism and a strong cord, the motion of the piston of the engine throughout an entire revolution is communicated to a small drum attached to, and forming a part of the indicator. The movement of the drum is rotative, and in a direction at right angles to the movement of the pencil. The forward stroke of the engine piston causes the drum to rotate through part of a revolution and at the same time a clock spring connected within the drum is wound up. On the return stroke the motion of the drum is reversed, and the tension of the spring returns the drum to its original position and also keeps the cord taut.

To the outside of the drum a piece of blank paper of suitable size is attached and held in place by two clips. Upon this paper the pencil in its motion up and down traces a complete diagram of the pressures and other interesting events transpiring within the engine cylinder during the revolution of the engine. In fact the diagram traced upon the paper is the compound result of two concurrent movements. First, that of the pencil caused by the pressure of the steam against the indicator piston; second, that of the paper drum caused by, and coincident with, the motion of the engine piston. The upper end of the indicator cylinder is always open to the atmosphere, the steam acting only upon the underside of the small piston, and when the cock connecting the cylinders of the engine and indicator is closed, both ends of the indicator cylinder are open to atmospheric pressure, and the pencil then stands at its neutral position. If now the pencil is held against the paper and the drum rotated either by hand or by connecting it with the cord, a horizontal line will be traced. This line is called the atmospheric line, meaning the line of atmospheric pressure, and it is a very important factor in the study of the diagram.

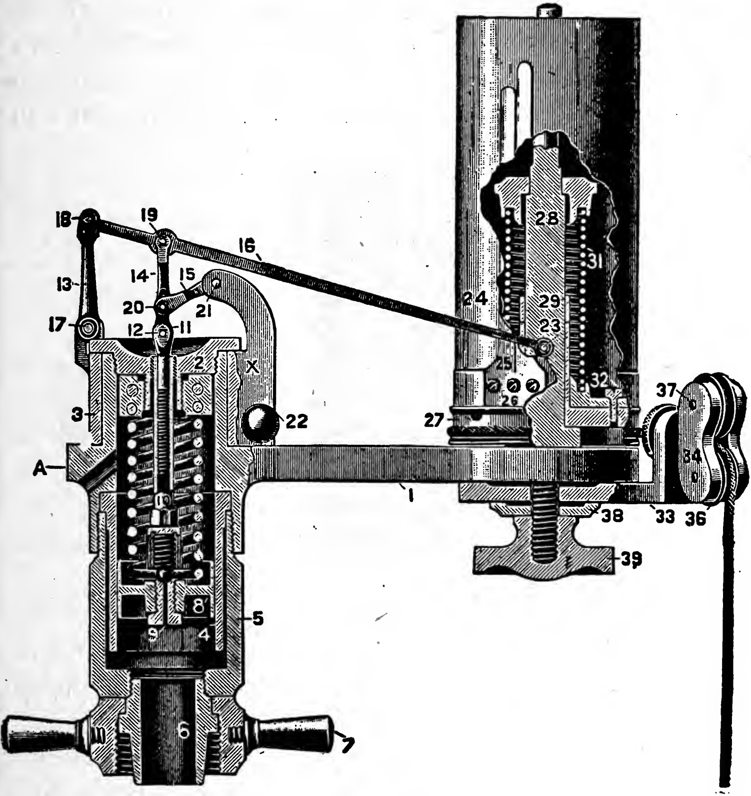


FIG. 161
SECTIONAL VIEW CROSBY INDICATOR

Figure 161 shows a sectional elevation of the Crosby indicator, and will give the student a good idea of its interior construction. Figure 162 shows the spring.

If the engine is a non-condensing engine the pencil in tracing the diagram will, or at least, should not fall below the atmospheric line at any point, but will on the return stroke trace a line called the line of back pressure at a distance more or less above the atmospheric line and very nearly parallel with it. If the engine is a condensing engine the pencil will drop below the atmospheric line while tracing the line of back pressure on the diagram, and the distance this line is below the atmospheric line will depend upon the number of inches of vacuum in the condenser.

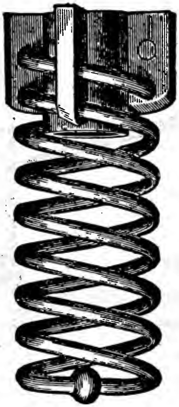


FIG. 162
CROSBY INDICATOR SPRING

As before stated, the length of stroke of the indicator piston, and the pencil movement as well is controlled by a spiral steel spring which acts in resistance to the pressure of the steam. These springs are made of different tensions in order to be suitable to different steam pressures and speeds, and are numbered 20, 40, 60, etc., the number meaning that a pressure per square inch in the engine cylinder corresponding to the number on the spring will cause a vertical movement of the pencil through a distance

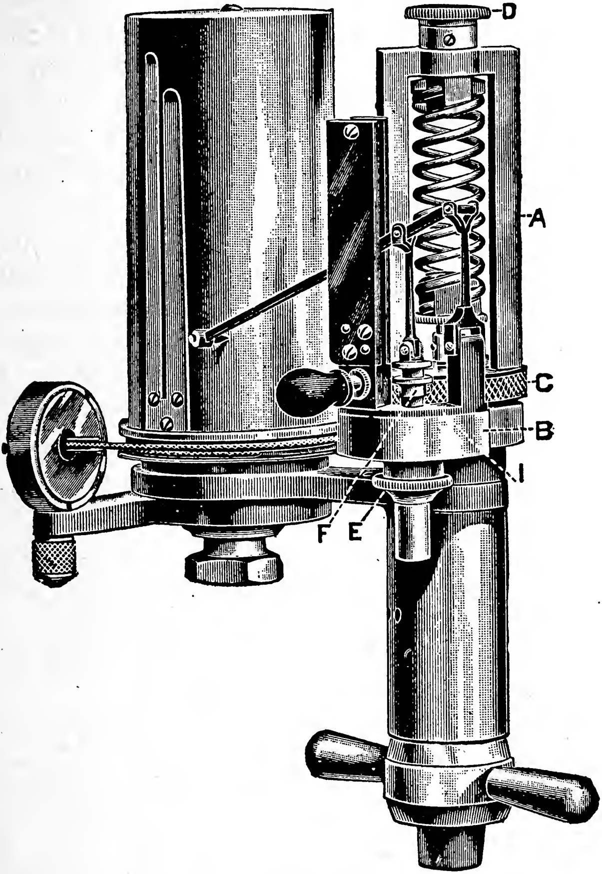


FIG. 163

IMPROVED TABOR INDICATOR WITH OUTSIDE CONNECTED SPRING

Ashcroft Mfg. Co., N. Y.

of one inch. Thus, if a number 20 spring is used and the pressure in the cylinder at the commencement of the stroke is 20 lbs. per square inch, the pencil will be raised one inch, or if the pressure is 30 lbs., the pencil will travel 1½ in., and if there is a vacuum of 20 in. in the condenser. the pencil will drop ½ in. below the atmospheric line for the reason that 20 in. of vacuum corresponds to a pressure of about 10 lbs. less than atmospheric pressure or an absolute pressure of about 4 lbs. If a 60 spring is used a pressure of 60 lbs. in the engine cylinder will be required to raise it one inch, or 90 lbs. to raise it 1½ inches. Figure 163 shows the Tabor indicator, with outside connected spring. The spring is placed on top of the small cylinder, which arrangement removes it from the influence of the heat of the steam in the cylinder, and leaves it subject only to the temperature of the surrounding atmosphere. It is claimed that as a result of this, the accuracy of the spring is insured, and that no allowance need to be made in its manufacture for expansion caused by the high temperature to which it is subject when located within the cylinder. Another good feature of this design is, that the spring can be easily removed without disconnecting any one part of the instrument in case it is desired to change springs.

Figure 164 shows a view of the American indicator with outside connected spring.

The spring remains cool and can be changed without removing the piston or allowing the indicator to cool. It is in line with the piston, and is supported by two standards connected at the top by a cross bar, having a screw for attaching the upper end of the spring. The lower end is connected to the top of the piston. The piston rod and connections are made hollow and as light as possible to prevent error from the inertia of the moving parts.

To remove the spring, unscrew the nurled nut at the top until the end of the spring is released, and turn the spring

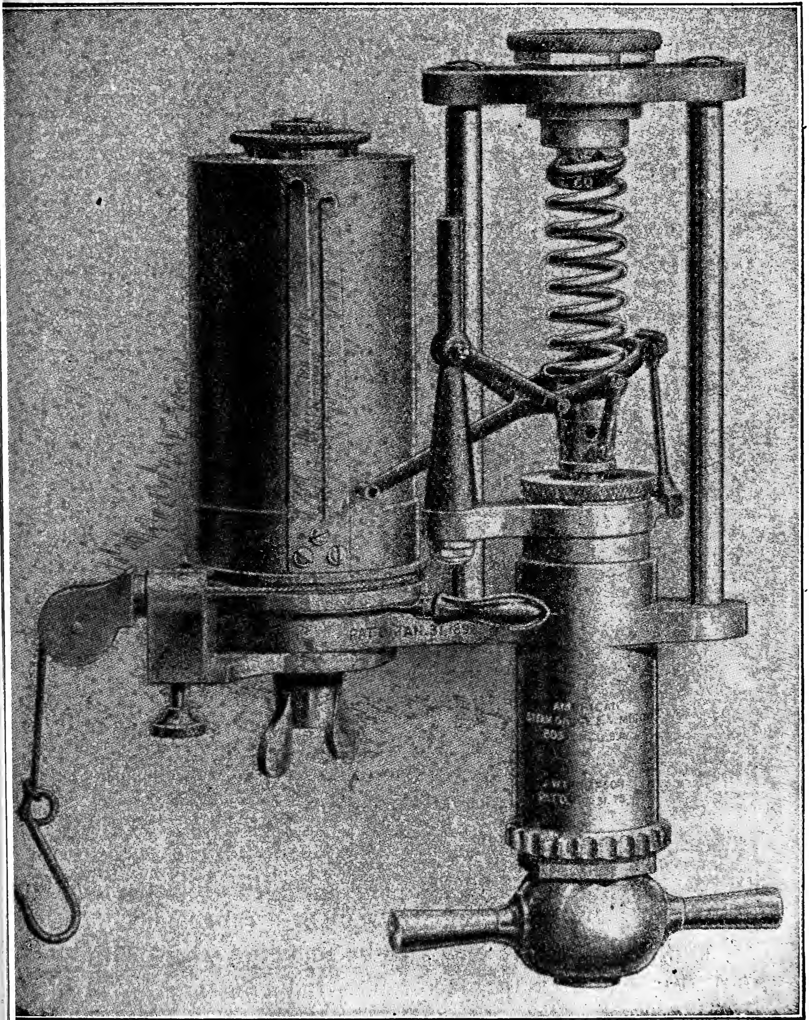


FIG. 164
AMERICAN OUTSIDE SPRING INDICATOR

until it is free from the base. To prevent the piston from turning while removing the spring, insert a steel pin, furnished with the indicator, in holes in the spring base.

Figure 165 shows the three-way cock for attaching the indicator to the cylinder of the engine.

Reducing Mechanism. Probably the only practically universal mechanism for reducing the motion of the crosshead is the reducing wheel, a device in which, by the employment of gears and pulleys of different diameters, the motion is reduced to within the compass of the drum, and the device is applicable to almost any make of engine, whether of high or low speed. Some makers of indicators attach the reducing wheel directly to the indicator, thus producing a neat and very convenient arrangement.

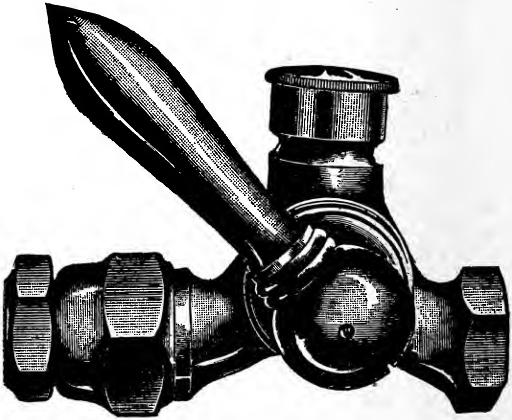


FIG. 165

Figure 166 illustrates a Crosby reducing wheel with the indicator mounted in place. The reducing motion is entirely distinct from the indicator, and terminates at the bottom with a swivel joint by which it is attached to the indicator cock. On top, the arm of the reducing motion is finished to receive the swivel joint of the indicator itself, which is attached, as shown in the figure, in such a position

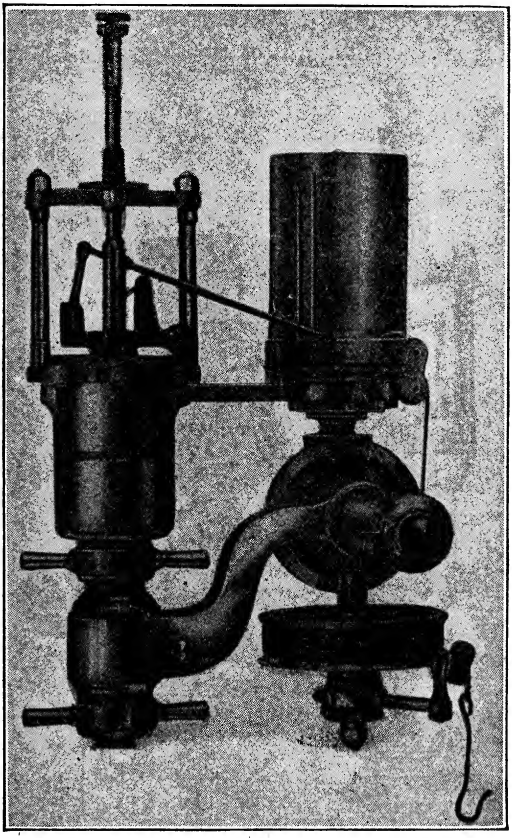


Fig. 166

CROSBY INDICATOR AND REDUCING MOTION ASSEMBLED

that the cord pulley of the indicator drum is directly over the small sheave about which the cord from the paper barrel is passed. Fig. 167 shows this position to better advantage. The principal object sought and attained by this design and arrangement of reducing wheel and indicator is rigidity. As the wheel or its frame does not depend from the indicator proper, the strength of the combination is good. The pull of the cross-head is resisted and

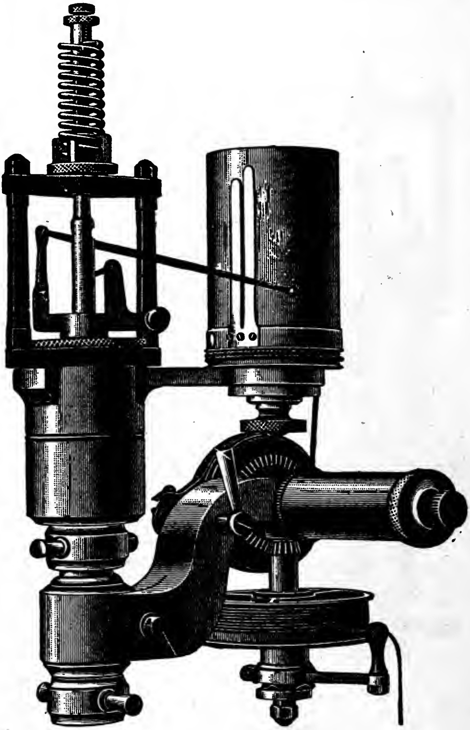


Fig. 167

the cord is returned by the helical spring A, Fig. 168, contained in the horizontal spring case B. Adjustment of this spring is made by the milled head which closes the outer end of the case and carries one end of the spring. This head slips over the squared end of the horizontal shaft D, and is secured in place by the thumb screw E. The shaft is carried on ball bearings F and G in the frame H, and

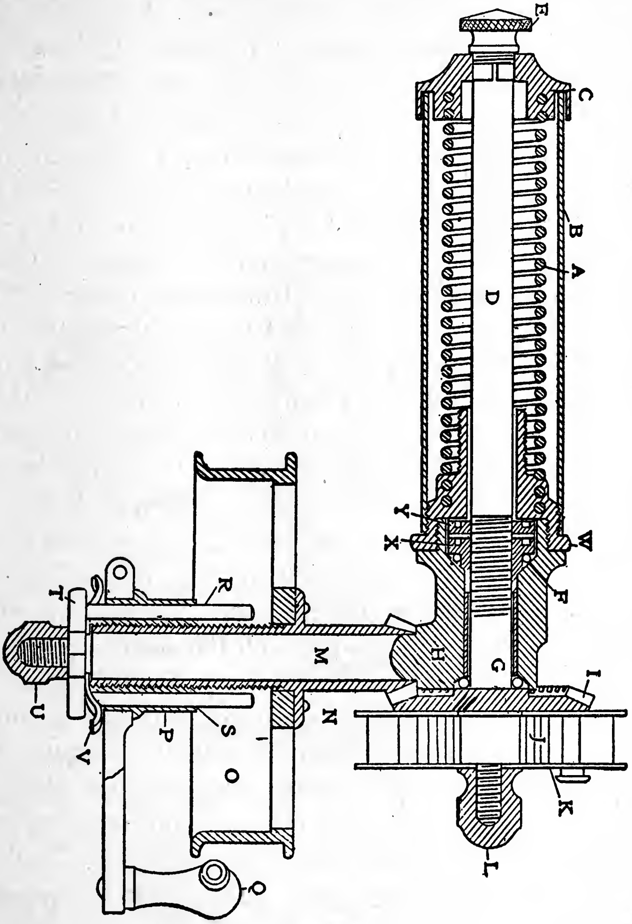


Fig. 168

SECTIONAL VIEW OF CROSBY REDUCING MOTION

the web and gear I of the small sheave are a part of the horizontal shaft. On this small sheave are the bushings J which are taken off or added to, to get the proper ratio of motion for the paper drum. The bushings are held in place by a flange K, and thumb screw L.

The main frame H is a casting, and from it depends the vertical shaft M, upon which revolves the sleeve N carrying the smaller of the bevel gears and the cord-receiving sheave O. Beneath the large sheave and turning therewith is a screw engaging with the cross-head P which carries the cord guide Q. The cross-head is prevented from turning by two guide pins R and S, upon which it slides, and these pins are supported by a plate T at the bottom of the vertical shaft. This plate is secured by an hexagonal nut U. The arm carrying the cord guide is clamped around the cross-head, and may be turned to lead in any direction. Above the bottom plate T is a stiff four-leaved spring V to receive the cross-head without shock in case it is allowed to run way down, as it would by the breakage of the cord.

When ready to use the reducing motion, first mount the wheel frame on the indicator cock, and the indicator on the frame, as shown in Figs. 166 and 167. Then, after determining the size of bushing to go on the small sheave, put it in place and secure it under the flange K with the nut L. Pass the cord from the paper drum once around the small sheave, slipping the end through the hole in the flange and securing it to the cleat thereon. Be sure that there is enough cord on the large sheave to accommodate the longest engine stroke for which the wheel will be used. Then pass the end through the guide pulley Q and there fasten it to resist the tension of the spring, leaving enough more cord to reach the cross-head of the engine. The cross-head P of the reducing motion must be just low enough for the guide pulley to lead the cord from the bottom flange of the large sheave, as shown in Fig. 166. Then the cord from the paper drum must be brought down and around the small sheave to the hole in the flange, so that while the motion is at rest, as in Fig. 166, it will pass around the sheave, in the direction of its travel, far enough to pass over the circumference of the bushing on the sheave. Before fastening to the cleat, the cord must be drawn taut, so that the paper drum will have just left its rest stop.

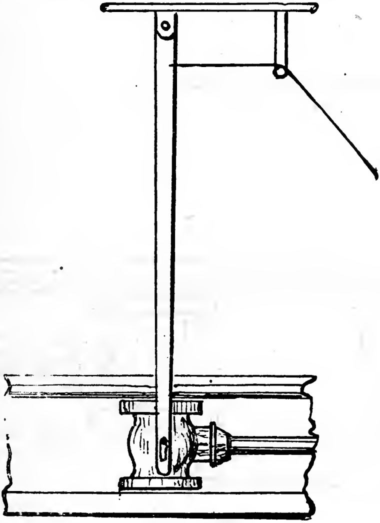


Fig. 169

To alter the tension on the recoil spring of this reducing motion, remove the nut E, and grasping the milled head C between the thumb and forefinger, pull it from the case far enough to allow it to be turned. Then twist it to the right, if more tension is desired, and allow it to slide onto the square end of the horizontal shaft again and replace the nut. To reduce the tension of the spring, allow the milled head to fall back to the left.

If at any time the horizontal shaft D appears to be loose in its bearings and needs adjustment, remove nut E, grasp the head W in the fingers and back it off from its place. This will carry the spring, case and milled head from their positions and expose the adjustment X and its lock nut Y. Back off the lock nut and adjust the bearings with the other nut, after which lock the two nuts together again. Always try the bearings again after setting up on the lock nut.

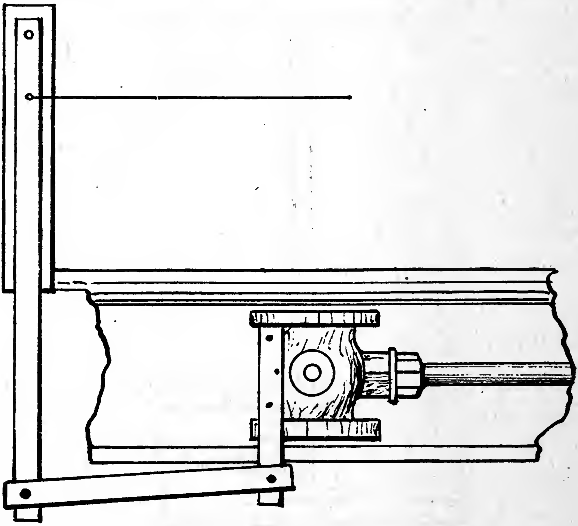


FIG. 170

One of the most accurate and easily applied devices for reducing the motion of the piston is the wooden pendulum in its various forms. (See Figs. 169, 170 and 171.) It consists of a flat strip of pine or other light wood of a length not less than one and a half times the stroke of the engine, and if made longer it will be better. It should be from ¾ to ⅞ in. thick and have an average width of about 4 in. If the engine to be indicated is horizontal the bar or pendulum is to be pivoted at a fixed point directly above, and in line with the side of the crosshead, as that is generally the most convenient point of attachment. The pivot can be fixed to a permanent standard bolted to the frame of the engine, or it may be secured to the ceiling of the room or even to a post fastened to the floor. If the engine is vertical the bar can be pivoted to the wall of the room, or a strong post firmly secured to the floor. The connection with the crosshead is best accomplished by means of a short bar or link. A convenient length for this bar is one-half the stroke of the engine. To locate the correct point for the pivot, assuming the length of the short bar to be one-half the length of the stroke, proceed as follows:

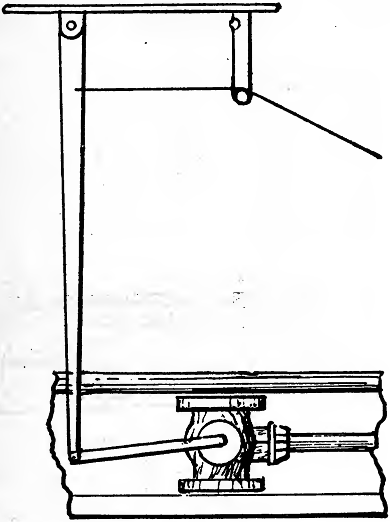


Fig. 171

Place the engine on the center with the crosshead at the end of the stroke towards the crank. Then having previously bored a hole for the pivot in one end of the pendulum bar, and in the other end a hole for connecting with the link, suspend the pendulum by a temporary pin, as a large wood screw, directly above and in line with the stud or bolt hole which has previously been tapped into the crosshead at any convenient point. The pendulum should be temporarily suspended at such a height that when it hangs perpendicular the hole in its lower end will line up accurately with the hole or stud in the crosshead. Now swing the pendulum in either direction a distance equal to

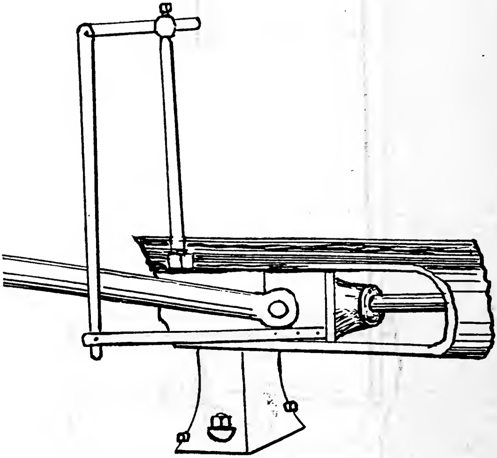


FIG. 172

the length of the link (one-half the stroke of the engine) from the crosshead connection and note the distance that the bottom hole is above a straight edge laid horizontal and in line with the center of the stud in the crosshead. This will give the total vibration of the free end of the link from a line parallel with the line of the engine, and the permanent location of the pivot should be one-half of this distance below the temporary point of suspension. This will allow the link to vibrate equally above and below the center of its connection with the crosshead. Fig. 172 shows a complete connection of this character.

Sometimes the end is slotted and thus directly connected to the stud in the crosshead, dispensing with the link. In this case it is necessary to locate the pivot at a point perpendicular to the center of travel of the stud in the crosshead. (See Fig. 169.) The link connection is to be preferred, however. The cord can be attached to the pendulum at a point near the pivot which will give the desired length of diagram. This point can be determined by multiplying the length of the pendulum by the desired length of diagram and dividing the product by the stroke. For convenience these terms should be expressed in inches. Thus, assume stroke of engine to be 48 in., length of pendulum 1½ times length of stroke=72 in. Desired length of diagram 3 in. Then 72×3÷48=4.5 in., which is the distance from center of pivot to point of connection for the cord. This can be either a small hole bored through the pendulum, or a wood screw to which the cord can be attached. From this point the cord should be led over a guide pulley located at such height that when the pendulum is vertical the cord will leave it at right angles. After leaving the guide pulley the cord can be carried at any angle desired. One of the neatest and most easily applied devices for reducing the motion of the crosshead is the pantograph. (See Fig. 173.) No dimensions are essential except that it shall be made reasonably strong of some light, tough variety of wood, and that the pins and holes be nicely fitted to each other so that while the movement may be free there shall at the same time not be too much lost motion. The pantograph should be of such capacity that it will just close up nicely when the engine is at mid stroke and open out nicely when at its extreme travel. The two ends, C and D, are each to be fitted with a pin extending through far enough so that pin C can be hooked into a hole or socket on the crosshead, while pin D rests in a socket in the top of a post secured to the floor at a point opposite the center of travel of the crosshead, and of such height as will allow the pantograph to lie in a horizontal position. Also the distance of the post from the guides must be adjusted so as to allow the device to close up at mid stroke, and open out at full stroke without any straining of the parts. The point F of connection for the cord will always have a motion parallel with, and simultaneous with, that of the crosshead; the pin to which the cord is attached can be set in any one of the holes that will give the desired length for the diagram. The motion given by this device is accurate, although it may become necessary in some cases, especially with long stroke engines, to introduce a guide pulley to carry the cord from the pantograph.

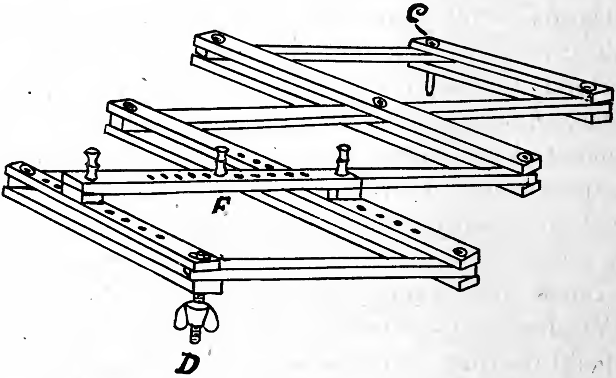


FIG. 173

Attaching the Indicator. The cylinders of most engines at the present time are drilled and tapped for indicator connections before they leave the shop, which is eminently proper, as no engine builder, or purchaser either, should be satisfied with the performance of a new engine until after it has been accurately tested and adjusted with the indicator.

The main requirements in these connections are that the holes shall not be drilled near the bottom of the cylinder where water is likely to find its way into the pipes, neither should they be in a location where the inrush of steam from the ports will strike them directly, nor where the edge of the piston is liable to partly cover them when at its extreme travel. An engineer before he undertakes to indicate an engine should satisfy himself that all these requirements are fulfilled. Otherwise he is not likely to obtain a true diagram. The cock supplied with the indicator is threaded for one-half inch pipe, and unless the engine has a very long stroke it is the practice to bring the two end connections together at the side or top of the cylinder, and at or near the middle of its length, where they can be connected to a three way cock. The pipe connections should be as short and as free from elbows as possible in order that the steam may strike the indicator piston as nearly as possible at the same moment that it acts upon the engine piston.

The work of taking diagrams is very much simplified by having both ends of the cylinder connected to one common tee or a three way cock as above described, but for long stroke engines there should be two indicators, one for each end and the diagrams should be taken simultaneously if it is desired to adjust the valves by the indicator. In this case an assistant would be required to manipulate one of the instruments.

The pipes should always be thoroughly blown out by allowing the steam to blow through the open cock during several revolutions of the engine, before connecting the indicator. If this is not done there is a moral certainty that grit and dirt will get into the cylinder of the indicator, where the presence of the least atom of grit will cause the delicate instrument to work badly.

Selecting a Spring. The proper number of spring to use depends upon the boiler pressure in the case of an automatic cut off engine, but for an engine with a fixed cut off and throttling governor the number of the spring to be selected will depend upon the initial pressure in the cylinder. A convenient rule is to select a spring numbered one-half as high as the pressure; for instance, if the boiler pressure is 80 lbs., use a No. 40 spring, which will give a diagram 2 in. in height.

Care of the Instrument. The indicator should be cleaned and oiled both before and after using. The best material for wiping it is a clean piece of old soft muslin of fine texture, as there is not so much liability of lint sticking to or getting into the small joints. Use good clock oil for the joints and springs, and before taking diagrams it is a good practice to rub a small portion of cylinder oil on the piston and the inside of the cylinder, but when about to put the instrument away these should be oiled with clock oil also. None but the best cord should be used for connecting the paper drum with the reducing motion, as a cord that is liable to stretch will cause trouble. Suitable cord and also blank diagrams can generally be secured from firms manufacturing and selling indicators. After the indicator has been screwed on to the cock connecting with the pipe, the cord must be adjusted to the proper length before hooking it on to the drum. This must be done while the engine is running, by taking hold of the loop on the cord connected with the reducing motion with one hand, and with the other hand grasp the hook on the short cord attached to the drum, then by holding the two ends near each other during a revolution or two it will be seen whether the long cord needs to be shortened or lengthened.

The length of the diagram is determined by the point of connection of the cord to the pendulum as has been heretofore explained. Care should be exercised in placing the paper on the drum, to see that it is stretched tight and firmly held by the clips. The pencil point having been first sharpened by rubbing it on a piece of fine emery cloth or sand paper should be adjusted by means of the pencil stop with which all indicators should be provided, so that it will have just sufficient bearing against the paper to make a fine, plain mark. If the pencil bears too hard on the paper it will cause unnecessary friction and the diagram will be distorted. The best method of ascertaining this fact and also whether the travel of the drum is equally divided between the stops, is to place a blank diagram on the drum, connect the cord and while the engine makes a revolution hold the pencil against the paper. Then unhook the cord, remove the paper and if the travel of the drum is not divided correctly it can be changed.

Having thus arranged all the preliminary details, place a fresh blank on the drum, being careful to keep the pencil out of contact with it, connect the cord, open the cock admitting steam to the indicator and after the pencil has made a few strokes to allow the cylinder to become warmed up, then gently swing it around to the paper drum and hold it there while the engine makes a complete revolution. Then move the pencil clear of the paper, close the cock and unhook the cord. Now trace the atmospheric line by holding the pencil against the paper while the drum is revolved by hand. This method of tracing the atmospheric line is preferable to that of tracing it immediately after closing the cock and while the drum is still being moved by the engine, for the reason that there is not so much liability of getting the atmospheric line too high owing to the presence of a slight pressure of steam remaining under the indicator piston for a second or two just after closing the cock; also the line drawn by hand will be longer than one drawn while the drum is moved by the motion of the engine, and will therefore be more readily distinguished from the line of back pressure.

Having secured a truthful diagram, it now remains to take as many as are desired, and if the object is to set the valves of the engine, the diagrams from each end of the cylinder should follow each other as quickly as possible in order that the conditions of load and steam pressure may be the same. When the indicator is connected so that diagrams can be taken from both ends without changing it, the above conditions can generally be realized. But if diagrams can only be taken from one end at a time, the only way to arrive at correct conclusions in relation to the adjustment of the valves will be to see that the boiler pressure is practically the same at the time of taking diagrams from either end and that the position of the governor is also the same, assuming that the load on the engine is practically constant. This applies of course to an automatic cut off.

As soon as the diagrams are taken the following data should be noted upon them: The end of the cylinder, whether head or crank; boiler pressure; and time when taken. Other data can be added afterwards. If the engine is an automatic cut off of the Corliss type, and the point of cut off on one end does not coincide with the other, the difference can generally be adjusted while the engine is running by changing the length of the rods extending from the governor to the tripping device. These rods are, or should be, fitted with right and left threads on the ends for this purpose. Any changes in the valves, such as giving them more lead, compression, etc., and which necessitates changing the length of the reach rods connecting them with the wrist plate, will have to be made while the engine is stopped, although with slow speed engines and the exercise of caution it is possible to make alterations in these rods while the engine is running.

DIAGRAM ANALYSIS.

Before proceeding to the study of indicator diagrams, it is well to define the different points, lines and curves of a diagram in order that the young student may get these matters firmly fixed in his mind, and that there may be no confusion.

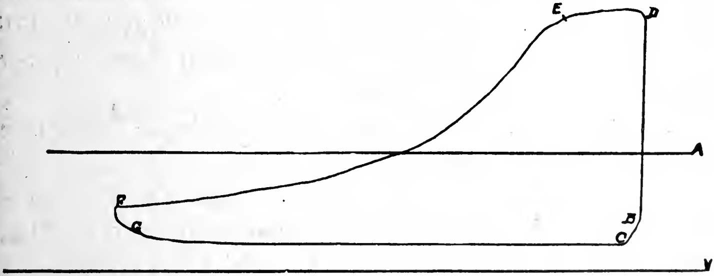


FIG. 174

Referring to Fig. 174, from C to B is the compression curve, which in this particular diagram is somewhat lighter than is ordinarily given to engines. This is due to the fact that the engine from which Fig. 174 was taken is of slow speed and long stroke, and therefore does not require as heavy a cushion as does a high speed, short stroke engine.

From B to D is the admission line, which being practically perpendicular to the atmospheric line A, shows sufficient lead and ample port area. From D to E is the steam line. Cut off occurs at E, and from E to F is the expansion curve. At F the point of release is quite sharply defined, as it should be. From F to G is the exhaust line, and from G to C the line of back pressure, sometimes called the line of counter pressure for the reason that the pressure indicated by it acts counter or in opposition to the forward pressure of the steam on the piston. This engine is a simple condensing engine, and the nearness of the back pressure line to the line of perfect vacuum V shows that an excellent vacuum was maintained in the condenser.

It should be noted that all of the diagrams referred to in the following pages are reproductions of actual diagrams taken under ordinary working conditions. Figs. 175, 176 and 177 are reproductions of diagrams taken from a Cooper Corliss non condensing engine.

The dimensions of the engine are as follows: Diameter of piston, 34 in.; length of stroke, 42 in.

At the time Fig. 175 was taken the boiler pressure was 105 lbs., but it was increased a few months later to 110 lbs., as was the load also, when Figs. 176 and 177 were taken.

These diagrams are fairly good working cards, but there are some defects which it might be well to point out.

Referring to Fig. 175, it will be noticed that the initial pressure at s, on the head end, is 94 lbs., while on the crank end the initial pressure runs up to 99 lbs. above the atmospheric line.

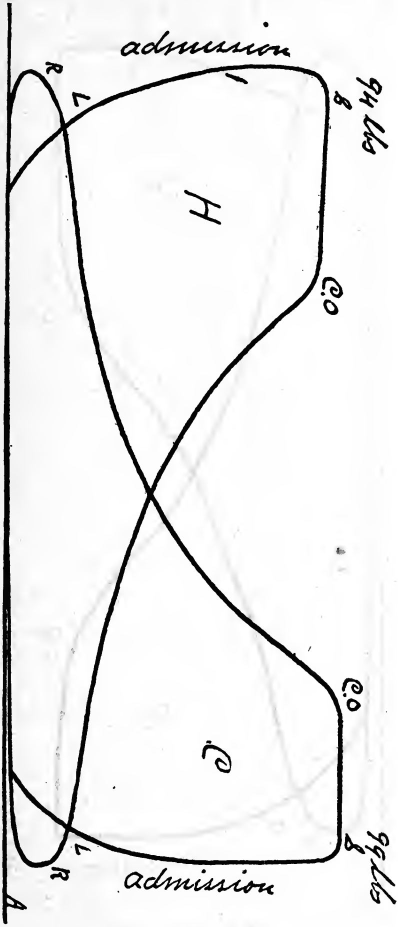


FIG. 175

This decrepancy is caused by insufficient lead on the head end, plainly shown by the inclination inward of the admission line, and the rounded corner at s.

The compression is excessive, especially on the head end, as indicated by the curve at L.

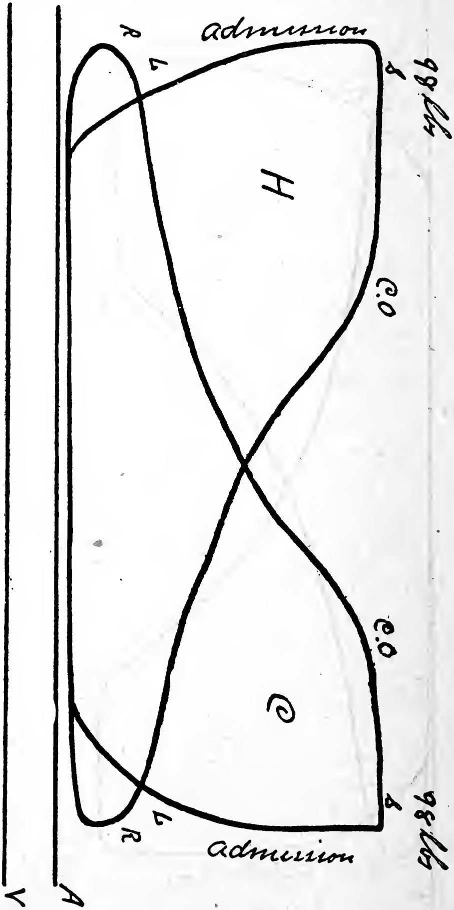


FIG. 176

These two factors, lead and compression, may always be distinguished by observing the character of the admission line.

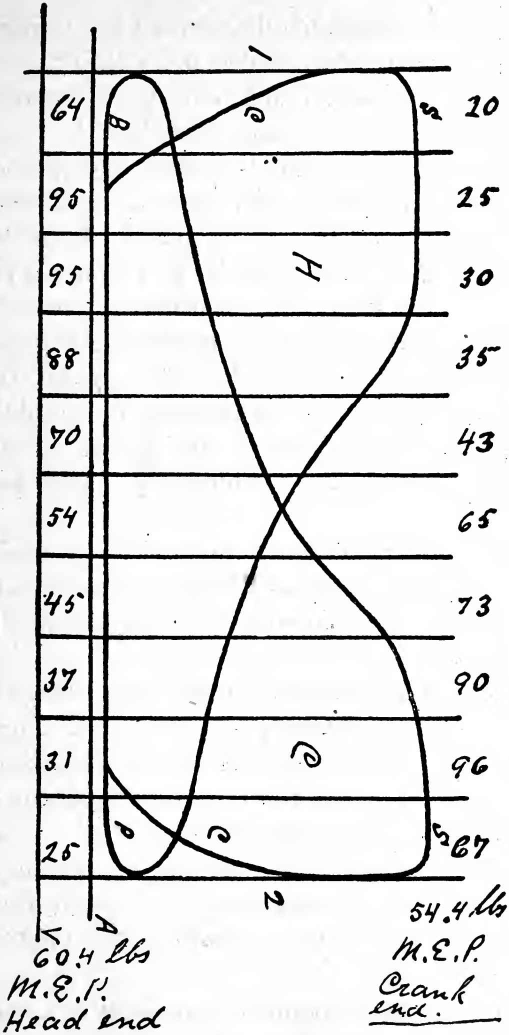


FIG. 177

A curve, such as shown at L, denotes too early closure of the exhaust, and the rounded corner at s, and inward inclination of the admission line from l to s is a pretty sure indication that the steam lead is not sufficient.

The diagram from the crank end is much better, although there is more compression than is needed.

The cut-off is not equalized, that on the crank end takes place earlier in the stroke than the same event does on the head end, and the consequence is that the M. E. P. for the head end is 60.4 lbs. while the M. E. P. for the crank end is 54.4 lbs. (see Fig. 177), a difference of 6 lbs. more pressure per square inch being exerted against the piston as it travels from the head end of the cylinder, than there is exerted against it as it travels from the crank end, and this unequal strain, or push is felt by the moving parts of the engine 160 times a minute, the engine making 80 R. P. M.

It is unnecessary to again emphasize the need of care and good judgment in the adjustment and equalizing of the points of cut off. On an engine, a very simple calculation will be sufficient.

The diameter of the piston under consideration is 34 in., area 907.92 sq. in., pressure per sq. in. 6 lbs. Then 907.92 $\times 6 = 5447.52$ lbs., which divided by 2,000=2.72 tons more pressure against the piston when traveling from the head end, than there is on the return stroke.

Figure 176 is a much better appearing diagram, the lead on the head end having been slightly increased, thus practically equalizing the initial pressure, and improving the rounded corner at s.

The variation in the points of cut off at c. o. still exists, and the compression is still too great.

As before stated, the three diagrams shown are all from the same engine and figure 177 is introduced for the purpose of illustrating the method of obtaining the M. E. P. by the use of ordinates, as they are termed, they being the vertical lines, drawn in order to facilitate the measurement of the pressures shown by the steam line, and expansion curve above the line of atmospheric pressure, or if the engine is a condensing engine these measurements must be made from the vacuum line, as drawn by the indicator pencil.

The first requisite in this process is to correctly draw these ordinates, spacing them equidistant apart.

First draw lines 1 and 2 at each end of the diagram, and perpendicular to the atmospheric line.

Then measure the distance between these two lines, and this distance, whatever it may be, should be divided into ten equal spaces, although it is not absolutely necessary that there should be ten spaces, as any other number of spaces will serve, provided they are of equal width.

Ten is usually chosen, owing to the fact that this number is the most convenient to use in calculations.

In Fig. 177 the distance across the face of the diagram from line 1 to line 2 is found to be nearly $3\frac{15}{16}$ in. or 63 sixteenths, which divided by 10 equals a little more than 6 sixteenths or $\frac{3}{8}$ in.

Therefore the width of the spaces will be $\frac{3}{8}$ in. and the vertical lines should be drawn that distance apart.

Having drawn the lines, the next step is to measure the pressure by using the scale corresponding to the spring that was used. These different scales 40, 50, 60, 80, etc. are supplied by the makers of the indicator, and should accompany each outfit.

Again referring to Fig. 177, beginning at the head end, lay the scale along the middle of the first space with the zero mark on the compression curve, and the pressure from c to s is found to be 64 lbs.

This is the effective pressure exerted against the piston at this point in the stroke notwithstanding the fact that the boiler pressure was 110 lbs.

Right here the query might arise, why this decrease in pressure? and it might be well to explain the cause of it.

The actual work area of the diagram is only that portion confined within its own boundary lines as traced by the pencil when in motion. The lines of atmospheric pressure, and vacuum are traced by hand, and their purpose is to facilitate measurements only.

Therefore the pressure can only be measured from points c and s in the two spaces at the beginning of the stroke.

It is evident therefore that too much compression, or too much lead tends to lessen the work area of the diagram at the beginning of the stroke, thus placing a limit on the capacity of the engine for doing work.

Measurements for pressure on the remaining spaces of Fig. 177 may be made from the atmospheric line, except that when measuring the diagrams from the crank end the same rule governs the measurement of the pressure in the space at the beginning of the stroke, viz., measure from the compression curve, c, to the steam line s. The pressure in this case is found to be 67 lbs.

In space two (crank end) the pressure measured from the atmospheric line is found to be 96 lbs., and on the head end it is 95 lbs.

After all the ten spaces have been measured, say from the head end, and the results added together, it is found that the total is 604, which divided by 10 equals 60.4 lbs., which is the M. E. P. for that end.

Proceeding in the same manner with the crank end the M. E. P. is found to be 54.4 lbs.

The cause of this difference of 6 lbs. between the two diagrams, and its effect upon the engine has already been explained.

In order to obtain the average M. E. P. it is necessary to add the two results together and divide the sum by 2, thus: $60.4+54.4\div2=57.4$ lbs.

Before proceeding to calculate the H. P. there is another factor to be considered, viz., the back pressure, which is always present in a greater or less degree, and which in Fig. 177 is found to be 4 lbs.; ascertained by measuring with the scale the distance from the atmospheric line to the line of back pressure, B. P.

This 4 lbs. is to be deducted from the average M. E. P.; thus $57.4-4=53.4$ lbs., which is the net pressure for power calculations.

It should be noted that the number of the spring used on Fig. 177 was 60.

The process of ascertaining the M. E. P. by ordinates, and also by the use of the planimeter will be enlarged upon later on in this discussion.

Great care should be exercised in these calculations, especially in taking measurements of the pressure by the use of ordinates, on diagrams taken from engines using steam of high initial pressure, 150 to 250 lbs. per sq. in., where springs of high tension (80 to 125 lbs.) are required.

The lines on such scales are so close together, and the figures are so small, that it is very difficult to distinguish them. However, there are other and more simple methods that can be used, and the results are just as accurate.

Figures 178 and 179 are reproductions of diagrams taken from a 14x30 in. engine, and are introduced for the purpose of showing the need of care and good judgment in the selection of a spring.

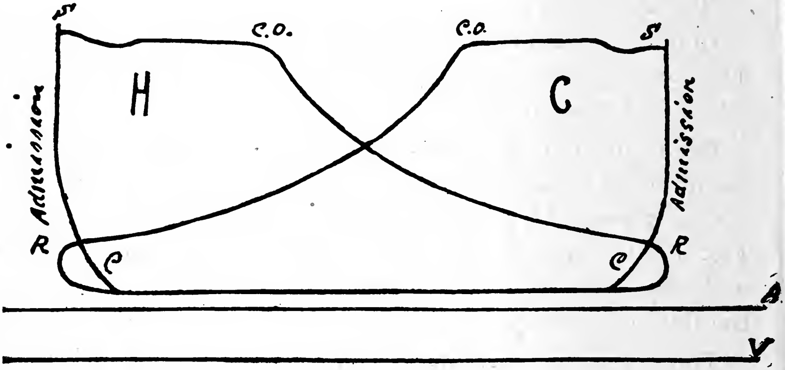


Fig. 178

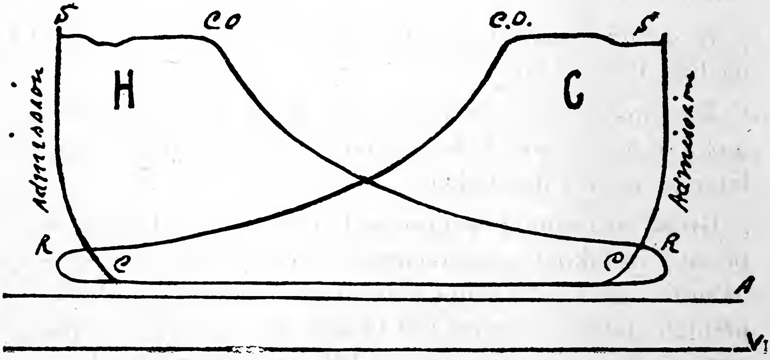


Fig. 179

The boiler pressure at the time the cards were taken was 90 lbs. per sq. in. but a 60 spring was used, when a much better diagram might have been secured with a 50 spring.

The fluctuations in the steam lines S to C O are caused by the spring being of too high tension, and they are brought about in the following manner.

Initial pressure is high enough at the beginning of the stroke to run the admission line up to 82 lbs. on the head end of Fig. 178 and to 78 lbs. on the crank end, but the high tension of the 60 spring immediately causes the indicator piston to drop slightly, and remain so until about 1-12th of the stroke is completed, when the steam pressure slowly overcomes the tension of the spring, and the pencil again slowly rises, and remains steady until cut off occurs.

The same defect appears in Fig. 179 taken from this engine running with a somewhat lighter load.

The engine is 14x30 in. running at a speed of 100 R. P. M. The exhaust steam passes through heating coils in a dry kiln, which accounts for the high back pressure lines on the diagrams.

Aside from the above mentioned defects the diagrams are good. The valves appear to be properly adjusted for compression, lead, and cut off, these events all occurring in their regular order.

Unequal cut off. The unequal division of forces, or pressures acting alternately upon the piston of a steam engine, to propel it back and forth, may be likened, in a measure, to two men working a ratchet drill, or pumping a hand car.

If one of the men is a small, weak man and his partner is a big strong-armed man, the result will be that the big man will do most of the work, even though the small man may be willing enough, and does all that he is able to do.

With an engine, this unequal division of pressures, in other words, unequal cut off, may be easily remedied through the instrumentality of the indicator.

The bad effects of unequal cut off will make themselves felt, and heard also in time. The engine will not develop the power that it is capable of developing, the coal consumption per H. P. per hour will be greater than it should be, and it will be a much harder task to keep the engine running smoothly under such conditions than it would be if the cut off was equalized, and the mean effective pressures were the same or nearly so for each stroke.

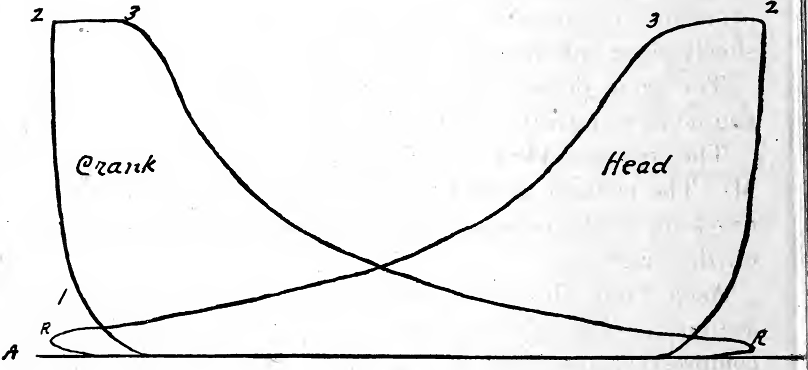


FIG. 180

Figure 180 is a reproduction of a diagram taken from a Corliss engine 30 in. bore by 48 in. stroke, running 82 R. P. M.

One of the minor defects of the diagram is that it occupies too much space, meaning that it is too high, and too long. The fault in height is caused by using too light a spring in the indicator, allowing the indicator piston to rise too high.

The boiler pressure at the time the cards were taken was 120 lbs., but the spring used was a 50 lbs. spring, when it should have been a 60 lb.

The spring, or scale as it is often designated, should be selected in accordance with the boiler, or gauge pressure.

For instance, if the gauge pressure is 120 lbs. a 60 spring should be used. If the gauge pressure is 90 or 100 lbs. a 50 spring is strong enough.

A good rule to observe in this matter is, to use a spring, or scale of as nearly one-half the gauge pressure as it is possible to get it.

The diagram will then be about 1½ in. in height, which is much more easily measured than one that is two inches in height, such as Fig. 180 shows.

Of course it must be understood that these measurements are to be made from the atmospheric line A.

The cause of the excessive length of the diagram is too long a stroke of the reducing motion. This is easily remedied also.

A convenient length for a diagram is from two to two and a half inches.

The lead and compression lines shown at 1-1, Fig. 180, are practically perfect. It is plain from these lines that lead begins where compression lets go, which is as it should be.

The admission lines 1 to 2 on both crank and head ends are good also, and indicate prompt opening of the steam ports.

The release at R′ also shows good economy, and there is practically no back pressure on the piston for either stroke.

But here is where our favorable criticism of Fig. 180 ends, except that we might say with reference to the expansion curve, 3 to R′, of the crank end diagram, that it compares favorably with the theoretical expansion curve.

The main trouble with the engine, as shown by the diagram is unequal cut off, that on the head end being considerably later in the stroke than it should be, while cut off on the crank end occurs a little too soon.

This is also shown by measurement of the mean effective pressures, that on the crank end being 42.1 pounds while that from the head end is 48.2 pounds, showing that there is 48.2 minus 42.1 equals 6.1 pounds more M. E. P. on the head end than on the crank end.

This means that the piston which is 30 inches in diameter having an area of 706.86 square inches has 706.86x 6.1 equals 4311.84 pounds more pressure exerted against its surface during the stroke from the head of the cylinder than it has on the opposite stroke.

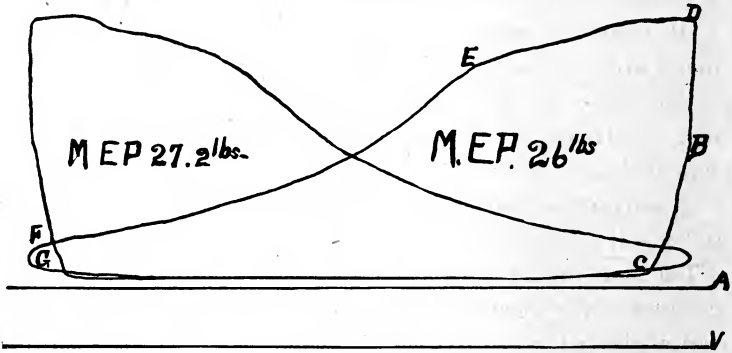


FIG. 181

It also means that the strains are unequally divided so far as regards the moving parts of the engine. The engineer in charge reports that he has lots of trouble with his engine in his efforts to keep it running quietly, but this is to be expected considering the unequal cut offs, and the difference in the pressures upon the piston at each stroke.

The H. P. developed by the engine as indicated by Fig. 180 is 564.8.

Effects of Wire Drawing. Fig. 181 is from a Buckeye automatic cut off engine having a shaft governor and, what is termed a riding cut off, that is the cut off valve slides to and fro on the back of the main valve. The engine is horizontal non-condensing, the cylinder being 28 in. bore by 56 in. stroke, and, at the time the diagram was taken, developed 357.58 horse power with a piston speed of 728 ft. per minute. The steam consumption per I. H. P. per hour was 26 pounds, a rather high rate, but this was owing to the fact that the engine was located too far from the boilers, and as there were a large number of elbows in the steam pipe the pressure was greatly reduced at the engine. Thus wire drawing of the steam was caused, which is plainly indicated by the downward inclination of the steam line, D E.

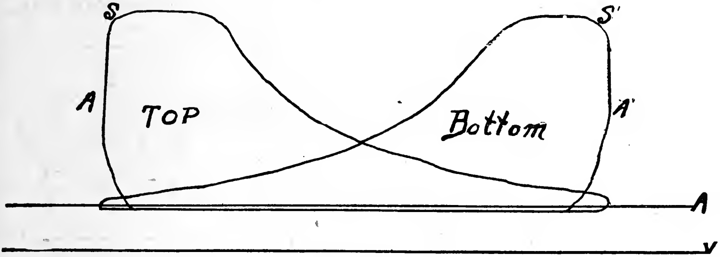


FIG. 182

In a well proportioned engine having a steam pipe of sufficiently large area, the steam line should parallel the atmospheric line up to the point of cut off. Fig. 181 indicates proper release of the steam at F, and the back pressure from G to C, which is 3 pounds above the atmospheric line, shows a reasonably free passage of the exhaust steam.

Figs. 182 to 187 illustrate diagrams from three new vertical Corliss engines supplying power for an electric lighting plant, which the author was requested to test and adjust after they had been in operation a few months. The valves had previously been set by the erecting engineer at the time the engines were set up. Each one of these engines exhausted into a separate condenser of the Jet type, into which the condensing water was forced under pressure, and from which the overflow was discharged by gravity into a sewer. There was no air pump and as a consequence the vacuum maintained was very low, usually from 10 to 15 in., and at times still less, so that the beneficial results of condensing were only partially realized.

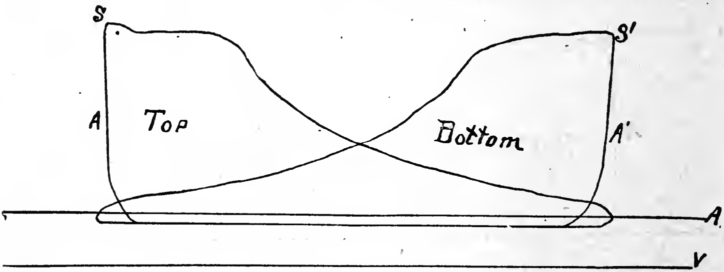


FIG. 183

For convenience the diagrams from each engine will be treated in numerical order, beginning with engine No. 1. This engine was 24x48 inches, running 70 R. P. M., with a boiler pressure of 68 pounds. A 40 spring was used in the indicator. The principal defect was the lack of sufficient lead on both ends, as indicated by the inclination inward of the admission lines and the rounded corners of the steam lines at the beginning of the stroke. (See Fig. 182.) There was also more compression, especially on the bottom end, than was necessary, considering the size of the engine, and the speed. The necessary changes having been made, the indicator was again applied and the diagram, Fig. 183, was obtained, which shows the distribution of the steam to be satisfactory, although at the time of taking this diagram the boiler pressure was only 60 pounds, while it should have been 68 or 70 pounds, because with the latter pressure still better results could have been attained. The I. H. P. was 235 and the steam used per I. H. P. per hour was 18 pounds.

Fig. 184 is the original diagram from engine No. 2, and shows bad valve adjustment all around, with the exception of lead on the top end. The variation in the points of cut off is the worst feature; cut off taking place on the bottom at 29 per cent. of the stroke, while on the top end it does not occur until the piston has traveled through 42 per cent. of the stroke. There is more compression also than is needed. This engine was 18x42 inches, running at a speed of 78 R. P. M., and the steam consumption, according to diagram Fig. 184, was 33 lbs. per I. H. P. per hour. Having equalized the cut off and reduced the compression by making the necessary changes in the valve gear, the indicator was again applied, resulting in diagram Fig. 185, which may be considered practically perfect. The boiler pressure was 68 pounds and the spring used was a No. 40. The steam consumption was reduced to 22 pounds per I. H. P. per hour as compared to 33 lbs. in Fig. 184.

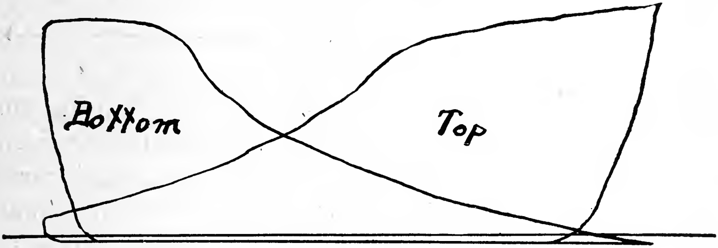


Fig. 184

Figs. 186 and 187 represent diagrams from engine No. 3, which was the same size as No. 1, viz., 24x48 in., and running at 72 R. P. M. The original diagram, Fig. 186, shows too little lead on both ends, but especially on the top. There is also lack of compression on the bottom end. The boiler pressure was 60 pounds, and the scale of spring 40. Fig. 187, taken after the necessary adjustments had been made, shows much better valve performance. The horse power developed was 251 and the steam consumption was 20.5 pounds per I. H. P. per hour. The rather high rate of steam consumption for this engine as compared with engine No. 1, which was the same size but consumed only 18 pounds of steam per I. H. P. per hour, was due to two causes. First, a low vacuum; second, low initial pressure necessitating a late cut off.

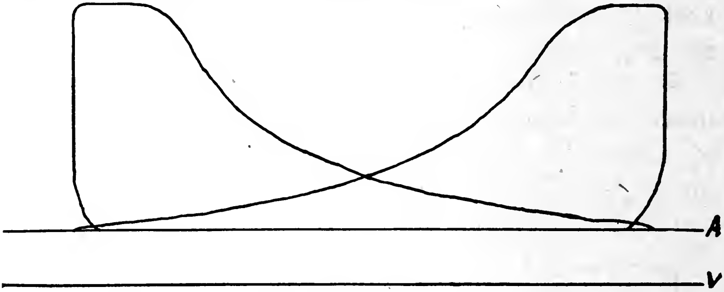


FIG. 185

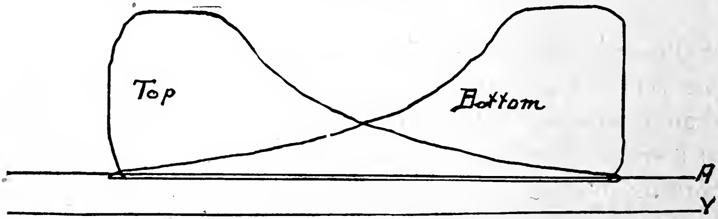


FIG. 186

Figs. 188 to 191 are reproductions of diagrams taken from a new horizontal non-condensing engine which had been running about eight or nine months when it fell to the author's lot to apply the indicator to the engine, not only for the purpose of adjusting the valve motion, but also to make a series of tests for the purpose of ascertaining the amount of power delivered by the engine to each one of several different departments which were receiving power from this source.

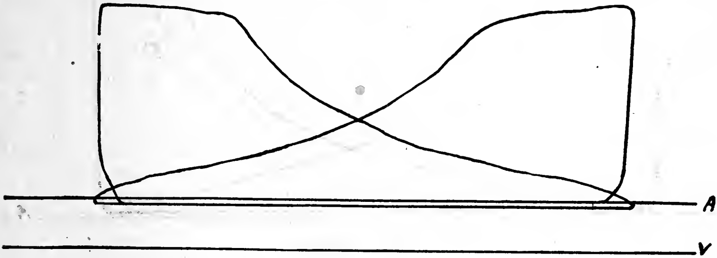


Fig. 187

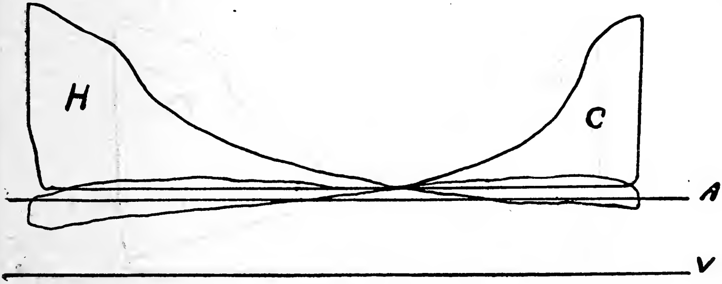


Fig. 188

The dimensions of the engine were as follows: bore of cylinder, 32 in.; stroke, 5 ft. At the time Fig. 188 was taken the engine was making 62 R. P. M. and the boiler pressure was only 50 pounds. A 30 spring was used. Although the load on the engine was very light at the time, yet the diagram served as a guide to some extent in setting the valves, and by taking off the bonnets from the valve chests and making the necessary changes in the adjustment by the marks on the valves a pretty fair job was made of it, as will be seen by referring to Fig. 189. The reducing motion was a pantograph, and as it is very easy to vary the travel of the paper drum with this motion, diagrams of different lengths were taken until the one which appeared to be the most satisfactory was obtained. The slight hump in the expansion curve immediately after cut off, was probably caused by a speck of dirt or grit which momentarily checked the indicator piston on the down

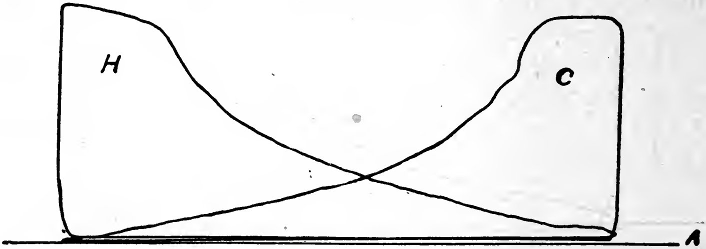


Fig. 189

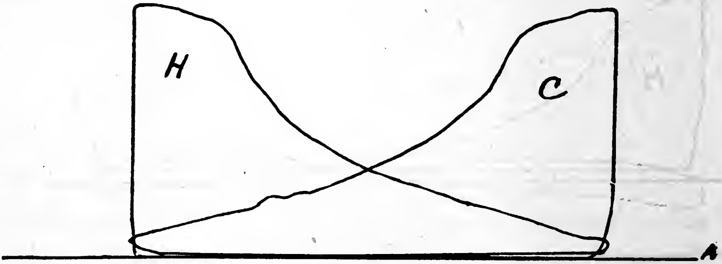


Fig. 190

stroke. The compression on the crank end is not sufficient and the exhaust valve rod on that end was slightly lengthened, resulting in the production of diagram Fig. 190. In this diagram the familiar hump in the crank end expansion curve reappears, but in a different location, being nearer the end of the stroke. It will also be noticed that the length of Fig. 190 has been considerably reduced from that of Fig. 188, it being about one inch shorter.

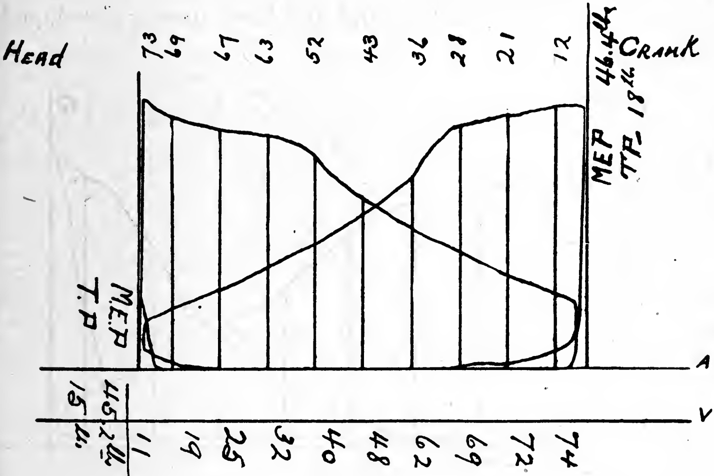


FIG. 191

The boiler pressure and the load on this engine were gradually increased from time to time, from 50 pounds, and a light load (as shown by Fig. 188) to 60 pounds and 335 horse power (as indicated by Fig. 189 taken some three months later), and when Fig. 191 was taken, about two years and eight months later, the boiler pressure had been increased to 87 pounds and the I. H. P. was over 700.

Diagram Fig. 191 shows good economy in the use of steam in spite of the fact that the cut off occurs rather late.

There is no back pressure worth mentioning, the back pressure line forming part of the atmospheric line through the largest part of the stroke. The reason for this is that the areas of the exhaust ports, as well as the exhaust pipe were sufficiently large to permit a free passage for the steam. The exhaust pipe, also, was made as short and direct as possible and all superfluous elbows were dispensed with. The steam consumed per I. H. P. per hour as per diagram Fig. 191 was 22.3 pounds, and the horse power developed was 710.6.

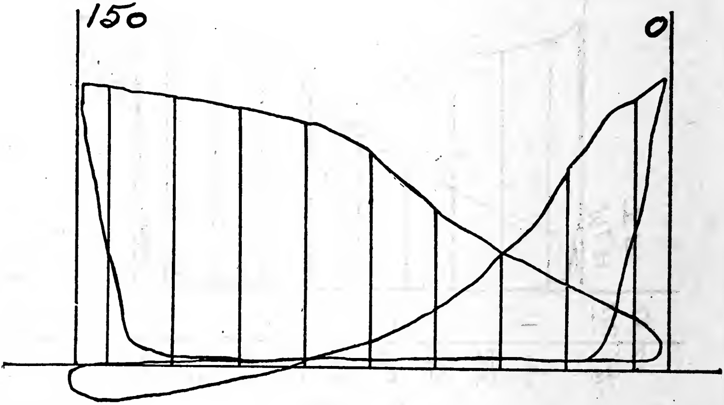


FIG. 192

Figs. 192 to 194, inclusive, represent diagrams from a Buckeye engine 24x48 inches, and are introduced for the purpose of emphasizing the need of caution and good judgment in setting valves by the indicator when the load on the engine is variable. Fig. 192, which was the first to be taken, would seem to indicate that the valve was badly adjusted, but when Fig. 193 was taken immediately afterwards, the cause of the trouble became apparent. The engine was furnishing power for operating an electric street railway on a small scale, and the variation in the points of cut off was caused by the stopping and starting of the cars.

Fig. 193 is a notable example of the quick and delicate action of the shaft governor, as it will be seen that during four successive revolutions there was a different load each time, as shown by the diagram from the crank end.

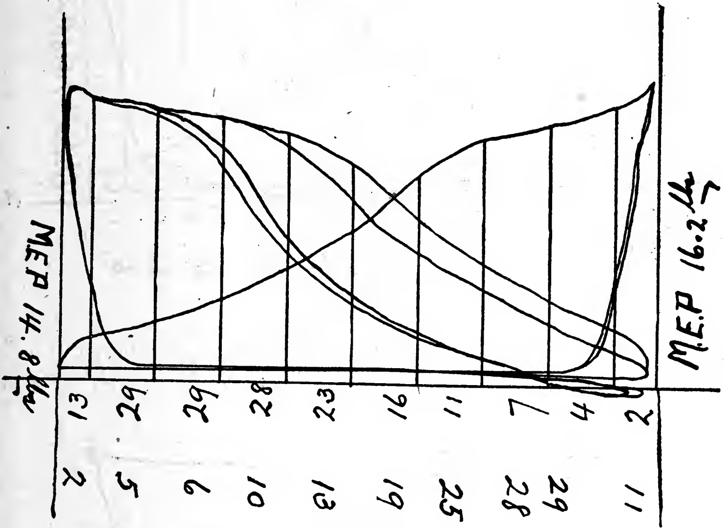


FIG. 193

Fig. 194 was secured by quick manipulation of the instrument when it was known that the load was to be steady for a few seconds.

Fig. 195 is from an Atlas single valve automatic cut off engine with shaft governor. This engine was 16x24 inches, running at 105 R. P. M., and at the time the diagram was taken the boiler pressure was only 50 pounds. The spring used was a No. 30. The diagram is a fairly good one for the type of engine. Owing to the variation in the angular advance of the single eccentric actuated by a shaft governor, the degree of compression varies with the point of cut off in the single valve engine, the compression

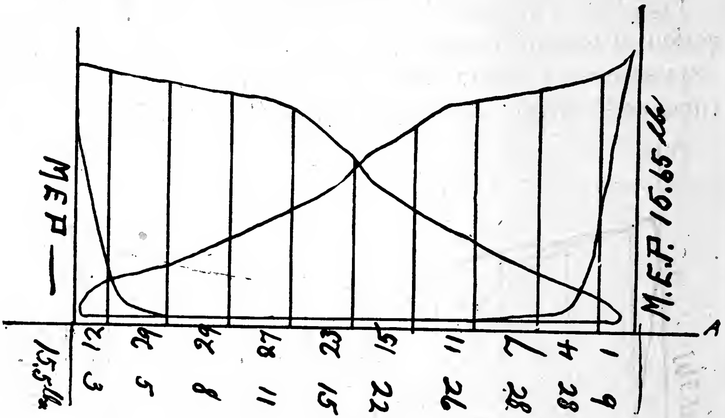


FIG. 194

being higher with an early cut off than it is when cut off occurs later in the stroke. The loop at A is caused by too

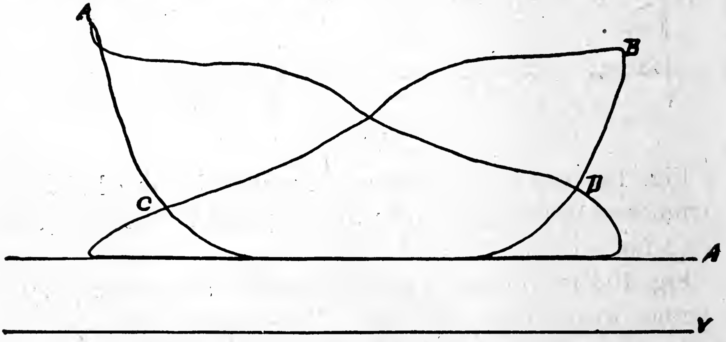


FIG. 195.

much lead which, together with the compression, caused a momentary rise in the pressure above the normal. The lead at B is approximately correct. The difference in terminal pressures at C and D is the result of shifting of the points of cut off caused by variations in the load. The back pressure lines are almost identical with the atmospheric line, showing that the exhaust is in no way restricted or cramped. I. H. P. is 65.7 and steam consumption 21 pounds per I. H. P. per hour.

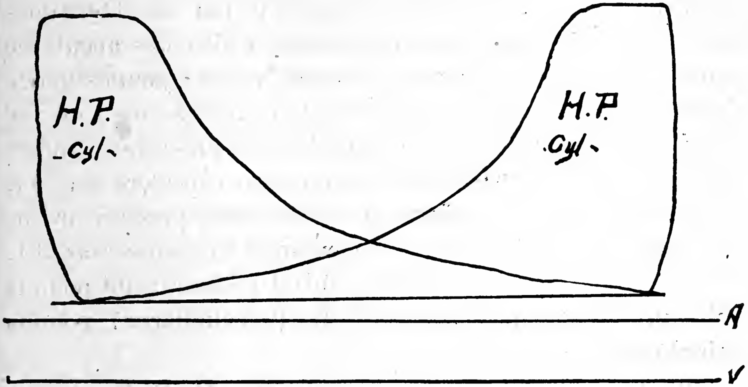


FIG. 196

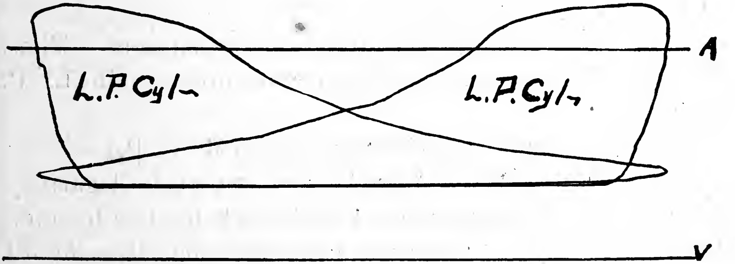


FIG. 197

Figs. 196 and 197 are diagrams taken from a cross compound condensing Corliss engine. The high pressure cylinder was 24x48 inches, and the low pressure cylinder was 44x48 in. The steam from the high pressure exhausted into a receiver, and from thence into the low pressure cylinder. The receiver pressure was 5.3 pounds above atmospheric pressure. The ratio of piston areas was 3.36 to 1. That is, the area of the low pressure piston was 3.36 times the area of the high pressure piston, which was about the correct ratio for the pressure carried, viz., 84 pounds gauge or 99 pounds absolute. A No. 40 spring was used on the high pressure and a No. 12 on the low pressure cylinder. The number of expansions in the two cylinders was 14. Thus, the ratio of expansion in the high pressure cylinder was 4.5 and in the low pressure the ratio was 3.1. Then $4.5 \times 3.1 = 14$; or, Thus, initial pressure=99 pounds absolute, terminal pressure in L. P. cylinder=7 pounds absolute; then $99 \div 7 = 14$.

To illustrate the process of finding the M. E. P. without the use of ordinates when the absolute initial and terminal pressures and the number of expansions in each cylinder are known, the following problems will be worked out:

Find M. E. P. in L. P. cylinder.

First, find initial pressure.

Rule. T. P. multipled by number of expansions. Thus, $7 \times 3.1 = 21.7$ pounds absolute initial pressure in L. P. cylinder.

Second, find mean forward pressure (M. F. P.).

Rule. Multiply initial pressure by hyperbolic logarithm of number of expansions plus 1, and divide product by number of expansions. Thus the hyperbolic logarithm of 3.1 $= 1.1314$, to which add $1 = 2.1314$. Then $\frac{21.7 \times 2.1314}{3.1} =$ 14.9 pounds M. F. P. Deduct from this the back pressure, which was 5 pounds absolute. Thus, $14.9 - 5 = 9.9$ pounds M. E. P. in L. P. cylinder.

Next find M. E. P. in H. P. cylinder.

First, find T. P. in H. P. cylinder.

This will equal the initial pressure in the L. P. cylinder +2 per cent. for loss in the receiver. Thus, $21.7+.4=22.1$ pounds, terminal pressure in H. P. cylinder.

Second, find initial pressure in H. P. cylinder.

Rule. Multiply T. P. by number of expansions. Thus, $22.1\times4.5=99.4$ pounds absolute initial pressure in H. P. cylinder.

Third, find mean forward pressure (M. F. P.).

The hyperbolic logarithm of $4.5=1.5041$, add $1=2.5041$. Then $\frac{99.4\times2.5041}{4.5}=55$ pounds, M. F. P. in H. P. cylinder. Deduct back pressure 22.1; thus, 55 pounds—22.1 pounds=32.9 pounds, M. E. P. in H. P. cylinder.

The ratio of piston areas being 3.36 to 1, it may be of interest to pursue the subject a little farther and ascertain how the distribution of the steam in the two cylinders corresponds to the ratio of areas. The ratio and pressures may be expressed as follows:

Ratio of areas—H. P. cylinder, 1; L. P. cylinder, 3.36. M. E. P.—H. P. cylinder, 32.9; L. P. cylinder, 9.9 pounds which is very nearly correct; sufficiently so for all practical purposes, and clearly demonstrates that with the intelligent use of the indicator it is possible to so adjust the valves, and establish the points of cut off on a compound, or triple expansion engine, that the work done in each cylinder will be practically the same. As for instance, the product of the area of the H. P. piston and the M. E. P.=14,883.6 pounds, and that of the L. P. piston × M. E. P.=15,052.9 pounds, a difference of only 169.3 pounds. If the two products had been equal, the horse power exerted in the two cylinders would have been the same. As it was, the horse power of the H. P. cylinder was 263.4 and that of the L. P. cylinder was 266.4, showing a difference of only three horse power in the amount of work done in each cylinder.

Fig. 198 was taken from one of a pair of Fishkill Corliss engines connected to a common crank shaft. The engines were each 24x48 inches, and run at 65 R. P. M., with a boiler pressure of 65 pounds. They were equipped with a jet condenser, and a bucket plunger air pump served for both engines. These engines had been in continuous service for nearly seventeen years when the author was called upon to indicate them and adjust the valves. A diagram taken at the same time from the mate of this engine was very nearly an exact counterpart of Fig. 198. The horse power, as shown by Fig. 198, was 248, and the steam per I. H. P. per hour was 15.2 pounds. The vacuum gauge showed 27 inches and a 50 spring was used.

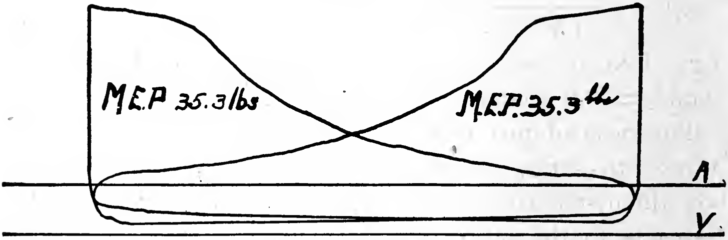


FIG. 198

Figs. 199 and 200 are from an old Fishkill Corliss engine 16×42 inches, to which the author applied the indicator, after he had set the valves, according to the ordinary rules for valve setting, by the marks placed on the ends of the valves and valve chests. These diagrams are introduced especially for the purpose of showing the need of exercising the greatest of care to prevent dirt or grit of any kind from getting into the indicator cylinder. After the indicator pipes had been blown out sufficiently, as it was thought, the indicator, which was a thoroughly reliable instrument, was attached and diagram Fig. 199 was obtained. It showed the valve adjustment to be very nearly correct, but the perfectly straight steam lines, and the sharp corners and sudden drop at cut off were a puzzle, especially in an old engine where the valves and valve seats were known to be much worn down. After taking several more diagrams with precisely the same result, the indicator was removed, and upon taking out the piston a quantity of dirt was found on it, and also on the inside of the cylinder. This fully explained the cause of the sharp corners, etc.,

Fig. 199

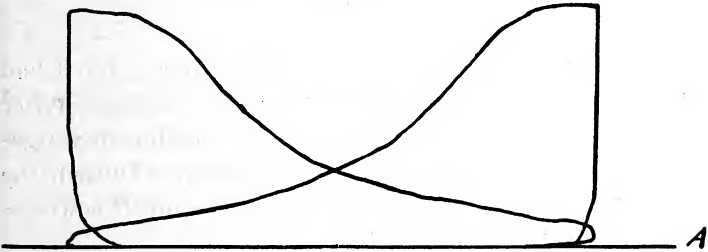


Fig. 200

on the diagram. After the indicator had been cleaned and oiled it was again connected, and Fig. 200 was produced, which is a truthful presentation of the performance of the steam in the cylinder.

Many diagrams are misleading, owing to causes similar to the above, and a diagram with too sharp angles at cut off, or release should be regarded with suspicion until it is proved beyond all doubt to be truthful.

Fig. 201 represents a diagram from a vertical non-condensing engine 14x16 inches, with riding cut off, which the author was called upon to adjust. This engine was nearly new, having been run but a few months, and although the size of it was ample to do all the work required, yet it had failed, so far, to supply one-half the power needed. After taking the diagram and making a few outside investigations, the cause of the trouble was apparent. Indeed, the wonder was that the engine had supplied as much power as it had under the circumstances.

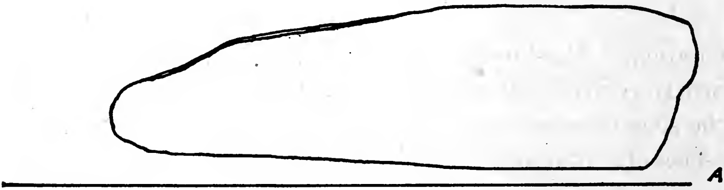


Fig. 201

First. It was situated too far from the boiler plant, being fully 1,200 feet, and although a pressure of 85 pounds was carried at the boilers and the steam was conveyed through a 6-inch pipe, yet owing to the many drains on the pipe for heating buildings, running other small engines, etc., by the time the steam reached the engine in question the pressure was reduced so much that a 30 spring was found to be too strong, although that was the scale of Fig. 201.

Second, the end of the exhaust pipe was found to be submerged in a nearby pond of water to which it had been carried, probably with a view of making a condensing engine out of it! It was also found that there were no less than four superfluous elbows in the exhaust pipe that could easily be dispensed with. The diagram shows that the cut off was practically useless. That the back pressure was nearly 6 pounds above the atmosphere, and that the engine was using 55 pounds of steam and 7 pounds of coal per horse power per hour, all of which conditions were about as bad as they could be.

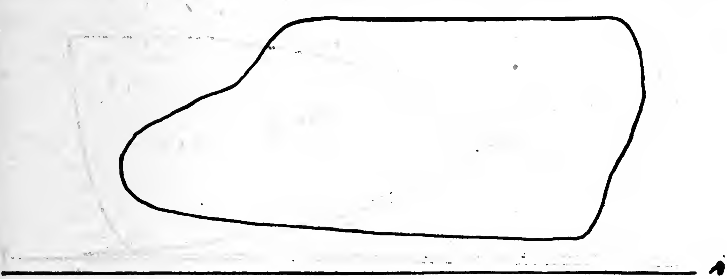


FIG. 202

After increasing the lead and adjusting the cut off a No. 16 spring was used and Fig. 202 was produced which, although still showing late admission, is an improvement over the original diagram. The initial pressure being only 30 pounds above the atmosphere, further work with the indicator was deferred until changes were made in the steam and exhaust pipes, by which the initial pressure was increased to 55 pounds and the exhaust pipe was freed of extra turns and raised from its watery grave into the open air. The engine has since then given perfect satisfaction.

Fig. 203 is from a Buckeye automatic cut off engine 18x36 inches. The engine had been running for several years with the valves in the condition shown by the diagram, and in the meanwhile, the load having been increased from time to time, the engine finally refused to run up to speed and something had to be done. The superintendent of the plant said that he had an idea that something was the matter with the engine but could not ascertain what it was, and so he finally called upon the author to apply the indicator. The result was that diagram Fig. 203 was obtained, showing that the principle cause of the trouble was unequal cut off. After equalizing the cut off and increasing the lead on the crank end by a small fraction diagram Fig. 204 was taken, and after this the engine gave no further trouble. The depression in the steam lines might have been rectified to some extent by increasing the boiler pressure, thus giving a higher initial pressure and an earlier cut off. The speed of the engine was 94 R. P. M., with a boiler pressure of 70 pounds. A 40 spring was used with the indicator.

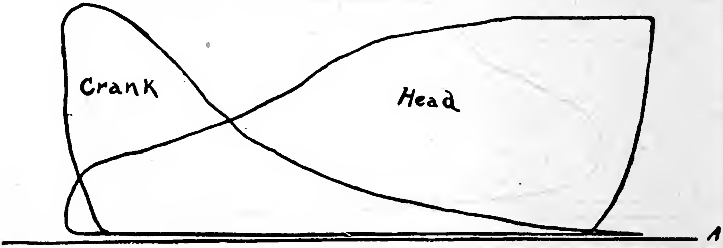


Fig. 203

In order to more fully illustrate the process of ascertaining the M. E. P. without dividing the diagram into ordinates, the following computation is given together with rules, etc. In this process two important factors are necessary, viz., the absolute initial pressure, and the absolute terminal pressure, and they can both be obtained from the diagram by measuring with the scale adapted to the spring used. Thus, in Fig. 204 the absolute initial pressure measured from the line of perfect vacuum V to line B is 77 pounds, and the absolute terminal pressure measured from V to line B′ is 21 pounds. The ratio, or number of expansions, is found thus:

Rule. Divide the absolute initial pressure by the absolute terminal pressure; thus, 77÷21=3.65=number of expansions.

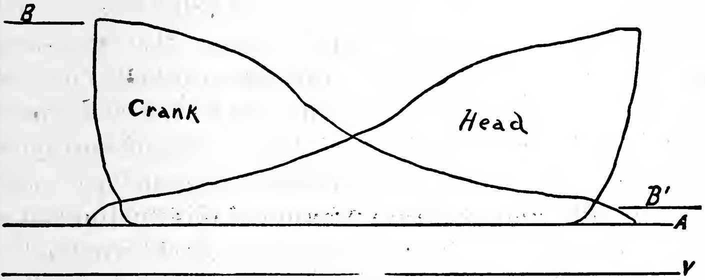


FIG. 204

Second. Find mean forward pressure.

Rule. Multiply absolute initial pressure by the hyperbolic logarithm of number of expansions plus 1, and divide product by number of expansions. Thus, referring to Table 33, it will be seen that the hyperbolic logarithm of 3.65 is 1.2947, to which 1 must be added. Then $\frac{77 \times 2.2947}{3.65} = 48.4$ pounds, which is the absolute mean forward pressure. From this deduct the absolute back pressure, which is 16 pounds or 1 pound above atmosphere; thus, 48.4—16=32.4 pounds M. E. P.

Third. Find I. H. P.

Area of piston minus one-half area of rod × M. E. P. × piston speed in feet per minute, divided by 33,000. Thus (the diameter of rod being 3 in.), $\frac{250.96 \times 32.4 \times 564}{33,000}$ $=138.9$ I. H. P.

The steam consumption per I. H. P. per hour may also be computed by means of Table 34, which was originally calculated by Mr. Thomson, and is based upon the following theory:

A horse power=33,000 feet pounds per minute, or 1,980,000 feet pounds per hour, or 1,980,000×12=23,760,000 inch pounds per hour, meaning that the same amount of energy required to lift 33,000 pounds one foot high in one minute of time would lift 23,760,000 pounds one inch high in one minute of time. Now if an engine were driven by a fluid that weighed one pound per cubic inch, and the mean effective pressure of this fluid upon the piston was one pound per square inch, it would require 23,760,000 pounds of the fluid per horse power per hour. But, if in place of the heavier fluid we substitute pure distilled water of which it requires 27.648 cubic inches to weigh one pound, the consumption per I. H. P. per hour will be considerably less; as, for instance, 23,760,000÷27.648=859,375 pounds, which would be the rate per hour of the water driven engine if the M. E. P. of the water was one pound per square inch, and if the M. E. P. was increased to 20 pounds then twenty times more power would be developed with the same volume of water, but the weight of water consumed per H. P. per hour would be proportionately less. Now if the engine is driven by steam it will consume just as much less water in proportion as the water required to make the steam is less in volume than the steam used. Therefore if the above constant number, 859,375, be divided by the M. E. P. of any diagram, and by the volume of the terminal pressure, the quotient will be the water (or steam) consumption per I. H. P. per hour.

Referring to Table 34, the numbers in the W columns are the quotients obtained by dividing the constant, 859,-375, by the volumes of the absolute pressures given in the columns under T. P. and which represent terminal pressures. The table is considerably abridged from the original, which was very full and complete, the pressures advancing by tenths of a pound from 3 pounds to 60 pounds; but it is seldom that in ordinary practice there is needed such accuracy. If at any time, however, a diagram should show a terminal pressure not given in the table, the correct factor for that pressure can be easily found by dividing the constant 859,375, by the relative volume of the pressure as found in Table 17 of the properties of saturated steam.

Referring again to Fig. 204, it is seen that the terminal pressure is 21 pounds absolute, and by reference to Table 34 and glancing down column T. P. until 21 is reached, it will be seen that the number opposite in column W is 732.69. This number divided by the M. E. P. of the diagram Fig. 204, which is 32.4 pounds, gives 22.6 pounds per I. H. P. per hour as the steam consumption. The rate thus found makes no allowance for clearance and compression, however, and these two very important items will be treated upon in succeeding pages.

TABLE 34

POWER FACTORS.

T. P.	W.	T. P.	W.	T. P.	W.
3	117.30	13.	466.57	23	798.10
3.5	135.75	13.5	483.43	23.5	814.39
4	153.88	14	500.22	24	830.64
4.5	171.94	14.5	517.07	24.5	846.96
5	186.75	15	533.85	25	863.25
5.5	207.60	15.5	550.64	25.5	879.49
6	225.24	16	567.36	26	895.70
6.5	242.97	16.5	584.10	26.5	911.86
7	260.54	17	600.78	27	927.99
7.5	278.06	17.5	617.40	27.5	944.07
8	295.44	18	633.96	28	960.12
8.5	312.80	18.5	650.46	28.5	976.27
9	330.03	19	666.90	29	992.38
9.5	347.27	19.5	683.38	29.5	1008.46
10	364.40	20	699.80	30	1024.50
10.5	381.57	20.5	716.27	30.5	1040.51
11	398.64	21	732.69	31	1056.48
11.5	415.73	21.5	749.06	31.5	1072.42
12	432.72	22	765.38	32	1088.32
12.5	449.69	22.5	781.76	32.5	1104.35

Fig. 205 is from a Hamilton Corliss non-condensing engine 32⅝ in. bore by 72 in. stroke. A No. 60 spring was used, the boiler pressure being 85 pounds gauge. The I. H. P. was 652.2 and the steam consumption per I. H. P. per hour was 22.9 pounds.

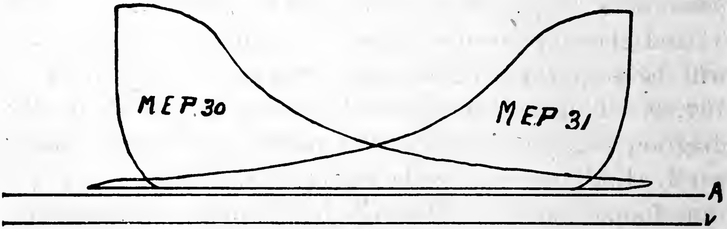


FIG. 205

There are but few points about the diagram that are open to criticism. The compression is rather high for so large an engine and the steam lines should be maintained more nearly horizontal up to the point of cut off.

Steam Consumption from Indicator Diagrams. In calculating the steam consumption of an engine, two very important factors must not be lost sight of, viz., clearance and compression. Especially is this the case in regard to clearance when there is little or no compression, for the reason that the steam required to fill the clearance space at each stroke of the engine is practically wasted, and all of it passes into the atmosphere or the condensor, as the case may be, without having done any useful work, except to merely fill the space devoted to clearance. On the other hand, if the exhaust valve is closed before the piston completes the return stroke, the steam then remaining in the cylinder will be compressed into the clearance space and can be deducted from the total volume which, without compression, would have been exhausted at the terminal pressure.

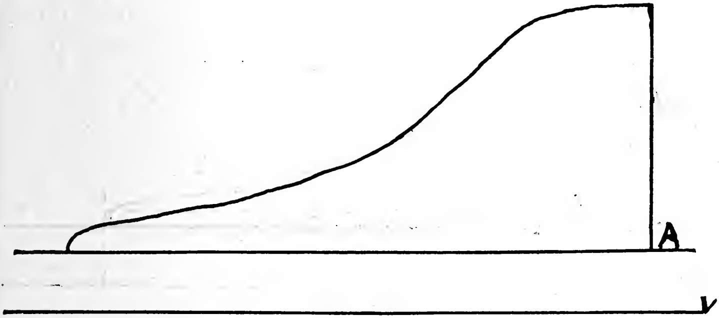


FIG. 206

Figs 206 and 207, which are reproductions of diagrams taken by the author while adjusting the valves on a 16x 42 inch Corliss engine, will serve to graphically illustrate this point. Fig. 206, which was the first one to be taken, shows no compression. The point of admission at A is plainly defined by the square corner at the extreme end of the stroke. The clearance of this engine is 4 per cent. of the volume of the piston displacement. The engine being 16 inch bore by 42 inch stroke, the piston displacement is found by the following calculation: Area of piston, 201.06 square inches × stroke, 42 inches=8444.52 cubic inches. The volume of clearance space is equal to 8444.52 cubic inches × .04=337.78 cubic inches, which divided by 1,728 =.195 cubic feet.

By reference to Fig. 207, taken after adjusting the valves for compression, it will be noticed that the steam is there compressed to 37 pounds, the compression curve beginning at C and ending at B. There is therefore compressed during each stroke a volume of steam equal to .195 cubic feet at a pressure of 37 pounds gauge, or 52 pounds absolute.

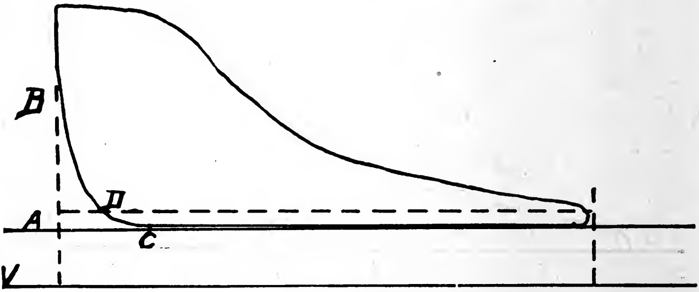


FIG. 207

One cubic foot of steam at 52 pounds absolute pressure weighs .1243 pounds, and .195 cubic feet will weigh .1243 ×.195=.0242 pounds.

The engine was running at 70 R. P. M., or 140 strokes per minute. Thus, according to Fig. 207, the total weight of steam compressed and doing useful work during one hour, and which without compression would have passed out through the exhaust pipe, is equal to .0242×140×60 =203.28 pounds.

Now in order to estimate the steam consumption of the above engine from diagram Fig. 206, it would be necessary to account for all the steam occupying not only the volume of the piston displacement at the end of the stroke, but the clearance as well, for the reason, as before stated, that it would all be released before exhaust closure. This would equal 8444.52 cubic inches + 337.78 cubic inches=8782.3 cubic inches, which divided by 1,728=5.08 cubic feet each stroke, or 10.16 cubic feet each revolution.

The absolute terminal pressure of Fig. 206 is 20 pounds. One cubic foot of steam at this pressure weighs .0507 pounds, and the weight of steam consumed each revolution would therefore be 10.16×.0507=.515 pounds, which multiplied by 70 R. P. M.=36.05 pounds per minute, or 2,163 pounds per hour. The horse power developed by the engine at the time was 80. Therefore the steam consumption per I. H. P. per hour=2,163÷80=27 pounds.

Referring again to Fig. 207 it will be remembered that the total weight of steam compressed during one hour was 203.28 pounds. The weight of steam consumed per hour, therefore, equals 2,163—203.28=1959.7 pounds.

Owing to compression, the work area of Fig. 207 is somewhat smaller than that of Fig. 206, amounting in fact to the area of the irregular figure enclosed between the points A, B and C. The work represented by this figure amounts to a very small proportion of the total work indicated by Fig. 206, still in order to arrive at correct conclusions, it should be deducted therefrom.

Assuming the negative work to be equal to .55 horse power, we have 80—.55=79.45 I. H. P. as the work represented by Fig. 80. As the total weight of steam consumed in one hour was 1959.7 pounds, the steam consumption per

I. H. P. per hour will be 1959.7÷79.45=24.67 pounds, a saving by compression of 2.33 pounds per H. P. per hour, besides the great advantage of having a cushion of steam in contact with the piston at the termination of the stroke, thus bringing the moving parts of the engine to rest quietly without shock or jar.

The steam consumption may also be computed from the diagram, regardless of the dimensions of the cylinder or the horse power developed. The mean effective pressure and also the absolute terminal pressure must, however, be known. This method has already been referred to, but in the computation therein made, no correction was made for clearance and compression.

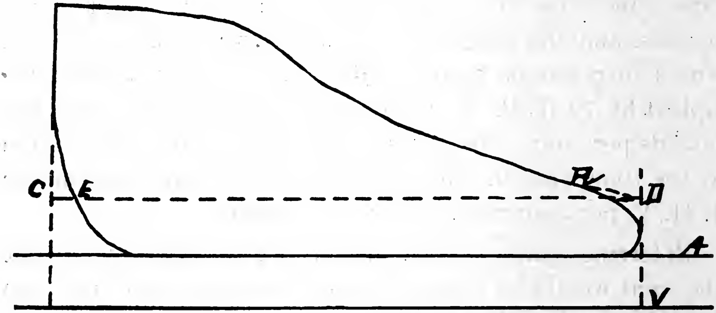


Fig. 208

Having reviewed these two factors at considerable length it will now be in order to more fully explain the methods of treating diagrams when it is desired to make these corrections.

First, draw vertical lines C and D, Fig. 208, at each end of the diagram, and perpendicular to the atmospheric line. Draw line V, representing perfect vacuum, 14.7 pounds below the atmospheric line, as indicated on the scale adapted to the diagram, which in this case is 50 pounds to the inch. Continue the expansion from R, where release begins, until it intersects line D V, from which point the absolute terminal pressure can be measured.

Having ascertained the terminal pressure, which for Fig. 208 is 30 pounds, draw line D E, which may be called the consumption line for 30 pounds. The terminal being 30 pounds, refer to Table 34 and find in column W, opposite 30 in column T. P., the number 1,024.5. Divide this number by the M. E. P. which in Fig. 208 is 41 pounds, and the quotient, which is 24.99 pounds, is the uncorrected rate of steam consumption. This rate stands for the total consumption throughout the whole stroke represented on the diagram by the distance from D to C, which measures 3.25 inches, but it is evident that there is a small portion of the return stroke, that indicated by the distance from E to C, during which the steam compressed in the clearance space should not be charged to the consumption rate, but should be deducted therefrom. In order to do this, multiply the uncorrected rate by the distance from D to E, which is 3⅛ inches, or 3.125 inches, and divide the product by the distance from D to C, 3¼ inches, or 3.25 inches. Thus,

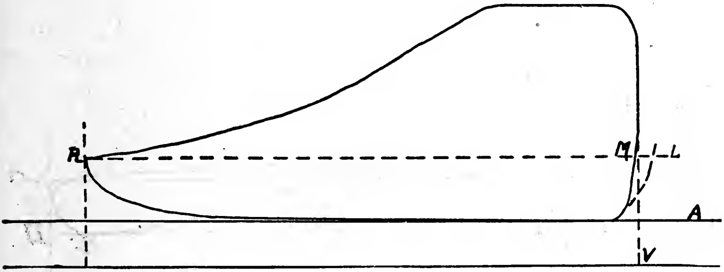


Fig. 209

24.99×3.125÷3.25=24.03 pounds, which is the corrected rate and represents a saving by compression of 24.99—24.03 =.96 pounds, or nearly 3.7 per cent.

In many cases the terminal pressure greatly exceeds the compression, an illustration of which is given in Fig. 209 which is a reproduction of a diagram from an old Wheelock engine. It now becomes necessary to extend the compression curve to L, a point equidistant from the vacuum line with the terminal at R. The consumption line R. L. now becomes longer than the stroke line R. M., therefore the corrected rate will exceed the uncorrected rate by just so much; as for instance, terminal pressure=34 pounds. The factor, as per Table 34,=1152.26, and the M. E. P. of the diagram is 47 pounds. Then, 1,152.26÷47=24.5 pounds, uncorrected rate; 24.5×3.125 inches (distance R. L.)÷3 inches (distance R. M.)=25.52 pounds, corrected rate, a loss of a little more than one pound, or about 4 per cent.

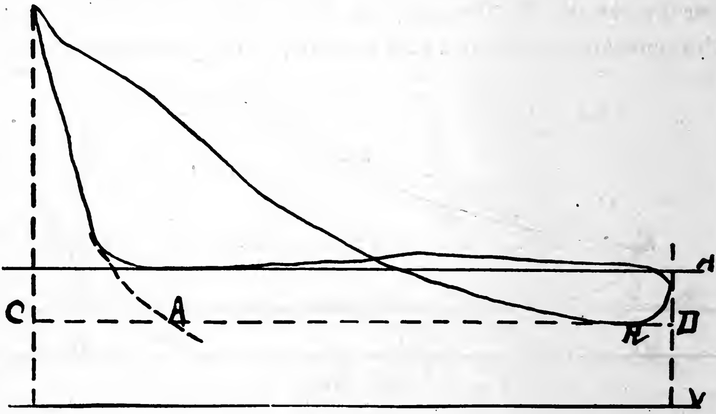


Fig. 210

There is another class of diagrams very frequently encountered in which the terminal pressure is considerably below the compression curve, and in order to compute the consumption rate by the above method it becomes necessary to continue the compression curve downwards until it meets the terminal, as illustrated at A, Fig. 210, which is a friction diagram from a Buckeye engine. R is the point of release, D A represents the consumption line, and D C the stroke. The terminal is 8.5 pounds, and the factor for that pressure, according to Table 34, is 312.8. Dividing this number by the M. E. P., which was 7 pounds, gives 44.6 pounds as the uncorrected rate. The distance D to A, where the compression curve intersects the consumption line, is 2.625 inches, and the total length of the diagram C to D is 3.375 inches. Then $44.6 \times 2.625 \div 3.375 = 35$ pounds as the corrected rate. The extremely high rate is owing to the fact that the engine was running light, no load except a line of empty shafting.

Theoretical Clearance. The expansion and compression curves of a diagram are created by the expansion and compression of all the steam admitted during the stroke. This includes the steam in the clearance space as well as in the cylinder proper. It is evident, therefore, that the volume of the clearance is one of the factors controlling the form of these curves, and when the clearance is known a correct expansion or isothermal curve may be theoretically constructed, as will be explained later on. Also if the actual curves, either expansion or compression, of a diagram assume an approximately correct form, the clearance, if not already known, may be determined theoretically from them; although too much confidence should not be put in the results as they are liable to show either too little, or too much clearance, generally the latter, especially if figured from the compression curve.

For the benefit of those who may desire to test this method of ascertaining the percentage of clearance of their engines, several illustrations will be given of its application to actual diagrams taken from engines in which the clearance was known.

Fig. 211 is from an engine in which the clearance was known to be 5 per cent. As compression cuts but a very small figure in this diagram, the expansion curve alone will be utilized for obtaining the theoretical clearance, and the process is as follows:

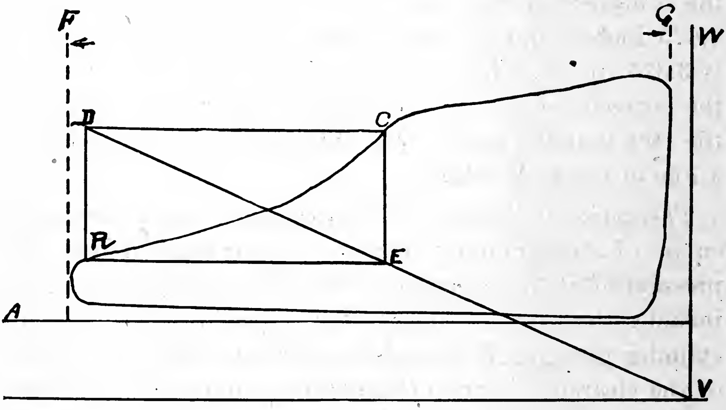


FIG. 211

Select two points, C and R, in the curve as far apart as possible, but be sure that they are each within the limits of the true curve. Thus C is located just after cut off takes place, and R is at a point just before release begins. From C draw line C D parallel with the atmospheric line. From D draw line D R, and from C draw line C E, both perpendicular to the atmospheric line. Then from R draw line R E, forming a rectangular parallelogram, C D R E, with two opposite corners, C and R, within the curve. Now through the other two corners, D and E, draw the diagonal D E, extending it downwards until it intersects the vacuum line V. From this point erect the vertical line V W, which is the theoretical clearance line.

To prove the result proceed as follows: Measure the length of diagram from F to G, which in this case is 3.75 inches, representing piston displacement. Next measure the distance from F to the clearance line V W, which is 3.91 inches, representing piston displacement with volume of clearance added. Then 3.91—3.75=.16, which represents volume of clearance; and .16×100÷3.75=4.3 per cent, which is approximately near the actual clearance, which, as before stated, was 5 per cent.

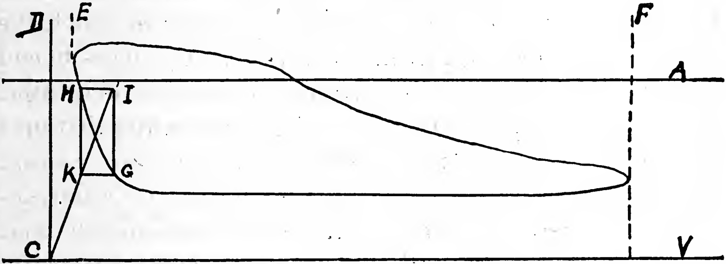


Fig. 212

Fig. 212 serves to illustrate the same method applied to the compression curve. This diagram is a reproduction of one taken from the low pressure cylinder of a large compound condensing Corliss engine in which the actual clearance was 2.25 per cent. Two points, G and H, are selected in the compression curve, and from them the parallelogram G H I K is erected with two of its opposite corners, G and H, well within the limits of the curve, while through the other two corners, I and K, the diagonal I K C is drawn intersecting the vacuum line at C, thus locating the point from which the clearance line C D can be drawn. The measurements in this case are as follows:

Total length of diagram, E to F=3.75 inches.

Distance from clearance line, D C, to F=3.875 inches.

Volume of clearance=3.875—3.75=.125 inches.

.125×100÷3.75=3.33 per cent clearance, which is 1.08 per cent more than the known clearance.

However, notwithstanding the liability to error in many cases, still this method of computing clearance may often be utilized to good advantage.

Another and more practical method of measuring clearance is as follows: Place the engine on the dead center. Remove the valve chest cover and take out the valve. Close the cylinder cock on that end of the cylinder to which the piston has been moved, leaving the cock on the opposite end of the cylinder open and disconnected from its drip pipe, so as to give an opportunity for catching any water that may leak past the piston while measuring the clearance space. Then having first provided a known weight of water, always making sure of having a little more than enough, pour it into the steam port until the clearance space is filled to a level with the valve seat. When this is done, weigh the water that is left and deduct it from the original quantity, and the remainder will be the number of pounds of water required to fill the clearance, from which it is an easy matter to compute the number of cubic inches or cubic feet in the space devoted to clearance. If any water leaks past the piston during the operation it should be weighed and deducted from the total quantity poured into the port.

In the case of an engine having the valve chest on the side of the cylinder it will be necessary to close the steam port either by blocking the valve against it or by fitting a piece of soft wood into it, making it water tight. The water can then be poured into the clearance space through a pipe connected to the indicator opening in that end of the cylinder. Care should be exercised to allow a vent for the air to escape as it is displaced by the water.

The Theoretical Expansion Curve. According to Boyle's law the volume of all elastic gases is inversely as their pressures, and steam being a gas conforms substantially to this law; although the expansion curves of indicator diagrams are affected more or less by the loss of heat transmitted through the cylinder walls, and by the change in the temperature of the steam produced by the changes in pressure during the progress of the stroke. The pressure generally falls more rapidly during the first part of the stroke, and less rapidly during the last portion than it should in order to conform strictly to the above law, and the terminal pressure usually is greater than it should be to agree with the ratio of expansion. But this fullness of the expansion curve of the diagram near the end compensates in a measure for the too rapid fall near the beginning of the stroke. Therefore, if the engine is in fairly good condition with the valves properly adjusted, and not leaking, and the piston rings are steam tight, it may be assumed that the expansion of the steam in the cylinder takes place according to Boyle's law and it is found that the expansion curve drawn by the indicator practically coincides with a hyperbolic curve constructed according to that law.

Fig. 213 graphically illustrates the application of the hyperbolic law to the expansion of gases. The horizontal lines represent volumes and the vertical lines represent pressures. The base line, A F, represents the full stroke of a piston in the cylinder of an engine, and the vertical line

A I represents the pressure of the steam at the commencement of the stroke.

Suppose there is no clearance and that the steam has been admitted up to point H when it is cut off. The rectangle A B H I is the product of the pressure multiplied by the volume of the steam thus admitted. When the piston has traveled from A to C the volume of the steam has been doubled and the pressure C L has been reduced to just one-half what it was at A I, but the area of the rectangle A C L M is equal to the area of the initial rectangle, and, as before, is the product of the pressure C L multiplied by the volume A C. As the piston travels still farther, as from A to D, the steam is expanded to four volumes while the pressure at D K will only be one-fourth that of the initial pressure; but the new rectangle A D K N is still equal in area to either of the others, A B H I or A C L M.

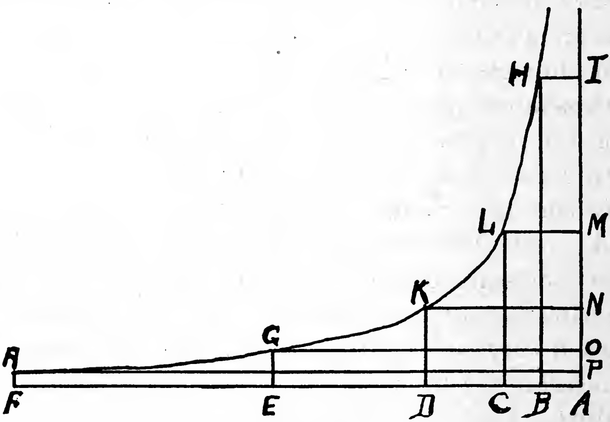


FIG. 213

The same law applies to each of the remaining rectangles; A E G O representing five volumes and one-fifth of the initial pressure, and A F R P representing six times the initial volume and one-sixth of the initial pressure, but each having the same area as the initial rectangle A B H I. Now the area of the rectangle A B H I represents the work done by the steam up to the point of cut off, and the area of the hyperbolic figure enclosed by the lines B H R F represents the work done by the expansion of the steam after cut off occurs.

This area and the amount of work it represents may be computed by means of the known relations of hyperbolic surfaces with their base lines; as for instance, if the base lines A B, A C, A D, etc., extend in geometrical ratio, as 1, 2, 4, 8, 16, etc., the successive areas, B H L C, B H K D, B H G E, etc., increase in arithmetical ratio, as 1, 2, 3, 4, etc.

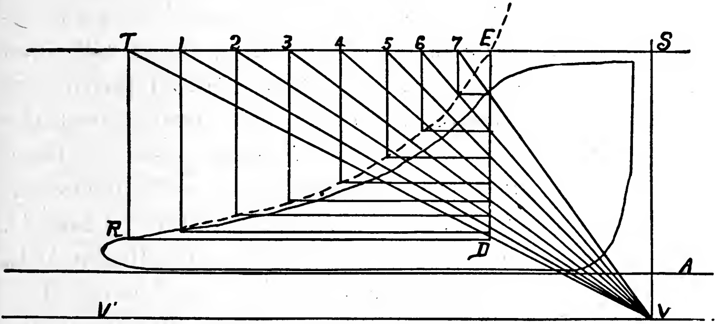


FIG. 214

On the principles of common logarithms, which represent in arithmetical ratio natural numbers in geometrical ratio, tables of hyperbolic logarithms (see table 33) have been computed for the purpose of facilitating the calculation of areas of work due to different degrees of expansion.

A theoretical curve may be constructed conjointly with the actual expansion curve of a diagram by first locating the clearance and vacuum lines, and then pursuing the method illustrated by Fig. 214. A curve so produced is called an isothermal curve, meaning a curve of the same temperature.

Referring to Fig. 214, suppose, first, that it is desired to ascertain how near the expansion curve of the diagram coincides with the isothermal curve, at or near the point of cut off. Select point R near where release begins, but still well within the expansion curve. From this point draw the vertical line, R T, parallel with the clearance line, V S. Then draw the horizontal line, S T, parallel with the atmospheric line, and at such a height above it as will equal the boiler pressure as measured by the scale adapted to the diagram; such measurement to be made from the atmospheric line to correspond with the gauge pressure. From T draw the diagonal T V, and from R draw the horizontal line R D parallel with the atmospheric line. From D, where this line intersects T V, erect the perpendicular D E, thus forming the parallelogram R D E T, and as line T V passes through two of its opposite angles and meets the junction of the clearance and vacuum lines, the other two angles, R and E, will be in the theoretical curve, and R being the starting point, it is obvious that this curve must pass through E, which would be the theoretical point of cut off on the steam line S T.

Two important points in the theoretical curve have now been located, viz., E as the cut off, and R as the point of release. In order to obtain intermediate points, draw any desired number of lines downward from points in S T, as 1, 2, 3, 4, 5, etc., and continue them downwards far enough to be sure that they will meet the intended curve, and from the same points in S T draw diagonals 1 V, 2 V, 3 V, 4 V, 5 V, etc., all to converge accurately at V. From the intersection of these diagonals with D E draw horizontal lines parallel with V V′, and the points of junction of these lines with the vertical lines will be points in the theoretical curve. It will now be an easy matter to trace the curve through these points. If, on the other hand, it be desired to compare the curves toward the exhaust end of the diagram, draw lines E D and E T, Fig. 215, also T R, locating R near where release commences, after which draw line R D, completing the parallelogram E T R D, fixing R as a point in the theoretical curve started at E. After drawing the diagonal T V, proceed in the same manner as before to locate the intermediate points.

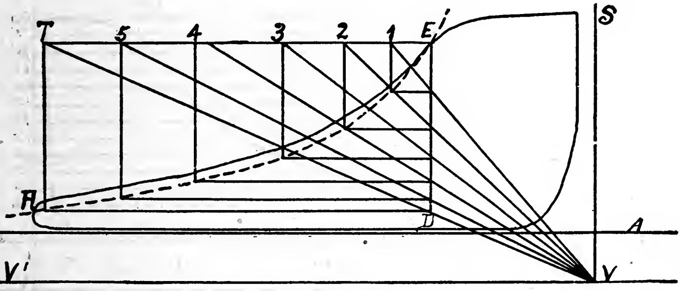


Fig. 215

It will be observed that in order to ascertain the performance of the steam near the beginning of the stroke, the starting point of the isothermal curve must be near the point of release, and conversely, if the starting point of the curve is located near the point of cut off and coincident with the actual curve, the test will apply towards the end of the stroke. It is not to be expected that the expansion curve of any diagram taken in practice will conform strictly to the lines of the isothermal curve, especially towards the latter end of the stroke, owing to the reëvaporation of water resulting from the condensation of steam which was retained in the cylinder by the closing of the exhaust valve. This reëvaporation commences just as soon as the temperature of the steam, owing to reduction of pressure due to expansion, falls below the temperature of the cylinder walls, and it continues at an increasing rate until release occurs. The tendency of this reëvaporation, or generation of steam within the cylinder during the latter portion of the stroke is to raise the terminal pressure considerably above what it would be if true isothermal expansion took place. The terminal pressure may also be augmented by a leaky steam valve, while, on the other hand a leaky piston would cause a lowering of the terminal and an increase in the back pressure.

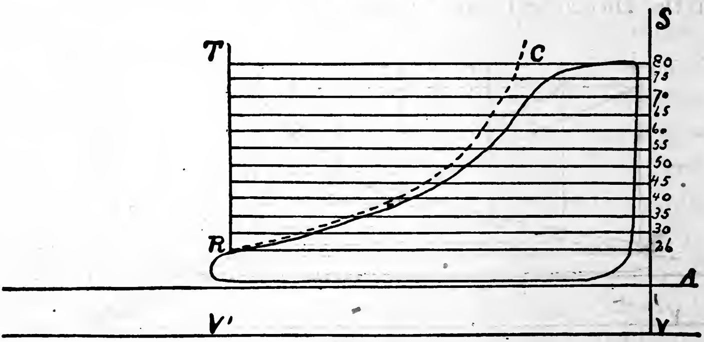


Fig. 216

The Adiabatic Curve. If it were possible to so protect, or insulate the cylinder of a steam engine that there would be absolutely no transmission of heat either to or from the steam during expansion, a true adiabatic curve or "curve of no transmission" might be obtained. The closer the actual expansion curve of a diagram conforms to such a curve, the higher will be the efficiency of the engine as a machine for converting heat into work.

Fig. 216 illustrates a method of figuring a curve which, while not strictly adiabatic, will be near enough for all practical purposes, while at the same time it will give the student an opportunity to study the laws governing the expansion of saturated steam.

To draw the curve, first locate the clearance and vacuum lines V S and V V′. Next locate point R in the expansion curve near where release begins, making this the starting point, and also the point of coincidence of the expansion curve with the adiabatic curve. The other points in the curve are located from the volumes of steam at different pressures during expansion; the pressures being measured from the line of perfect vacuum, and the volumes from the clearance line.

The absolute pressure at R, Fig. 216, is 26 pounds. From point R erect the perpendicular R T. Also draw horizontal line R 26 parallel with the vacuum line and at a height equal to 26 pounds above vacuum line V V′, as shown by the scale, which in this case was 40. The length of line R 26, measured from R to the clearance line, is $3\frac{1}{16}$ inches, or 3.0625 inches. By reference to Table 17 it will be seen that the volume of steam at 26 pounds absolute, as compared with water at 39°, is 962. Now if the length of line R 26 be divided by this volume, and the quotient multiplied by each of the volumes of the other pressures represented at points 30, 35, 40, 45, etc., up to the initial pressure, the products will be the respective distances from the clearance line of points in the adiabatic curve. These points can be marked on the horizontal lines drawn from the clearance line to line R T.

Starting with line R 26, it has been noted that its length is 3.0625 inches, and that the volume was 962. 3.0625÷962=.003. Then the volume of steam at 30 pounds is 841, which being multiplied by .003=2.5 inches, the length of line 30. Next the volume at 35 pounds=728. Multiplying this volume by .003=2.1 inches, length of line 35, and so in like manner for each of the other points.

The process involves considerable figuring and careful and accurate measurements, which should be made with a steel rule with decimal graduations. It is not expected that the cut Fig. 216 will be found accurate enough in its measurements to serve as a standard; it being intended only to serve as an illustration of the process. The diagram from which the illustration was drawn was taken from a 600 H. P. engine situated some 200 feet from the boilers, and there was a considerable cooling of the steam by the time it reached the engine, the effect of which is apparent. The curve produced by the measurements is shown by the broken line. The process can be applied to any diagram.

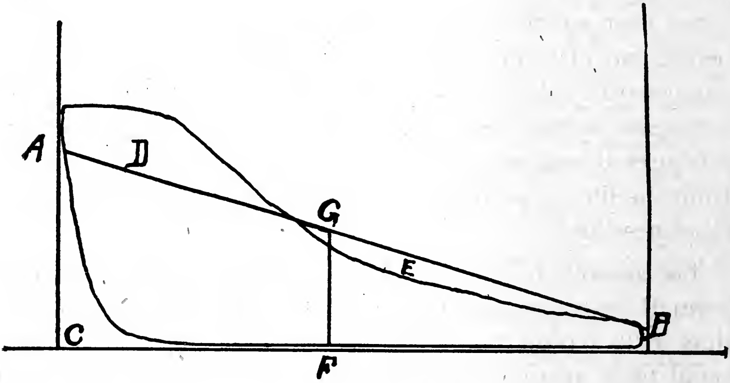


FIG. 217

Power Calculations. The area of the piston (minus one-half the area of rod) multiplied by the M. E. P., as shown by the diagram, and this product multiplied by the number of feet traveled by the piston per minute (piston speed) will give the number of foot pounds of work done by the engine each minute, and if this product be divided by 33,000, the quotient will be the indicated horse power (I. H. P.) developed by the engine.

Therefore one of the first requisites in power calculations is to ascertain the M. E. P. Beginning with the most simple, though only approximately correct, method of obtaining the average pressure, as illustrated by Fig. 217, draw line A B touching at A and cutting the diagram in such manner that the space D above it will equal in area spaces C and E taken together, as nearly as can be estimated by the eye. Then with the scale measure the pressure along the line F G at the middle of the diagram, which will be the M. E. P.

The process is based upon the theory that the average width of any tapering figure is its width at the middle of its length. This method should not be relied upon as accurate, but is convenient at times when it is desired to make a rough estimate of the horse power of an engine.

Ordinates. The method of calculating the M. E. P. by the use of ordinates has already been alluded to, and will be here enlarged upon. The process consists in drawing any convenient number of vertical lines perpendicular to the atmospheric line across the face of the diagram, spacing them equally, with the exception of the two end spaces, which should be one-half the width of the others, for the reason that the ordinates stand for the centers of equal spaces, as for instance, line 1, Fig. 218, stands for that portion of the diagram from the end to the middle of the space between it and line 2. Again, line 2 stands for the remaining half of the second space and the first half of the third, and so on. This is an important matter, and should be thoroughly understood, because if the spaces are all made of equal width, and measurements are taken on the ordinates, the result will be incorrect, especially in the case of high initial pressure and early cut off, following which the steam undergoes great changes.

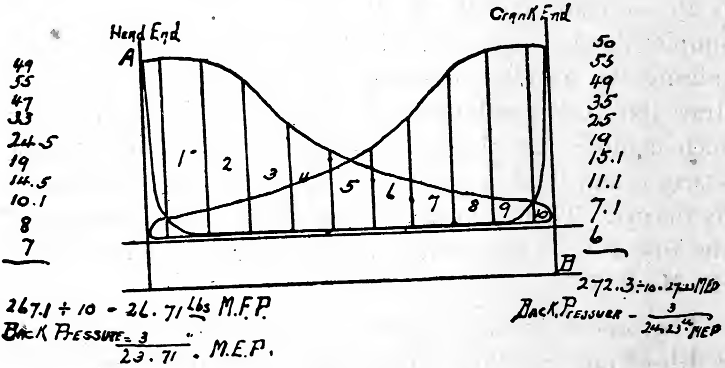


FIG. 218

If the spaces are all made equal, the measurements will require to be taken in the middle of them, and errors are liable to occur, whereas if spaced as before described, the measurements can be made on the ordinates, which is much more convenient and will insure correct results. Any number of ordinates can be drawn, but ten is the most convenient and is amply sufficient, except in case the diagram is excessively long. For spacing the ordinates, dividers may be used, or a parallel ruler may be procured from the makers of the indicator; but one of the most convenient and easily procurable instruments for this purpose is a common two-foot rule, and the method of using it is illustrated in Fig. 218.

First draw vertical lines at each end of the diagram, perpendicular to the atmospheric line, and extending downwards to the vacuum line, or below it if necessary, in order to have a point on which to lay the rule. In Fig. 218 points A and B are found to be the most convenient. Now lay the rule diagonally across the diagram, touching at A and B, and the distance will be found to be $3\frac{3}{4}$ inches, or 60 sixteenths.

Suppose it be desired to draw 10 ordinates. Divide 60 by 10, which will give 6 sixteenths, or $\frac{3}{8}$ inches as the width of the spaces, but as the two end spaces are to be one-half the width of the others, there will be 11 spaces altogether, the two outer ones having a width equal to one-half of $\frac{3}{8}$ or $\frac{3}{16}$. Now apply the rule again in the same manner, touching at points A and B, and with a sharp pointed pencil begin at A and mark the location of the first ordinate according to the rule, at a distance of $\frac{3}{16}$ from the end. Then $\frac{3}{8}$ from this mark make another one, which will locate the second ordinate, and proceed in like manner to locate the others. The last two or three marks generally come below the diagram, and if the diagram be taken from a condensing engine it may be necessary to tack it on to a larger sheet of paper in order to get these points. Having correctly located the ordinates, they may now be drawn perpendicular to the atmospheric line or vacuum line, either of which will answer.

It should be noted that, owing to the diagonal position of the rule with relation to the atmospheric line, the spaces are not of the actual width as described by the rule, but this is unimportant, so long as they are of a uniform width.

This method can be applied to any diagram, no matter what its length may be, and point B may be located at any distance below the atmospheric or vacuum lines, wherever it is the most convenient for the subdivisions on the rule, sixteenths, eighths, etc., so long as it is in line with the end of the diagram. Having thus drawn the ordinates, the M. E. P. may be found by measuring the pressure expressed by each one, using for this purpose the scale adapted to the spring used, adding all together and dividing by the number of ordinates which will give the average pressure.

Referring to Fig. 218, begin with ordinate No. 1 on the diagram, from the head end of the cylinder. In this case a 40 spring was used. Lay the scale on the ordinate with the zero mark where it intersects the compression curve. The pressure is seen to be 49 pounds. Set this down at that end of the card and measure the pressure along ordinate No. 2, which is 55 pounds. Proceed in this manner to measure all the ordinates, placing the resulting figures in a column, after which add them together and divide by 10. The result is 26.71 pounds, which is the mean forward pressure (M. F. P.). To obtain the mean effective pressure, deduct the back pressure, which is represented by the distance of the exhaust line of the diagram above the atmospheric line in a non-condensing engine, and in a condensing engine the back pressure is measured from the line of perfect vacuum, 14.7 pounds, according to the scale below the atmospheric line.

In Fig. 218 the back pressure is found to be 3 pounds. Therefore the M. E. P. of the head end will be $26.71-3=23.71$ pounds. On the crank end the M. F. P. is 27.23 pounds, and $27.23-3=24.23$ pounds=M. E. P. The average effective pressure on the piston, therefore, will be $23.71+24.23\div2=23.97$ pounds.

Unless great care is exercised in the measurements, errors are liable to occur in applying this method, especially with scales representing high pressures, as 60, 80, etc. The most convenient and reliable method is to take a narrow strip of paper of sufficient length, and starting at one end, apply its edge to each ordinate in succession, and mark their lengths on it consecutively, with the point of a knife blade or a sharp pencil. Having thus marked on the paper the total length of all the ordinates, ascertain the number of inches and fractions of an inch thereon, the fractions to be expressed decimally, and divide by the number of ordinates. The quotient will be the average height of the diagram, and as the scale expresses the number of pounds pressure for each inch, or fraction of an inch in height, if the average height of the diagram be multiplied by the number of the scale, the product will be the M. F. P.

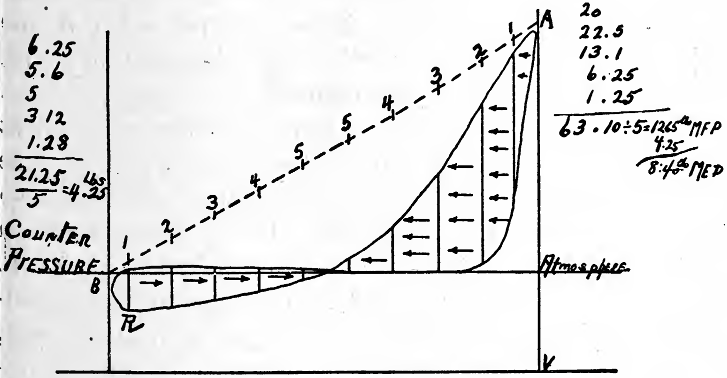


Fig. 219

Referring again to Fig. 218, if the lengths of the ordinates drawn on the head end diagram be measured, their sum will be found to be 6 8/12 or 6.666 inches. Dividing this by

10 gives .666 inches as the average height. The mean forward pressure will then be as follows: .666×40=26.64 pounds, or practically the same as found by the other method.

Fig. 219 illustrates a type of diagram frequently met with, and one which requires somewhat different treatment in estimating the power developed. It will be noticed that, owing to light load and early cut off, the expansion curve drops considerably below the atmospheric line, notwithstanding that the engine from which this diagram was taken is a non-condensing engine. When release occurs at R, and the exhaust side of the piston is exposed to the atmosphere, the pressure immediately rises to a point equal to, or slightly above, that of the atmosphere.

Fig. 219 was taken during a series of experiments made by the author for the purpose of ascertaining the friction of shafting and machinery, and the engine it was obtained from is a Buckeye 24x48 inches. The boiler pressure at the time was only 40 pounds, and a No. 20 spring was used. The ordinates are drawn according to the method illustrated in Fig. 218. By placing the rule on points A and B, the distance between those two points is found to be 3⅝ inches, or 58 sixteenths. Dividing this by 10 gives 5.8 sixteenths, or nearly ⅜ inches, as the width of the spaces; the two end spaces being one-half of this, or $\frac{3}{16}$ inches wide. The first five ordinates, counting from A, express forward pressure, represented by the arrows. The remaining five ordinates, counting from B, express counter or back pressure, represented by the arrows pointing in the opposite direction. Measuring the pressures along the first five ordinates, and adding them together, gives 63.1 pounds, which divided by 5 gives 12.65 pounds as the mean forward pressure (M. F. P.).

Then figuring up the counter pressure in the same manner on the other five ordinates, beginning at B, the result is 4.25 pounds. The M. E. P. therefore will be 12.65—4.25 =8.4 pounds.

Obtaining the M. E. P. with the Planimeter. The area of the diagram represents the actual work done by the steam acting upon the piston. In a non-condensing engine the lower, or exhaust line of the diagram must be either coincident with or slightly above the atmospheric line in order to express positive work. Any deviation of this line, either above or below the atmospheric line, represents counter pressure, the amount of which may be ascertained by measurements with the scale, and should be deducted from the mean forward pressure.

On the other hand, the exhaust line of a diagram from a condensing engine falls more or less below the atmospheric line, according to the degree of vacuum maintained, and the nearer this line approaches the line of perfect vacuum, as drawn by the scale, 14.7 pounds below the atmospheric line, the less will be the counter pressure, which in this case is expressed by the distance the exhaust line is above that of perfect vacuum.

The prime requisite therefore in making power calculations from indicator diagrams is to obtain the average height or width of the diagram, supposing it were reduced to a plain parallelogram instead of the irregular figure which it is.

The planimeter, Figs. 220-221, is an instrument which will accurately measure the area of any plane surface, no matter how irregular the outline or boundary line is, and it is particularly adapted for measuring the areas of indicator diagrams, and in cases where there are many diagrams to work up, it is a very convenient instrument and saves much time and mental effort. In fact, the planimeter has of late years become an almost indispensable adjunct of the indicator. It shows at once the area of the diagram in square inches and decimal fractions of a square inch, and

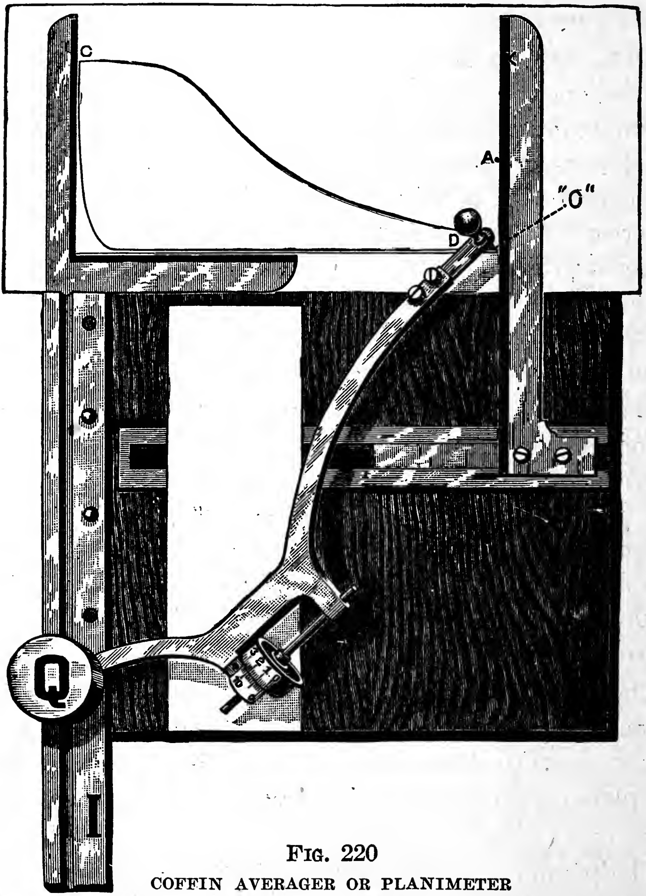


Fig. 220
COFFIN AVERAGER OR PLANIMETER

when the area is thus known it is an easy matter to obtain the average height by simply dividing the area in inches by the length of the diagram in inches. Having ascertained the average height of the diagram in inches or fractions of an inch the mean or average pressure is found by multiplying the height by the scale. Or the process may be made still more simple by first multiplying the area, as shown by the planimeter in square inches and decimals of an inch, by the scale, and dividing the product by the length of the diagram in inches. The result will be the same as before, and troublesome fractions will be avoided.

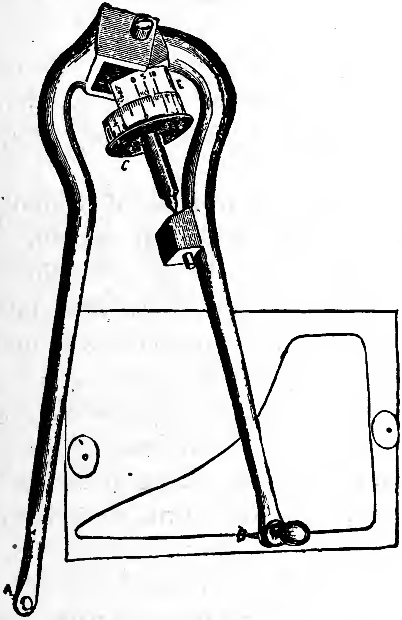


FIG. 221

QUESTIONS AND ANSWERS.

401. What two important points are gained by the use of the indicator?

Ans. First—It shows the average pressure upon the piston throughout the stroke. Second—It shows the action of the valve or valves in admission, cut off and release of the steam.

402. What is the first principle of the indicator?

Ans. Pressure of the steam in the engine cylinder during an entire revolution, against a small piston in the cylinder of the indicator.

403. What resistance is in front of the indicator piston?

Ans. A spiral spring of known tension.

404. What is the second principle of the indicator?

Ans. By means of a multiplying mechanism of levers, the stroke of the indicator piston is communicated to a pencil moving in a straight line.

405. What is the third principle of the indicator?

Ans. By means of a reducing mechanism and cord, the motion of the engine piston during an entire revolution is imparted to a small rotating drum, to which is attached a piece of blank paper.

406. How is a diagram obtained?

Ans. The pencil is held against the paper and thus traces a diagram of the action of the steam within the engine cylinder.

407. What is the atmospheric line?

Ans. A line drawn by the indicator pencil before communication is established between engine cylinder and indicator cylinder.

408. Where should a diagram from a non-condensing engine appear relative to the atmospheric line?

Ans. It should appear above the atmospheric line.

409. Where should the diagram from a condensing engine appear?

Ans. Partly above, and partly below the atmospheric line.

410. What is the best reducing motion to use?

Ans. The reducing wheel.

411. How is the indicator attached to the engine cylinder?

Ans. By means of half-inch pipe tapped into the side of the cylinder near the ends.

412. How are the springs numbered?

Ans. They are made for various pressures, and numbered accordingly.

413. What is a good rule to follow in selecting a spring?

Ans. Select one numbered one-half as high as the boiler pressure, which will give a diagram about two inches high.

414. What data should be noted upon the diagrams when they are taken?

Ans. Boiler pressure; time when taken, and which end of cylinder, head, or crank.

415. What pressure must always be deducted from the mean forward pressure (M. F. P.) in calculations for power?

Ans. The back pressure.

416. What bad effects follow unequal cut off?

Ans. The engine will not develop the power that it is capable of—uneven strains will be set up.

417. What is a convenient size for a diagram?

Ans. 1½ or 2 inches high, and 2 or 2½ inches long.

418. What precaution regarding the pipe connections of the indicator should always be observed before taking diagrams?

Ans. They should be thoroughly blown out, and cleaned of all dirt.

419. How is the ratio of expansions found?

Ans. Divide absolute initial pressure by absolute terminal pressure.

420. Name a very important factor in the calculation of steam consumption of an engine.

Ans. The clearance space.

421. What is one of the first requisites in power calculations?

Ans. To ascertain the M. E. P.

422. How is this done?

Ans. In several ways, for instance by means of ordinates, or it may be obtained by the use of the Planimeter.

Friction and Lubrication

Next to the all important problems of keeping the water in the boilers at the proper level, and maintaining a sufficient supply of steam, comes the proper lubrication of the bearings, and other rubbing surfaces on the engine. If these are not oiled as they should be, the efficiency of the engine will be reduced, and besides there is a constant danger of some one of the heavy bearings becoming heated, and most likely cause a shut-down.

In discussing the problem of lubrication it is well to first study the laws of friction of plane surfaces in contact.

There are five of these laws which are commonly accepted relative to this subject.

Friction is the resistance caused by the motion of a body when in contact with another body that does not partake of its motion, and the laws that control this resistance are as follows:

First—Friction will vary in proportion to the pressure on the surfaces, that is if the pressure increases, the friction will be increased, and vice versa.

Second—Friction is independent of the areas of the surfaces in contact, but if the pressure, or friction be distributed over a larger area, the liability of heating and abrasion becomes less than it would be if the friction is concentrated on a smaller area.

Third—Friction increases with the roughness of the surfaces, and decreases as the surfaces become smoother.

Fourth—Friction is greatest at the beginning of motion. Greater force is required to overcome the friction at the instant of starting to move a body, than is required after motion has commenced.

Fifth—Friction is greater between soft bodies than it is between hard bodies.

These five laws were formulated in the years 1831-33 by Gen. Arthur Morin, a French engineer, who made many experiments relating to the friction of plane surfaces in contact, but numerous experiments in later years by many eminent engineers have demonstrated that these laws are not altogether rigid, and that they can only be accepted in so far as they relate to the friction of dry surfaces in contact, or lubricated surfaces moving under light pressures, and at slow speed. As friction is always a resisting, and retarding factor, its tendency is to bring everything in motion to a state of rest. With machinery in motion the friction between the surfaces of the parts moving in contact tends to cause them to adhere to each other.

Therefore in order to successfully and economically operate the machinery, it is absolutely necessary that a lubricant be used that will distribute itself over these surfaces, and thus prevent them from coming in direct contact with each other.

Friction, however, is useful in many ways, as for instance, the friction of the belt in contact with the rim of the pulley causes power to be transmitted from the engine to the machines throughout the shop. Then also the friction or adhesion of the driving wheels of the locomotive makes it possible for the engine to start a heavy train and keep it moving.

The friction of the brake shoes on the car wheels makes it possible to stop a train in much less time than if it were allowed to stop of its own accord.

There are two kinds of friction in mechanics, viz., the friction of solids, and the friction of liquids. It is the friction of solids that the engineer has to deal with mainly, and this kind of friction for convenience may be again divided into two classes, viz., rolling friction, as for instance a journal revolving in its bearings, or a crank pin in its brasses, and second, sliding friction, as the cross-head on the guides, or the piston traveling back and forth in the cylinder.

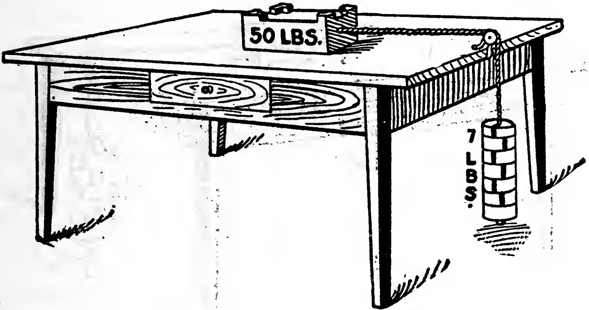


Fig. 222

Co-Efficient of Friction. By this term is meant the relation that the power required to move a body, bears to the weight or pressure on that body.

This definition may be expressed in another, and perhaps plainer form, as follows:

The co-efficient of friction is the ratio between the resistance to motion, and the perpendicular pressure, and is determined by dividing the amount of the former by the latter. Figures 222 and 223 will serve to illustrate in a graphic manner the second law of friction, and also explain one method of determining the co-efficient of friction.

A block of iron or other metal is drawn across the surface of the table top by means of weights suspended from a cord attached to one end of the block, and passing over a small pulley or roller at one end of the table. The block has a flat surface on one side, while on the opposite side there are four small projections or legs, one on each corner, and each leg has a sectional area of one square inch. The size of the block may be assumed to be 8 inches wide, 12 inches long and 2 inches thick, and its weight may be taken at 50 pounds. In Figure 222 the block is placed upon the table with its flat, or largest bearing surface down. This surface has an area of 8 inches by 12 inches=96 square inches in contact with the surface of the table, and it is found that by placing weights on the cord until the block begins to move, and keep moving requires a weight of 7 pounds. Now it might be supposed that if the block were reversed so that it would rest on its four legs it could be moved across the table with much less weight on the cord than was required in the position shown in Figure 222, but such is not the case, as shown by Figure 223 and which can also be mathematically demonstrated.

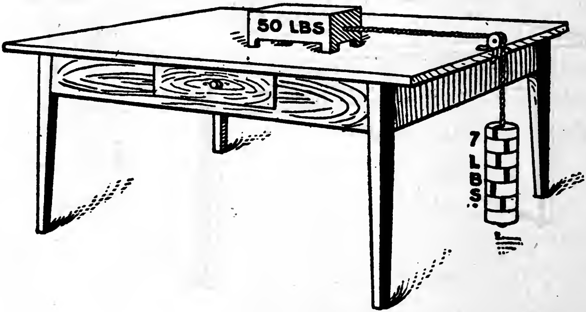


FIG. 223

In the experiment illustrated in Figure 222 the co-efficient of friction is resistance 7 pounds divided by weight or pressure 50 pounds=.14; that is it requires a force of 14 pounds to move one pound of weight. The pressure per square inch of area=weight 50 pounds divided by area 96 square inches=.52 pounds. The co-efficient being .14 pounds, the pull per square inch of surface required to move the block is .52×.14=.0729 pounds, which multiplied by the total area 96 square inches equals 6.9888 or practically 7 pounds. Referring to Figure 223 where the block is reversed, and stands on four legs, each leg having an area of one square inch in contact with the surface of the table, the total contact is four square inches, but the pressure remains the same, viz., 50 pounds. Therefore the pressure per square inch of area=50÷4=12.5 pounds, which when multiplied by the co-efficient .14 equals 1.75, which is the pull per square inch of surface, and there being 4 square inches, the total pull=1.75×4=7 pounds. It will thus be seen that the extent of surface in contact does not affect the friction so long as the weight or pressure remains constant, but by allowing the larger area of surface to come into contact with the table surface thus distributing the pressure over a greater area, reduces the liability of heating and abrasion because the pressure per square inch is so much less.

In machine design, especially engine bearings, and crank pins, the object should be to obtain as large a surface as possible in order that the pressure per square inch may be reduced. By making the bearings of proper proportions, by using bearing metals having the greatest anti-friction value, by keeping the shafting in line, and by the use of the best and most suitable lubricants, and lubricating devices, or by using self-oiling bearings wherever possible, the friction losses may be reduced to a very small percentage of the total power developed by the engine. Modern engine construction, and methods of lubrication have in recent years been brought to such a degree of mechanical refinement that the friction loss per horse power is only 2 or 3 per cent. This low per cent of friction loss has been brought about in the case of high speed engines by properly proportioning, and balancing the rotating parts, and by the use of lubricating apparatus that keeps the bearing continuously flooded in a bath of oil.

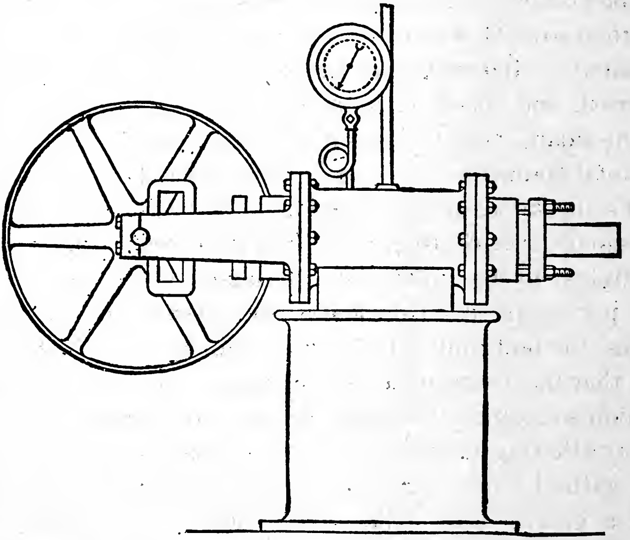


Fig. 224

Great care should be exercised by the engineer in the selection of piston rod, and valve stem packing, and in its application and adjustment, as otherwise there will be considerable friction loss, especially if the packing is unsuitable or becomes hard from too long service, or has been screwed up too tightly.

Prof. Chas. H. Benjamin, in a paper presented at the meeting of the A. S. M. E. December, 1900, gives the results of a series of tests made by himself, at the Case School of Applied Science, in Cleveland, Ohio, to determine the amount of friction caused by various kinds of piston packin. Figure 224 shows the device used by Prof. Benjamin in making the tests.

Figure 225 is a sectional view of the same machine, which consisted of a cast iron cylinder 6x12 inches, fitted at each end with a suitable head, and stuffing box and gland arranged for a two-inch piston rod. The rod was given a reciprocating motion, through the medium of a slotted crosshead, and crank, and a pulley on the crank shaft was connected by a belt to a dynamometer. Steam was admitted to the cylinder through the pipe shown in Figure 224 and the water of condensation was drawn off at the bottom, while a steam gauge showed the pressure in the cylinder. The gland nuts were usually tightened with the fingers only, but when a wrench was used, a spring balance was attached, and the turning moment was noted. The stroke of the rod was 4.25 inches, and the revolutions were 200 per minute,

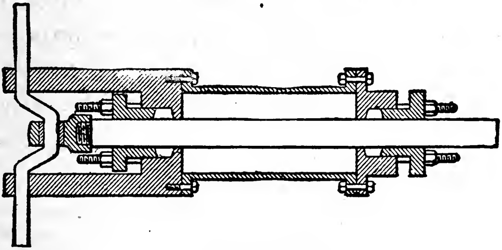


FIG. 225

giving a piston speed of 141 feet per minute. Seventeen different kinds of packing were used, the materials of which were rubber, cotton, asbestos, hemp, lead, and flax.

Some of these packings were combined with mica, graphite, and paraffine. The various packings were fitted according to the directions of the makers, and the routine of the tests as they were conducted was as follows:

The machine was first run without packing, in order to determine the friction of the empty apparatus. The packing was then inserted, and steam turned on, the gland nuts being tightened just sufficient to prevent leakage, and the packing was then tested under various pressures, each test lasting from 15 to 40 minutes. The gland nuts were then tightened with the wrench, and spring balance to various pressures, and other sets of readings taken, after which

TABLE 35

Kind of Packing	No. of Trials	Total Time of Run in Minutes	Average H. P. Consumed by each box.	H. P. Consumed at 50 lbs. Pressure.	Remarks on Leakage, etc.
1	5	22	.091	.085	Moderate leakage.
2	8	40	.049	.048	Easily adjusted; slight leakage.
3	5	25	.037	.036	Considerable leakage.
4	5	25	.159	.176	Leaked badly.
5	5	25	.095	.081	Oiling necessary; leaked badly.
6	5	25	.368	.400	Moderate leakage.
7	5	25	.067	.067	Easily adjusted and no leakage.
8	5	25	.082	.082	Very satisfactory; slight leakage.
9	3	15	.200	.182	Moderate leakage.
10	3	..	.275	....	Excessive leakage.
11	5	25	.157	.172	Moderate leakage.
12	5	25	.266	.330	Moderate leakage.
13	5	25	.162	.230	No leakage; oiling necessary.
14	5	25	.176	.276	Moderate leakage; oiling necessary.
15	5	25	.233	.255	Difficult to adjust; no leakage.
16	5	25	.292	.210	Oiling necessary; no leakage.
17	5	25	.128	.084	No leakage.

cylinder oil was applied to the rod, and the difference in friction noted. These tests were measured by means of a Flather recording dynamometer, and a Weber box gear dynamometer, the readings being taken at short intervals and averaged. The results of these tests are summed up in Tables 35 and 36. Table 35 gives a summary of the results, showing the average horse power absorbed by each packing at various pressures, and for purpose of comparison, the power at 50 pounds of steam pressure. Table 36 shows the increased friction caused by tightening the gland nuts, and also the beneficial effect of oiling the rod. The different packings are numbered.

The general conclusions arrived at from this series of tests are as follows:

First—That the softer rubber, and graphite packings absorb less power in friction than the harder kinds do.

Second—That oiling the piston rod will reduce the friction of any kind of packing.

TABLE 36

Kind of Packing	Horse-power Consumed by Each Box, when Pressure was Applied to Gland Nuts by a Seven-inch Wrench						H. P. Before and After Oiling Rod.	
	5 Lbs.	8 Lbs.	10 Lbs.	12 Lbs.	14 Lbs.	16 Lbs.	Dry	Oiled
1	.120	....	.136					
3	....	....	....	....	....	....	.055	.021
4	....	.248	....	.303	....	.390	.154	.123
5	....	.220						
6	....	.348	.430	....	....	....	.323	.194
7	....	.126	.228	.260	.330	.340	.067	.053
8	....	.363	.500	.535	.520	.533	.533	.236
9	....	.666	....	....	....	....	.666	.636
11	....	.405	.454	....	....	....	.454	.176
12	....	.161	.242	.359	.454	....	.454	.122
13	....	.317	.394	.582				
15	....	.526						
16	....	.327	.860					
17	....	.198	.277	.380				

Third—That there is almost no limit to the friction loss that can be caused by the injudicious use of the wrench.

Variations of friction of lubricated surfaces occur with every change of condition of either the bearing or journal surfaces, or of the lubricant applied to them. The conditions that produce the greatest differences in ordinary lubrication are, the nature and quality of the lubricant, the nature and condition of the wearing surfaces, and the speed, pressure, and temperature.

Lubricating Oils. The engineer in charge of a plant will always find on the market a wide range of petroleum products to choose from to meet the various conditions that will show up in the proper lubrication of the machinery under his charge. The ordinary facilities of the engine room do not usually afford means to make elaborate tests of oils, and other lubricants, but an engineer can make valuable comparative tests of different grades of oil on his engine, or other machinery.

For instance by means of a thermometer placed in the bearing, with the bulb resting on the shaft, or immersed in the oil chamber, the temperature of the bearing may be noted, while it is being lubricated with various grades of oils, and their qualities thus determined. Of course in tests of this kind, care should be taken that the rate of oil feed, the belt tension, the pressure on the bearings, and the speed remain as near constant as possible, and an allowance should also be made for any difference in the temperature of the room during the tests. A good and efficient lubricant should possess the following characteristics:

First, sufficient "body" to keep the surfaces apart, but the greatest possible fluidity consistent with this.

Second, a minimum co-efficient of "internal" friction in actual service.

Third, must not dry or "gum," and must not contain free acids or other corrosive ingredients.

Fourth, must not be readily thinned, vaporized or ignited by heat, or stiffened by the cold encountered in the service to be performed.

Fifth, must be absolutely free from all gritty foreign substances.

Sixth, it must be especially adapted to the conditions for which it is chosen.

Experience has proved that in lubrication the best is nearly always the cheapest in the end, and that the consumer can better afford to use the highest priced lubricants the market affords, than accept those of lower value as a gift.

The cost of lubrication is not merely the market price of lubricants, but their cost *plus the cost of the friction accompanying their use.* The *value,* not the *cost,* of the lubricant, is the point worthy of greatest consideration. What it will *do, not what it costs* per pound or per gallon. No greater error can be made than to economize upon the *quality* of lubricants, for even under the most extravagant conditions the cost of lubricants represents but a very small fraction of the cost of fuel, and repairs and depreciation of poorly lubricated engines and machinery.

The best lubricant for a bearing under normal conditions may not do so well after heating commences, a thick viscous oil which under ordinary conditions on high speed machinery would be comparatively wasteful of power is often an excellent lubricant for a hot bearing, and for the following reason: an engineer on finding a bearing heating up will apply the ordinary oil freely, and at the same time loosen up the bolts so as to allow for increased expansion and free flow of oil; if the heating continues, and the engine or machinery must be kept in operation at all hazards, he will turn to his cylinder oil, apply it freely, and often with good results. The reason of this is that the cylinder oil, owing to its high fire test (from 550 to 600) became thin and limpid without burning, and flowed freely between the close-fitting surfaces and kept them apart, and at the same time, absorbed the heat that would otherwise have gone into the metal and carried it away, while the engine oil, being of lower flash test, vaporized, and if the bearing got hot enough, caught fire.

In many cases the use of pure graphite or plumbago, as it is sometimes called, will prove to be beneficial, especially on heavy bearings that are inclined to heat.

The essential function of graphite is that of an auxiliary, or accessory lubricant, with which to perfect and maintain the working surfaces in a condition of high polish and great smoothness, so that the oils and greases used as the actual lubricating film may the more successfully perform their particular service. They have only to separate two highly-polished and perfectly fitted surfaces and to reduce friction to the lowest possible point.

Graphite allows the safe and satisfactory use of less oil or grease than would otherwise be necessary, because there is far less actual wearing out of the oil between the smooth surfaces.

Inasmuch as metallic wear is nearly eliminated, the oil does not become rapidly charged with fine metal particles and lose its lubricating value.

Thinner lubricants can generally be used. Graphite increases the endurance and efficiency of oil, and grease lubricants because it relieves them of a very great part of the duty they otherwise have to perform.

Whether graphite is fed at regular intervals or only occasionally the results are much the same, inasmuch as the coating of graphite persists for a considerable period after application.

In 1902 Professor W. F. M. Goss of Purdue University conducted a long series of tests to determine the value of Dixon's Flake Graphite as a general lubricant for bearings, and as applied to railroad air brake equipment.

The tests extended over a period of many months and were made, not to create arguments in favor of Dixon's Graphite but to enlarge the sum of information on the subject of graphite lubrication.

The following extracts are taken from the report:

"From the earlier and rather limited uses of graphite in lubrication, the field has gradually widened to include its use with light oils, with water, and, in some cases, unmixed with other materials. It is no longer regarded merely as a material for an emergency, but now has a place in the ordinary and usual routine of the engineer's day. . . .

"The demand for graphite has come because men charged with the responsibility of keeping machinery moving have found it beneficial in their work, and not because manufacturers and plant owners pressed its use upon them.

"It is not to be presumed that because a material is sold as graphite it will give good results in lubrication; it must be free from grit and other impurities and properly graded for the work. . . .

"Graphite does not behave like oil, but associates itself with one or the other of the rubbing surfaces. It is worked into every crack and pore in the surfaces and fills them, and if the surfaces are ill-shaped or irregularly worn, the graphite fills in and overlays until a new surface or more regular outline is produced. When applied to a well fitted journal the rubbing surfaces are coated with a layer so thin as to appear hardly more than a slight discoloration. If, on the other hand, the parts are poorly fitted, a veneering of graphite of varying thickness, which in the case of a certain experiment was found as great as $\frac{1}{16}$ inch, will result. The character of this veneering is always the same, dense in structure, capable of resisting enormous pressure, continuous in service without apparent pore or crack, and presenting a superficial finish that is wonderfully smooth and delicate to the touch."

In the lubrication of the interior wearing surfaces of the valves, and cylinders of steam engines, conditions will be met which are altogether different from those encountered in the lubrication of bearings and journals.

In the latter case, the working and comparing of one oil with another, and the results obtained can be easily determined by noting the changes of temperature, etc., but in internal lubrication, the conditions are altogether different.

In the case of journals and bearings, the oil can be applied directly to the surface to be lubricated; in cylinder lubrication one must depend upon the flow of steam to convey the oil to the parts or wearing surfaces requiring lubrication.

The points that govern the conditions of interior lubrication are: The conditions of the surfaces, the steam pressure, the amount of moisture in the steam, the piston speed, weight and fit of the moving parts, and the make or type of the engine.

An automatic cut off engine with balanced, or piston valves will usually require less oil than an engine with a heavy unbalanced valve.

A large cylinder whose piston is supported by a "tail-rod" is more easily lubricated than one whose heavy piston drags back and forth over the bottom of the cylinder.

An oil to be used as a cylinder lubricant in order to give good results must possess certain essential properties.

It must be of high flash test, so that it will not volatilize, or vaporize when in contact with the hot steam; it must have good viscosity, or body when in contact with the hot surfaces, and should adhere to, and form a coating of oil so as to prevent wear and reduce as much as possible the friction of the moving parts.

While the quality of a cylinder oil as shown by the use of testing instruments will give one a general idea of its lubricating value, the engineer who is studying the question of cylinder lubrication can determine more accurately its exact value by experimenting on his engines, and pumps and under the conditions peculiar to his own plant.

LUBRICATING APPLIANCES.

Lubricating Appliances. The successful lubrication of an engine depends in a large measure upon the character of the appliances that are used to convey the lubricant to the wearing surfaces.

For steam cylinder lubrication the hydrostatic, or sight feed type of lubricator is in most general use; this type of lubricator depends for its operation upon the displacement of the oil by a body of water which is formed by the condensing of the steam in the condensing chamber of the lubricator, the water in passing into the oil chambers displaces the oil, forcing it up through the sight-feed glass, whence it flows through the discharge pipe to the cylinder.

The construction and operation of this class of lubricators will be better understood by reference to Figures 226 and 227. Figure 226 is an exterior view of the well-known Detroit sight-feed lubricator, while Figure 227 is a sectional view showing the interior construction. The pipe P shown in Figure 227 connects with a passage from the condenser A-2 Figure 226 and when the water feed valve A-4 Figure 226 is opened, the water in the condenser will pass down the pipe P to the bottom of the lubricator, and, being heavier than oil, will stay at the bottom, the oil floating above it. The pipe S Figure 227 leads from the lower sight-feed arm to the upper part of the body of the lubricator. The action of the lubricator is as follows:

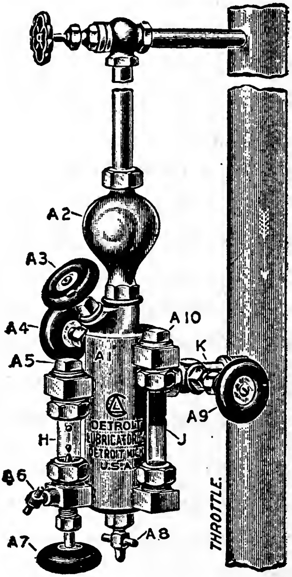


FIG. 226
EXTERIOR VIEW DETROIT LUBRICATOR

The body A-1 is filled with oil. Steam from the main steam pipe passes in the connecting pipes above the lubricator, and condenses, filling the condenser A-2 and part of the pipe above it with water. The steam also passes into the support arm and through the internal tube T into the sight-feed glass, where it condenses, filling the glass with water.

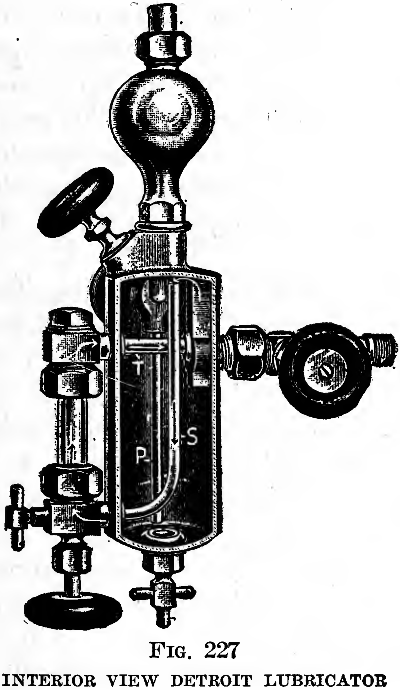


FIG. 227
INTERIOR VIEW DETROIT LUBRICATOR

As soon as the valve A-4 is opened, the oil in the body of the lubricator is subjected to the pressure of the column of water extending through the pipe P, the condenser and part of the pipe above it, amounting to about 2 pounds to the square inch, and in addition to the pressure of the steam above the water, amounting to say 100 pounds to the square inch, or a total pressure of about 102 pounds to the square inch. This we may call the positive pressure. Liquids communicate pressure equally in all directions, so the oil in the body of the lubricator will press in every direction with a force of about 102 pounds to the square inch. It will therefore press down through the tube S with this force of 102 pounds to the square inch. Then, if the valve A-7 is opened, a force acting in the opposite direction is encountered, which we may call the back pressure. When the lubricator is connected as shown, this back pressure will consist of the column of water in the sight-feed glass, and in addition, the steam pressure back of this column entering through the support arm, and amounting to 100 pounds to the square inch.

The positive steam pressure being just the same as the back steam pressure, these two forces will neutralize each other, and we have left, the positive pressure of the column of water extending through the pipe P, the condenser and part of the pipe above it, and the back pressure of the column of water in the sight-feed glass. As the latter is much less than the positive pressure, the drop of oil is forced through the nozzle. As soon as it leaves the nozzle it is no longer acted upon by the positive pressure, and it rises through the water in the glass from the force of gravity, it being lighter than the water. After rising through the sight-feed glass it floats through the tube T, Figure 227, and through the support arm into the main steampipe and goes with the current of steam to the steam chest and cylinder. The positive pressure must always be greater than the back pressure, or the lubricator will not work.

For instance, if a lubricator be connected to a horizontal steampipe by being suspended below it, the back pressure would be greatly increased, and in order to get sufficient positive pressure the condensing pipe should rise 18 inches to 24 inches above the horizontal steampipe and then descend to the condenser. This will give a column of water for positive pressure higher than the column of water which acts as back pressure.

TO RE-FILL AND OPERATE.

Close valves A-4 and A-7. Open drain valve A-8, then remove filler plug A-3 and the water will drain out rapidly.

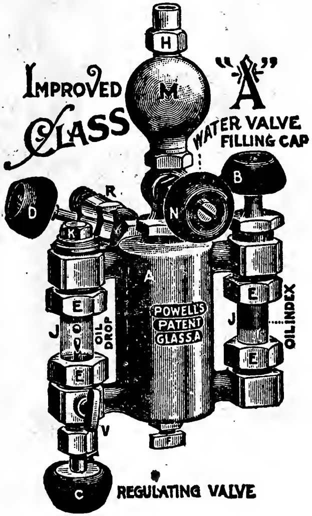


FIG. 228

POWELL LUBRICATOR

A, Oil reservoir. B, Filling cup. C, Valve to regulate oil drops. D, Shut-off valve. E, Packing nuts. F, Drain valve. H, coupling for condensing pipe. JJ, Sight feed and index glasses. K, Plug for removing and inserting glasses. M, Condensing chamber. N, Valve to regulate water from the condenser. V, Valve to drain sight feed glass. R, Attaching shank and valve.

When water is all out, close valve A-8, fill with oil, and replace filler plug A-3. Then open valve A-4, and regulate the flow of oil with valve A-7. The valve A-9 is to be closed only when desiring to shut off steam from the lubricator in case of accidental breakage of the glass, or when there is danger from freezing. Before starting the lubricator, time should be allowed for the sight-feed glass, and condensing chamber to fill with water from condensation. When there is danger from freezing when lubricator is not in use, empty the lubricator, and leave open valves A-4, A-8 and A-6. Then close valve A-9 and the small angle valve in condensing pipe above the lubricator.

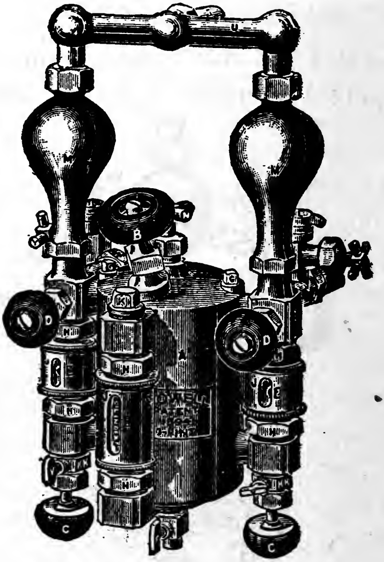


FIG. 229

POWELL'S DUPLEX CONDENSER LOCOMOTIVE LUBRICATOR

Figure 228 shows an external view of the Powell lubricator "Class A," for single cylinder engines, and Figures

229 and 230 show exterior, and sectional views of the Powell duplex condenser and double, up-feed lubricator for use on compound and triple expansion engines. In this lubricator there may be two or three sight-feeds combined with one oil chamber. The letters designate the different parts, and the operation of this lubricator will be easily understood by a study of Figure 230.

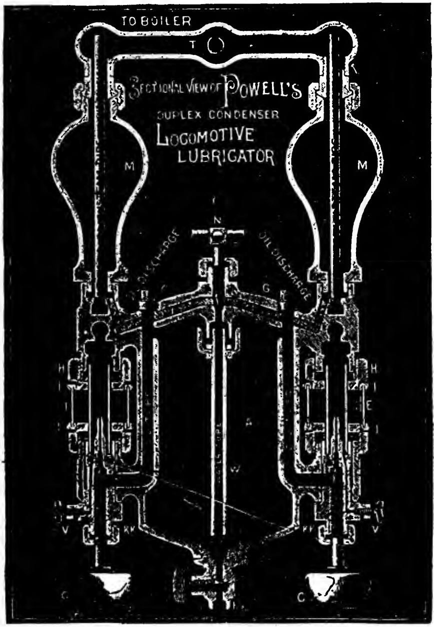


Fig. 230

DESCRIPTION OF INTERNAL PARTS

A, Oil chamber. CC, Oil drop regulating valves. EE, Brass protecting shields. F, Drain valve. GG, Removable plugs to clean oil tubes. HH, Packing nuts. II, Adjustable rings. JJ, Sight glasses. KK, Removable cages to replace glasses. MM, Condensers. N, Water valve. T, Connecting coupling to boiler. VV, Cleaning valves for sight glasses. W, Water tube. X, Water and oil trap.

The force feed, or mechanically operated lubricator, has come into favor largely within recent years, and it certainly has the merit of being positive, while at the same time it is not wasteful of oil, being governed by the speed of the engine or pump that it is lubricating. This type of lubricator is made in single, double, triple, and quadruple style, and is operated by attaching the connecting rod of the oil pump to any movable part of the engine that will give it a reciprocating motion.

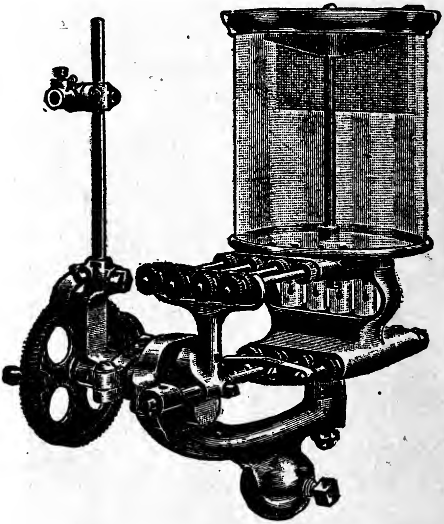


Fig. 231

MANZEL QUADRUPLE FEED, OIL PUMP

Figure 231 shows the Manzel quadruple feed oil pump. These pumps are also made with five and six feeds. Manzel Brothers Co. also make an agitating force, and sight-feed oil pump for the purpose of feeding graphite mixed with the oil. Graphite being a mineral and not easily suspended in oil it has always been a rather difficult problem to feed it properly along with the oil, but the device illustrated in Figure 232 has proved to be very successful in feeding the mixture of oil and graphite. The action of this appliance will be easily comprehended by a reference to Figure 232. The spiral agitating device that revolves in the cup is operated by means of the belt-drive on the wheel, and bevel gears on the cup. The construction is simple and durable. Two fillers are used, one for oil and one for graphite. No fixed rule can be laid down for the amount of graphite to be used, as some engines require more than others. Two or three good teaspoonfuls to a pint of valve oil, would be a good rule to start on, and the engineer can

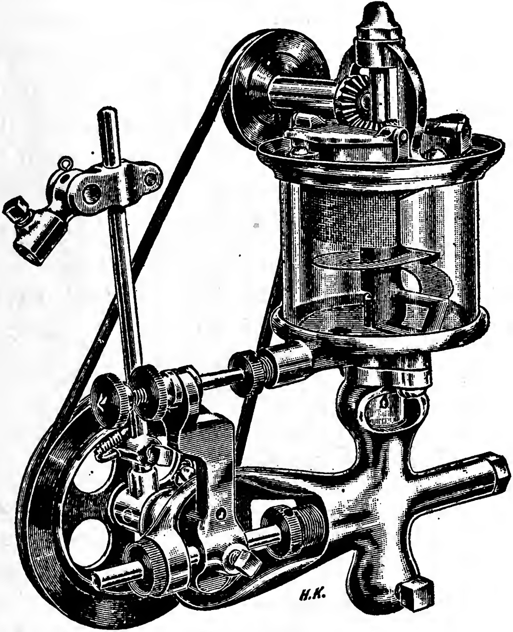


FIG. 232

THE MANZEL AGITATING, FORCE AND SIGHT FEED OIL PUMP then watch results and ascertain for himself the proper quantity to use.

Another rule might be, three teaspoonfuls of graphite per day for a 150 horse power engine.

To Attach the Manzel Oil Pump. Place the pump on the frame of an engine, or pump where it is most convenient to get motion. It can be bolted to a stud or stand. Attach connecting rod of the pump to any movable part that travels back and forth such as a valve rod to an engine, or rocker arm of a pump. Connect the pipe to the pump cylinder. Use ⅛ inch pipe for ½ pint and pint pumps, and ¼ inch pipe for all other sizes; the end of pumps and check valves are threaded for these sizes, and run to, and enter the steam line or steam chest above or below the throttle, as desired. Equip the oil pipes as near as possible to the steam line with check valve; the end marked "S" toward the steam line. By using a reducer, ⅛ inch pipe can be used on the larger size pump.

The feed on the "MANZEL IMPROVED" Pump is regulated while in operation on the engine, on the upper plungers. To increase the feed, screw plunger inward, to decrease the feed, screw plunger outward, then tighten lock-nut. Particular attention is called to the regularity of the feed that is obtained on these pumps under all conditions. They can be regulated to feed from nothing or one drop to a stream of oil with every stroke of the plunger.

Another good force feed lubricator is the Dietz high pressure force feed lubricator made by the Pearl Manufacturing Co. of Buffalo, New York. This device is made either single, or double acting, and with from one to six feeds.

Figure 233 shows a double acting three-feed Deitz high pressure lubricator, and it is claimed by the manufacturers that it will feed any mixture of oil and graphite without becoming clogged, owing to the fact that the valves are of the poppet type, and made of steel, and when not opened by the cams, are held to their seats by a strong spiral spring in addition to the pressure. This oil pump is fitted with a crank, by means of which it may be worked by hand, in starting, or should an extra amount of oil be required at

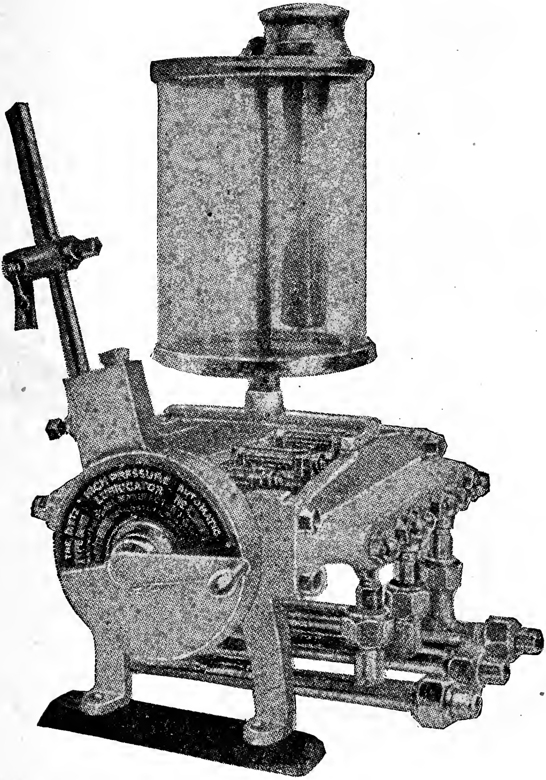


FIG. 233
DIETZ HIGH PRESSURE FORCE FEED LUBRICATOR

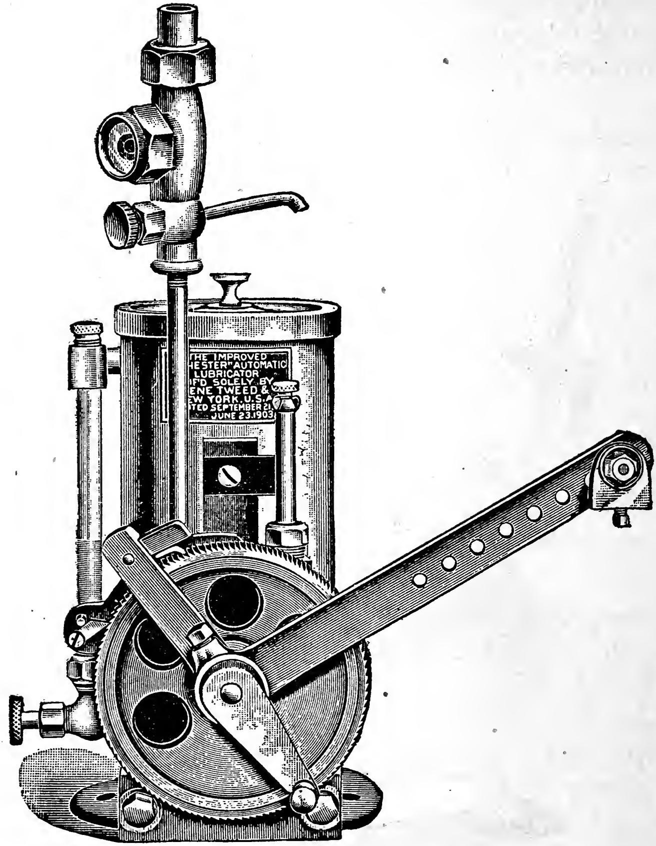


Fig. 234

ROCHESTER FORCE FEED LUBRICATOR WITH MONITOR SIGHT FEED APPLIANCE

any time. The pump is driven in the usual way by connecting to the valve rod of the engine and the feed is regulated by varying the travel of the rocker arm.

Figure 234 shows the Rochester force feed lubricator, as it appears with the Monitor sight-feed attachment screwed onto the delivery pipe, by means of which the engineer is enabled to see the drops of oil as they are being fed to the cylinder or bearings. The number and size of the drops can be regulated to suit the requirements of the engine.

QUESTIONS AND ANSWERS.

423. What is one of the most important problems connected with engine operation?

Ans. The proper lubrication of the bearings.

424. What is friction?

Ans. The resistance caused by the motion of a body in contact with another body that does not partake of its motion.

425. What is the first law of friction?

Ans. Friction varies in proportion to the pressure on the surfaces in contact.

426. Define the second law of friction.

Ans. Friction is independent of the areas of surface in contact.

427. What is the third law of friction?

Ans. Friction increases with the roughness of the surfaces, and decreases as the surfaces become smoother.

428. What is the fourth law of friction?

Ans. Friction is greatest at the beginning of motion.

429. Give the fifth law of friction?

Ans. Friction is greater between soft bodies than it is between hard bodies.

430. When, and by whom were these laws first formulated?

Ans. In 1831-33 by Gen. Arthur Morin, a French engineer.

431. What is the tendency of friction with machinery in operation?

Ans. It tends to cause the parts to adhere to each other.

432. How may this friction be largely obviated?

Ans. By proper lubrication of the rubbing surfaces.

433. Does friction serve any good purpose?

Ans. Yes, for instance the friction of the belt in contact with the rim of the pulley, also the friction of the driving wheels of a locomotive.

434. How many kinds of friction are there in connection with machinery in operation?

Ans. Two, viz., the friction of solids, and the friction of liquids.

435. What is meant by the term co-efficient of friction?

Ans. The ratio of the power required to move a body, and the pressure on that body.

436. What should be the object sought in the design of engine bearings?

Ans. To obtain as large a rubbing surface as possible.

437. Mention some of the qualities that a good lubricating oil should possess.

Ans. It should have a good "body"—must not dry or "gum;" must not be easily thinned by heat, or thickened by cold. Must be free from all gritty substances.

438. What is the proper kind of oil to use on a bearing that has started to heat?

Ans. Cylinder oil, owing to its high fire test.

439. Is graphite, or plumbago a good lubricant?

Ans. It is in many cases.

440. What is the essential function of graphite?

Ans. It is an auxiliary, or accessory lubricant.

441. Mention some of the points that govern interior lubrication of engine parts.

Ans. The conditions of the surfaces; the steam pressure; the amount of moisture in the steam; piston speed; weight, and fit of moving parts, etc.

442. What properties should a good cylinder oil possess?

Ans. It must be of high flash test; must have good viscosity, or body when in contact with hot surfaces.

443. Upon what does the successful lubrication of an engine largely depend?

Ans. Upon the character of the lubricating appliances used.

444. What system of lubrication for cylinders, and valves is most largely used?

Ans. The hydrostatic, or sight-feed type of lubricator.

445. What other system has come into extensive use in late years?

Ans. The force feed, or mechanically operated oil pump.

The Steam Turbine

Although the turbine principle of utilizing the heat energy in steam and converting it into useful work has been experimented upon for many years, it is only since the inauguration of the twentieth century that steam turbines have been brought to the front as efficient power producers.

The piston of the reciprocating engine is driven back and forth by the static expansive force of the steam, while in the steam turbine not only the expansive force is made to do work, but a still more important element is utilized, viz., the kinetic energy, or heat energy latent in the steam, and which manifests itself in the rapid vibratory motion of the particles of steam expanding from a high, to a low pressure, and this motion the steam turbine transforms into work.

Notwithstanding the fact that much has been said and written during the past four years regarding the steam turbine, the machine is to-day a mystery to thousands of engineers, not because they do not desire information upon the subject, but because of a lack of opportunities for obtaining that information. The author therefore considers that a space devoted to this subject would no doubt be of benefit to his readers.

The steam turbine is simple and compact in design, having few working parts as compared with the reciprocating engine, and any engineer who is capable of operating and caring for an engine of the latter type, can also run and take care of a steam turbine. But, as in the case of the

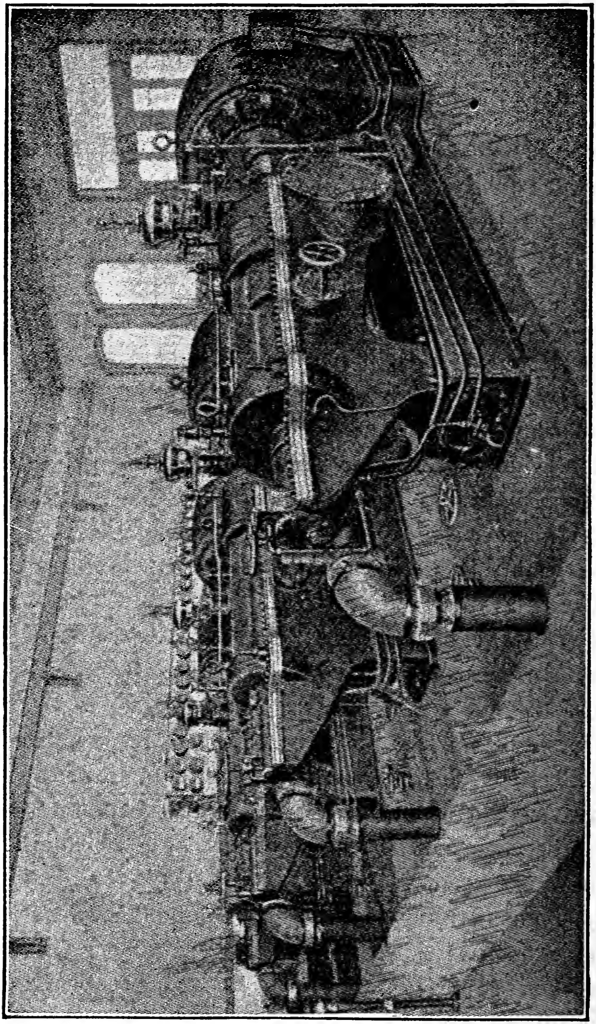


FIG. 235
FOUR WESTINGHOUSE-PARSONS STEAM TURBINES

reciprocating engine, the engineer in charge of a turbine plant should be familiar with the interior construction of the machines under his charge, and he should know what to do, and what to avoid in order to keep them in continual and efficient operation.

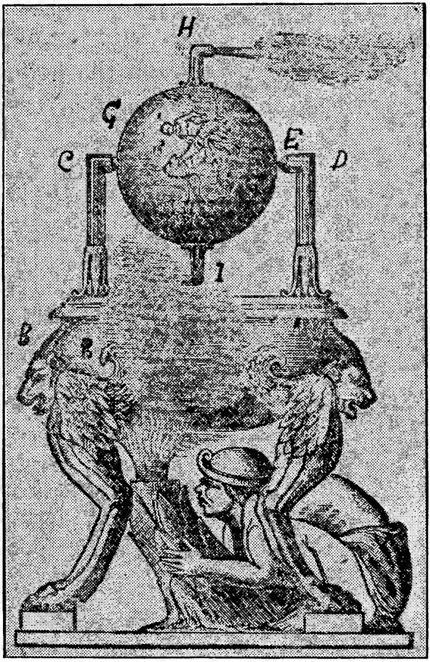


FIG. 236

The steam turbine in principle, and even in type is not new, being in fact the first heat motor of which we have any record in steam engineering.

One of the earliest descriptions of a device for converting the power of steam into work was recorded by Hero, a learned writer who flourished in the city of Alexandria in Egypt, in the second century before Christ. Hero describes a machine called an Aeolipile or "Ball of Aeolus," illustrated in Fig. 236. B is the boiler under which a fire was made. G is a hollow metallic globe that revolved on trunnions C and D, one of which terminated in a pivot at E, while the other was hollow and conveyed the steam generated in the boiler B to the interior of the globe or ball, from which it escaped through the hollow bent tubes H and I, and the reaction of the escaping steam caused the globe to revolve. This was the first steam turbine, and it worked on the reaction principle.

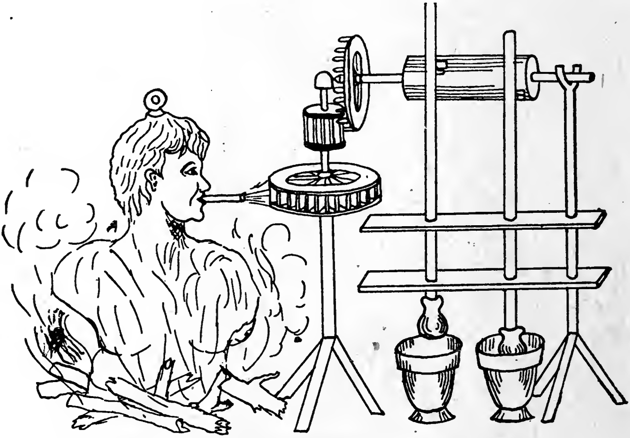


Fig. 237

Many centuries later, in the year A. D. 1629, Branca, an Italian, described an engine which marks a change in the method of using the steam. Branca's engine consisted of a boiler A, Fig. 237, from which the steam issued through a straight pipe, and impinged upon the vanes of a horizontal wheel carried upon a vertical shaft, causing it to revolve. This device was the germ of the impulse turbine, and these two principles, viz., reaction and impulse, either one or the other, and sometimes a combination of both, are the fundamental principles upon which the successful steam turbines of the present age operate.

Steam expanding through a definite range of temperature and pressure exerts the same energy whether it issues from a suitable orifice or expands against a receding piston.

Two transformations of energy take place in the steam turbine; first, from thermal to kinetic energy; second, from kinetic energy to useful work. The latter alone presents an analogy to the hydraulic turbine.

The radical difference between the two turbines lies in the low density of steam as compared to water, and the wide variation of its volume under varying temperatures and pressures.

A cubic foot of steam under 100 lbs. pressure, if allowed to discharge into a vacuum of 28 inches, would attain a theoretical velocity of 3,860 feet per second and would exert 59,900 ft. lbs. of energy.

A law of turbo-mechanics specifies that in order to obtain the highest efficiency in the operation of turbines (whether water or steam) the relation between bucket speed and fluid speed, (steam in this case), should be as follows:

For purely impulse wheels, bucket speed equals one-half of jet speed.

For reaction wheels, bucket speed equals jet speed.

Assuming the velocity of the jet of steam issuing from the nozzle to be 4,000 feet per second, this would mean a peripheral speed of 2,000 feet per second for an impulse wheel, and for a wheel 1 foot in diameter the speed would be 38,100 R. P. M. But such a speed is beyond the limits of strength of material, and the speed of steam turbines is accordingly kept within the bounds of safety, and strength of material.

Form of Blade.—The blades or buckets should be of such form, and curvature as will permit the steam to expand to the desired final, or terminal pressure with the smallest possible friction and eddy current losses. As to directing the flow in the desired course, the direction of exit from the guide, and rotating wheel is of the greatest importance. In order to get the desired angle, the last part of the blade should be kept straight, at least to the foot of the perpendicular dropped from A_1, or the length A B in Fig. 238. From there on, the channel should lead in easy curvature to the angle a_1. The construction according to a in Fig. 238 would obviously be too sharp, and would cause the steam stream to separate from the wall.

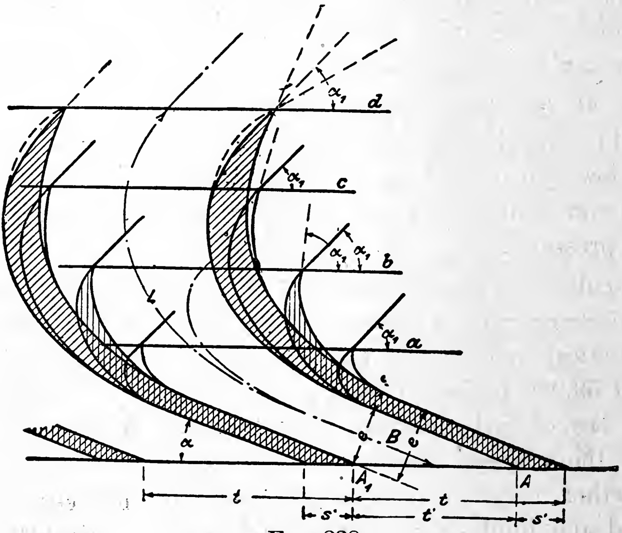


Fig. 238

The construction according to b would suffice, and the wheel radius would depend, above all, upon how far we wish to diminish the shock at entrance. For the profile b the angle a_1 is taken as the slope of the blade back, from which we obtain for the guiding blade surface the somewhat large angle a_1'. This would be more favorable with c, and d, but the latter would obviously give a needlessly long steam path. Besides, a pointing of the blade such that a_1 is half of a_1', as is shown dotted at d, could be considered just as correct as the first mentioned. By drawing the absolute steam path and finding the decrease of peripheral speed, we get useful results concerning the regularity of delivering work.

The proper length of the channel, or steam path can only be determined by practical experience, and with a given curvature the ratio of length to breadth can be considered fairly constant.

Stuffing Boxes.—The stuffing boxes are the most important and delicate part of the steam turbine. As they are subjected to high temperature on account of their proximity to the steam space, the problem of getting rid of their own heat of friction becomes all the more difficult. The advantage of the stuffing box used on reciprocating engines, where the rod for part of the time is exposed to the air, and cools at least its surface by radiation, cannot be considered with the rotating shaft. Water-cooling may be an effective means, but creates considerable loss by condensation in the surrounding steam spaces.

The majority of designers get around this difficulty by avoiding contact between packing and shaft, and secure tightness only by the least possible clearance. This is the principle of the so-called "labyrinth stuffing box" that was first generally used by Parsons. This is shown in Fig. 239, in which A is the shaft, B the stuffing box. The rings on both parts form alternately a narrow space x, and a large space y. The velocity of the steam flowing through this narrow space is destroyed by eddy-currents in the large space, so that for further velocity, a part of the drop in pressure is utilized. With a large number of rings, and with very small spaces x; the loss is greatly decreased.

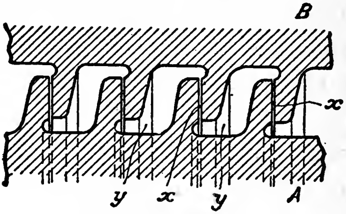


FIG. 239

LABARYNTH STUFFING BOX

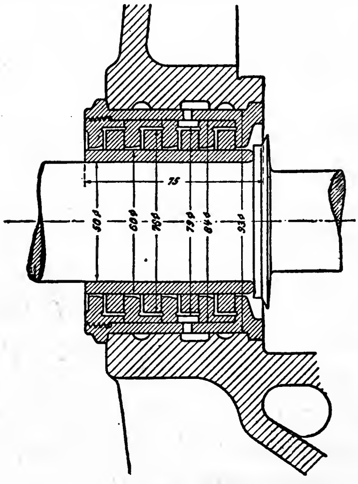


FIG. 240

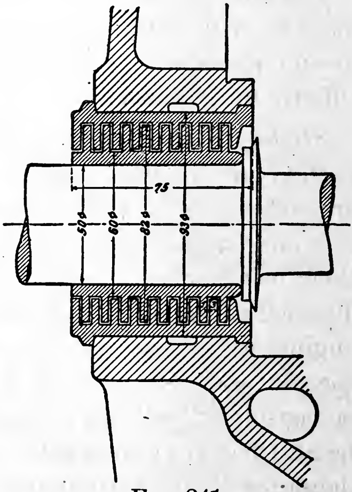


FIG. 241

It also seems to have a favorable influence when the steam in leaving this narrow space flows radially inwards, that is, it helps to overcome its centrifugal force.

Fig. 240 shows the stuffing box of a *Schulz* turbine. No provision is here made for enlarged spaces, but the necessary throttling is accomplished by the great length of the labyrinth path. The designer hoped to limit his clearance to 1 mm. (0.039 in.). The outer box is made in two parts.

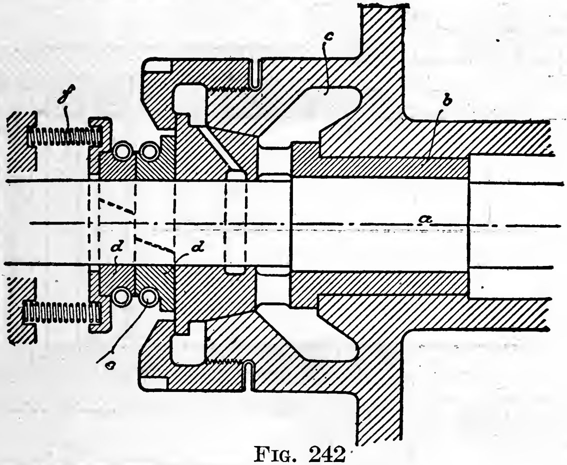


FIG. 242

Fig. 241 shows a stuffing box by the same designer, built of rings, in which the inner rings are loose, but are made with a neat fit.

The Rateau stuffing box is shown in Fig. 242. The main part consists of the shaft, a, enclosed by a close fitting box b, of suitable metal. The steam leaking through this space flows into chamber c, where a constant pressure of about 12 lbs. absolute is maintained by a reducing valve. From the valve the steam is led to a condenser. Chamber c, is kept steam tight from the outside by two bronze rings d, d, each made in three parts, which are held against the shaft with slight pressure by the spiral springs e. A pressure in an axial direction is caused by springs f. The chambers of all the stuffing boxes of the turbine are connected together. Thus a portion of the steam that leaves the high pressure chamber will be drawn into the low pressure side. When running light, partial vacuum exists in all the stuffing boxes, the reducing valve allowing live steam to enter, thus preventing air from being drawn in.

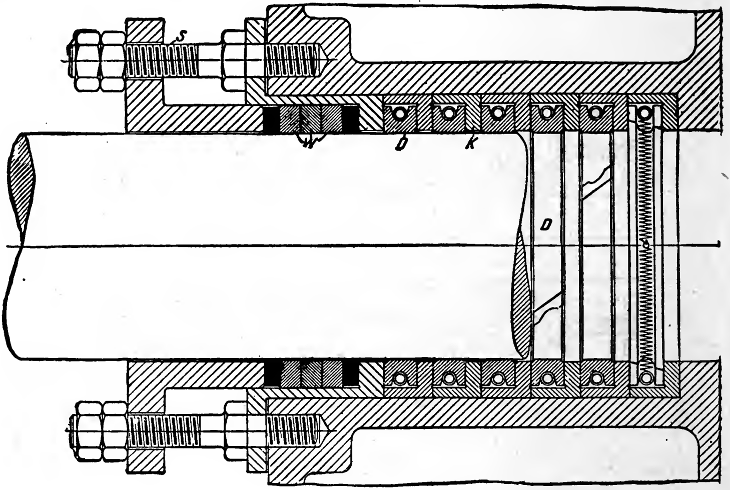


Fig. 243

Steam is led in Figs. 240 and 241 through the ring passages, and excludes thereby the air, so that the vacuum does not suffer.

The construction of a turbine stuffing box as steam tight as that of the steam engine is still an unsolved problem. For this reason we might add the excellent stuffing box of Schwabe, that is used in steam-engine work, shown in Fig. 243. This consists of a large number of rings D made in three parts, held together by a circumferential spiral spring. These rings (for the steam engine) press on one another, and should either not touch the shaft at all, or with only the slightest pressure. With turbines, the soft packing at the outer end will of course be omitted, and the rings must be prevented from turning, and so constructed as to be tight against either pressure or vacuum. The inside and outside ends of the box are provided with means for oiling.

The Regulation of the Steam Turbine.—The regulation in the majority of different systems is acomplished by simple throttling, thus decreasing, at the very beginning, the available work of the steam, and consequently the economy of the turbine. The loss is measured by the product of the increase of entropy and the absolute temperature of the exhaust steam, which can easily be determined from the entropy tables.

The ideal conditions would be to constantly work with a full initial pressure, and to make all cross-sections of steam passages suitable to the power required. Constructively, this idea is most easily applicable to the single stage impulse turbine, in which the nozzles are opened or closed one after another by means of a regulator.

The following description of the construction, and principles controlling the action of the leading types of steam turbines manufactured in the United States is presented, with the hope that it may prove to be not only interesting, but instructive as well, to the student.

It may be said in general of the steam turbine, that it has passed the experimental stage, and has come to the front as an efficient power producer, having a bright future before it. It has solved the problem of using superheated steam, owing to the absence of all rubbing parts exposed to the steam. This permits the use of steam of high temperature, thus making it possible to realize the advantages of economical operation.

The Westinghouse-Parsons Steam Turbine

The Westinghouse-Parsons Steam Turbine operates on both impulse and reaction principles, and by a system of compounding, which will be explained later on, the peripheral velocity of the machine has been so reduced as to bring it within practical limits, while at the same time the power value of the steam is utilized to a high degree of efficiency.

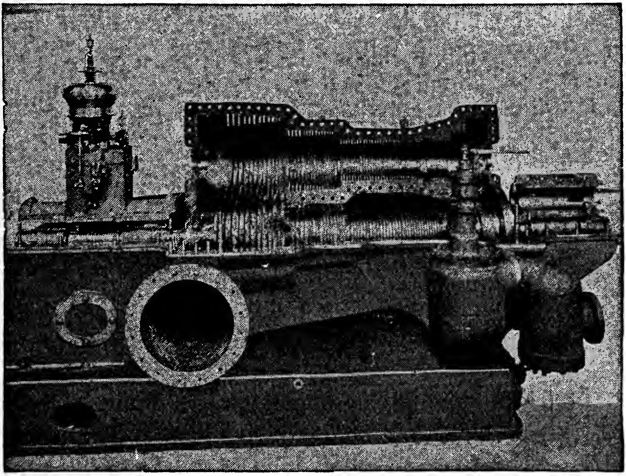


FIG. 244

The speed of the Westinghouse-Parsons turbine varies from about 750 R. P. M. for a 5,000 K. W. machine, to 3,600 R. P. M. for a 400 K. W. turbine.

The Westinghouse-Parsons turbine is fundamentally based upon the invention of Mr. Charles A. Parsons, who, while experimenting with a reaction turbine constructed along the lines of Hero's engine, conceived the idea of combining the two principles, reaction and impulse, and also of causing the steam to flow in a general direction parallel with the shaft of the turbine. This principle of parallel flow is common to all four types of turbines, but is perhaps more prominent in the Westinghouse-Parsons, and less so in the De Laval.

Fig. 235 shows a general view of four Westinghouse-Parsons steam turbines, and Fig. 244 shows a 600 H. P. machine with the upper half of the cylinder, or stator as it is termed, thrown back for inspection. Fig. 245 is a sectional view of a Westinghouse-Parsons turbine, and it will be noticed that there are three sections or drums, gradually increasing in diameter from the inlet A, to the third and last group of blades. This arrangement may be likened in some measure to the triple compound reciprocating engine.

Fig. 246 shows the complete revolving part of a 3,000 H. P. turbine. Its weight is 28,000 lbs., length over all 19 feet 8 inches, and 12 feet 3 inches between bearings; the largest diamater, 6 feet.

By reference to Fig. 244 it will be seen that the inside of the cylinder is studded with rows of small stationary blades, and that the rotor or revolving part of the machine is also fitted with rows of small blades, similar in shape and dimensions to the stationary blades. When the upper half of the cylinder is in position, each row of stationary blades fits in between two corresponding rows of moving blades. This arrangement may perhaps be better

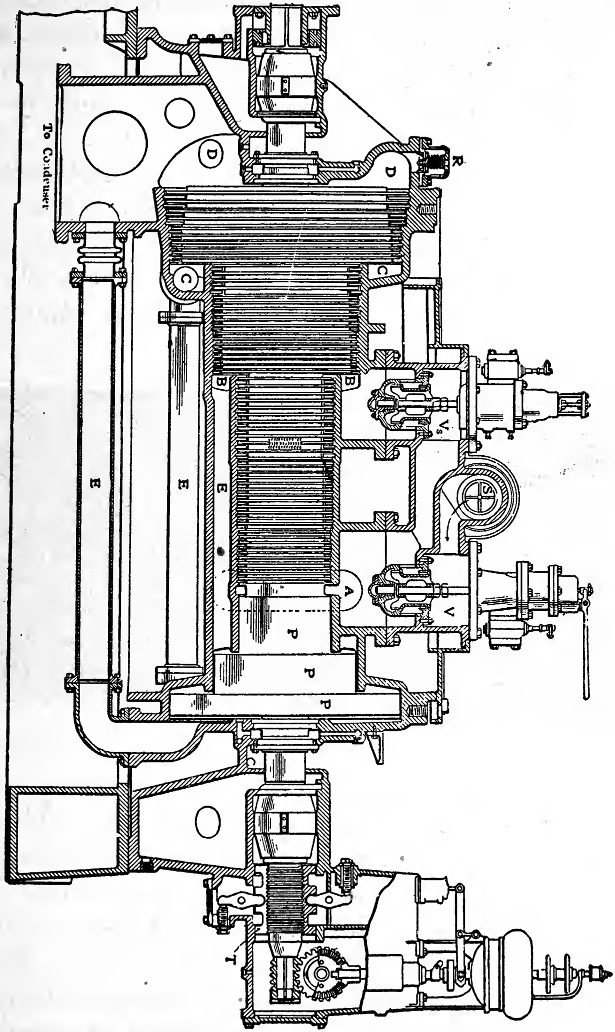


FIG. 245

SECTION OF STANDARD WESTINGHOUSE SINGLE FLOW TURBINE understood by reference to Fig. 247, which illustrates the relation of the stationary blades to the moving blades when in position, and also shows by the arrows the course of the steam and its change of direction caused by the stationary blades.

For the purpose of explanation the moving blades or vanes may be considered as small curved paddles projecting from the surface of the rotor, and there is a large number of them, as for instance, taking a 400 K. W. machine, there are 16,095 moving blades and 14,978 stationary blades, a total of 31,073.

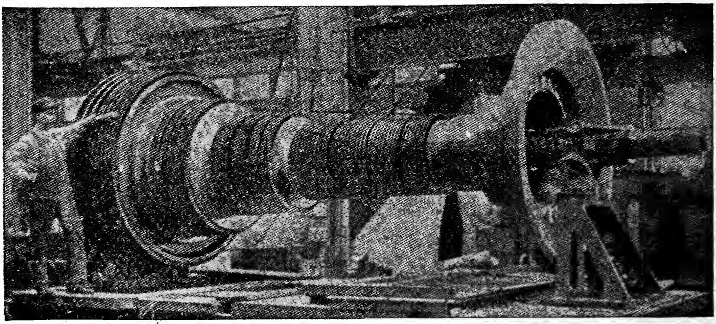


FIG. 246

The stationary vanes, as previously explained project from the inside surface of the cylinder. Both stationary and moving vanes are similar in shape, and are made of hard drawn material, and they are set into their places and secured by a caulking process. The blades vary in size from ½ to 7 in. in length, according to where they are used. Referring to Fig. 244, it will be observed that the shortest blades are placed at what might be termed the steam end of each section or drum of the rotor and cylinder, and that their length gradually increases, corresponding with the increased volume of steam, until a mechanical limit is reached, when a new group of blades begins on a succeeding drum of larger diameter. Referring to Fig. 247, which is a sectional view of four rows of blades, it will be noticed that all the blades, whether stationary or moving, have the same curvature. Also that the curves are set opposite each other. The reason for this will be apparent as the diagram is studied. The steam at pressure P first comes in contact with row 1 of stationary blades. It expands through this row, and in expanding the pressure falls to P′.

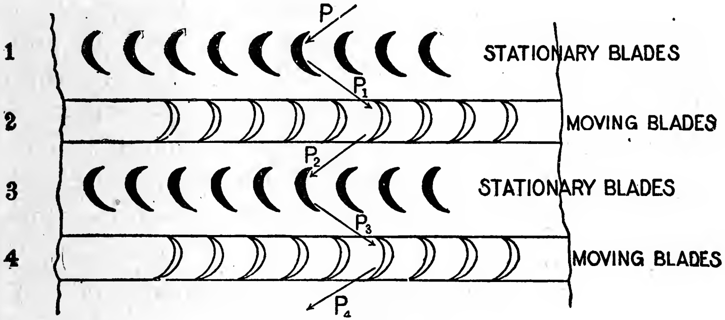


FIG. 247

The energy in the steam is converted into velocity, and it impinges upon row 2 of moving blades, driving them around in their course by impulse. A second expansion now occurs in row 2, and again the energy is converted into velocity, but this time the reaction of the steam as it leaves the blades of row 2 also tends to impel them around in their course. The moving blades thus receive motion from two causes—the one due to the impulse of the steam striking them, and the other due to the reaction of the steam leaving them.

This cycle is repeated in rows 3 and 4, and so on throughout the length of the rotor until the exhaust end is reached.

It should be noted that the general direction taken by the steam in its passage through the turbine is in the form of a spiral or screw line about the rotor. The clearance between the blades as they stand in the rows is ⅛ in. for the smallest size blades and ½ in. for the larger ones, gradually increasing from the inlet to the exhaust. In the 5,000 K. W. machine the clearance at the exhaust end between the rows of blades is 1 in. It will thus be seen that there is ample mechanical clearance, also allowance for lateral motion for adjustment of the rotor, although this is very slight, as the rotor is balanced at all loads and pressures by the balancing pistons PPP, Fig. 245, to which reference is now made. These pistons revolve within the cylinder, but do not come in mechanical contact with it; consequently there is no friction. The diameter of each piston corresponds to the diameter of one of the three drums.

The steam entering the chamber A through valve V presses against the turbine blades and goes through doing work by reason of its velocity. It also presses equally in the opposite direction against the first piston P, and so the shaft or rotor has no end thrust. On leaving the first group of blades and striking the second group the pressure in either direction is again equalized by the balance port E allowing the steam to press against the second balance piston P. The same event occurs at group three, the steam acting upon the third piston P.

The areas of the balancing pistons are such that, no matter what the load may be, or what the steam pressure or exhaust pressure may be, the correct balance is maintained and there is practically no end thrust. Below is shown a pipe E connecting the back of the balancing pistons with the exhaust chamber. This arrangement is for the purpose of equalizing the pressure at this point with the pressure in the exhaust chamber.

It might be thought that the blades, on account of their being so light and thin, would wear out very fast, but experience so far shows that they do not. This may be accounted for in two ways. First, the reduction of the velocity of the steam, the highest velocity in the Parsons turbine not exceeding 600 ft. per second; secondly, the light steam thrust on each blade, said to be equal to about 1 oz. avoirdupois. This is far within the bending strength of the material. A steam strainer is also placed in the admission port, to prevent all foreign substances from entering the turbine.

A rigid shaft and thrust or adjustment bearing accurately preserves the clearances, which are larger in this turbine than in other types, owing to the fact that the entire circumference of the turbine is constantly filled with working steam when in operation.

The bearings shown in Fig. 245 are constructed along lines differing from those of the ordinary reciprocating engine. The bearing proper is a gun metal sleeve, see Fig. 248, that is prevented from turning by a loose-fitting dowel. Outside of this sleeve are three concentric tubes having a small clearance between them. This clearance is kept constantly filled with oil supplied under light pressure, which permits a vibration of the inner shell or sleeve and at the same time tends to restrain or cushion it. This arrangement allows the shaft to revolve about its axis of gravity, instead of the geometrical axis, as would be the case if the bearing were of the ordinary construction. The journal is thus to a certain degree a floating journal, free to run slightly eccentric according as the shaft may happen to be out of balance.

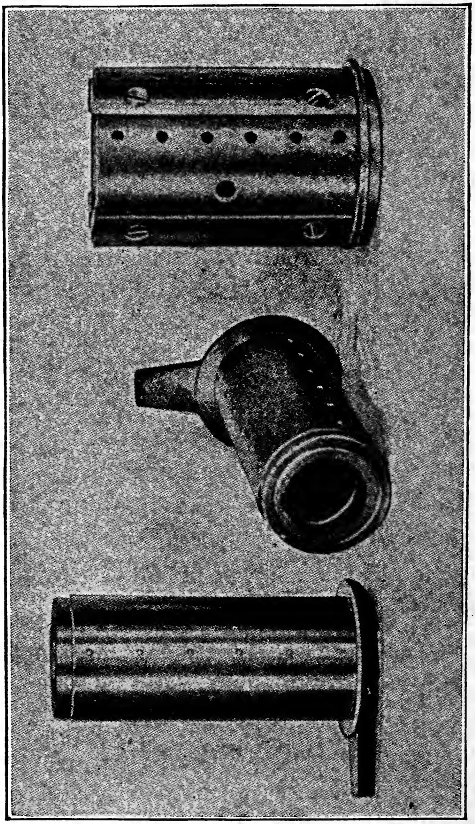


Fig. 248

A flexible coupling is provided, by means of which the power of the turbine is transmitted to the dynamo or other machine it is intended to run. The oil from all the bearings drains back into a reservoir, and from there it is forced up into a chamber, where it forms a static head, which gives a constant pressure of oil on all the bearings. A secondary valve is located at Vs, by means of which high pressure steam may be admitted to the steam space E on the same principle that high pressure steam is admitted to the low pressure cylinder of a compound engine. This valve opens automatically in cases of emergency, such as overload, failure of the condenser to work, etc.

The shaft, where it passes through either cylinder head, is packed with a water seal packing, consisting of a small paddle wheel attached to the shaft, which, through centrifugal action, maintains a static pressure of about 5 lbs. per sq. in. in the water seal, thus preventing all leakage while at the same time it is frictionless.

Governor.—The speed of the Westinghouse-Parsons turbine is regulated by a fly ball governor constructed in such manner that a very slight movement of the balls serves to produce the required change in the supply of steam. Fig. 249 is a diagram of the governor mechanism. The ball levers swing on knife edges instead of pins. The governor works both ways, that is to say, when the levers are oscillating about their mid position a head of steam corresponding to full load is being admitted to the turbine, and a movement from this point, either up or down, tends to increase or to decrease the supply of steam.

Referring to Fig. 249, B is a piston directly connected to the admission valve. Steam is admitted to this piston under control of the pilot valve A, which has a slight but continuous reciprocating motion derived from the eccentric rod C, and the function of the governor is to vary the plane of oscillation of this valve, thus causing it to admit more or less steam to piston B. The admission valve, being actuated exclusively by piston B, is thus caused to remain open for a longer or shorter period of time, according to the load upon the turbine.

The vibrations of the admission valve, although very slight, are continuous and regular, about 165 per minute, and are transmitted primarily by means of an eccentric, the rod of which is shown at C, Fig. 249.

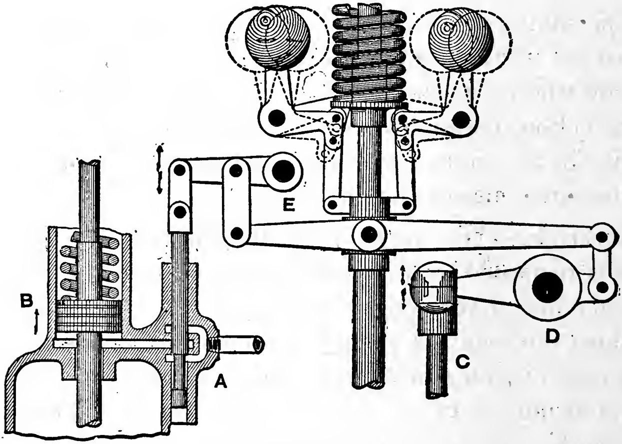


FIG. 249

The governor sleeve is used as a floating fulcrum, and the points D and E are fixed. By means of this very ingenious device the steam is admitted to the turbine in puffs, either long or short, according to the demand for steam. At full load the puffs merge into an almost continuous blast. When the load has increased to the point where the valve is wide open continuously, a full head of steam is being admitted. Beyond this the secondary valve comes into action, thus keeping the speed up to normal.

The rotor requires perfect balancing to insure quiet running, but this is easily accomplished in the shop by means of a balancing machine used by the builders.

Steam turbines generally show higher efficiency in the use of steam than reciprocating engines do, and this fact is due to three leading causes. First, it is possible with the turbine to use highly superheated steam which, owing to the difficulties attending lubrication, could not be used in the reciprocating engine. Second, a larger proportion of the heat contained in the steam is converted into work, for the reason that the steam is allowed to expand to a much lower pressure, and into a higher vacuum. In addition to this, the velocity of the expanding steam is utilized in a much higher degree in the turbine as compared with the reciprocating engine. Third, mechanical friction or lost work is reduced to the minimum. Under test a 400 K. W. Westinghouse-Parsons steam turbine, using steam at 150 lbs. initial pressure and superheated about 180°, consumed 11.17 lbs. of steam per brake horse power hour at full load. The speed was 3,550 R. P. M. and the vacuum was 28 in.

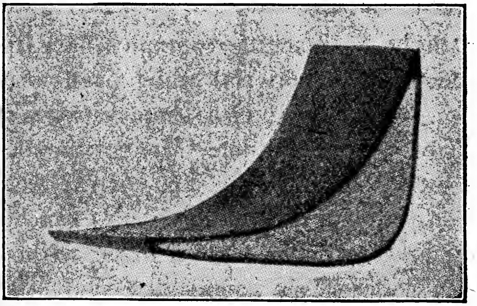


FIG. 250
NEW BLADING MATERIAL

With dry saturated steam the consumption was 13.5 lbs. per B. H. P. hour at full load, and 15.5 lbs. at one-half load.

A 1,000 K. W. machine, using steam of 150 lbs. pressure and superheated 140°, exhausting into a vacuum of 28 in., showed the very remarkable economy of 12.66 lbs of steam per E. H. P. per hour.

A 1,500 K. W. Westinghouse-Parsons turbine, using dry saturated steam of 150 lbs. pressure with 27 in. vacuum, consumed 14.8 lbs. steam per E. H. P. hour at full load, and 17.2 lbs. at one-half load.

The Westinghouse machine company have recently introduced a new blade material which is now used in all Westinghouse turbines. It is a copper-coated steel blade, or, as designated by the builder, "Monnot metal," in which the copper coating (seen in Fig. 250) is chemically welded to the steel so thoroughly that the blades can be drawn to the desired shape from the original ingot, without weakening the union between the copper and steel. The process of drawing makes the copper coating somewhat thicker at the inlet and outlet edges of the blade, though the remaining portions of the blade surfaces are coated with an absolutely uniform thickness of copper. The only portion of the blade where steel is exposed, is the small surface of the tip of the blade where, however, corrosion is the least detrimental, for should the tips corrode, the copper coating would still remain intact, thus leaving the working blade surfaces untouched and the blade clearances unaltered.

Figs. 251 and 252 show sectional elevations of the double flow type of steam turbines now being manufactured by the Westinghouse company, in addition to the standard single flow turbine already described.

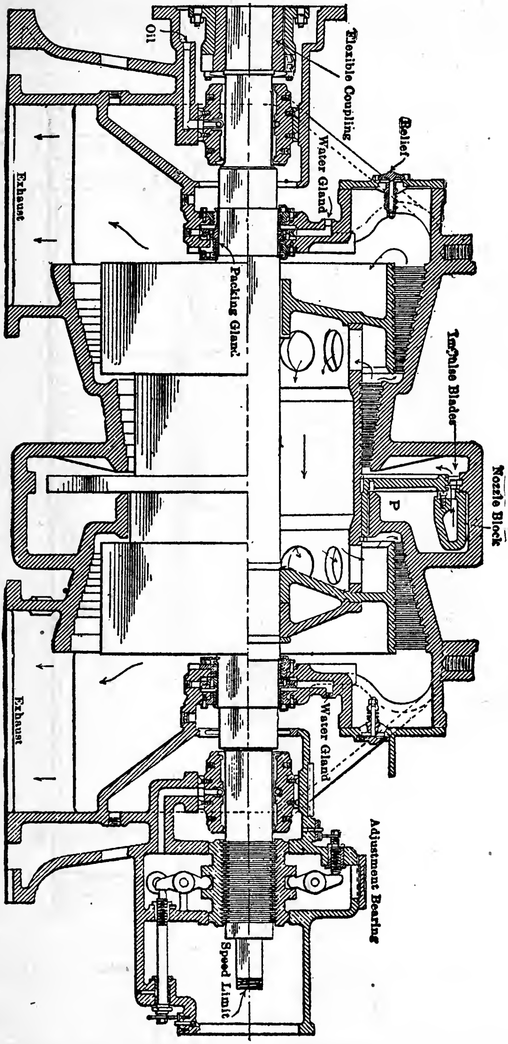


FIG. 251

SECTION OF WESTINGHOUSE DOUBLE FLOW TURBINE

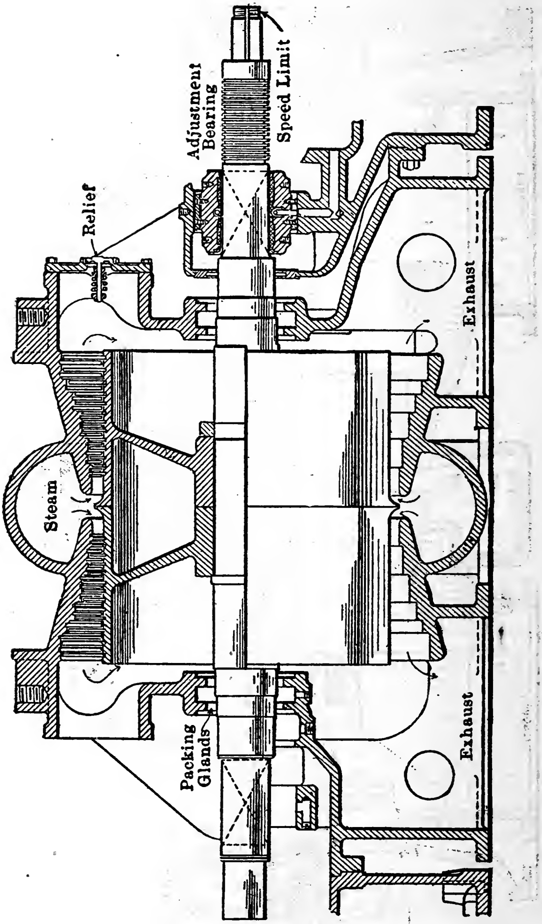


FIG. 252

WESTINGHOUSE DOUBLE FLOW LOW-PRESSURE TURBINE
Sectional Elevation

Fig. 251 shows the machine as adapted for using steam of high initial pressure, in fact an impulse turbine, in which the steam admitted first to the nozzle block, is expanded in nozzles arranged about the periphery, and impinges upon the impulse buckets of the central rotation wheel. There are two rows of moving blades upon the impulse wheel, with an intermediate set of reversing blades as shown. Issuing from the delivery side of this wheel with its velocity energy practically all abstracted, the steam passes, as shown by the arrow, to an intermediate set of Parsons blading. As this blading has no counterpart upon the other side of the turbine, the pressure upon it must be counterbalanced, and this is done by making the extension of the hub by which the impulse wheel is keyed to the shaft, into a piston or dummy of the mean diameter of the intermediate stage, as shown at P. After passing the intermediate stage the steam divides, one portion passing directly to the low-pressure blading at the left, while the rest passes through the hollow shell of the rotor to the similar pressure blades upon the right. As these sections are equal and symmetrical they counterbalance each other, so that no further dummies are required than the small one already referred to.

For regulating the steam supply in accordance with the load, two methods other than that of simple throttling with its sacrifice of temperature head are available.

The admission area may be varied by the cutting in and out of nozzles.

The duration of the time of admission through a constant area may be varied.

The first is the Curtis method, impracticable for a full-admission turbine like the Parsons; the second, that which has been developed by the Westinghouse engineers for the Parsons as they build it. The adoption of the partial admission for first stage in the double flow machine gave the

Westinghouse designers their option of the two methods, but they have preferred to continue the variable duration puff system, already described in connection with single flow machines. A disadvantage of the variable nozzle method of regulation is, that if the area of the nozzles of the succeeding stages is correctly proportioned to pass along the steam admitted by a certain number of primary nozzles, it will be too great when fewer nozzles are in action, and too small when there are more. This will result in a considerable variation of the pressure in the succeeding stages, and of the pressure ratios of expansion and jet velocity acquired in those stages, and interfere with the designer's intention with regard to the distribution of work and the relation of blade to jet velocity. This could be overcome only by adjusting the nozzles of the succeeding individual stages in harmony with those of the initial stage.

If, on the other hand, the passages through the turbine are permanently arranged in the correct relation to each other, this relation will persist whether the flow is continuous or intermittent, and the energy developed can be regulated to the demand by making the flow more nearly continuous, as the load approaches the rated capacity of the machine. So far as the change in initial pressure due to the alternate letting on and shutting off of the steam is concerned, theory indicates, and experiment proves that where the expansion in each stage is but a small part of the total range, as in the Parsons turbine, the initial and terminal pressures of each stage rise and fall, resulting in a fairly constant pressure ratio at each successive expansion; in other words, for small ranges, and throttle governing, the nozzle and blade areas are reasonably correct through a wide range of load and pressure distribution. For this reason the impulse section of the Westinghouse turbine, doing, say, only one-fifth of the total work, is properly proportioned for a wide range in load and may be governed without resorting to intermediate nozzle control, and without sacrifice of economy and fractional loads.

Advantage Gained.—The balancing pistons have been reduced to a minimum. In the single-flow types the high-pressure dummy occupies fully one-half of the total dummy piston length on the shaft, while the low-pressure piston is 2½ times the high-pressure diameter.

A reduction of nearly 50 per cent in shaft span between bearings. Owing to the rotor construction a better loading of the shaft is also obtained; that is, the rotor weight is transmitted to the shaft at points nearer the bearings than in the single-flow rotor, where the weight is largely distributed.

An increase to about double rotative speed made possible by the reduction in shaft span and loading; that is, to a general greater rigidity of the double-flow construction.

A reduction of about 70 per cent in the bulk of the main parts of the machine with practically the same output.

Internal cylinder stresses due to high-pressure and high-temperature steam are avoided by isolating the incoming steam within separate nozzle chambers, so that the main body of the turbine is subjected to steam having not much over 75 pounds gauge pressure with practically no superheat.

The bulk of the low-pressure stage is better distributed and the length of the low-pressure blades greatly reduced by subdividing this stage into two parts located at opposite ends of the rotor.

As will be plain from what has preceded, the advantages sought in this form of turbine are constructional and mechanical rather than economic. For high-pressure work the standard Westinghouse-Parsons single-flow turbine will be built up to capacities of 3,000 kilowatts; above 5,000 kilowatts all units will be built upon the double-flow principle. The latter construction will also be used for the low-pressure turbines to which it is so admirably adapted, as shown in Fig. 252, which is a section of the Westinghouse low-pressure, double-flow, steam turbine designed for utilizing the exhaust steam from non-condensing reciprocating engines. Fig. 253 shows a view of a double-flow steam turbine without the generator attached.

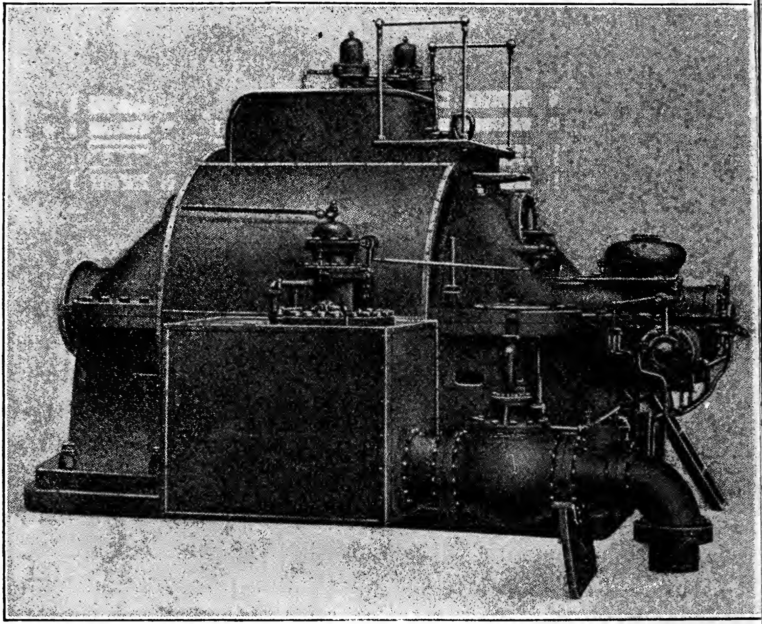


FIG. 253

3,000 K. W. WESTINGHOUSE DOUBLE FLOW STEAM TURBINE

The Curtis Steam Turbine

In the Curtis turbine the heat energy in the steam is imparted to the wheel, both by impulse and reaction, but the method of admission differs from that of the Westinghouse-Parsons, in that the steam is admitted through expanding nozzles in which nearly all of the expansive force of the steam is transformed into the force of velocity. The steam is caused to pass through one, two, or more stages of moving elements, each stage having its own set of expanding nozzles, each succeeding set of nozzles being greater in number and of larger area than the preceding set. The ratio of expansion within these nozzles depends upon the number of stages, as, for instance, in a two-stage machine, the steam enters the initial set of nozzles at boiler pressure, say 180 lbs. It leaves these nozzles and enters the first set of moving blades at a pressure of about 15 lbs., from which it further expands to atmospheric pressure in passing through the wheels and intermediates. From the pressure in the first stage the steam again expands through the larger area of the second stage nozzle to a pressure slightly greater than the condenser vacuum at the entrance to the second set of moving blades, against which it now impinges, and passes through still doing work, due to velocity and mass.

From this stage the steam passes to the condenser. If the turbine is a four-stage machine and the initial pressure is 180 lbs., the pressure at the different stages would be distributed in about the following manner: Initial pressure, 180 lbs.; first stage, 50 lbs.; second stage, 5 lbs.; third stage, partial vacuum, and fourth stage, condenser vacuum.

Fig. 254 gives a general view of a 5,000 K. W. turbine and generator. The generator is shown at the top, while the turbine occupies the middle and lower section. A portion of the inlet steam pipe is shown, ending in one nozzle group at the side. There are three groups of initial nozzles, two of which are not shown. The revolving parts of this unit are set upon a vertical shaft, the diameter of the

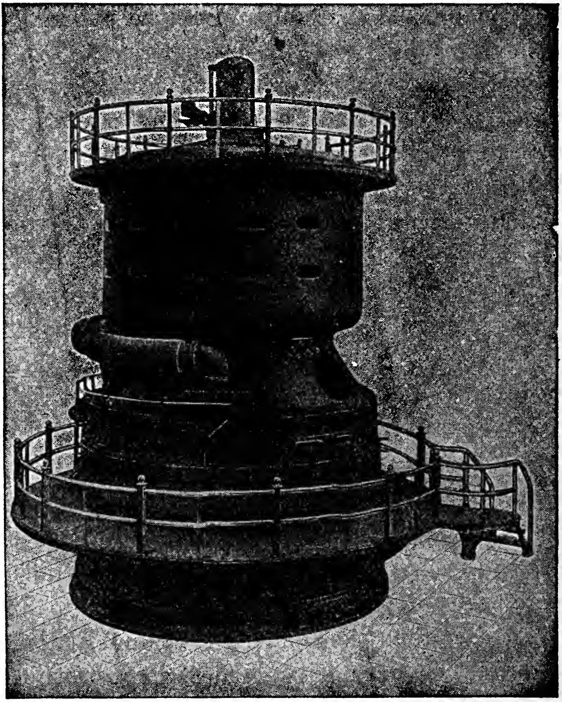


FIG. 254

5,000 K. W. CURTIS STEAM TURBINE DIRECT CONNECTED TO 5.000 K. W. THREE-PHASE ALTERNATING CURRENT GENERATOR shaft corresponding to the size of the unit. For a machine having the capacity of the one illustrated by Fig. 254 the diameter of the shaft is 14 in.

The shaft is supported by, and runs upon a step bearing at the bottom. This step bearing consists of two cylindrical cast iron plates, bearing upon each other and having a central recess between them into which lubricating oil is forced under pressure by a steam or electrically driven pump, the oil passing up from beneath. A weighted accumulator is sometimes installed in connection with the oil pipe as a convenient device for governing the step bearing pumps, and also as a safety device in case the pumps should fail, but it is seldom required for the latter purpose, as the step bearing pumps have proven, after a long service in a number of cases, to be reliable. The vertical shaft is also held in place and kept steady by three sleeve bearings, one just above the step, one between the turbine and generator, and the other near the top. These guide bearings are lubricated by a standard gravity feed system. It is apparent that the amount of friction in the machine is very small, and as there is no end thrust caused by the action of the steam, the relation between the revolving and stationary blades may be maintained accurately. As a consequence, therefore, the clearances are reduced to the minimum.

The Curtis turbine is divided into two or more stages, and each stage has one, two or more sets of revolving blades bolted upon the peripheries of wheels keyed to the shaft. There are also the corresponding sets of stationary blades, bolted to the inner walls of the cylinder or casing. As in the Westinghouse-Parsons type, the function of the stationary blades is to give direction to the flow of steam.

Fig. 255 illustrates one stage of a 500 K. W. turbine in course of construction. It will be observed that there are three wheels, and that in the spaces between these wheels the stationary buckets or vanes are placed, being firmly bolted to the casing. Fig. 256 shows sections of both revolving and stationary buckets ready to be placed in position. The illustration in Fig. 255 shows the lower or last stage. The clearance between the revolving and stationary blades is from $\frac{1}{32}$ to $\frac{1}{16}$ in., thus reducing the wasteage of steam to a very low percentage. The diameters of the wheels vary according to the size of the turbine, that of a 5,000 K. W. machine being 13 ft.

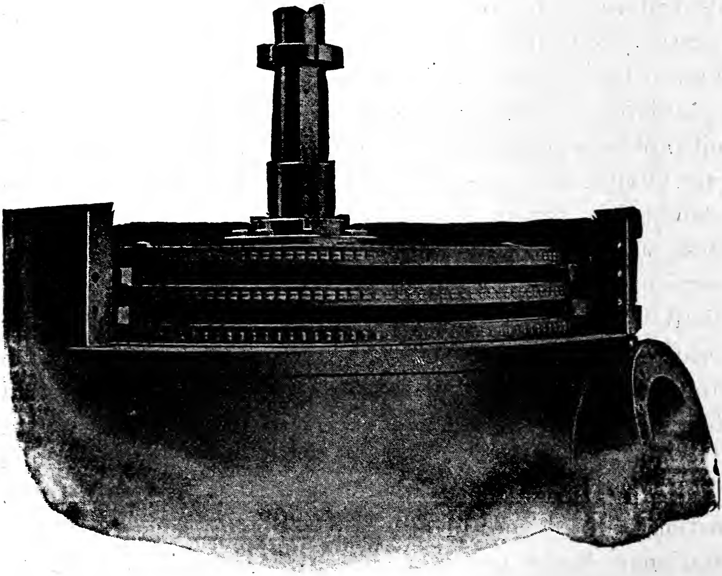
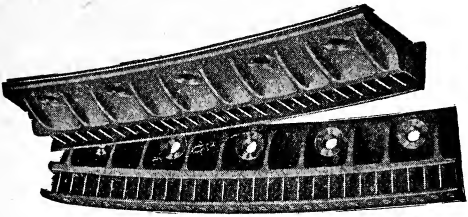
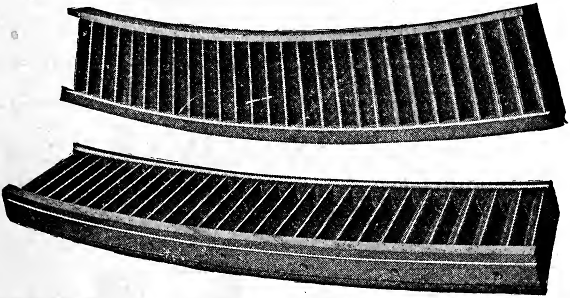


FIG. 255

500 K. W. CURTIS STEAM TURBINE IN COURSE OF CONSTRUCTION



REVOLVING BUCKETS FOR CURTIS STEAM TURBINE



STATIONARY BUCKETS FOR CURTIS STEAM TURBINE

FIG. 256

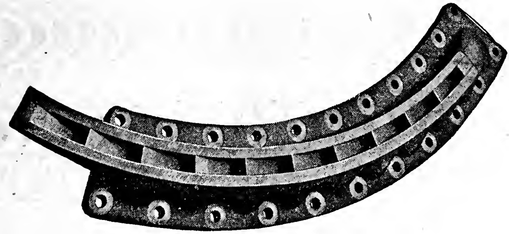


FIG. 257

NOZZLE

Fig. 257 shows a nozzle diaphragm with its various openings, and it will be noted that the nozzles are set at an angle to the plane of revolution of the wheel.

Fig. 258 is a diagram of the nozzles, moving blades and stationary blades of a two-stage Curtis steam turbine. The steam enters the nozzle openings at the top, controlled by

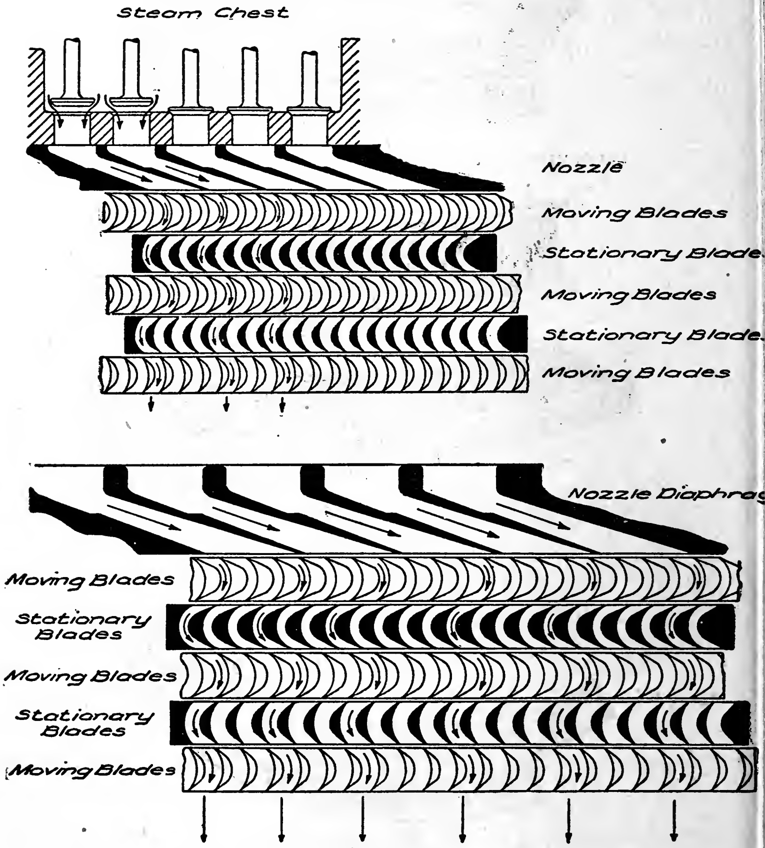


FIG. 258

DIAGRAM OF NOZZLES AND BUCKETS IN CURTIS STEAM TURBINE

the valves shown, the regulation of which will be explained later on. In the cut Fig. 258 two of the valves are open, and the course of the steam through the first stage is indicated by the arrows. After passing successively through the different sets of moving blades and stationary blades in the first stage, the steam passes into the second steam chest. The flow of steam from this chamber to the second stage of buckets is also controlled by valves, but the function of these valves is not in the line of speed regulation, but for the purpose of limiting the pressure in the stage chambers, in a manner somewhat similar to the control of the receiver pressure in a two-cylinder or three-cylinder compound reciprocating engine.

The valves controlling the admission of steam to the second, and later stages differ from those in the first group in that they partake more of the nature of slide valves and may be operated either by hand, or automatically; in fact, they require but very little regulation, as the governing is always done by the live steam admission valves.

Action of the Steam in a Two-stage Machine.—As previously stated, the steam first strikes the moving blades in the first stage of a two-stage machine at a pressure of about 15 lbs. above atmospheric pressure, but with great velocity. From this wheel it passes to the set of stationary blades between it and the next lower wheel. These stationary blades change the direction of flow of the steam and cause it to impinge the buckets of the second wheel at the proper angle.

This cycle is repeated until the steam passes from the first stage into the receiving chamber, or steam chest for the second stage. Its passage from this chamber into the second stage is controlled by valves, which, as before stated, are regulated either by hand, or automatically. The course of the steam through the nozzles and blades of the second stage is clearly indicated by the arrows, and it will be noted that steam is passing through all the nozzles.

At this point it might be well to consider the question which no doubt arises in the mind of the student in his efforts to grasp the underlying principles in the action of the steam turbine. Why is it that the impingement of the steam, at so low a pressure, against the blades or buckets of the turbine, imparts such a large amount of energy to the shaft?

The answer is, because of velocity, and a good example of the manner in which velocity may be made to increase the capacity of an agent to do work is illustrated in the following way: Suppose that a man is standing within arm's length of a heavy plate glass window and that he holds in his hand an iron ball weighing 10 lbs. Suppose the man should place the ball against the glass and press the same there with all the energy he is capable of exerting. He would make very little, if any, impression upon the glass. But suppose that he should walk away from the window a distance of 20 ft. and then exert the same amount of energy in throwing the ball against the glass, a different result would ensue. The velocity with which the ball would impinge the surface of the glass would no doubt ruin the window. Now, notwithstanding the fact that weight, energy and time involved were exactly the same in both instances, yet a much larger amount of work was performed in the latter case, owing to the added force imparted to the ball by the velocity with which it impinged against the glass.

Speed Regulation.—The governing of speed is accomplished in the first set of nozzles, and the control of the admission valves here is effected by means of a centrifugal governor attached to the top end of the shaft. This governor, by a very slight movement, imparts motion to levers, which in turn work the valve mechanism. The admission of steam to the nozzles is controlled by piston valves, which are actuated by steam from small pilot valves which are in turn under the control of the governor Fig. 259 shows the

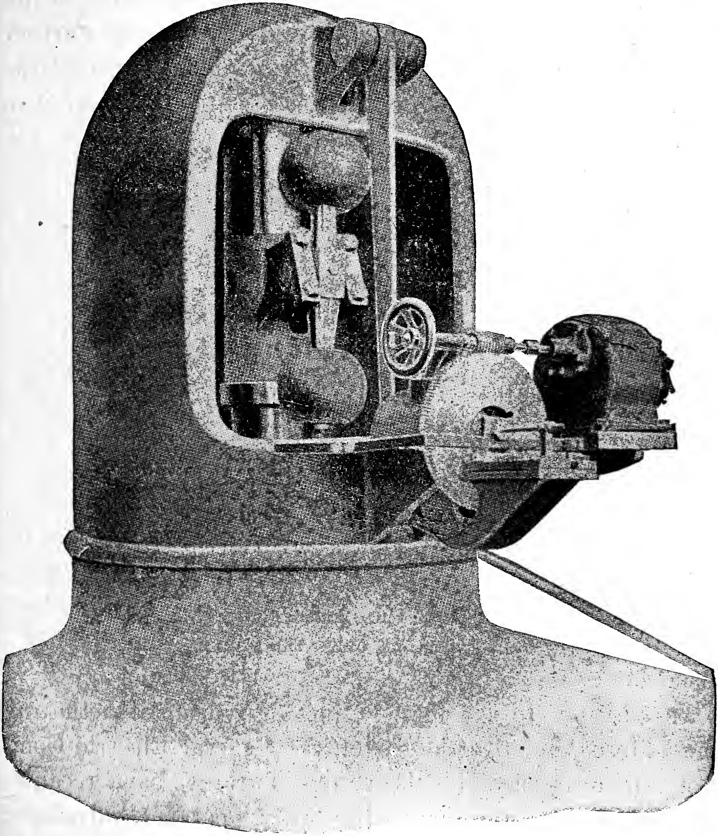


FIG. 259
GOVERNOR FOR 5,000 K. W. TURBINE

form a governor for a 5,000 K. W. turbine, and Fig. 260 shows the electrically operated admission valves for one set of nozzles.

Speed regulation is affected by varying the number of nozzles in flow, that is for light loads fewer nozzles are open, and a smaller volume of steam is admitted to the turbine wheel, but the steam that is admitted impinges the moving blades with the same velocity always, no matter whether the volume be large or small. With a full load and all the nozzle sections in flow, the steam passes to the wheel in a broad belt and steady flow.

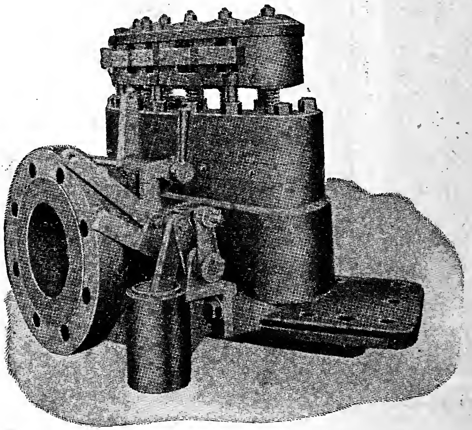


Fig. 260

ELECTRICALLY OPERATED VALVE

In addition to the method just described, of actuating the addmission valves by steam, the General Electric Company, manufactures of the Curtis Turbine, have recently introduced a system of hydraulicaly operated valves for speed regulation.

These valves are also of the poppet type, and each is closed by a helical spring in compression. In the closed position they are held tight by steam pressure, against which they are opened. The valves on one machine are all duplicates, and are opened in rotation by cams (one for each valve) mounted on a shaft, each cam being given in succession an angular advance over its predecessor. This

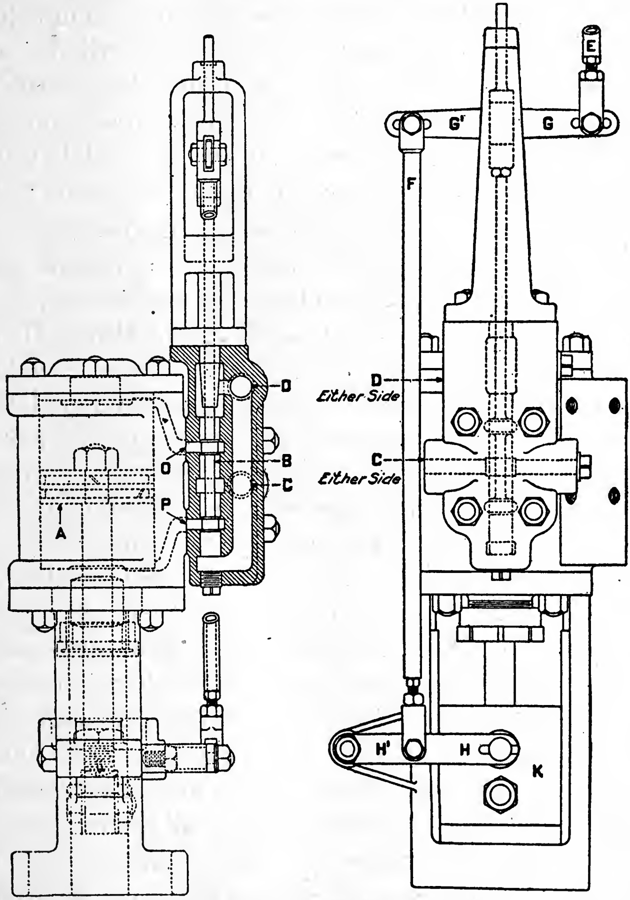


FIG. 261

cam shaft is rotated by the piston in a hydraulic cylinder, the cylinder being mounted either on the generator or valve casing.

The valves open gradually; that is there will be throttling on the opening, or closing valve, before the next one in either side is opened or closed, so that the exact amount of steam required can be admitted for any definite load. Fig. 261 shows a section of the hydraulic cylinder, and controlling valve. The position of piston A is controlled by a balanced piston valve B. The liquid under pressure is admitted at C, and discharged at D. The rod E is connected with the governor, and rod F with the piston rod.

Operation.—The rod E receives its motion from the governor, and occupies a fixed position for any given speed between the limits through which the governor is designed to operate. The lever arms G and G′, and H and H′ are so proportioned that the piston A will occupy a definite fixed position to correspond with any position of rod E.

Therefore as the crosshead K transmits its motion through connecting rod N; (see Fig. 262) to the crank L on the cam shaft M, there will be a fixed number of valves open for any position of the governor. While the turbine is operating at a fixed speed, the piston valve will occupy a central position, closing both ports O and P. When there is a drop in speed, the governor causes rod E to move down, thus opening part O to discharge, and port P to admit liquid under piston A which them moves upwards, opening more valves to satisfy the demand for steam. In moving up the piston transmits its motion through rod F to the piston valve B, restoring it to the central position. When operating on a fixed, or slightly varying load, the main piston should not continuously move over a distance greater than that corresponding to the lap of the piston valve, and under no condition of governing should the main piston continually travel back and forth over a dis-

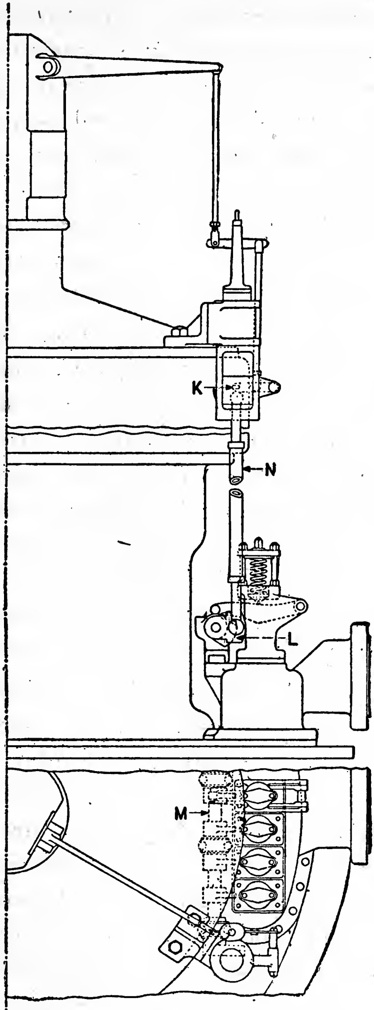


Fig. 262

tance greater than this. Any larger movements should only occur when greater or less power is demanded for considerable variation in load. Any continuous opening and closing of the valves during a steady load is an indication of excessive friction in the governor rigging, or piston valve, and it should be eliminated as soon as possible.

It is essential that the pistons on the piston valve B, Fig. 261 be reduced in diameter at their centers $\frac{1}{32}$ in. as indicated in the illustration. If this is not done it may be responsible for sticking of the piston valve, thereby interfering with the satisfactory regulation of the machine.

For different machines the connections may be altered, and in some the operation is reversed, by crossing the ports, so that the piston A will move in the same direction as the piston valve B, and in the application of the gear to later machines of large capacity, it has been found advisable to place the cylinder horizontal, operating crank shafts of valve casings by means of rack and pinion with bevel gear transmission, or with racks operating directly on pinions on cam shafts, but the principle of operation is the same, only modified in application to suit particular cases.

Adjustment.—With the piston A, and the piston valve B, both in their mid positions, the rod F should be of such a length that the lever G will be horizontal. The connecting rod N is adjusted so that with piston A at the extreme end of its up stroke, all the steam valves are open, and the first one just ready to close. With the piston A in this position (i. e., at the extreme end of its stroke,) and the governor at the low speed position, the rod E should be adjusted so that the piston valve B, will be in its mid position.

Precautions.—(1) It is absolutely essential that all connections between governor and valve be entirely free from friction.

(2) The piston valve B must move freely for the whole length of its stroke, so that if the rod E be disconnected from the arm G, the valve will drop of its own weight, either with pressure on or off.

(3) There must be absolutely no binding at any of the joints through the whole travel.

(4) The liquid used must be entirely free from dirt, or grit, of any nature.

(5) On the main steam valves; in the closed position, when the roller has ridden off of the cam, it must not press on the cam shaft, as this will prevent valve seating properly.

(6) The piston valve and bore must be perfectly round and absolutely straight, or an excessive leakage will be established on one side of the valve, causing it to bind.

(7) The pressure exerted by the main valve springs in the open position must be in excess of that sufficient to overcome steam pressure on rod, and any friction that may exist in packing.

(8) The plate below main valve springs must be a sliding fit in guides at all temperatures.

(9) Care must be taken in the adjustment of the length of the rods E and F, that in no position of the governor, or piston, can the piston valve become jammed at the end of its stroke.

(10) A heavy oil must not be used or the action will be sluggish.

Piping.—Fig. 263 shows a diagram of piping for a machine using oil to operate the valves. This is supplied by the same pumps that furnish lubrication for the guide bearings. A relief valve R, is adjusted to the desired pressure for operating the gear. When the speed is constant and the valve not taking any oil, the excess supplied by pumps will be discharged through this relief valve.

The special reducing valve shown in Fig. 264, and at S, Fig. 263, is provided to control the amount of oil supplied to the bearings.

This valve can be closed, or adjusted over a wide range, by altering the effective length of baffler.

Referring to Fig. 263, the tank marked "air chamber" is provided in order to give a reserved capacity of oil should the pumps for any reason stop, and also to form an air cushion on the system. The valve at the top of this tank should be kept closed, and the oil allowed to compress the air contained in the tank, and from time to time the tank should be completely emptied and refilled with air. The

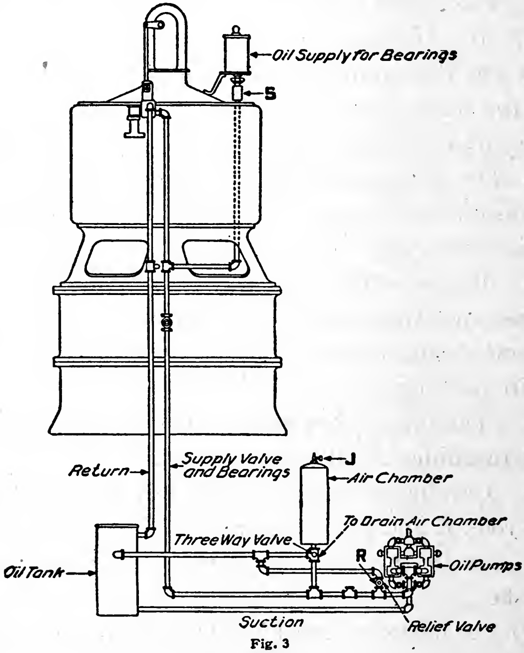


FIG. 263

emptying can be easily accomplished by opening the three-way valve to discharge to the oil tank. This need not interfere with the operation of the machine. After the air chamber is emptied, valve J should be closed, and the three-way valve open to admit oil to the chamber.

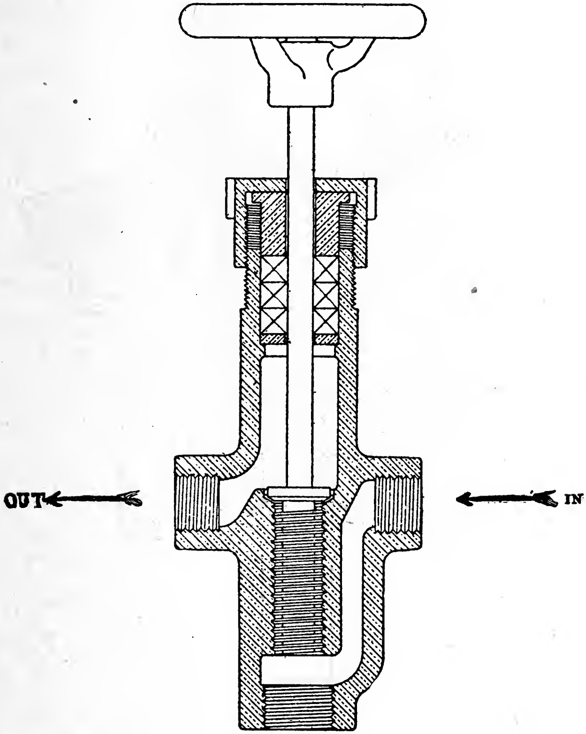


Fig. 264

In installations where oil is used for the turbine step bearing, oil for the operating gear and bearings may be taken from the high pressure pipe line, on the pump side of the step baffler, through a reducing valve. The piping system remains as shown diagramatically in Fig. 263 except for change in source of supply of operating fluid.

In case the station installation includes an air compressor, this equalizing tank may be piped in the system, the connection being made on the side of the tank (as provided for). The refilling of the tank is thus much simplified, and its capacity for emergency operation greatly increased

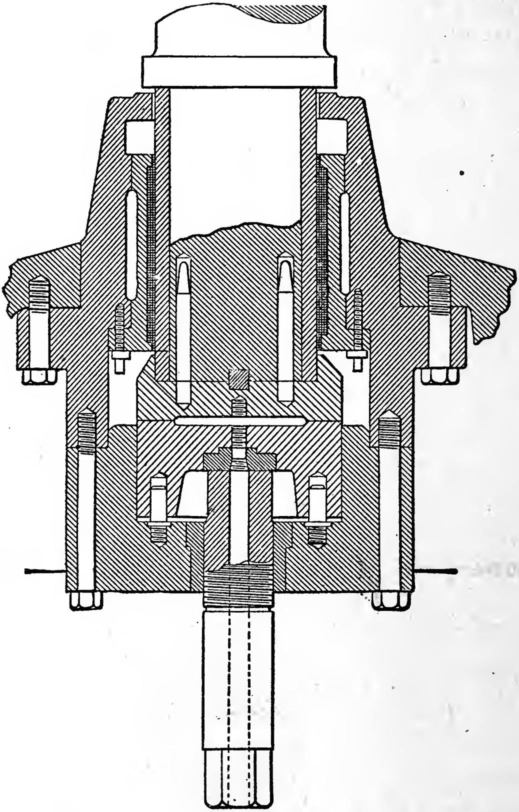


Fig. 265

Care should be taken to insure tightness of both valve controlling air supply to tank, and pet cock at the top.

Step Bearing.—Fig. 265 is a section through the cast iron step blocks. The lower block in the illustration has two holes drilled in it to match the two dowel pins seen projecting from the other block. There is another hole through the center of the lower block threaded for ¾″ pipe—The step lubricant (oil or water) is forced up through this hole, and out between the raised edges in a film, thus floating the rotating elements of the turbine on a frictionless disk of lubricant. The upper side of the top step block is counterbored to fit the lower end of the turbine shaft, in which there is also a slot for the reception of a key that is fitted across the top end of the step block.

The counterbore centers the block, the dowel-pins guide the key into the slot, and the key causes the block to turn with the shaft. These are all close fits, and when it becomes necessary to remove the block for inspection or repairs, it must be pulled off by means of a screw introduced into a threaded hole in the under side of the lower block. The whole is supported by, and rests upon a large screw that passes up through a block of cast-iron which has a threaded bronze bushing that forms the nut for the screw. The large block termed the cover plate is held to the base of the turbine by eight 1½ inch cap screws. A good idea of the construction may be gained by reference to Fig. 266 which is a section of the lower portions. It will be noticed that the ¾ in. oil supply pipe passes up through the entire length of the large step supporting screw, and connects with the oil passage through the lower step block.

Clearance.—With the Curtis turbine, the matter of clearance is very important. There must be no rubbing contact between the revolving and stationary buckets. Neither must there be too much clearance. Provision is therefore made for inspection, and adjustment of the clearance in the following manner. A two inch hole is drilled and tapped into each stage, sometimes opposite a row of moving blades and sometimes opposite the stationary blades.

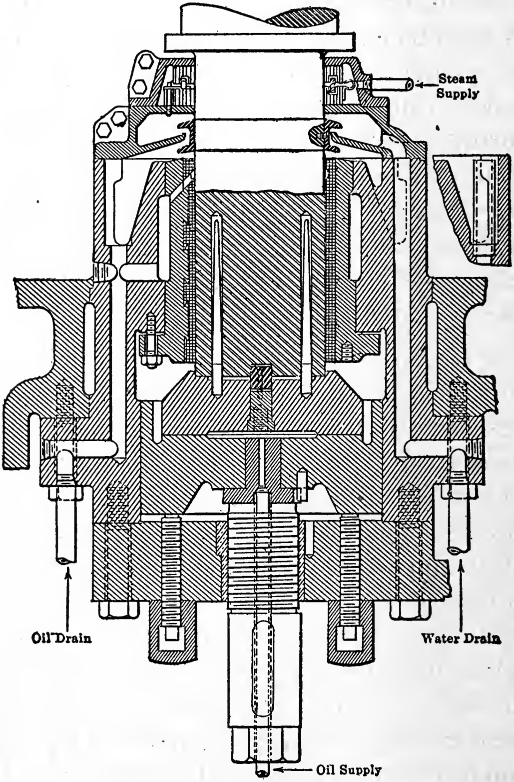


Fig. 266

Two inch plugs are screwed into these holes, to be removed when an inspection is to be made. The clearance is not uniform in all the stages, but is least in the first stage, and greatest in the last. The clearances in each stage of a 1500 K W machine for instance are as follows: 1st stage 0.06 to 0.08, 2nd stage 0.08 to 0.1, 3d stage 0.08 to 0.1, 4th stage 0.08 to 0.2.

These clearances are measured by clearance gages, which are tapering slips of steel about ½-in. wide accurately ground and graduated by markings, the difference in thickness of the gage between graduations being 0.001-in., the graduations being ½-in. apart.

When it is desired to measure the clearance, one of the 2 inch plugs is taken out, and a clearance gage which has previously been rubbed with red lead is inserted between the revolving and stationary buckets as far as it will go, and then pulled out.

The red lead marking on the gage will show how far it went in, and the nearest graduation in thousandths of an inch will show the clearance, after noting which, the red lead is rubbed on the gage again, and it is tried on the other side, and if there is any difference either high or low it is corrected by placing the wheel as nearly in the middle of the clearance space as possible, which is done by means of the step supporting screw shown in Fig. 266.

The clearance may be adjusted while the machine is running at full speed in the following manner: turn the step supporting screw until the wheels are heard or felt to rub slightly, then mark the screw, and turn it in the opposite direction until the wheels rub again. After marking the screw at this point, it should be turned back half way between the two marks.

This method of adjusting the clearance requires great skill, and experience, and it would seem that the gage method is to be preferred for safety.

Packing.—The shaft of the Curtis turbine is packed with carbon packing, where it passes through the top head of the wheel case. This packing consists of blocks of carbon made into rings, each ring consisting of three segments which break joints. These rings are fitted to the shaft with a slight clearance, and soon get a smooth polish which is not only frictionless but steam tight. The rings are held close to the shaft either by light springs, or the pressure of the steam in the case.

The Baffler.—This is a device for restricting the flow of water, or oil to the step and guide bearing. Its most important function is to steady the flow from the pump, and maintain a constant oil film as the pressure varies with the load, and in cases where several machines are operating on the same step-bearing system, the baffler fixes the flow to each machine. The amount, and pressure of oil or water required to float a turbine, and lubricate the guide bearing depend upon each other, and also upon the condition of the step bearing. Usually from 4½ to 5½ gallons per minute flowing under a pressure of from 425 to 450 lbs. per sq. in. is found to be correct for a 1500 K W machine; of course larger machines require a heavier pressure. The area of the step bearing must be considered also. The principle upon which the baffler operates is as follows: into the barrel or body of the device is inserted a plug which is simply a square threaded worm, the length of which, and the distance it enters the barrel of the baffler determining the amount of flow. The more turns that the water must pass, the less will be the flow.

The De Laval Steam Turbine

The De Laval steam turbine, the invention of Carl De Laval of Sweden, is noted for the simplicity of its construction and the high speed of the wheel—10,000 to 30,000 R. P. M. The difficulties attending such high velocities are, however, overcome by the long, flexible shaft and the ball and socket type of bearings, which allow of a slight flexure of the shaft in order that the wheel may revolve about its center of gravity, rather than the geometrical center or center of position. All high speed parts of the machine are made of forged nickel steel of great tensile strength. But one of the most striking features of this turbine is the diverging nozzle, also the invention of De Laval.

It is well known that in a correctly designed nozzle the adiabatic expansion of the steam from maximum to minimum pressure will convert the entire static energy of the steam into kinetic. Theoretically this is what occurs in the De Laval nozzle. The expanding steam acquires great velocity, and the energy of the jet of steam issuing from the nozzle is equal to the amount of energy that would be developed if an equal volume of steam were allowed to adiabatically expand behind the piston of a reciprocating engine, a condition, however, which for obvious reasons has never yet been attained in practice with the reciprocating engine. But with the divergent nozzle the conditions are different.

Referring to Fig. 267, a continuous volume of steam at maximum pressure is entering the nozzle at E, and, passing through it, expands to minimum pressure at F, the temperature of the nozzle being at the same time constant, and equal to the temperature of the passing steam. The principles of the De Laval expanding nozzle are in fact more or less prominent in all steam turbines. The facilities for converting heat into work are increased by its use, and

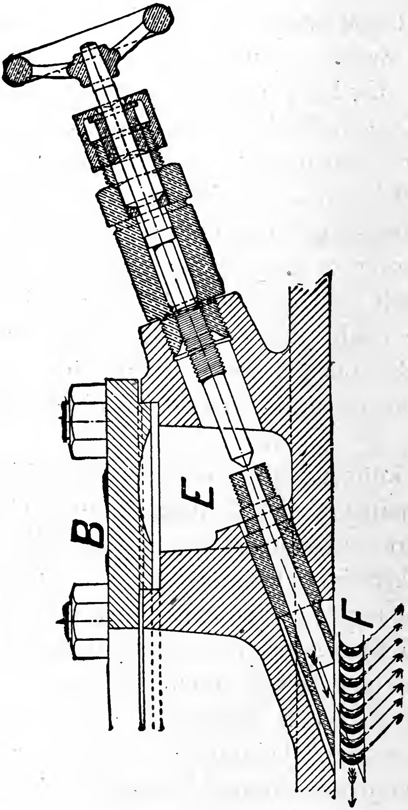


Fig. 267
DE LAVAL NOZZLE

the losses by radiation and cooling influences are greatly lessened.

The De Laval steam turbine is termed by its builders a high-speed rotary steam engine. It has but a single wheel, fitted with vanes or buckets of such curvature as has been found to be best adapted for receiving the impulse of the steam jet. There are no stationary or guide blades, the augular position of the nozzles giving direction to the jet. Fig. 268 shows the form of wheel and the nozzles. The nozzles are placed at an angle of 20° to the

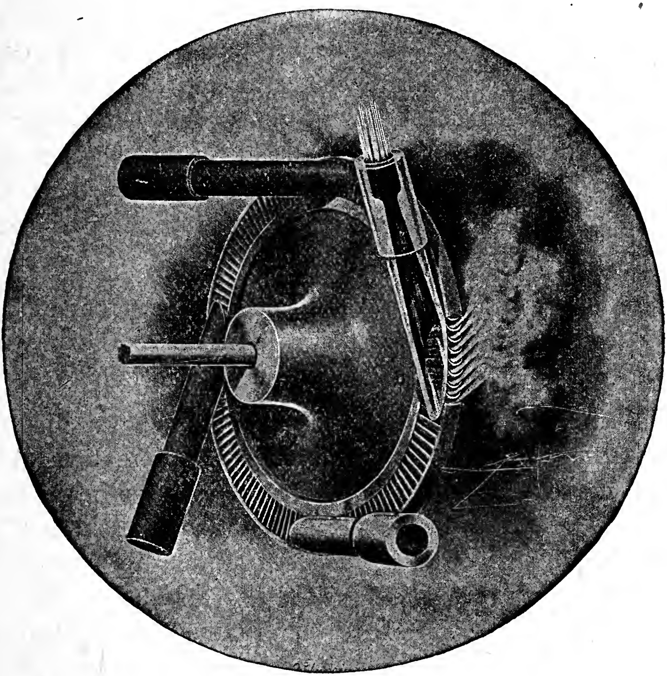


FIG. 268

THE DE LAVAL TURBINE WHEEL AND NOZZLES

plane of motion of the buckets, and the course of the steam is shown by the illustration.

The heat energy in the steam is practically devoted to the production of velocity in the expanding or divergent nozzle, and the velocity thus attained by the issuing jet of steam is about 4,000 ft. per second. To attain the maximum of efficiency the buckets attached to the periphery of the wheel against which this jet impinges should have a speed of about 1,900 ft. per second, but, owing to the difficulty of producing a material for the wheel strong enough to withstand the strains induced by such a high speed, it has been found necessary to limit the peripheral speed to 1,200 or 1,300 ft. per second.

Fig. 269 shows a De Laval steam turbine motor of 300 H. P., which is the largest size built up to the present time, its use having been confined chiefly to light work.

The turbine illustrated in Fig. 269 is shown directly connected to a 200 K. W. two-phase alternator. The steam and exhaust connections are plainly shown, as also the nozzle valves projecting from the turbine casing. The speed of the turbine wheel and shaft is entirely too high for most practical purposes, and it is reduced by a pair of very perfectly cut spiral gears, usually made 10 to 1. These gear wheels are made of solid cast steel, or of cast iron with steel rims pressed on. The teeth in two rows are set at an angle of 90° to each other. This arrangement insures smooth running and at the same time checks any tendency of the shaft towards end thrust, thus dispensing with a thrust bearing.

The working parts of the machine are clearly illustrated in Fig. 270, and a fairly good conception of the assembling

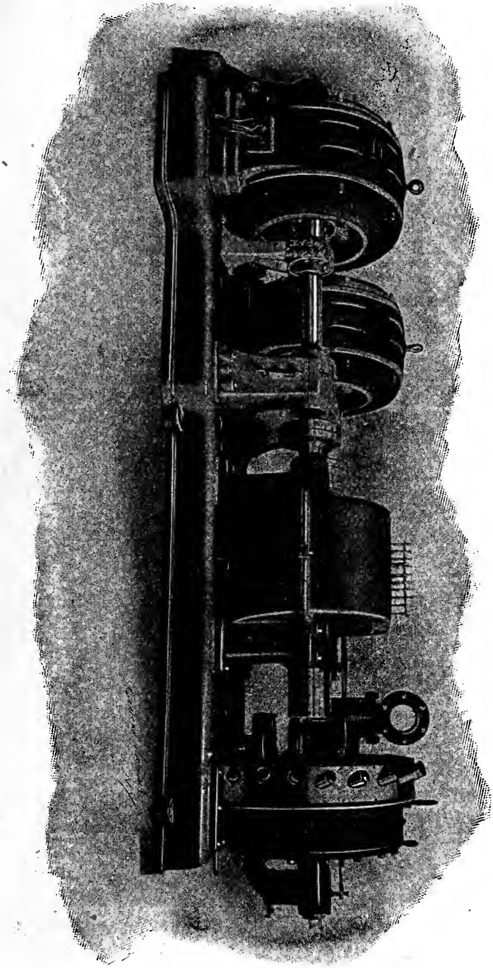


FIG. 269

of the various members, and especially the reducing gears, may be had by reference to Fig. 271, which shows a 110

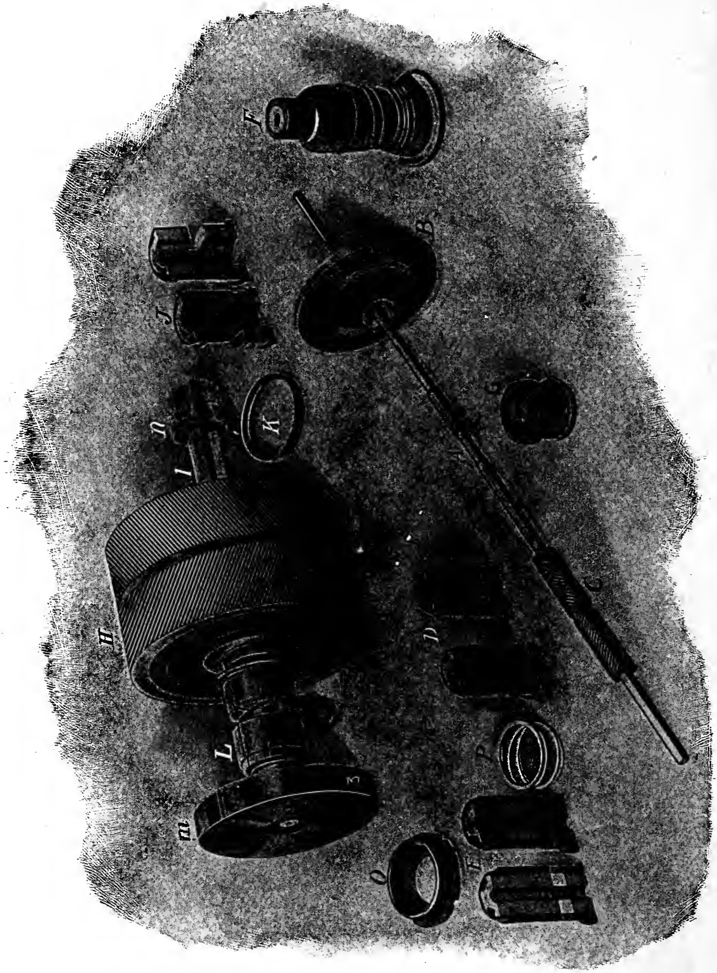


Fig. 270

H. P. turbine and rotary pump with the upper half of the gear case and field frame removed for purposes of inspec-

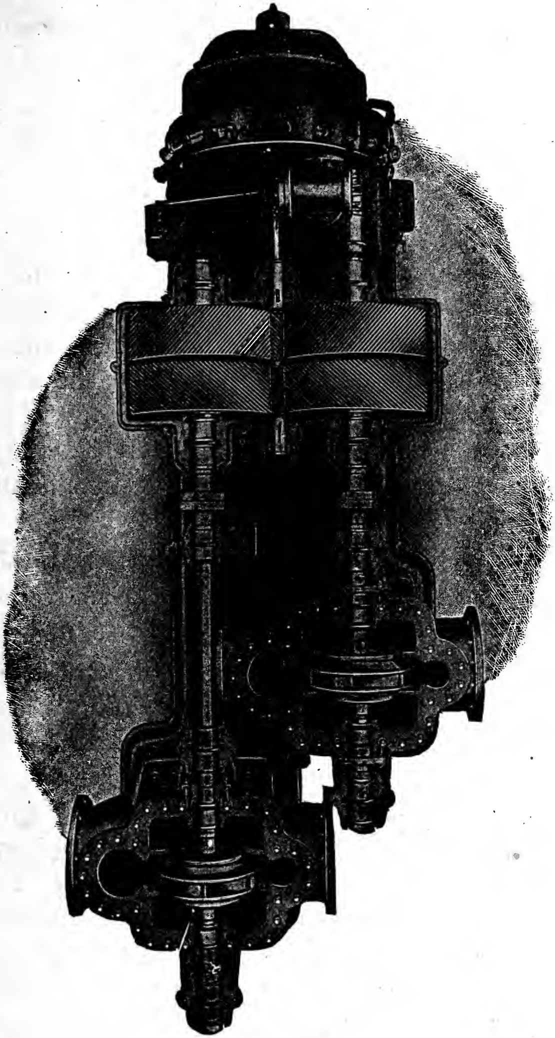


FIG. 271

tion. The slender shaft is seen projecting from the center of the turbine case, and upon this shaft are shown the small pinions meshing into the large spiral gears upon the two pump shafts.

Referring to Fig. 270, A is the turbine shaft, B is the turbine wheel, and C is the pinion. As the turbine wheel is by far the most important element, it will be taken up first. It is made of forged nickel steel, and it is claimed by the builders, the De Laval Steam Turbine Co., of Trenton, New Jersey, that it will withstand more than double the normal speed before showing any signs of distress. A clear idea of the construction of the wheel and buckets may be had by reference to Fig. 268. The number of buckets varies according to the capacity of the machine. There are about 350 buckets on a 300 H. P. wheel. The buckets are drop forged, and made with a bulb shank fitted in slots milled in the rim of the wheel.

Fig. 272 is a sectional plan of a 30 H. P. turbine connected to a single dynamo, and Fig. 273 is a sectional elevation of the same.

The steam, after passing the governor valve C, Fig 273, enters the steam chamber D, Fig. 272, from whence it is distributed to the various nozzles. The number of these nozzles depends upon the size of the machine, ranging from one to fifteen. They are generally fitted with shut-off valves (see Fig. 269) by which one or more nozzles can be cut out when the load is light. This renders it possible to use steam at boiler pressure, no matter how small the volume required for the load. This is a matter of great importance, especially where the load varies considerably, as, for instance, there are plants in which during certain hours of the day a 300 H. P. machine may be taxed to its utmost capacity and during certain other hours the load on the same machine may drop to 50 H. P. In such cases

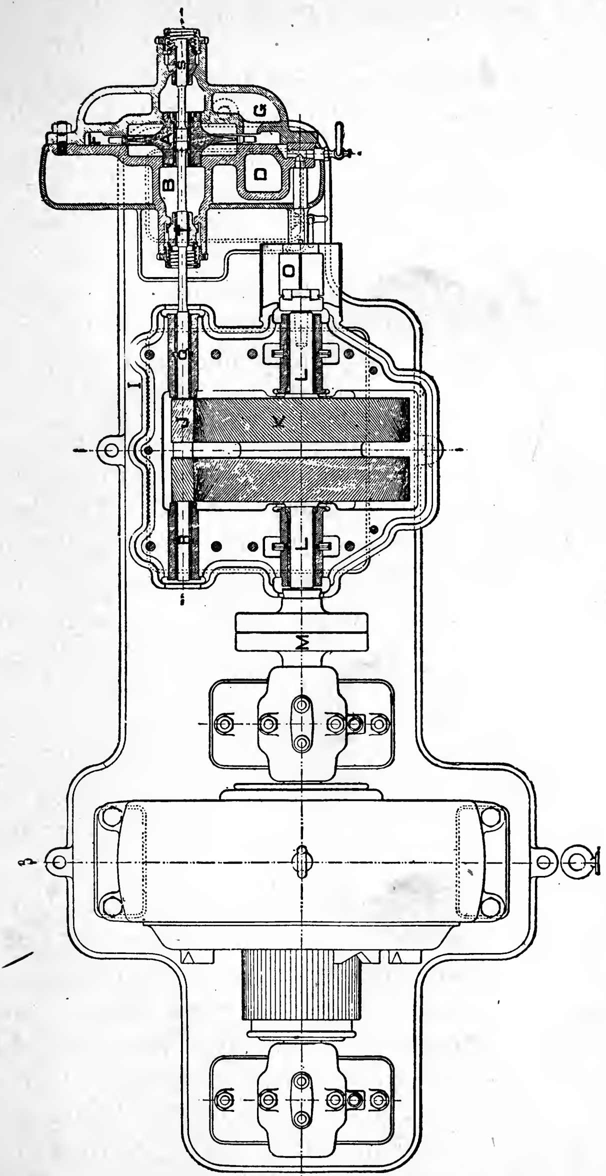


FIG. 272

the number of nozzles in action may be reduced by closing the shut-off valves until the required volume of steam is admitted to the wheel. This adds to the economy of the machine. After passing through the nozzles, the steam, as elsewhere explained, is now completely expanded, and in impinging on the buckets its kinetic energy is transferred to the turbine wheel. Leaving the buckets, the steam now passes into the exhaust chamber G, Fig. 272, and out through the exhaust opening H, Fig. 273, to the condenser or atmosphere as the case may be.

The gear is mounted and enclosed in the gear case I, Fig. 272. J is the pinion made solid with the flexible shaft and engaging the gear wheel K. This latter is forced upon the shaft L, which, with couplings M, connects to the dynamo, or is extended for other transmission.

O, Fig. 273, is the governor held with a taper shank in the end of the shaft L, and by means of the bell crank P operates the governor valve C. The flexible shaft is supported in three bearings, Fig. 272. Q and R are the pinion bearings and S is the main shaft bearing which carries the greater part of the weight of the wheel. This bearing is self-aligning, being held to its seat by the spring and cap shown.

T, Fig. 272, is the flexible bearing, being entirely free to oscillate with the shaft. Its only purpose is to prevent the escape of steam when running non-condensing, or the admission of air to the wheel case when running condensing. The flexible shaft is made very slender, as will be observed by comparing its size with that of the rotary pump shaft in Fig. 271. It is by means of this slender, flexible shaft that the dangerous feature of the enormously high speed of this turbine is eliminated.

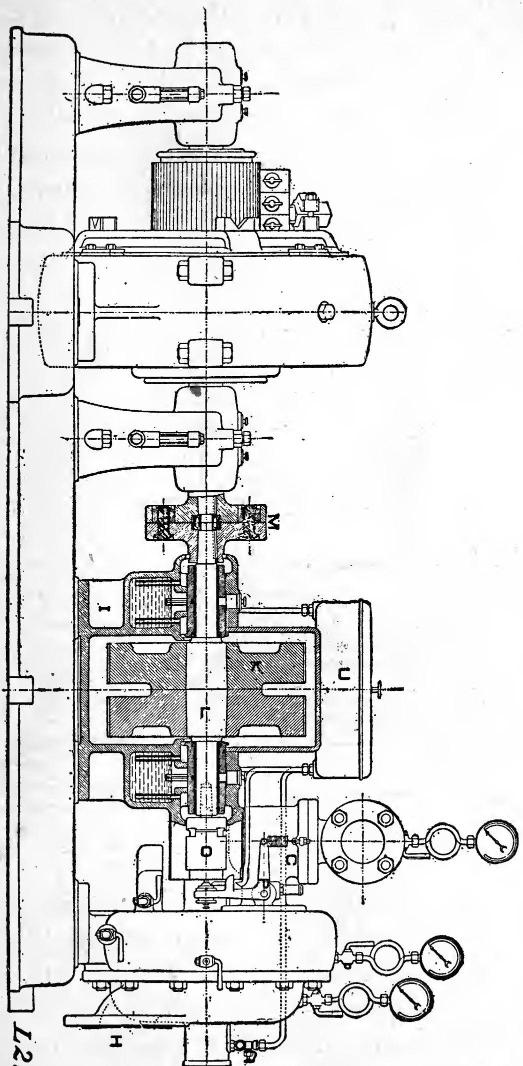


FIG. 273

The governor is of the centrifugal type, although differing greatly in detail from the ordinary fly ball governor, as will be seen by reference to Fig. 274. It is connected directly to the end of the gear wheel shaft. Two weights B are pivoted on knife edges A with hardened pins C, bearing on the spring seat D. E is the governor body fitted in the end of the gear wheel shaft K and has seats milled for the knife edges A. It is afterwards reduced in diameter to pass inside of the weights and its outer end is threaded to receive the adjusting nut I, by means of which the tension of the spring, and through this the speed of the turbine, is adjusted. When the speed accelerates, the weights, affected by centrifugal force, tend to spread apart, and pressing on the spring seat at D push the governor

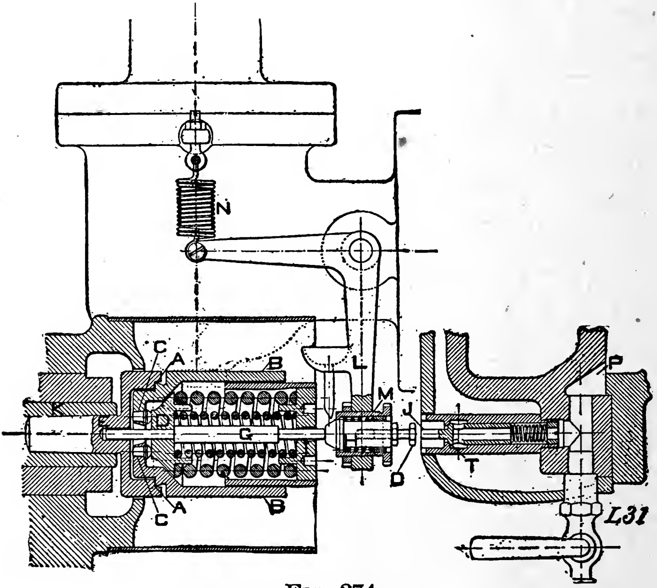


Fig. 274

pin G to the right, thus actuating the bell crank L and cutting off a part of the flow of steam.

It has been found necessary with this turbine, when running condensing, to introduce a valve termed a vacuum valve, also controlled by the governor, as it has been found that the governor valve alone is unable to hold the speed of the machine within the desired limit. The function of the vacuum valve is as follows: The governor pin G actuates the plunger H, which is screwed into the bell crank L, but without moving the plunger relative to said crank. This is on account of the spring M being stiffer than the spring N, whose function is to keep the governor valve open and the plunger H in contact with the governor pin. When a large portion of the load is suddenly thrown off, the governor opens, pushing the bell crank in the direction of the vacuum valve T. This closes the governor valve, which is entirely shut off when the bell crank is pushed so far that the screw O barely touches the vacuum valve stem J. Should this not check the speed sufficiently, the plunger H is pushed forward in the now stationary bell crank, and the vacuum valve is opened, thus allowing the air to rush into the space P in which the turbine wheel revolves, and the speed is immediately checked.

The main shaft and dynamo bearings are ring oiling. The high-speed bearings on the turbine shaft are fed by gravity from an oil reservoir, and the drip oil is collected in the base and may be filtered and used over again.

The fact that the steam is used in but a single stage or set of buckets and then allowed to pass into the exhaust chamber might appear at first thought to be a great loss of kinetic energy, but, as has been previously stated, the static energy in the steam as it enters the nozzles is converted into kinetic energy by its passage through the divergent nozzles, and the result is a greatly increased volume of steam leaving the nozzles at a tremendous velocity, but at a greatly reduced pressure—practically exhaust pressure—impinging against the buckets of the turbine wheel and thus causing it to revolve.

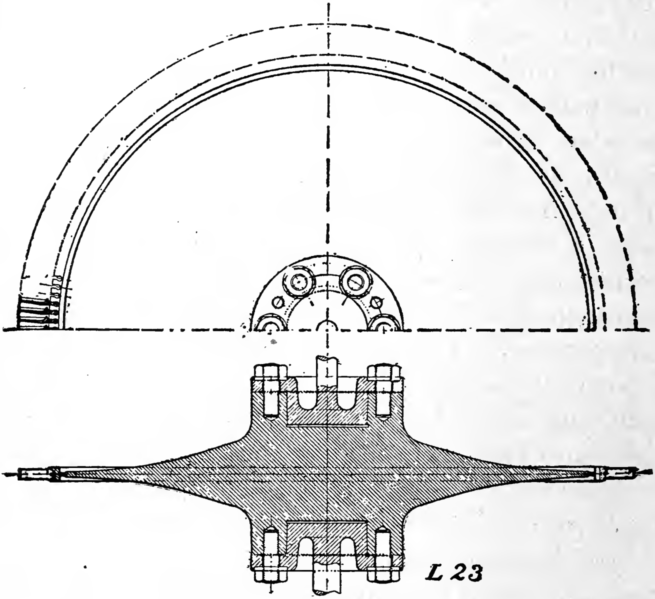


FIG. 275

Efficiency tests of the De Laval turbine show a high economy in steam consumption, as for instance, a test made by Messrs. Dean and Main of Boston, Mass., on a 300 H. P. turbine, using saturated steam at about 200 lbs. pressure per sq. in. and developing 333 Brake H. P., showed a steam consumption of 15.17 lbs. per B. H. P., and the same machine, when supplied with superheated steam and carrying a load of 352 B. H. P., consumed but 13.94 lbs. per B. H. P. These results compare most favorably with those of the highest type of reciprocating engines.

Fig. 275 shows a cross section of a 300 H. P. De Laval wheel, showing the design necessary for withstanding the high centrifugal stress to which these wheels are subjected. All De Laval wheels are tested to withstand the centrifugal stress of twice their normal velocity without showing signs of fatigue.

A characteristic feature of the De Laval steam turbine is that none of its running parts are subject to the full pressure of the steam, as the steam is fully expanded in the nozzle before it reaches the turbine wheel. This feature, which will not be found in *any other* heat motor, is of great value and promising future in the direction of using high pressures with resultant increase in economy of fuel. The restriction as to the steam pressure that can be used is found only with the boiler, and as far as the steam turbine itself is concerned, it has been operated successfully with a pressure as high as 3,000 lbs. per square inch.

Allis-Chalmers Steam Turbine

Fig. 276 shows a general view of the Allis-Chalmers steam turbine, and although it is essentially of the "Parsons" type, still there are a number of modifications in details of construction, as compared with the Westinghouse-Parsons steam turbine, some of which, no doubt may be considered as adding to the efficiency, and durability of the machine.

Fig. 277 is a sectional view of the "elementary" Parsons type of steam turbine, and its various parts are described as follows:

Main bearings, A and B. Thrust bearing, R. Steam pipe C. Main throttle valve, D, which is balanced, and operated by the governor. Steam enters the cylinder through passage E, passes to the left through the alternate rows of stationary and revolving blades, leaving the cylinder at F and passes into the condenser, or atmosphere through passage G. H, J and K are the three steps or stages of the machine. L, M and N are the three balance pistons. O, P and Q are the equalizing passages, connecting the balance pistons with the corresponding stages.

Fig. 278 shows a sectional veiw of the "Parsons" turbine with the Allis-Chalmers modifications. L and M are the two balance pistons at the high pressure end. Z is a smaller balance piston placed in the low pressure end, yet having the same effective area as did the larger piston N shown in Fig. 277. O and Q are the two equalizing passages for pistons L and M. Passage P is omitted in this construction, and balance piston Z is equalized with the third stage

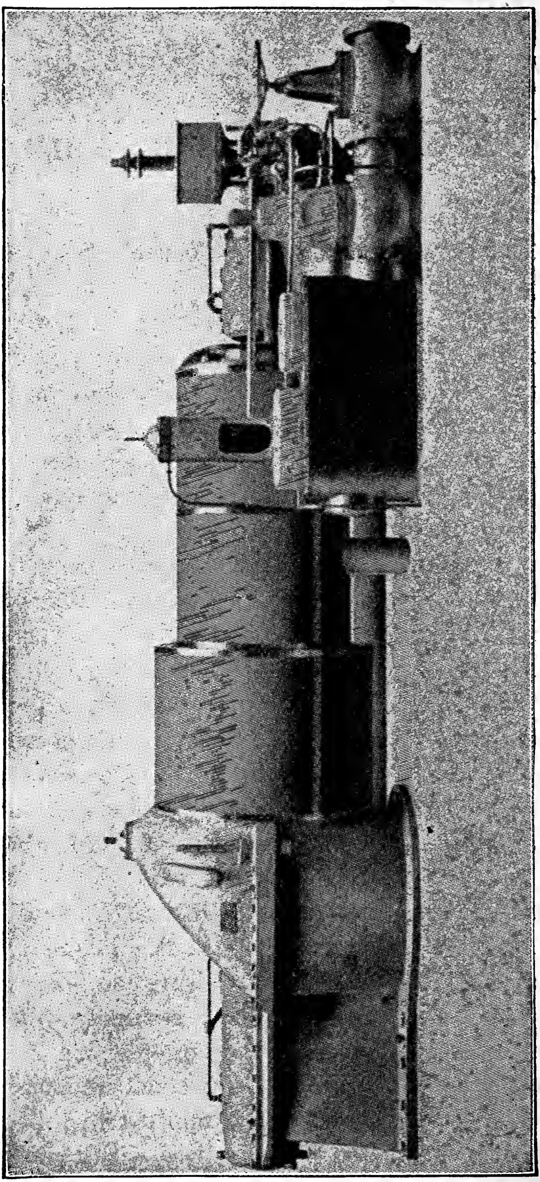


FIG. 276

THE ALLIS-CHALMERS STEAM TURBINE

pressure at Y. Valve V is a by-pass valve to allow of live steam being admitted to the second stage of the cylinder in case of a sudden overload. This by-pass valve is the equivalent of the by-pass valve used to admit live steam to

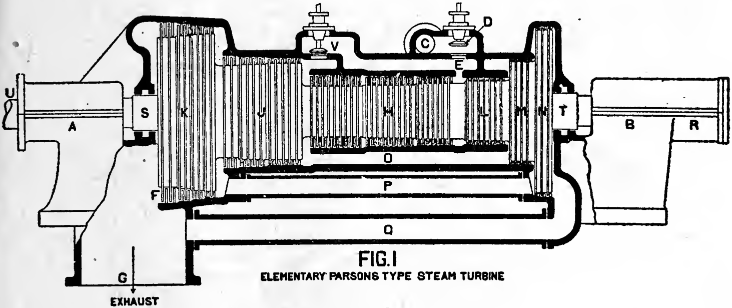


FIG.I
ELEMENTARY PARSONS TYPE STEAM TURBINE

Fig. 277

the low pressure cylinder of a compound reciprocating engine. Valve V is arranged to be operated, either by the governor or by hand, as the conditions may require. Frictionless glands made tight by water packing are provided at S and T where the shaft passes out of the cylinder. The shaft is extended at U and connected to the generator shaft by a flexible coupling.

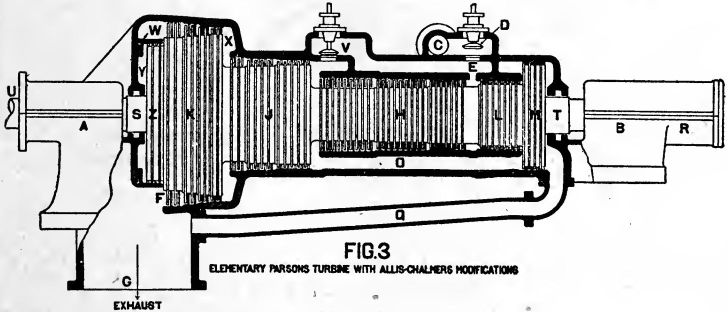


FIG.3
ELEMENTARY PARSONS TURBINE WITH ALLIS-CHALMERS MODIFICATIONS

Fig. 278

The action of the steam, and the general arrangement of the stationary, and moving blades is practically the same in the two turbines, with the exception that, in the larger sizes of the Allis-Chalmers turbine the "balance" pistons for neutralizing the end thrust, are arranged in a different manner, the largest one of the three pistons (piston N—Fig. 277) is replaced by a smaller balance piston.

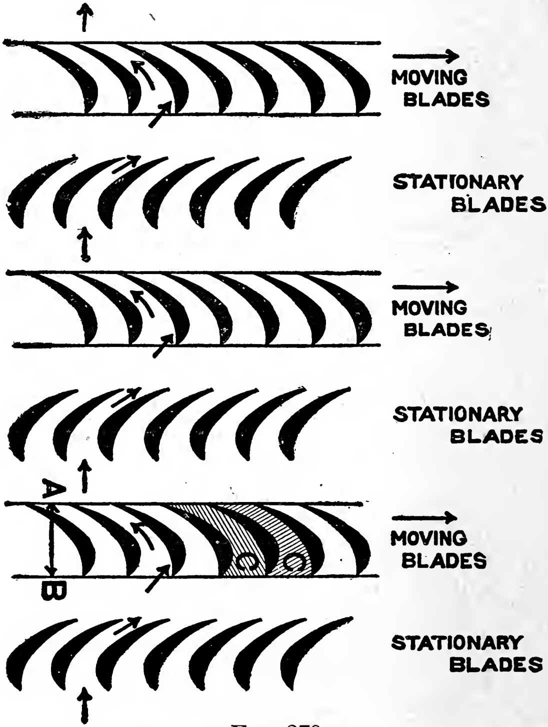


Fig. 279
Showing Arrangement of Blading and Course of the Steam in Parsons Steam Turbine

This piston presents the same effective area for the steam to act upon, as did the larger piston, for the reason that the working area of the latter in its original location consisted only of the annular area included between its periphery and the periphery of the next smaller piston. The pressure of the steam is brought to bear upon this equalizing piston in its new position, by means of passages or ports through the body of the rotor, connecting the third stage of the cylinder with the supplementary cylinder, in which the piston revolves. Fig. 279 shows the arrangement of blading, the course of the steam being indicated by the arrows. The clearances between the edges of the revolving and stationary blades, as shown in the cut are relatively out of proportion to the actual clearances allowed.

This clearance is preserved by means of a small thrust-bearing provided inside the housing of the main bearing.

This thrust-bearing can be adjusted to locate and hold the rotor in such a position as will allow sufficient clearance to prevent actual contact between the moving and stationary blades, and yet reduce the leakage of steam to a minimum.

The method by which the blades are fitted to and held in the rotor and cylinder of the Allis-Chalmers steam turbine is as follows: Each blade is individually formed by special machine tools, so that its root or foot is of an angular, or dove-tail shape, and at its tip there is a projection. In order that the roots of the blade may be firmly held in position, a foundation ring, A, Fig. 280, is provided, which after being formed to a circle of the proper diameter, has slots cut in it by a special milling machine.

These slots are formed of dove-tail shape to receive the roots of the blades, and are at the same time accurately spaced, and inclined so as to give the required pitch and angles to the blades.

The foundation rings are also of dove-tail shape in cross-section, those holding the stationary blades are inserted in dove-tail grooves in the cylinder and those holding the revolving blades being pressed into the rotor or spindle.

The rings are firmly held in their places by key-pieces driven into place and upset into under-cut grooves, thus positively locking the whole structure together, and making it practically impossible for a blade to get out of place.

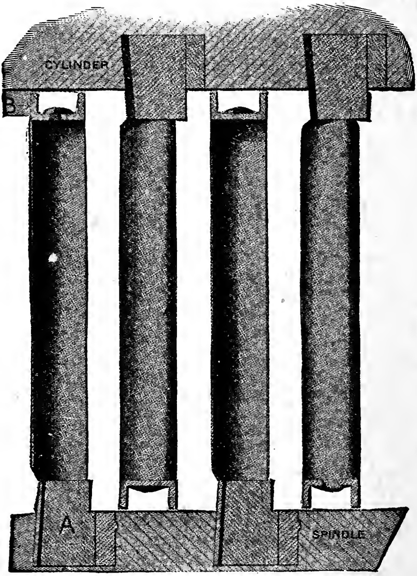


Fig. 280

The tips of the blades are held and firmly bound together by a shroud-ring, B, Fig. 280.

The shroud-rings are made channel-shape, in cross-section, the flanges being made thin in order to prevent dangerous heating in case of accidental contact with either the walls of the cylinder or the surface of the rotor.

The bearings of this turbine are of the self-adjusting ball and socket type, designed for high speed. Shims are provided for proper alignment. The lubrication of the four bearings, two for the turbine, and two for the generator, is accomplished by supplying an abundance of oil to the middle of each bearing and allowing it to flow out at the ends where it is caught, passed through a cooler, and pumped back to the bearings.

The fact that the oil is supplied in large quantities to the bearings does not involve a heavy oil bill.

The journals are practically floating on films of oil, thus preventing that "wearing out" of the oil that occurs when it is supplied in small "doses."

The governor is driven from the turbine shaft by means of cut gears working in an oil-bath.

The governor operates a balance throttle valve by means of a relay, except in very small sizes in which the valve is worked direct.

In order to provide for any possible accidental derangement of the main governing mechanism, an entirely separate safety, or over-speed governor is furnished. This governor is driven directly by the turbine shaft without the intervention of gearing, and is so arranged and adjusted that if the turbine should reach a predetermined speed above that for which the main governor is set, the safety governor will come into action and trip a valve, shutting off the steam and stopping the turbine. A strainer is provided through which the steam is passed before admission to the turbine.

For connecting the rotors of the turbine and generator a special type of flexible coupling is used to provide for any slight inequality in the wear of the bearings, to permit axial adjustment of the turbine spindle, and to allow for differences in expansion. This coupling is so made that it can be readily disconnected for the removal of the turbine spindle, or of the revolving field of the generator. Provision is made for ample lubrication of the adjoining faces of the coupling. The coupling is enclosed in the bearing housing, so that it is completely protected against damage, and cannot cause injury to the attendants.

Waste of heat by radiation is prevented in the following manner:

The hot parts of the turbine, up to the exhaust chamber are covered with an ample thickness of non-conducting material and lagged with planished steel.

For large Allis-Chalmers turbines the bedplate is divided into two parts, one carrying the low-pressure end of the turbine and the bearings of the generator, the other carrying the high-pressure end of the turbine. The turbine is secured to the former, while the latter is provided with guides which permit the machine to slide back and forth with differences of expansion caused by varying temperature, at the same time maintaining the alignment.

Fig. 281 shows the spindle, or rotor of the Allis-Chalmers turbine. The rings which carry the blades are pressed on the shaft. Fig. 282 illustrates the blades as they appear when fitted on to the rotor. The shroud ring protecting the tips of the blades is also shown in place. Fig. 283 shows another view of the blade construction. This is a half-ring of blades inserted in the foundation ring before being placed upon the rotor.

Fig. 284 shows several rows of stationary blades as they appear, fitted in the cylinder of an Allis-Chalmers steam turbine.

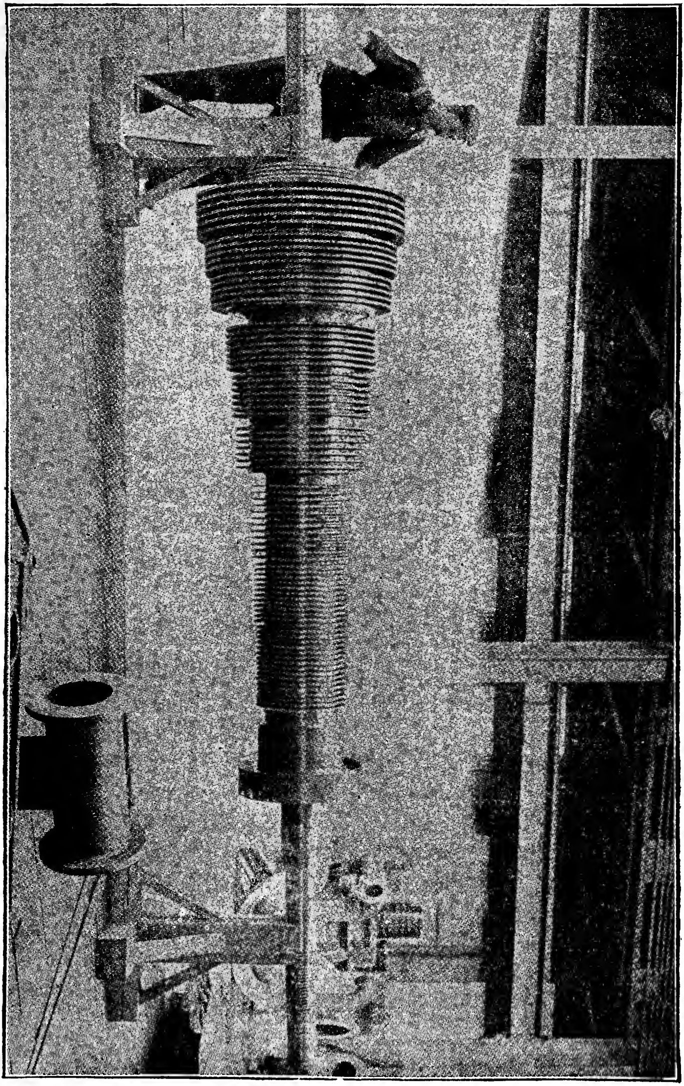


FIG. 281

ROTOR OF ALLIS-CHALMERS STEAM TURBINE

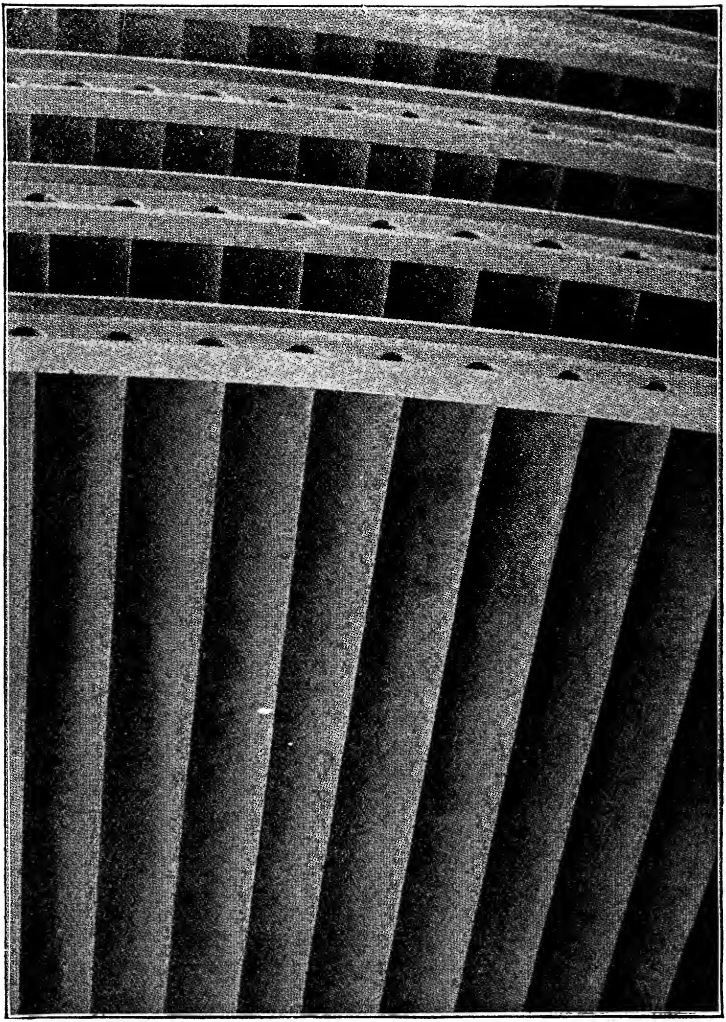


FIG. 282

Starting Up.—As a rule in preparing to start a steam turbine, especially one of the "Parsons," type, the first move is to open the throttle slightly, to allow as much steam as possible to flow through the turbine without causing it to start. This requires but a few seconds, and about an equal period of time is required to start the auxiliary oil pump. The inlet valve is always left open to the surface condensers, so they are always full of water. The outlet valve is quickly opened a certain number of turns, which is known to be sufficient for all purposes, and this is easily done before the moderate amount of steam flowing through has had time to heat the condenser unduly. By this time the oil is sufficiently high in the reservoir to permit the turbine to be started very slowly, and it doubtless warms up rather more evenly when turning over than when standing. When the oil has reached its normal level in the reservoir, the turbine is given more steam, and the field cut in.

The principal precautions to be observed are, not to start without properly warming up, also to be certain that the oil is circulating freely through the bearings.

The vacuum should not be on until the water glands seal, and care should be taken not to run on vacuum without a load on the turbine.

If a turbine vibrates objectionably when started after a moderate time has been allowed for warming, say 6 minutes for a 500-kilowatt, 10 minutes for a 2000-kilowatt, and 15 or,perhaps 20 minutes for larger sizes, it is highly probable that there is something structurally wrong with it, and any longer period will do but little, if any, good; furthermore, it will be subject to mysterious "spells" or "fits" of vibration upon changes of load or vacuum.

In Operation.—The throttle, and inlet gages should be closely watched, to see that neither the pressure, nor the steam temperature varies much. The vacuum should also

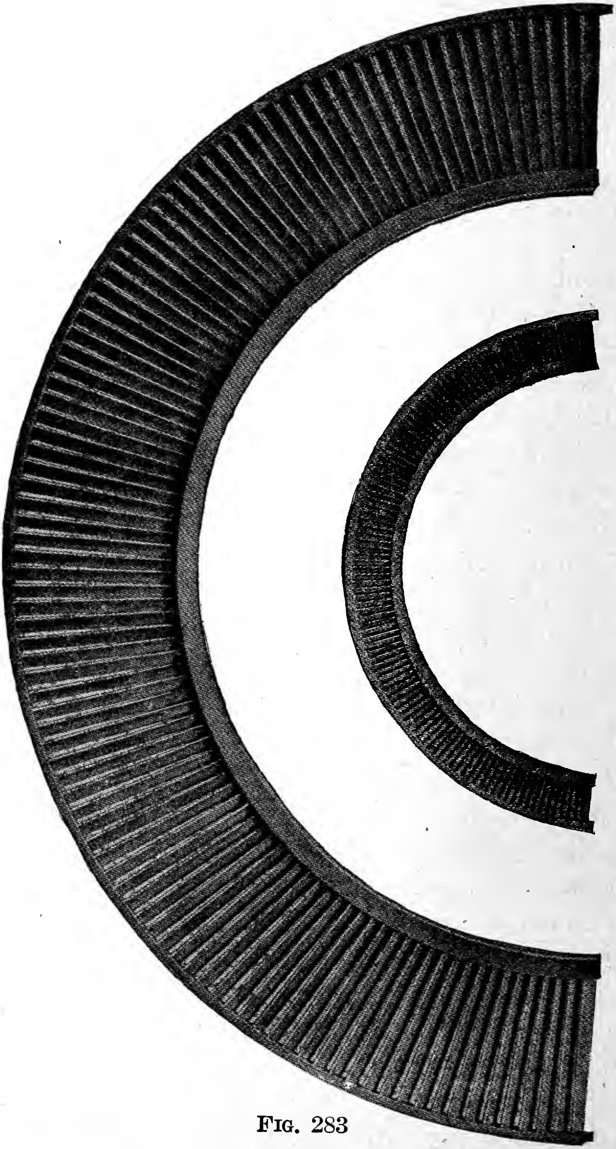


Fig. 283

be kept constant, as well as the water glands, and those pressures indicated by the oil gages. The temperature of the oil flowing to and from the bearings should not exceed 135° Fahr.—.

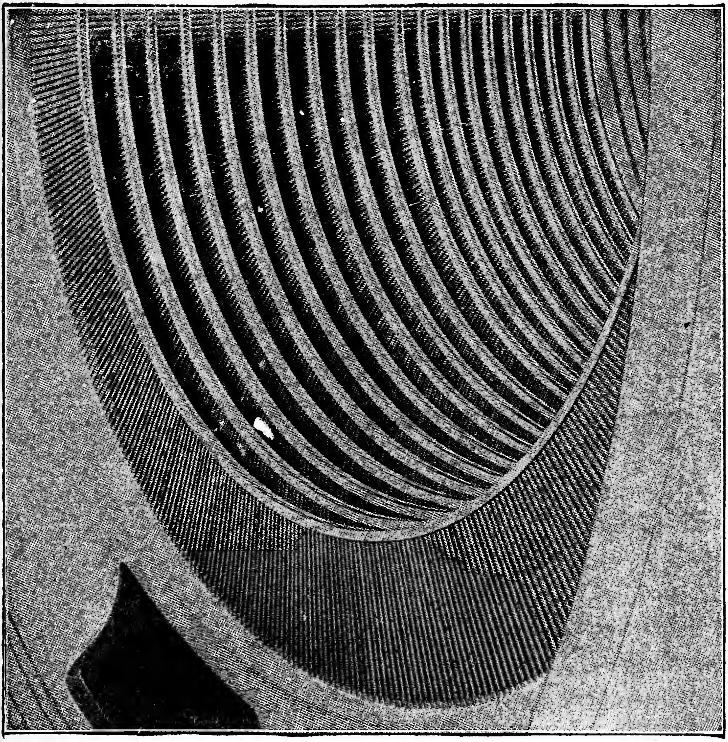


Fig. 284
Shows a Number of Rows of Stationary Blades Fitted in the Cylinder of an Allis-Chalmers Steam Turbine

The governor parts also should be oiled at regluar intervals.

Stopping the turbine is practically the reverse of starting, the successive steps being as follows: starting the auxiliary oil pump, freeing it of water and allowing it to run slowly; removing the load gradually; breaking the vacuum when the load is almost zero, shutting off the condenser injection and taking care that the steam exhausts freely into the atmosphere; shutting off the gland water when the load and vacuum are off; pulling the automatic stop to trip the valve and shut off steam and, as the speed of the turbine decreases, speeding up the auxiliary oil pump to maintain pressure on the bearings; then, when the turbine has stopped, shutting down the auxiliary oil pump, turning off the cooling water, opening the steam chest drains and slightly oiling the oil inlet valve-stem. During these operations the chief particulars to be heeded are: not to shut off the steam before starting the auxiliary oil pump nor before the vacuum is broken, and not to shut off the gland water with vacuum on the turbine. The automatic stop should also remain unhooked until the turbine is about to be started up again.

General Suggestions.—Water used in the glands of the turbine must be free from scale-forming impurities, and should be delivered at the turbine under a steady pressure of not less than 15 pounds. The pressure in the glands will vary from 4 to 10 pounds. This water may be warm. In the use of water for the cooling coils and of oil for the lubricating system, nothing more is required than ordinary good sense dictates. An absolutely pure mineral oil must be supplied, of a nonfoaming charcter, and it should be kept free through filtering from any impurities.

These suggestions apply more particularly to steam turbines of the "Parsons" type, exhausting into condensers. For turbines built to be run non-condensing the portion relating to vacuum does not of course apply.

Hamilton-Holzwarth Steam Turbine

In order to thoroughly understand the underlying principles of the steam turbine, and the action of the steam within it, one must get definitely fixed in his mind this fact, viz., that there is no similarity between it and the reciprocating engine, and the action of the steam upon the piston in driving it back and forth. In fact, there is more similarity between the reciprocating engine and the rotary engine than there is in the case of the turbine. In the rotary engine the steam pushes a piston in the same manner as it does in the reciprocating engine, with the exception that the piston of the rotary engine travels entirely around the shaft, while the piston of the reciprocating engine travels back and forth in a straight line motion. It will be much easier to get a clear idea of the action of the turbine if one will for the time being drop all knowledge he may have of reciprocating and rotary engines. He will then be able to more readily grasp, and better understand the action of the steam turbine.

One of the most comprehensive, and at the time most simple explanations of the action of the steam upon the blades of the turbine, and also upon the piston of the reciprocating engine, in both of which cases rotary motion is produced, but in two different ways, is given by Hans Holzwarth. He says: "Take a large wheel which is fastened to a vertical shaft. Grasp this wheel at the rim at a certain point, and walk continuously around the shaft, always retaining the hold, like a horse walking around a capstan fastened to a bar or pole which he pulls after him.

Or stand still in a certain spot and take the wheel by the rim and cause it to revolve (like opening and closing a valve by hand), by changing hands so that the whole rim is constantly revolving."

The first illustration clearly explains the manner in which the shaft of the reciprocating engine is caused to revolve, by means of the static expansion force of the steam acting upon the crank pin, through the medium of the piston, piston rod, cross head, and connecting rod. In the second illustration, in which the man turns the wheel by simply standing still in one place, and causing the wheel to revolve by grasping the rim and giving it a push, first with one hand, and then with the other, we have a simple explanation of how the steam causes the shaft of the turbine to revolve, by a constant series of pushes, or impulses against the movable blades that are key seated to the drum, which in turn is keyed to the shaft, the moving blades representing the rim of our wheel.

Every one knows that in order to be able to turn the aforesaid wheel the man must have a good floor to stand upon, and he must also have a good foothold on the floor, because he exerts the same amount of pressure on the floor, that he exerts against the rim of the wheel. This explains why there must be stationary blades, as well as revolving blades in a turbine.

The actual pressure exerted upon any single blade in a turbine is in reality very light. Take, for example, a 300 K. W. Westinghouse turbine. There are altogether in a machine of this size 31,073 blades, of which 16,095 are moving blades. The pressure that each blade exerts in turning the shaft is a little over one ounce, but owing to the large number of blades, and the velocity of the steam, the power is developed.

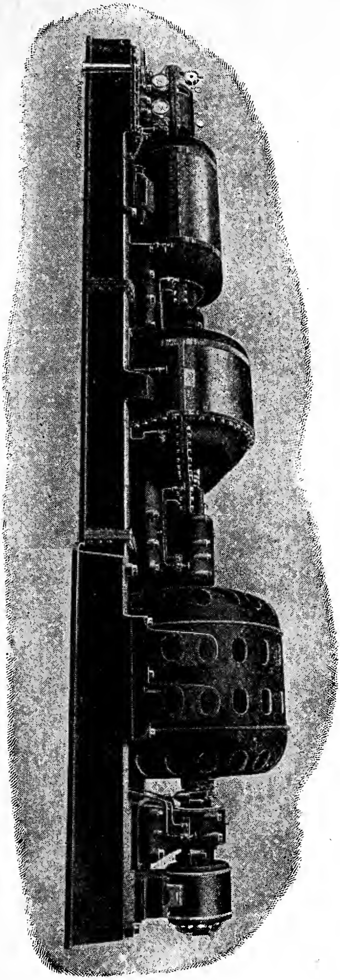


Fig. 285

HAMILTON-HOLZWARTH STEAM TURBINE

The Hamilton-Holzwarth steam turbine resembles in many respects the Westinghouse-Parsons turbine, prominent of which is that it is a full stroke turbine; that is, the steam flows through it in one continuous belt, or veil in a screw line, the general direction being parallel with the shaft. But unlike the Parsons type, the steam in the Hamilton-Holzwarth turbine is made to do its work only by impulse, and not by impulse and reaction combined. The smaller sizes are built in a single casing or cylinder, but for units of 750 K. W. and larger there are two parts, viz., high and low pressure, thus resmbling in some respects a compound reciprocating engine.

The Hamilton-Holzwarth steam turbine is based upon and has been developed from the designs of Prof. Rateau, of Paris, and is being manufactured in this country by the Hooven-Owens-Rentschler Co., of Hamilton, Ohio. It is horizontal, and placed upon a rigid bed plate of the box pattern. All steam, oil and water pipes are within and beneath this bed plate, as are also the steam inlet valve and the regulating and by-pass valves.

There are no balancing pistons in this machine, the axial thrust of the shaft being taken up by a thrust ball-bearing. The interior of the cylinder is divided into a series of stages by stationary discs which are set in grooves in the cylinder, and are bored in the center to allow the shaft, or rather the hubs of the running wheels that are keyed to the shaft, to revolve in this bore.

Clearance.—The clearance allowed is as small as practicable, as it is in this clearance between the revolving hub and the circumference of the bore of the stationary disc that the leakage losses occur. It should be noted that between each two stationary discs there is located a running wheel, and that the clearance between the running vanes and the stationary vanes is made as slight as is consistent with safe practice; otherwise leakage would occur here also, and besides this there would be a distortion of the steam jet and entrainment of the surrounding atmosphere, resulting in a rapid decline in economy if the clearance between the stationary and moving elements was not reduced to as small a fraction as possible.

As before stated, the stationary discs are firmly secured to the interior walls of the casing. At intervals on the outside periphery of these discs are located the stationary, or guide vanes. These are made of drop forged steel. They are set in a groove on the outside edge of the disc and fastened with rivets. Both disc and vanes are then ground, giving the vanes the profile that they should have for the most efficient expansion of the steam. After this is done a steel ring is shrunk on the outside periphery of the vanes and the steam channels in the disc. These discs are then placed in the grooves in the casing at regular intervals, and in the spaces between them are the running wheels.

The casing is divided into an upper and lower half. The running wheels are built with a cast steel hub having a steel disc riveted on to each side, thus forming a circumferential ring space into which the running vanes are riveted. A thin steel band or rim is tied on the outer edge of the vanes, thus forming an outer wall to the steam channels and confining the steam within the vanes. These vanes are also milled on both edges, on the influx, and efflux side of the wheel, thus forming them to the shape corresponding to the theoretical diagram.

In all steam turbines one of the main requisites for a quiet-running machine is that the revolving element or rotor shall be perfectly balanced. The rotary body of the Hamilton-Holzwarth turbine consists of a plurality of running wheels, each one of which is balanced by itself before being placed upon the shaft. All the bearings are lubricated in a thorough manner by oil forced up into the bottom bushing or shell under slight pressure. Flexible couplings are used between the high and low-pressure shafts, and for connecting the turbine shaft to the generator shaft or other shaft to be driven. By means of the thrust ball-bearing on the exhaust end of the turbine the shaft may be adjusted in an axial direction in such a manner as to accurately preserve the desired position of the running wheels.

Fig. 285 shows a general view of the Hamilton-Holzwarth turbine, and the action of the steam within the machine may be described as follows: After leaving the steam separator that is located beneath the bed plate, the steam passes through the inlet or throttle valve, the stem of which extends up through the floor near the high-pressure casing and is protected by a floor stand and equipped with a hand wheel, shown in Fig. 285. The steam now passes through the regulating valve. From this valve it is led through a curved pipe to the front head of the high pressure casing or cylinder. In this head is a ring channel into which the steam enters, and from which it flows through the first set of stationary vanes. In these vanes the first stage of expansion occurs.

Construction of the Stationary Blade.—A stationary blade is constructed in the following manner: A circular cast-iron disc a, Fig. 286, has a bore b corresponding to the diameter of the shaft, with the necessary clearance. On the outer circumference of this disc there is cut a groove c. The stationary guides, consisting of a vane of proper curvature and the adjoining piece, are of drop-forged steel, milled on all sides of the adjoining piece which fits into the circular groove c. These vanes are arranged all around the circumference so that one adjoining piece touches another and they are held in place and fastened securely, by rivets e, to the disk. The outer circumference of these vanes is turned off to the right size, and then a steel ring f is shrunk over them. This shrunk ring projects into the grooves of the housing.

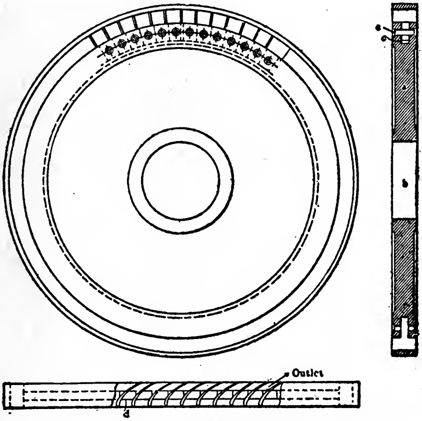


Fig. 286

The Running Wheel.—While in the stationary blade the weight is not of great importance, in the running wheel it is very essential to reduce the weight as much as possible. It will be readily understood that the lighter the running wheels are, the less the bearings will have to support, and therefore the shorter they may be constructed, and the better they will work. Furthermore, by keeping down the weight of the running wheel the shaft diameter is kept within small limits. This determines the bore of the stationary blade, and with that the circular space between the bore of the stationary blade and the shaft can be kept within small limits; therefore in the construction of this running wheel every dead and unnecessary weight is avoided.

The running wheel is made up as follows: A steel hub or spider a, Fig. 287, has a bore b fitting closely to the shaft diameter. On both side of the hub are riveted steel discs c. The groove on the outer circumference of the steel disc is turned out and forms a receptacle for the running vanes. The running vane itself consists of the properly curved blade, with an adjoining piece made in one section of drop-forged steel. The adjoining piece is finished and fits closely into the grooves of the steel disc. The running vanes are held in place and rigidly connected to the steel discs by rivets d, so that the centrifugal force of each vane is taken up by a rivet and transmitted through the rivet to the steel disc. The outer edge f of the vane is turned off and thus provided with an annular groove forming a receptacle for the steel band g, which is tied all around the wheel. It is held in place and secured to the

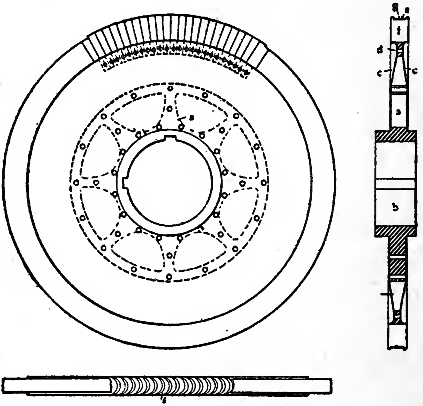


FIG. 287

vanes by riveting over the projecting ends of the vanes. The ends of the band are brazed together.

Reference to Fig. 288, which is a vertical section of this turbine, will serve to make more clear the action of the steam within the machine. The turbine casing a, is made of cast iron of cylindrical shape, and split in the horizontal axis, into the upper half, a, and the lower half, b. In the horizontal points the two halves are bolted together steam tight. The lower half, b, is cast together with the pedestal, c, which is the support for the low pressure bearing, d, and the groove, e, for the stuffing box, f. The outlet opening, g, is arranged in the lower half, b. This lower half is supported on pads of the bed plate, h, with two feet extending on the sides, and fastened thereto. The front head, i, is bolted steam tight to the flange, k, on the front side of the casing. In front of the head, i, is located the regulating mechanism pedestal, l, which combines the high pressure bearing with the housing for regulating mechanism, n, and housing, o, for the governor, p. A live steam pipe, g′, is connected to an inlet valve, r, and this to a main regulating valve, s, to the inlet flange of the front head, i. The passage of the steam into this front or high pressure head has already been referred to. In the grooves cut in the housing are the stationary blades, t, and in the space between the two following stationary blades is the running wheel, u. All running wheels fit on the shaft, v, and are keyed to the shaft. The shaft, v, is supported in the high pressure bearing, m, on one end, and in the low pressure bearing, d, on the other end. The low pressure bearing has an arrangement which allows the adjustment of the shaft, v, lengthwise in the direction of the turbine. On the outer end of the shaft is the coupling, w, keyed to the

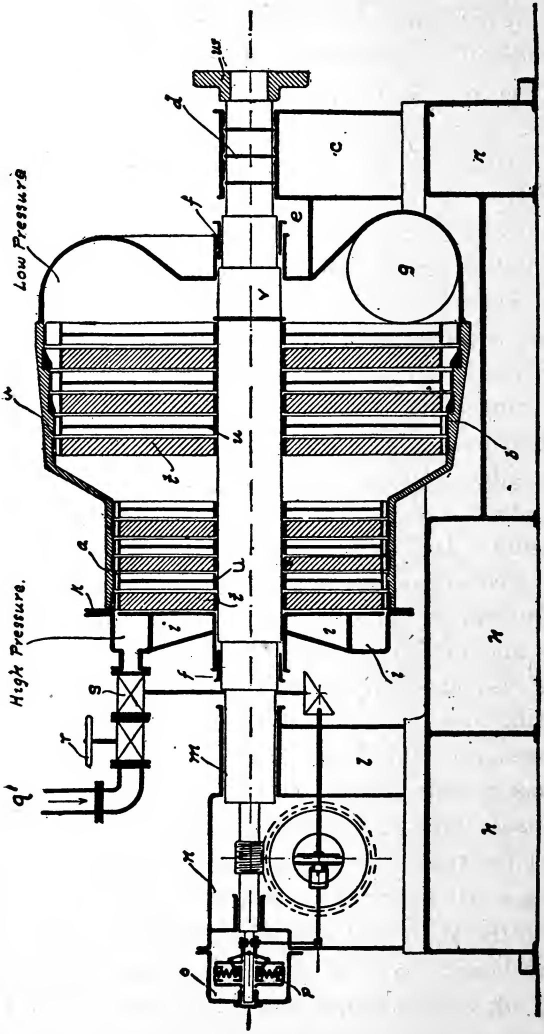


FIG. 288
HAMILTON-HOLZWARTH STEAM TURBINE
Sectional Elevation

shaft. This coupling allows connection to be made to the generator, pump, or blower, which is to be driven by the turbine.

The flow of the steam from the inlet valve, r, to the exhaust outlet, g, and the manner of the working of the steam in the turbine is as follows: The steam passing through the main regulating valve, s, enters the circular channel of the front head, i, and from here it flows through a circular slot to the first stationary blade, t. Opposite this circular slot is arranged a multitude of vanes, x, Fig. 289, which give the steam the right expansion in the right direction. With this velocity attained in the stationary blades, the steam impinges upon the vanes, u, of the first running wheel, and the bore of the housing can be kept within larger limits, because the steam flowing through the vanes is prevented from flowing rapidly outward by means of a band secured around the outer circumference of the running wheel.

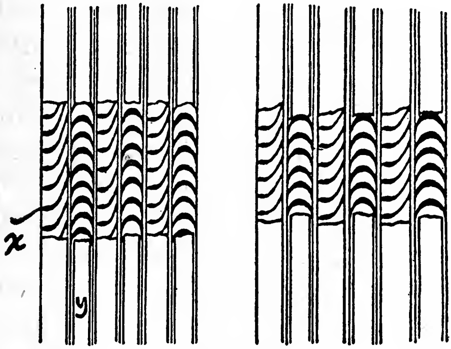


FIG. 289

The running vanes conform in section somewhat to the Parsons type, but the action of the steam upon them, and also within the stationary vanes is different. The expansion of the steam, and consequent development of velocity takes place entirely within the stationary vanes, which also change the direction of flow of the steam, and distribute it in the proper manner to the vanes of the running wheels, which, according to the claims of the makers, the steam enters and leaves at the same pressure, thus allowing the wheel to revolve in a uniform pressure.

In the low-pressure casing, which is larger in diameter than the high-pressure, the steam is distributed in the same manner as it is in the high-pressure casing. There is, however, in the front head of the low-pressure casing an additional nozzle through which live steam may be admitted in case of overload. The design of this nozzle is such that the live steam entering and passing through it, and controlled by the governor exerts no back pressure on the steam coming from the receiver, but, on the contrary, its action is similar to the action of an injector, that is, it tends to suck the low-pressure steam through the first set of stationary vanes of the low-pressure turbine.

The first stationary disc of the low-pressure turbine has guide vanes all around its circumference, so that the steam enters the turbine in a full cylindrical belt, interrupted only by the guide vanes. To provide for the increasing volume as the steam expands in its course through the turbine, the areas of the passages through the distributers and running vanes must be progressively enlarged. The gradual increase in the dimensions of the stationary vanes permits the steam to expand within them, thus tending to maintain its velocity, while at the same time the vanes guide the steam under such a small angle that the force with which it impinges the vanes of the next running wheel is as effective as possible. The curvature of the vanes is such that the steam while passing through them will increase its velocity in a ratio corresponding to its action.

The purpose of the stationary discs is, as has been stated, to distribute the steam to the running wheel. They also take the back pressure of the steam as it impinges the vanes of the running wheels, thus in a sense acting as balancing pistons.

The governor is of the spring and weight type, adapted to high speed, and is designed especially for turbine governing. It is directly driven by the turbine shaft, revolving with the same angular velocity. Its action is as follows: Two discs keyed to the shaft drive, by means of rollers, two weights sliding along a cross bar placed at right angles through the shaft and compressing two springs against two nuts on the cross bar. Every movement of the weights, caused by increasing or decreasing the angular velocity of the turbine shaft, is translated by means of levers to a sleeve which actuates the regulating mechanism. These levers are balanced so that no back pressure is exerted upon the weights. The whole governor is closed in by the discs, one on each side, and a steel ring secured by concentric recesses to the discs. In order to decrease the friction within the governor and regulating mechanism, thrust ball-bearings and frictionless roller-bearings are used.

As previously stated, the regulating valve is located beneath the bed plate. One side of it is connected by a curved pipe with the front head of the high-pressure cylinder, and the other side is connected with the inlet valve. The regulating valve is of the double-seated poppet valve type. Valves and valve seats are made of tough cast steel, to avoid corrosion as much as possible, and the valve body is made of cast iron.

Immediately below the regulating valve and forming a part of it in one steam chamber is located the by-pass regulating valve. Thus the use of a second stuffing box for the stem of this valve is avoided. The function of this valve is to control the volume of the live steam supply that flows directly to the by-pass nozzles in the front head of the low-pressure casing. This valve is also a double-seated poppet valve.

The main regulating valve is not actuated directly by the governor, but by means of the regulating mechanism. The construction and operation of this regulating mechanism is as follows: The stem of the regulating valve is driven by means of bevel gears by a shaft that is supported in frictionless roller-bearings.

On this shaft there is a friction wheel that the governor can slide across the face of a continuously revolving friction disc by means of its sleeve and bell crank lever. This revolving disc is keyed to a solid shaft which is driven by a coupling from a hollow shaft. This hollow shaft is driven by the turbine shaft through the medium of a worm gear. The solid shaft, with the continuously revolving friction disc, can be slightly shifted by the governor sleeve so that the two friction discs come into contact when the sleeve moves, that is, when the angular velocity changes. If this change is relatively great, the sleeve will draw the periodically revolving friction disc far from the center of the always revolving one, and this disc will quickly drive the stem of the regulating valve and the flow of steam will thus be regulated. As soon as the angular velocity falls below a certain percentage of the normal speed, the driving friction disc is drawn back by the governor, the regulating valve remains open and the whole regulating mechanism rests or stops, although the shaft is still running

Should the angular velocity of the shaft reach a point 2.5 per cent higher than normal, the governor will shut down the turbine. If an accident should happen to the governor, due to imperfect material or breaking or weakening of the springs, the result would be a shut-down of the turbine.

In order to change the speed of the turbine while running, which might be necessary in order to run the machine parallel with another prime mover, a spring balance is provided, attached to the bell crank lever of the regulating mechanism. The hand wheel of this spring balance is outside of the pedestal for regulating mechanism and near the floor-stand and hand wheel. With this spring balance the speed of the turbine may be changed 5 per cent either way from normal.

All the bearings of the turbine are thoroughly lubricated with oil forced under pressure by the oil pump driven by means of worm gearing by the turbine itself. After flowing through the bearings the oil is passed through a filter, and from thence to the oil tank located within the bed plate, from whence it is taken by the oil pump. All revolving parts are enclosed, and the principal part of the regulating mechanism operates in a bath of oil.

The Stuffing-Box.—An effective means of packing a swiftly revolving shaft is a long sleeve surrounding the shaft with a very small radial clearance. The reason for this will be found in the throttling action of the steam particles revolving with the shaft. These steam particles have a tendency to fly outwardly and so prevent the steam from passing axially through the small clearance between the shaft and the sleeve. The reader will readily understand that it would not be practical to use such a long sleeve in the construction of a steam turbine, as this arrangement would considerably increase the length of the free shaft. For the reason that the deflection of the shaft depends upon the third power of the free length of the shaft, it is absolutely necessary to restrict this free length as much as possible.

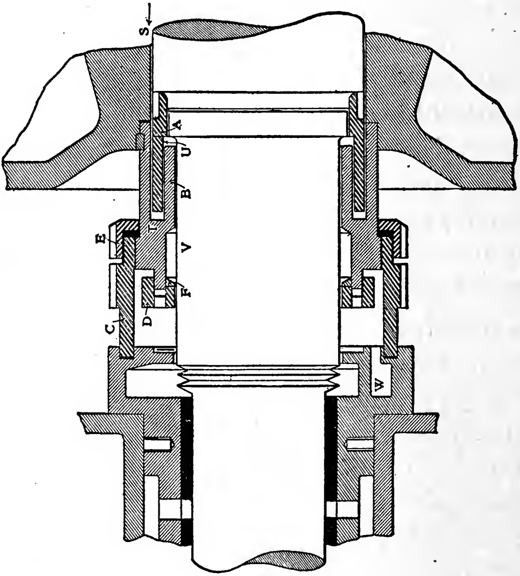


Fig. 290

In the Hamilton-Holzwarth turbine, use is made of the telescopic idea; that is the entire length of the sleeve is split into several parts, and these single parts are shifted together. In Fig. 290 the ring A screwed upon the shaft projects axially into a groove of the ring B, and revolves within it. The ring B does not move at all, but is held in place, and pressed tightly against the turbine casing by means of the ring C which presses against the bushing of the bearing. By screwing the ring C on the ring B, both rings are forced axially in opposite directions. From the casing S the steam seeking to escape, flows axially to T. From there it flows back to U, and then forward to V, being very much throttled in the process. The ring B has an annular groove which must be packed with soft packing. Any accumulating water is collected in the chamber W, in the bushing of the bearing, from whence it is properly drained. The ring E serves only the purpose of tightening the threads between rings C and B.

The Rateau Steam Turbine

The Rateau turbine is purely an impulse turbine, using wheels of thin plates pressed into a slightly conical form. These are mounted on a common shaft, and separated from each other by division walls. The first wheels have partial peripheral admission, so that the peripheral velocity may be high from the very beginning without using too short blades. The guide blades are set into division walls, and the rotating blades are bent from a single piece of bronze, or steel plate, and are riveted to the double turned rim of the wheel-disc. The shaft bearings were originally built as part of the cover of the turbine, but now are made independent. At the low pressure end the shaft is made steam tight by means of a simple stuffing box, into which sufficient water is allowed to flow to secure steam tightness. As the same pressure exists on both sides of each rotating wheel, the axial thrust has only the small value due to the pressure on the area of the end of the front journal.

Fig. 291 shows a sectional view of the machine, in which it is to be noted that the wheel discs are riveted to their hubs.

Fig. 292 shows a view of the turbine with generator, and oil equipment. The construction of the wheels, and division walls can easily be seen in Figs. 293, 294 and 295. The construction according to the latter figure, with division walls made in sections is preferred, because after taking away the casing cover, all the interior parts are easily accessible.

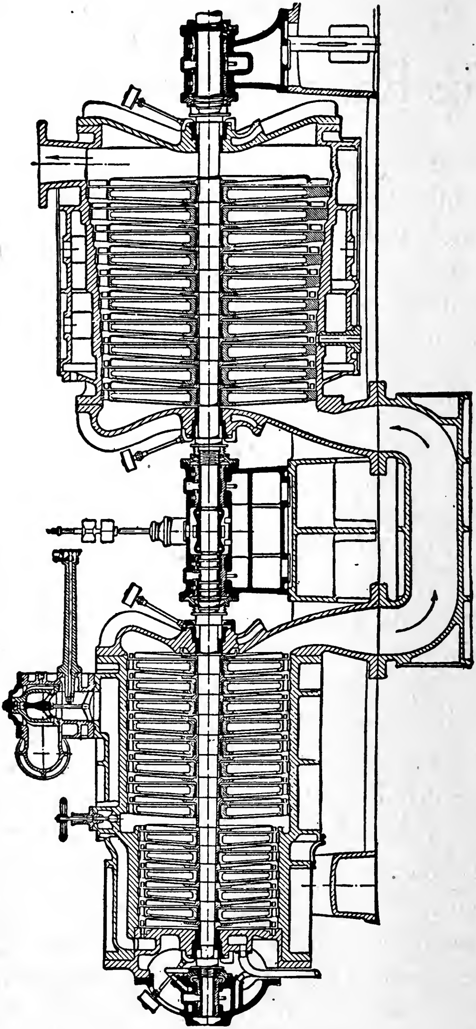


FIG. 291

The most recent Rateau turbine is of the action type, that is to say, expansion of the steam is fully carried out in

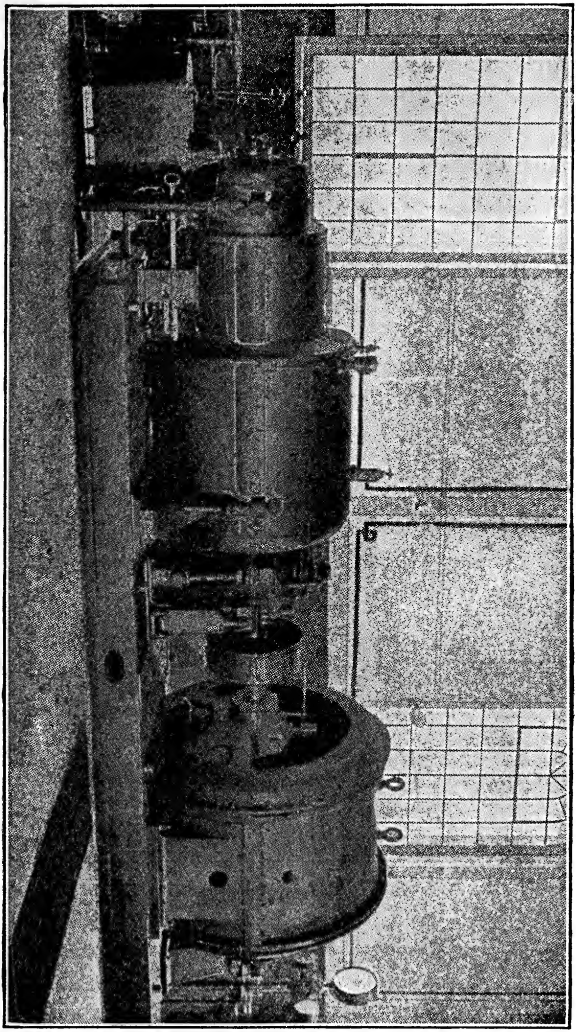


FIG. 292

the distributor for each group consisting of a distributor and one moving wheel. The steam therefore acts by its velocity and not by its pressure. These turbines are moreover multicellular, that is to say, they consist of a certain number of elements, each element comprising one distributor and one moving wheel.

This turbine has been developed by the firm of Sautter-Hartle, of Paris, France, from designs by Prof. A. Rateau, who is also the inventor of the Rateau steam regenerator, through which the exhaust from non-condensing reciprocating engines may be passed to a low-pressure turbine, thus resulting in the development of power from steam which otherwise would be wasted. A very complete and

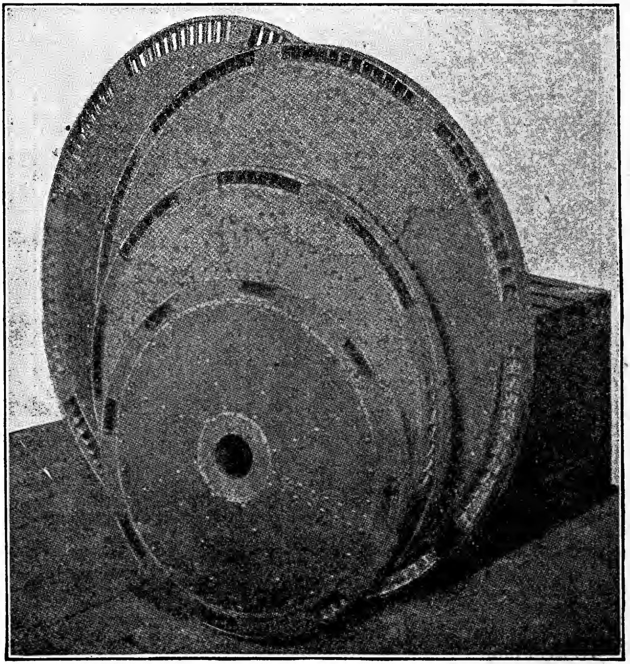


Fig. 293

successful installation of this character has been in operation for some time at the extensive steel works of the International Harvester Company at Chicago, Ill., and judging from the results of an exhaustive series of tests conducted by Mr. F. G. Gaesch, and published in the June, 1907, issue of "Power," the system possesses considerable merit. The following description of the installation at the Harvester Company's plant, is supplied by courtesy of the Western Electric Co., of Chicago.

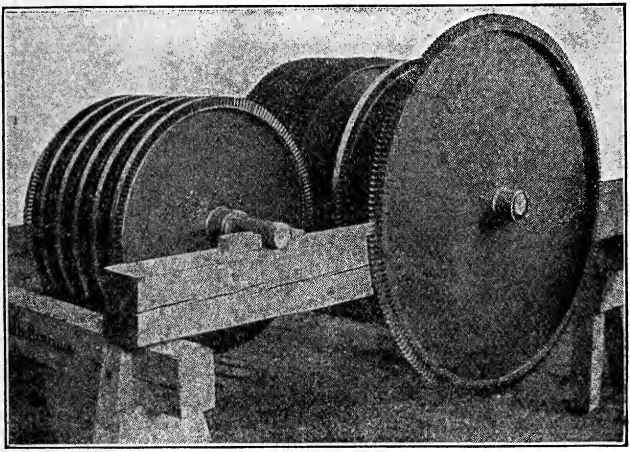


Fig. 294

The Steam Regenerator, or accumulator, consists of a cylindrical wrought-steel shell 3/8 of an inch in thickness, 11 feet 6 inches in diameter, and 30 feet long, having a central horizontal diaphragm which divides the regenerator into two similar compartments. In each compartment there are six elliptical tubes or steam-distributing conduits, A, Fig. 296, which extend from end to end in pairs, and are so placed as to leave spaces, B, between them. (The sectional view is from another installation and only shows four tubes.) Baffle plates, C, are arranged above the space between each pair of tubes. The spaces surrounding the conduits, and, under certain conditions, even the conduits themselves, are filled with water to the extent that the top of the latter is usually submerged three or four inches. The sides of the conduits are perforated with a great many ¾-inch holes to allow of the lateral escape of steam through the water, with, occasionally, a further escape from the bottom openings. A large baffle plate in the upper steam space serves for a perfect separation of entrained moisture from the steam. The steam enters by the pipe shown at the left hand of the side elevation, passes to the interior of the elliptical tubes, and escapes into the spaces through the perforations. The circulation of the water takes place in the direction of the arrows; the baffle plates placed above each pair of tubes prevent the water from being thrown

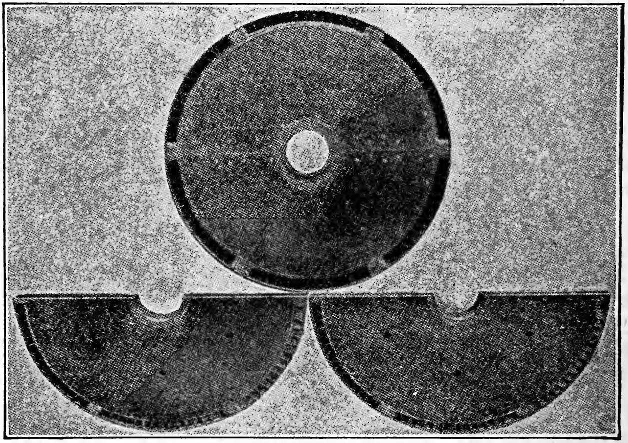


Fig. 295

into the steam space. This flow of steam gives an extreme degree of steam saturation to the water; and the slight back pressure which at first might be expected, owing to the head of water above the rows of perforations, is thereby reduced to insignificant proportions.

When the supply of steam from main engine ceases, the water liberates part of the heat it has absorbed, and an even flow of low-pressure steam is given off, while the steady demand of the turbine reduces the pressure in the accumulator, causing the steam still retained in the tubes to escape, maintaining the circulation of the water, and facilitating the liberation of the steam. Experience has shown that the whole of the contained water participates in the regenerative action. The steam is taken from the top of the accumulator to the turbine, and the pressure can be regulated by the relief valve shown. The water level is maintained constant by a ball float contained in a small tank arranged at the back of the regenerator. Generally there is a slight overflow at all times, representing among other things the "make up" from the exhaust steam supply. The regenerator at this plant has a capacity of 55 tons of water, sufficient by actual test to deliver all the steam for a 50 per cent overload on the turbine for a period of 430 seconds. At full load this would correspond to a period of 390 seconds. The regenerator or accumulator is fitted with the following accessories: First, an adjustible relief valve, which regulates the limits of pressure in the accumulator, and allows the steam to escape when the turbine is stopped, or working on a light load; it also prevents back pressure in the cylinders of the reciprocating engine.

This valve may be connected to the condenser so that in case the turbine is shut down for a period, the main engines may have the benefit of the vacuum.

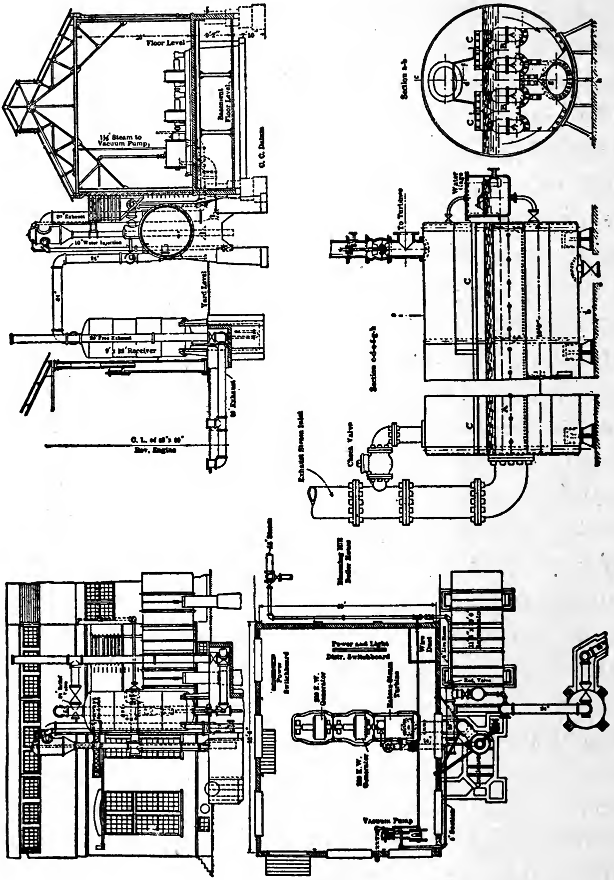


FIG. 296

PLAN AND ELEVATION OF LOW-PRESSURE TURBINE INSTALLATION, WITH TRANSVERSE AND LONGITUDINAL SECTIONS OF REGENERATOR

Second, a non-return water valve, necessary with water accumulators, to prevent any possibility of reflux of water toward the main engines during periods of stoppage.

Third, automatic level regulators, and gauge glasses, and automatic drains.

Fourth, piping beginning at the inlet of the receiving drum, including the steam header and mains from the regenerator to the turbine, the exhaust piping from the turbine, and condenser, and the piping between the condenser and air pump.

Fifth, a vertical receiving drum 9 feet in diameter, and 22 feet long, with baffle plates, and separating chambers, the function of which is to allow the ready escape of steam from the main engines without increase of back pressure on the system. The expansions allowed in this drum conduce to a more even flow of steam in the steam regenerator.

Sixth, a 30-inch barometric condenser of the Alberger type, complete with air cooler, exhaust entrainer, expansion joint, and an air pump 8x6x12 inches.

The exhaust steam from a 42x60 McIntosh & Hemphill, rolling mill engine, passes through the regenerator and into a Rateau low-pressure turbine, to the shaft of which is connected two direct current generators, each of 250 K. W. capacity, at 250 volts, and designed so that they may be operated in parallel. The bearings are of the ring-oiled reservoir type, with water jackets. The plant is designed with a view of adding another similar unit, but the evidence of the tests shows that a 750 K. W. unit can be operated with the steam that is available, without allowance for the steam (about 6,000 lbs. per hour) that is available from auxilliary machinery.

Part of these auxiliaries already exhaust into an open feed water heater, but the steam regenerator, constituting a perfect feed heating device, can more appropriately receive all the steam from the auxiliaries, with the advantage of some addition to the capacity of the turbine equipment.

Fig. 297 shows a view of the regenerator and attached equipment.

The leading objects of the tests made by Mr. Gaesch were, first to determine the steam consumption of the turbine per unit of power, and second, to measure the actual amount of steam available for the use of the turbine as delivered from the main engine.

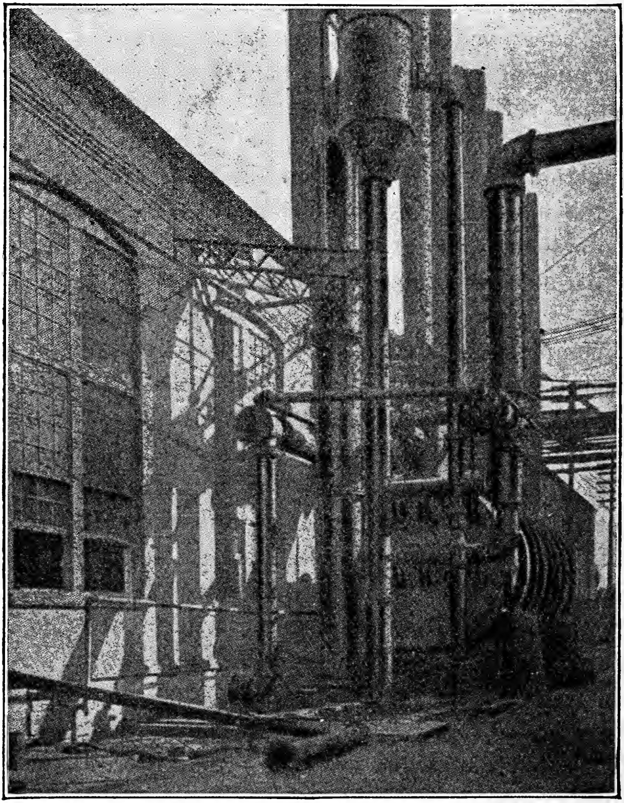


Fig. 297

RATEAU REGENERATOR, AND ATTACHED CONDENSER

Space prohibits a detailed description of the method of conducting the tests, and the results derived therefrom.

The average brake horse power developed by the turbine according to the report of one of the tests was 544 with a steam consumption per B. H. P. per hour of 37 lbs. The average steam pressure at the turbine was 16.6 lbs. absolute. The average I. H. P. of the main engine during the same test was 820, with a steam consumption of 61.2 lbs. per I. H. P. per hour. The total weight of steam available per hour from regenerator to turbine was 56.100 lbs.

The main engine, the dimensions of which have already been given, was a reversing rolling mill engine. The stuffing box used in the Rateau turbine is clearly illustrated in Figs. 240 to 243.

The Reidler-Stumpf Steam Turbine

This turbine is manufactured in Germany and its essential characteristics are the peculiarly formed, parallel return buckets derived from the Pelton water wheel, also the rectangular nozzles that allow a homogeneous jet of steam to be directed against the wheel. Fig. 298 shows a view of one of the wheels, and Fig. 299 shows sections of a bucket, and nozzle.

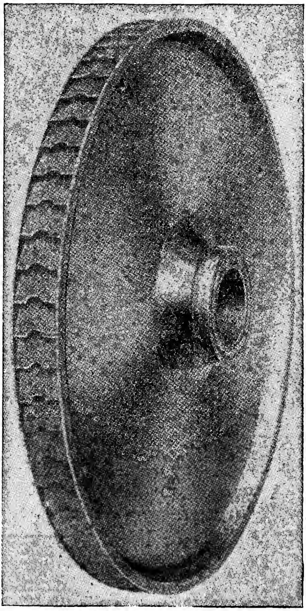


FIG. 298

The buckets are worked out of a solid forged wheel with a milling cutter, consequently they are very strong, and durable.

The steam jet enters the bucket C from the nozzle B, and is deflected through an angle of 180 degrees, the direction of its exit being parallel to that of its entrance, as shown by the arrows (Fig. 299).

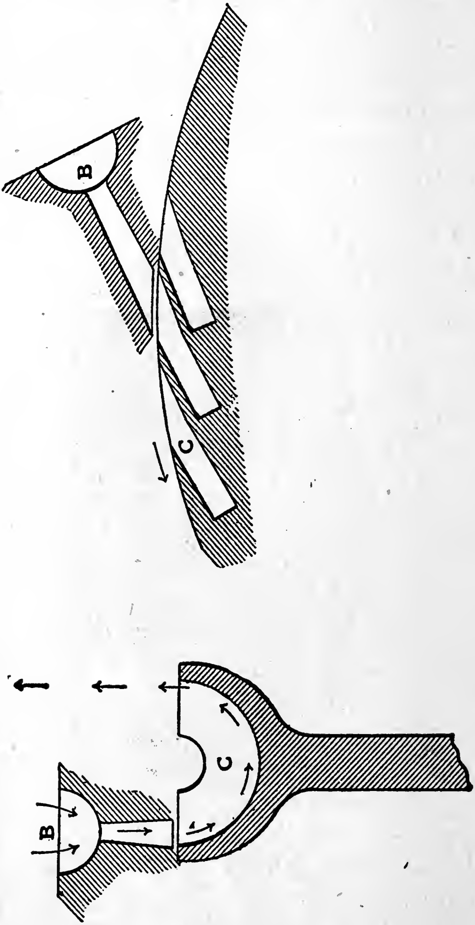


Fig. 299

This type of wheel has but a one-sided discharge—Fig. 300 shows another type of this turbine, in which the stationary buckets D, of the reverse guide are opposed to the rotating buckets C of the wheel in such a manner as to form a continuous closed cylinder in which the steam in

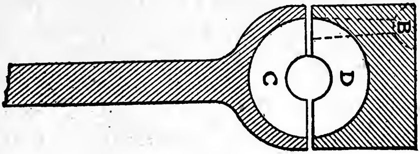


Fig. 300

its course through the wheel continually whirls or spirals around and around. With this type of turbine the steam enters the bucket wheel from the nozzle as shown in Fig. 299, but instead of escaping after it has passed once through the bucket, it is caught by the guide or stationary bucket and returned to the wheel, this process being repeated again and again until practically all of the energy in the steam has been abstracted.

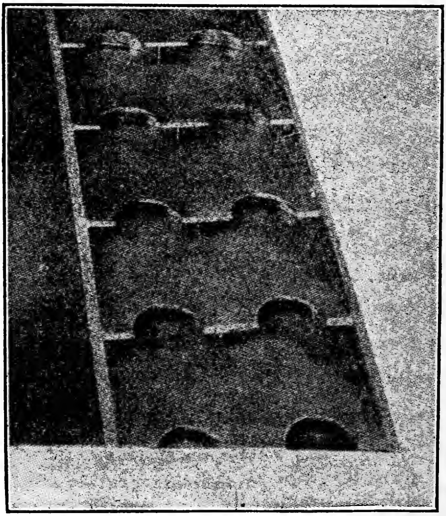


Fig. 301

Fig. 301 shows a portion of the rim of this style of wheel with its symmetrical double buckets. The steam jet is split into two symmetrical parts by the sharp middle partition. The direction of flow of the two steam streams is now reversed, and they are returned to the middle plane of the wheel by the reverse blades, and again brought to the wheel as a united jet. Nearly the entire periphery has primary, or secondary admission, and as a result of this the fan work of the idle blades is reduced to a minimum.

Disposal of the Exhaust Steam of Steam Turbines

As in the case of the reciprocating engine, the highest efficiency in the operation of the steam turbine is obtained by allowing the exhaust steam to pass into a condenser, and experience has demonstrated that it is possible to maintain a higher vacuum in the condenser of a turbine than in that of a reciprocating engine. This is due, no doubt, to the fact that in the turbine the steam is expanded down to a much lower pressure than is possible with the reciprocating engine.

The condensing apparatus used in connection with steam turbines may consist of any one of the modern improved systems, and as no cylinder oil is used within the cylinder of the turbine, the water of condensation may be returned to the boilers as feed water. If the condensing water is foul or contains matter that would be injurious to the boilers, a surface condenser should be used. If the water of condensation is not to be used in the boilers, the jet system may be employed. Another type of condenser that is being successfully used with steam turbines is the Bulkley injector condenser.

Among the steam turbines that were on exhibition at the St. Louis exposition in 1904 the Westinghouse-Parsons and the General Electric Curtis turbines were each equipped with Worthington surface condensers, fitted with improved auxiliary apparatus consisting of dry vacuum pumps, either horizontal of the well-known Worthington type, or rotative motor-driven, a hot well pump, and a pump for disposing of the condensed steam from the exhaust system. The two latter pumps were of the Worthington centrifugal type. The Hamilton-Holzwarth turbine was equipped with a Smith-Vaile surface condenser, fitted with a duplex double-acting air pump, a compound condensing circulating pump, and a rotative dry vacuum pump, motor-driven. The vacuum maintained was high, 28 to 28.5 in.

As an instance of the great gain in economy effected by the use of the condenser in connection with the steam turbine, a 750 K. W. Westinghouse-Parsons turbine, using steam of 150 lbs. pressure not superheated and exhausting into a vacuum of 28 in., showed a steam consumption of 13.77 lbs. per B. H. P. per hour, while the same machine operating non-condensing consumed 28.26 lbs. of steam per B. H. P. hour. Practically the same percentage in economy effected by condensing the exhaust applies to the other types of steam turbines.

With reference to the relative cost of operating the several auxiliaries necessary to a complete condensing outfit, the highest authorities on the subject place the power consumption of these auxiliaries at from 2 to 7 per cent of the total turbine output of power. A portion of this is regained by the use of an open heater for the feed water, into which the exhaust steam from the auxiliaries may pass, thus heating the feed water and returning a part of the heat to the boilers.

A prime requisite to the maintenance of high vacuum, with the resultant economy in the operation of the condensing apparatus, is that all entrained air must be excluded from the condenser. There are various ways in which it is possible for air to find its way into the condensing system. For instance, there may be an improperly packed gland, or there may be slight leaks in the piping, or the air may be introduced with the condensing water. This air should be removed before it reaches the condenser, and it may be accomplished by means of the "dry" air pump.

This dry air pump is different from the ordinary air pump that is used in connection with most condensing systems. The dry air pump handles no water, the cylinder being lubricated with oil in the same manner as the steam cylinder. The clearances also are made as small as possible. These pumps are built either in one or two stages.

A barometric or a jet condenser may be used, or a surface condenser. The latter type lessens the danger of entrained air, besides rendering it possible to return the condensed steam, which is pure distilled water, to the boilers along with the feed water, a thing very much to be desired in localities where the water used for feeding the boilers is impregnated with carbonate of lime, or other scale-forming ingredients.

In comparing the efficiency of the reciprocating engine and the steam turbine it is not to be inferred that reciprocating engines would not give better results at high vacuum than they do at the usual rate of 25 to 26 in., but to reach and maintain the higher vacuum of 28 to 28.5 in. with the reciprocating engine would necessitate much larger sizes of the low-pressure cylinder, as also the valves and exhaust pipes, in order to handle the greatly increased volume of steam at the low pressure demanded by high vacuum.

The steam turbine expands its working steam to within 1 in. of the vacuum existing in the condenser, that is, if there is a vacuum of 28 in. in the condenser there will be 27 in. of vacuum in the exhaust end of the turbine cylinder.

On the other hand, there is usually a difference of 4 or 5 in (2 to 2.5 lbs.) between the mean back pressure in the cylinder of a reciprocating condensing engine, and the absolute back pressure in the condenser.

It therefore appears that the gain in economy per inch increase of vacuum above 25 in. is much larger with the turbine than it is with the reciprocating engine. Mr. J. R. Bibbins estimates this gain to be as follows: between 25 and 28 in. there is a gain of 3½ to 4 per cent per inch of increase, and at 28 in. 5 per cent. These results have been obtained by means of exhaustive tests conducted by Mr. Bibbins. Other high authorities on the steam turbine all agree as to the great advantages to be derived by incurring the extra expense of erecting a condensing plant that is capable of maintaining the high vacuum necessary to high efficiency.

Another method by which the steam consumption of the turbine may be materially decreased, and a great gain in economy effected is by superheating the steam. The amount of superheat usually specified is 100°, and the apparatus employed for producing it may be easily mounted in the path of the waste gases. The steam may thus be superheated without extra cost in fuel, and an increase of 8 to 10 per cent in economy effected. The independent superheater requires extra fuel and labor, and the gain in this case is doubtful, but there can be no question as to the wisdom of utilizing the waste flue gases for superheating the steam.

As previously stated, the steam turbine is peculiarly adapted for the use of highly superheated steam, and high vacuum, and in these two particulars it excels the reciprocating engine. At the present time many large plants are equipped with turbine engines that are giving the best of results, and the outlook for the future employment of this type of power producer is certainly very promising.

Surface Condensers.—The demand for efficient service in the production of power by both the reciprocating engine, and the steam turbine has resulted in bringing to bear upon the design of the surface condenser, some of the thought, study and experiment which have heretofore been expended upon the other factors of the power plant. Up to within the past few years the surface condenser consisted principally of an indiscriminate collection of tubes within a metal box, with a flood of water following what happened to be the path of least resistance, with tubes subjected upon the steam side to a shower of water of condensation, keeping the steam from contact, and with pockets and quiet corners for steam and air and water, with an air-pump large enough for whatever happened, and little attention paid to the getting of the air into it, the surface condenser has satisfied the moderate demands of the past, and awaited the demands created by the turbine, and the strenuous central station man for scientific treatment along rational lines.

In a condenser taking care of 200,000 pounds of steam per hour, over 55 pounds of water are made upon the tubes per second. If this has to drip down over the bank below the point at which it is formed, it can readily be seen that the lower tubes are going to be busy cooling off feed-water instead of condensing steam, and that the greater rate of condensation will occur upon the upper tubes. By arranging the tubes in banks, the condensation from each of which is quickly drawn to the side and disposed of, by leading the steam to a positive and rapid flow among these tubes in a direction counter to the flow of the water, so that the final contact of the condensed steam and air is with the coolest water, and by subdividing the flow so that the circulating water travels positively and rapidly past every square foot of the cooling surface, the condenser is made to condense eighten or twenty instead of six pounds of steam per hour per square foot of surface. The significance of this, not only in first cost and space occupied, but in maintenance charges where, as in some of the large stations upon the Atlantic seaboard, tubes have to be renewed once in about three years, is easy to appreciate, and it is not the tube which is condensing lots of steam, but rather that which is loafing in an air pocket or an eddy, that is the most likely to corrode.

Notwithstanding the liability to corrosion of the tubes of surface condensers, many of the large engine plants, and practically all steam turbine plants have been equipped with surface condensers. This is due largely to the saving effected by returning the pure water of condensation to the boilers. But unless the condenser tubes are closely watched for signs of corrosion, there is danger of having in the course of time a mixture of cylinder oil and condenser leakage along with the water of condensation, which would be a very undesirable boiler feed. This applies to reciprocating engine plants. On the other hand a surface condenser in connection with a steam turbine is a better investment. The turbine water of condensation contains no lubricating oil and condenser leakage is the only source of trouble to be feared. To maintain this condenser leakage at the lowest practicable minimum is extremely important, as this will seriously affect (if the hot-well water is used for boiler feed) the percentage of corrosive and scale-forming elements fed into the boilers. Even under normal surface-condenser operation there is a small leakage, through the packing at the ends of the tubes, and to this is added leakage due to corrosion.

The danger of corrosion attacking the tubes of surface condensers is much greater in localities upon, or near the sea coast where the condensing water is largely impregnated with salt.

QUESTIONS AND ANSWERS.

446. Explain the chief points of difference between the action of the reciprocating steam engine, and the steam turbine.

Ans. The piston of the reciprocating engine is driven back and forth by the static expansive force of the steam; while in the steam turbine, not only is this static expansive force made to do work, but the velocity of the steam in expanding from a high, to a low pressure is also utilized in turning the rotor of the turbine.

447. What other important factors enter into the operation of a steam turbine?

Ans. The principles of reaction and impulse.

448. Name several of the more important advantages that the turbine has over the reciprocating engine.

Ans. First, highly superheated steam of a high initial pressure may be used in the turbine. Second, a larger proportion of the heat in the steam may be converted into work with the turbine. Third, there is much less friction with the turbine.

449. What is the most economical method of disposing of the exhaust steam from a turbine?

Ans. By allowing it to pass into a condenser.

450. Will the turbine expand the steam to as low a pressure as the reciprocating engine will?

Ans. Yes, and even lower.

451. What type of condensing apparatus is necessary with the steam turbine.

Ans. The same kind that is used on reciprocating engines.

452. How low will a well regulated turbine allow the steam to expand?

Ans. To within one inch of the vacuum existing in the condenser.

453. What is the theoretical velocity of steam under 100 lbs. pressure if allowed to discharge into a vacuum of 28 inches?

Ans. 3860 feet per second.

454. How many ft. lbs. of energy would one cubic ft. of steam thus exert?

Ans. 59,900 ft. lbs.

455. What is the ratio of bucket speed to jet speed for impulse wheels.

Ans. Bucket speed equals one-half of jet speed.

456. What should be the ratio between bucket speed and jet speed, for reaction wheels.

Ans. 1 to 1. That is, the two speeds should be equal.

457. What should be the form or curvature of the blades, or buckets?

Ans. They should be of such form as will permit expansion of the steam with the least amount of friction, or eddy currents.

458. How are the stuffing boxes of steam turbines usually kept cooled?

Ans. By means of water applied in various ways.

459. How is the speed of steam turbines usually regulated?

Ans. By simple throttling.

460. What are the ideal conditions under which a turbine should work?

Ans. A full initial pressure, and all cross sections of steam passages to be suitable to the power required.

461. Of what type is the Westinghouse-Parsons turbine?

Ans. It is both an impulse and reaction turbine.

462. How are the clearances between the blades preserved in this turbine?

Ans. By means of balancing pistons on the shaft.

463. What is the usual velocity of the steam in the Westinghouse-Parsons turbine?

Ans. 600 ft. per second.

464. How does the efficiency of steam turbines compare with that of reciprocating engines?

Ans. It is generally higher.

465. How is the heat energy in the steam imparted to the wheels of the Curtis turbine?

Ans. Both by impulse and reaction.

466. Describe the method of admission in the Curtis turbine.

Ans. The steam is admitted through expanding nozzles in which nearly all of the expansive force of the steam is transformed into the force of velocity. The steam is caused to pass through one, two, or more stages of moving elements, each stage having its own set of expanding nozzles, each succeeding set of nozzles being greater in number and of larger area than the preceding set.

467. What is the ratio of expansion in these nozzles?

Ans. The ratio of expansion within these nozzles depends upon the number of stages, as, for instance, in a two-stage machine, the steam enters the initial set of nozzles at boiler pressure, say 180 lbs. It leaves these nozzles and enters the first set of moving blades at a pressure of about 15 lbs.

468. In a four-stage machine, with 180 lbs initial pressure, what would be the pressures at the different stages?

Ans. First stage, 50 lbs.; second stage, 5 lbs.; third stage, partial vacuum, and fourth stage, condenser vacuum.

469. How are the revolving parts of the Curtis turbine supported?

Ans. Upon a vertical shaft, which in turn is supported by, and runs upon a step bearing at the bottom.

470. How is this step bearing lubricated?

Ans. Oil is forced under pressure by a steam or electrically driven pump, the oil passing up from beneath.

471. How is the speed of the Curtis turbine regulated?

Ans. By varying the number of nozzles in flow.

472. How are the clearances adjusted in the Curtis turbine?

Ans. By means of the large step screw at the bottom.

473. How is the shaft packed to prevent steam leakage?

Ans. With carbon blocks made into rings fitting the shaft.

474. What type of turbine is the De Laval?

Ans. It is purely an impulse wheel.

475. What is the speed of the wheel?

Ans. From 10,000 to 30,000 revolutions per minute.

476. How is the heat energy in the steam utilized in the De Laval turbine?

Ans. In the production of velocity.

477. What is the velocity of the steam as it issues from the expanding nozzles and impinges against the buckets?

Ans. About 4,000 ft. per second.

478. What is the usual peripheral speed of the wheel?

Ans. 1,200 to 1,300 feet per second.

479. Of what type is the Allis-Chalmers steam turbine?

Ans. It is essentially of the Parsons type.

480. How are the clearances between the revolving and stationary blades preserved?

Ans. By a thrust bearing.

481. What kind of bearings has the Allis-Chalmers turbine?

Ans. Self-adjusting ball and socket bearings.

482. What is the first move in preparing to start a steam turbine?

Ans. Open the throttle slightly and allow a small volume of steam to flow through in order to warm the turbine.

483. What should be done next?

Ans. Start the auxiliary oil pump.

484. What are the principal precautions to be observed when starting a steam turbine?

Ans. To see that the turbine is properly warmed, also to be certain that the oil is circulating freely through the bearings.

485. What type of turbine is the Hamilton-Holzwarth steam turbine?

Ans. It is an impulse turbine.

486. Describe in brief its construction?

Ans. There are no balancing pistons in this machine, the axial thrust of the shaft being taken up by a thrust ball-bearing. The interior of the cylinder is divided into a series of stages by stationary discs which are set in grooves in the cylinder and are bored in the center to allow the shaft, or rather the hubs of the running wheels that are keyed to the shaft, to revolve in this bore.

487. In what respect does this turbine resemble a compound reciprocating engine?

Ans. The steam is first admitted to the high pressure casing, and from there it passes into the low pressure casing, which is larger in diameter.

488. Describe the action of the steam upon the blades?

Ans. The expansion of the steam takes place entirely within the stationary blades, which also change the direction of its flow, distributing it to the running vanes.

489. What additional function do the stationary vanes perform?

Ans. They take the back pressure, thus acting as balancing pistons.

490. What type of governor has this turbine?

Ans. The spring and weight type.

491. How are the bearings lubricated?

Ans. The oil is forced into the bearings under pressure by an oil pump.

492. Of what type is the Rateau steam turbine?

Ans. It is an impulse turbine having wheels of thin plates, slightly conical.

493. How is the rotor balanced?

Ans. The same pressure exists on both sides of each rotating wheel.

494. Does the steam act by velocity or pressure?

Ans. By velocity in this case.

495. What are the essential features of the Reidler-Stumpf steam turbine?

Ans. The peculiar form of bucket, and the parallel return of the steam.

496. What is meant by parallel return of the steam?

Ans. The steam enters the buckets through nozzles, and is deflected through an angle of 180 degrees, thus leaving the rotating buckets in a direction parallel to that of its entrance.

497. Describe the action of the steam within the Reidler-Stumpf turbine.

Ans. Instead of escaping after having once passed through the buckets, it is caught by the guides or stationary buckets and returned to the wheel; this process being repeated again, and again until all of the energy in the steam has been made to do work.

498. How many types of this turbine are there?

Ans. Two, viz.: The single flow, and the double flow.

499. How is the highest efficiency obtained in the operation of the steam turbine?

Ans. By allowing the exhaust steam to pass into a condenser.

500. Is it possible to maintain as high vacuum with the turbine as with a reciprocating engine?

Ans. Experience demonstrates that a higher vacuum may be maintained in the condenser of a turbine than is possible with reciprocating engines.

501. What kind of condensing apparatus may be used with steam turbines?

Ans. Any one of the modern improved types.

502. What is required in order to maintain a high vacuum in any type of condenser?

Ans. That all entrained air be excluded.

503. How may this be accomplished?

Ans. By means of a dry air pump.

504. In what manner does the dry air pump differ from an ordinary air pump?

Ans. The dry air pump handles no water, and the clearances are made as small as possible.

505. To what extent does the steam turbine expand its working steam?

Ans. To within one inch of the vacuum existing within the condenser.

506. Is the steam turbine adapted to the use of superheated steam?

Ans. It is. Highly superheated steam may be used, and a high vacuum maintained.

507. Is the water of condensation from turbines desirable for boiler feed?

Ans. It is, for the reason that it contains no lubricating oil, and is a comparatively pure water.

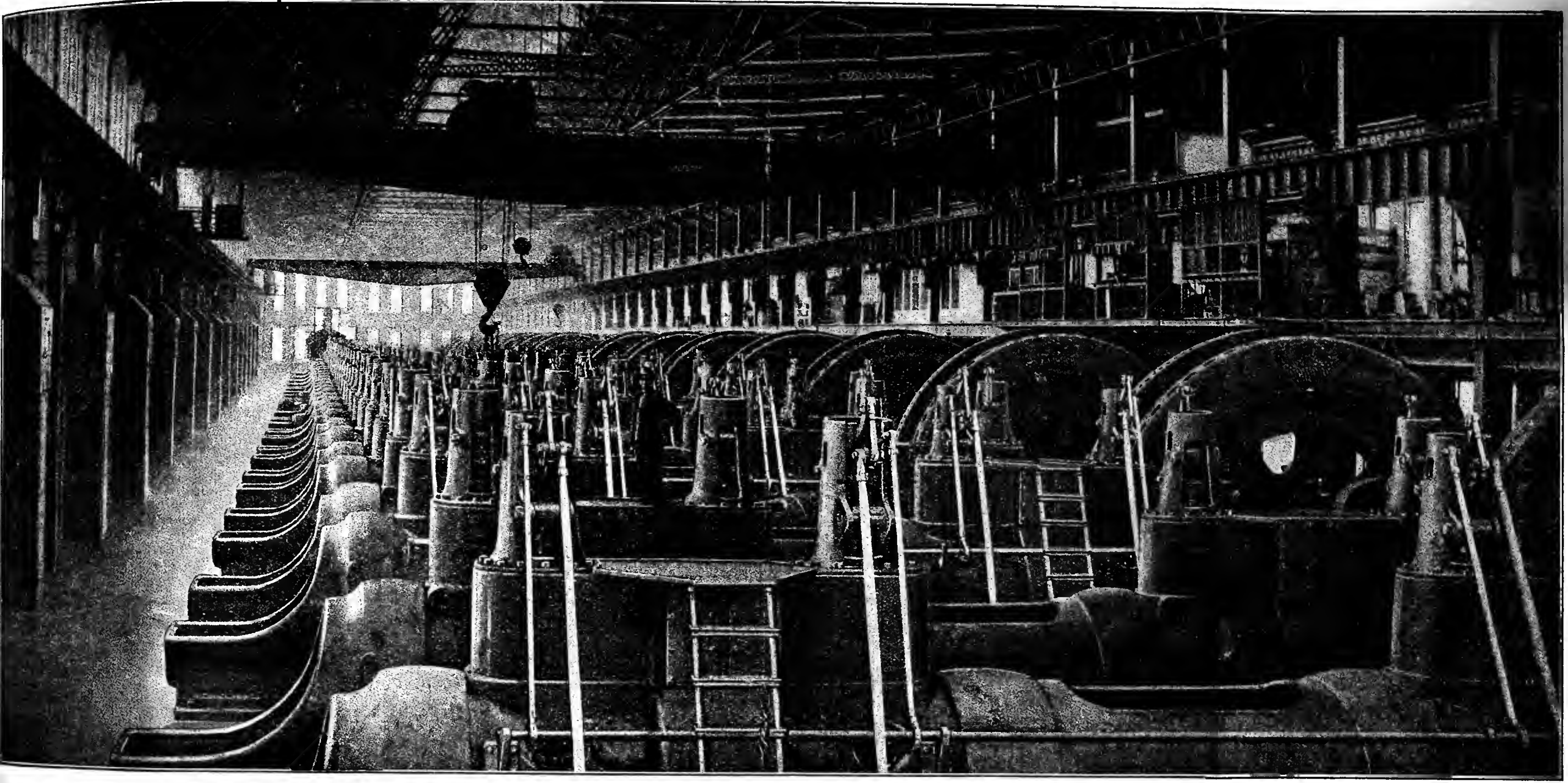


Fig. 302

ALLIS-CHALMERS GAS ENGINES AT ILLINOIS STEEL COMPANY'S PLANT, GARY, IND.

The Gas Engine

The gas engine differs structurally from the steam engine in two particulars, it is much more ponderous than a steam engine of equal output and has usually a much heavier crank-shaft. The difference in total weight must not be laid to the higher mean pressures exerted in the cylinder, for, in engines of a certain power, the mean pressure in the gas-engine cylinder will be higher than that in the steam-engine cylinder, so that for a given power per stroke, the gas engine may have the smaller cylinder. But the four-stroke-cycle gas engine has only one working stroke in four. For a given power, therefore, its cylinder area must be four times the area of the steam-engine cylinder, per pound of mean effective pressure. Since this latter will be as 3 to 2, approximately, the actual cylinder area will be as 2.66 to 1, or the diameter ratio will be 1.63 to 1.

Approximately the gas engine appears fully 50 per cent the larger when its piston speed is the same as that of the steam engine. This is a very strong inducement to the designer to produce an engine which shall do work in both ends of the cylinder. Such a design, however, necessitates a piston-rod stuffing-box, gland and cooling devices. It involves double the number of explosions per minute in the cylinder and it renders possible a reduction of the cylinder ratio, as compared with a steam engine, to 1.33 to 1. Regarding single acting, or double acting gas engines, the difference in stress on the crank shaft must be taken into account. A single-acting engine produces a torsion in the shaft which is reversed on the next stroke when the shaft is pushing back the piston. Reversing stresses are about 50 per cent more destructive than stresses in one direction only. The crank-shaft strength ratio is thus not simply 4:1, as between a four-stroke and a one-stroke method of working, but it is as 6:1, or diametrally as 1.8:1, the strength varying as the cube of the diameter. This is why gas-engine crank shafts are so very large and this point must be of great importance on the score of cost. Indeed the four-stroke engine embodies a large amount of material which does very little work during a large proportion of its working hours.

The gas engine is a prime mover which derives its power or energy from the heat generated by the combustion within its cylinder, of a mixture of gas and air in the proper proportion to form an explosive. The combustion of this charge of gas and air is occasioned under a close or heavy compression, a result of the inward movement of the piston after the charge is admitted and all valves closed. The result of igniting this mixture under the heavy compression is what is commonly called an explosion, which is nothing more than a quick burning or rapid combustion of the mixture. This sudden explosion causes a high degree of heat within the cylinder behind the piston, and, the resultant high initial pressure against the piston drives it forward, and, through the medium of connecting rod and crank, motion is imparted to the main engine shaft. The original gas engines, and a majority of the smaller sizes of today, operate upon the Beau de Rochas cycle or four stroke cycle, sometimes termed the Otto cycle, meaning that an engine completes a cycle in four acts, defined as follows: (1) Induction—During an outstroke of the piston, air and gas in suitable proportions are drawn into the cylinder. (2)

Compression—The following instroke compresses the combustible mixture into the clearance space. (3) Explosion—Ignition of the compressed charge causes a rapid rise of pressure and subsequent expansion of products. (4) Expulsion—The expanded gases are expelled by the returning piston. In this type of gas engine, two revolutions of the crank shaft are necessary in order to complete one cycle.

Many small engines and some of those of largest power are designed upon the 2-stroke cycle, which is as follows: (1) Compression of the charge. (2) Ignition, explosion and expansion, and at the end of the stroke the exhaust products are expelled and the cylinder filled by a mixture of gas and air under pressure. In the two cycle engine, two compression chambers are necessary, due to the fact that in this type of gas engine consisting of two cylinders, either side by side, or tandem, the charge of gas and air is being received in one cylinder, while the previous charge in the other cylinder is being compressed, preparatory to explosion. A two-cycle engine thus explodes a charge, and receives an impulse at each revolution. It is important to admit only pure air and gas into engine cylinders. Dust and grit, or tarry matters cause rapid wear of interior surfaces. Care is also necessary to insure the induction of cold charges, in order that maximum density of gas and air may be obtained.

The usefulness of the gas engine as a prime mover is greatly enhanced by the fact that suitable power gas may now be produced from almost any form of commercial fuel; the cheapness or relative fuel value of the combustible having very little bearing on the value for power purposes of the gas produced. For the efficient generation of steam the choice of coals is confined within narrow limits; for gas production relatively wide limits exist. Thus gas engines are operating with practically the same thermal efficiency on fuel gases ranging from 1,500 B. T. U. per cubic foot, to 90 B. T. U. per cubic foot. The former is a rich distillate from oil refining, the latter a waste product from blast furnaces. The one contains practically no combustible, the other as high as 8 per cent.

Table 37 gives the origin, and some of the properties of the usual commercial gases; Table 38 of the usual constituent gases.

The power derived from the combustion of these gases is, however, far more uniform than at first appears from their relative calorific value. For perfect combustion a definite amount of air must be mixed with the gas, depending upon the amount of combustibles to be neutralized by the oxygen in the air. For instance Pittsburg natural gas requires about 10 to 12 cu. ft. of air per cubic foot of gas, while for producer gas about equal volumes of gas and air are required. The calorific value of the mixture entering the gas engine cylinder thus forms the basis of all calculations rather than the heat of the gas itself, and in this respect relatively little difference exists between the heat value of suitable mixtures, whether the gas be rich or poor. For this reason the gas engine is enabled to work efficiently with most gases, however lean, provided of course that they are properly cleaned or purified from sulphur—no dust—no tar, etc.

Combustion.—In gas engine work it is important to obtain a speed of combustion neither too rapid nor too sluggish. Much then depends upon the relative constituents of the gas. Hydrogen burns with the greatest rapidity—seven times faster than methane, and if present in large quantities, forms an undesirable element with high compressions, on account of its tendency to premature ignition from the heat of compression. On the other hand, the comparatively sluggish combustion of methane and other heavy hydro-carbons, and the presence of large quantities of inert gases such as CO_2 and N tends to retard the combustion of hydrogen, so that a permanent gas, although containing a high percentage of hydrogen, if modified by a high percentage of more sluggish gases, will prove to be a suitable power gas. If, on the other hand, sufficient sluggish constituents are not present, compression in the engine must be largely reduced. Thus blue water gas (uncarburetted) is unsuited to gas engine work on this account. Enriched with oil gas (carburetted), water gas becomes somewhat more adaptable; likewise crude oil water gas.

Coke oven gas may become unsuitable if drawn off for too long a period during the coking process. In most forms of modern by-product coke ovens the richer gases are drawn off during the first 40 or 50 per cent of the coking period (10 hrs. in 24 hr. coke, 16 hrs. in 30 hr. coke); those gases given off during the latter part being used for heating the ovens. During the latter period the percentages of methane and hydrogen are rapidly reversed so that hydrogen may run as high as 60 or 70 per cent of the total volume of gas, which makes it quite unfit for power work. The gas delivery must, therefore, be carefully controlled, if utilized for power purposes.

Blast furnace gas, which is simply the product of more or less incomplete combustion of carbon in a coke furnace, contains less than one-third combustible matter, but forms an excedingly satisfactory fuel gas. It is comparatively

TABLE 37

COMMERCIAL POWER GASES—GENERAL PROPERTIES.

	GAS	ORIGIN	GENERAL CHARACTERISTICS FOR POWER WORK	Value for Power Gas.
1	Natural Gas	Geological.—Results from decomposed vegetation.	Ideal power gas. Rich, pure, rather slow burning. Requires no cleaning.	1
2	Oil Gas	Vaporizing crude oil. Used to enrich water gas.	Very rich in hydro-carbons. Liable to carbon deposits. Seldom used for power except in small oil (petrol) engines.	9
3	Coal Gas	Destructive distillation of coal in closed retorts.	Excellent gas, resembling natural gas. Not hard to clean. Manufacturing costs usually too high for general power purposes.	8
4	Coke Oven Gas (By-product)	Liberation of volatiles of coal in closed chambers without combustion.	Gas should be drawn off during early part of coking run. Good gas, rather high in H & S, requiring much purification.	5
5	Water Gas	Decomposition of steam on incandescent coke. Hydrogen freed, carbon burned to CO.	Pure gas, too snappy (high in H) for gas engines. More suitable if enriched with oil gas. Rather expensive gas for general power purposes.	10
6	Oil-Water Gas	Decomposition of steam and oil in retort heated by crude oil.	Rich gas, high in H, and rather snappy. Free from impurities, except S. Manufacturing cost low.	6
7	Producer Gas	Obtained from coal, coke, peat, lignite or wood. Largely incomplete oxidation of carbon to CO by a steam air blast. H_2O decomposes into free H. Some CO_2 formed.	Cheapest and best of artificial fuel gases, lean and comparatively slow burning. Made from any grade fuel.	2
8	" Bituminous	Bituminous coal. Breaking up of volatile hydro-carbons and conversion of fixed carbon into CO.	Richest of producer gases. Tar distillate difficult to remove. Most grades of coal suitable, including slack, lignite and wood.	2
9	" Anthracite	Anthracite coal. Practically no volatiles. Conversion of fixed carbon.	Gas free from tar,—requiring little cleaning. Excellent power gas. Buckwheat size coal may be used.	3
10	" Coke	Coke or charcoal.—No volatiles.—Conversion of fixed carbon.	Gas practically clean, except dust. Most suitable for small producers. Fuel rather expensive.	7
11	Blast Gas	By-product of blast furnaces.—Conversion of fixed C in coke into CO by air blast. Some CO_2 formed.	Gas very lean, dusty, and sluggish. Difficult to clean except mechanically. Excellent gas for engines taking high compressions.	4

TABLE 38

CONSTITUENTS OF POWER GASES.

Gas		Heating Value		Characteristics—Where Found
Name	Chemical Symbol	B.T.U. Cu. Ft. Net	Relative	
Hydrogen	H	278	1	Element formed from decomposition of steam (H_2O) or hydro-carbon compounds. Burns very rapidly with high flame temperature.
Oxygen	O	0		Element, not considered a combustible as it displaces an equal amount of (O) in air for combustion.
Nitrogen	N	0		Element. Inert gas entering with air (N-79%, O-21%). Retards speed of combustion.
Carbon Monoxide or Carbonic Oxide	CO	326	1.17	Valuable constituent. Product of incomplete combustion (oxidation) of C in presence of excess carbon.
Carbon Dioxide	CO_2	0		Inert gas. Product of complete combustion of C. Occurs in all producer and blast gases. Retards speed of combustion.
Methane or Marsh Gas	CH_4	913	3.29	Most valuable constituent evolved by natural or artificial decomposition of vegetable matter, coal or crude oils.
Acetylene Ethylene or Olefiant Gas Ethane Benzene or Benzol	C_2H_2 C_2H_4 C_2H_6 C_6H_6	1427 1490 1615 3955	51.4 53.6 58.1 131.5	Higher hydro-carbons, usually as "illuminants"—occur in small quantities in the richer gases, liberated during destructive distillation of coal or oil—Acetylene used alone for lighting.
Carbon	C			C oxidizes to CO (incomplete) and CO_2 (complete). CO oxidizes to CO_2.
Sulphur	S			S oxidizes to SO_2 forming H_2SO_4 (sulphuric acid) with water.

slow burning, thus permitting compressions as high as 160-200 lbs. per sq. in. and can be cleansed of dust without great difficulty; no tar is, of course, encountered. Owing to the fact that nearly 40 per cent less heat is contained in a cu. ft. of blast furnace gas mixture than with natural gas, larger cylinders are provided on blast furnace gas engines for developing the same horse power. The slight increase in friction is, however, largely overcome by increased thermal efficiency due to higher compression, and gas engines designed for this gas give practically the same efficiency as those operating on richer gases.

Induction.—The charge of gas and air in definite proportions is drawn into the cylinder by the suction of the engine piston, and the velocity of entry is in direct proportion to the piston speed. The air valve is usually opened before the gas valve, but inasmuch as there is no suction created until the opening of the air valve, some makers set the valves so that the gas valve is approaching its maximum lift by the time that the air valve has commenced to open, thus ensuring a well mixed charge. Usually, however, the settings are arranged so that the first portion of the induced charge is of air only, then air and gas, and finally air with the small quantity of gas swept in by the still moving current of air from the passages connecting the gas and air valve seats. The cams operating the valves are carefully designed to permit maximum lift with swift, but gradual opening and closing, to accord with the induced velocity set up by the linear speed of the piston at each point of the stroke. The air valve, governing the entry of the entire charge, is opened well in advance of the inner dead center of the engine, and is kept from closing until after the outer dead center, so that full effect of the momentum imparted to the entering gases at the highest rate of piston speed can be utilized without restriction, it being possible by such means to obtain a better filled cylinder.

Compression.—Modern practice in gas engine design aims at securing the economical advantages coincident with high compression pressures, but the limit of allowable maximum compression pressure depends upon the relative proportion of hydro-carbon gases, and hydrogen contained in the mixture or charge admitted to the cylinder. Hydrogen will ignite at a much lower temperature than the other constituents, and owing to the additional heat during compression, it becomes necessary to so design the relative volumes of piston displacement, and clearance, that self ignition is practically impossible. With blast furnace gas containing only about two per cent of hydrogen, compression pressures of 200 lbs. per sq. in. and over may be safely used, and with producer gas, 150 to 200 lbs. are common and safe pressures, but with illuminating gases the maximum is placed at 120 lbs. per sq. in. unless special precautions are taken to insure efficient cooling and cleaning of the cylinders. This is effected by the injection of water or cold air through the clearance spaces and valve ports during the charging stroke, or by pressure during compression.

Ignition.—The increase of compression pressures, and the use of poor gases for power purposes has brought electrical ignition devices into common use. Hot tubes of porcelain or hecnum are still used for engines designed to suit illuminating gas, but the impossibility of quickly adjusting the instant of explosion when running, the rapid deterioration of timing valves, and cost of renewals have emphasized the superior advantages of electrical firing.

While with petrol engines the current from a primary or secondary battery is utilized with intensifying coil, and jump sparking plug, the usual method adopted for gas engines is that of a positive break by mechanical separation of two electrodes through which current is passing from a magneto machine. In a magneto the lines of force flowing between opposite poles of a permanent magnet of great strength are alternately deflected from, and passed through an interposed armature by means of a shield or deflector operated by suitable mechanism from the half speed shaft. Upon maximum rapidity of the armature cutting the magnetic lines of force a strong current is induced in the windings and passes through a circuit formed by an insulated wire connected to a fixed, well-insulated electrode through the second and movable electrode in electrical contact with the engine frame and through this to the armature. It is of course very necessary to time the mechanism making the "break" so that it synchronizes with the period of the most powerful induced current in the armature. Most of the difficulties encountered with magnetos have been owing to the slipping of the actuating mechanism from the coned seating on the armature spindle, but once the correct setting has been noted and marked, attendants have found that very little other attention is necessary.

Primary Batteries.—Those used are of two kinds, dry and wet batteries. Before the dry cell became so common, the cell that was used mostly for bells, and other open circuit work, (by open circuit work is meant intermittent work, like a bell that rings occasionally, or ignition purposes; a closed circuit is one where the current flows continuously) was the wet sal ammoniac cell. The elements in this cell are commonly carbon and zinc; the earlier types had the carbon contained in a porous cup and surrounded by broken carbon and the depolarizer, but the later and more improved forms have the depolarizer compound mixed with the carbon, and the whole formed into a cylinder, while the zinc element is in the form of a pencil or rod about three-eighths of an inch in diameter and passes through a porcelain sleeve in the center of the carbon so that it is insulated from it. This form of zinc exposes very little surface to the solution, and the internal resistance of the cell is high. Some makers have endeavored to overcome this by making a large sheet zinc, which either encloses the carbon, or is enclosed by it. This increases the amperes that can be drawn from the cell, but unfortunately, as there is no porous cup to help resist it, local action soon takes place and the cell soon runs down, even if it is not worked, while the small pencil zincs will stand for years; but their ampere output is low, from 3 to 6 at a voltage of 1.6 so that as a rule they are not as good as the dry cell for ignition purposes, unless connected in series parallel, when they will give good service.

The Copper Oxide Battery is another type that is frequently used. This battery has elements composed of copper oxide compressed into a flat firm plate, and a zinc plate, both of which are suspended in a solution of caustic potash; the voltage is very low, a little less than 1 volt per cell, but the amperage is very high. In fact, the batteries are sold on an ampere rating very similar to that of storage batteries. The ampere hours capacity of the cell determining its price (an ampere hour, is one ampere flowing for one hour, or its equivalent). These cells are usually arranged so that all parts fail at nearly the same time, that is, the solution is exhausted at the same time that the elements are used up, so at the end of each run all that is left is the jar and element holders. It should be borne in mind when installing cells of this character, that on account of their low voltage it is necessary to install one cell for each volt wanted.

The Storage Battery is perhaps the best battery for spark producing purposes, as its voltage is high, starting at 2 volts, and working strongly till towards the last, when it drops to 1.8 and should be recharged while its amperage is very high; in fact, drawing current from a storage cell has been likened to taking water from a pail, one can get any quantity that it contains, from a drop at a time to the whole amount by tipping the pail over. In the same way current can be taken from a storage cell by regulating the resistance so that any amount can be drawn off from .001 of an ampere, to several hundred amperes.

A Storage Cell consists of several grids or skeleton frames of lead which are filled part of them with red lead for the positive plates, and the rest with litharge for the negative plates; under the action of the electric current, these turn into plain lead for the negative, and peroxide of lead for the positive. These are immersed in a mixture of sulphuric acid and water, about 6 parts of water to 1 of acid, and then subjected to the action of an electric current, and while they do not (as their name might indicate) "store electricity" a chemical action takes place which renders them capable of giving off a large proportion of the current which they receive.

A Dry Battery is not, as its name might indicate, dry; it is, rather a moist battery, for as soon as it becomes "dry" its usefulness is ended. This is one reason why it is necessary to be certain that the batteries are new and fresh when buying them.

As commonly made, a dry battery consists of a round zinc case, which forms one of the elements, and which contains a piece of carbon in the center that forms the other element. This carbon element is made in various shapes according to the manufacturer's ideas, as each maker is striving to get as large a surface as possible in order to reduce the internal resistance of the cell and get a large output in amperes. The carbon is usually surrounded by some powdered carbon containing what is called the "depolarizer" (though this depolarizer may be incorporated in the exciting paste). This depolarizer has a great influence on the life of the cell for the reason that, under the action of the exciting fluid when the cell is working, bubbles of hydrogen form on the carbon and to quite an extent insulate it, thus preventing the action of the excitant on it, so much so that it seriously weakens the action or output of the cell. The depolarizer to a great extent counteracts this by absorbing the bubbles and thus sustains the cell, keeping the output more nearly uniform. When a cell is "run down," a rest allows this depolarizer to continue its action, and after a time the cell will be found in much better condition, though as both the exciting fluid and the depolarizer are weakened, it will never be as good as before.

The exciting fluid is a solution of sal ammoniac with other ingredients added. The precise formulas are kept secret by the manufacturers, but plaster of paris, mixed with oxide of zinc and other chemicals, which keep the plaster in an open and porous condition so that the exciting fluid and gases can easily pass through it, are used. This mixture is firmly packed in the space between the carbon and the zinc after a piece of blotting paper has been rolled up and placed next to the zinc to act as a porous cup to prevent actual contact between the mixture and the zinc.

The usual test for a dry cell is with an ampere meter, and they are rated as to what they will show; for instance one showing less than ten amperes is considered as poor, while one showing twenty-five amperes is considered excellent. This style of testing and rating, while it is the only convenient and quick way known at the present time, is not very reliable owing to the uncertainty as to the exact condition of the cell. According to ohms law, current in amperes equals electromotive force in volts divided by resistance in ohms; expressed by the formula $C = \frac{E}{R}$. Now the internal resistance of the cell may be high, and the result is that when drawn upon for current this resistance will restrict the volume of flow to a low reading on the ammeter, or if the internal resistance of the cell is low a larger volume of current will flow, and the reading of the ammeter will be higher, while the voltage remains the same.

Of course the low reading may just as well come from the cell not being in good condition and having very little in it. While on the other hand the low internal resistance and high reading cell is exposed to the dangers of local action, that is, the current works inside of the cell itself, wearing it out while standing in much the same way that a leak might start in a pail of water if the sides and bottom were extremely thin.

Another element of uncertainty lies in the internal resistance of the ampere meters used for testing. If the resistances of its working coils are low, it will show high reading, if they are high the readings will be low, for the reason that the small voltage of the cell cannot push the heavy current through against the high resistance of the meter; some meters are supplied with a conducting cord to reach across where it is difficult to get at the cells. A decided difference in the reading will be noticed when using this cord for the same reason spoken of above, as the resistance of the cord, while it is small, cuts down the current very appreciably. While the high resistance meters are not favorites with the battery dealers, for the reason that they do not show amperage enough, they are the best for practical use as they do not draw so heavily on the battery, and as soon as one gets accustomed to how low cells can be worked, according to their particular meter reading, it matters very little what that reading is, provided that it does not change.

One trouble with the common cheap meters is, that they depend for their accuracy upon the difference in pull between a permanent magnet and an electro magnet which is energized by the cell to be tested. As long as the strength of the permanent magnet remains the same, the reading remains the same, but as the permanent magnets are usually made from cast iron, the magnetism does not remain the same, but it is continually getting weaker. As the electro magnet remains practically the same, this allows it to pull the needle further and further as the permanent magnet weakens more and more so that the readings are continually getting higher and higher; for this reason it is well to have the meter tested occasionally in series with some large standard make.

From the foregoing it can be easily seen that all connections should be kept clean and tight, for dirt adds greatly to the resistance that the battery has to overcome. A dirty connection is a hard trouble to find at times when the wiring runs through obscure places as it usually does around ordinary gas engines. A loose connection will also cause lots of trouble and be difficult to find for the reason that it will work at times, and not at other times, giving one the impression that the trouble may be in the carbureter, or plug.

Magnet Ignition.—There are three types of magneto ignition. The most recent type is the inductor type of magneto, which has no moving wires, commutators or brushes and which generates a sine wave of alternating current.

The second type is a dynamo type of magneto, which has a commutator and brushes, and a little drum wound armature, and which has a permanent magnetic field. This type of magneto is merely a dynamo with permanent magnets instead of electric magnets for its field.

The third type is an alternating current magneto which is equipped with its own circuit breaker and distributor, commonly called a high tension magneto. This type of magneto is also often made with a circuit breaker and distributor, and a primary winding on it, which operates on a coil, external to the magneto. It is a low tension magneto, but is also frequently called a high tension magneto, on account of its producing a jump spark.

Spark Coils.—Soft platinum points should not be used but an alloy of such percentage of iridium and platinum as will permit a very hard and dense point, and one which will not weld itself together as soon as it warms up. It must be borne in mind that pure platinum is a very soft and spongy metal, and will weld together at temperatures extremely low for welding heat.

Irido platinum contact points require a very much higher temperature before they will weld or seize together.

In the construction of spark coils the very best of insulating material should be employed, and after the windings are made, they should be pumped out in a hot vacuum, thus exhausting all of the air and moisture and they should then be impregnated while under vacuum with a dielectric of heat and moisture resisting qualities, which would seal up the windings, making them impervious to moisture, and preventing all electrical discharges and leakage between its turns and layers.

This method of treating spark coils is quite recent, and is by no means as yet universal among the various spark coil builders. If spark coils were all built properly, with the proper kind of windings, and the proper kind of vibrators used, and the coils used in connections with the proper kind of timers, that is, timers which do not have an unnecessarily long period of contact, it would be found that the battery consumption could be reduced very materially.

Proper timing of ignition devices has a direct result upon the economical working of the engine. If the mechanism is set too early on the compression stroke, combustion of the charge occurs at, or before the inner dead center of the engine, resulting in violent shocks, excessive strain upon the piston, connecting rod, and bearings and involving great waste of power. If too late, the piston has commenced to accelerate under the influence of momentum stored up in the flywheel, so that the explosive force follows the piston without attaining its maximum thrusting effort, and with some loss of compression pressure, due to the re-expansion of the charge before ignition is effected.

The speed of flame propagation varies with the percentage of hydrogen contained in combustible mixtures, and it is convenient for means to be provided to adjust the instant of ignition to suit varying qualities of gas. For this reason many makers fit a device permitting an attendant to set the "break" at the most suitable instant, and there is no doubt that with such facilities a careful man can thus obtain good results even with very variable mixtures such as often occur with poor gases generated by producers. Some leading manufacturers, however, realize that, by carelessness or neglect, the provision of such means of adjustment is liable to misuse, and they prefer to arrange two firing points only—one very late for starting up at slow speeds, and another for normal speeds, the variations in inflammability of charges being deemed of less importance than the variations of the average skill and intelligence of attendants.

*The Explosive Mixture.**—"Theoretically, ignition must be effected early enough and be so efficient that the whole of the power charge is ignited when the piston reaches the inner dead center position. Thus the condition of maximum heat development will occur with the minimum cooling surface, and in a space which is specially designed to withstand high temperatures and pressures. Purity, calorific value, temperature and compression of the mixture, as well as the position and efficiency of the sparking apparatus, the form of combustion chamber and other conditions, will cause inflammation to spread faster, or slower, which phenomenon becomes quite clearly visible on the indicator card, provided the latter be taken on a drum with continuous travel.

In several types of large modern gas engines the point of mixing the gas and air is rather superficially treated,

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*Franz Ehrich Junge.

while Reichenbach, who certainly deserves consideration as an authority on the subject, puts very much emphasis on this feature in all his designs from the earliest down to the very latest. It is interesting to examine what has actually been done to clarify this question, and which view the serious student of the gas problem is justified in holding.

Gas and air properly mixed in chemical proportions, so that just sufficient oxygen is present in the combination to ensure perfect combustion, will give the highest temperature of explosion which it is possible to obtain. Above and below this ideal condition there is a wide range of inflammability wherein more or less oxygen in the form of air may be mixed with the gas, than is necessary for its chemical combustion, so that a mixture of such composition will yet ignite but will burn at a slower rate of flame propagation and, consequently, will not develop the maximum temperature corresponding to its calorific value. If with a certain gas there be mixed about 4.7 times the amount of air that is necessary to establish the condition of chemical balance, the mixture will be that which is theoretically best suited for adoption in gas-engine practice. Theory and practice often differ, and so it is found advantageous to employ in actual practice far more air in the internal combustion process than is theoretically required. The reasons are threefold: To reduce temperatures all round, to prevent premature explosions which might be provoked by the high heat of compression, and to supply to the gas, even when poorly mixed with the air, always sufficient oxygen for combustion, and consequently to reduce the loss of unburnt gases leaving the exhaust to a minimum.

If one examines by thermodynamic calculation the combustion efficiency of lean mixtures under whatever cyclic conditions they may be transformed into work, it will be found that maximum economy is attained by compressing the weakest mixture to the highest possible degree, but here again one is confronted by an upper limit which is rigidly drawn by the lack of inflammability of such mixtures. Desire for thermal excellence of the working process forces us to approach this upper limit as much as possible, but the decreasing calorific value of the power charge per unit of contents, and the decreasing capacity of the engine keeps the actual practice far below this extreme ideal. In average practice it is customary, at normal loads and with lean gases, to work with a surplus of air of from 30 to 40 per cent over what is theoretically required; with gases of high heat value, even more air is provided, so that the dynamic medium in the engine cylinder possesses a calorific value of from 44 to 62 B. t. u. per cubic foot."

Explosion and Expansion. The mean pressure upon the area of the piston throughout the stroke is, of course, of great importance and directly affects the power given out from the engine. High initial explosion pressures *per se* do not create the most powerful efforts behind the piston, neither are low terminal expansion pressures indicative of maximum economy.

Exhaust. Before the expansion, or power stroke is fully completed the exhaust valve commences to open—usually when the piston has still to travel one-tenth of its stroke.

On small high speed engines the exhaust valve should open 15 to 40° before center on the power stroke depending on the size and the speed of the engine. The last part of the power stroke is not noticeably effective in delivering power to the crank shaft and the exhaust valve is opened early to get rid of the heat after it has done its work. In an engine with 6-inch stroke the piston travels only $\frac{11}{16}$ inch in the last 40° of the power stroke as shown in Figs. 303 and 304. The exhaust valve should never close before dead center on the scavenging stroke.

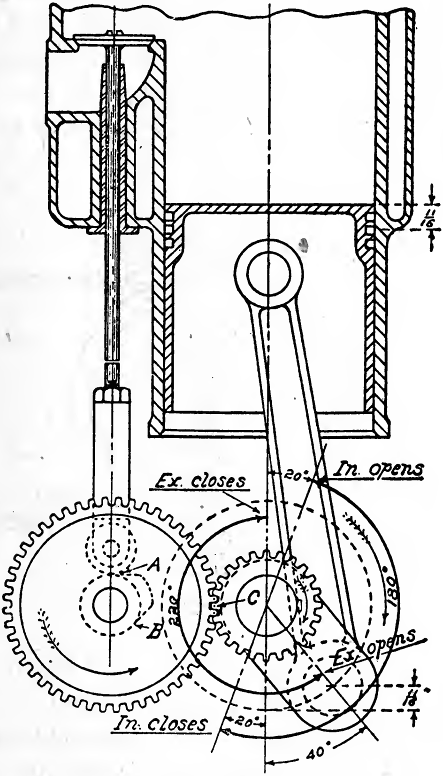


FIG. 303

For slow moving engines with large, easy valve ports and passages, the exhaust opening may be fixed at 15 to 20° before center instead of 40°, and the inlet opening and closing points may be fixed at center to 10° after center.

For very high speed engines the inlet closing should be delayed to 30 or 40° past center instead of 20° as shown. A point to keep in mind is that it is impossible to change the time a valve opens without changing the closing time correspondingly earlier or later, unless a new cam of different design is used. This is indicated by A and B, Fig. 303. If, for example, it is desired to open the valve later without changing the closing point at B, the cam must be made so the beginning of the lift at point A will be carried around further toward B.

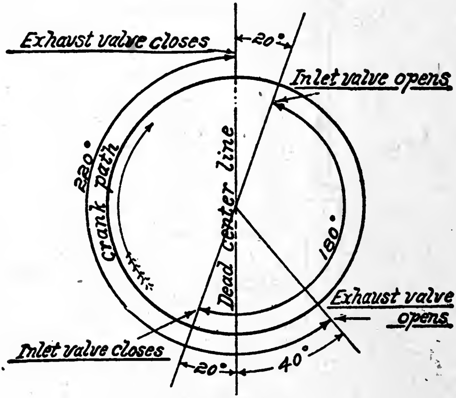


Fig. 304

If an engine is known to be properly timed and is to be taken apart it will save much trouble later, to see that the gears are marked as shown at C, Fig. 303, before taking the machine to pieces. The gears can then be readily reassembled and the timing will be just as before. The terminal expansion pressures are about 25 to 30 lbs. above atmosphere, and the velocity with which the burnt product leaves the cylinder due to such pressure imparts considerable momentum to the column of escaping gases, thus helping to effect their thorough evacuation. With long exhaust pipes not unduly restricted, the energy of the moving column of gases is taken advantage of.

Valve Timing.—Timing the valves of a gas engine means practially the same thing as "setting" the valves of a steam engine. It means to so set the gears, cams, and contributory adjustments that admission and exhaust valves will be opened and closed at a point a certain number of degrees from dead center in the travel of the crank, and with relation to the piston stroke. The first thing, therefore, is to know positively just when the crank is on the dead centers. The piston is, of course, at the extreme ends of its sroke when the crank is at dead center. Owing, however, to the fact that the crank moves a number of degrees on each side of the center without perceptible movment of the piston, it is impossible to tell accurately when dead center is reached by watching the position of the piston. Guess work will not do.

The following instructions apply more particularly to the smaller sized, high speed engines. Large sized engines will be taken up later on.

Fig. 305 illustrates a simple, accurate method of finding the dead centers. First provide a stationary pointer on the engine as at C. It will be better if this pointer can be arranged close to the face of the flywheel. As the flywheel is keyed securely to the crank shaft its movement corresponds to the movement of the crank. Now turn the crank to one side of center as shown by the full lines in the drawing; insert a rod, A, through a hole in the head letting it rest firmly against the piston; make a mark on the face of the flywheel at D as indicated by the stationary pointer, C; also make a mark, B, on the rod, A. Now turn the crank to the other side of center as shown by the dotted lines; when the mark, B, on rod A, is at the same position as before with relation to its guide, and to the piston the crank will be at exactly the same distance from center as before; now make the mark, E, on the face of the flywheel

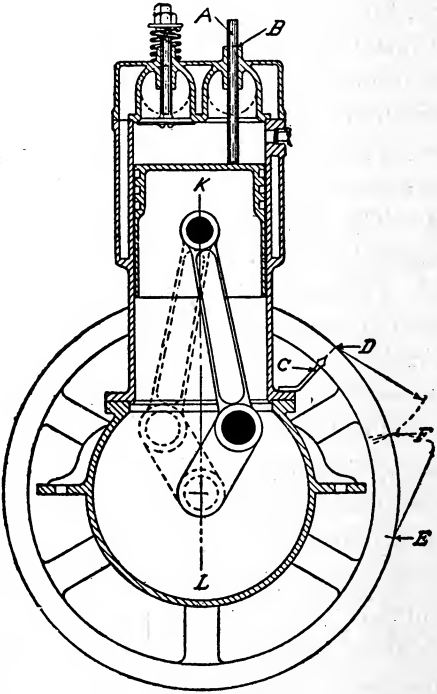


FIG. 305

as indicated by the pointer C. As marks D and E are at equal distances on each side of center, it follows that in bisecting the distance from D to E, as shown, and bringing the central mark, F, to the fixed pointer, C, we will bring the crank to the exact dead center for that end of the stroke. The opposite center is found in the same way. After the dead center marks are made on the flywheel the stationary pointer, which is left permanently in position, will show at any time when the crank is on dead center.

Fig. 305, shows valves in the head one of which has been removed to insert the rod, A, for finding the exact dead centers. The valve stem guide makes a good guide for the rod, A, of similar size. Where the valves are not in the head, any other opening, as for spark plug or igniter may be utilized by making a special block to fit the opening and drilling in it a guide hole for the rod A.

By measuring the distance in inches before or after the dead center mark on the flywheel to the point at which the valves open and close, the number of degrees can be quickly determined. For example, suppose we find the exhaust valve opening 10 inches (as measured in the face of the flywheel) before the crank reaches center on the power stroke of the piston. If the flywheel is 25 inches in diameter we have $25'' \times 3.1416 = 78.54$ circumference of the wheel; (360° always represents the circumference of a wheel of any size) then we have $360° \div 78.54 = 4.58°$ for every inch on the face of the 25 inch flywheel. If as stated the exhaust valve is opening 10 inches before center we have $4.58° \times 10 = 45.8°$ before dead center at the end of the power stroke. The closing point of the exhaust valve and the movement of the inlet valve (if it is operated with a cam and gear) can be checked up in the same way.

Owing to the fact referred to that the crank moves a number of degrees at the ends of its stroke without perceptible movement of the piston, there is a range of 15 or 20° in valve setting within which it is difficult to detect material difference under equal conditions of port passages and engine speed. In fact it is the valve lift, size and length of inlet and exhaust passages, and the engine speed, or corresponding speed of the gas flow that decide the best valve setting for any particular engine. If the engine runs slowly, and the inlet valve and passage are of ample size, the intake valve may open and close at dead center with excellent results. If the incoming charge comes into the cylinder at high speed, as is usually the case with high speed engines, a late closing of the inlet valve is necessary, because of the greater vacuum following the piston, and the inertia or moving force of the incoming charge. A late opening of the intake valve (from 10 to 20° past center) is recommended to secure better action of the carbureter.

Relative Efficiency of Power Gases. Apart from the calorific values of one cubic foot of the various powergases when burnt in sufficient air to support complete combustion, it is necessary to differentiate them in terms of calorific value per cubic foot of gas and air mixture when only just sufficient air is present. For gas engines, however, it is necessary to dilute the gas still further in order to control ignition as, varying with the percentage of hydrogen present, theoretical mixtures are impossible, owing to risks of pre-ignition and violent shocks caused by the rapidity of the propagation of flame. Experience has determined that while hydrogen is of the greatest value in obtaining good results, yet it is important that its volume should be only about 7 per cent in gas engine mixtures.

Gas Engine Indicator.—The principles governing the action of the gas engine indicator are precisely similar to those of the steam engine indicator which has already been described in the section on steam engines. The only difference between the two instruments lies in the details of construction, the gas engine indicator being more strongly made in order to withstand the sudden shock, and higher pressure of that engine, as compared with the steam engine. Firms manufacturing indicators make a combined steam and gas engine indicator, the piston used for indicating gas engines being one half the area of the piston used for steam engines, and as the same springs may be used with either piston, the scale is doubled when the smaller piston is used. Fig. 306 shows a Crosby combined gas, and steam engine indicator with the small piston in place for gas engine work. The pencil arm is of extra strength to withstand the shock due to the explosive pressure exerted upon the piston. The drum is of small diameter and extremely light to reduce the effect of inertia to a minimum.

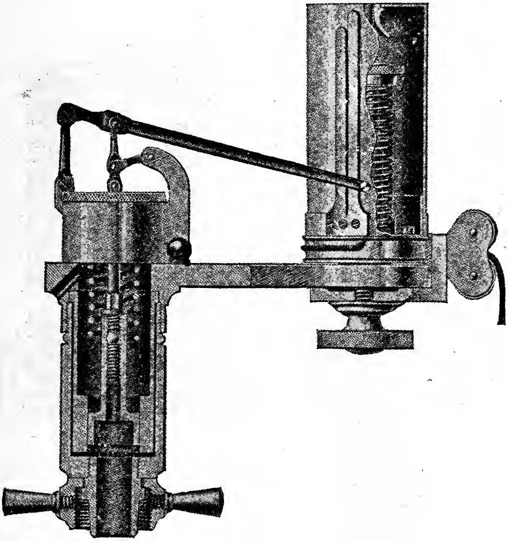


Fig. 306

The tension of the drum spring may be readily changed in accordance with the speed of the engine upon which the indicator is to be used. The initial vertical position of the pencil point with respect to the drum may be raised or

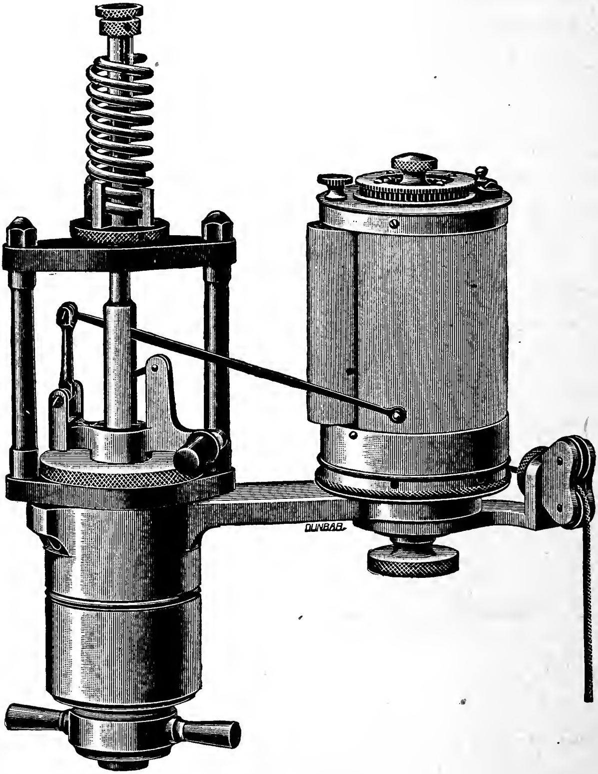


Fig. 306A

lowered on the paper according to the size of the diagram to be taken.

Fig. 306^A shows the new Crosby indicator designed for taking continuous diagrams. The drum is designed to use a roll of paper 2 inches wide and 12 feet long, upon which is made in the operation of the indicator a series of diagrams. In the center of and concentric with the drum is a cylinder upon which the paper is wound as it is used. When the roll is exhausted, the cylinder can be withdrawn through an opening in the top of the drum and the paper easily detached. Above the cylinder is a knurled head loosely attached to the drum spindle which can be adjusted to take continuous diagrams, varying in number from 6 to 100 per feet of paper.

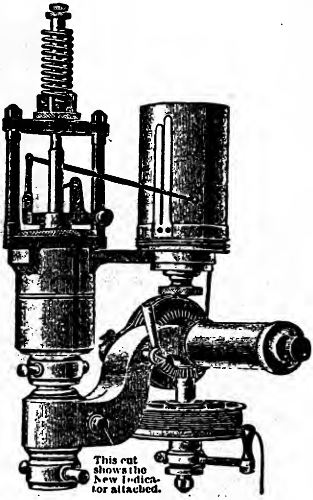


Fig. 306B

Fig. 306B shows the Crosby reducing wheel with *Detent*—This detent when applied to the reducing wheel does not affect the connection between it and the engine; and does not allow the cord leading from the indicator drum to the

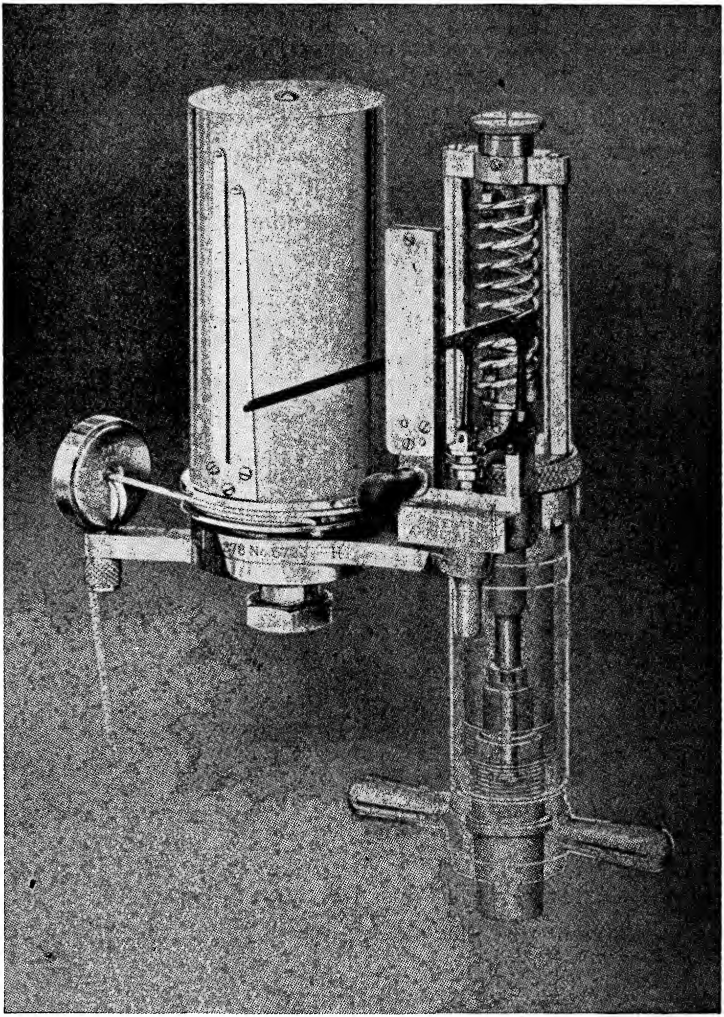


FIG. 307

TABOR INDICATOR WITH OUTSIDE SPRING

Combined Steam and Gas Engine Type

reducing wheel to slacken. When the clutch is thrown in, the indicator drum is revolved to the end of the stroke and held there by the drumcord, while the mechanism of the detent controls the cord leading from the reducing wheel to the cross-head of the engine.

When the clutch is released, and the motion of the engine is again communicated to the drum, the latter takes up the motion without shock from the point where it stopped, because it starts from a state of rest at the end of the stroke. This is important, for if a drum is stopped and held by a detent in mid-stroke, where the piston is running at its highest speed, at the release of the detent, the drum will necessarily start again at such highest speed with a shock. Moreover, as such a detent must engage at the highest speed, it often fails to operate and always wears rapidly.

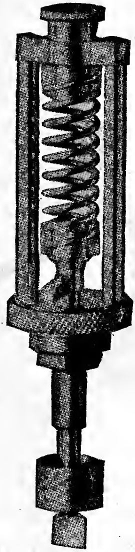


FIG. 308

Fig. 307 is the Tabor combined steam and gas engine indicator, and is supplied with two sizes of pistons as in the case of the indicator just mentioned. The spring is placed outside of the indicator cylinder in order that the hot gases from the engine will not affect the temper of the spring, and thereby change the scale.

Fig 308 shows the piston, piston rod, cap and spring, removed from the indicator for cleaning.

Fig 309 shows the parallel motion, or straight line motion of the Tabor indicator. The curved cam slot provides for a perfectly true vertical motion of the pencil, and further provides rigidity and tends to reduce vibration.

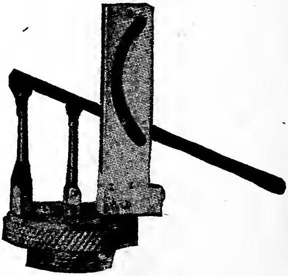


Fig. 309

This indicator is made with the regular ½-inch area piston and cylinder for steam, and is furnished with a secondary and longer piston of ¼-inch area which operates in the upper portion of the cock tube, to give the necessary increase in range to the spring, for extremely high pressures. This style indicator can be made with either size standard drum.

All indicators of this type, employing a pressure piston and spring, require careful calibration where extreme accuracy is essential. On account of the inertia of the piston and pencil mechanism, and that of the oscillating drum, engines of very high speed cannot be indicated by the forms of indicator just described. They have been found to be reasonably accurate at speeds as high as 500 revolutions per minute, although at this speed they can be used successfully only by experienced hands.

Indicators for High Speed.—To overcome this objection and to be able to indicate engines of speeds as high as 2,000 revolutions per minute or more, indicators employing a beam of light thrown upon a sensitive photographic plate are now used. In this case a small mirror is caused to move in two planes at right angles to each other, one movement being produced by the motion of the piston, the other by the pressure, which is transmitted through a thin steel diaphragm. The angular motion of the mirror is so small and the parts so light that the effect of inertia becomes practically negligible.

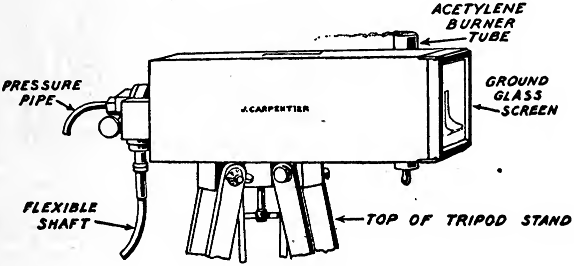


FIG. 310

Fig. 310 shows the general appearance, and Fig. 311 two sections of one type of the indicator referred to. This instrument is called the Hospitalier-Carpenter Manograph and is manufactured in Paris.

Some makers manufacture special heavy indicators with ¼-inch pistons to suit the pressures involved in gas engine indication. Springs from 80 pounds to 200 pounds scale are very efficient in recording expansion, combustion and compression lines, as these effects are all high pressure. If the low pressure lines, such as the suction and exhaust, do not show up to advantage when taken with high scale springs, low scale springs of from 10 lbs. to 30 lbs., may be used for obtaining those lines.

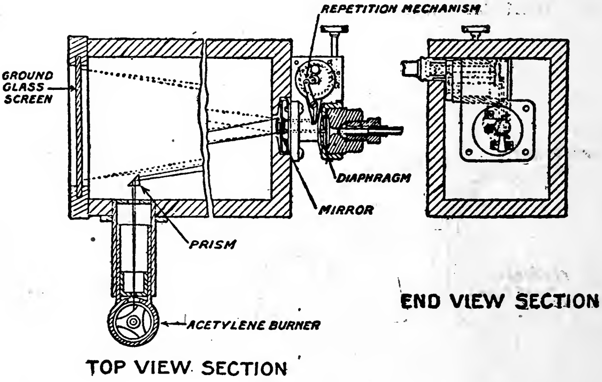


FIG. 311

HIGH SPEED ENGINE INDICATOR

Diagrams from Gas Engines.—The process of obtaining indicator diagrams from gas engines being similar to steam engine practice, it is not necessary to repeat a description of it. Attention will therefore be devoted to several reproductions of typical diagrams from gas engine. Fig. 312 shows a characteristic diagram from a four cycle engine. On the forward stroke of the engine the piston draws into the cylinder a charge of explosive mixture, the pencil of the indicator tracing the line A-B. It will be seen that this line drops slightly below the atmospheric line A-F. This slight drop is due to the partial vacuum produced within the cylinder during the "suction stroke" of the engine. From point B, the piston returns to its original position compressing the mixture in the clearance space, the indicator tracing the line B-C, which is known as the compression curve. At this point ignition takes place with a sudden increase in pressure, the indicator tracing the line C-D, which is nearly vertical. On the next or third stroke, the gases are expanded to point E, at which time the exhaust valve opens, the indicator having traced the line D-E, which is known as the expansion curve. At E there is a drop in pressure as the gases issue from the exhaust port and from F to A the gases are swept from the cylinder which causes a line to be drawn by the indicator slightly above the atmospheric line A-F, as shown. This completes the cycle. The vertical distance from the atmospheric line to point C is proportioned to the compression pressure above atmosphere; the distance to point D is proportional to the explosion or maximum pressure, and the distance to point E is proportional to the release pressure.

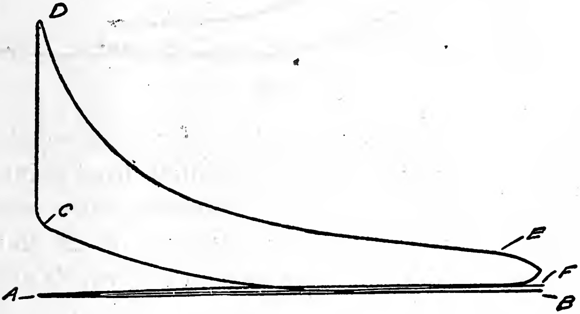


Fig. 312

Figure 313 shows a card from a two-port two-cycle gas engine. It will be noticed that the suction and exhaust lines are absent, the suction stroke being completed in an enclosed crank case, or a separate cylinder or pump. The exhaust takes place at A and requires about one-tenth of the stroke. The exhaust and inlet ports are covered, and uncovered by the piston and are definitely fixed points.

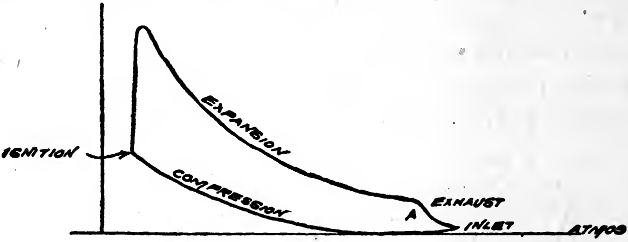


FIG. 313

Figure 314 shows a very good diagram, where combustion is very nearly complete, the mixture of air and gas being practically correct. The ignition line points slightly to the right at the top, and is nearly perpendicular. The exhaust is shown to open at the right time about ninety degrees of the stroke. The suction and exhaust lines run very near the atmospheric line, thereby denoting correctly proportioned inlet, and exhaust valves and passages for same.

FIG. 314

Figure 315 shows a condition existing when the suction to the cylinder is in some way choked, the suction line of the card or diagram being away below the atmospheric line. This condition may be caused by the valve being too small, improper setting of the valve, too small an area of the suction pipe, which may be caused in some cases by too many bends or short elbows.

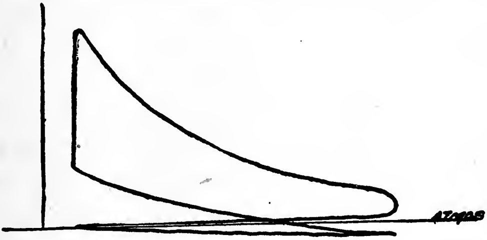


Fig. 315

In figure 316, the exhaust line is shown at too great a height above the atmospheric line, thus showing that the discharge of exhaust gases is choked. In theory, there should be no back pressure, during the exhaust stroke, but in actual practice a pressure is recorded, varying in different makes of engines.

Fig. 316

Back pressure as shown in the diagram figure 316 may result from the following conditions: The exhaust valve being too small in area, setting of valve incorrect, too long an exhaust pipe, too many bends or too small a diameter of same.

If the compression curve B C, Fig. 312, shows a lack of sufficient compression pressure and all other conditions are perfect, this is probably due to leaky piston rings, valves, or joints.

Figure 317 shows a low spring card and gives the different lines. The suction line is shown starting at C, the point where the exhaust line strikes the atmospheric line, and extending to the point A where the compression line commences.

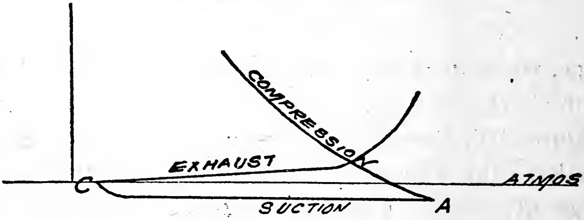


FIG. 317

The mean effective pressure of gas engine diagrams is found by precisely the same method as that pursued with diagrams from steam engines.

Indicated Horse Power.—This is a computation based upon the mean effective pressure developed at each explosion and is usually calculated from the same formula used in connection with steam engines: I. H. P.= $\frac{P\,L\,A\,N}{33{,}000}$ where P=mean effective pressure; L=length of stroke (ft.); A=area of cylinder; N=number of explosions per minute. This formula does not discriminate between mechanical friction and losses in "fluid" friction.

To get acurate results it is necessary to obtain the mean effective pressure after measuring the indicator diagrams recorded during both "power" and "cut-out" cycles as also "compression" and "suction" cards.

It requires a considerable knowledge of gas engine practice to make use of the above formula. What is needed is one that is more arbitrary and fits the majority of cases and, moreover, requires the use of only a few facts, such as the diameter of cylinder, length of stroke and revolutions per minute. Such a formula will be of great value in estimating the probable power a gas engine should develop if well designed and properly built.

Such a formula is given as follows:

$$\text{I. H. P.} = \frac{V \times \text{r. p m.}}{10{,}000}$$

which means that the indicated horse power is equal to the volume of the cylinder in cubic inches multiplied by the number of revolutions per minute and divided by 10,000. The constant used varies from 9,000 to 14,000, depending upon certain types of engines; 10,000 is an average figure to use for four cycle engines. The brake horse power will be from 65 to 85 per cent of the result obtained; 80 per cent may be taken as an average:
For example, a 6½"x9" engine at 300 r. p. m. gave by test 7.2 horse power.

The area of the piston is 33.2 square inches and the volume of the cylinder is 298.8 cubic inches; multiplying by 300 and dividing by 10,000 gives 9.0 indicated horse power, or for a mechanical efficiency of 80 per cent 7.2 brake horse power.

Economy of Gas Engines.—As fuel is ordinarily used, at present, for light, heat and power, the losses are so great that, of the total calorific value of the coal, less than 5 per cent on an average is converted into useful work, while the largest and best power stations utilize only about 10 per cent.

With gas-engine-driven units, however, fuel economy is the distinguishing characteristic, resulting in a delivery at the engine shaft of not less than 16 to 20 per cent of the energy contained in the fuel.

Notably is this true of lignite coal, immense quantities of which are to be found in various parts of the country. The calorific value of such coal averages only about 8,000 B. T. U. per pound as fired; but, when utilized in a gas producer and gas engine, it is possible to develop a brake horse power on less than 2 pounds of lignite.

Owing to the difficulty of securing, with this fuel, proper combustion under a steam boiler, the gas producer offers practically the only means of using it on a commercial basis.

The same is true of slack coal, bone coal, etc.

A recent bulletin of the United States Geological survey calls attenion to the possibilities of the producer gas plant, as above indicated, and states that lignite beds underlying from 20,000,000 to 30,000,000 acres of public land, heretofore supposed to be practically useless, are now shown to have a large value for power development. This is of particular importance to the West, making possible a great industrial development there.

Producers now made will also successfully gasify nearly all grades of bituminous coal, as well as anthracite, or coke.

Additional Advantages of Gas Engines.—The standby losses during a period of idleness are practically negligible, and are included in the fuel estimate per brake horse power as given above, leakage losses are reduced and the smoke nuisance is abolished.

In localities where the water supply is scarce, or of poor quality, a gas power plant offers additional advantages, and, by the use of cooling towers, the water consumption can be reduced to a very small quantity.

PRODUCER GAS.

Producer gas, whether from anthracite or bituminous coal, lignite, wood, charcoal, or coke, is remarkably uniform in quality, and a very desirable gas if properly cleansed from dust, tar and sulphur. As practically all the combustible matter of coke and charcoal is fixed carbon, these fuels are most readily gasified, and on this account are favorite fuels for small gas plants of the suction producer type. Anthracite coal contains a small quantity of volatile matter, but is also a very desirable fuel, the gas requiring but little cleaning. Bituminous coal, lignite and wood, although giving a desirable power gas, at the same time yield considerable amounts of hydro-carbon vapors condensible in the form of tar and pitch, the removal of which from the gas is attended with some difficulty.

Complete producer gas plant equipments may be had of several types, suited either to bituminous or non-bituminous fuels, and with, or without apparatus for the reclamation of by-products, such as ammonia, tar and other hydrocarbons. The majority of these systems are simple in construction and operation, and yield a net efficiency considerably in excess of the steam boiler plant.

In localities where natural gas is not available, the producer gas plant affords a comparatively simple, and inexpensive means of generating a suitable fuel gas. It is less complicated in its workings than the average steam plant, and its efficiency is higher, as will be seen by reference to

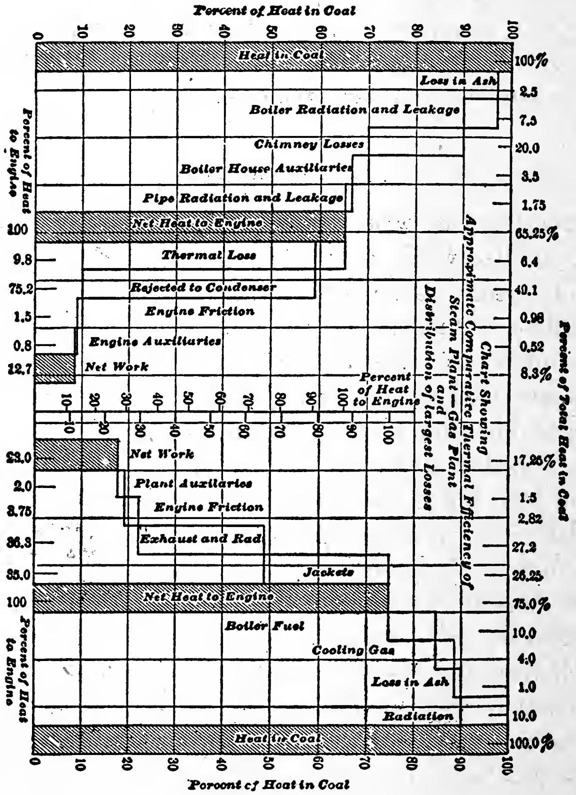


Fig. 318

COMPARATIVE EFFICIENCY OF GAS AND STEAM PLANT

Fig. 318, which compares the net work obtainable from coal in modern well-equipped steam and gas plants of moderate size. The producer transmits 75 per cent of the fuel energy, the boiler 70 per cent; the gas engine delivers at the shaft 25 per cent of the energy supplied, the steam engine 13 per cent; as a whole the gas plant realizes over 17 per cent of the fuel energy, the steam plant about 8 per cent. On this basis the gas plant could afford to use fuel costing twice as much as steam fuel; as a matter of fact it can utilize fuel much cheaper and of such low grade as to be quite unsuited for efficient boiler working.

The gas producer takes the coal, ignites it, and by supplying a limited amount of air, and a proportionate amount of water keeps the fire at a dull red glow, just the right temperature to produce a good uniform quality of gas and prevent formation of clinkers. As the load on the engine is varied a greater or lesser quantity of gas is required but it is important that the quality or heat power remain the same.

At present three distinct types of gas producer are offered to the power user. They are the suction producer, the steam-pressure producer, and the induced down-draft producer.

The Suction Producer.—In this type the fuel is fed into the generator from a hopper at the top. Ashes and clinkers are removed from the bottom, and air is usually admitted below the grate, first passing through economizers, where it is heated and passed over a body of hot water to absorb the necessary moisture. In some makes of producer the air is admitted direct from the engine room, and a small, regulated amount of water is fed into a space prepared around the grate, where it is evaporated and is carried as steam along with the air up into the fuel bed.

In this type of producer, coke or anthracite coal can only be used and not even these fuels in the very small sizes. It is not easy to note the condition of the fire, as the generator cannot be opened at the top without admitting air and causing a poor mixture of gas; the only thing to do in this emergency is to feed in more coal to stop the chimney holes in the fire-bed, or quickly insert a poker bar and thoroughly tamp the fuel. The latter is the better way, even though it has to be done blindly.

In operating this type of producer, trials and tribulations may be many and varied, depending largely upon how the producer is made and the basis of its horse power rating. A suction gas producer rated at more than 12½ pounds of coal per square foot of grate area, or area of fuel-bed cross-section, is very apt to be too small, and a producer so small for the power it has to develop that it must be driven to furnish sufficient gas will immediately develop clinker troubles, variable gas troubles or excess CO_2. If an attempt is made to correct clinker troubles with an oversupply of steam, an excess of hydrogen will result, with its attendant engine difficulties of back-firing, or premature explosions.

Even with a producer of the proper size, the regulation of the volume of steam or water to the volume of air must be closely watched. Too frequent raking of the fire will waste good fuel, and induce draft holes through the fuel bed. Too much poking from the top will pack the fire, and necessitate an increased vacuum. Too fine a fuel will produce the same troubles, and any coal that fuses easily will not do for this type of producer. Anthracite running high in slate mixture tends to run high in sulphur, and high sulphur with slate makes bad clinkers at any time, and if the fire is forced at all will soon necessitate a shut-down to clean out. The producer should be of ample size

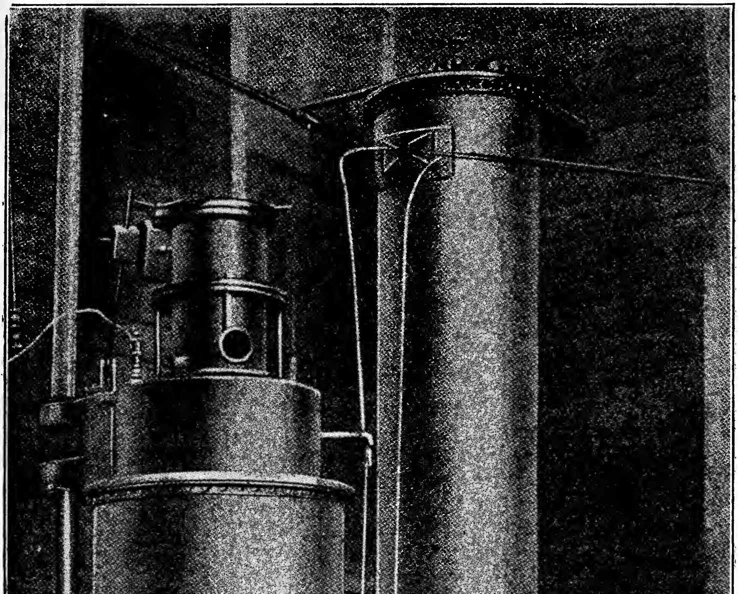


FIG. 319
MONAHAN SUCTION PRODUCER

—10 pounds of coal per square foot of internal area—and rated on $1\frac{1}{4}$ pounds of coal per horse power hour.

It is not good practice to use a suction gas-producer plant of over 150 horse power when the engine has to draw the gas from the producer by the vacuum in the cylinder. Sizes larger than this should be equipped with exhaust fans which will relieve the engine of this work, the exhausters being driven by motors, or other auxiliary power.

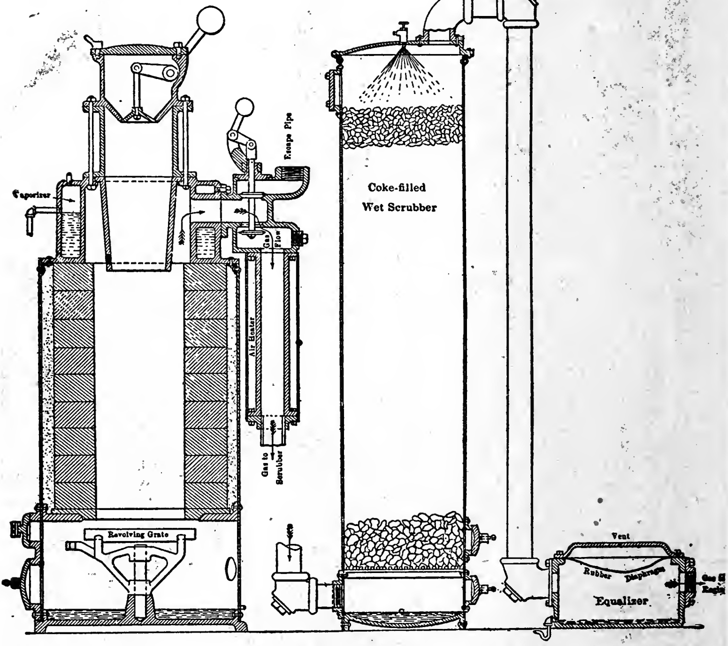


Fig. 320

SECTIONAL VIEW OF MONAHAN PRODUCER

The Monahan Suction Producer.—This producer, a full view of which is shown in Fig. 319, is of the suction type, and consists of the usual generator, scrubber, and equalizing tank. The vaporizer for supplying steam to the fuel bed is an upper extension of the generator, but is located so that the hot gases from the fuel bed do not impinge squarely on the bottom of the vaporizer. This is clearly shown in the sectional view, Fig. 320, in which the revolving grate, and air heater are also shown. The scrubber is of the wet, coke-filled type, and the equalizing tank is a simple drum within an equalizing chamber formed in its cover, and separated from the drum by a rubber diaphragm.

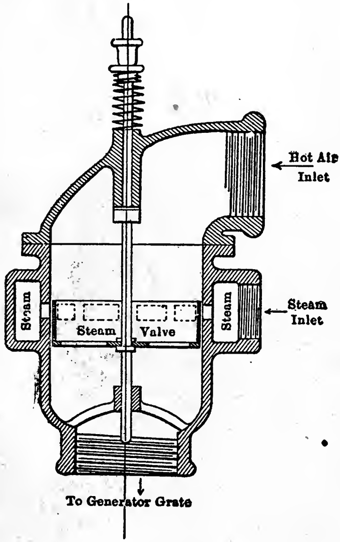


Fig. 321
STEAM REGULATOR

A small vent in the cover allows air to pass in or out slowly, forming a sort of brake on the fluctuations of pressure within the drum. The regulator controlling the admission of steam to the fuel bed is shown in section in Fig. 321. The outlet at the bottom is connected to the ash pit of the generator. The upper intake admits air only, and the intake near the middle admits steam. When running light the suction is insufficient to pull down the valve, and air alone passes through the fire. As the load increases, the increasing suction gradually pulls down the valve (which is a piston valve) until the steam ports are uncovered to an extent depending upon the load. This

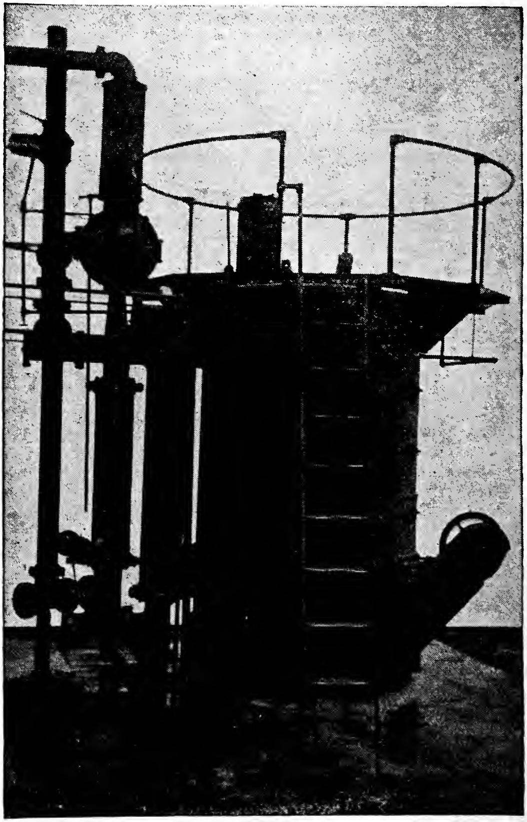


Fig. 322

SMITH AUTOMATIC SUCTION GAS PRODUCER

arrangement prevents the chilling of the fire with steam at very light loads, and graduates the supply for heavier loads.

Smith Suction Producer.—Fig. 322 shows a view of the Smith Automatic Suction gas producer, built by the Smith Gas Power Co., Lexington, Ohio—Fig. 323 is a sectional view of the regulator, which is also shown in perspective in Fig. 324 mounted upon the superheater with which this producer is equipped. The hot exhaust from the gas engine is piped into this superheater which heats the incoming air for the producer and turns the proportionate amount of water required into steam. The regulator consists of a curved iron tube E through which the air is drawn into the superheater, then on and through the fire bed in the producer. Vane V, Fig. 323, is located in the curved tube and is connected to water cylinder G which is mounted on knife edge bearings so it will rotate freely. The vane V and the connecting arm H are accurately balanced by the adjustable weight K. Weight L serves to counteract the pressure of the air which passes with more or less force (according to the needs of the engine) through curved tube E. The water cylinder G is supplied with a needle

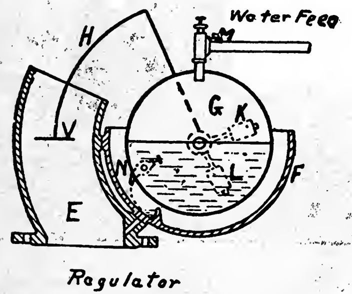


FIG. 323

valve feed at N and an overflow next to its axis. The feed water from needle valve N runs directly into the air passage E.

It will be readily seen that when more air is passing through the curved tube E the vane V will be drawn down rotating water cylinder G. As the water keeps its level there will be more head water above the needle valve feed N, causing an increase in the water feed in proportion to the increase of air. When the load on the engine runs light, and less air is drawn through tube E, there is less pressure on vane V, and the weight L rotates water cylinder G in the opposite direction, decreasing the head of water on needle valve N. The proportion of water and air under all the varying conditions is thus automatically held uni-

FIG. 324

form. As the flow of the column of air passing through the curved tube E, and past vane V is practically constant there are no sudden fluctuations of the vane and water cylinder but a smooth gradual adjustment to meet the any changing conditions.

This machine is arranged to operate either up draft or down draft as may be required, and can be utilized on anthracite, semi-anthracite, coke, charcoal, lignite, wood or bituminous coal, as conditions may require. The machine is a straight suction producer and is complete in all particulars as shown in Fig. 322. The gas pipe at the upper left hand corner passes directly to the engine.

The Steam-Pressure Producer.—This type has an upward draft, the air being drawn in around a steam jet through a Körting nozzle of the Bunsen type. Anthracite and coke are the only kinds of fuel available, unless tar extractors, and other expensive mechanical auxiliaries are provided to clean the gas. When the producer is equipped with such cleaning apparatus, bituminous coals or fuels containing volatile hydrocarbons may be used, but as these are condensed and washed out of the gas, the thermal efficiency of the producer is reduced to the extent of the loss of the heat units contained in the extracted hydrocarbons, which are the richest part of the fuel.

With a pressure producer it is necessary to have gas-storage capacity, so that gas-holders must be provided regardless of the kind of fuel used, and these must hold enough gas to run the engine while the fire is being poked, and the ashes removed. Coal is fed through a tightly closing hopper on top of the generator, and ashes are removed from the bottom when the generator is not in operation. It is almost impossible to poke, or bar the fire while the producer is running, as any outlet for this purpose will be flooded with burning gas escaping under whatever pressure the steam jet is maintaining at the time.

Induced Down-Draft Producer.—In the down-draft producer the gas is drawn down through the fire by an exhauster or fan, and forced by the exhauster through the main to the point of use. There is probably more horsepower of these producers in use than in all of the others put together, but they are mostly of large size and the plants only number about one-fourth of the total.

Essentially these are bituminous-coal producers. They are operated with an open top, where the fire is seen by the operator, and any blow-holes or passages in the fire are easily closed by the use of the poker or tamping bar, and fresh fuel is fed as necessary. The volatile hydrocarbons of the fuel, being distilled at the top of the fuel bed, mix with the in-drawn air and steam, and pass down through the bed of incandescent carbon, where they combine with the other gases and leave at the bottom of the producer, as a fixed non-condensable gas. This combination of gases then passes directly into the bottom of a vertical tubular boiler and out at the top, thence into the bottom of the wet scrubber, where the outlet is under water to form a seal and prevent the gas from returning to the producer. From the top of the wet scrubber the gas passes to the exhauster, and is forced through the dry scrubber to the gas-holder.

The boiler, which is a part of the producer installation, supplies a large part of the steam necessary for the producer, and also the amount necessary to run the engine driving the exhauster. This steam is made from the heat given up by the gas in its passage through the boiler, and all heat that is not absorbed by the water is delivered up to the wet scrubber. Once a week these producers have to be entirely cooled down to be cleaned, and as the steam pressure in the boiler is down at this time, an auxiliary boiler has to be provided to start up again. Some time during the week, especially toward the last days, the fuel beds become so clogged with the accumulation of ashes and clinkers, that water-gas runs have to be made every few moments; the load on the engine driving the exhauster increases, and both these conditions so increase the demand for steam that the auxiliary boiler has to be brought into use.

For continuous 24-hour service with this type of producer it is necessary to have a spare unit, in order that it can take the place of the one that has been in service for a week. A single spare unit in an installation of a large number of units does not add a very large percentage to the original investment, but a spare unit to a single outfit nearly doubles the cost. The following timely suggestions regarding gas engine practice are presented by the Gas Power Section of the A. S. M. E.:

"*Engine Efficiency.* Should be expressed in terms of effective heat value, until a combined gas-vapor cycle comes into use. For the present, let us not confound a definite engine efficiency by introducing the indefinite factor of latent heat of water vapor. Engine efficiencies should be given for full, to half load at least.

"*Producer Capacity.* The producer should be rated upon its ability to gasify coal. It would be more accurate to rate on B. t. u. of standard gas, but this is impracticable. Should the builder desire to rate on a special coal, he might insert a clause limiting some of the constituents. In specifying sizes, a maximum as well as a minimum screen should be mentioned. A mixture of many sizes packs the producer as badly as a very small fuel. As a usual thing the flexibility of the producer will more than meet the overload possibilities of the engine.

"*Producer Efficiency.* Can only be specified in terms of B. t. u. output, involving volumetric measurement, which it is usually impossible to determine except by calibration of the engine. As we are dependent upon the engine as a gas meter, we must be consistent, and determine the efficiency of the producer in like terms, that is, the ratio between heat output in standard gas, and heat input in fuel for the fire.

"*Producer Regulation.* An important point is the property of the producer as regards the regulation of heat value of the gas, and its pressure as delivered to the engine. Quality regulation is covered by the engine-capacity clause 'with gas of not less than so many B. t. u. heat value per cubic foot.'

"*Hydrogen Content.* This may be expressed as a percentage by volume of the gas, a percentage by volume of combustible in the gas, a percentage of the heat value of the gas per mixture, or a percentage by volume of the mixture. The last appears to be the most explanatory. The first conveys no impression of the commercial value of the gas. The second is better in this respect. The third presents widely varying values."

ALLIS-CHALMERS GAS ENGINE.

Figure 325 presents a view of a four cycle, double acting tandem gas engine as built by Allis-Chalmers Companay, of Milwaukee, Wis. This engine is using natural gas. Fig.

326 shows a four cycle double acting twin-tandem gas engine by the same company.

The distinctive features of the gas engines built by Allis-Chalmers Co., or those which appeal most strongly to engineers who have seen them in service, are the extreme simplicity of design, the solidity of construction, and the quiet operation. Maximum overloads are handled as easily, and with the same freedom from vibration that characterize their operation under normal conditions; the engines turn their centers as quietly as a slow-running Corliss machine and with apparent indifference to the rapid changes in load which they are often called upon to sustain.

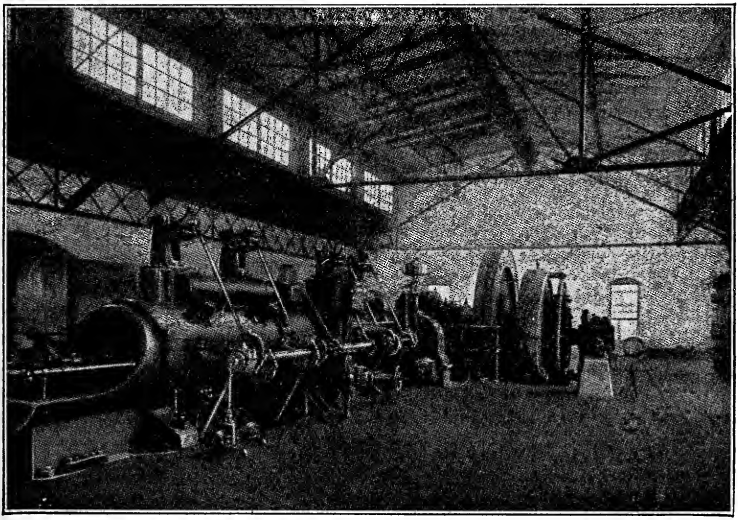


FIG. 325

ALLIS-CHALMERS FOUR-CYCLE, DOUBLE-ACTING, TANDEM GAS ENGINE DIRECT-CONNECTED TO AN ALLIS-CHALMERS CONTINUOUS CURRENT GENERATOR—NATURAL GAS USED

While the engines are, as a whole, exceptionally rigid and heavy, the weight is concentrated in the frame, cylinders, and tie pieces in the direct line of stresses to which an engine of this type is subjected. In the frame is illustrated the principal difference between European and American design. This frame is designed for a side crank, in place of the double throw crank which represents the standard practice abroad. The stresses transmitted to the frame in a side crank engine are very great, but, even in the largest sized gas engines, they are no greater than Allis-Chalmers Company has for many years successfully provided for in steam engine practice.

The jaw, which is subjected to peculiarly severe stress, is made in a form to insure maximum strength of the casting, and is further strengthened by two steel tie bolts carried above the shaft, which are made of sufficient size to carry their proportion of the load without appreciable elongation. This construction eliminates entirely any bending stresses in the frame at this point.

The engine frames for the 2,500 K. W. units weigh approximately 90 tons each, and one-half of each frame is buried in the foundation, in order to raise the floor line to a point which will make the slides on the valve gear readily accessible.

The pistons and rods are water-cooled, water being introduced at the center and flowing forward to a discharge in the frame for the front piston, and backward to a discharge in the tail guide for the rear piston, each piston having its separate supply. For dismantling or for cleansing, the rod is made in two parts joined at the central slide, the rear half going out at the back of the engine and the other half going through the frame, which is made open at the top for convenience.

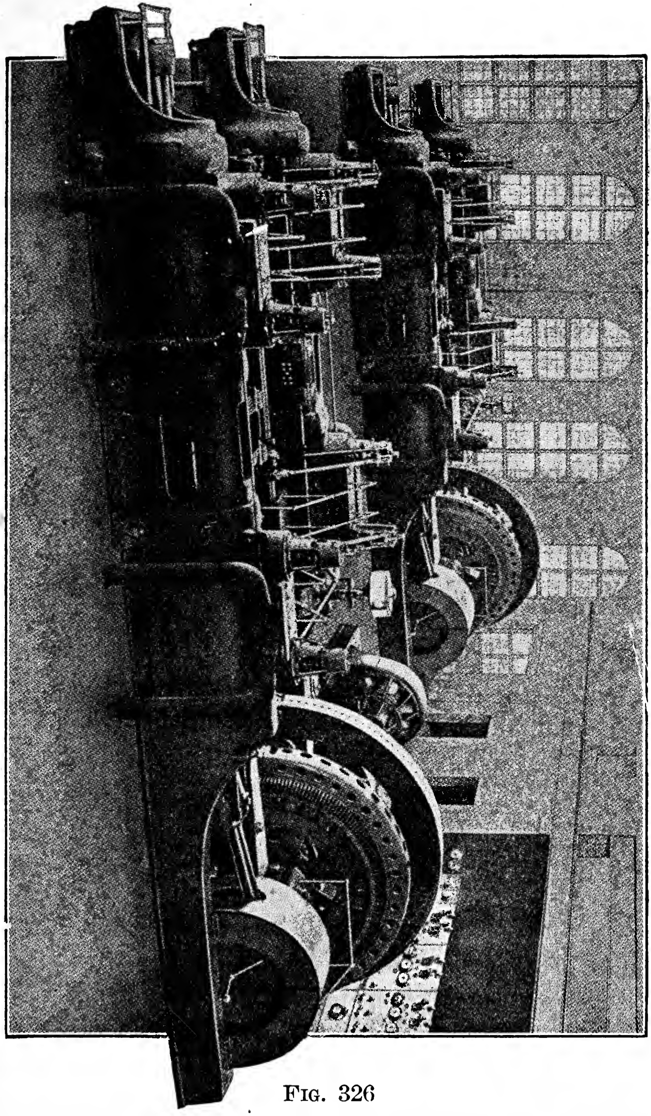


FIG. 326

ALLIS-CHALMERS, FOUR-CYCLE, DOUBLE-ACTING TWIN-TANDEM GAS ENGINES, EACH OF 2,000 H. P. CAPACITY

Driving Allis-Chalmers Alternating Current Generators in the Power House of the Milwaukee-Northern Railway, Port Washington, Wis.

The Valve Gear.—On twin tandems the valve gear is located between the engines, concentrating it in such a way as to make it very convenient for the operating engineer.

This gear is of Allis-Chalmers Co.'s stratification type, and the engine operates with constant compression, thus tending to insure smooth running under the highly variable loads to which it is subjected. The inlet gear is extremely simple, consisting of a main inlet valve of the single beat poppet type, eccentric operated, thus insuring long life and quiet running. The mixture of the air and gas is thoroughly effected before entering the cylinder by means of a patented annular mixing chamber located under the main inlet bonnet; the design and operation of this device is such that, at the instant of closing of the main inlet valve, there is practically no explosive mixture left outside the cylinder. The gas valve is of the double beat poppet type, controlled by a variable lift rolling lever operated by a single link connection to the main inlet, the lift of the valve and consequently the amount of gas admitted, and the time of admission being regulated by the governors. The exhaust gear is of the single beat poppet valve type, eccentric operated, and is in this respect a duplicate of the main inlet gear. A feature of this engine is the location of the exhaust bonnet with its valve at the bottom of the cylinder, where all the dirt is removed by the action of the exhaust gases, and the provision of a substantial jack to lower the entire exhaust mechanism out of place to allow inspection and regrinding of the valve, which also serves to swing the valve chamber, with the valve and its operating mechanism complete, out to one side where it can be reached by the crane hoist. The removal of one pin, either in the inlet, or exhaust mechanism, is all that is necessary to allow the removal of either the inlet or exhaust bonnets, with their valves and entire operating apparatus, without disturbing any adjustment whatever.

The igniters are electrically controlled, and so arranged that the time of ignition may be regulated by a single hand wheel. Direct current at 80 volts is used in the ignition system. Duplicate independent igniters are provided at each end of the cylinder to insure prompt firing of low heat value gases, and also to avoid the danger of shut down due to short circuit.

The air starting device consists of a small poppet inlet air valve at each end of each cylinder, operated by the layshaft. Air is admitted to each cylinder in turn at what would be the working stroke. As the high compression carried prevents the engine from stopping on the dead center, this arrangement insures the prompt starting of even a tandem engine without the use of a barring gear. These engines being twin tandem will, of course, start from any position.

Lubrication.—All wearing surfaces, including the main bearings, slides, crank and cross-head pins, are arranged for a continuous oiling system and the cylinders are lubricated by carefully timed admission of the cylinder oil, sight-feed oil pumps being used.

The engines shown in Fig. 326 are of the following dimensions: Each engine has four cylinders 32 inches in diameter by 42 inches stroke, and operates at 107 revolutions per minute. Each unit is rated at 1,000 K. W. but both engines and generators were designed for large overload capacities.

The engines shown in Fig. 302 are said to have the largest cylinder diameter of any gas engine yet built in the

United States, the dimentions being 44 inches diameter by 54 inches stroke.

WESTINGHOUSE GAS ENGINE.

Figs. 327 and 328 show respectively front and rear views of the Westinghouse gas engine of the vertical type. These builders also manufacture a horizontal heavy duty double acting type of gas engine of large capacity.

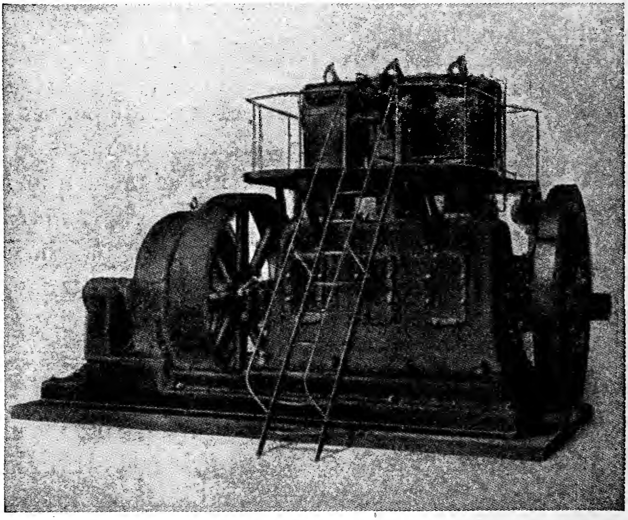


FIG. 327

WESTINGHOUSE THREE-CYLINDER VERTICAL GAS ENGINE

Front View—Direct Connected Type

Fig. 329 is a vertical section through one of the Westinghouse cylinders, showing the gas and air distribution, water jacket, and also shows the valve gear. The inlet and exhaust valves are located at opposite ends of the vertical cylinder diameter, as shown in Fig. 329. Both valves, at each end of a cylinder, are operated by a single eccentric through wipers and rocker-arms; this construction is also shown in Fig. 329. The exhaust valve is of the mushroom type, hollow, with a tube extending up the stem into the center of the head for discharging the cooling water; the water is introduced through the annular passage between the outlet tube and the wall of the valve-stem. The valve cage sets into a circular housing projecting downward from the cylinder.

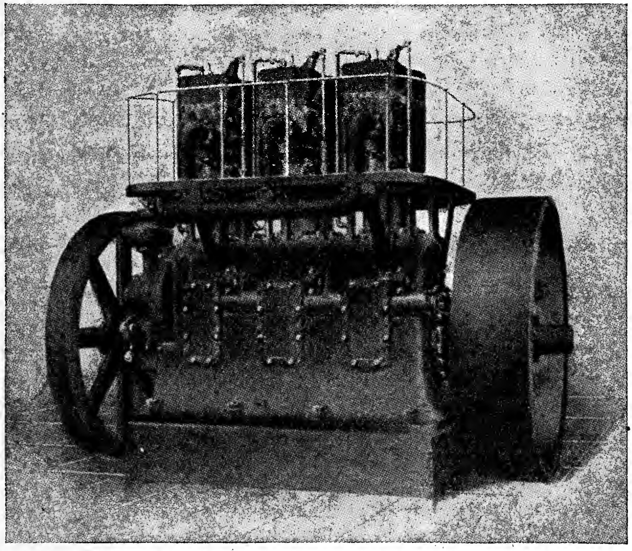


Fig. 328

WESTINGHOUSE THREE-CYLINDER VERTICAL GAS ENGINE

Rear View—Belted Type

The main inlet valve is of the simple disk type, and is opened and released by the eccentric and wiper levers always at the same points of the piston travel. There is mounted on the valve-stem, however, a cylindrical valve

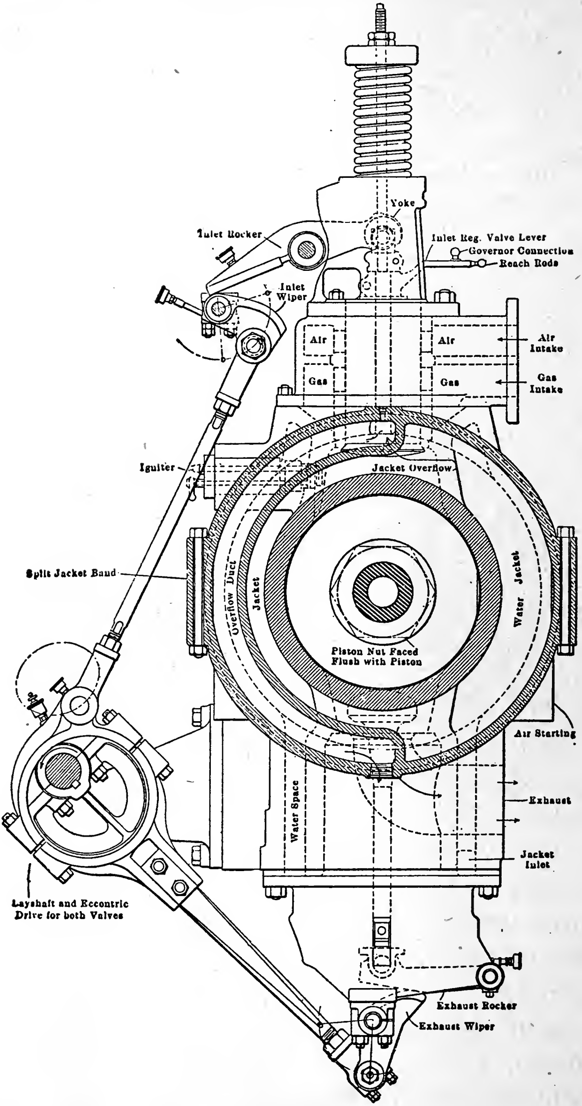


FIG. 329

VALVE GEAR, WESTINGHOUSE GAS ENGINE

which controls the quantity of air and gas admitted, this being under the control of the governor. It is not shown in Fig. 329, but the connection for the governor rod is shown. The cylindrical valve fits closely in the bore of the valve cage, and has ports in its wall which correspond to the ports leading into the cage from the air and gas passages. When the admission valve is on its seat, the ports in the cylindrical valve are above those in the cage wall, and the latter are therefore closed, preventing gas from backing up into the air passage. When the inlet valve is depressed by the valve-gear, the cylindrical valve goes with it, and its ports then come into horizontal alignment with the air and gas ports in the wall. The governor controls the quantity of air and gas admitted by rotating the cylindrical valve on the disk-valve stem; in the full-load position the ports are all in exact alignment when the valve is depressed, and at lesser loads the valve is twisted around by the governor so as to shut off part of the port opening. The four cylindrical valves of one side of the engine are all connected together by reach-rods, so that the governor adjusts all four valves simultaneously and alike. The two sets of regulating gear are connected by double reach-rods, so that there is no lost motion between the two sides. The pistons are centered in the cylinders by adjustments at the three crossheads. Each piston is equipped with four sectional packing rings; the sections of each ring are joined by brass keepers and set out by flat steel springs. The piston-rods are hollow, of course, to admit and discharge cooling water to and from the pistons, and they are turned without any camber.

Governor.—In the Westinghouse gas engine, regulation is obtained through two elements, governor and mixing valve. The flyball governor or regulator is geared direct to the main engine shaft. From the rise and fall of the governor sleeve, with corresponding changes in speed, the essential motion is derived for operating the mixing valve through a simple and direct linkage. With this mechanism the governor is able to record without the least delay the slightest change in speed of the engine, due to change in load.

A slight range in speed is desirable for parallel operated units. This is provided for by two springs on the mixing valves, which can be adjusted while the engine is running, so as to alter the position of the governor.

Mixing Valve.—This important detail part accomplishes in a single mechanism two fundamental functions—one, the proper proportioning of air and gas, and the other, the control of the quantity of mixture delivered to the cylinders. A vertical free moving cylindrical valve with suitable ports is surrounded by two independent sleeves, correspondingly ported, capable of rotation by handles through a small arc as indicated by two graduated dials. By rotating these sleeves, when the engine is running on a certain kind of gas, it is easy to "feel" for the best mixture. The mixing valve then accomplishes the desired regulation as controlled by the governor. In producer gas plants, foreign matter such as dust and tar makes it difficult to keep this type of valve in working order, so that a poppet type is used instead, operating on the same principle.

In the Westinghouse engines the "make and break" or "hammer break" type igniter is employed, this type having been found by experience to be the least susceptible to irregular working, and to give the longest life. Essentially the "make and break" system, comprises a source of electrical current and a spark plug, inserted through the walls of the combustion chamber. This interrupts the current at the proper moment, causing an electrical discharge across the opening in the circuit, the heat from which starts combustion of the compressed gas mixture.

An igniter plug is shown in Fig. 330. To obtain the necessary interruption, one of the poles of the igniter is stationary, the other movable, and actuated from the outside by a trip. This igniter mechanism interrupts the current flow only at the beginning of each power stroke. The opposing contact points are protected by tips of platinum, or other heat resisting metal.

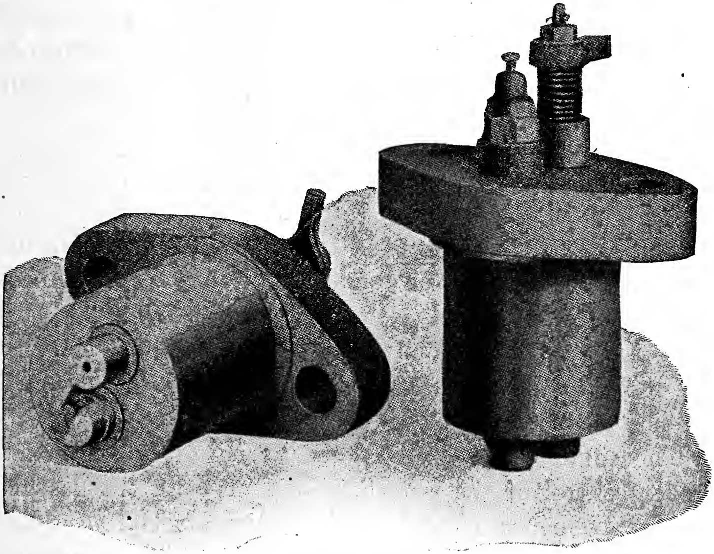


Fig. 330

IGNITER

Starting.—While small gas motors may readily be started by hand with a turn of the fly wheel, such a method is quite impracticable in large engines. An automatic system has been incorporated in the Westinghouse engine by which compressed air under 100-250 pounds pressure (according to the size of the engine), is admitted at the proper moment to one of the cylinders which then operates, for the instant, as an air motor. During the succeeding rotation of the engine, the other power cylinders are carried through their respective cycles, and normal combustion begins in one or the other upon the second or third revolution. Compressed air is then shut off, the air valves automatically return to their seats, and normal combustion in the remaining cylinder begins.

SNOW GAS ENGINES.

The Snow twin unit has cylinders 16 inches in diameter by 30 inches stroke. The cranks are set at 90 degrees apart, thus giving four impulses to the shaft per revolution. The combustion chamber is on the side, with the inlet valves in the top, and the exhaust valve in the bottom of each combustion chamber.

The engine speed is regulated by cut-off valves which, under control of the governor, shut off both the gas and air supply sooner or later in the suction strokes, according to the speed changes. The arrangement of inlet valves for one end of a cylinder is shown by Fig. 331. The air and gas pass to the mixing chamber M through separate ports, shown closed by the valve discs A and G, respectively. From the mixing chamber the mixture is admitted to the cylinder by the main inlet valve I at the beginning of the suction stroke; at the point in the stroke determined by the governor, the cut-off valve A G is released and allowed to close under the influence of its spring. The baffling disc B is adjustable so as to obtain the desired proportion of gas to

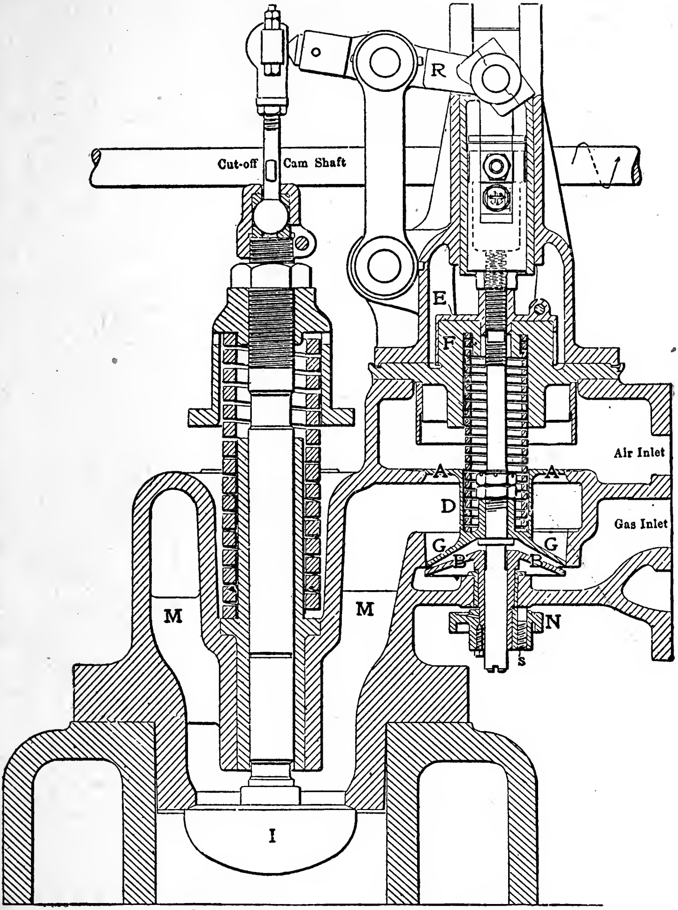


FIG. 331

SECTIONAL ELEVATION OF INLET AND CUT-OFF VALVES AND GEAR. SNOW GAS ENGINE

air, the adjustment being made by means of the knurled head N, which is locked in the proper position by the set-screw s. The shank of the baffling disc serves also as a guide for the lower end of the stem of the cut-off valve. The valve discs A and G are connected by a short barrel D, the whole being a single casting. The gas valve G is provided with a tapered seat, and the valve-stem is adjusted in the block at its upper end until both discs seat simultaneously.

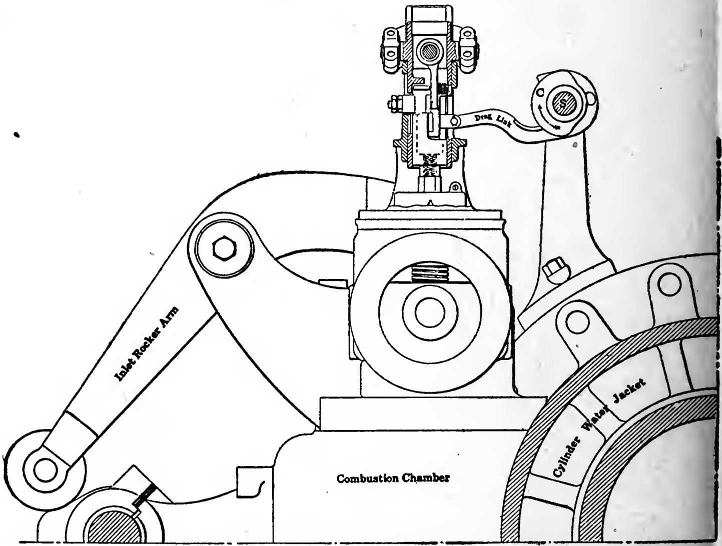


Fig. 332

END ELEVATION OF INLET AND CUT-OFF MECHANISM. SNOW GAS ENGINE

The main inlet valve I is opened and closed always at the beginning, and termination of the suction stroke, by the inlet rocker-arm (Fig. 332), and its stem is linked to a short rocker-arm R, Fig. 331, to the other end of which is pivoted a block arranged to slide vertically in a guide. To this block is hung the pivoted latch L, shown in Fig. 332, the end of which normally engages a dog on the block which is screwed on the upper end of the stem of the cut-off valve. When the main inlet valve is opened, the latch L lifts the discs A and G of the cut-off valve. At the proper point of the suction stroke, the cam C, Fig. 332, engages a lug and draws the drag-link over, thereby pulling out the latch L and allowing the cut-off valve to drop. The drag-link is pivotally attached to a lug on the latch L, and its other end is curved around the cut-off shaft S, the upper leg of the bend resting on the journal box and holding the link in place as it slides back and forth. Before the succeeding suction stroke begins, the cam C has turned to the "low" side and the latch L is thrown into engagement with the valve-stem dog by a small helical spring. When the cut-off valve drops, it is cushioned by the inverted cup E, Fig. 331, acting as a dash-pot, the plug F constituting the plunger. The cut-off cam-shaft S rotates continuously at one-half the crank-shaft speed, and its angular position with respect to that of the crank-shaft is adjusted by the governor through the well-known "floating" bevel gear.

DU BOIS TANDEM GAS ENGINE.

The Du Bois Iron Works, Du Bois, Penn., has developed and is now building a line of single-acting tandem gas engines which embody several interesting features. Fig. 333 is a view of one of these engines, from which it will be evident that the design conforms to the standard European practice of locating the inlet valves in the top, the exhaust valves in the bottom, and the valve-gear shaft alongside of the cylinders. Another characteristic European feature is the use of center-crank construction. Beyond these few points, however, the design cannot be said to follow strictly any classified practice.

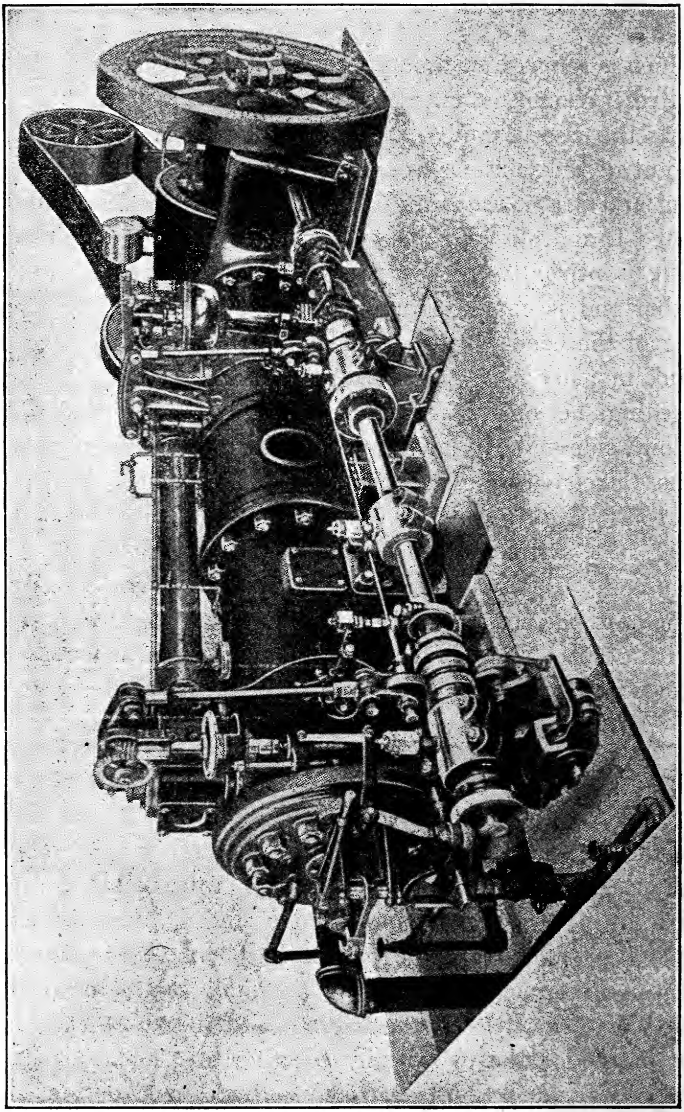


Fig. 333

DU BOIS TANDEM GAS ENGINE

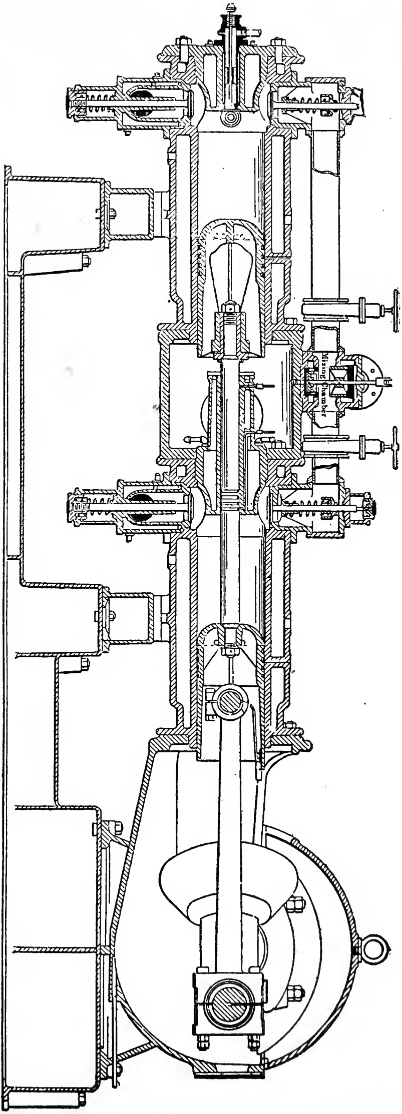


FIG. 334 LONGITUDINAL SECTION OF DU BOIS TANDEM GAS ENGINE

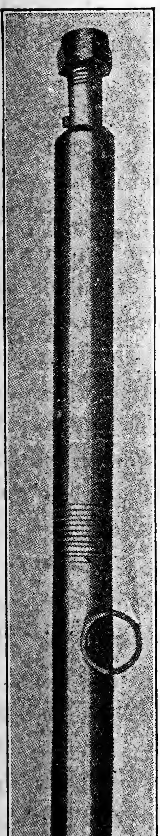


FIG. 335 PISTON ROD OF DU BOIS GAS ENGINE

The longitudinal section, Fig. 334, gives an excellent idea of the internal construction of the engine, and shows clearly the unusual method employed for packing the piston-rod hole in the rear end of the front cylinder. Instead of providing a stationary packing cage, and having the rod slide through rings contained therein, the packing rings are put on the rod, like those on the piston, and they slide back and forth with the rod in a sleeve formed in the head of the front cylinder and a rearward extension of it. It might seem at first glance that this arrangement would entail an unduly long engine structure, but the fact is that even if stationary packing rings were mounted in a housing in the cylinder head, the engine could not be shortened up without sacrificing accessibility to the rear piston, and ease of dismounting the front cylinder head. Fig. 335 is a view of the piston rod with its packing rings and the flanged sleeve to which the rear piston is bolted.

The pistons are of the trunk type, and are built with convex heads, in order to obtain the requisite strength with a moderate weight of metal.

The construction of the water jackets, cylinder heads, connecting rod and crank case is so clearly shown by Fig. 334 as to require no verbal description. The crank shaft, crank cheeks, and pin are all cast in one piece of steel; the balancing weights are bolted on.

Valves, Valve Gear and Governor.—Simple, flat poppet valves of forged steel, with beveled seats, are used throughout the engine, and the need for cooling the exhaust valves in larger sizes is obviated by the use of auxiliary exhaust ports uncovered by the pistons at the end of the forward stroke. These ports consist of a series of round holes through a rib connecting the water-jacket wall and the

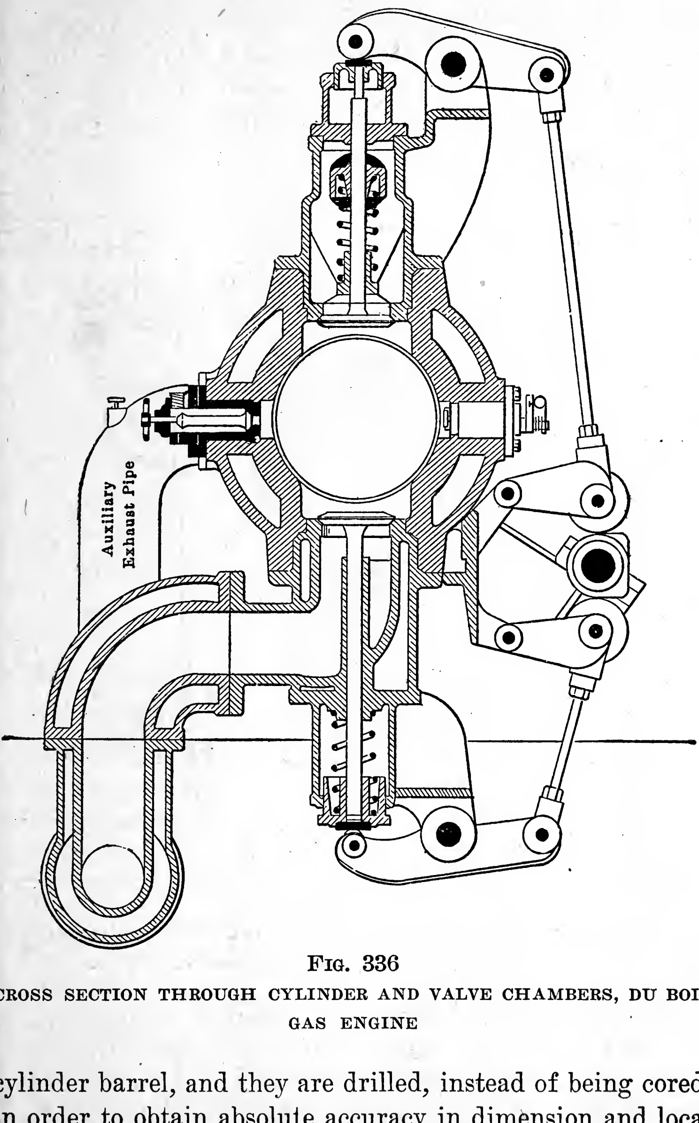


Fig. 336

CROSS SECTION THROUGH CYLINDER AND VALVE CHAMBERS, DU BOIS GAS ENGINE

cylinder barrel, and they are drilled, instead of being cored, in order to obtain absolute accuracy in dimension and location. The inlet and exhaust valves of each cylinder are opened by a cam, two push rods and four rocker arms, as indicated in Fig. 336. Rollers are provided, of course, to take the thrust of the cam and to deliver the motion of the rocker arms to the valve stems.

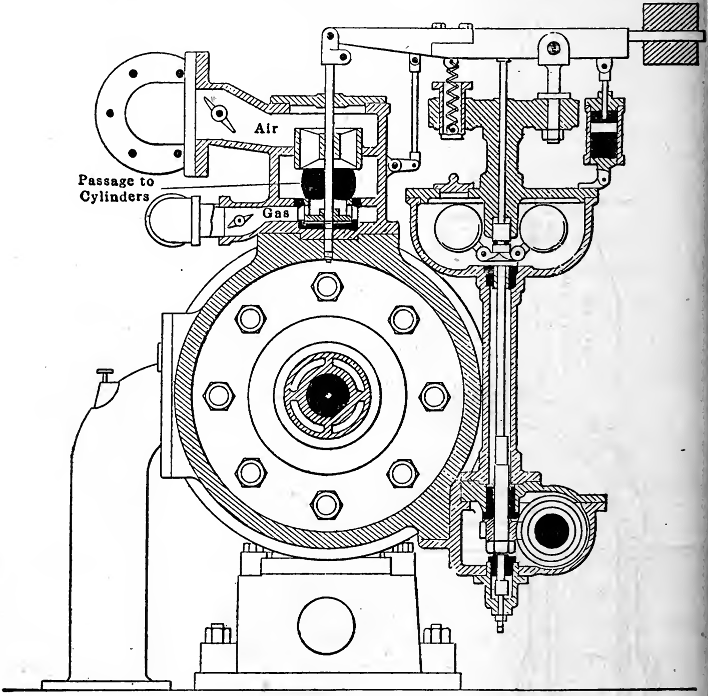


Fig. 337

CROSS SECTION THROUGH CYLINDER, MIXING-VALVE CHAMBER AND GOVERNOR, DU BOIS GAS ENGINE

One mixing valve serves both cylinders, as indicated in Fig. 334, where the mixing valve is shown immediately above the rear end of the piston-rod packing sleeve. Fig. 337 shows more of the details. The valve stem carries two pistons, the upper one controlling the air supply by varying the space between its upper edge and the top of the cage, and the lower one varying the gas supply by means of ports in its wall and corresponding ports in the wall of its cage. The proportion of gas to air is adjusted manually by means of the butterfly valves in the supply passages, except in such cases as require variation of the mixture proportions, simultaneously with variation in the quantity of mixture admitted. For such conditions, the lever which raises and lowers the mixing valve is also linked to the butterfly valves, the linkage being adjusted so that the mixture is made richer as the load decreases (and the compression is reduced), and poorer as the load increases. This automatic mixture control is not necessary except when running on very lean gases. The mechanism is adjusted usually to give the best mixture proportions at full rated load, but a wide range of adjustment is practicable.

The governor is of the flyball type, but differs essentially from the common construction, as Fig. 337 clearly shows. The spindle is driven through spiral gears from the cam shaft, and the balls and sliding member are inclosed in a stationary housing, as shown in Fig. 337. The governor gears are located between the forward cam and the main shaft; consequently, the angular velocity of the governor is not disturbed or made irregular by the tensional yielding of the cam shaft to the stresses imposed by the cams and valve mechanism. The cam shaft is driven from the crank shaft through spiral gears running in an oil bath.

Ignition.—Igniters of the mechanical make-and-break class are used. The reciprocating mechanism which trips each igniter is driven by an eccentric on the cam shaft, as shown by Fig. 338. The individual igniter is timed by

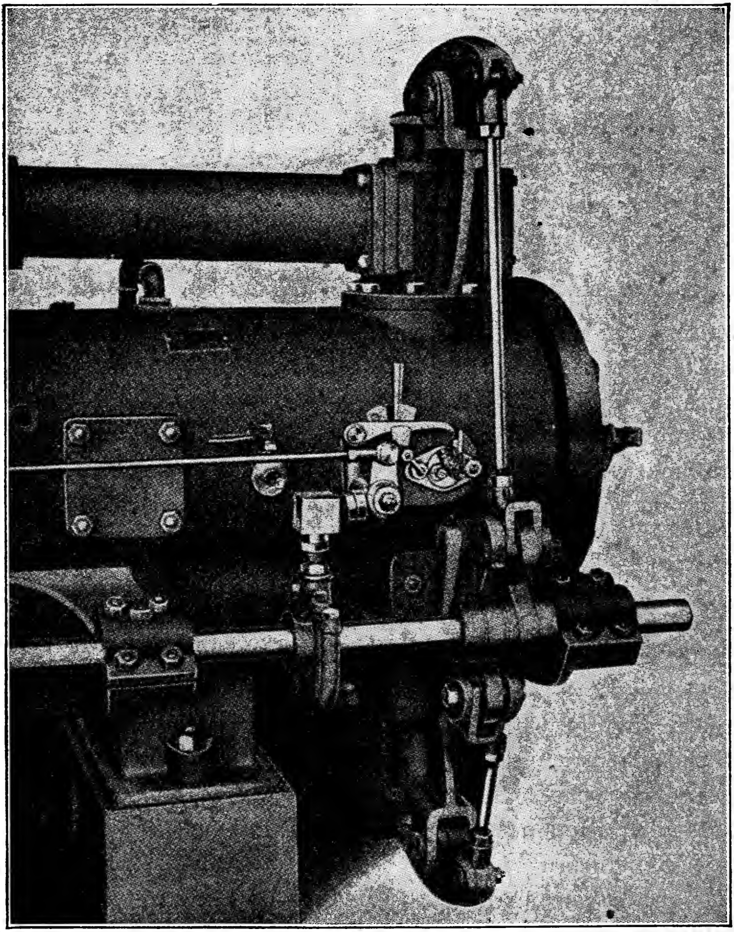


Fig. 338

DU BOIS IGNITER MECHANISM

means of the vertical handle near the cylinder; this raises or lowers the horizontal finger with the bent end which trips the igniter, and thereby alters the point of ignition.

The reach rod leading from the igniter mechanism to the left extends to the other igniter, and adjustment of this rod to the right or left retards or advances the timing of both igniters simultaneously. The levers to which the ends of this rod are pivoted are fastened to the ends of sleeves which are eccentric to the rocker studs, and the igniter rockers are mounted on these sleeves; turning the sleeves on the studs alters the relation between the rockers and the igniter triggers and thereby changes the timing. A handle at the middle of the reach rod serves for manipulating it, and a clamp holds it wherever it is set.

The engine is arranged so as to be oiled by a central gravity-feed system. Since the piston trunks are more than full-stroke length, they always cover the oil holes in the cylinder walls; timed lubrication is therefore unnecessary.

The engine is equipped with a valve in the head of the rear cylinder for starting with compressed air, and the valve disc is located at the inner face of the cylinder head, so that when it is closed no pocket is formed in the combustion-chamber wall. This construction is shown in Fig. 334. The indicator openings are provided with similar valves, as shown in Fig. 336. This drawing also shows the unusual feature of a water-jacketed exhaust pipe with which every Du Bois engine is equipped. Another unusual feature, although not original on this engine, is the injection of cooling water into the exhaust pipe; this cools the exhaust gases so suddenly that a muffler is not required. The water jacket around the exhaust pipe is chiefly for the purpose of obviating the exposure of dangerously hot surfaces where attendants are likely to come in contact with them, although the water jacket also cools the exhaust gases considerably.

The compression pressure is about 140 pounds absolute for natural gas, and 180 pounds for producer gas, and the engine can be changed from the one to the other compression in a few minutes.

THE TOWER GAS ENGINE.

Fig. 339 shows a view of the Tower heavy duty gas engine built by the Tower Engineering Company, Buffalo, N. Y. This engine is designed for using producer gas, and has some very pronounced features embodying the best practice and the most recent development in gas engine design.

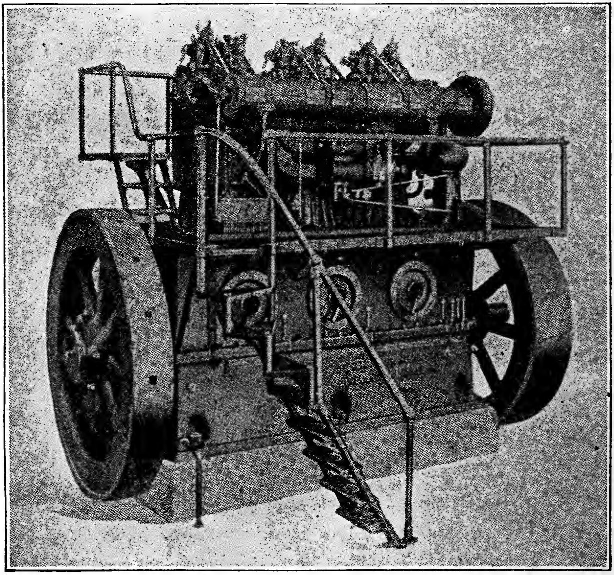


FIG. 339
200 H. P. TOWER GAS ENGINE

The engine is of the three cylinder, vertical, single acting type operating on the four stroke-cycle principle. It is rated at 200 h. p. upon producer gas of approximately 135 b. t. u. per cubic foot measured under standard conditions of 62° Fahr. temperature and 30 in. mercury pressure. The cylinders are each 16½ in. diameter and the stroke is 18 inches. The area of the piston is 213.8 sq. in., the piston displacement is 3850 cu. in. The piston speed under normal operation of 257 r. p. m. is 771 feet per minute. The mean effective pressure in each cylinder as calculated from the above data is 53 pounds per sq. in. of piston area.

The height of the engine is 12½ feet, the length 14 1/6 feet, the width 8½ feet, the floor space occupied is 120 sq. ft.

The weight of the complete engine with its fittings is 61,000 pounds which gives a weight of metal of 305 pounds per horse power. Each of the two fly wheels is seven feet in diameter and weighs 10,000 pounds. The peripheral speed of the wheels is 5,600 feet per minute which is far too low to give any cause for fly wheel explosions. Provision is made for belting off one fly wheel if necessary, and for barring the engine over, during times of inspection from the other, by means of holes drilled in the face of the fly wheel.

The crank shaft is of forged open hearth steel with high ultimate, and elastic limits, combined with reasonable ductility to suit the conditions of service. The matter of crank shafts for vertical three cylinder engines has received considerable study of late, in view of the fact that there have been several breakages of late, in engines of supposedly good design. The pressures exerted on the crank at the time of the explosion are very great and, due to the rotation of the crank shaft, the stresses are reversed from tension to compression so that if any defects or initial stresses are in the material, there is great liability to rupture due to "fatigue" or crystallization of the metal. The use of the best material, of good proportions, and large bearing surfaces, easy to adjust and keep in correct alignment is the solution of the crank shaft problem. The two end crank shaft bearings are each 20 in. long and the two center bearings are each 14 in. long, with wedge take-up adjustments. The diameter of the crank shaft is 8 in., that of the crank pin bearings is 8½ in., with a length of 7¾ in. The piston pin has a diameter of 5½ in., and the length of the bearing surface is 8 in. The oil reservoir supplies a sight feed indicating distributer in full view of the engineer. There are separate oil feeds piped from this distributer to each of the bearings, and the engineer can easily adjust the flow to each bearing, and with a glance of his eye observe whether oil is going to every bearing or not. The feeding device starts and stops with the engine, the oil is collected in the pit of the crank case, passes through the filter, and is pumped to the reservoir with little waste.

The cylinder heads contain the inlet and exhaust valves of the poppet type; the latter is water cooled. The valves themselves are placed in cages which may be readily removed from the cylinder heads. The construction is such that neither valve can fall into the cylinder—a very wise precaution, as engines have been badly damaged by having an inlet valve drop into a cylinder.

The valves are operated by eccentrics which are encased, and dip into a bath of oil. The entire eccentric shaft can be exposed for inspection by lifting the cover of the case.

The governor case, as shown to the right under the end of the eccentric case in the illustration, encloses two fly-balls immersed in oil, running at engine speed. The cover to the case can be removed for easy inspection. Means are provided for changing the speed of the engine, while running, by turning a knurled adjusting nut. Connections are made to the governor valve by two reach rods; one to control the gas, and one to control the air supply.

The governor valve, for controlling the quality of the mixture, and the compression of the engine, is multiported and operates on ball bearings to insure minimum friction and sensitiveness. An indicator is provided to show, at all times, the position of gas and air ports at all conditions of load. The adjustment provided on the reach rods and governor, allows of the variation of air and gas separately, or the adjustment of both simultaneously, while engine is operating.

The special feature of ignition is important. Two spark plugs are used in a plate, and by throwing a lever either plug may be thrown into service.

A defective plug may thus be removed without losing a power stroke. An adjustable timing device, allows the timing of each cylinder separately, or advancing and retarding the spark in all the cylinders at the same time.

No batteries are used. The cylinder, cylinder head, exhaust valve and exhaust manifold are water cooled. Water is piped to each cylinder independently, and connection is made externally from cylinder, to cylinder head. The water from the cylinder head is discharged into an open funnel so that the engineer can see at a glance that each cylinder is getting its proper share of cooling water. This is an important matter to consider as practice has shown that cylinders heat differently, and trouble due to one hot cylinder may seriously injure the engine.

The starting of the engine is effected by compressed air. The auxiliary apparatus consists of two air storage tanks, a two cylinder air compressor, and a 4 horse power gasoline engine.

THE REEVES GAS ENGINE.

Figures 340 and 341 show views of the Reeves gas engine built by the Reeves Engineering Co., Mt. Vernon Ohio.

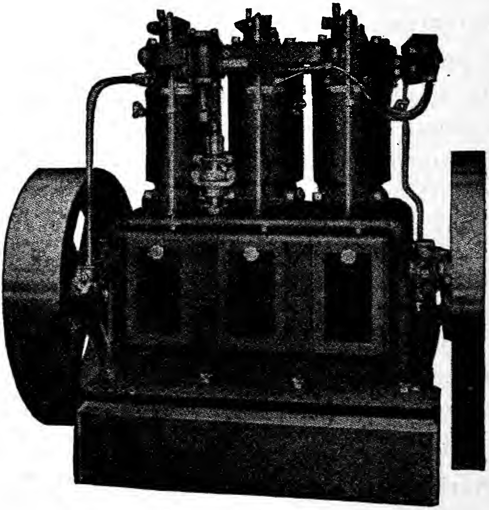


Fig. 340

REEVES THREE-CYLINDER GAS ENGINE

This engine is designed to be operated on natural or producer gas, and can also be operated on gasoline if necessary.

As will be noted by the illustrations these engines are of the vertical, multiple cylinder single acting type.

The crank shafts and connecting rods on this engine are forged without welds from open hearth steel. Crank pin bearings are of marine type, and cast from phosphor bronze; the adjustment of wear on these bearings being made by a special system of liners, each one consisting of a number of sheets of brass, each being 0.003 of an inch in thickness and a number made into a unit constitute a liner. In making an adjustment the removal of one sheet on each side gives equal adjustment all over the bearing. The pin is made from tool steel, hardened and ground to exact size.

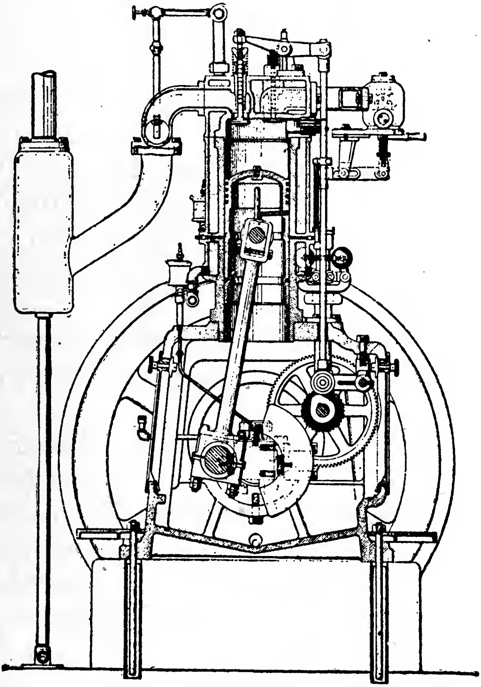


FIG. 341

SECTIONAL VIEW OF THE REEVES GAS ENGINE

Pistons are of special hard gray iron, and are unusually long affording a liberal wearing surface. By referring to

Fig. 341 the extreme length of the piston will be apparent. It will also be noted that the packing ring system consists of five narrow rings, four at top for holding compression and one ring at the bottom which acts as an oil retainer, making lasting compression possible.

The cylinder head has no offset firing chambers and the surface exposed to heat is thereby reduced to a minimum, which together with the high compression gives low fuel consumption. To protect the gasket between the cylinder and the cylinder head from the firing of the charge, the cylinder head is fitted with a male flange which projects and makes a close fit in to a corresponding counterbore in the cylinder. The valve stem guides on both intake and exhaust are made from close grained cast iron bushings inserted in the cylinder head.

The cylinder head is thoroughly water jacketed, and has a system for injecting cooling water directly around the exhaust valve seat.

Cylinders are cast from semi-steel, the flange for bolting same to housing being set three inches from end of cylinder. The extension below this flange is a slip fit to correspond to bore in housing; this centralizes the cylinder on the bed and also adds to the rigidity. They are bolted (at the bottom) direct to the housings, which consruction allows for contraction and expansion without throwing cylinder out of true.

The governor is the throttling type, the engine taking impulses regularly, each impulse being graduated by governor according to load the engine is carrying. The engine is fitted with a patent proportional throttle valve, which gives a constant proportion of air and fuel under all loads.

Either jump spark, or make and break ignition is fitted, according to the charcter of work or fuel on which engine is to be operated. For natural gas, or gasoline the jump spark is undoubtedly the best, but for producer gas a mechanically operated system of make and break spark is used.

The timer is arranged so that the firing point can be changed while the engine is in motion.

The spark plug is located directly underneath the inlet valve.

Splash lubrication has been abandoned, and its place is taken by an individual oiler on each bearing. All drip oil is collected in the base of the engine and drawn off through a drain pipe in the back. All lubrication devices are accessible on outside for oiling while the engine is in operation. Each cylinder has two sight feed lubricators, located on opposite sides of cylinder.

THE GASOLINE ENGINE.

The principles governing the action of the gasoline engine are essentially the same as those of the gas engine. In fact the term, "gas engine" applies equally well to gasoline and oil engines, and there is very little difference in their action. An engine using gas may be easily changed to use gasoline, or a gasoline engine may, by a few simple changes, be fitted to use natural, or artificial gas. The principal difference between the gas engine proper, and those engines such as gasoline, oil, etc., that use a liquid fuel is, that with the latter the gas is generated within the engine itself while in operation. whereas with the former the gas is supplied from outside sources. In early gas engine practice a gasoline or oil vapor gas was made by passing air in close proximity to a large surface of the liquid fuel. The air was thus saturated with the vapor of the gasoline or oil, and became a vapor gas similar to artificial or natural gas. This vapor gas was piped to the engine and mixed with air in proper proportion to secure the quickest and best combustion. This principle of mixing is used now with natural, artificial and producer gas. The next development in the use of liquid fuel was the mixer or carbureter by which a minute quantity of the gasoline or oil is measured and supplied with each charge of air entering the engine cylinder.

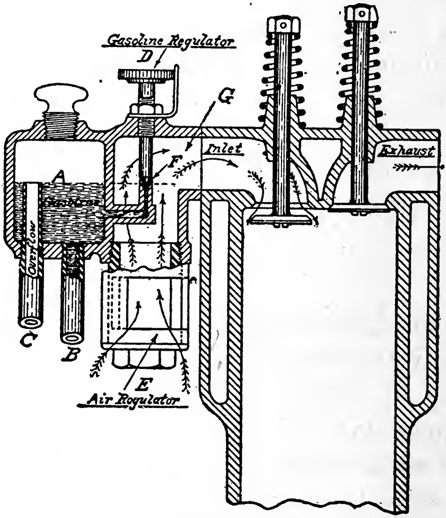


Fig. 342

With the stationary, single cylinder, industrial engines in common use the device for measuring the liquid fuel is called a mixer, and is usually made a part of the engine. A gasoline or fuel pump and constant level overflow cup is provided so that the gasoline tank may be located outside of the building in compliance with insurance regulations about the storage of gasoline. For multiple cylinder, and lighter engines the measuring device is called a carbureter, and is generally an accessory to the engine.

Fig. 342 shows the principle of the constant level overflow Mixer System commonly employed in the single cylinder stationary engine. A is the constant level overflow cup showing how the gasoline or liquid fuel rises in the spray nozzle, F, to the same level maintained in the cup. B is the pipe from the gasoline pump, and C is the overflow pipe that leads the surplus gasoline back to the tank which, as stated, may be outside the building if so required. D is the gasoline regulator, E the air regulator, F the spray nozzle and G the short passage to the inlet valve of the engine. At a given speed the engine draws in a certain amount of air by the regulator, E. The air rushing past spray nozzle, F, draws a small quantity of gasoline, measured by regulator, D, from the spray nozzle, and carries it into the cylinder of the engine. The natural heat in the air supply, assisted by the heat of the cylinder, turns the gasoline spray into a gas that burns like a flash or "explodes" when compressed and ignited by the engine, provided of course that the right proportion of air and gasoline has been obtained. This is easily known by adjusting the fuel and air regulators, and observing the action of the engine, especially under load. The greatest amount of air with the least amount of gasoline for the strongest pull at a given speed will be the correct position for the regulators. For easy starting the air regulator should be closed a little, then opened again when the engine gets up speed.

Fig. 343 is an illustration of a 1908 accessory carbureter, such as is commonly used on multiple cylinder and light motors, although it is applicable to any type of engine. A float, M, controlling a valve, O, takes the place of pump and overflow system shown in Fig. 342, maintaining a constant level of the fuel in the spray nozzle, L. The float chamber is placed around the spray nozzle so that in traction or marine work, involving various angles and positions of the machine, there will be no variation of the fuel level in the spray nozzle. The fuel tank is usually placed above the carbureter, and connected by pipe P to float valve O. The liquid fuel is thus fed to the float chamber by gravity. By using a light air pressure in the tank it may be placed below the carbureter but this is not often done. The mixer as shown in Fig. 342 is designed for a given engine speed. If the engine speed is changed the air and gasoline regulators must also be changed to get the best results. The

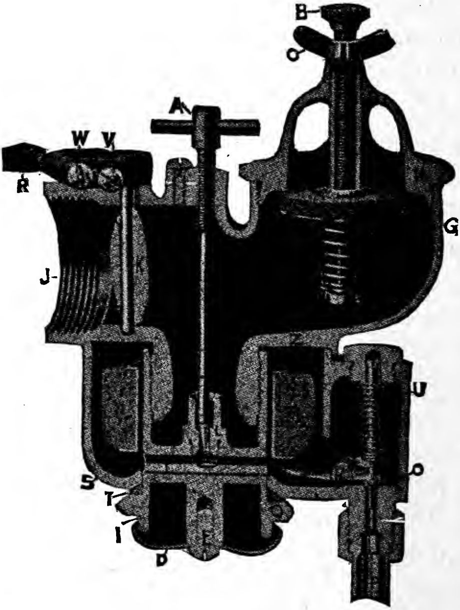


Fig. 343

carbureter is generally designed to automatically adjust itself to a considerable range of engine speed. Thus in Fig. 343 the air for starting, and slow speed enters at I. As the engine speed increases the compensating valve, G, opens, more air is admitted and the syphon force exerted on the spray nozzle, L, is kept in fairly accurate proportion to the requirements of the engine.

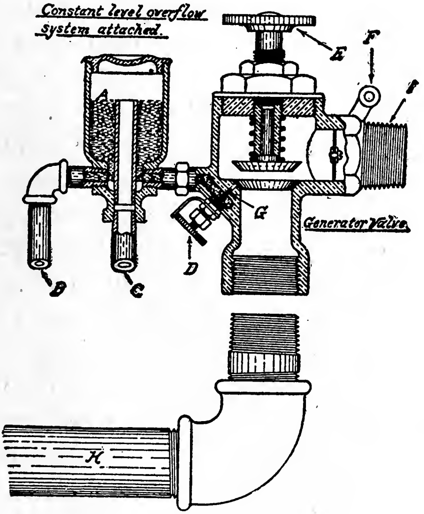


Fig. 344

K is a butterfly throttle valve for governing either automatically, or positively the amount of mixture admitted to the engine, and thus controlling the speed and power. Some makers connect the needle valve, A, to the throttle lever, R, in such a way that on full open throttle the needle valve is given additional opening. Other designs like the one illustrated in Fig. 343 depend entirely on the compensating valve for the proportion of liquid fuel and air, covering the range of speed and power required of the engine. Aside from the differences in regulation and control, the essential principles of the overflow, and float feed systems are practically the same.

Fig. 344 illustrates the principle of the generator or mixing valve, a very common method of measuring the liquid fuel for making each charge of gas for a gas engine. The liquid fuel (generally from a tank higher than the valve) is supplied to the fuel regulator, D. When the intake stroke of the engine draws air through the valve a small quantity of gasoline or fuel oil, measured by regulator, D, is drawn from the drilled opening to the valve seat, G. When not in action the valve is held to its seat by a light tension spring, thus preventing the continued flow of the liquid fuel. This type of mixer or measuring device is especially well suited to two port two cycle engines, but has been successfully employed by large numbers of four cycle engines as well. E is a regulator for the stroke of the valve. F is a butterfly valve for controlling the amount of mixture admitted and the speed and power of the engine.

Where insurance regulations or other considerations make it desirable to dispense with a considerable gravity head of fuel, the pump and overflow systems may be attached as shown in the drawing, Fig. 344. A is the overflow cup showing the small quantity of head fuel supply. B is the pipe from the gasoline pump, and C the pipe leading the overflow back to the tank.

Owing to the pulsations of the valve on some types of engines a small amount of vapor is blown back from the valve with each stroke. A piece of pipe, 8 or 10 inches long, to be attached as indicated by H will effect quite a saving of gasoline or fuel oil.

These illustrations show the principles of the various devices now in general use, for making gas out of gasoline, kerosene or other liquid fuel. It must be kept in mind that they are chiefly measuring devices, and depend on the heat of the incoming air and the heat of the cylinder for the vaporization or gasification of the liquid measured for each charge. The lighter and more volatile the liquid fuel the better the vaporization. This is the reason gasoline is so generally used. The complete vaporization of the heavier oils and spirits such as kerosene and alcohol requires special attention for equally successful results. Even gasoline in cold weather needs hot air for the first few charges in starting. Some makers of engines provide a generating cup to hold a small amount of gasoline for heating the intake pipe for easy starting in cold weather.

The higher the speed of the engine the less time there is for the thorough gasification of the measured liquid for each charge. The heat of the cylinder has less effect. The use of multiple cylinders has brought greatly increased practical speeds. These facts, together with the very desirable purpose of serving each cylinder of an engine with an equal quantity of an equally carbureted mixture, seems likely to bring further improvements in gas generating devices for liquid fuel. The present practice is to put the measuring mixer, carbureter or generator valve, as the case may be, as close to the cylinder intake valves as possible, and depend principally on the heat of the cylinders for completing the gasification. A complete gasification of the charge before it reaches the cylinders would certainly add to the fuel economy, smoothness and reliability of action in high speed multiple cylinder engines, if it can be accomplished in a practical way, and without possible ignition of the mixture in the carbureter and intake manifold.

LUBRICATION OF GAS ENGINES

Engines which are air cooled require more lubrication in the cylinders, as well as a heavier oil because the temperature of the metal is invariably higher, than where the water cooled system is in use.

An oil suitable for this purpose must have three characteristic points, i. e., a good body, low in carbon, and lastly it must have a very high fire test. That is, the temperature at which the vapor coming from the oil would ignite should not be lower than 500 to 600 degrees.

Any lubricant leaving a large amount of carbon or residue should be carefully avoided.

For the crank and crankshaft bearings, the same grade of lubricant as is used for the cylinder gives the best results, and the amount should be three to four drops per minute with the gravity system and a proportionately small amount with the force feed system.

This method of lubrication is now being adopted on a large number of gas engines because of its reliability. A tank holding a quantity of oil is located at some convenient point on the engine. A small force pump is worked from the crank, or cam shaft as the case may be, and forces the oil through brass or copper tubes directly to the bearings and by means of check valves located at the pump and also near the sight feed a pressure of several pounds to the equare inch is obtained and each drop of oil is assured of reaching the proper place. This system requires practically no attention other than an occasional refilling of the tanks.

Where grease cups are used the caps or plungers should be screwed down at least two turns each hour. If a small quantity of graphite, about one tablespoonful to one pound of grease is used, one full turn of the cap or plunger each hour will be sufficient. The graphite and grease should be thoroughly mixed before filling the cup.

The fact that the lubricators are feeding is not a sign that the oil is reaching the proper place. Be sure the ducts are open and the lubricant goes to the bearing.

Where the splash system of lubrication is used the oil holder or base should be carefully cleaned before each filling. Wipe the inside of the holder with waste or a piece of cloth, being careful to remove all the particles of grit and sediment which will collect on the sides and bottom.

Cylinder Lubrication.—In cylinder lubrication extreme caution should be exercised. Just enough oil should be used to thoroughly lubricate the piston and no more. An excess will be burned by the high heat, and will form carbon on the rings, cylinder walls and piston. This carbon will, in a short time, become heated causing pre-ignition and in a four cycle engine frequent regrinding of the valves will be necessary. The piston rings will also stick, causing them to wear uneven, and thereby much of the compression will be lost, as well as a large amount of the power which should be delivered.

From eight to ten drops of oil per minute should be delivered to the cylinder, where common cups or in other words where the gravity system is used. With force feed this amount may be cut to five or six drops a minute, as they are much larger. An excess of oil in the cylinder will make itself known by the smoke from the exhaust pipe.

QUESTIONS AND ANSWERS.

508. In what respect does the gas engine differ from tne steam engine structurally?

Ans. It is a much more ponderous machine than a steam engine of equal output, and usually requires a much heavier crank shaft.

509. Why should this be?

Ans. Because the ordinary four-stroke-cycle, gas engine has only one working stroke in four, and requires four times as much cylinder area for a given amount of work, as would a steam engine for the same work.

510. Define the difference between a single acting four stroke cycle and a double acting or two stroke cycle gas engine in their operation.

Ans. In the four stroke engine two revolutions of the crank are required for one cycle. In the double acting or two stroke, the cycle is completed in one revolution of the crank.

511. Why are gas engine crank shafts made larger in proportion than those of steam engines?

Ans. In order that they may withstand the increased torsional strains.

512. What causes the pressure behind the piston of the gas engine?

Ans. The combustion within the cylinder of a charge of gas and air properly mixed to form an explosive, and admitted at the proper moment.

513. When is this proper moment?

Ans. When the piston is at the end of its instroke ready to start outward.

514. Define the stages of a four cycle engine.

Ans. First, induction; during an out stroke of the piston, air and gas are drawn into the cylinder in the proper proportions. Second, compression; on the return stroke the piston compresses this combustible mixture into the clearance space. Third, explosion; ignition of the compressed charge causes a rapid rise of pressure and subsequent expansion of products. Fourth, expulsion; the expanded gases are expelled by the returning piston.

515. Define the stages of a two cycle gas engine.

Ans. First, compression of the charge. Second, ignition, explosion, and expansion, and at the end of the stroke the expanded products are expelled, and the cylinder filled by another charge of air and gas under pressure.

516. How many compression chambers are needed for the two cycle gas engine?

Ans. Two; for the reason that this type of gas engine requires two cylinders, either side by side, or tandem, and the charge of gas and air is being received in one cylinder, while the previous charge in the other cylinder is being compressed preparatory for explosion.

517. How is the usefulness of the gas engine as a prime mover made apparent?

Ans. By the fact that a suitable power gas may now be produced from almost any kind of commercial fuel.

518. What are the relative volumes of gas and air required for combustion in a gas engine?

Ans. This depends upon the kind of gas. Natural gas requires 10 to 12 cu. ft. of air per cubic feet of gas, while producer gas requires equal volumes of gas and air.

519. Is blast furnace gas suitable for fuel gas?

Ans. Yes, because it is slow burning, thus permitting high compression.

520. To what pressures may it be compressed?

Ans. 160 to 200 lbs. per sq. in.

521. Is there as much heat in a given volume of blast furnace gas as in the same volume of natural gas?

Ans. No, there is about 40 per cent less.

522. How is the charge of gas and air drawn into the cylinder of a gas engine?

Ans. By the suction of the piston.

523. What precaution should be observed regarding the admission of the air and gas?

Ans. The air should be pure and free from dust, and the gas should not contain tarry matters if it can be avoided.

524. How are the induction valves usually set?

Ans. So that the first portion of the charge is air only, then air and gas, and finally air with a small quantity of gas.

525. How is the air valve controlling the entry of the entire charge adjusted?

Ans. It is set to open well in advance of the inner dead center of the engine, and is kept from closing until after the outer dead center.

526. Why is this valve so set?

Ans. In order that the full effect of the momentum imparted to entering gases at the highest rate of piston speed may be utilized.

527. Upon what does the allowable compression pressure depend?

Ans. Upon the relative proportions of hydro-carbon gases, and hydrogen contained in the mixture.

528. What per cent of hydrogen is considered within the limits of safety?

Ans. Not over 7 per cent.

529. What are the usual compression pressures carried with blast furnace gas?

Ans. 200 lbs. per sq. in.

530. What pressure may be safely carried when producer gas is used?

Ans. From 150 to 200 lbs. per sq. in.

531. If illuminating gas is used, what is the maximum safe pressure?

Ans. 120 lbs. per sq. in.

532. How is the cylinder cooled and cleaned?

Ans. By the injection of water or cold air through the clearance spaces, and valve ports during the charging stroke, or by pressure during compression.

533. What other methods are available for cooling the cylinder and piston rod?

Ans. By means of a water jacket that surrounds the cylinder. The piston rod may be hollow and water circulated through it.

534. How is the charge of gas and air ignited?

Ans. Formerly by hot tubes of porcelain or hecnum, which are still used to some extent, but at the present day electrical ignition devices are used principally.

535. What kind of electrical devices are used for this purpose?

Ans. Primary batteries, storage batteries, and magneto machines, or the current may be taken from the lighting, or power circuit.

536. How many types of primary batteries are in common use?

Ans. Two—Dry and wet batteries.

537. What are the elements commonly used in the wet battery?

Ans. Carbon and zinc immersed in a jar or cell containing a solution of sal ammoniac, or sulphate of copper.

538. Describe the copper oxide battery.

Ans. It consists of a plate of copper oxide, and a zinc plate, both being immersed in a solution of caustic potash.

539. What is the usual voltage of these cells?

Ans. From 1 to 2 volts per cell.

540. Describe in brief the construction of the storage cell?

Ans. It consists of gridded frames of lead, part of which are filled with red lead for the positive plates, and those for the negative plates are filled with litharge, all being immersed in a solution of 6 parts of water to 1 part of sulphuric acid.

541. How is a dry battery made?

Ans. A round zinc case forms one of the elements, and a piece of carbon in the center of the case forms the other element.

542. Are there any other ingredients?

Ans. Yes—A mixture of powdered manganese, carbon, and flour is packed around the carbon, while the rest of the can is filled with a plaster mixture of oxide of zinc and flour, and the whole is soaked in a solution of sal ammoniac and zinc chloride.

543. In what manner does the electric current ignite the charge of gas in the cylinder?

Ans. By means of the jump spark caused by alternately making and breaking the circuit.

544. What is one of the most important features connected with ignition?

Ans. To see that ignition occurs at the proper moment.

545. At what point in the stroke of the piston should ignition occur?

Ans. This depends upon the quality of the gas used. With the maximum allowable percentage of hydrogen, ignition should not occur until after the piston has passed the inner dead center. Otherwise the result will be violent shocks, and strains upon the working parts.

546. Do high initial explosions create the most powerful efforts behind the piston?

Ans. They do not.

547. What are the usual terminal pressures for gas engines?

Ans. 25 to 30 lbs. above atmospheric pressure.

548. How is the horse power of a gas engine calculated?

Ans. Usually from the same formula used in connection with the steam engine, and the computation is based upon the mean effective pressure developed at each explosion.

549. What percentage of the total calorific value of the coal is usually converted into useful work with the steam engine?

Ans. From 5 to 10 per cent.

550. What percentage of the energy contained in the fuel is it possible to utilize with a modern gas-driven unit?

Ans. From 16 to 20 per cent.

551. How many type of apparatus are in use for the production of gas for power?

Ans. Three: the suction producer, the steam pressure producer, and the induced down draft producer.

552. What kind of fuel must be used in the suction, and steam pressure producers?

Ans. Coke, or anthracite coal.

553. What kind of fuel is the induced down draft producer adapted for?

Ans. Bituminous coal.

554. How may gas engine efficiency be expressed?

Ans. In terms of heat value.

555. Is there any difference of importance between a gas engine, and a gasoline or oil engine?

Ans. None of any importance. A gas engine may be easily converted into a gasoline engine, or vice versa.

556. Wherein lies the principal difference between the two kinds of engines?

Ans. In the gas engine proper the gas is supplied to the cylinder by the producer. In the gasoline engine the gas is generated within the cylinder, from a charge of gasoline.

557. How may the action of the gas within the cylinder of a gas engine be ascertained?

Ans. By means of diagrams taken with an indicator.

558. Is there any difference between a steam engine indicator, and an indicator adapted for gas engines?

Ans. None in principle. The gas engine indicator is made somewhat stronger owing to the high pressures used.

Modern Types of Oil Engines

Diesel Engine.—This engine is built in both the four-cycle and two-cycle styles. Vaporization of the oil takes place within the cylinder itself, where the pressure of compression is carried sufficiently high to cause combustion of the fuel. The oil is injected through a valve at the top of the cylinder, which is vertical, and as the fuel enters the cylinder after the period of compression, about 600 pounds pressure per square inch is required for the injection. This pressure is supplied by an independent air compressor. The air necessary to support combustion is introduced through an air inlet valve.

Figure 1 represents cross-sections of the working cylinder and head of a stationary two-stroke motor. The arrangement of slots in the cylinder wall, through which the exhaust gases leave the working cylinder, as the piston comes near the lower dead point,

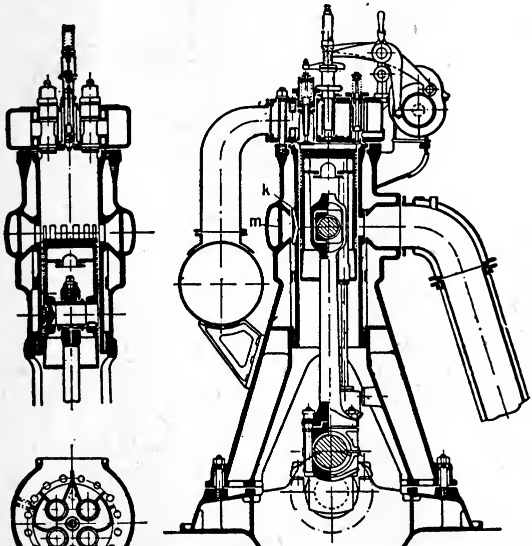


FIG. 1

Sectional view of Diesel two-stroke cycle engine.

is, of course, a typical feature of two-stroke motors. This arrangement is an undoubted advantage over four-stroke motors, which discharge their exhaust gases through valves. The admission of scavenging and charging air is affected through four valves, arranged symmetrically in the cylinder head.

As seen from the figure, the piston comprises at its upper end a cooling compartment, pistons above a given size having to be cooled with water or oil. Telescoping tubes through which a water jet in free contact with air is projected directly against the bottom of the piston serve to admit and carry away cooling water, an arrangement which avoids any stuffing boxes.

It is true that the two-stroke process entails the use of a special scavenging pump to discharge the exhaust gases. Four-stroke motors, which are more simple from a constructive point of view,

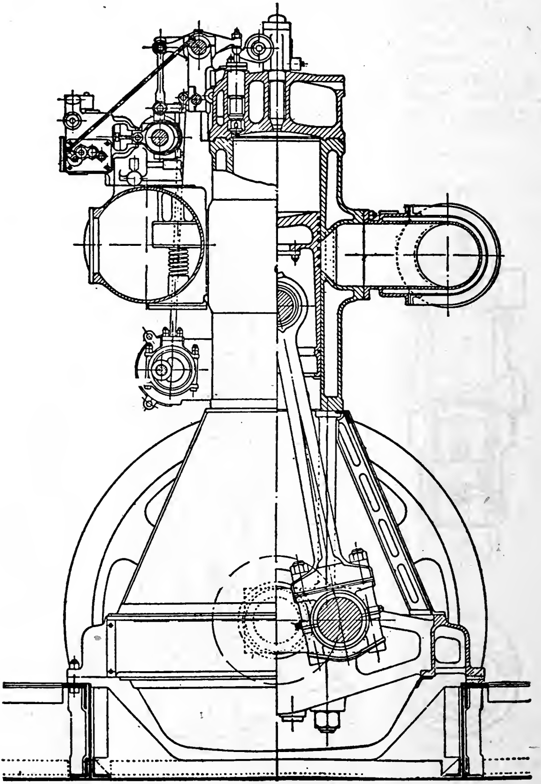


FIG. 2

Section of Diesel two-stroke marine engine.

are therefore generally preferable for small and medium installations. In connection with large units, the addition of an air pump, however, is of much less importance, the more so as the pump discharging the scavenging air works at very low pressures and accordingly under extremely favorable conditions. On the other hand, the reduction in weight is of paramount importance for large units, the frames, bases and flywheels of large four-stroke motors being so heavy that their transportation and erection entail serious difficulties.

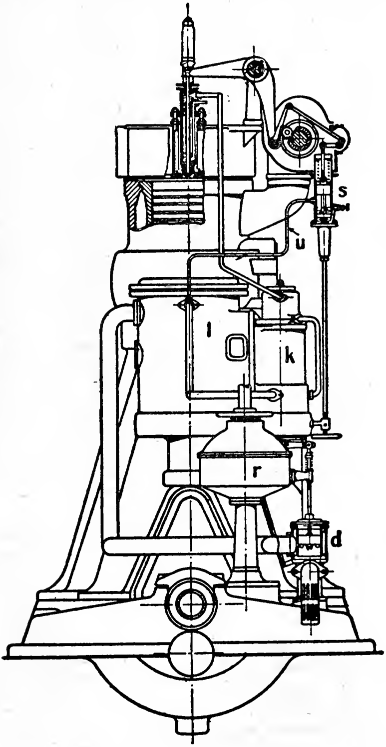


FIG. 3
Scheme of injection air regulation.
Diesel Engine.

The two-stroke Diesel motor resembles the four-stroke type as far as its outside arrangement is concerned. The cylinders are likewise vertical; their jackets are cast of one piece with the frame, the working cylinders are encased and the piston is designed as crosshead. Apart from the compressed air pump, which serves to introduce fuel oil into the cylinder and to start the engine, two-stroke motors comprise a scavenging air pump arranged, in accordance with local conditions, in the basement or above the floor. The scavenging air valves, like the other valve, are arranged in the cylinder head. The exhaust valves are, however, replaced by slots in the working cylinder, and the fuel supply is regulated automatically in accordance with the load on the engine. All motors of this type have an attachment for changing speed during operation.

Figure 2 shows a cross-section through a directly reversible Sulzer-Diesel marine engine, which has likewise been designed as two-stroke.

In connection with large units the special regulation developed by the constructors would seem to deserve more than passing notice. These engines are thus in a position to deal with any sudden fluctuations in load with least variation in speed and at the same time can be readily connected up in parallel with any other prime movers of the same or any different type, such as steam engines, gas motors and water turbines. The working of the regulator will be understood by referring to Figure 3.

The governor controls, in accordance with its adjustment, all the factors on which the output of the engine depends. These factors in the case of Diesel motors are the amount of fuel injected, the amount and pressure of the injection air required for vaporizing and injecting the fuel, as well as the variable admission of the vaporizer valve in accordance with the amounts of air and fuel. The amount of fuel, as well as the amount of pressure of the injection air, are adjusted for directly from the regulator. The regulation of the amount of injection air in the present instance is affected by adjusting a slide fitted into the suction conduit of the first stage of the injection air pump. The adjustment of the duration of opening of the fuel valve, on account of the valve resistance, however, requires much more energy, so that the action of the regulator itself would not be sufficient. A pilot valve S has therefore been provided, which is operated by the pressure

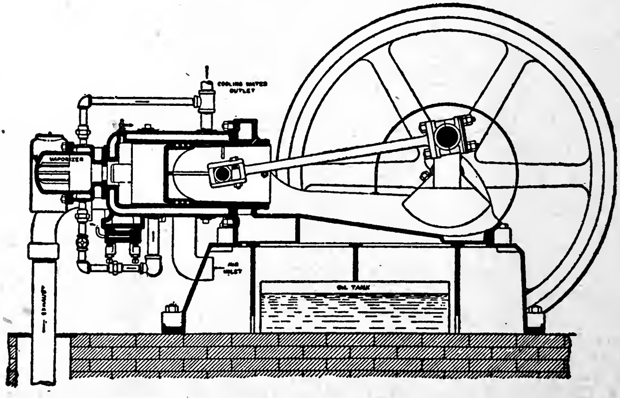


FIG. 4
Hornsby-Akroyd horizontal engine.

from one of the stages of the injection air pump. In the present instance the pressure obtaining between the first stage l, and the second stage k, of the injection pump is used for this purpose, the conduit u serving to transmit this pressure to the pilot valve S.

HORNSBY-AKROYD OIL ENGINE.—In this engine, a sectional view of which is shown in Figure 4, the oil is first introduced in liquid form into the vaporizer shown at the back of the cylinder. The heat necessary for vaporizing the oil is supplied at starting by external lamps, but when the engine is in operation the continued combustion of the fuel supplies sufficient heat for both vaporiza-

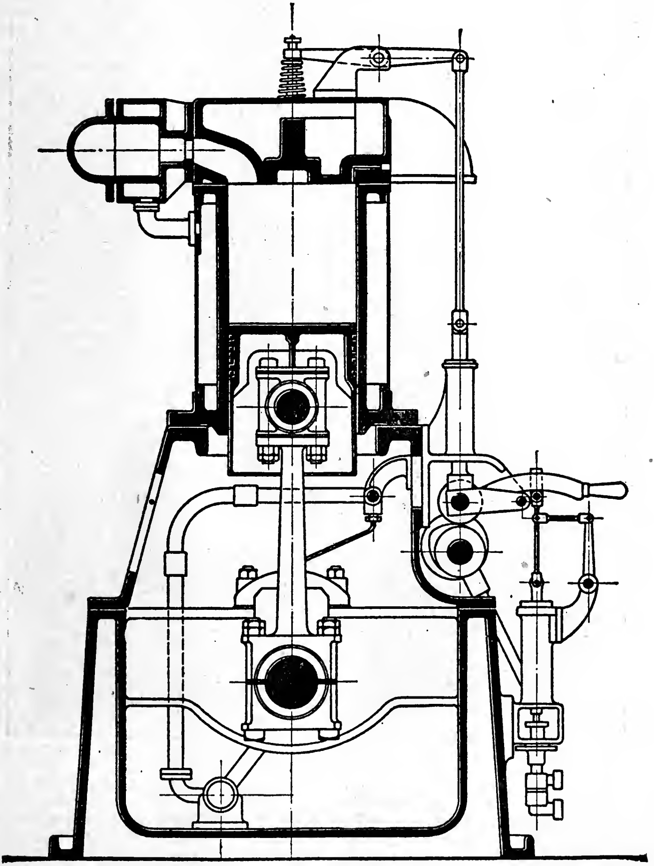


FIG. 5

Hornsby-Akroyd vertical engine.

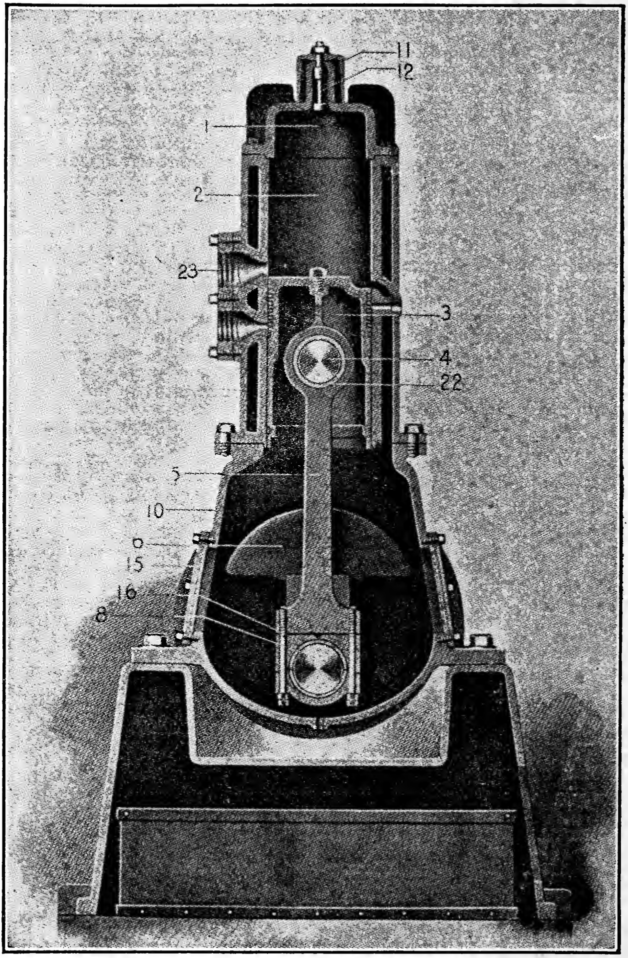


FIG. 6

Names of Parts.

13 Oil spraying nozzle.
14 Control lever.
15 Hand hole cover.
16 Crankpin brasses.
17 Flywheel.
18 Governor weight.
19 Cam.
20 Stud carrying governor weight.
21 Crankcase end plate.
22 Wrist pin bushing.
23 Exhaust pipe flange.
24 Speed control segment.
25 Bracket carrying control lever.

tion and ignition. Air necessary for combustion is introduced into the cylinder during the suction period of the cycle, this being a four-cycle engine. Thus the cylinder becomes charged with air and the vaporizer becomes filled with a spray of oil, both events occurring simultaneously. During the compression period the air in the cylinder, being forced into the vaporizer, becomes properly mixed with the oil and an explosive mixture is formed. The deposit of carbon frequently found where crude oil is used does not enter the cylinder nor come in contact with the piston or piston rings, but is formed in the vaporizer cap. A flange cover at the back of the cap allows the quick removal of this deposit periodically, usually about every sixty hours of running. In the vertical type of the Hornsby-Akroyd engine, shown in section in Figure 5, the vaporizer is placed horizontally on the side of the cylinder, while the air and exhaust valves are located in housings in the top cover. As is the case with the horizontal type, shown in Figure 4, the ignition of the gases in the cylinder is caused automatically by the heat of compression, together with the heat stored in the walls of the vaporizer. The method of governing consists in the automatic lengthening and shortening of the stroke of the oil supply pumps, thus giving very close regulation.

REMINGTON OIL ENGINE.—The Remington oil engine is of the vertical type, operating on the two-stroke cycle, the fuel being introduced into the combustion chamber as a liquid and gasified within this chamber. The engine is valveless, the gases being moved into and out of the cylinder through ports uncovered by the movement of the piston, which itself performs also the function of a pump. The action is as follows:

On the up-stroke of the piston a partial vacuum is created in the enclosed crankcase, causing air to rush in when the bottom of the piston uncovers the inlet port seen directly under the exhaust port (23), Figure 6. On the next down-stroke this air is compressed in the crankcase to about four or five pounds pressure per square inch. Meanwhile the mixture of oil, vapor and air already in the cylinder is burning and expanding. When the piston approaches the end of its down-stroke, it uncovers the exhaust port (23), permitting the burnt charge to escape, until its pressure reaches that of the atmosphere. Directly afterward the transfer port on the opposite side of the cylinder is uncovered by the piston, thereby allowing a portion of the air compressed in the crankcase to rush into the cylinder, where it is deflected upwards by the shape of the top of the piston and caused to fill the cylinder, thereby expelling the remainder of the burnt charge. The piston now starts upward, compressing the fresh charge of air into the hot cylinder head. Near the end of the stroke a small oil pump, mounted on the crankcase and controlled by the governor, injects the proper amount of oil through the nozzle (13), Figure 7, into the compressed and heated air.

This oil is atomized in a vertical direction through a hole near the end of the nozzle. It is therefore vaporized and gasified before there is a possibility of its reaching the cylinder walls.

The spray of oil is ignited by the nickel steel plug (12), which is kept red hot by the explosions, because the iron walls surrounding it are protected from radiation by the hood (11). By the burning of the oil spray in the air the pressure is gradually increased and the piston forced downward, this being the power or impulse stroke. Near the end of the down-stroke the exhaust port is again uncovered and the burnt gases discharged.

The operations above described take place in the cylinder and crankcase with every revolution. Each up-stroke of the piston draws fresh air into the crankcase and compresses the air transferred to the cylinder. Each down-stroke is a power stroke and at the same time compresses the air in the crankcase preparatory to transferring it to the cylinder by its own pressure at the end of the stroke.

The same volume of air enters the cylinder under all conditions, and the power is regulated by modifying the stroke of the oil pump, which may be done by hand or automatically by the governor in the flywheel.

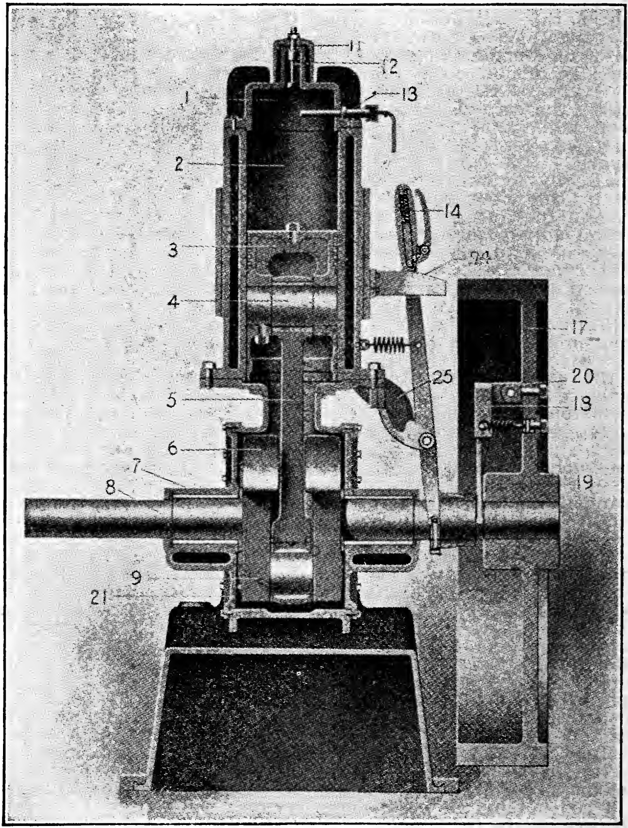


FIG. 7

Names of Parts.

1 Cylinder head.
2 Cylinder.
3 Piston.
4 Wrist pin.
5 Connecting rod.
6 Counter balance weights.
7 Main bearing cap.
8 Crankshaft and crankpin.
9 Crank oil hole.
10 Crankcase.
11 Hood on cylinder head.
12 Igniter plug of nickel steel.

Governor and Control.—The governor is of the centrifugal type. It has an L-shaped weight (18), Figure 7, pivoted to the piece (20) attached to the flywheel. As the engine speed increases the weight (18) tends to swing outward toward the flywheel rim, and thereby moves the arm attached to it so as to shift the cam (19) along the crankshaft toward the left in the figure.

This cam turns with the shaft, and operates the kerosene oil pump. According to the position of the cam on the shaft, it will impart to the pump plunger a long or a short stroke, thereby injecting more or less oil into the cylinder. The long lever pivoted on the bracket (25) moves with the cam (19) and is used for controlling the engine's speed by hand. To stop the engine the handle (14) of the lever is pulled towards the flywheel, thereby interrupting the pump action altogether.

The handle of the control lever can be fitted with an adjustable speed regulator when required. This device is for use on marine engines to enable the operator to slow down the engine. The speed regulator does not interfere with the action of the governor, but acts in conjunction with it. Whatever the speed of the engine may be, it is under the control of the governor. The engine can be controlled from the pilot house if such an arrangement is desirable.

All Remington oil engines are built to operate on all grades of ordinary kerosene oil, while several sizes are built especially to operate on lower grade, semi-refined fuels, which have a variety of names and composition, such as fuel oil, Diesel oil, distillate, solar oil, gas oil, etc.

Starting.—To start the engine, the hollow cast-iron projection rising from the cylinder head is heated by the kerosene torch furnished with the engine. When it is hot, a single charge of oil is injected into the cylinder by working the hand lever connected with the pump. The flywheel is now turned smartly backward, thereby compressing the charge, which ignites before the piston reaches the highest point, and starts the engine in the forward direction.

After the engine has been started the starting torch may be extinguished. Ignition will take place continuously and the engine will not miss fire under varying loads.

Cylinder.—The cylinder is provided with a water jacket extending practically its full length. This insures thorough cooling of the piston and increases the efficiency of the lubrication.

This water jacket is provided with two long hand hole plates on opposite sides of the cylinder, which may be conveniently removed for inspecting and removing sediment from the water jacket space.

Ignition.—Rising from the center of the head is a hollow cast-iron projection, which contains the nickel steel igniter plug by which the oil gas is ignited. This plug is practically indestrucible by heat, and as it is permanently located at an exact point found correct by trial, it fires the charge at the right moment under all conditions.

Fuel Pump.—The fuel pump is made of bronze. The valves are made of bronze and are specially designed with very large areas and are very carefully fitted and ground. The plunger is made of tool steel and is hardened and ground. A bronze cup strainer is attached to the lower end of the pump to prevent sediment or foreign matter from reaching the pump valves.

Head.—The cylinder head is cast separately from the cylinder and has no water jacket about it. The packing between the head and cylinder is copper-asbestos. The head can be removed any number of times without injuring the packing. The nuts which hold the head are fitted to the cylinder studs so that they can be removed without pulling out the studs.

Air Compression

The compression of air always develops heat, and owing to the fact that compressed air always cools down to the temperature of the surrounding medium before it is used, there is a certain amount of work lost through the dissipation of this heat, the lost work being represented by the mechanical equivalent of the dissipated heat. In order to have a given volume of compressed air, at a given pressure at the locality where it is to be utilized for industrial purposes it is necessary to carry a higher pressure in the air compressor, for the reason that the heat of compression increases the volume of the air, and the work done in maintaining this excess pressure is work lost, heat energy dissipated. Another source of loss of power in air compression is the friction of the air in the pipes through which it is conveyed. Then there are dead spaces to be kept filled; leakages; the resistance offered by the valves; insufficient valve area, and various other causes of loss. The loss of the heat developed by compression is unavoidable. All of the mechanical energy that the compressor-piston exerts upon the air taken into the cylinder is converted into heat, and this heat being dissipated by radiation and conduction, its mechanical equivalent is lost work. It might be inferred from the above statement that the work, or in other words, the heat energy expended in running an air compressor, is expended upon a useless toy, merely for amusement; but not so, because the compressed air, when it again reaches thermal equilibrium with the surrounding atmosphere, expands and does work by reason of that intrinsic energy which is exerted by it in the effort it always makes to change from a given temperature, and volume, to a state of total absence of heat, and indefinite expansion. It is unnecessary to enlarge upon the usefulness of the air compressor, nor to mention the many ways in which compressed air is made to conduce to the welfare and comfort of man, as these facts are well known. A short section will be devoted to a discussion of the various methods employed in the utilization of this great natural force.

Air compression is generally accomplished by one of the two methods, technically termed *Isothermal,* wherein the heat of compression is carried away as fast as it is developed; and *Adiabatic* in which no heat is removed from the air, and a consequent rise of temperature attends the operation. Diagrams indicating the line of compression will demonstrate the resulting loss of power, due to not extracting the heat developed by compression.

In the first case the compressed air will be delivered at a temperature corresponding to that at which it entered the cylinder.

In the second, the air delivered under pressure will be at the high terminal temperature corresponding to that pressure. The first kind of compression is the theoretical ideal; but impossible of attainment. The second method of compression is the one which all pneumatic engineers endeavor to avoid as much as possible. The actual results secured in the best compressors are intermediate between these, but nearer to the second. Other things being equal, the economy of an air compressor is proportional to the degree in which the heat of compression is removed as fast as it is developed. The efficiency of the compressor, therefore, may be said to depend upon the effectiveness of

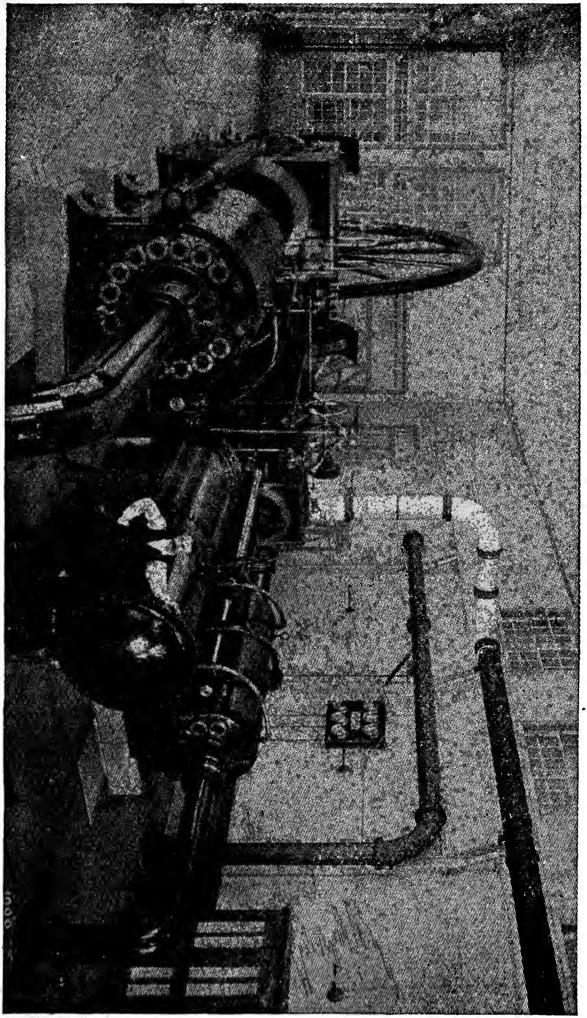


FIG. 345

THE LARGEST AIR COMPRESSOR IN THE WORLD

Ingersoll-Sergeant Corliss Air Compressor—Compound Steam and Compound Air Cylinders with Semi-Tangye Frame. Steam Cylinders, 32 and 60 Inches; Air Cylinders, 52¼ and 32¼ Inches; Stroke, 72 Inches.

the cooling devices adopted, provided that what is gained in this way is not elsewhere wasted in whole or in part. After long experience modern practice in air compressor design recognizes only two practical methods of removing the heat of compression: viz., jacket cooling and inter-cooling. These will be considered in order.

Jacket Cooling.—Jacket cooling seeks to remove the heat of compression as it arises, through the cylinder walls which are kept at a low temperature by cold water circulating in a surrounding jacket. A brief consideration of the conditions will show that jacketed barrel cooling alone can be only a partial and very unsatisfactory solution of the problem.

With the piston at the beginning of its stroke, the maximum cold cylinder surface is exposed and the cylinder is filled with air at its lowest pressure and temperature. As the piston advances, pressure and temperature increase, while the exposed area of cooling surface diminishes; and when the maximum pressure and temperature are attained near the end of the stroke, there is practically none of the cylinder walls exposed except on the other, or intake, side of the piston; and if the head, too, is jacketed, it alone remains to exert any cooling influence. Furthermore, throughout the stroke only the outside layer of the air can be in contact with the cold surface and, air being a poor conductor of heat, none of the heat from the interior of the air volume is absorbed in the cooling water. Cylinder jacketing is advisable and even essential, in keeping the metal of the working parts at a low temperature, preventing the coking of lubricant upon the cylinder walls and other evils of a hot machine. But it cannot of itself be considered as an adequate solution of the problem of cooling during compression.

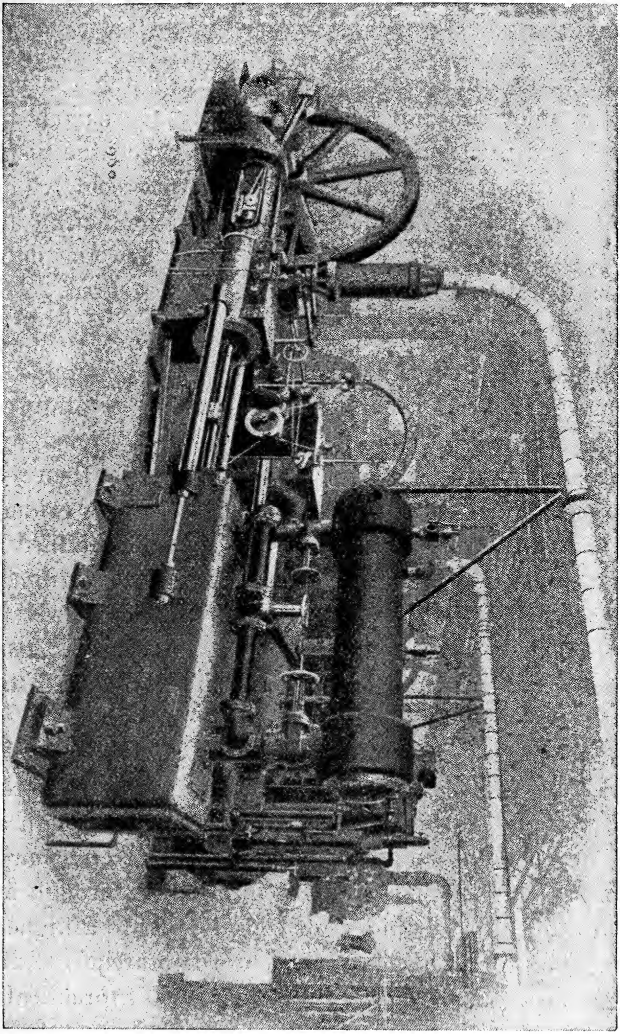


Fig. 346

ONE OF THE TWO LARGEST HIGH PRESSURE AIR COMPRESSORS IN THE WORLD

Ingersoll-Sergeant Corliss High Pressure Air Compressor—Compound Steam and Four Stage Air Cylinders with Semi-Tangye Frame. Steam Cylinders, 20 and 40 Inches; Air Cylinders, 37¼, 20¼, 12½ and 6 Inches; Stroke, 48 Inches; Capacity, 2,000 Cubic Feet Per Minute. Pressure, 950 Pounds.

However, in those constructions involving the use of a piston inlet tube and valve, not only the barrels but the heads and inlet valves, too, are chilled; and the piston and tube themselves are kept relatively very cold. Thus the air enters through a cold passage, is in contact on all sides with cold metal throughout the stroke and the maximum effect obtainable from jacketing alone is secured.

Compound Compression—Intercooling.—If at several points in the stroke, the piston should be stopped for a moment and the air, already partially compressed and heated, be withdrawn long enough to be cooled by some external means to its initial temperature, and then returned to the cylinder to be further compressed, it is evident that a fairly uniform temperature could be maintained in the air volume throughout the range of pressures from initial to terminal. The result would be in effect nearly that of isothermal compression. But while mechanical considerations forbid in practice such repeated starting and stopping of the piston, practically the same results may be secured by carrying on the process of compression in several cylinders, in the first of which a given low pressure is reached, and the air, at this pressure is discharged through a cooling device to a second cylinder, in which it is compressed to a still higher pressure, and discharged through another cooler to a third cylinder for compression to a higher pressure, the process being repeated until the required pressure is reached. Such a process, developed to a practical working basis is the compound method of air compression in multi-stage cylinders which has become practically standard in air compressors for the higher pressures.

Multi-Stage Compression.—Theoretically there is a gain in compound compression, regardless of the pressure, but with the lower pressures the saving is so small as to be offset by the greater expense and complication involved in having several cylinders, and the losses that are unavoidable in the operation of the additional parts. After extended experience, makers of air compressors have fixed upon 70 to 100 lbs. gauge as the maximum terminal pressure that can be best attained in simple cylinders, and for pressures from 75 lbs. up they have adopted compound compression in two, three, and four stage machines, the number of stages increasing with the pressure required at terminal. At high altitudes, however, with large volumes, and expensive fuel, this dividing line may come at a lower pressure. It is elastic, and depends somewhat upon the conditions.

The cylinder ratios in a correctly designed compound air compressor are such that the final temperature, and the mean effective pressures are equal in all cylinders, and all of the pistons are therefore equally loaded. The air compressed in the first cylinder to a pressure determined by the cylinder ratios is discharged through the outlet valves to an intercooler, where it is split up into thin streams passing over cold surfaces. The best practice involves a nest of tubes through which cold water circulates, and over, and between which the stream of air passes, a complete breaking up and subdivision of the stream being secured by baffle plates, and the tubes themselves. In cases of very high pressure the air may pass through the tubes, for structural reasons. A properly designed intercooler having sufficient cooling area for the volume of air may reduce the temperature of the air compressed in the first cylinder to at least outgoing water temperature.

From the intercooler this air, entering the second cylinder cold, is compressed to a higher pressure and again

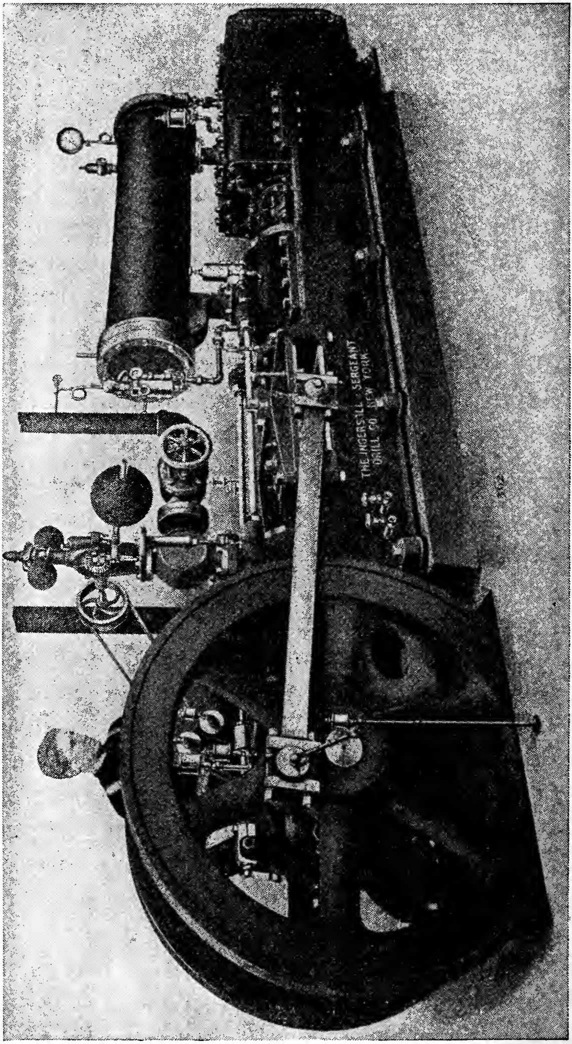


FIG. 347

INGERSOLL-SERGEANT CLASS "A-2" THREE STAGE STRAIGHT LINE STEAM DRIVEN AIR COMPRESSOR reaches a temperature about the same as that attained in the first cylinder. In two stage machines this air will be discharged directly to the receiver without further cooling, unless conditions are such as to render advisable the use of an aftercooler. In three stage machines the second cylinder will be known as the intermediate, from which the air will pass to the second intercooler, undergo a second reduction of temperature, and enter the third cylinder for final compression to required pressure.

It is seen that multi-stage compression is in effect identical with the theoretical process already suggested, in which the compressing piston was stopped and the air cooled at intervals during the stroke. The maximum cooling effect and saving is secured by making the intercoolers of ample proportions, and providing for the splitting-up of the air stream into thin sheets exposed to cooling action.

Reduced Strains.—When compression is carried on in a single cylinder, the difference in the pressures at the beginning and end of stroke is the total difference between initial and terminal pressures, implying a great variation in strains on the driving mechanism and the structure of the machine. The greatest strains come near the end of the stroke, and are almost instantly relieved when the inlet valves open. Thus the terminal strain on a 20-inch cylinder having 314 square inches area at 100 pounds pressure will be 31,400 pounds or nearly 16 tons. At 100 revolutions this strain is repeated 200 times per minute and demands a very rugged construction. This is a condition not conducive to easy operation in any but the most massively proportioned compressors. In compound compression, on the other hand, the difference between initial and terminal pressures in each cylinder is but a fraction of the total range of pressure. The pressures, furthermore, are partially balanced in the several cylinders. The working strains on valves and other parts are consequently greatly diminished, resulting in a greatly reduced wear and liability to breakage, and securing free lubrication and a noticeable improvement in the smooth, easy operation of the machine. These are all facts which contribute to continuous and satisfactory service, with the least possible adjustment and attention.

As a matter of fact, compounding the air cylinders transfers so much of the load from the later to the earlier part of the stroke that the maximum terminal strain on bearings is reduced fully 45 per cent over those in single stage compression; in the above case, from 3,140 "ton minutes" to 1,727—obviously a much easier proposition, mechanically. Misled by this point, it has been common practice to reduce the weight and size of bearings accordingly, the mistake being evident, however, when it is remembered that the stoppage of circulating water in the cooler at once raises the load on the low pressure piston; while a broken or damaged outlet valve on the high pressure cylinder may at any moment throw the same load on all parts as with a single cylinder machine.

Improved Steam Economy.—The more equable distribution of the load throughout the stroke in compound compression, just noted, also aids in securing a higher economy in steam consumption at the other end of the machine; for it makes possible an earlier cut-off in the steam-cylinder and a consequently greater steam expansion with its attendant saving; late cut-offs not being so necessary to prevent "centering". Multi-stage compression with effective intercoolers between stages, also permits a higher piston speed, which is another factor in steam economy.

Higher Volumetric Efficiency.—The air remaining in the clearance space at the end of the stroke must be expanded on the return stroke to atmospheric pressure before free air can enter through the inlet valves. The higher the pres-

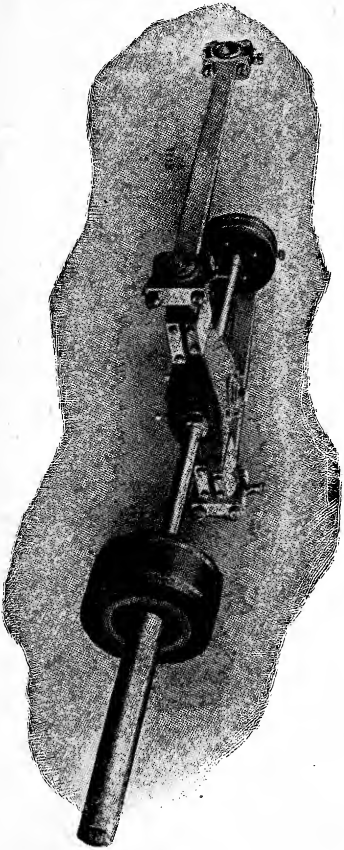


FIG. 348

AN ILLUSTRATION OE THE "STRAIGHT LINE" PRINCIPLE

Showing the Arrangement of the Crosshead, Pistons, Piston Rods and Connecting Rods of the Class "A" Machine sure in this clearance space, the greater will be the volume of expansion and the lower the intake efficiency of the cylinder.

In single stage compression, the clearance pressure is the working pressure, while in compound compression, clearance pressure in each cylinder is terminal pressure in that cylinder. But in the intake cylinder this terminal pressure is low usually not over 25 lbs. when the final working pressure is 100 lbs. The volumetric efficiency of compound compression cylinders is higher for this reason, the clearance in the low pressure cylinders only being in question. Another condition conducive to high volumetric efficiency resulting from compound compression is the fact that terminal pressures, and consequently terminal temperatures are lower than in single stage cylinders.

The cylinder walls, and more particularly the heads, with the valves and ports which may be in the heads, are therefore kept much cooler, and the entering air is not much heated by contact with these parts. A third element entering into the question of capacity is the reduced leakage in stage compression cylinders, through valves, and past pistons and rods, with consequent loss of power. It is evident that the higher the pressure the greater the liability to leakage; and the smaller range of partly balanced pressures in multi-stage cylinder reduces this loss.

Drier Air.—One of the greatest difficulties encountered in air power transmission is the freezing of the moisture in the air, either in the pipe line, or at the exhaust ports of the air motors. One of the great advantages of the subdivision of compression into several stages lies in the opportunity it affords for cooling the compressed air at intermediate stages to a temperature at which its moisture will be precipitated. Of course, practically all of this condensation occurs in the inter, and aftercoolers: and herein appears the necessity for a design which will pass the air at low velocity with full opportunity for cooling on the water tubes. The moisture in suspension is withdrawn through the drain pipe. It is needless to say that unless some provision is made for arresting and withdrawing the condensed water from the intercooler, the value of the latter as an air drier is lost; for the moisture is carried over into the compression cylinders, producing a condition of cutting and leakage in valves and rings and finally working out into the pipe line. Aftercoolers are in some instances as important as intercoolers in removing moisture.

Better Lubrication.—If air be compressed in a single cylinder from atmospheric pressure and temperature of 60° F. to a final pressure of 100 pounds, the maximum temperature attained may be 484° F. This temperature is manifestly destructive to common lubricants, and oils of ordinary quality are burned into a solid, gritty, coke-like or gummy substance which gives the very reverse of proper lubrication, unless proper jacketing devices are employed to keep the parts cold. This deposit, moreover, collecting in ports and valves, may so obstruct and clog them as to cause leakage, and throw an added load on the compressor. If, however, this same volume of air be compressed in the first cylinder to a pressure of 25 pounds, the highest temperature which can be reached is only 233°—a heat which will not leave a deposit or destroy the lubricating qualities of good oils such as should be used in compressor work. This air, passing through the intercooler, will be brought back to about the original temperature of 60° and compressed (in a two stage compressor) from 25 to 100 pounds in the second cylinder. Here the maximum temperature attained will be but little (if any) in excess of that in the first cylinder, since the heat of compression is a function of the number of compressions, and is almost wholly independent of the initial pressure. In multi-stage compressors, therefore, the conditions of temperature are seen to be most conducive to thorough lubrication of pistons and valves, tending toward durability and tightness of working parts, with long life and high efficiency of the machine.

For pressures exceeding 100 pounds per square inch, for economy and safety, compounding is recommended, and for pressures exceeding say 400 pounds per square inch, multi-stage compression.

For pressures under 100 pounds per square inch, factors must enter into consideration upon which local conditions have a bearing, viz., first cost, comparing cost of installation of single, and two stage machines, cost of fuel, and horse power developed.

Table 39 of horse powers developed under multi-stage compression is upon the following basis: Water-jacketed cylinders with temperature of air reduced to 60° F. in the intercoolers. Atmosphere at 60°. Three per cent approximately allowed for friction of piston for each cylinder.

TABLE 39

HORSEPOWER REQUIRED TO COMPRESS 100 CUBIC FEET FREE AIR FROM ATMOSPHERE TO VARIOUS PRESSURES.

Gauge Pressure, Pounds.	One-Stage Compression, D. H. P.	Gauge Pressure, Pounds.	Two-Stage Compression, D. H. P.	Four-Stage Compression, D. H. P.
10	3.60	60	11.70	10.80
15	5.03	80	13.70	12.50
20	6.28	100	15.40	14.20
25	7.42	200	21.20	18.75
30	8.47	300	24.50	21.80
35	9.42	400	27.70	24.00
40	10.30	500	29.75	25.90
45	11.14	600	31.70	27.50
50	11.90	700	33.50	28.90
55	12.67	800	34.90	30.00
60	13.41	900	36.30	31.00
70	14.72	1000	37.80	31.80
80	15.94	1200	39.70	33.30
90	17.06	1600	43.00	35.65
100	18.15	2000	45.50	37.80
...	.....	2500	.....	39.06
...	.....	3000	.....	40.15

TABLE 40

CONTENTS OF CYLINDER IN CUBIC FEET FOR EACH FOOT IN LENGTH.

Diameter in Inches.	Cubic Contents.	Diameter in Inches.	Cubic Contents.	Diameter in Inches.	Cubic Contents.
1	.0055	8¾	.4175	21	2.405
1¼	.0085	9	.4418	21½	2.521
1½	.0123	9¼	.4668	22	2.640
1¾	.0168	9½	.4923	22½	2.761
2	.0218	9¾	.5185	23	2.885
2¼	.0276	10	.5455	23½	3.012
2½	.0341	10¼	.5730	24	3.142
2¾	.0413	10½	.6013	25	3.409
3	.0491	10¾	.6303	26	3.687
3¼	.0576	11	.6600	27	3.976
3½	.0668	11¼	.6903	28	4.276
3¾	.0767	11½	.7213	29	4.587
4	.0873	11¾	.7530	30	4.909
4¼	.0985	12	.7854	31	5.241
4½	.1105	12½	.8523	32	5.585
4¾	.1231	13	.9218	33	5.940
5	.1364	13½	.9940	34	6.305
5¼	.2503	14	1.069	35	6.681
5½	.1650	14½	1.147	36	7.069
5¾	.1803	15	1.227	37	7.468
6	.1963	15½	1.310	38	7.886
6¼	.2130	16	1.396	39	8.296
6½	.2305	16½	1.485	40	8.728
6¾	.2485	17	1.576	41	9.168
7	.2673	17½	1.670	42	9.620
7¼	.2868	18	1.767	43	10.084
7½	.3068	18½	1.867	44	10.560
7¾	.3275	19	1.969	45	11.044
8	.3490	19½	2.074	46	11.540
8¼	.3713	20	2.182	47	12.048
8½	.3940	20½	2.292	48	12.566

Air compression at mountain, or high altitudes is considerably more expensive than at sea level. This is due to the fact that the capacity of the compressor decreases in a greater ratio than does the power necessary to compress. At an altitude of 10,000 feet above sea level this extra expense amounts to over 20 per cent. Table 41 gives the efficiencies of the compressor at various altitudes.

TABLE 41

EFFICIENCIES OF AIR COMPRESSORS AT DIFFERENT ALTITUDES.

Altitude in Feet	Barometric Pressure		Volumetric Efficiency of Compressor, Per Cent	Loss of Capacity, Per Cent.	Decreased Power Required, Per Cent.
	Inches Mercury.	Pounds per Sq. In.			
0	30.00	14.75	100	0	0
1000	28.88	14.20	97	3	1.8
2000	27.80	13.67	93	7	3.5
3000	26.76	13.16	90	10	5.2
4000	25.76	12.67	87	13	6.9
5000	24.79	12.20	84	16	8.5
6000	23.86	11.73	81	19	10.1
7000	22.97	11.30	78	22	11.6
8000	22.11	10.87	76	24	13.1
9000	21.29	10.46	73	27	14.6
10000	20.49	10.07	70	30	16.1
11000	19.72	9.70	68	32	17.6
12000	18.98	9.34	65	35	19.1
13000	18.27	8.98	63	37	20.6
14000	17.59	8.65	60	40	22.1
15000	16.93	8.32	58	42	23.5

Table 42 gives the volume in cu. ft. of free air that will flow from circular openings, of diameter from 1/64 in. to 2 inches, and under pressure of from 2 lbs. to 100 lbs. per sq. in.

TABLE 42

FLOW OF AIR THROUGH AN ORIFICE IN CUBIC FEET OF FREE AIR PER MINUTE.

Flowing from a Round Hole in Receiver into the Atmosphere.

Diam. of Orifice in Inches.	RECEIVER GAUGE PRESSURE. 2 Pounds.	5 Pounds.	10 Pounds.	15 Pounds.	20 Pounds.	25 Pounds.	30 Pounds.	35 Pounds.
1/64	.038	.0597	.0842	.103	.119	.133	.156	.173
1/32	.153	.242	.342	.418	.485	.54	.632	.71
1/16	.647	.965	1.36	1.67	1.93	2.16	2.52	2.80
⅛	2.435	3.86	5.45	6.65	7.7	8.6	10.00	11.2
¼	9.74	15.40	21.8	26.70	30.8	34.5	40.	44.7
⅜	21.95	34.60	49.0	60.	69.	77.	90.	100.
½	39.0	61.60	87.0	107.	123.	138.	161.	179.
⅝	61.0	96.50	136.	167.	193.	216.	252.	280.
¾	87.6	133.	196.	240.	277.	310.	362.	400.
⅞	119.5	189.	267.	326.	378.	422.	493.	550.
1	156.	247.	350.	427.	494.	550.	645.	715.
1¼	242.	384.	513.	665.	770.	860.	1000.	....
1½	350.	550.	780.	960.	....	....	.....	....
2	625.	985.	....	....	....	....	.....	....

TABLE 42—CONTINUED

FLOW OF AIR THROUGH AN ORIFICE IN CUBIC FEET OF FREE AIR PER MINUTE.

Flowing from a Round Hole in Receiver into the Atmosphere.

Diam. of Orifice in Inches.	RECEIVER GAUGE PRESSURE.							
	40 Pounds.	45 Pounds.	50 Pounds.	60 Pounds.	70 Pounds.	80 Pounds.	90 Pounds.	100 Pounds.
1/64	.19	.208	.225	.26	.295	.33	.364	.40
1/32	.77	.843	.914	1.05	1.19	1.33	1.47	1.61
1/16	3.07	3.36	3.64	4.2	4.76	5.32	5.87	6.45
⅛	12.27	13.4	14.50	16.8	19.0	21.2	23.50	25.8
¼	49.09	53.8	58.2	67.	76.	85.	94.	103.
⅜	110.45	121.	130.	151.	171.	191.	211.	231.
½	196.35	215.	232.	268.	304.	340.	376.	412.
⅝	306.80	336.	364.	420.	476.	532.	587.	645.
¾	441.79	482.	522.	604.	685.	765.	843.	925.
⅞	601.32	658.	710.	622.	930.	1004.	....	....
1	785.40	680.	930.	....	....	.....	....	....
1¼	......	....	....	....	....	.....	....	....
1½	......	....	....	....	....	.....	....	....
2	......	....	....	....	....	.....	....	....

TABLE 43

LOSS OF PRESSURE THROUGH FRICTION OF AIR IN PIPES FOR EVERY ONE HUNDRED FEET LENGTH OF PIPE. INITIAL GAUGE PRESSURE, 80 POUNDS AT RECEIVER.

Equivalent Volume of Free Air Discharged per Minute.	SIZE OF PIPE.													
	1 Inch.	1¼ Inch.	1½ Inch.	2 Inch.	2½ Inch.	3 Inch.	4 Inch.	5 Inch.	6 Inch.	7 Inch.	8 Inch.	10 Inch.	12 Inch.	14 Inch.
25	.24	.12	....	....	.....	....	....	....	.....	.....	.....	.....	.....	.....
50	1.00	.45	.18	....	.....	....	....	....	.....	.....	.....	.....	.....	.....
75	2.4	1.0	.4	....	.....	....	....	....	.....	.....	.....	.....	.....	.....
100	....	1.7	.7	.13	.....	....	....	....	.....	.....	.....	.....	.....	.....
200	....	....	3.0	.5	.175	....	....	....	.....	.....	.....	.....	.....	.....
300	....	....	....	1.2	.38	.15	....	....	.....	.....	.....	.....	.....	.....
400	....	....	....	2.15	.67	.27	.06	....	.....	.....	.....	.....	.....	.....
500	....	....	....	3.3	1.1	.40	.10	.03	.012	.....	.....	.....	.....	.....
750	....	....	....	....	2.5	.91	.22	.07	.03	.013	.....	.....	.....	.....
1000	....	....	....	....	.....	1.8	.40	.12	.05	.023	.012	.....	.....	.....
1500	....	....	....	....	.....	4.0	1.00	.30	.12	.052	.027	.....	.....	.....
2000	....	....	....	....	.....	....	1.60	.50	.20	.095	.048	.017	.....	.....
3000	....	....	....	....	.....	....	3.70	1.20	.45	.22	.115	.036	.015	.....
4000	....	....	....	....	.....	....	....	2.00	.80	.39	.20	.07	.026	.012
5000	....	....	....	....	.....	....	....	....	1.30	.60	.30	.10	.041	.018
6000	....	....	....	....	.....	....	....	....	1.9	.85	.43	.15	.06	.028
7500	....	....	....	....	.....	....	....	....	3.	1.40	.68	.22	.09	.04
10000	....	....	....	....	.....	....	....	....	.....	2.5	1.25	.40	.17	.075

As before stated there is considerable loss of pressure caused by friction of compressed air in its passage through pipes, and the resistance offered by elbows and valves. Table 43 gives the loss of pressure due to friction for every 100 feet of pipe varying in diameter from 1 inch to 14 inches, with an initial pressure of 80 lbs at the receiver.

For the compression part only, of the stroke when compressing and delivering air from one atmosphere to a given gauge pressure in a single cylinder, the mean effective pressure is always lower than the mean effective pressure for the whole work. This is shown for both Adiabatic, and Isothermal compression by Table 44.

Table 44

MEAN EFFECTIVE PRESSURES.

		Adiabatic Compression	Isothermal Compression
Gauge Pressure	1	.44	.43
Gauge Pressure	2	.96	.95
Gauge Pressure	3	1.41	1.4
Gauge Pressure	4	1.86	1.84
Gauge Pressure	5	2.26	2.22
Gauge Pressure	10	4.26	4.14
Gauge Pressure	15	5.99	5.77
Gauge Pressure	20	7.58	7.2
Gauge Pressure	25	9.05	8.49
Gauge Pressure	30	10.39	9.66
Gauge Pressure	35	11.59	10.72
Gauge Pressure	40	12.8	11.7
Gauge Pressure	45	13.95	12.62
Gauge Pressure	50	15.05	13.48
Gauge Pressure	55	15.98	14.3
Gauge Pressure	60	16.89	15.05
Gauge Pressure	65	17.88	15.76
Gauge Pressure	70	18.74	16.43
Gauge Pressure	75	19.54	17.09
Gauge Pressure	80	20.5	17.7
Gauge Pressure	85	21.22	18.3
Gauge Pressure	90	22.	18.87
Gauge Pressure	95	22.27	19.4
Gauge Pressure	100	23.43	19.92

Table 45 will serve to show the requirements at sea level, of rock drills driven by compressed air, and Table 46 gives the increase of pressure required at various altitudes. The factor of multiplication is also given in Table 46 for the different altitudes and pressures.

TABLE 45

APPROXIMATE AMOUNT OF AIR REQUIRED AT SEA LEVEL FOR SPECIFIC SIZES ROCK DRILLS.

Size of Cylinder.........	2	2¼	2½	2¾	3	3⅛	3¼	3½
Diam. of Hole Drilled..	1-1½	1⅛-1½	1-2	1¼-2½	1½-3	1½-3	1½-3	1¾-3
Air Pressure.	Air Compression at Sea Level of one Drill—Cubic feet per minute of free air.							
60	60	65	70	80	90	100	110	120
70	70	75	80	90	105	115	125	135
80	80	85	90	100	115	130	140	150
90	85	90	95	115	130	140	150	170
100	95	100	110	125	140	155	170	185

TABLE 46

FACTORS FOR COMPUTING REQUIREMENTS FOR DRILLS AT VARIOUS ALTITUDES.

Altitude in Feet Above Sea Level	Atmospheric Pressure Pounds per Square Inch	FACTOR OF MULTIPLICATION				
		Pressure at Drill				
		60 Lbs.	70 Lbs.	80 Lbs.	90 Lbs.	100 Lbs.
....	14.7	1.00	1.133	1.26	1.40	1.535
500	14.45	1.015	1.15	1.28	1.425	1.563
1,000	14.12	1.03	1.17	1.31	1.45	1.59
1,500	13.92	1.048	1.19	1.33	1.48	1.62
2,000	13.61	1.06	1.21	1.35	1.50	1.645
3,000	13.10	1.10	1.25	1.40	1.55	1.70
4,000	12.61	1.131	1.287	1.443	1.60	1.755
5,000	12.15	1.17	1.33	1.495	1.652	1.81
6,000	11.75	1.20	1.37	1.537	1.705	1.87
7,000	11.27	1.24	1.42	1.59	1.76	1.935
8,000	10.85	1.282	1.465	1.645	1.825	2.00
9,000	10.45	1.32	1.51	1.70	1.90	2.07
10,000	10.10	1.365	1.56	1.755	1.968	2.143

Installation.—It should be the first care in installing an air compressor to provide it with a suitable foundation. The compressors are self-contained and need foundations only of such design and strength as will insure the compressor remaining rigidly in place. A poor foundation costs almost as much as a good one, and as a compressor is usually a permanent fixture, it is advisable to put in a good foundation.

Blue prints are usually furnished showing location and proper size of foundation bolts for each machine, from which a template can be made by which the foundation bolts can be accurately located. It is of great importance that space should be left around foundation bolts so that they may be left free to move. The setting of the compressor is rendered much easier by taking this precaution. A good way to do is to put a short piece of pipe around each foundation bolt, carrying it up with the foundation, thus leaving the desired space behind it. In case a concrete foundation is installed, the pipe should be full length around each rod.

Setting Compressor.—After the compressor has been placed in position, block the compressor off the foundation about ¼ inch by means of iron wedges, upon which the compressor should set level. Then the cement should be run into the bolt holes, and also between the base of the compressor and foundation to insure true bearing all around.

Pipe Connections.—The steam and exhaust pipes should be as free from L's as possible, and should be used only in so far as is demanded by expansion of pipes. All pipes should be thoroughly cleaned before starting the compressor, so that metal chips from cutting pipes may not be carried into the steam chest and score the valves and seats.

Proper allowance should be made for the expansion of the steam pipes in connecting them up.

A drain pipe or bleeder should be provided for live steam, connection being made directly above throttle valve and with the drain, so that the water of condensation may not have to pass through the steam cylinders. If steam connection for the compressor is taken from the main steam line instead of direct from the boilers, the connection should be taken from the top of the steam pipe, thus avoiding the carrying of condensation.

The cocks and drains provided for both steam and air ends should be opened after the pump ceases operation, so that the water may be thoroughly drained, thereby avoiding any possibility of freezing.

In connecting water pipe to jacket around the air cylinder care should be exercised to allow for proper drainage of cooling surface and pipes. In cold weather the water should be drained, or breakage from freezing might occur in cylinder or jacket.

In piping air discharge pipe use lead in all joints, and screw up tight, as air leaks are expensive.

INGERSOLL-RAND AIR COMPRESSOR.

Fig. 347 shows a view of an Ingersoll-Rand Class "A" straight line air compressor. Its distinctive principle is the direct application of power to resistance, being in itself a distinct unit. This is clearly shown in Fig. 348. In the single stage types the heads, and barrel of the air cylinder are completely water jacketed, thus insuring economical compression.

This is supplemented in the two stage Class "A-2" types by a horizontal intercooler of effective design. In three stage modifications, high and intermediate pressure cylinders, with their valves and high pressure intercooler, are completely submerged in water-box coolers.

Fig. 349 will serve to give to the student a good idea of the internal construction of this type of air compressors, each part being numbered and the designation of the parts given in the caption.

The Meyer cut-off valve gear is clearly shown in the steam end, and the Ingersoll-Sargeant piston inlet valves are shown in the air cylinder, an enlarged view of which is presented in Fig. 350. Formerly all Class "A" compressors, except 30-inch stroke machines, were fitted with A5 Air and A14 Steam Regulators, now called "Unloader" and "Regulator."

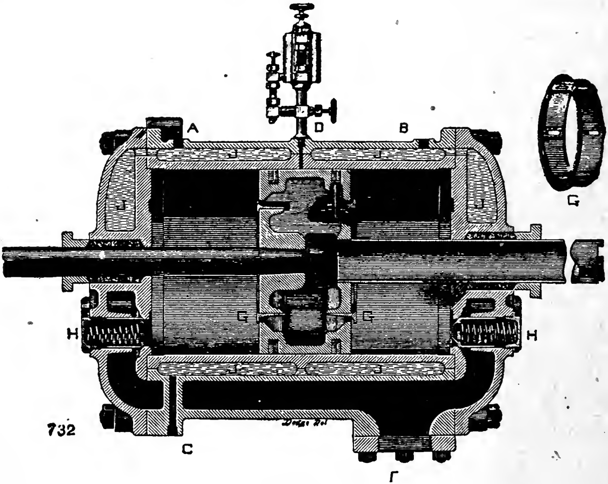


Fig. 350

INGERSOLL-SERGEANT PISTON INLET VALVE CYLINDER

The standard governor for all Class "A" compressors is the type known as the *"Air-Ball" Governor.*

Unloader and Regulator.—The function of the unloader and regulator is to take the load off the air piston when the pressure reaches the desired point, and, at the same instant, to throttle the supply of steam to a point just sufficient to keep the compressor

List of Duplicate Parts of Class "A" Compressors—

No.	Name of part.
1	Bedplate.
2	Rocker shaft.
3	Rocker shaft bearing.
4	Rocker shaft bearing bolts and nuts.
5	Rocker shaft bearing tap bolts.
6	Rocker shaft collar.
7	Rocker shaft collar set screw.
8	Fly-wheel.
9	Fly-wheel key.
10	Main shaft.
11	Crank pin.
12	Guide bar.
13	Guide bar bolts and nuts.
14	Main bearing top and bottom brasses.
15	Main bearing quarter brasses.
16	Main bearing cap.
17	Main bearing plates.
18	Main bearing adjusting set screws.
19	Main bearing set screw jam nuts.
20	Main bearing adjusting nuts.
21	Main bearing bolts and nuts.
22	Main bearing guard.
23	Main bearing guard bolts.
24	Main bearing oil cup cover.
25	Steam cylinder.
26	Steam cylinder front head.
27	Steam cylinder back head.
28	Steam cylinder head studs and nuts.
29	Steam cylinder chest cover.
30	Steam cylinder chest cover studs and nuts.
31	Steam cylinder bolts and nuts.
32	Steam piston spider.
33	Steam piston bull-ring.
34	Steam piston follower.
35	Steam piston ring.
36	Steam piston ring spring.
37	Steam piston bolts.
38	Steam piston rod.
39	Steam piston rod nut.
42	Steam piston rod gland.
43	Steam piston rod gland studs and nuts.
44	Main valve.
45	Main valve rod.
46	Main valve rod link.
47	Main valve rod gland.
48	Main valve rod gland studs and nuts.
49	Main valve rod nuts.
50	Main valve rod eye pin and nut.
51	Steam pipe flange.
52	Steam pipe flange studs and nuts.
53	Exhaust pipe flange.
54	Exhaust pipe flange studs and nuts.
55	Eccentric.
56	Eccentric strap (2 pieces).
57	Eccentric strap bolts and nuts.
58	Eccentric brasses (2 pieces).
59	Eccentric strap eye set screw.
60	Eccentric strap eye set screw jam nut.
61	Eccentric strap eye set screw nut.
62	Eccentric strap eye pin and nut.
63	Eccentric key.
64	Eccentric key washer and nut.
65	Eccentric gib.
66	Main rocker arm.
67	Main rocker arm set screw.
68	Eye piece for valve rod.
69	Eye piece check nut.
70	Eye piece bolts and nuts.
71	Eye piece set screw.
72	Eye piece set screw jam nut.
73	Eye piece brass (2 pieces).
74	Ball and socket joint, ball end.
75	Ball and socket joint, screw end.
76	Throttle valve body.
77	Throttle valve body studs and nuts.
78	Throttle valve bonnet.
79	Throttle valve bonnet studs and nuts.
80	Throttle valve gland.
81	Throttle valve gland studs and nuts.
82	Throttle valve hand wheel.
83	Throttle valve valve.
84	Throttle valve seat.
85	Throttle valve stem.
86	Throttle valve stem nut.
87	Throttle valve nut for bonnet.
88	Steam regulator body.
89	Steam regulator body studs and nuts.
90	Steam regulator cover.
91	Steam regulator cover studs and nuts.
92	Steam regulator valve and stem.
93	Steam regulator stuffing box.
94	Steam regulator gland.
95	Steam regulator gland nut.
96	Air cylinder.
97	Air cylinder bushing.
98	Air cylinder front head.
99	Air cylinder back.
100	Air cylinder head studs and nuts.
101	Air cylinder bolts and nuts.
102	Air piston.
103	Air piston ring.
104	Air piston ring spring.
105	Piston inlet valve.
106	Piston inlet valve pins.
107	Piston screw plugs.
108	Piston inlet pipe.
108A	Piston inlet pipe gland.
108B	Piston inlet pipe gland studs and nuts.
109	Air piston rod.
110	Air piston rod nut.
113	Air piston rod gland.
114	Air piston rod gland studs and nuts.
115	Air pipe flange.
116	Air pipe flange tap bolts.
117	Cross-head gibs.
118	Cross gib tap bolts.
119	Discharge valve.
120	Discharge valve spring.
121	Discharge valve cap.
122	Discharge valve for regulator pipe.
123	Cross-head.
124	Cross-head washers.
125	Cross-head washers bolts.
126	Cross-head swivel-block.
127	Cross-head pin (2 pieces).
128	Cross-head pin bolt and nut.
129	Cross-head pin washer.
130	Cross-head set screws and nuts.
131	Connecting rod.
132	Connecting rod large strap.
133	Connecting rod small strap.
134	Connecting rod long bolts.
135	Connecting rod short bolts.
136	Connecting rod bolt nuts.
137	Connecting rod bolt nuts set screws.
138	Crank pin brasses (2 pieces).
139	Cross-head pin brasses (2 pieces).
140	I. A. 5 Air regulator plunger cylinder.
141	I. A. 5 Air regulator plunger tap bolts.
142	I. A. 5 Air regulator plunger.
143	I. A. 5 Air regulator plunger pin.
144	I. A. 5 Air regulator main valve cylinder.
145	I. A. 5 Air regulator main valve cylinder head.
146	I. A. 5 Air regulator main valve.
147	I. A. 5 Air regulator main guide and nut.
148	I. A. 5 Air regulator auxiliary valve.
149	I. A. 5 Air regulator lever.
150	I. A. 5 Air regulator lever pins.
151	I. A. 5 Air regulator weight, nut and rod.
152	I. A. 5 Air regulator large weight.
153	I. A. 5 Air regulator small weight.
154	I. A. 5 Air regulator studs and nuts.
155	A. 14 Steam regulator adjusting cylinder.
156	A. 14 Steam regulator adjusting cylinder head.
157	A. 14 Steam regulator adjusting piston.
158	A. 14 Steam regulator adjusting nut.
159	A. 14 Steam regulator latch.
160	A. 14 Steam regulator adjusting cylinder stud and nut.
161	A. 14 Steam regulator adjusting cylinder stud and nut.
162	Steam cylinder lubricator.
163	Air cylinder lubricator.
164	Tie rods and nuts.
165	Foundation bolt and nuts.
166	Foundation washers.
203	A. 14 Steam regulator attachment yoke and set screw.
204	A. 14 Steam regulator attachment spring.
205	A. 14 Steam regulator attachment washer.
206	A. 14 Steam regulator attachment nut.
207	Swivel block steam jam nut.
208	Swivel block Air jam nut.
209	Starting bar.
210	Rocker.
211	Connecting rod.
212	Bell crank.
213	Pawl.
214	Stop pawl.
215	Crank pin oiling devices.
216	Cross-head pin oiling devices.
217	Main bearing and eccentric oiling devices.
218	Air and steam piston rod oiling devices.
219	Guide bar oiling devices.
220	Rocker bolt.
221	Connecting rod bolt.
222	Connecting rod pin.
223	Bell crank bolt.
224	Pawl pin.
225	Stop pawl bolt.
226	Dowel.

Additional Parts for Compressors with Meyer's Cut-Off Valve Gear—

167	Cut-off eccentric.
168	Cut-off eccentric strap (2 pieces).
169	Cut-off eccentric strap bolt and nuts.
170	Cut-off eccentric strap brass (2 pieces).
171	Cut-off eccentric strap eye set screw.
172	Cut-off eccentric eye set screw jam nut.
173	Cut-off eccentric strap eye set screw nut.
174	Cut-off eccentric strap eye set pin and nut.
175	Cut-off eccentric key.
176	Cut-off eccentric key washer and nut.
177	Cut-off eccentric gib.
178	Cut-off rocker arm.
179	Cut-off eye-piece for valve rod.
180	Cut-off eye-piece for check nuts.
181	Cut-off eye-piece for bolts and nuts.
182	Cut-off eye-piece for set screw.
183	Cut-off eye-piece for set screw jam nut.
184	Cut-off eye-piece for brass (2 pieces).
185	Cut-off ball and socket joint—ball end.
186	Cut-off ball and socket joint—screw end.
187	Cut-off valve rod.
188	Cut-off valve rod link.
189	Cut-off valve rod large gland.
190	Cut-off valve rod large gland studs and nuts.
191	Cut-off valve rod small gland.
192	Cut-off valve rod small gland studs and nuts.
193	Cut-off valve rod eye pin and nut.
194	Cut-off valves.
195	Cut-off valve nuts.
196	Index bracket.
197	Index bracket bolts.
198	Index bracket sleeve.
199	Index bracket sleeve nuts.
200	Index pointer.
201	Index hand wheel.
202	Index hand wheel nut.

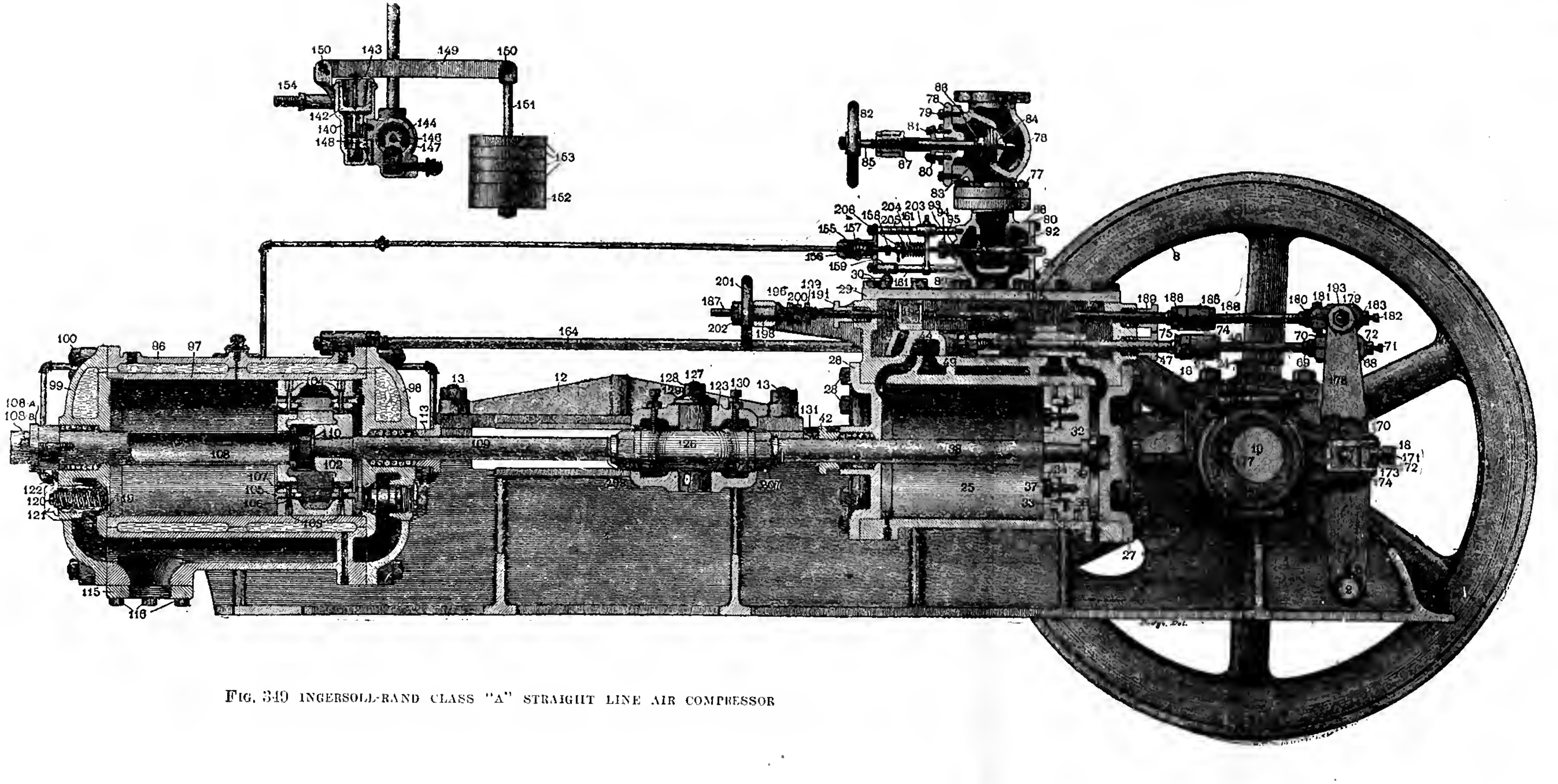


FIG. 349 INGERSOLL-RAND CLASS "A" STRAIGHT LINE AIR COMPRESSOR

List of Duplicate Parts of class A.

Compressor—

Pieces of [illegible]

Bedplate.
Rocker shaft.
Rocker shaft bearing
Rocker shaft bearing bolts and nuts
Rocker shaft bearing [illegible]
Rocker shaft collar.
Rocker shaft bolts and nuts.
Fly-wheel.
Fly-wheel key.
Main shaft.
Crank pin.
Crank key
Coupling bolts and nuts.
Main bearing top and bottom [illegible]
Main bearing [illegible]
[illegible]
Main bearing [illegible]
Main bearing [illegible]
Main bearing [illegible]
Main bearing [illegible]
Main bearing [illegible]
Main bearing [illegible]
Main bearing caps or bolts.
Main bearing oil [illegible]
Steam cylinder.
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
Steam piston [illegible]
Steam [illegible]
Steam gland and [illegible]
Steam piston packing [illegible]
Main valve.
Main valve rod.
Main valve rod [illegible]
Main valve rod guide [illegible]
Main valve rod [illegible]
Main valve rod [illegible]
Main valve rod [illegible]
Steam pipe flange.
Steam pipe flange [illegible]
Exhaust flange.
Exhaust pipe flange [illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
Eccentric key.
Eccentric [illegible]
Eccentric gib.
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
Throttle valve body
Throttle valve body studs and nuts.

turning over. When the pressure of air goes down past the limit, usually ten pounds below the running pressure, the load is thrown on and the steam again admitted, when compression is resumed in the regular way. This is accomplished as follows: When the weighted lever is lown the pipes leading from the unloader to the discharge alves, and to the steam regulator cylinder (No. 155), are illed with air at receiver pressure. The result of this is hat the discharge valves act in the nature of check valves, etting the compressed air out of the cylinder, but not in gain, and the steam regulator valve (No. 92) is held open, hus admitting of the compression and discharge of the air. hen the air pressure rises above the point at which the air to be carried the weight will lift, resulting in the air which was under pressure in the pipes referred to) being hausted. When this pressure is relieved the discharge lves throw wide open, and stay wide open, the result ing, of course, that the inlet valves are held shut, the ston has receiver pressure on both sides, and moves back d forth in equilibrium. At the same instant the steam gulator valve closes to a point which admits just enough eam to overcome the engine friction and keep it moving st enough to prevent centering. The extent to which steam regulator valve closes is regulated by screwing the justing nut (No. 158), Fig. 349, one way or the other, en the compressor is running without a load, until the per speed is secured. The pressure at which the com- ssor ceases to discharge air into the receiver may be de- mined by the weights hung on the regulator. The safety- ve on the receiver is set to blow at about ten pounds ve the regulator pressure, and in practice should rarely never blow. See that the stop-cocks on the pipes leading from the regulator to the discharge valves are wide open.

The causes for the regulator not working properly, if the pipes are clear, are to be looked for as follows. See that packing is not too tight, and that the steam valve moves freely. See that valve (No. 146) moves freely. See that plunger (No. 142) moves freely, and that lever does not bind. An occasional cleaning out with kerosene may be necessary if there is any tendency to gum up, which is rarely the case.

To Remove Inlet Valves.—Loosen the jam nut on the air piston rod, and screw rod out of swivel block; remove back head (No. 99), on air cylinder; slide air piston out on plank; remove piston rings; unscrew screw plugs (No. 107); remove inlet valve pins (No. 106); these are tapered and can be started out with a drift sent with the compressor for that purpose. When these pins are all out the valves can be removed, and the whole operation can be performed in a short time.

The valves can then be inspected, and proper repairs made. If there is any deposit of dust or gum in the piston, it can be removed while it is out. If new inlet valves are to be put in, the seat should be scraped, so as to allow the valves to seat air-tight; but this will rarely be necessary. If the valve pins are worn flat where the valve has been striking them, put in a new set of pins when replacing the valve, or turn the pins around so that the valve has a true surface of the pin to strike against. Do not set the pins so that valve will strike against a sharp corner on same, as it tends to wear the valve very rapidly. When putting in valves it is best to use new pins.

When replacing the piston, those ends of the rings having the same marks should go together; thus, 1-1, 2-2 and 3-3 go together. A piece of stout cord lapped around the rings and tied will hold them in place until slipped beyond the counterbore, after which the cord is to be removed.

To Set the Cut-Off Eccentric.—Different portions of the stroke are laid out along the cross-head slide in reference to each end of the stroke; the cut-off valves are screwed on the rod together, and the cross-head being set at any desired part of the stroke the cut-off valve is moved (by turning the hand wheel) so that it just cuts off the port on the main valve. The cross-head is then moved to a corresponding position at the other end of the stroke, when the other cut-off valve should just close the port on main valve. If it does not, the valve stem should be lengthened or shortened in the eye piece, or one cut-off valve can be put on the stem a thread or two sooner than the other, thus equalizing them for both ends of the stroke.

There is only one position where they will cut off exactly the same on both ends, and if varied from this the cut-off will be different on both ends of the stroke, being greater relatively on one side if increasing the cut-off, and less relatively on the same side when diminishing the cut-off.

In other words the cut-off valve may be arranged to close correctly at one half (or any other fixed part of the stroke) but at one fourth cut-off, one valve will be a little ahead of the other, and at three-fourths cut-off the opposite end will be the other way, so that the best that can be done with this style of cut-off is to obtain one correct point of cut-off; that may be one half, or any other desired point, but at all other points it will not be exactly correct. A good way to get the engine on its exact dead center is as follows: Turn the fly-wheels till the piston is within an inch or so of the end of its stroke. Scribe a fine vertical line across the edge of the cross-head and guides; scribe another line across the face of the fly-wheel, horizontally, or any convenient part of the rim, guiding the scriber across the planed edge of a board nailed rigidly in position. Now turn past the centre till the cross-head comes back exactly to the line, and scribe across the straight edge on the rim again. Now draw another line across the rim, exactly half way between the first two, and when the fly-wheel is turned to bring this last line even with the straight edge, the engine will be exactly on the dead centre. The centre at the other end of the stroke may be marked in the same way, after which you can turn to either centre instantly and without liability of error.

Air Ball Governor.—This device is at the same time a speed regulator or governor, and a means for holding a constant air pressure in the receiver. It consists of a special balanced throttle valve, the spindle of which is connected to a fly-ball governor belted from the engine shaft. This throttles the steam supply when the engine speed exceeds the desired limit.

At one side of the governor is a small air cylinder, the piston of which presses against a lever on which is a sliding weight. This cylinder is connected with the air receiver. The inner end of the weighted lever connects with the spindle of the balanced throttle through a link which makes the action of the small air cylinder independent of the fly-ball governor, so that when the pressure in the receiver exceeds that for which the governor is set, the weighted lever is raised, and the balance throttle closed to a point which admits steam enough to turn the machine over at the speed necessary to supply a volume of air equal to that being drawn from the receiver.

If from any cause the air pressure in the receiver drops, the weighted lever is allowed to drop, by the decrease of pressure in the small cylinder. This opens the throttle, admitting more steam to the engine. If an air pipe should break, or too great a demand is made upon the compressor, keeping the air pressure down so that the air piston does not work, the engine speeds up to a point where the centrifugal governor partially closes.

Setting Meyer Slide Valves.—Set the main eccentric, actuating the lower valve, so that the angle centre advance is somewhere near fifteen degrees, thus:

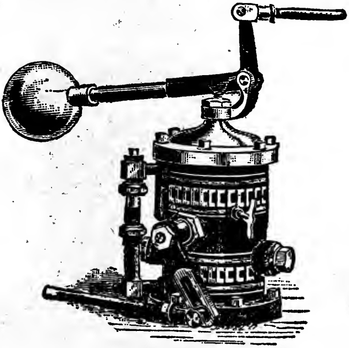


Fig. 351

MASON PUMP GOVERNOR

Put the crank on either dead centre and set the main valve at that end so that it has about 1-64th inch lead, and set the nuts against valve temporarily; now turn the wheels to the other dead centre, and see how far the port edge of valve is from the edge of port. Whatever this distance is, the valve should be moved *one-half* this distance along its stem, by loosening the nuts on one side and screwing up on the other. When this distance has been *exactly* divided the nuts should be jammed up tight, so that they just bear against the valve. The valve stem will then be of the correct length. With the crank at dead center move the eccentric around so that the valve has 1/64 inch lead, and fasten the eccentric there; then turn the crank to the opposite dead center, and note if the lead is the same—if not, average it as close as possible.

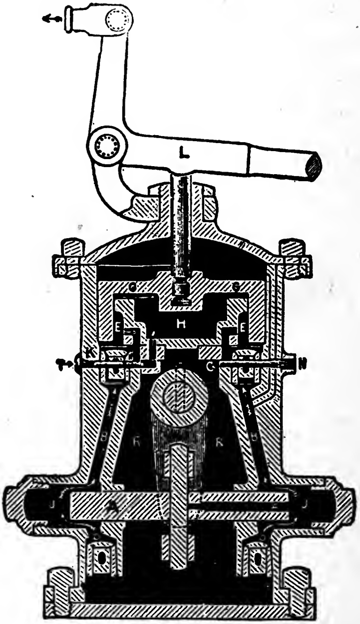


Fig. 352

MASON PUMP GOVERNOR—SECTIONAL VIEW

Mason Pump Governor.—Figs. 351 and 352 show the Mason Pump Governor which is used only on compressors for the Pohle air lift outfits, or in case a constant speed is desired irrespective of the load.

The Mason Pump Governor attaches directly to the eccentric rod of the compressor, and operates a balanced valve placed in the steam pipe, thereby exactly weighing the amount of steam to the needs of the compressor and economizing the same. By using the Mason Governor the compressor can be set or changed to run any required speed, which will be maintained in spite of variation in load or steam pressure. As all the working parts of the governor are immersed in oil, the wear is reduced to a minimum.

The Mason Governor consists of a cylindrical shell or reservoir filled with oil or glycerine. The plunger AA (Fig. 352) is connected through the arm I to some reciprocating part of the pump or engine, and works in unison with the strokes of the compressor, thereby drawing the works in unison with the strokes of the compressor, thereby drawing the oil up through the check valves DD into the chambers JJ, whence it is forced alternately through the passages BB, through another set check valves into the pressure chamber EE. The oil then returns through the orifice C, the size of which is controlled by a key inserted at N, into the lower chamber, to be repumped as before. In case the engine works more rapidly than is intended, the oil is pumped into the chamber EE faster than it can escape through the outlet C, and the piston GG is forced upward, raising L with its weight and throttling the steam. In case the compressor runs slower than is intended, the reverse action takes place, the weight on the end of the lever L forces the piston GG down and more steam is let on. As the orifice at C can be increased or diminished by adjusting the screw at N, the governor can be set to maintain any desired speed. The piston GG fits over the stationary piston forming an oil dash pot, thereby preventing fluctuation of the governor. This dash pot is fed from pressure chamber E through a passage which is controlled by an adjusting screw K, which is set by a screwdriver (after removing the cap screw T). It requires no further attention when once adjusted.

The governor is placed on the compressor, where the requisite motion can be obtained for operating it, and also in such a way that a rod can be run from the knuckle joint on the top lever to the valve in the steam pipe. Now place the valve in the pipe so that the stem shall be in a direct line with the knuckle joint on the lever, pull out the valve stem to its full extent, then, with the ball on the governor in its lowest position, connect the valve rod with the lever. The governor is then ready to fill. To do this remove the plug in the top of the gauge glass, and with a good clean, light grade of mineral oil fill the governor about half full. The governor is then ready for work.

To Start.—First start the compressor at about the desired speed, and get it working well; then, placing the key in the key-hole on the side of the governor, turn to the right until the speed of the compressor has diminished slightly. Then open the throttle valve wide, and the compressor will be under full control of the governor. Should there be much jumping, or fluctuating of the ball remove the screw T, insert a small screwdriver, and screw adjusting screw in at K until it ceases. After the governor has run a little while it will be found that the oil in the glass gauge has lowered considerably. It should then be refilled, so that the glass will stand about half full when the governor is at work. Under no circumstances should the gauge be full, as it will prevent the ball from coming down and opening the valve when the steam lowers. As there is no pressure upon the gauge, the governor may be refilled while in motion by removing the plug in the top of the gauge glass.

THE DALLETT AIR COMPRESSOR.

Fig. 353 shows a sectional elevation of the Dallett Air Compressor built by the Thomas H. Dallett Company of Philadelphia, Pa. This compressor incorporates the essential features of having all parts requiring adjustment or renewals readily accessible, and employing a liberal amount of metal, so placed as to insure rigidity in operation.

The frame is of the open-fork center-crank type, designed to obtain on each size of compressor a greater range of capacity by substituting, when desired, a cylinder of the next larger size than the standard to operate at 100 pounds pressure.

The main bearings are lined with babbitt metal, which is thoroughly peened in to obviate shrinkage, and then bored and scraped to fit the crankshaft. The duplex-belt, duplex-steam and single-steam machines are supported on deep, rigid sub-bases, thus making the entire machine self-contained.

The steam cylinder and valve gear of the steam-driven machines are designed to give high efficiency. All steam ports are short and direct, and the clearance has been reduced to a minimum. A plain D balanced slide valve is used on the small and medium-sized machines, and the Meyer balanced adjustable cutoff valve in the larger machines. To provide efficient insulation, all steam cylinders are lagged with mineral wool and jacketed with sheet steel.

The governor of the steam-driven machine is equipped with a safety-stop device. The governor pulley is situated on the end of the shaft outside of the fly-wheel on the single-steam machine, thus bringing the flywheel as close to the bearing as possible. Formerly, in the case of duplex

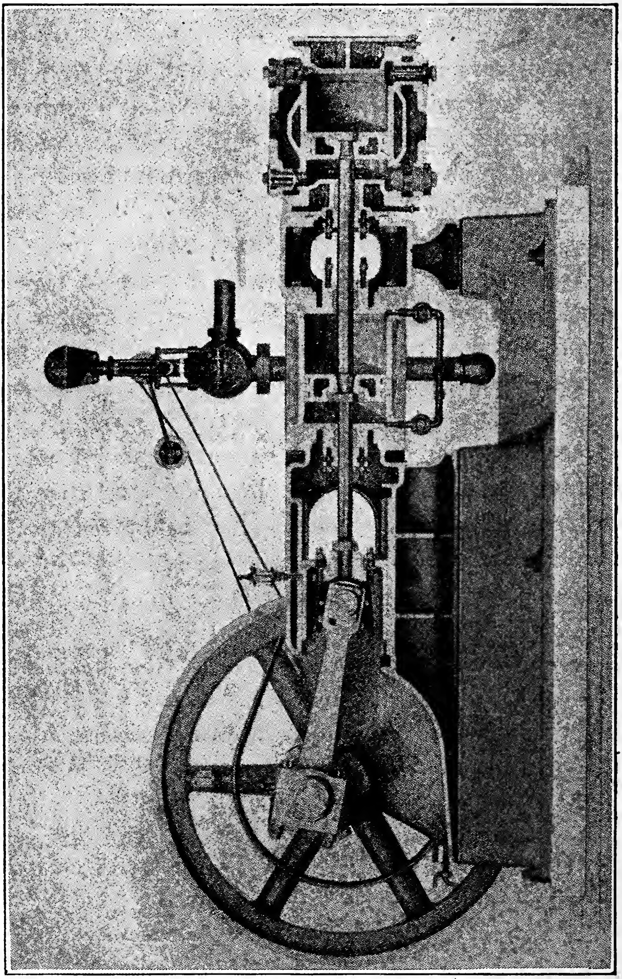


Fig. 353

SECTIONAL ELEVATION OF DALLETT STEAM DRIVEN AIR COMPRESSOR

compressors with compound steam cylinders, if the machine stopped with the high-pressure side on the dead center, it would not start automatically, due to the fact that the high-pressure side takes steam from the line. This trouble has been overcome by using a reducing valve which reduces the live-steam pressure for use in the low-pressure cylinder. The air and steam cylinders are tied together and held in position by means of an internally flanged tie or distance piece.

Mechanically operated inlet valves are supplied on any size of compressor if desired. These valves are ground to gage and the valve holes lapped to size.

The air-intake and discharge valves are special features of these compressors. The intake valve is of the automatic poppet type, contained in a malleable-iron cage.

ALLIS-CHALMERS AIR COMPRESSOR.

For single-stage air compressors, and in the high-pressure cylinders of two-stage air compressors, the Allis-Chalmers Company, of Milwaukee, uses as a standard the arrangement of valves shown in Fig. 354. Rotary valves are used for the inlet, and plain, single-beat poppet valves for the discharge. The inlet valves are driven by an eccentric on the main shaft, and, by means of the wrist-plate, they are given the quick opening and closing, and the slow movement when the ports are covered and the valves under pressure, which is characteristic of the Corliss valve-gear. The inlet ports are of ample size, short and direct, and the air is guided into the cylinder by an easy curve, thus reducing the entering friction, and insuring the complete filling of the cylinder with as little loss in pressure, and at as nearly the outside pressure as possible.

The discharge valves are of the drawn-steel cup type and open automatically when the pressure in the cylinder equals the discharge pressure.

A modification of the valve-gear shown by Fig. 454 is illustrated in Fig. 355. In this gear the inlet valves are operated the same as in Fig. 354, but the discharge valves are mechanically closed, being free to open automatically, and positively closed by plungers operated by connections to a wrist-plate driven by an eccentric on the main shaft. The movement of the plungers of the discharge valves is so timed as to positively bring the valves to their seats just as the piston reaches the end of its stroke, thus avoiding any slip of air back by the valves and also to avoid slamming when the piston commences to return. As soon as the valves are closed the plungers recede, leaving the valves held to their seats by the discharge air pressure until that point in the return stroke of the piston is reached where

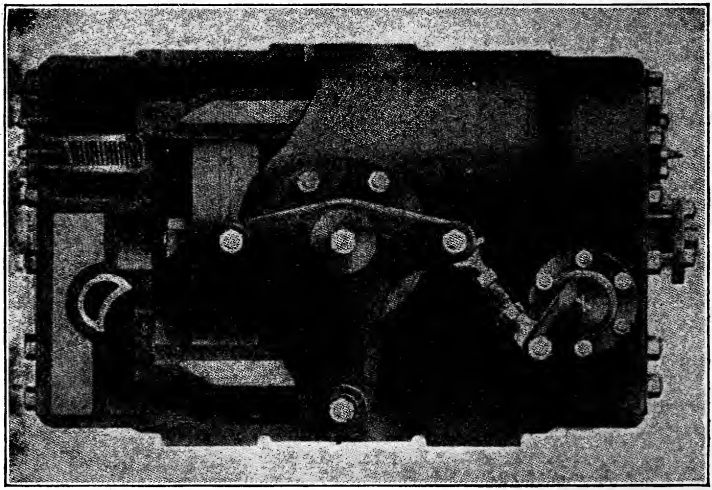


FIG. 354

AIR CYLINDER WITH AUTOMATIC DISCHARGE—ALLIS-CHALMERS AIR COMPRESSOR

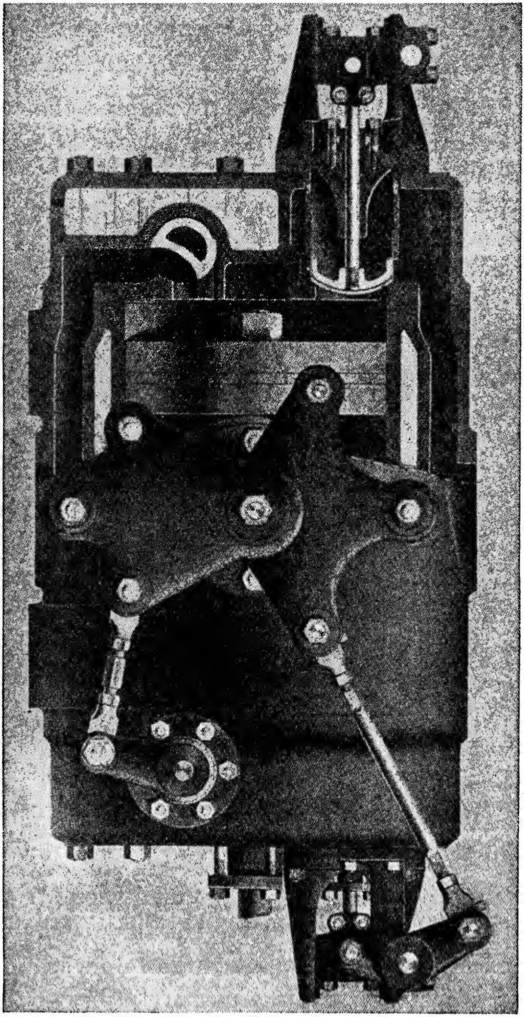


FIG. 355

AIR CYLINDER WITH MECHANICAL DISCHARGE VALVE—ALLIS-CHALMERS AIR COMPRESSOR the pressure in the cylinder equals the discharge pressure, when the valves are free to open automatically. In closing, the air between the plunger and valve forms a cushion which is so adjusted, and gradually reduced that the valve is brought gently to its seat without noise or pounding.

A third type of valve-gear is shown in Fig. 356. In this both the inlet and discharge valves are of the rotary pattern, positively operated by independent eccentrics on the main shaft. The inlet valves are the same as described in the two preceding types. The discharge valves are so proportioned and adjusted as to close positively just as the piston reaches the end of its stroke, and to open at any predetermined maximum discharge pressure required. In addition to the rotary discharge valves, the cylinder is fitted with

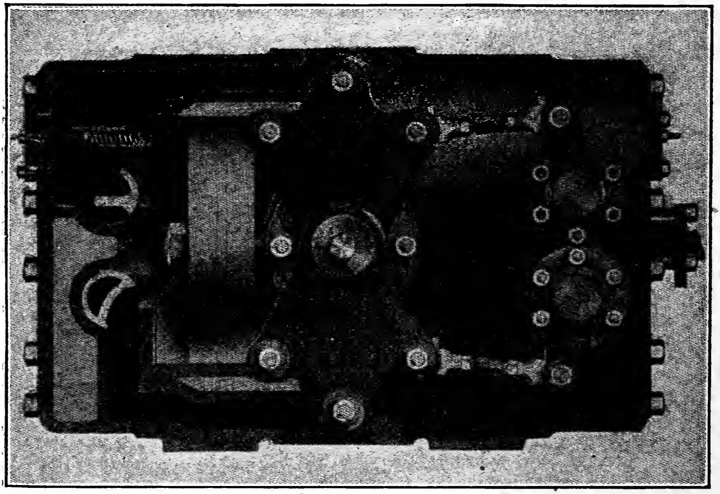


Fig. 356

AIR CYLINDER WITH MECHANICAL DISCHARGE VALVE—ALLIS-CHALMERS AIR COMPRESSOR auxiliary poppet valves of the steel-cup type, which serve as relief valves in case the eccentric should slip; or for allowing the air to be discharged from the cylinder, should the pressure, for any cause, fall below that at which the main discharge valves are set to open.

QUESTIONS AND ANSWERS.

599. What is one of the results of compressing air?

Ans. The development of heat.

560. What amount of work is lost by the development and dissipation of this heat?

Ans. The work represented by the mechanical equivalent of the heat developed.

561. Mention another cause of more or less lost work in air compression?

Ans. Friction of the air in the pipes through which it is conveyed.

562. By what two methods is air compression generally accomplished?

Ans. Isothermal, by which the heat of compression is carried away as fast as developed; and adiabatic, by which no heat is removed from the air.

563. Which of the two is the ideal method of compression?

Ans. The isothermal.

564. Is it possible of attainment?

Ans. Not entirely.

565. What may be said of the adiabatic method?

Ans. It is one which should be avoided as much as possible.

566. What are the actual results secured in the best compressors?

Ans. They are intermediate between the two methods just mentioned, but nearer to the second method.

567. Upon what does the efficiency of an air compressor depend principally?

Ans. Upon the effectiveness of the cooling devices.

568. How many practical methods of removing the heat of compression are there?

Ans. Two—jacket cooling, and intercooling.

569. Is jacket cooling of the compressor-cylinder effective?

Ans. Not entirely, except with single-stage compression.

570. What is an intercooler?

Ans. It is a cooling device interposed between the cylinders of a compound or multi-stage machine, through which the air passes on its way from one cylinder to the next one.

571. Describe the process of compression by the multi-stage method?

Ans. A multi-stage compressor has two or more cylinders, the intake or low pressure cylinder being the largest in diameter, and in which the air is first compressed to a low pressure, and then passed on into the next cylinder which is of smaller diameter, where the air is compressed to a still higher pressure, and so on in increasing ratio.

572. How should the cylinder ratios be proportioned?

Ans. So that the M. E. P. and the final temperature are equal in all the cylinders.

573. Describe the construction of an intercooler?

Ans. It usually consists of a nest of tubes through which cold water circulates, and between which the stream of air passes.

574. Which method, single-stage, or multi-stage, approaches nearest to the theoretical ideal?

Ans. The multi-stage, with intercoolers.

575. Mention another point in favor of multi-stage compression?

Ans. It permits a higher piston speed, thus economizing in steam.

576. What is one of the greatest difficulties encountered in air power transmission?

Ans. Freezing of the moisture in the air, either in the pipe line, or at the exhaust ports of the air motors.

577. How may this condition be avoided to a large extent?

Ans. By the proper cooling of the air during compression, which will precipitate the moisture, which may then be withdrawn by drain pipes.

578. What would be the resultant temperature of air compressed from atmospheric pressure, and 60° Fahr., to a final pressure of 100 lbs., provided there was no cooling device?

Ans. 484° Fahr.

579. What effect would this have upon the cylinder lubricant?

Ans. It would be burned, and be useless.

580. What would be the temperature of the same volume of air if compressed in the first, or intake cylinder of a multi-stage machine to a pressure of 25 lbs.?

Ans. 233° Fahr.

581. If passed through an intercooler on its way to cylinder No. 2, what would its temperature be?

Ans. It would be brought back to its original temperature of 60° Fahr. and enter the second cylinder under a pressure of 25 lbs.

582. What would the temperature of the same air be if compressed in cylinder No. 2 from 25 lbs. to 100 lbs. pressure?

Ans. It would be but little in excess of that attained in the first cylinder, viz., 233° Fahr.

583. Why would it not attain the temperature stated in the answer to question 578, viz., 484° Fahr.?

Ans. Because the heat of compression is a function of the number of compressions, and practically independent of the initial pressure.

584. Why is air compression at high altitudes more expensive than at sea level?

Ans. Because the capacity of the compressor decreases in a greater ratio than does the power necessary to compress.

585. At an elevation of 10,000 ft. above sea level, what is the increase in expense?

Ans. Over 20 per cent.

586. What should be the first care in the installation of an air compressor?

Ans. To provide a suitable foundation.

587. What precautions should be observed in the piping?

Ans. First, there should be as few L's as possible, and second, all pipes should be thoroughly cleaned before starting the compressor; third, allowance should be made for expansion.

588. What is the function of the unloader on the Ingersoll-Rand air compressor?

Ans. To take the load off the air piston when the pressure reaches the desired point.

589. What is the function of the regulator?

Ans. To regulate the supply of steam to the steam end of the compressor.

590. What type of air inlet valves is this compressor equipped with?

Ans. Piston inlet valves.

591. Describe the action of these valves?

Ans. The air enters and passes through the piston, thus tending to keep it cooled.

592. What is the function of the Mason pump governor, with which some air compressors are equipped?

Ans. To maintain a constant speed regardless of the load.

593. What kind of inlet valves is the Dallett air compressor fitted with?

Ans. Either mechanically operated valves, or automatic poppet valves, as desired.

594. With what type of valves are the Allis-Chalmers air compressors usually equipped?

Ans. Rotary valves for the inlet, and single-beat poppet valves for the discharge.

595. How are the inlet valves operated?

Ans. By an eccentric on the main shaft, and a wrist plate.

596. What other type of valve-gear are some of these compressors equipped with?

Ans. Both inlet, and discharge valves are actuated by independent eccentrics on the main shaft.

Refrigeration

The process of refrigeration consists in the abstraction of heat from a substance, and if air, water, or ice is at hand at a lower temperature than it is desired to attain in the body or substance to be cooled, the cooling element may be employed to perform the refrigeration directly without the aid of a machine.

If a temperature of 32 degrees and not lower is desired ice can be used directly, but if it is necessary to reach a temperature lower than 32 degrees, a mixture of salt and ice or other freezing mixture must be used.

By mixing one pound of calcium chloride with 0.7 lbs. of snow a solution is produced which will give a temperature of 67° below zero. But freezing mixtures are too expensive to be used for practical purposes, and it therefore becomes necessary to employ machinery.

The theory and practice of mechanical refrigeration are based upon the two first laws of thermo-dynamics, that is to say, first: that mechanical energy and heat are mutually convertible; and second, that an external agent is necessary in order to complete or bring about the transformation.

The generally accepted theory concerning the nature of heat together with definitions of the terms, specific heat, latent heat, the mechanical equivalent of heat, etc., are fully discussed in another section of this book and therefore it will not be necessary to enlarge upon these subjects in this connection except to state that the phrase commonly used, "heat is generated by compression," is somewhat misleading, because the amount of heat in the universe is a fixed quantity, and the intrinsic energy possessed by any gas is, under given conditions a quantity that can be actually calculated. Thus if a pound of air at a temperature of 70 degrees Fahrenheit, and at normal atmospheric pressure be taken as an example, the total quantity of energy it possesses is at once known. If this air be placed in a compressor, and its volume be reduced to say one-half of its original volume, and if this be done so rapidly that there is no time for heat to escape at the end of the compression, that is to say, adiabatically or instantaneous compression without transmission of heat, then its energy, will have been increased by the amount of work done upon it. Its static pressure will be increased, and its temperature will also have risen, by reason of its changed state or condition internally. Now if the temperature be reduced to its former amount, that is to say, to 70 degrees Fahrenheit, its volume will contract, so that a small additional quantity of air will have to be forced in in order that the pressure may remain unchanged as the temperature is reduced. It will be seen that there will be now, consequently upon the above, rather more than a pound of air to deal with at the higher pressure, and this is what actually occurs in practice, but is a point which is easily overlooked. Now if this air be allowed to expand in a cylinder, it will give up more of its heat in order to overcome the resistance, and in this way it will lose or part with more heat. The amount of work done is shown by the indicator card, and can be estimated. The mechanical work done by the air in this expansion is exactly the same as that done upon it during its compression, but there is in addition the further loss of energy, due to the internal work done in the air during the expansion, so that what has been done to the air during the entire process has been to extract some of its original store of heat, thus reducing its temperature; and the cold air is now ready to restore its deficiency at the expense of the surrounding hotter bodies.

It should be borne in mind by the student that all bodies contain more or less heat and that heat can neither be created nor destroyed because it remains a fixed quantity throughout the universe.

Therefore the only method by which the temperature of a body or substance can be reduced is by the transference of more or less of the heat contained in the body to some other body or substance.

The work demanded of a refrigerating machine is to extract heat from a body, say from the air in an enclosed space, such as a refrigerating chamber, and by the expenditure of mechanical energy, to sufficiently raise the temperature of this heat to admit of its being carried away by a suitable external agent, the latter being most usually water, which is not only the cheapest one available, but also has a greater capacity for heat, weight for weight, than any other known substance, and is taken as the standard of comparison, its specific heat being taken as unity.

A refrigerating or ice-making machine may then properly be defined as a heat-pump for the simple reason that its main function is the abstraction of heat from one body (the body to be cooled), and continuously and automatically transferring that heat to the refrigerating or cooling agent.

REFRIGERATING MACHINES.

The various inventions for refrigerating and ice-making that are now in use, can be conveniently classified for the present purpose under the following five principal heads, viz.:

First, those wherein the more or less rapid dissolution, or liquefaction of a solid is utilized to abstract heat. This is, strictly speaking, more a chemical process.

Second, those wherein the abstraction of heat is effected by the evaporation of a portion of the liquid to be cooled, the process being assisted by an air-pump. This is known as the vacuum system.

Third, those wherein the abstraction of heat is effected by the evaporation of a separate refrigerating agent of a more or less volatile nature, which agent is subsequently restored to its original physical condition by mechanical compression and cooling. This is called the compression system.

Fourth, those wherein the abstraction of heat is effected by the evaporation of a separate refrigerating agent of more or less volatile nature under the direct action of heat, which agent again enters in solution with a liquid. This is termed the absorption system.

Fifth, those wherein air or other gas is first compressed, then cooled, and afterwards permitted to expand whilst doing work, or practically by first applying heat, so as to ultimately produce cold. These are usually designated as cold-air machines.

Of the various systems of refrigeration using different refrigerating mediums, only two, namely, the ammonia compression system and the ammonia absorption system have come into anything like general use in this country, and these two systems the author proposes to take up and discuss in a practical way beginning with the compression system.

A compression plant consists of a high-pressure system made up of a condensing coil surrounded by cooling water, with pipes connecting it to the compressor and regulating valve, and a low-pressure system consisting of an evaporating coil surrounded by brine, or open to the cold chamber, with connecting pipes. A small brine pump for circulating the brine is required.

In this system the process of refrigeration is divided into three distinct stages, viz., compression, condensation, and expansion.

Anhydrous ammonia is selected as the refrigerating medium on account of its low boiling point (—28.6° F.), its high latent heat of vaporization, its non-corrosive effect on iron and steel, and because the pressures under which it is used are such as to render it perfectly safe to handle with properly constructed apparatus.

When nitrogen and hydrogen combine to form ammonia, one volume of nitrogen unites with three volumes of hydrogen, hence the chemical formula of ammonia is NH_3. As the atomic weight of nitrogen is 14 and of hydrogen 1, the formula also indicates that 14 parts, by weight, of nitrogen, combine with 3 parts of hydrogen, to create 17 parts of ammonia.

Gaseous ammonia can be liquefied at a pressure of 128 lbs. to the square inch, at a temperature of 70° Fahr., and at a pressure of 150 lbs. at a temperature of 77° Fahr., the pressure required to produce liquefaction rising very rapidly with the temperature. To liquefy by cold it requires to be reduced to a very low temperature, viz., —85.5° Fahr.

The gaseous ammonia is drawn into the ammonia compressor, or pump, and is there compressed to a pressure varying from 125 to 175 pounds per square inch.

During this compression, the latent heat of the vapor (that is, that quantity of heat which was imparted to it to effect its expansion from a liquid to a vapor) is converted into active or sensible heat.

The vapor, under this high pressure, is forced into the condenser, consisting of a series of pipes over which cold water is allowed to flow (atmospheric condenser), or through pipe coils submerged in a body of cold water (submerged condenser), where the now active and sensible heat developed during compression is transferred to the cooling water, thus withdrawing from the vapor that heat which was necessary to keep it in a gaseous condition, and re-converting it into a liquid at the temperature and pressure existing in the condenser.

The ammonia, so liquefied in the condenser, is then allowed to pass in small quantities through a regulating or expansion valve into pipe coils placed in the rooms to be cooled, or in a bath of brine, when it again expands into a vapor, owing to the lower pressure maintained in such pipes, *taking up from whatever substance surrounds it, an amount of heat exactly equivalent to that which was given up during condensation.*

The expanded vapor is then drawn back into the compressor, again compressed, condensed, and expanded, the cycle of operation being repeated indefinitely with the same ammonia, which is used continuously and which never comes in contact with the substance to be refrigerated.

There are two systems of refrigeration by compression, viz., the "wet" system and the "dry" system.

A dry compression plant with an expansion evaporating system requires:

One. A medium size compressor.

Two. A large size evaporating system.

Three. A large amount of ammonia.

On the other hand, a wet compression plant having a wet compression evaporating sytem requires:

One. A large size compressor.

Two. A medium size evaporating system.

Three. A medium quantity of ammonia.

According to Vollman the "wet" system has the following advantages over the "dry" compression system:

One. "By allowing the ammonia vapors to return to the compressor in a partially wet state, we are enabled to work with a higher back pressure, thereby having the ammonia gas in the refrigerator pipes of a higher density than if the vapors were perfectly dry. Furthermore, we are enabled to keep the refrigerator pipes partially filled with liquid ammonia, in consequence of which the surface of the refrigerator can be materially reduced."

Two. "By keeping the compressor parts at a cool temperature, the compressor draws in a greater amount of vapors than where the parts are highly overheated. With a dry compressor, although the cylinder is water-jacketed, the internal parts are kept at a very high temperature, and when the dry ammonia vapors are drawn into the compressor, they immediately get heated up, and by expanding prevent the compressor from drawing in its full amount of vapors."

Three. "By keeping the compressor at a cool temperature, the compressor oil which is taken into the compressor through the stuffing box cannot evaporate, but is kept in its liquid state, and as such deposited in the oil collector."

Four. "With the wet compressor system, the engineer in charge knows if sufficient ammonia is circulated through the system or not, by placing his hand on the delivery pipe. If this is fairly warm, a sufficient amount of ammonia is passed through the system."

Regarding Vollman's theory (2), that a larger volume of vapor could be handled by the wet compressor at each stroke, the fact must not be overlooked that the interchange of heat between the ammonia and the walls of the compressor cylinder is much greater than is generally anticipated. With the vapor wet after compression, the capacity of the plant is reduced, and also the coefficient of performance, so that this condition should be avoided. When superheating is allowed, the capacity is increased, but again the ideal coefficient of performance is reduced slightly. Experiments seem to indicate, however, that a moderate amount of superheat, say 10° to 20°, results in a decided improvement in efficiency. This may be due to the reduction thereby caused in the mechanical losses inside the cylinder, and also in the heat leakage into the ammonia vapor from the cylinder walls during compression. But this is more or less counterbalanced by the widening of the temperature range, so that the coefficient of performance may be reduced, may remain steady, or may be increased according to the charge of ammonia present.

On the whole there does not seem to be much to choose between "wet" and "dry" compression. The former gives a slightly higher coefficient of performance, the latter a slightly greater amount of refrigeration.

THE LINDE ICE MACHINE.

As the Linde ice machine, Fig. 357, is a good example of the workings of the "wet" or humid system, a short description of the construction and operation of the machine will be given.

The theory of the action of the Linde machine is as follows:

"So long as ammonia vapor is in a humid or saturated condition (that is, while still in contact with any of its originating liquid), temperature and pressure are functions of one another, and to a given temperature belongs a certain pressure.

"On the contrary, when ammonia (now properly called a gas) is not in contact with any of its mother liquid, its temperature may be very much higher than that corresponding to its pressure.

"For example, the pressure of the steam in a boiler depends entirely upon its temperature, which is always equal to that of the remaining water. It is therefore evident that in the case of steam, while in contact with the originating water, temperature and pressure are interdependent.

"Separate the steam from the water, and apply heat (superheat it), and it may have the same pressure at widely different temperatures."

When a gas or vapor is compressed, the heat equivalent of the mechanical work of compression tends to raise its temperature, and consequently its pressure, more rapidly than would be the case if it would be maintained at constant temperature.

In the compression of a dry gas, unless heat is withdrawn by means of a water-jacket, or other cooling device,

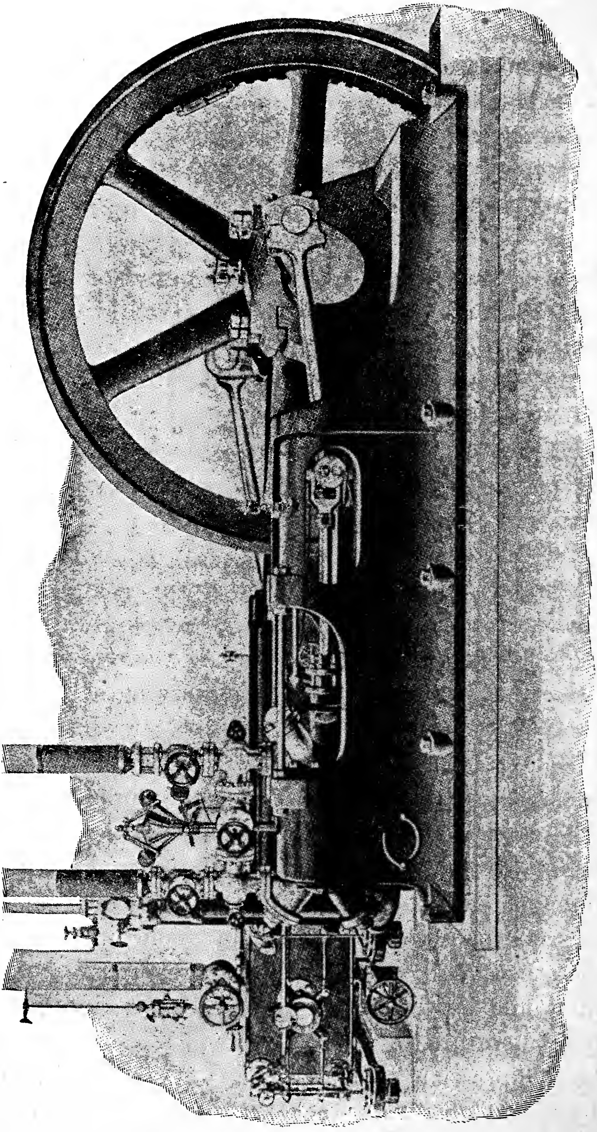
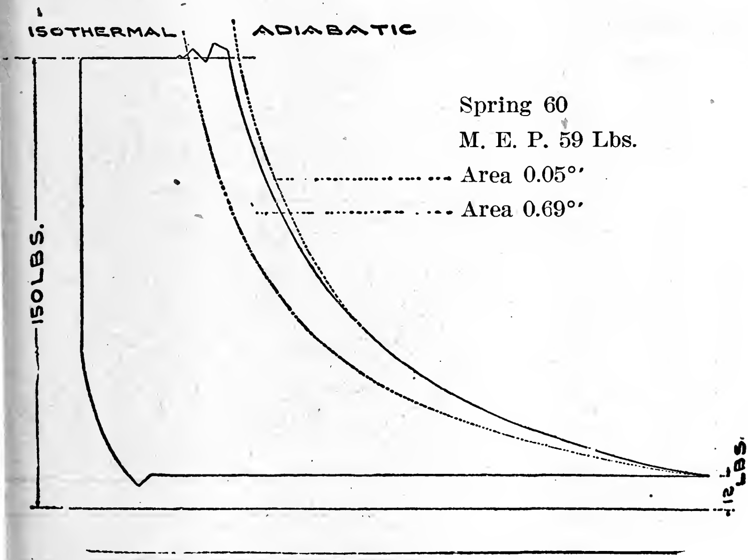


FIG. 357 LINDE ICE MACHINE

the adiabatic curve will be traced on the indicator diagram. This is the curve which represents the compression or expansion of a gas without loss or gain of heat.

In the Linde machine the cooling of the vapor in the compression cylinder is effected by the introduction into the latter of a small quantity of liquid ammonia with the gas or vapor at the commencement of each stroke, whereby it is cooled down to a refrigerating temperature. The ammonia is carried back to the compressor in a saturated condition, and the heat of compression is taken care of in the unexpanded ammonia which in the form of fog or vapor, entered the compressor on the suction stroke.

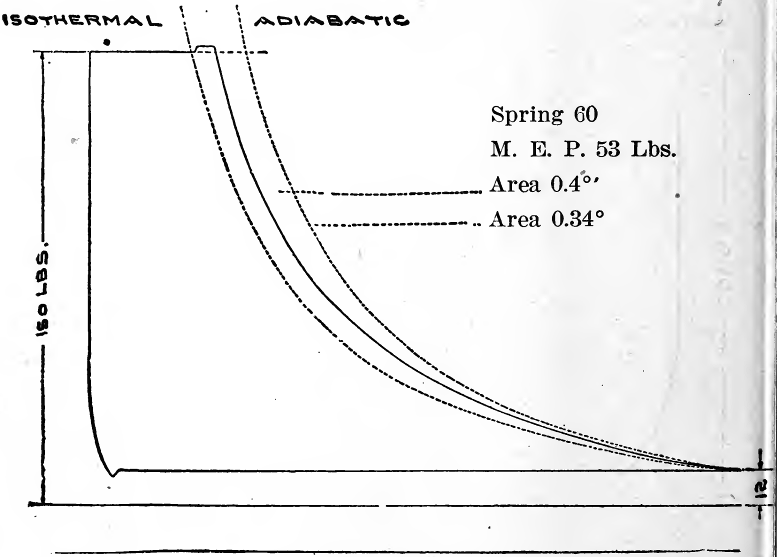


Dry Gas.

Fig. 358

The diagrams Figs. 358 and 359 illustrate the comparative efficiency of this method of cooling the compression cylinder, termed the "wet" system, and the other method wherein a water-jacket system is employed termed the "dry" gas system.

The initial volume and pressure, and the terminal pressure are the same in each case. In the compression of the dry gas, the compression curve necessarily follows for a considerable distance the adiabatic line.



Saturated Vapor.

FIG. 359

This for the reason that the gas coming into the cylinder from the expansion coils is at a temperature of —5° F. and no heat can be transmitted from it to the cooling water in the water-jacket until the temperature of the gas has been raised above that of the water, which is probably 60° to 70° F.

The compression curve then leaves the adiabatic and during the last part of the stroke, before the discharge valve opens, approaches the isothermal line.

In the compression of saturated vapor, the unexpanded ammonia begins immediately to absorb the heat of compression, and the compression curve at once leaves the adiabatic and approaches the isothermal line, making a diagram that is much smaller in area and which therefore represents work requiring less power.

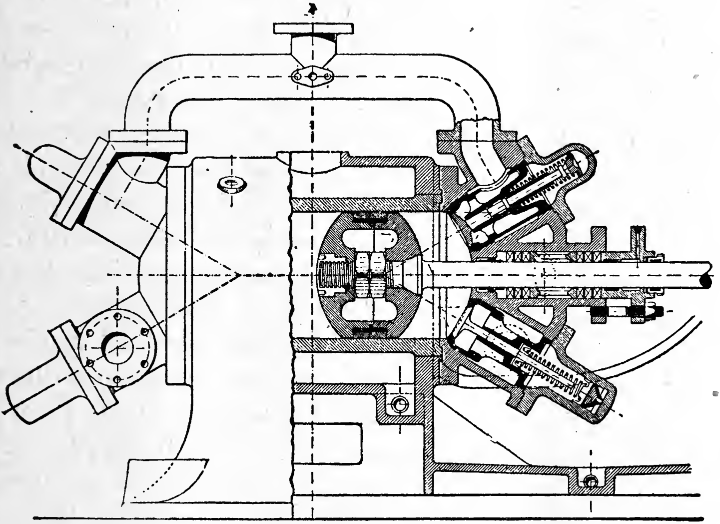


FIG. 360

SECTIONAL VIEW OF THE LINDE COMPRESSOR CYLINDER AND VALVES

The efficiency ratio of any cylinder cooling device is found by dividing the area between the actual compression curve and the adiabatic curve, by the total area between the adiabatic and isothermal curves.

"Assuming that the diagrams shown are from eighteen by thirty inch double-acting compressors, running at fifty revolutions per minute, the effective horse-power required for the compression of the saturated vapor would be 102.1 horse-power, as against 113.7 horse-power for the dry-gas machine, *a gain of* 10.2% *in favor of the humid system of operation.*"

Fig. 360 shows a sectional view of the Linde compressor cylinder, piston and valves.

It will be observed that the piston and heads are spherical and of the same radius. The valve discs conform absolutely to this radius, and when the valves are seated these discs are exactly flush with the heads.

The clearance between the piston and the cylinder head is very small, being only $\frac{1}{32}$ in., therefore the clearance losses are very small, being less than two per cent. of the total cylinder volume. The cylinders are made of clear, hard iron, tested to 1,000 lbs. hydrostatic pressure. The finishing cut through the cylinder is made after it is placed in the frame, the final cut on crosshead guides being taken at the same time, and on the same boring bar, thus insuring their correct alignment. Proper openings are provided for the application of the indicator.

The lubrication of the piston is accomplished in large measure by the moisture in the ammonia itself. Oil is used to seal the stuffing box against the leakage of ammonia. Very little of this oil is carried into the cylinder on the piston rod.

The piston is ground on the tapered shoulder of the piston rod, and is secured by lock nuts, as shown in Fig. 360. The follower head is then screwed on and held firmly in place by the flush nut, which in turn is prevented from backing off by a screw set into the face of the follower and riveted over. Those who have experienced the annoying effect of pistons working loose on the rod will appreciate the advantages of this method, permitting, as it does, the ready removal of the piston when necessary, while at the same time absolutely precluding the possibility of its accidentally becoming loose. *Many serious accidents have resulted from inattention to this detail.* The piston is packed with removable bull rings and cast-iron packing rings.

The valves are of large area, the discharge valve being placed at the lowest point of the cylinder, insuring the perfect draining of any liquid present at the end of the compression period. The importance of this feature cannot be overestimated; the many records of compressors wrecked by the piston coming in contact with incompressible liquid being familiar to all users of this class of machinery. The stems and discs are of the finest forged steel, set in cast-steel housings. The valve lift is governed by positive stops and controlled by springs. The suction valve is provided with a safety stop to prevent its falling into the cylinder.

The Linde stuffing-box is shown in section, in Fig. 361—to which reference is now made. The numbers 2, 4, 5, 9, 10, 12 and 14 indicate composition packing rings. These should never be used solid but should be cut as shown in sketch "A." Numbers 3, 6, 8 and 11 represent metal rings, made from pure tin. They are intended to keep the rubber rings in proper condition. These rings should always be one-sixteenth of an inch larger than the rod, and should never be cut in two, as otherwise they are apt to score the rod. If necessary to put in new metal rings, disconnect the piston rod from the crosshead and slip the rings over the end of the rod. *Under no circumstances pack the compressor without the metal rings.*

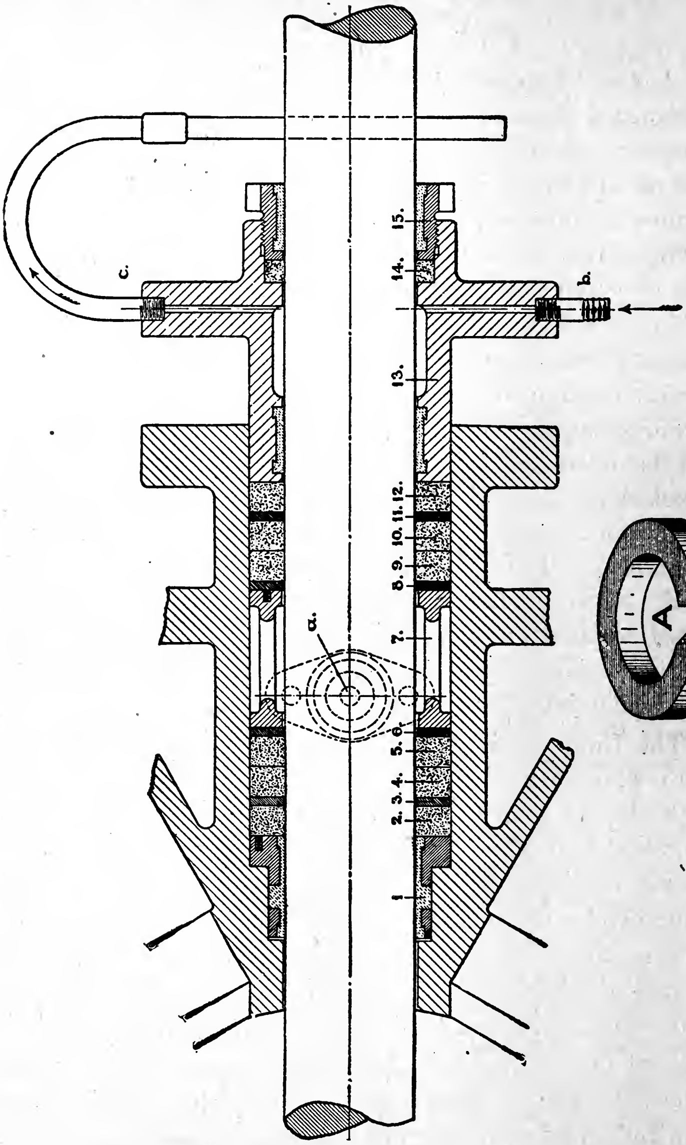


FIG. 361
SECTIONAL VIEW OF LINDE STUFFING BOX

Number 7 designates the lantern which forms an oil storage in the middle of the stuffing box. The oil supply is taken in at the point marked "a" through a pipe connection from the oil trap. This passage being always open, the oil is forced into the stuffing-box by the high pressure gas in the oil trap, keeping this stuffing-box and lantern always full, and instantly replacing what little oil is carried into the cylinder on the rod. Number 13 is the stuffing-box gland which is supplied with oil through the inlet "b" from a small oil pump operated from the main shaft. This oil overflows at "c" and is led back to the oil pan to be recirculated.

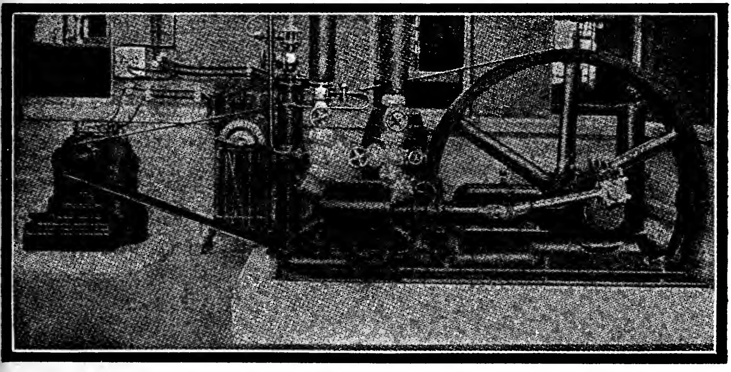


Fig. 362

12-TON LINDE ICE MACHINE—MOTOR OPERATED

Number 15 is the oil gland which should be kept just tight enough to keep the oil in the stuffing-box gland. The points of contact with the rod are numbers 1, 13, and 15, and they must fit the rod properly. If it becomes scored and is turned down, these parts must be rebabbitted.

When repacking be sure to place the different parts of the packing in strict accordance with the above instructions and with the cut shown, insuring the best results. Great care should be used not to tighten the stuffing gland 13 more than is necessary to prevent the ammonia from leaking.

The Linde compressor is of the horizontal double-acting type, and consequently the lines of strain are brought close to, and parallel with the foundations. The machine is so constructed, as to be easily attached to any steam engine, either by being direct connected, or by belting from a counter shaft. In small plants, electric motors are often used for operating these machines. Fig. 362 shows an installation of this kind.

DE LA VERGNE REFRIGERATING MACHINE.

In the De La Vergne refrigerating machine the cooling of the heated gas is effected by passing it through pipes surrounded by running water. The characteristic feature of this machine consists in the patented system for preventing the occurrence of any leakage of gas taking place past the stuffing-box, piston, and valves, and of extracting the heat from the gas during compression, by the simple device of injecting into the compressor, at each stroke, a certain quantity of oil or other suitable lubricating fluid. By means of this sealing, lubricating, and cooling oil, not only are the stuffing-box, piston, and valves effectually sealed, and the heat developed during compression taken up, but all clearances are entirely filled up. This latter is a matter of great importance, as it ensures a complete discharge of the gas from the pump cylinder, and obviates the above-mentioned loss of power and efficiency.

This method of sealing the stuffing-box and piston prevents leakage and consequent introduction of air into the pump, or wasting of the refrigerating gas at each alternate stroke of the piston without necessitating the packing of piston so tightly as to cause excessive friction. Fig. 363 shows a sectional view of a double-acting De La Vergne compressor fitted with Louis Block's arrangement of valves, the main object of which is to secure the discharge of the oil at the lower end of the cylinder taking place immediately after all the gas is gone and not before, as in the latter case re-expansion will take place, resulting in loss of efficiency of the pump. To effect this, two valves are provided in the lower end of the compressor cylinder, one above the other.

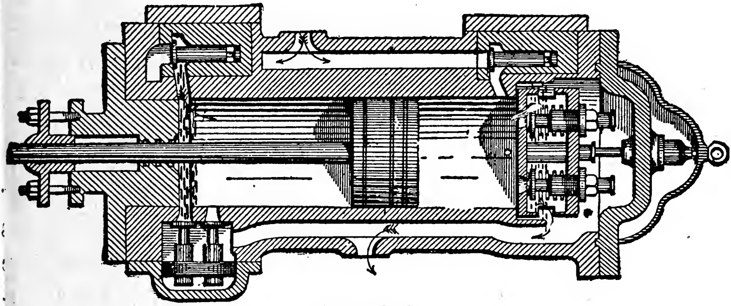


Fig. 363

DOUBLE-ACTING TYPE OF DE LA VERGNE AMMONIA COMPRESSOR

Either, or both of these valves may open on the down stroke of the piston, until the latter covers the upper one, when only the lower one is left open to the condenser. During the remainder of the stroke of the piston, after the lower valve is also closed, the other or upper one opens communication with an annular chamber formed in the said piston. In the bottom of this annular chamber are provided, moreover, valves which open as soon as all the other outlets from the underside of the piston are closed, to ensure which they are loaded with springs, so arranged as to require somewhat more pressure to open them than the discharge valves on the side of the cylinder. The gas, and afterwards the oil, then all pass out through the piston, no trace of the former being present at the completion of the down stroke. In this manner the oil system of sealing can be advantageously retained, and the pump will work as well at the lower side as the upper.

Fig. 364 shows a complete installation of a refrigerating plant on the De La Vergne system, the vertical compressor being driven by a horizontal engine. The circulation of the ammonia, and the sealing oil is as follows: A is the compressor cylinder, double-acting, and similar in construction to that shown in section in Fig. 363. R is the steam engine cylinder. B is the pipe through which the gas is drawn from the evaporating coils into the compressor A. The gas is then discharged by the action of the compressor through the pipe C, into the pressure tank D, where the sealing oil or liquid falls to the bottom. Suitable cast-iron baffle plates are fitted in the upper portion of the pressure tank, which serve to retain the oil, and insure its deposition. From the pressure tank D the gas which still retains the heat due to compression, passes through pipe E into the bottom or lower pipe of the condenser F, wherein, by the cooling action of cold water running over the pipes, the heated gas is first cooled and then liquefied. The ammonia, in this liquid condition, is then led by the small liquid pipes G, through the liquid header H, into the storage tank I, from whence it flows through the pipe J into the lower

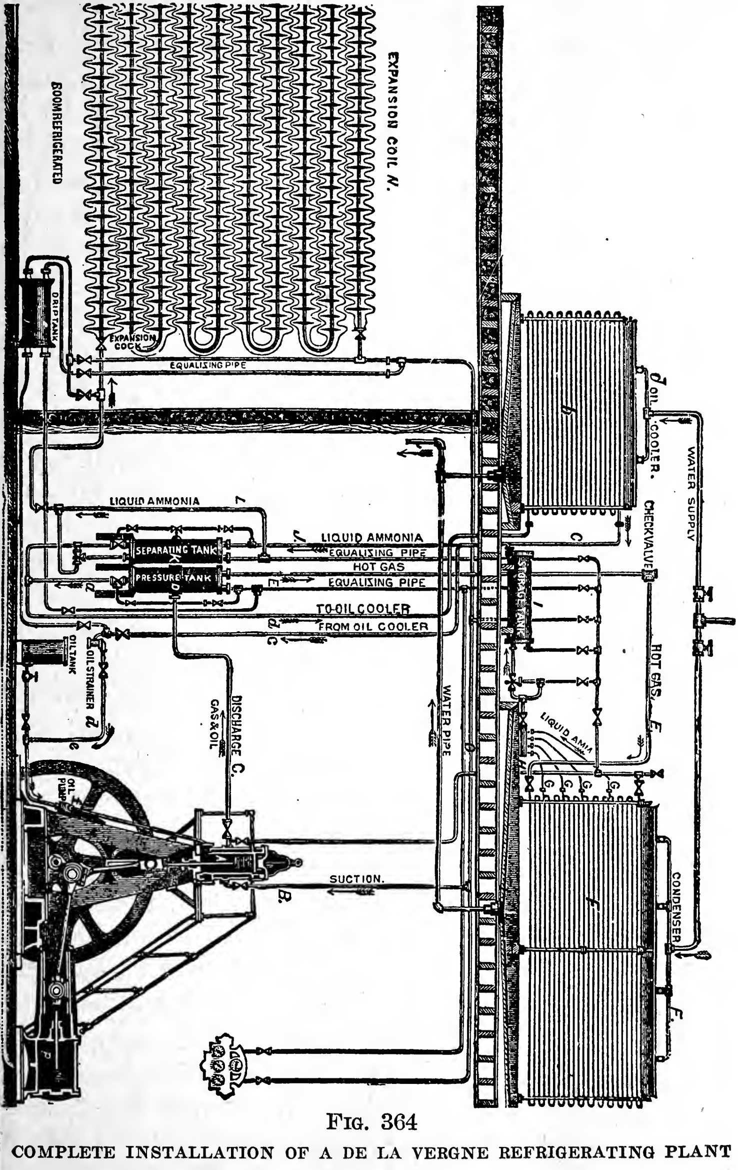


Fig. 364

COMPLETE INSTALLATION OF A DE LA VERGNE REFRIGERATING PLANT part of the separating tank K, which latter must be constantly maintained at the very least three-quarters full. L is a pipe of small bore, through which the liquid ammonia is forced, by reason of the pressure to which it is now subjected, to the expansion cock or valve, through which it is injected into the evaporating or expansion coil N which is situated in the room or chamber to be refrigerated or cooled.

The ammonia gas resulting from the expansion and evaporation of the liquid ammonia in the evaporating or expansion coil N, having absorbed or taken up the heat from the surrounding atmosphere, passes away through the pipes O and B, back again into the compressor cylinder, and the cycle of operations of compressing, etc., are again performed as above.

Secondly. Following the course of the oil employed for sealing, lubricating, and cooling purposes, which, as previously mentioned, is heated with the gas during compression, and is passed into the tank D, to the bottom of which it falls. From the bottom of the tank D, the heated oil is conducted through a pipe a to the lowermost pipe of the oil-cooler b, which is practically similar in construction, but on a smaller scale, to the ammonia condenser, and is likewise cooled by sprayed or atomized cold water. After being sufficiently reduced in temperature in the oil-cooler b, the oil flows through the pipe c, strainer d, and pipe e, into the oil pump f, which latter is so constructed that it delivers the cooled oil into the compressor, distributing it to either side of the piston or plunger during its compression stroke, that is to say, in such a manner that no oil is furnished during the suction stroke of the piston, but only during the time of compressing, thereby cooling the gas during its period of heating. The heated oil, after leaving the compressor, then again returns, together with the hot compressed gas, to the pressure tank D, and follows the same round through the oil-cooler b, strainer d, and oil pump f, back to the compression cylinder. It will be obvious that the oil, as well as the ammonia, is used over and over again, no loss or waste of either taking place except that which may occur through leakage.

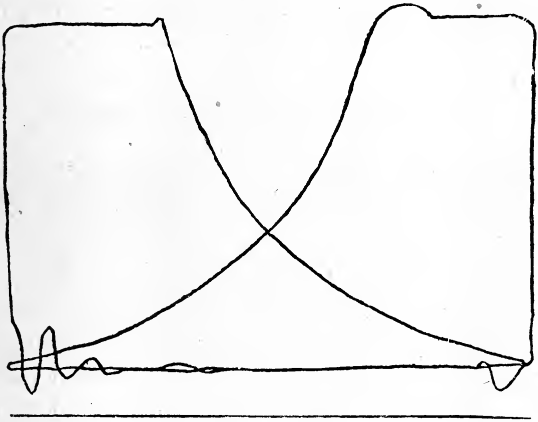


FIG. 365

DIAGRAM FROM DE LA VERGNE COMPRESSOR

Any small quantities of oil, however, that may be carried over with the current of the gas from the pressure tank D into the condenser F, pass along with the liquid ammonia into the separating tank K, where, by reason of its greater weight, this oil falls to, and collects at the bottom of the tank. As soon as a sufficient quantity of oil has become thus deposited, it is drawn off, and passed through the oil cooler back to the oil pump. The oil reservoir or tank is also connected to the oil pump F. When the apparatus is employed for the manufacture of ice, the evaporating coils N are placed in a tank containing brine, sufficient space being left between them to allow of the insertion of cans or moulds containing the water to be frozen. As before stated, the exhaust steam of the engine driving the compressor is condensed and purified, and supplies the water to be made into ice.

The various parts are clearly indicated in Fig. 364—and the routes taken by the ammonia, the sealing oil, the lubricating and cooling oil, and the steam are shown by the arrows.

THE TRIUMPH ICE MACHINE.

Fig. 366 shows a sectional view of the compressor cylinder and valves of the Triumph double-acting ammonia compressor.

It will be seen from the illustration that the compressor is provided with five valves, viz., three suction valves and two discharge valves, the third, or auxiliary suction valve, being much lighter than the main valves, and perfectly balanced, and it being claimed by the makers tending greatly to increase the economy of the machine.

Obviously the main suction valves must necessarily be of sufficient dimensions to admit the charge quickly at the commencement of each stroke, and the springs controlling them must consequently have an appreciable tension. It will be readily seen that owing to this fact the pressure of the gas in the cylinder, during admission, must be less than it is in the suction pipe by an amount equal to the tension of these springs. By the use of the above mentioned third, or auxiliary suction valve, which is comparatively light, and is consequently operated with a very light spring, the pressures in the compressor pump are equalized, and a fuller charge is obtained at each stroke, thereby increasing the efficiency of the machine.

The valves comprise each a guard screwed on to the stem, fitted inside a cage, and so ribbed as to reduce the port area, the bottom of the stem being enlarged for that reason. Stems extending from both the suction and discharge valves to the exterior, and passing through stuffing-boxes, admit of their being adjusted from the outside, and any desired degree of tension being put upon the springs. The object of this arrangement is to adjust the machine for working at different pressures, and the relative temperatures thereof.

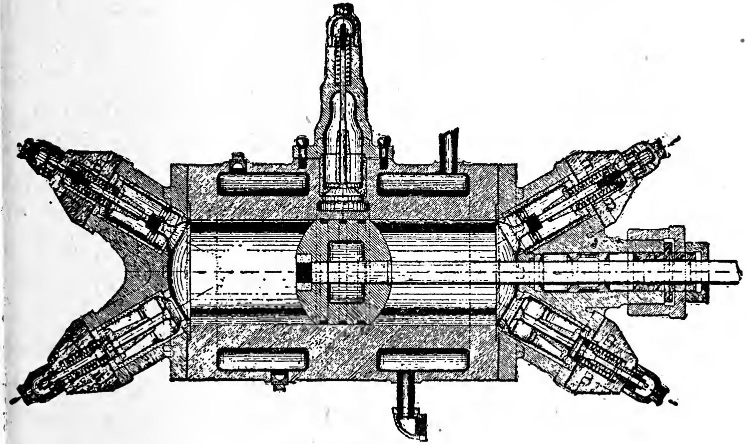


FIG. 366

DOUBLE-ACTION HORIZONTAL TYPE OF TRIUMPH AMMONIA COMPRESSOR

There are three packing compartments in the piston-rod stuffing-box, and it is fitted with a suitable relief valve communicating with the suction. The heads are formed concave, and of a radius which enables a larger valve area to be secured. The principal shut-off valves are of such a form of construction as to admit of their being packed while the machine is working, and a feature in the design of this machine which is of by no means inconsiderable advantage, is that every portion of the compressor is easily accessible.

CONSOLIDATED REFRIGERATING MACHINE.

Fig. 367 shows the general form of the Consolidated ice-making and refrigerating machine. It is a compression type of machine, having two single-acting, vertical compressors, and either a horizontal or a vertical engine, which is connected to a center crank, on either side of which are large journal bearings. Power thus transmitted to the shaft is regulated by two flywheels which are of sufficient weight to carry the engine smoothly over the point of maximum compression, and to deliver the power to the compressor.

It is an advantage to have the crank in the center of the shaft, and to place a flywheel between the engine crank and each pump crank, because this construction gives uniformity and steadiness of motion and diminishes torsional strain, vibration and friction of the crank shaft. It also permits the use of a long-stroke Corliss engine, since the stroke of the engine is not limited to the stroke of the ammonia pump, as is the case where the compressor and engine are connected to the same crank pin. In this way, the builders claim to effect a saving of from 10 to 15 per cent in the steam consumption.

Heavy pump columns terminate at the bottom in broad flanges bolted to a substantial foundation plate, cast in one piece and provided with four journal bearings for the crank shaft. Convenient stairways and galleries are provided to furnish access to the upper part of the machine. As seen in Fig. 368 the compressor or ammonia pump is single-acting, compressing only on the up-stroke, and the gas has free entrance to, and exit from the cylinder below the piston, thus keeping the pump cylinder and piston cool.

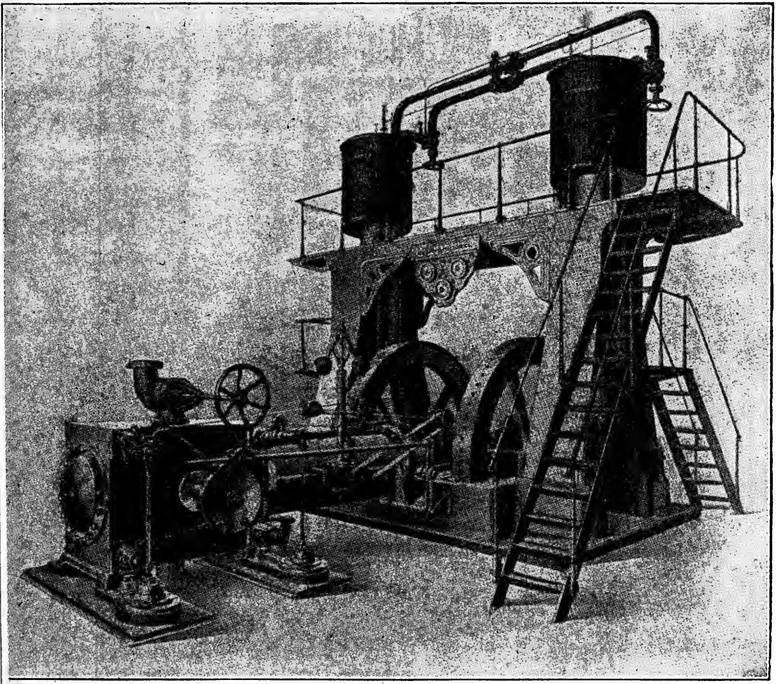


FIG. 367

VERTICAL CONSOLIDATED REFRIGERATING MACHINE

An oil chamber, which effectually seals the stuffing-box around the pump piston rod, is formed in the lower part of the pump. As the pressure on the stuffing-box end of

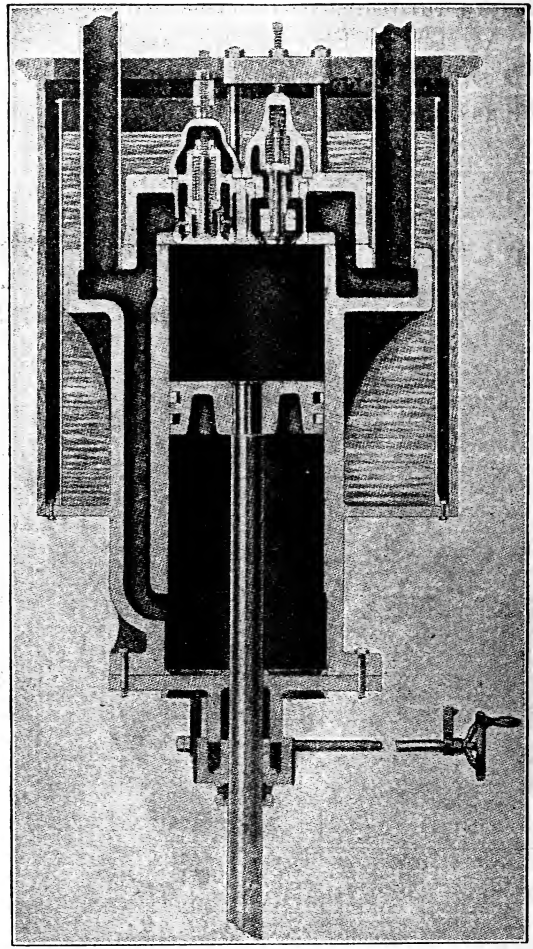


FIG. 368

CROSS-SECTION OF THE SIMPLE-ACTING AMMONIA COMPRESSOR

the pump is only the direct evaporator pressure, there is no chance for the escape of ammonia. Equalization of the temperature and cooling of the compressor is effected by encasing it in a copper water jacket.

In the construction of the piston, no bolts or nuts are used, and there are, therefore, no cavities or chambers into which the gas can be compressed. Since the piston travels flush with the pump head, all of the gas is expelled at each stroke. The pistons are fitted with spring rings that are first turned elliptical, and afterward returned on a mandrel until they fit the cylinder exactly.

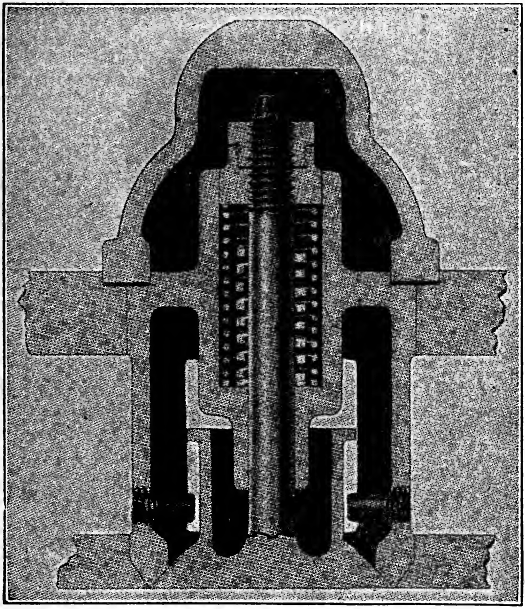


Fig. 369

SUCTION VALVE SHOWING SAFETY DEVICE

As shown in Fig. 368 the stuffing-boxes are operated by a worm-gear device so that, while the machine is running, a turn of the hand-wheel accurately adjusts the stuffing-box gland and thus makes unnecessary the different and frequently dangerous use of a wrench or spanner and also avoids the possibility of cutting the piston rod by uneven adjustment of the gland.

Connections for the suction and discharge pipes are made outside of the pump head so that, when it is desired to remove the head, neither of these connections need be disturbed. Discharge and suction valves, compressor heads, piston and piston rods, all are easily removed without breaking any ammonia connections.

Fig. 368 shows the suction and discharge valves which are located in the pump head. The suction valve, Fig. 369, is balanced, thus allowing the pump to fill with expanded gas from the evaporator with no loss of pressure. As shown in Fig. 369, the valves are provided with a safety device which renders it impossible for them to get into the cylinder. Cushioning of the discharge valves ensures noiseless action and, since both suction and discharge valves are set in steel cages, and held in position in the pump head by means of yokes and set screws, it is but a moment's work to remove a valve and put a duplicate in place.

As seen in Fig. 367 the machine is driven by a Featherstone Corliss engine resting on substantial base plates which are extended on one side for the dashpots. The valve motion is of the improved Corliss type, having the liberating catches made of hardened steel of such form that eight wearing surfaces are available, by change of position, each new position restoring the valve motion to its original setting.

Horizontal Type. In this form, the Featherstone machine is built with a horizontal engine and a horizontal, double-acting compressor, and has a straight crank shaft

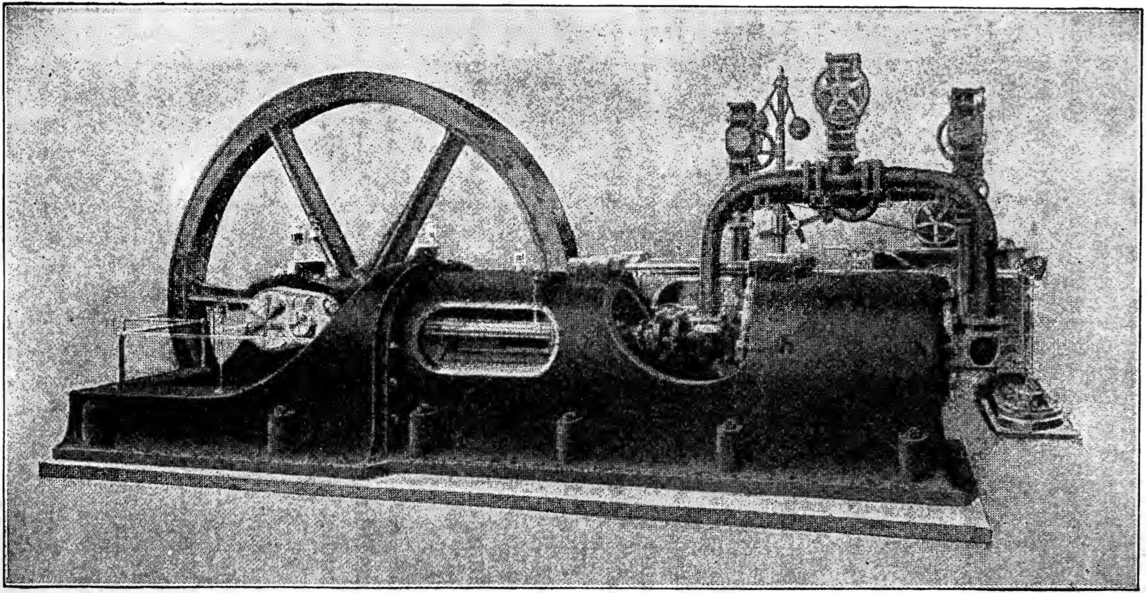


FIG. 370
HORIZONTAL DOUBLE-ACTING MACHINE

with the flywheel placed in the middle between the two main bearings as shown in Fig. 370. These machines are mounted on the heavy duty Tangye frame which is almost universally used by builders of double-acting compressors. Provision is made for cooling the compressor cylinder by means of a water jacket so that it may be operated as a dry, or humid gas machine. As shown in Fig. 370, the machine is driven by a Featherstone-Corliss engine, having a heavy frame similar to that of the compressor, but any type of engine may be used and, if necessary, the compressor can be driven by belt.

Figure 371 shows the manner in which the compressor cylinders are pressed into the frame so as to form a water jacket. The valves are placed in the compressor head in a way that will permit of their easy removal and, since the discharge valves are located at the lowest part of the cylinder, perfect draining at the end of the compression period is assured. This makes it impossible for the machine to be wrecked by the piston coming in contact with an incompressible liquid at the end of the stroke. The clearance is less than $\frac{1}{32}$ inch, thus giving good efficiency by permitting the piston to discharge all of the gas at each stroke, so that on commencing a new stroke, gas is immediately drawn into the cylinder.

In the horizontal machine, the valves are like those used in the consolidated compressors, the stems and discs being of forged steel set in cast-steel housings. Lift of the valves is given by cushion springs and controlled by compression springs and the suction valves are of the Featherstone safety type, so that it is impossible for them to fall into the cylinder. The piston is screwed to the piston rod by a jam nut, and the connecting rod is pro-

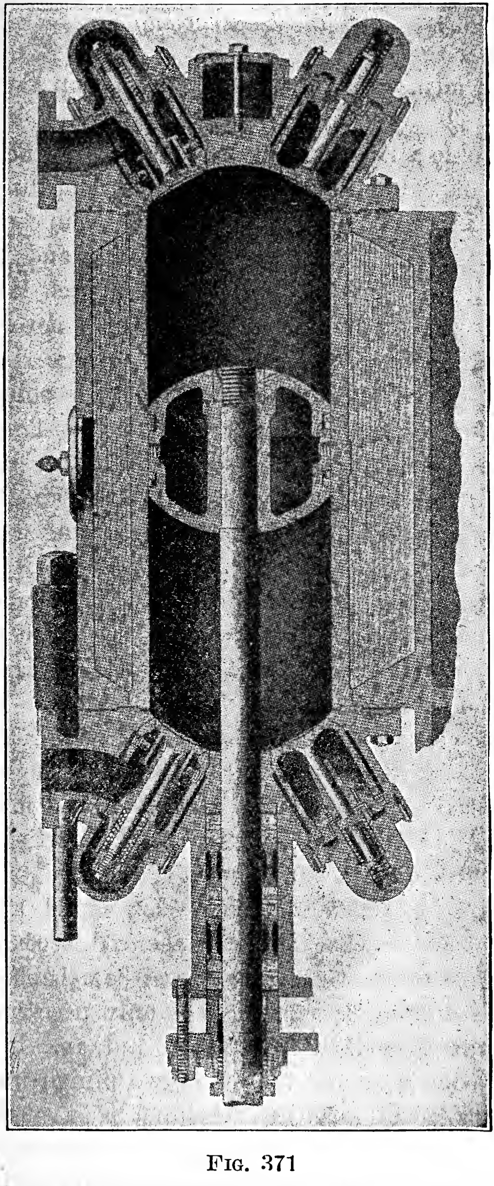


Fig. 371
SECTION OF COMPRESSOR SHOWING WATER JACKET

vided with adjustable wedges for taking up the wear of the boxes.

In a double-acting, ammonia compressor, the stuffing-box is one of the most vital parts. Referring to Fig. 372, letters A, B, C, D, E and F indicate composition split packing rings and letters Q, R, S, U, V and W denote pure tin rings of an inside diameter $\frac{1}{16}$ inch larger than that of the piston rod. These rings should never be split.

J is a lantern which forms an oil storage reservoir in the stuffing-box, the oil being taken in at the point marked K from a pipe connected to the oil trap. This passage being always open, the oil is forced into the stuffing-box by the high pressure of the gas in the oil trap, thus keeping the lantern full and instantly replacing what little oil is carried into the cylinder by the rod. L is a lantern which at the point marked M has a pipe connection to the suction line so that any ammonia gas which may have escaped the packing rings C, D, E and F is drawn back. By this device, packing rings A and B have to withstand only the suction pressure. N is the stuffing-box gland which has a chamber supplied with oil through O from a small rotary oil pump operated from the main shaft. P is the oil gland which should be kept just tight enough to keep the oil in the stuffing-box gland.

Points of contact with the rod are G, H and I and they are made an exact fit. If the rod becomes scored and is turned down, these parts must be rebabbitted. To tighten the stuffing-box gland it is only necessary to adjust the nut T, which is a pinion nut and is in mesh with the inside gear and the other two pinion nuts.

As shown in Fig. 373, the dashpot is of a special design, and allows for the adjustment of both vacuum and cushion. It is placed on an extension of the cylinder foot

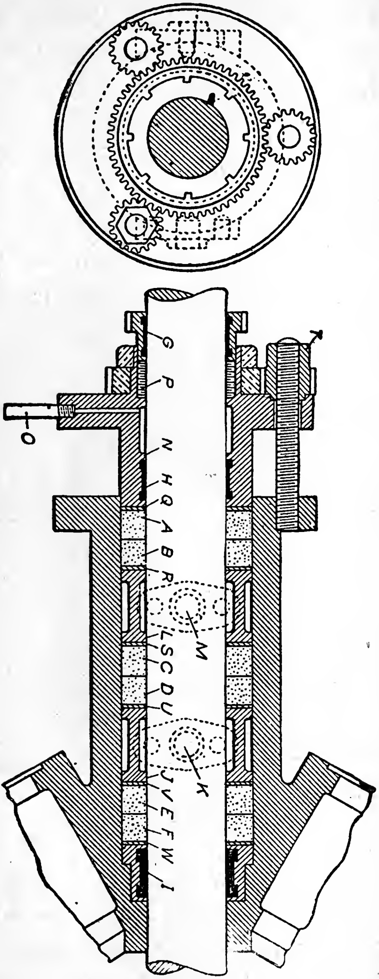


Fig. 372

STUFFING-BOX OF THE DOUBLE-ACTING COMPRESSOR

and connected by the usual vertical link rod to the crank on the valve stem. The central cylinder A acts as a guide and piston, while the pot B rises and falls, and by so doing draws air into the chamber C through the passage D, the vacuum C being regulated by the position of the needle valve E. As the pot falls, air escapes from C through valve H, and the fall is free until the lower end of the pot cushions into a chamber K formed by drawing up the ring F by means of the screw G. The position of F determines the amount of the cushioning and the leather washer R prevents hammering at the end of the fall.

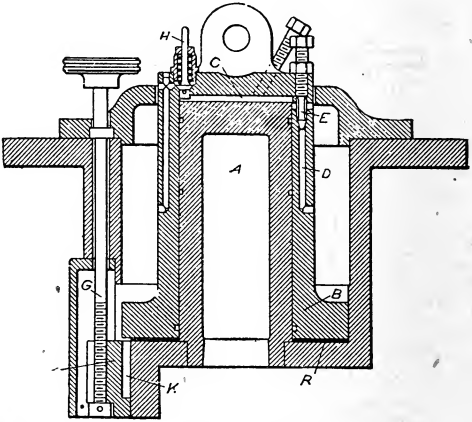


Fig. 373

SECTION OF THE DASHPOT

Double-pipe Ammonia Condenser. This type of condenser consists of two series of coils, one within the other, and is usually built in four different forms having 2-inch and 1.25-inch, 2.5-inch, 3-inch and 2-inch pipes or, having the upper outside pipes 2.5 inches and the lower pipes with all of the inner pipes 1.25 inch. Of these forms, the first is used most extensively, but the second is used whenever extra strong pipe is required, and the third when extremely dirty water is to be handled. The ammonia circulates downwards through the annular space between the two sets of pipe coils. By this arrangement a comparatively small charge of ammonia is required, owing to the narrowness of the space between the pipes.

Occupying small space, the condenser can be placed in a basement or other convenient place. Since the flow of ammonia gas and the cooling water are in opposite directions, the hottest gas comes in contact with the hottest water and thus fully utilizes the cooling effect of the water.

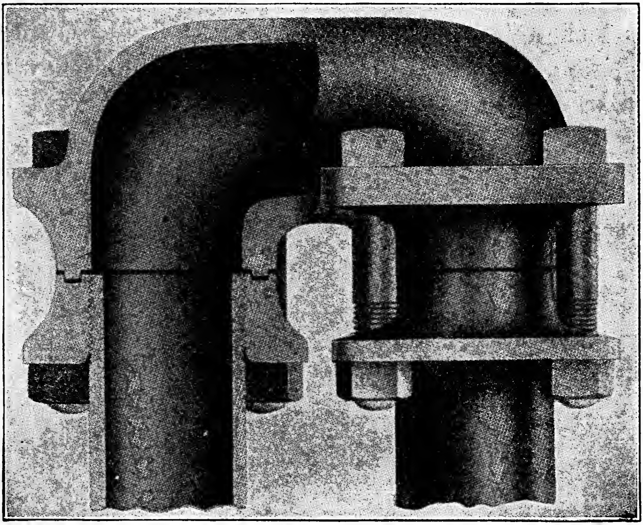


FIG. 374

RETURN BEND FOR THE ATMOSPHERIC CONDENSER

Fig. 374 shows a sectional view of the atmospheric condenser return bend, and Fig. 375 a view of the return bend which is used for the double-pipe ammonia condenser and also for the brine cooler. Fig. 376 shows the double-pipe condenser in which, owing to the construction of the return bend, it is possible to remove and replace any length of pipe without tearing down the whole coil as is necessary where double-pipe connections are made with screwed bends.

Condensers are furnished complete with gas, liquid, pump-out, and water headers and one of the special features is the construction of the liquid and purge headers which are made with special tee valves. Owing to the design, additional sections can be added at any time as enlargement of the plant may require.

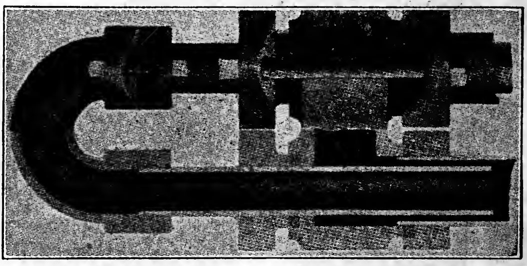


Fig. 375

DOUBLE-PIPE RETURN BEND

Fig. 377 shows a double-pipe brine cooler, which is built on the same general plan as the ammonia condenser, but is made of 2 and 3-inch pipes. Liquid ammonia enters and is expanded in the bottom pipe and the gas is drawn off at the top, while the brine is pumped into the top and circulates downward, through the annular space between the two pipes.

There are two distinct methods of utilizing refrigeration, viz., the *Brine System* and the *Direct Expansion System.* In the former the coils of pipe in which the ammonia is expanded are placed in a tank containing a

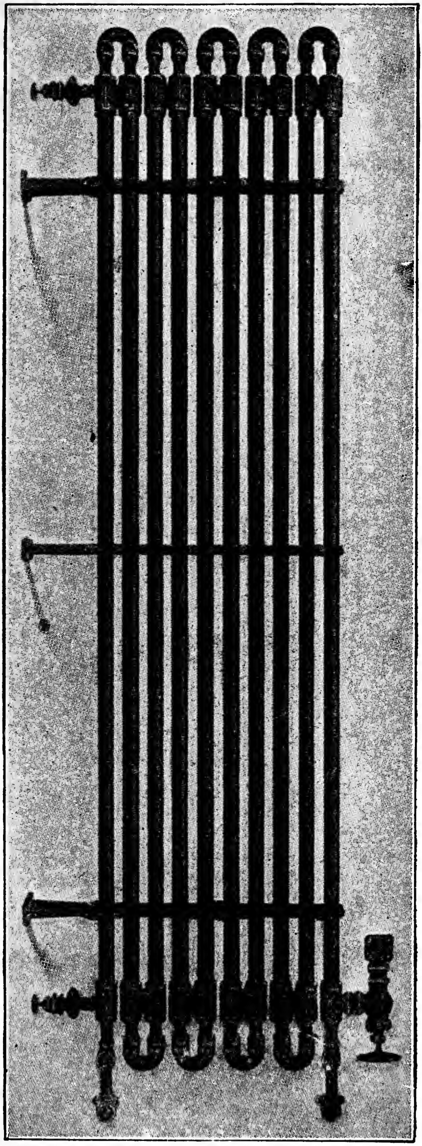


FIG. 376

DOUBLE-PIPE AMMONIA CONDENSER

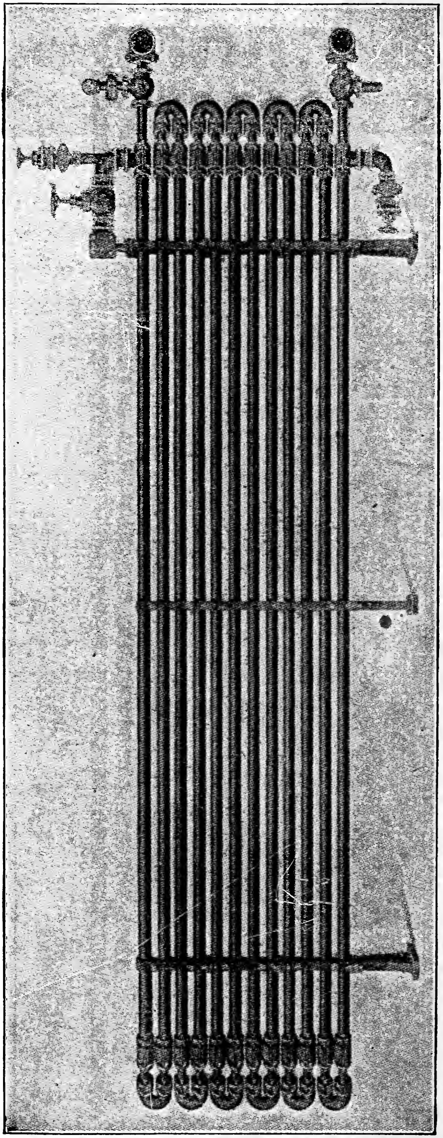


Fig. 377
DOUBLE-PIPE BRINE COOLER

solution of salt, or calcium chloride of such density as to insure a low freezing point. This body of brine, after being reduced to a low temperature by the transfer of its heat to the expanding ammonia, is pumped through coils of pipe in the rooms to be cooled, taking up from the atmosphere of such rooms a part of its heat. It is then returned to the brine tank, recooled and again circulated through the rooms.

In the direct expansion system, the expansion pipes are placed in the rooms to be cooled, the heat necessary for the expansion of the ammonia being drawn directly from the atmosphere surrounding the pipes.

Of the two systems, the direct expansion system is probably the most efficient as may be seen by the following summary of its advantages over the brine system:

1st. All intermediate agencies are dispensed with, the refrigeration being produced at the place where it is utilized. Every transfer of energy means loss. The brine tank, even if insulated, furnishes immense surface for loss by radiation.

2d. The whole plant is much simpler, considerable auxiliary apparatus, such as pumps, etc., is unnecessary, the requirement of power is therefore reduced, and repairs are correspondingly lessened.

3d. The expansion surface is enlarged and better distributed, making possible the using of the entire capacity of the compressor to the best advantage.

4th. The ammonia is expanded at a much higher temperature and pressure, and is therefore drawn back to the compressor at higher density, resulting in the machine circulating a much greater weight of ammonia per minute. Each pound of ammonia has just so much potential refrigerating energy, and the capacity of a compressor is therefore dependent solely upon the weight of ammonia pumped in a given time. For example, if it is desired to maintain a temperature of 32° F. in a certain room, it will require a compressor displacement of 22 per cent more with the brine system than with direct expansion.

5th. The brine system is much more expensive to install, owing to the far greater quantity of pipe required, the additional pumps, tanks, etc.

One of the advantages claimed for the brine system is the ability to store refrigerating energy in the brine tank, which may be drawn upon during the night, thus rendering the continued operation of the compressor unnecessary. It has been claimed that by doing this the fuel consumption is reduced; but this is not good logic, since just so much work must be done to produce a given quantity of refrigeration, and it makes no difference whether this work is distributed throughout the twenty-four hours, or is crowded into a shorter period. If the work is to be done in a short time the compressor must be correspondingly larger.

The development of the ice-making industry during the past ten years has been astonishingly rapid. This may be attributed to the fact that the ice-using public has come to a realization of the vast superiority, from a hygienic standpoint, of manufactured, over natural ice, and to the further fact that owners of electric light plants, mills, water-works and other power plants have found that the ice-making business is one that is peculiarly adapted to being operated in combination with other industries requiring the use of power.

Ice Making. Ice is made artificially by either the can system or plate system.

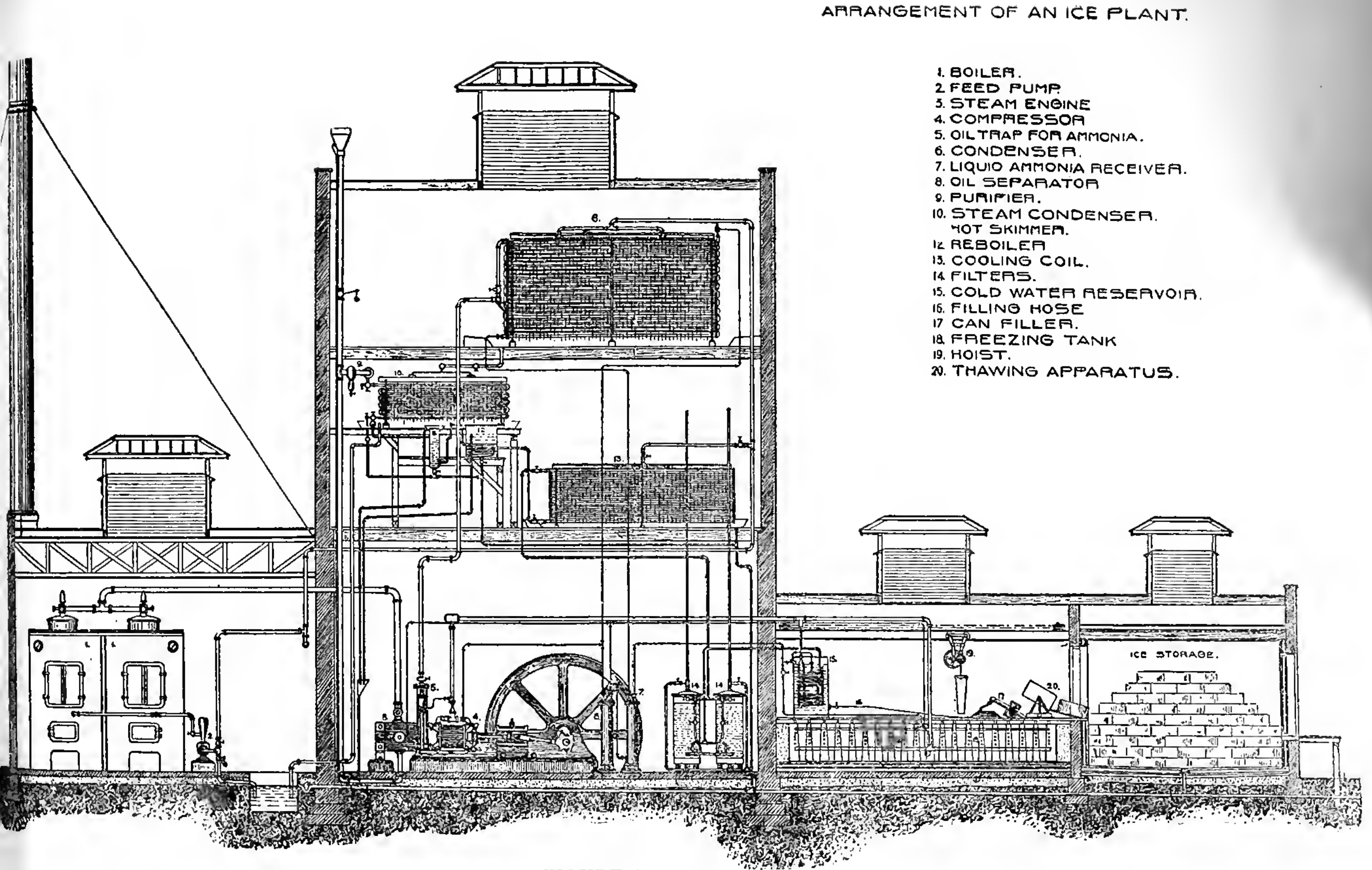

ARRANGEMENT OF AN ICE PLANT.
1. BOILER.
2. FEED PUMP.
3. STEAM ENGINE
4. COMPRESSOR
5. OIL TRAP FOR AMMONIA.
6. CONDENSER.
7. LIQUID AMMONIA RECEIVER.
8. OIL SEPARATOR
9. PURIFIER.
10. STEAM CONDENSER.
HOT SKIMMER.
12. REBOILER
13. COOLING COIL.
14. FILTERS.
15. COLD WATER RESERVOIR.
16. FILLING HOSE
17. CAN FILLER.
18. FREEZING TANK
19. HOIST.
20. THAWING APPARATUS.
ICE STORAGE.

FIGURE 378

In order to obtain absolutely pure and crystal ice by this system, a complete distilling and filtering process must be employed. Water, when evaporated into steam, parts with all of its impurities; the steam is condensed, the water of condensation being entirely pure. All the air must then be expelled from it, as otherwise it will freeze into opaque or so-called "snow" ice.

The inserted illustration, Fig. 378, shows an arrangement for the production of can ice from distilled water. The compression and condensation of the ammonia is carried on as already described, the ammonia being expanded in expansion coils placed in the freezing tank. (18.)

The steam generated in the boiler is first used to drive the steam-engine. The exhaust steam then passes to the steam condenser (10), first passing through an oil extractor (9), where any lubricating matter which has been carried along from the cylinder is removed. The steam condenser is designed on the same principle as the ammonia condenser, being a series of pipes over which cooling water is allowed to flow. The exhaust steam is not usually sufficient to make the full capacity of ice, and sufficient live steam is therefore supplied to the steam condenser to make up the deficiency. The water resulting from the condensing of the steam passes to the skimmer (11), where any oil that may pass the oil extractor is removed.

From the skimmer the water goes to the re-boiler (12), at the bottom of which is placed a small steam coil by means of which the water is kept boiling and the air contained in it expelled. It then passes to the flat cooler (13), an apparatus similar to a condenser, where its temperature is reduced to that of the cooling water available.

Thence it is led to the filters (14), which are furnished in duplicate so that one may be shut off and cleaned without interfering with the operation of the plant. In special cases, where the nature of the water requires it, sponge, silicate, or bone charcoal filters are used. From the filters the water passes to the cold-water storage tank (15), which contains an ammonia expansion coil. By the use of the coil the distilled water is reduced to the freezing temperature before going into the freezing cans.

By means of a can filler (17), so arranged that the water is automatically shut off when the can is filled to the proper depth, the galvanized iron freezing cans are filled with distilled water from the cold-water tank. The freezing tank (18) is usually made of iron or steel and thoroughly insulated at the bottom and sides. It is provided with suitable hardwood frame and covers, and has an efficient agitating device for keeping the brine in motion. The brine acts as a medium for the transfer of the heat from the distilled water within the cans to the expanding ammonia in the expansion coils, which are placed longitudinally of the tank and between which the cans are inserted.

The ice when frozen is hoisted out of the tank by means of the hoisting apparatus (19). The ice is loosened from the cans by the use of warm water from the condenser, either by employing a sprinkling apparatus (20) or by dipping the can bodily into a tank.

Table 47 gives the number of cubic feet of ammonia gas required per minute per ton of refrigeration in twenty-four hours:

Table 47

CUBIC FEET OF GAS THAT MUST BE PUMPED PER MINUTE AT DIFFERENT CONDENSER AND SUCTION PRESSURES, TO PRODUCE ONE TON OF REFRIGERATION IN TWENTY-FOUR HOURS.

Temperature of Gas in Degrees F.	Corresponding Suction Pressure, Lbs. per Sq. In.	Temperature of the Gas in Degrees F.								
		65°	70°	75°	80°	85°	90°	95°	100°	105°
		Corresponding Condenser Pressure (gauge), pounds per square inch.								
		103	115	127	139	153	168	184	200	218
	G. Pres.									
—27	1	7.22	7.3	7.37	7.46	7.54	7.62	7.70	7.79	7.88
—20	4	5.84	5.9	5.96	6.03	6.09	6.16	6.23	6.30	6.43
—15	6	5.35	5.4	5.46	5.52	5.58	5.64	5.70	5.77	5.83
—10	9	4.66	4.73	4.76	4.81	4.86	4.91	4.97	5.05	5.08
— 5	13	4.09	4.12	4.17	4.21	4.25	4.30	4.35	4.40	4.44
0	16	3.59	3.63	3.66	3.70	3.74	3.78	3.83	3.87	3.91
5	20	3.20	3.24	3.27	3.30	3.34	3.38	3.41	3.45	3.49
10	24	2.87	2.9	2.93	2.96	2.99	3.02	3.06	3.09	3.12
15	28	2.59	2.61	2.65	2.68	2.71	2.73	2.76	2.80	2.82
20	33	2.31	2.34	2.36	2.38	2.41	2.44	2.46	2.49	2.51
25	39	2.06	2.08	2.10	2.12	2.15	2.17	2.20	2.22	2.24
30	45	1.85	1.87	1.89	1.91	1.93	1.95	1.97	2.00	2.01
35	51	1.70	1.72	1.74	1.76	1.77	1.79	1.81	1.83	1.85

Absorption Process. Besides ammonia, there are various other refrigerating agents employed in the compression system, among which may be mentioned ether, methylchloride, sulphurous acid, and carbonic acid, but space will not permit a further discussion of the compression system, and the absorption process will now be taken up.

The principle involved in the operation of apparatus for the abstraction of heat by the evaporation of a separate refrigerating agent of a volatile nature under the direct action of heat, and without the use of power, which agent again enters into solution with a liquid, is, more a chemical, or physical action than a mechanical one. It is founded upon the fact of the great capacity possessed by water for absorbing a number of vapors having low boiling points, and of their being readily separable therefrom again, by heating the combined liquid; hence it is commonly known as the absorption process.

The absorption process was invented by Ferdinand Carré about the year 1850. This system involves the continuous distillation of ammoniacal liquor, and requires the use of three distinct sets of appliances, viz.:

First, for distilling, condensing and liquefying the ammonia. Second, for producing cold, by means of a refrigerator, and absorber, a condenser, a concentrator and a rectifier. Third, pumps for forcing the liquor from the condenser into the generator for redistillation. The three operations are each distinct from the other, but when the apparatus is in actual work they must be continuous, and are dependent upon one another, forming separate stages of a closed cycle.

An advantage of the absorption process is that the bulk of the heat required for performing the work is applied direct without being transformed into mechanical power. The first machines, however, constructed upon this principle were very imperfect in operation, by reason of the impossibility of securing an anhydrous product of distillation, and as the ammonia distilled over contained as much as 25 per cent of water, a very large expenditure of heat was required for evaporation, and the working of the apparatus, moreover, was rendered intermittent. This was owing to the distillation, which is the most important operation, and has of necessity to be executed in a rapid manner, being, in the first machines, very imperfectly effected, and the liquor resulting therefrom being naturally much diluted with water. Another serious result of the above defect was the accumulation of weak liquor in the

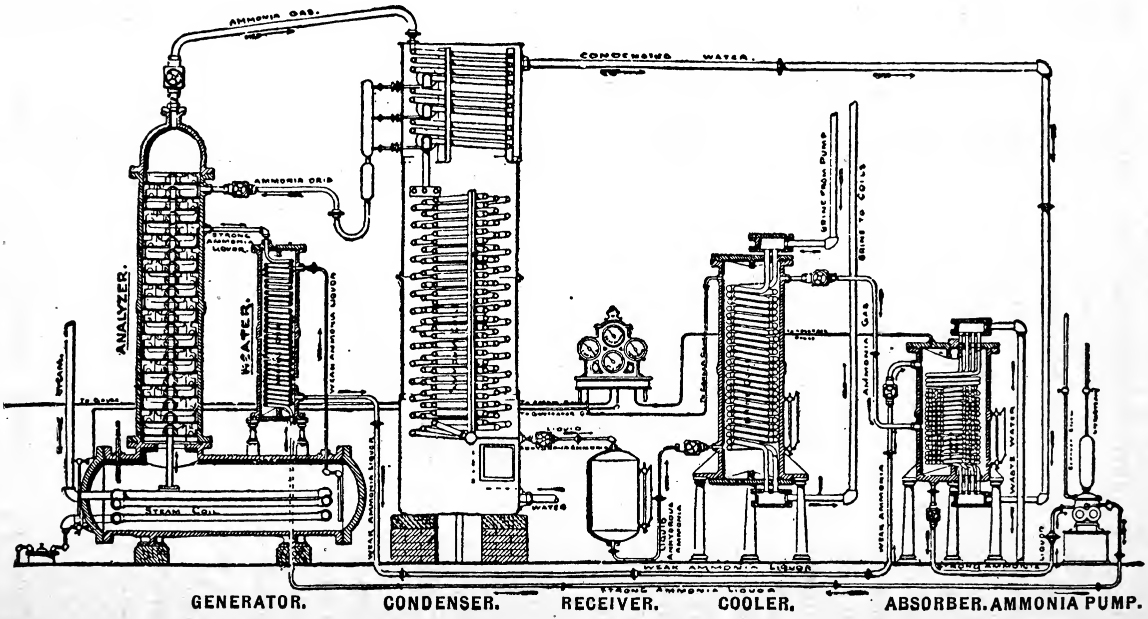


FIG. 379

DIAGRAM ILLUSTRATING LEADING TYPE OF AMERICAN AMMONIA ABSORPTION MACHINE refrigerator, and the consequent necessity for constant additions of ammonia.

Fig. 379 illustrates an ammonia absorption, refrigerating device, one of a leading American type, and will give a clear idea of the operation in general of the system.

A constant pressure of about 150 lbs. per square inch is maintained in the generator, and to prevent this pressure from being exceeded, a safety valve is provided on the dome of the generator. The gas that escapes through this safety valve is led through a suitable pipe to a small water tank, where it is absorbed. The operation is as follows:

The aqua ammonia is first introduced into the generator, the gas or vapor expelled therefrom by heat into the condenser; and, so that the process may be carried out continuously and not be arrested by the exhaustion of the solution, the exhausted or impoverished liquor is slowly drawn off at the bottom of the generator, an equal volume of fresh strong solution being constantly inserted at the top thereof. The united effects of the cooling and pressure produce liquefaction of the ammoniacal gas or vapor in the condenser, and the liquid ammonia passes to the refrigerator. It will be seen that the ammoniacal gas or vapor from the tubes of the refrigerator is reabsorbed, and a rich solution is formed to feed the generator, the absorbing water used being that withdrawn exhausted from the latter. Thus the generator and the condenser will keep up a continuous supply of the liquid, and the refrigerator will continue to freeze successive charges of water in the ice-cans or cases, provided, however, that the requisite heat to vaporize or gasify the ammonia is supplied to the generator. If, therefore, the entire apparatus be perfectly fluid-tight, as it is theoretically supposed to be, no escape could take place by leakage or otherwise, and the same materials would go on indefinitely producing the same uniform effect.

In starting a machine constructed on the absorption principle it must be first blown through to expel all the air. In Carré's apparatus the air escaping from the absorber is conducted by a suitable pipe into what is known as a purger, where it is passed below the surface of water to absorb or retain any ammonia that would otherwise escape with the air.

A large amount of water is required for cooling purposes in the condenser or liquefier, and absorber, and a considerable consumption of fuel is also necessary to heat the generator, when this is performed directly by means of a furnace. When, however, this is effected by steam-heated pipes, or, by coils of pipe heated by the exhaust steam from an engine, or even by direct or live steam from a boiler, there is a considerable saving on this head. Steam or other motive power is likewise required for driving the force pump.

The operation of Reece's improved apparatus is briefly as follows:

The charge of liquid ammonia (the ordinary commercial quality of a density of 26° Beaumé) is vaporized by the application of heat, and the mixed vapor of water and ammonia passed to the vessels called the analyzer, and the rectifier, wherein the bulk of the water is condensed at a comparatively high temperature, and is returned to the generator. The ammoniacal vapor or gas is then passed to the condenser, where it is treated in a substantially similar manner to that in Carré's apparatus, that is to say, it is caused to liquefy under the combined action of the condensation effected by the cooling water circulating around the condenser tubes, and of the pressure maintained in the generator. The liquid ammonia (in this case practically anhydrous) is then used in the refrigerator, and the vapor therefrom, whilst still under considerable tension, is admitted from the refrigerator to a cylinder fitted with a slide valve, and entry and exhaust ports, practically similar to those of a high pressure steam-engine, and is thus utilized to drive the force pump for returning the strong solution to the generator, after which it is passed into the absorber, where it meets, and is taken up by, the weak liquor from the generator, and the strong liquor so formed is forced back into the generator by means of a force pump.

The important features of the absorption machine are the expansion valve, the absorber and the strength of the liquor. The expansion valve should be handled very carefully, as it is delicate and will not bear rough usage.

The expansion valve may be likened to a throttle valve on a full-stroke engine. If opened wide, or more than is necessary to operate the machine a little above its capacity, it will draw on the generator as a wide-open pipe will draw on a boiler, and it will take from the generator more liquor than can be separated in the rectifier; and when it passes the rectifier it must go through into the cooler. As this liquor cannot evaporate at that temperature, it will plug up the cooler. This is termed a "boil-over."

Shutting off the gas valve also necessitates shutting off the expansion valve and the machine stops working, with the consequent raising of temperatures. Also, when the machine is purged and the gas and expansion valves are opened, 10 or 12 degrees in temperature will be lost, as it will be an hour or more before the machine gets to work reducing temperatures again, and if there is still bad liquor in the condenser, to come over, the machine will want purging again soon, with another rise in temperature.

The Absorber. The efficiency of the machine depends upon the condition of the absorber. If the absorber is cool, and free from air or poor gas, the cooler will give off its gas with ease. As long as the water and absorber are cool, it is difficult to know about the spray at the top. This spray device is simply a valve with three oblique holes.

If one side of the absorber gets warmer than the other, the valve should be turned down slightly, say one-eighth of a turn, and by a little manipulation the temperature of the entire absorber may be evenly maintained. If a small scale, or dirt should get over a hole, it will close that much of the valve. This valve does not regulate the flow of the poor liquor, but rather its distribution over the coils. The flow of the poor liquor is regulated by the valve near the exchanger, that at the generator being used only to shut off the poor liquor entirely. There should be just sufficient poor liquor thrown over to absorb the gas. More than this puts an extra load on the ammonia pump, exchanger and absorber.

At this point is where the expense of the absorption machine comes to be considered, as regards water, and also the capacity of the machine, the whole being limited by the amount of gas the absorber will take over from the cooler. When the absorber is cold, the poor liquor within it will have a large absorbing capacity, and it will take gas from the cooler even if it is gas of medium high percentage, but if the absorber becomes warmer, it will have less absorbing power, and do less work. If the temperature cannot be improved because of insufficient water, then the liquor coming over should be made weaker by turning more heat on the generator, and distilling more of the gas over into the condenser, which will carry a larger amount in storage. Under these conditions, the cooler will also need more gas, and this will tend to weaken the whole charge in the generator, thus requiring a higher temperature in the coils, and a higher pressure to distill the necessary gas from the weakened charge.

With the cooling water at a temperature of 60° or lower, a low pressure machine will operate at atmospheric pressure. With the water at 70°, the steam pressure may have to be raised two or three pounds; and if the temperature of the water is 75°, the pressure will need to be increased to 10 pounds. The pressures required depend upon the amount of heating surface in the generator. With water at a temperature of 60° the pressure in the generator may be from 90 to 100 pounds; but with the water at 75°, it will be necessary to carry generator pressure at 150 to 160 pounds.

It is possible to ascertain at any time whether or not the absorber is taking hold well, by observing the frost on the gas pipe. If this frost continues white, and keeps on accumulating, it is an indication that the absorber is working uniformly. If the frost begins to thaw, either the absorber has let go, or the cooler has become foul. The pipe at the bottom of the absorber should have a swivel joint, thus making it possible to swing it into or out of a pail of water. This is for the purpose of testing for the presence of air in the system. To make a test, place a bucket of cold water under the outlet, and open the valve one-eighth or one-quarter turn. If air is present, bubbles will rise to the surface of the water without noise.

Should there be but few bubbles, accompanied by a crackling sound similar to that made by water into which steam is being blown, it indicates the presence of gas, showing that this portion of the machine is all right. If, when air bubbles are rising, a lighted match be held over the pail of water and a pale yellow flame results, it shows that there is some foul gas mixed with air.

Half way up the absorber there is another purge pipe for drawing off foul gas. If this valve is slightly opened and the gas issuing therefrom is lighted, and continues to burn of itself, it shows foul gas, and the pipe should be turned into a pail of water until good gas comes, which can be told by the crackling sound. Do not make the mistake of holding a light under it only to light it. Ammonia gas will burn (if a light is kept under it) with a very similar flame. The pail of water tells the story.

There should be sufficient anhydrous ammonia in the system for the cooler to have all it wants, and allow the generator to keep a few inches in the condenser gage all the time, with the steam pressure down to the low point. This is with a cool absorber, and it is sometimes possible to have the liquor in a cool absorber so rich that the pump will not take it, the gas separating out in the pump, a condition which will be shown in the glass gage of the absorber, as when the pump lets go, the absorber fills up, and the liquor in the glass will effervesce like soda water. The remedy is to weaken the charge by throwing more of the gas over into the condenser, for a reservoir, and start the pump by pressure from the condenser.

The Generator. The coils for steam in the generator go in at about the center, and return near the bottom. When starting up a generator cold, do so easily, taking plenty of time. If possible, the better plan is to turn steam on at the bottom and let it work its way upward. If it is a large machine with a flange joint in the center, by turning steam on strong at the top, the top will be heated, and expand and open the joint at the bottom. Should this occur, stop the heat and let it cool. Take off one nut at a time, oil it and put it back and pull it up tight. This may stop it once or twice, only do not hurry the heating of the generator.

As soon as there is sufficient pressure to raise the liquor over through the weak-liquor pipe, open the valve and when the liquor shows in the absorber start the pump. This sets up a circulation in the generator and the danger is over. When the pressure is shown to be sufficient to liquefy the gas, which will be at 70 pounds, and it does not show on the gage in the condenser, open the expansion valve slightly so as to start circulation. The top of the steam coils is about at the center of the generator.

It is a good plan to make a gage from a pine strip marked in inches and half inches and fasten it to the gage fittings, with a mark showing the top of the coils. The charge in the generator should always be kept above the coils and usually near the top of the generator. This level will change, depending on the gas in the condenser and cooler, and the liquor in the absorber. Sometimes, purging the cooler will raise the level in the generator 4 or 5 inches. When a lot of the anhydrous ammonia is sent over into the condenser the level will be changed.

If there is no leakage around the ammonia pump, all loss will be of anhydrous ammonia, and it must be replenished with the same. Should there be leakage of liquor, it can be replenished with aqua ammonia, or with water and anhydrous ammonia. If water is used, it should be pure, distilled water, as impure water would cause foul gases.

The troubles caused by allowing the charge to get below the generating coils are two: If allowed for more than a short time the ammonia will corrode the pipes, and the hot pipes in the gas will decompose the gas. This will be shown up around the cooler, the frost everywhere being excessively heavy, as though everything was frozen up, and the gage on the absorber will show about as good vacuum as a condensing engine. The temperature of the brine will be high, as that is the only thing that does not show any low temperatures. The only remedy is a good charge of anhydrous ammonia and purging out the bad gas.

Rectifier. The rectifier is for drying out the gas and should be run cool enough to chill off the moisture but not cool enough to liquefy the gas, or any portion of it, as it would drain back into the generator and have to be distilled again. The last passage of water is through this vessel, and there is a bypass around it for the water so that the temperature can be regulated. There are thermometers for the rectifier, and water leaving it.

If considerable water is used because of the absorber, a large amount will go through the bypass. If water is economized and the absorber is warm, all of it may go through the rectifier. The thermometer should not register below 110°. The drain pipe should feel warm to the hand.

Dirty Coils. The condenser and absorber coils are liable to the same trouble where the water becomes warm and the flow sluggish. Corrosion, in the form of "barnacles" sets in, and the pipes gradually become filled. These coils have headers at both top and bottom and each coil has a valve at both ends.

There should be an air compressor on the premises capable of maintaining a pressure of 80 pounds through an open ¾-inch pipe. The headers should be connected to the air line, and also to a water pressure, with ½-inch pipe; the feed line will do.

Once a week the ammonia should be shut off, or rather, the machine should be stopped and the water drawn from the coils, the bottom valves closed, and air turned on. There should be a valve for the bottom header, in the bottom of the flange, which should be opened, and then the valves on the coils should be opened separately and the air allowed to blow through. The deposit will be soft and will easily clear out. After air has blown through, turn on the water in the same manner and wash the coils out. While the machine is idle, the brine temperature may have gone up one or two degrees, but it will readily come down again.

If the coils are badly coated the machine will have to be stopped for two or three days. The ammonia will have to be drawn from the condenser and absorber, as if warmed up the expansion would cause too much pressure. In drawing off the ammonia be careful not to reduce it too low all at once, or the freezing effect will be so great as to freeze the water coils.

Have prepared a sufficient quantity of a strong potash solution, draw the water from the coils, fill them with potash and let it stand for twenty-four hours, or longer if the machine can be spared. When the potash is drawn off, turn on the water from the small cleaning pipe and fill the coils. Close the valve to within one-half turn and turn on the air. Open one valve at the bottom of the coil header and keep it open until the water runs clear, then close that one and open another. After all have been blown, begin with the first and go over them again. They may require four or five blowings out before they will be clean.

When air and water issue from a pipe together, it will be noticed that it issues with a series of explosions, which appear to take place all through the coil and may be thought to do the cleaning, but this method has little effect without the potash. Water at from 125 to 150 degrees appears to do better work than cold water, as the vapor from the warm water makes the explosions stronger.

Brine.—For brine, chloride of calcium should be used instead of chloride of sodium, because it cleans the pipes better, prevents corrosion, and will carry lower temperatures. Care should be taken to get the purest, but even with this there is a sludge that will stop circulation in small pipes, and sometimes in good-sized pipes. Place a steam pipe in the tank for dissolving purposes and do not fill the tank full of water after the calcium is placed in it. When the mixing tank is charged, turn on steam until the tank boils, then close the steam valve. Skim off the scum that rises. It will be necessary to wait until the brine cools before pumping it into the system, otherwise it would raise temperatures. The skimming can be done without heating, but not as much of the impurities will rise as by heating, and not much time is gained, as the dissolving is so much slower. Heating saves lots of cleaning later, also.

Danger in Ammonia Fumes.—In case of accident, ammonia is a bad thing, as it takes but a small amount to overcome a person. Acetic acid is an antidote and is found in ordinary vinegar. A sponge soaked in vinegar and put over the nose will enable anyone to work in a strongly impregnated atmosphere, as far as breathing is concerned, but the eyes would not be protected. To work under such conditions it is necessary to wear a helmet, which should be kept charged at all times at 125 pounds pressure and regulated so that it will take one-half hour to reduce the pressure to 25 pounds.

Should anyone be in danger of suffocation, breathing the fumes from vinegar will neutralize it. Drinking warm milk will relieve a person partly suffocated from ammonia or any gas.

Workers around ammonia should not forget the strong affinity it has for water and the absorbing power of water. When there is a small leak of even the gas under pressure, a piece of water-soaked waste put over it will remove all trouble until the water is thoroughly saturated with it.

It is a good idea to practice using water for even unimportant leaks so as to be accustomed to it. A 1-inch hose and a 2½-inch hose under water pressure should always be handy, as by their use a big leak could be drowned; and these would be thought of instantly if one were accustomed to the use of water to take care of ammonia fumes.

There are various devices for detecting leaks, but the best is white litmus paper. This can be procured free from the dealer in ammonia. Take a strip ¼-inch wide and about 1½ inches long. With a thread, tie it onto a small stick 15 to 18 inches long. When using it, moisten it in water and hold it to the suspected place. If there is a leak the paper will turn red and the shade of red will show how strong the leak is. Litmus paper will detect leaks that cannot be smelled. Turn it away from the leak into pure air and it again becomes white. It can be used until completely worn out, all that is necessary, when using it, being to moisten it.

For putting screwed fittings together, or for material to put on flanges, use litharge and glycerine; for sheet packing, use pure rubber. Do not get fittings intended simply to receive the pipe that is to be screwed into them; get special ammonia extra-heavy fittings, either with a stuffing-box at each end of the fitting, in which rubber packing should be used or fittings with a lead ring in each outlet, and with provision to put in shot and allow a plug to be screwed in the top to force the shot down on the pipe.

Weak-liquor Pipe.—In regard to the weak-liquor pipe, it should be remembered that as the pressure in the generator is carried higher the flow through this line is increased unless throttled.

Charging.—When charging a new compression system, proceed as follows:

Make a proper connection between the outlet valve of the flask and the manifold where there are three valves. After creating a vacuum in the system close the right hand valve and open the other two. Carefully open the valve on the flask and the pressure will force the ammonia into the system, where it will expand and destroy the vacuum. To prevent this as much as possible use plenty of water on the condensers. Start up the compressor and run it slowly until all of the ammonia is out of the flask, when the bottom of it will begin to freeze. Care should be taken to have the outlet valve at the lowest part of the flask. Run the compressor until the back pressure gauge indicates zero, close the two valves used to admit the ammonia, and let the machine stand for about 15 minutes, before changing any of the valves on the system.

With the absorption system there is no compressor with which to create a vacuum in the pipes, but if the whole system is filled with steam before it is used at all, it will drive out the air, then by using water on the condenser and in the brine tank, this steam may be condensed and a vacuum formed for testing, as with the compression system. A light steam pressure will answer every purpose in this case. The absence of a pump also prevents the high pressure air test.

When charging the absorption system a partial vacuum may be secured as already described, when the pressure in the ammonia flask will cause the contents to escape into the system. Ammonia flasks should be weighed both before and after charging, so that the amount used may be definitely known. It is a good plan to test ammonia before putting it into a system, by drawing a small quantity of it out of the flask and, seeing that it will evaporate without leaving any sediment.

Starting.—When starting a compression system, open the regulating valve on the discharge pipe slightly at first, but do not allow the compressor to pump a vacuum on the coils, for the regulating valve should be open until there is perhaps 15 pounds back pressure, although there is no cast-iron rule for this purpose. It is well to calculate on about one-tenth of the high pressure, for the low or suction pressure side, so that if 200 pounds is carried on one, about 20 pounds will be right for the other. This is one of the many points that each engineer must decide for himself, for it will depend on circumstances. When the brine is warm, a high pressure on the condenser side is advisable, so that the full benefits of expansion may be secured, but if the brine is cooler, it is evident that a lower pressure will answer the purpose. High pressures are expensive, as it requires more steam to pump against them, and this should be taken into account, for there is no necessity of freezing the suction pipe back into the engine room, where the heat will cause water to drop on the machinery and the floor. When frost shows on the suction pipe just beyond the brine tank, or just outside of whatever room is to be cooled, it shows that the best results are secured.

In some cases, however, where a double-acting compressor is in use, it may become necessary to freeze back to the compressor in order to prevent undue accumulation of heat in the cylinder which would cause the machine to work at a disadvantage, and might burn out the fibrous packing around the rod, or injure the metallic packing, if such is used. On the other hand if the frost reaches back to the cylinder of a single-acting compressor, it may do much damage by freezing up the packing, so that here, as elsewhere about a refrigerating plant, much depends upon the good judgment of the engineer.

When running with wet compression, the discharge pipe should never get very warm, but with dry compression it may be hot enough to burn the hand, without doing any damage.

If trouble is encountered in keeping the stuffing-boxes tight on a vertical single-acting compressor, it may be due to the presence of weak liquor on the cylinder head, which flows down the piston rod, and causes an unpleasant odor to fill the room. If the glands are tightened up to stop it, the rods may be scored and badly damaged.

The safest method is to take the packing out, and allow this weak liquor to run out, and if there is a collar next to the rod, it may be necessary to take out the piston and sponge the liquor out, as the collar will prevent it from running out. Care must be taken to prevent oil from passing the oil separator. The oil should be purged out and not allowed to pass over into the coils where it is not wanted. If it does get into them, it is necessary to disconnect the pipes and blow live steam through them until it is all driven out. If they are badly coated, it may be necessary to clean them out with a solution of soda ash, and then blow steam through them, and afterwards air under pressure, to purify them.

Whenever a serious leak develops on the high pressure side of the apparatus, the valves must be so manipulated that the ammonia will be drawn from this side over into the suction side, while the compressor is run at a slow speed, when the proper valves should be shut to keep it locked up there until the repairs are completed. If the leak is on the suction side, the liquid valve must be closed and all of the ammonia pumped up into the condenser, then by closing the valve on the top of the condenser it may be retained there until the machine is again ready for use. Incompetent men in charge of these machines, have been known to allow all of the ammonia to escape into the air, when there was a leak in the pipes, to the extreme disgust of the neighbors, and the detriment of the owners, but in a majority of cases this is entirely unnecessary.

When it is time to shut down a machine of this kind, the liquid valve should be closed, and the suction pressure reduced to zero. Do not pump a vacuum at this time, for it may cause the system to be filled with air before starting up again.

Properties of Ammonia.—Ammonia is composed of one part of nitrogen and three parts of hydrogen, represented by the formula NH_3. It is a colorless gas, possessing a pungent odor. It is much lighter than air, having a specific gravity of 0.58, that of air being 1.

It can be obtained from the air, from sal ammoniac, nitrogenous constituents of plants and animals by process of distillation; as a matter of fact, there are very few substances free from it.

Ammonia in itself is a slight lubricant, and has no effect whatsoever on iron or steel, of which ice machinery is constructed. It will eventually purge and scour the entire system clean to the metal surfaces, the loose foreign matter being caught in the separators and interceptors provided for this purpose.

At the present day almost all the sal ammoniac and ammonia liquors are prepared from ammoniacal liquid a by-product obtained in the manufacture of coal gas and coke. Although ordinarily existing as a gas, it may be condensed to a liquid by cooling, and applying pressure. Liquid anhydrous ammonia formed in this way boils under atmospheric pressure at 28.5 degrees below zero, and its latent heat of evaporation is about 562 British thermal units at 32 degrees F., at which temperature 1 pound of the liquid evaporated under atmospheric pressure will occupy 21 cubic feet.

Pure ammonia liquid is colorless, having a peculiar alkaline odor, and caustic taste. It turns red litmus paper blue. Compared with water, its weight or specific gravity at 32 degrees F. is about 5/8 of water, or 0.6364. One cubic foot of liquid ammonia weighs 39.73 pounds, one gallon weighs 5.3 pounds, one pound of the liquid at 32 degrees will occupy 21.017 cubic feet of space when evaporated at atmospheric pressure. The specific heat of ammonia gas, as determined by Regnault (capacity for heat), is 0.50836. Its latent heat of evaporation, as determined by the highest authorities, is not far from 560 thermal units at 32 degrees, at which temperature one pound of liquid evaporated under a pressure of fifteen pounds per square inch, will occupy twenty-one cubic feet.

Table 48 gives the properties of saturated ammonia.

TABLE 48

PROPERTIES OF SATURATED AMMONIA—(Wood).

The critical pressure of ammonia is 115 atmospheres; critical temperature at 266° F. (Dewar); critical volume .00482 (calculated).

Temperature		Pressure, absolute		Heat of vaporization, thermal units	External heat, thermal units	Internal heat, thermal units	Volume of vapor per lb., cu. ft.	Volume of liquid per lb., cu. ft.	Weight of a cu. ft. of vapor, lbs.
Degrees F.	Absolute	Lbs. per sq. ft.	Lbs. per sq. in.						
— 40	420.66	1540.9	10.59	579.67	48.23	531.44	24.37	.0234	.0410
— 35	425.66	1773.6	12.31	576.69	48.48	528.21	21.29	.0236	.0467
— 30	430.66	2035.8	14.13	573.69	48.77	524.92	18.66	.0237	.0535
— 25	435.66	2329.5	16.17	570.68	49.06	521.62	16.41	.0238	.0609
— 20	440.66	2657.5	18.45	567.67	49.38	518.29	14.48	.0240	.0690
— 15	445.66	3022.5	20.99	564.64	49.67	514.97	12.81	.0242	.0779
— 10	450.66	3428.0	23.77	561.61	49.99	511.62	11.36	.0243	.0878
— 5	455.66	3877.2	25.93	558.56	50.31	508.25	10.12	.0244	.0988
0	460.66	4373.5	30.37	555.50	50.68	504.82	9.04	.0246	.1109
+ 5	465.66	4920.5	34.17	553.43	50.84	501.59	8.06	.0247	.1241
+ 10	470.66	5522.2	38.55	549.35	51.13	498.22	7.23	.0249	.1384
+ 15	475.66	6182.4	42.93	546.26	51.33	494.93	6.49	.0250	.1540
+ 20	480.66	6905.3	47.95	543.15	51.61	491.54	5.84	.0252	.1712
+ 25	485.66	7695.2	53.43	540.03	51.80	488.23	5.26	.0253	.1901
+ 30	490.66	8596.0	59.41	536.92	52.01	484.91	4.75	.0254	.2105
+ 35	495.66	9493.9	65.93	533.78	52.22	481.56	4.31	.0256	.2320
+ 40	500.66	10512	73.00	530.63	52.42	478.21	3.91	.0257	.2583
+ 45	505.66	11616	80.66	527.47	52.62	474.85	3.56	.0260	.2809
+ 50	510.66	12811	88.96	524.30	52.82	471.48	3.25	.0260	.3109
+ 55	515.66	14102	97.93	521.12	53.01	468.11	2.96	.0260	.3379
+ 60	520.66	15494	107.60	517.23	53.21	464.72	2.70	.0265	.3704
+ 65	525.66	16993	118.03	514.73	53.38	461.35	2.48	.0266	.4034
+ 70	530.66	18605	129.21	511.52	53.57	457.85	2.27	.0268	.4405
+ 75	535.66	20336	141.25	508.29	53.76	454.53	2.08	.0270	.4808
+ 80	540.66	22192	154.11	504.66	53.96	450.70	1.91	.0272	.5252
+ 85	545.66	24178	167.86	501.81	54.15	447.66	1.77	.0273	.5649
+ 90	550.66	26300	182.8	498.11	54.28	443.83	1.64	.0274	.6098

TABLE 48—CONTINUED

Temperature.		Pressure, absolute.		Heat of vaporization, thermal units.	External heat, thermal units.	Internal heat, thermal units.	Volume of vapor per lb., cu. ft.	Volume of liquid per lb., cu. ft.	Weight of a cu. ft. of vapor, lbs.
Degrees F.	Absolute.	Lbs. per sq. ft.	Lbs. per sq. in.						
+ 95	555.66	28565	198.37	495.29	54.41	440.88	1.51	.0277	.6622
+100	560.66	30980	215.14	491.50	54.54	436.96	1.39	.0279	.7194
+105	565.66	33550	232.98	488.72	54.67	434.08	1.289	.0281	.7757
+110	570.66	36284	251.97	485.42	54.78	430.64	1.203	.0283	.8312
+115	575.66	39188	272.14	482.41	54.91	427.40	1.121	.0285	.8912
+120	580.66	42267	293.49	478.79	55.03	423.75	1.041	.0287	.9608
+125	585.66	45528	316.16	475.45	55.09	420.39	.9699	.0289	1.0310
+130	590.66	48978	340.42	472.11	55.16	416.94	.9051	.0291	1.1048
+135	595.66	52626	365.16	468.75	55.22	413.53	.8457	.0293	1.1824
+140	600.66	55483	392.22	465.39	55.29	410.09	.7910	.0295	1.2642
+145	605.66	60550	420.49	462.01	55.34	406.67	.7408	.0297	1.3497
+150	610.66	64833	450.20	458.62	55.39	402.23	.6946	.0299	1.4696
+155	615.66	69341	481.54	455.22	55.43	399.79	.6511	.0302	1.5358
+160	620.66	74086	514.40	451.81	55.46	396.35	.6128	.0304	1.6318
+165	625.66	79071	549.04	448.39	55.48	392.94	.5765	.0306	1.7344

Testing Anhydrous Ammonia.—It is essential that the purity of the liquid anhydrous ammonia, or the strength of the aqua ammonia solution shall be up to standard and to determine this point tests must be made. Aqua ammonia is usually guaranteed to be not less than 26 degrees Baumé scale and its density can readily be measured with the hydrometer. Liquid anhydrous can be tested by the use of an ordinary glass testing tube 12 inches long or, if this cannot be had, take a piece of 1-inch pipe and cap one end. Securely fasten a piece of stiff wire about 12 inches long around the tube or pipe so that it can be held about a foot away from the hand and, after securing a piece of pipe of the same size as the cylinder valve, bend the threaded end so that the pipe will stand vertical when in position on the cylinder. Slip the test tube over the pipe almost to the bottom or about as far as it will go, open the cylinder valve gently, and draw a certain number of inches of the liquid into the tube, gradually withdrawing it from the bent pipe as it fills. When the desired amount of liquid ammonia has been drawn into the tube, remove it from the pipe and, after noting carefully the exact amount of anhydrous ammonia, pour the liquid into a shallow vessel and set it in cold water, or on a block of ice. Under these conditions the ammonia will boil and evaporate quickly, and any residue remaining is the amount of moisture and impurities originally in the liquid ammonia drawn into the tube. Dividing the amount of residue by the quantity of the liquid drawn into the tube and multiplying by 100 gives the percentage of moisture and impurities. Before the liquid is drawn into the tube a little of the gas should be allowed to escape in order to purge the bent pipe.

Hydrometers.—From among the instruments frequently used to ascertain the specific gravity of liquids, and by inference their strength, we mention those called hydrometers as based on the Archimedian principle. They are generally made of a weighted body (usually of glass), having a thinner stem at the upper end provided with a scale divided into degrees. The degrees may be arbitrary, or show specific gravities or the strength of some particular liquid or solution in per cents; in the latter case the instrument is called saccharometer, salometer, alcoholometer, acidometer, alkalimeter, etc., according to the liquid it is designed to test. Hydrometers for different liquids or purposes, provided they cover the same range of specific gravities, may be used for either liquid when the relation their degrees bear to each other is known.

QUESTIONS AND ANSWERS.

597. Of what does the process of refrigeration consist?

Ans. In the abstraction of heat from a substance.

598. Describe a freezing mixture that will give a temperature of 67 degrees below zero.

Ans. A mixture of one pound of calcium chloride, and 0.7 lbs. of snow.

599. Upon what are the theory, and practice of mechanical refrigeration based?

Ans. Upon the two first laws of thermo-dynamics.

600. What is the first of these laws?

Ans. Mechanical energy and heat are mutually convertible.

601. Define the second law.

Ans. An external agent is necessary to complete or bring about this transformation.

602. Is heat generated by compression, or by any other means?

Ans. It is not generated but developed, because there is a fixed amount of heat in the universe which can neither be increased nor diminished.

603. What is the result of compressing one pound of air at 70 degrees temperature and at atmospheric pressure, to one half its original volume?

Ans. An increase in its static pressure, also an increase in its temperature.

604. In order that the higher pressure may be maintained, as the temperature is reduced, what is necessary?

Ans. A small additional quantity of air will have to be forced into the compressor cylinder.

605. If the pound of compressed air be allowed to expand in a cylinder what will be the result?

Ans. A portion of the heat developed by compression will be given up.

606. What can be said of the mechanical work done by this air in its expansion?

Ans. In amount it is exactly the same as that done upon it during its compression.

607. How is the temperature of a body or substance reduced?

Ans. By transferring more or less of the heat contained in the body to some other substance or body.

608. What work is demanded of a refrigerating machine?

Ans. To extract heat from a body, and by the expenditure of mechanical energy to sufficiently raise the temperature of this heat to admit of its being carried away by a suitable external agent, usually water.

609. How may a refrigerating machine be defined, and what is its main function?

Ans. As a heat pump, its main function being the abstraction of heat from the body to be cooled, and transferring that heat to a cooling agent.

610. How may the various devices for refrigeration and ice making be classified?

Ans. Under five principal heads.

611. Explain the action of apparatus belonging to class one.

Ans. Heat is abstracted from the body to be cooled, by the dissolution or liquefaction of a solid, as for instance the cooling of water with ice.

612. Describe the vacuum system?

Ans. The abstraction of heat is effected by the evaporation of a portion of the liquid to be cooled, the process being assisted by an air pump.

613. How is refrigeration effected in machines belonging to the third class?

Ans. By the evaporation of a separate refrigerating agent, which is subsequently restored to its original physical condition by mechanical compression and cooling.

614. Describe the fourth or absorption system.

Ans. Heat is abstracted by the evaporation of a separate refrigerating agent, under the direct action of heat, which agent again enters in solution with a liquid.

615. Describe the action of machines belonging to the fifth class, known as cold air machines?

Ans. Air, or other gas is first compressed, then cooled, and afterwards permitted to expand while doing work.

616. What two systems have come into general use in the United States?

Ans. The ammonia compression system, and the ammonia absorption system.

617. What are the three distinct stages in the compression system?

Ans. Compression, condensation, and expansion.

618. What is the refrigerating agent or medium used in the compression system?

Ans. Anhydrous ammonia.

619. Of what does ammonia consist, and what is its chemical formula?

Ans. One part of nitrogen, and three parts of hydrogen. Its chemical formula is NH_3.

620. Under what two conditions may gaseous ammonia be liquefied?

Ans At a pressure of 128 lbs. per sq. in., and a temperature of 70° Fahr., or a pressure of 150 lbs. and a temperature of 77° Fahr. It may also be liquefied by cold if its temperature be reduced to 85.5° Fahr. below zero.

621. To what pressure is gaseous ammonia usually compressed?

Ans From 125 to 175 lbs. per sq. in.

622. Of what does a compression plant consist?

Ans. Of a high pressure system made up of a condensing coil surrounded by cooling water, and a low pressure system consisting of an evaporating coil surrounded by brine, or open to the room to be cooled.

623. What takes place during compression?

Ans. The latent heat of the vapor is converted into active, or sensible heat.

624. How is the vapor condensed, or liquefied?

Ans. It is forced into and through the condenser coils which are submerged in a body of cold water, or over which cold water is flowing, and the sensible heat developed during compression is thus transferred to the cooling water.

625. How are the refrigerating qualities of the ammonia in its liquefied state utilized?

Ans. It is allowed to pass in small quantities from the condenser into pipe coils placed in the rooms to be cooled, when it again expands into a vapor, and takes up an amount of heat exactly equivalent to that given up during condensation.

626. After being expanded into vapor, what becomes of it?

Ans. It is drawn back into the compressor, again compressed, condensed, and expanded, the cycle of operations being repeated indefinitely.

627. How many, and what are the systems of refrigeration by compression?

Ans. Two—the wet system, and the dry.

628. Describe the theory of the wet system.

Ans. The ammonia vapor is cooled by the injection into the compressor cylinder of a small quantity of liquid ammonia at the beginning of each stroke, and it is carried from the cooling room back to the compressor in a saturated state. It is thus kept in contact with a small portion of its originating fluid, and is kept comparatively cool.

629. Upon what does the pressure of steam in a boiler depend?

Ans. Upon its temperature, which is always the same as that of the water in the boiler.

630. What are the relations of temperature and pressure in the case of steam while in contact with the originating water?

Ans. They are interdependent.

631. What is the result if the steam is superheated?

Ans. It may still be of the same pressure, but its temperature will be higher.

632. What results from the compression of a dry gas without cooling?

Ans Its temperature may be much higher than that corresponding to its pressure.

633. What does the Adiabatic curve as traced by the indicator represent?

Ans. The compression, or expansion of a gas without loss or gain of heat.

634. Describe in brief the construction of the cylinder heads, and valves in the Linde ice machine.

Ans. The piston and cylinder heads are spherical, and of the same radius, and the valve discs conform to this radius.

635. What is the clearance between piston and cylinder head?

Ans One thirty-second of an inch.

636. How is the piston lubricated?

Ans. In a large measure by the moisture in the ammonia vapor.

637. In the De La Vergne refrigerating machine how is the heated gas cooled?

Ans. By passing it through coils of pipe surrounded by running water.

638. How many valves has the Triumph ice machine?

Ans. Five, three suction valves, and two discharge valves.

639. What advantage is said to be gained by the use of the third suction valve?

Ans. That it tends to increase the economy of the machine.

640. Describe the construction of a double pipe ammonia condenser.

Ans. It consists of two series of coils, one within the other.

641. How many methods are there of utilizing the brine system?

Ans. Two; the brine system, and the direct expansion system.

642. Describe in brief the brine system.

Ans. The coils of pipe in which the ammonia is expanded are submerged in a solution of salt, or calcium chloride. This brine after being reduced to a low temperature is pumped through coils of pipe in the rooms to be cooled.

643. Describe the direct expansion system.

Ans. The expansion coils are placed in the rooms to be cooled, and the cooling is effected directly by the expansion of the ammonia.

644. Which one of the two systems is the most efficient?

Ans. The direct expansion system.

645. Mention a few of the advantages that this system has over the brine system.

Ans. First—All intermediate agencies are dispensed with. Second—The whole plant is much simpler. Third—A larger expansion surface.

646. By what two systems is ice made or manufactured?

Ans. The can system and the plate system.

647. Mention other refrigerating agents besides ammonia that may be used in the compression system?

Ans. Ether, methyl-chloride, sulphurous acid, and carbonic acid.

648. How is refrigeration effected in the absorption system?

Ans. By the continuous distillation of ammoniacal liquor.

649. What advantage appertains to the absorption system?

Ans. The bulk of the heat required for the work is applied direct without being transformed into mechanical power.

650. What pressure is usually maintained in the generator?

Ans. 150 lbs. per sq. in.

651. Mention the more important features of the absorption machine?

Ans. The expansion valve, the absorber, and the strength of the liquor.

652. Upon what does the efficiency of the machine mostly depend?

Ans. Upon the condition of the absorber. If it is cool and free from air, or poor gas, better results will be realized.

653. What should be done if one side of the absorber should get warmer than the other?

Ans. The spray valve should be turned down slightly, say one-eighth of a turn.

654. Mention one of the troubles in the operation of this system.

Ans. A filling up of the coils with scale and dirt.

655. What is the remedy in such cases?

Ans. Stop the machine once a week, drain the coils, and blow them out with compressed air.

656. How is anhydrous ammonia formed?

Ans. By condensing ammonia gas to a liquid, and applying pressure.

657. Under atmospheric pressure, what is the boiling point of anhydrous ammonia?

Ans. 28.5 degrees delow zero Fahr.

658. What is the specific gravity of liquid ammonia compared with water?

Ans. At 32° Fahr. it is about 5/8 that of water, or 0.6364.

659. What is its latent heat of evaporation?

Ans. At 32 degrees temperature it is 560 thermal units.

660. If evaporated at 32° Fahr. and atmospheric pressure, how much space will one pound occupy?

Ans. Twenty-one cubic feet.

Elevators—Electric and Hydraulic

As the majority of stationary engineers, especially in large cities and towns, have more or less to do with elevators, either electric or hydraulic, the author deems it fitting and proper that a section should be devoted to this subject.

Therefore, the construction and operation of electric and hydraulic elevators will be taken up in order, and although the subject-matter will have to be somewhat condensed for want of space, still the leading types, including the numerous improvements which have been developed during the past ten years will be illustrated, and the mechanism described.

OTIS TRACTION ELEVATOR.

In the Otis traction elevator the working parts have been reduced to the simplest possible elements. The elevator engine, a view of which is presented in Fig. 380, consists essentially of a motor traction driving sheave, and a brake pulley, the latter enclosed with a pair of powerful springs actuated, electrically released brake shoes, all compactly grouped, and mounted on a heavy iron bed plate.

Instead of the high speed motor used with the geared electric elevator, a slow speed shunt-wound motor designed especially for the service is used. The armature shaft which is of high tensile steel, of unusually large diameter serves merely as a support for the load, and on it are mounted the brake pulley and the traction driving sheave.

The actual drive from the armature to the sheave is effected through the engagement of projecting arms on each, cushioned by rubber buffers, thus entirely eliminating all tortional strains to the shaft, and the use of keys. In this machine all intermediate gearing between motor and driving member is dispensed with, by the use of the slow speed motor, and the result is, that the starting, accelerating, retarding and stopping events are each, and all, remarkably even and quiet.

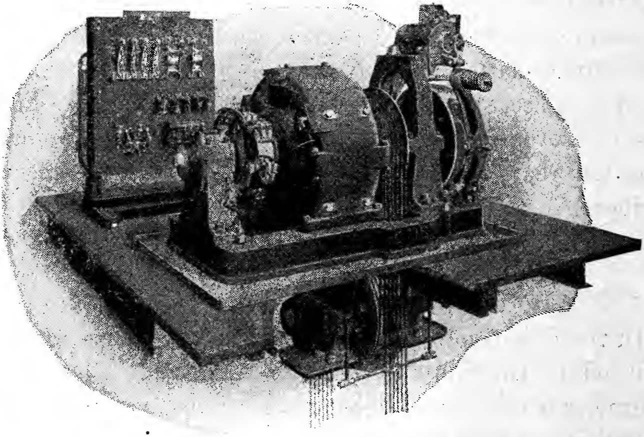


Fig. 380

OTIS TRACTION ELEVATOR

The driving cables, from one end of which the car is supported, while to the other end the counterweight is attached, pass partially around the traction driving sheave in lieu of a drum, continuing under an idler leading sheave, thence again around the driving sheave, thereby forming a complete loop around these two sheaves, which arrangement results in the necessary tractive effort for lifting the car. One of the striking advantages resulting from this arrangement of cables, and the method of driving the same is the decrease in traction which follows the striking on the bottom of the shaft of either the car or the counterweight, and the consequent minimizing of the lifting power of the machine, until normal conditions are resumed. Inasmuch as in any properly constructed elevator the parts are so arranged that the member (car or counterweight) which is at the bottom of the shaft must strike and come to rest before the other member can possibly come in contact with the overhead work, it will readily be seen that the above mentioned decrease in tractive effort is a valuable, and effective safety feature inherent in this type of elevator.

The controller is so designed in connection with the motor, that the initial retarding of the car in bringing the same to stop is independent of the brake, the latter being requisitioned to bring the car to a final positive stop and to hold it at the landings.

The motor is also governed in such a way, electrically, as to prevent its attaining any excessive speed with the car no matter what the load in same may be.

In designing the controlling equipment, one of the features demanding greatest consideration, in view of the very high speed at which the cars run, is the automatic retarding of their speed and the final positive stopping of same, automatically, at the upper and lower terminals of travel. This result is very satisfactorily attained with the installation, in the elevator hatchway, of two groups of switches located respectively at the top and bottom of the shaft, each switch in the series being opened one after another, as the car passes, resulting in a reduction of speed until the opening of the final switch brings the car to a positive stop, applying the brake. This operation is entirely independent of the operator in the car and is effective even though the car operating device be left in the full speed position.

Another feature of security of the greatest interest and importance is provided in the Otis Patented Oil Cushion Buffers. (See Fig. 381.) These are placed in the hoistway, one under the car and one under the counterweight, and are arranged to bring either the car or the counterweight to a positive stop, through the telescoping of the buffer—this occurring at a carefully calculated rate of speed, which is regulated by the escape of oil from one chamber of the buffer to another. The buffers have been proven capable by test of bringing a loaded car safely to rest from full

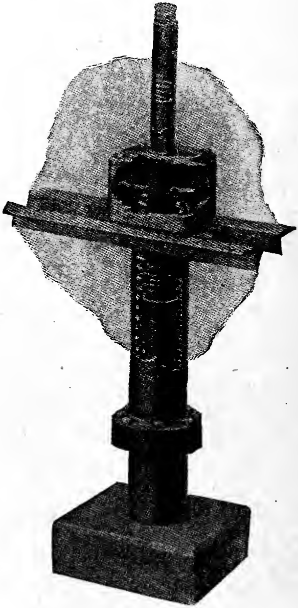


FIG. 381

OTIS PATENTED SPRING RETURN OIL BUFFER

speed, and in this respect are unique among elevator safety features of comparatively low cost.

The usual safety devices installed in connection with modern high grade apparatus are used with this type of elevator, including speed governors, wedge clamp safety devices for gripping the rails in case of the car attaining excessive speed, and potential switches.

OTIS GEARED TRACTION ELEVATOR.

The modern adaptation, in the Otis Traction Elevator, of the traction principle for elevator service which utilizes the patented feature of operating the car by means of driving the cables direct from the motor without the intervention of retarding rigging, showed so conclusively the merits of that principle that the question naturally arose as to the

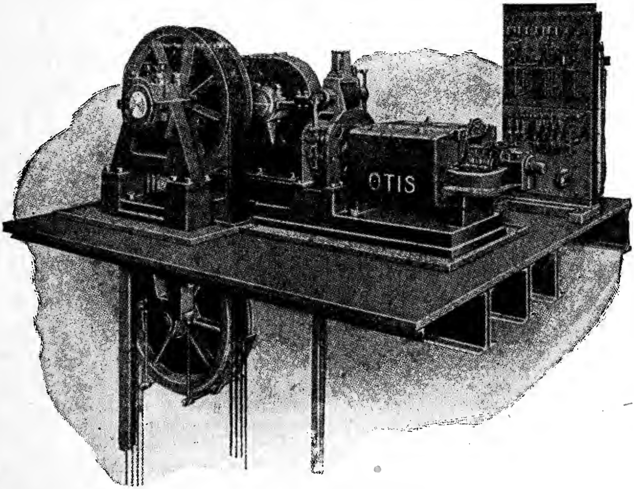


FIG. 382
OTIS DIRECT CURRENT TRACTION MACHINE FOR OVERHEAD INSTALLATION

feasibility of employing this method of drive in the low speed machines as well. The result was the introduction of what is commercially known as the Otis Geared Traction Elevator which embodies many of the good points of its larger contemporary.

It might be well to state here that the traction principle is neither new nor experimental, as is instanced by its use in the familiar type of carriage hoist, this being in reality a low duty hand power traction elevator driven by means of a hemp rope; also this method of drive has been employed on dumb-waiters for some time. However, as applied to the high speed passenger machines used in our tall office buildings, it must be referred to as a comparatively new and improved development of former types.

The Geared Traction machine is similar in appearance to the standard drum machine, except that a multi-grooved driving sheave is mounted in place of the drum, and a non-vibrating idler leading sheave takes the place of the vibrating sheave necessary on the drum type. The car and the counterbalance weight hang directly from the driving sheave—one from either end of the cables—in precisely the same manner as with the Otis Traction Elevator; the necessary amount of traction being obtained by the extra turn resulting from passing around the idler sheave.

The machines are built in two classes, double screw, and single screw, depending upon the duty required.

The double screw machine is designed for the heavier duties, and the gearing consists of a right and left hand worm, see Fig. 383, accurately cut from a solid forging. This worm, coupled directly to the electric motor, runs submerged in oil and meshes with two large bronze gear wheels, which in turn mesh with each other. The effect of the three-point drive thus obtained, in conjunction with the right and left hand thread, is the entire elimination of end thrust on the worm shaft—a most desirable feature. The complete gear is fully protected in an oil tight iron case and is well lubricated in every part.

To the forward gear wheel, that is the one furthest from the motor, there is bolted the iron buffer-neck, or what might be termed the driving spider. It is constructed in such a way that the use of keys is unnecessary to effect the drive, inasmuch, as the flange of the buffer-neck is bolted with through bolts directly to the bronze gear wheel near its periphery, and by means of four extending arms on its opposite end engages with similar arms on the driving sheave. A mechanically strong and perfect drive is thus obtained. The shaft passing through the driving sheave and buffer-neck serves merely as a support for the moving loads and is subject to absolutely no tortional strains. In order to protect the gears and elevator car from possible vibrations, large rubber buffers are placed under slight compression between the arms of the sheave and those of the buffer-neck.

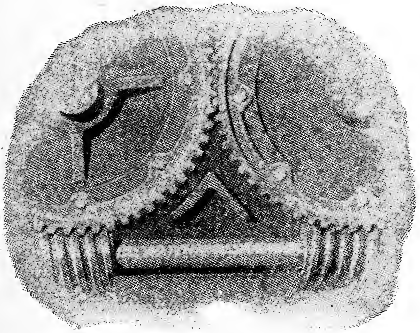


Fig. 383
THREE POINT DRIVE

The machine is equipped with a mechanically applied, and electrically released double shoe brake. The shoes are applied against a pulley of ample diameter and width to dissipate any heat generated, and serves as a coupling between the motor shaft and the worm shaft.

The brake shoes are normally bearing against the pulley with a pressure corresponding to the compression of the two helical springs. When current is admitted to the solenoid brake magnet, and then only, the action of the springs for the time is overcome, so that the shoes are released. It will be seen, therefore, that the brake will apply with full force should a failure of current occur; resulting in an immediate stop of the elevator.

The motor is compound wound, and runs at about eight hundred revolutions per minute at full car speed and load. The series field is used only at starting to obtain a highly saturated field in the shortest possible time, and is then short-circuited, leaving the motor to run as a plain shunt wound type.

In stopping, a comparatively low resistance field is thrown across the armature, providing a dynamic brake action and a gentle slowing down of the car, the mechanical brake being called upon only to effect the final stop and to hold the load at rest. Resistance in series with this "Extra Field," as it is called, is controlled by magnets which depend, in their operation, on the speed of the armature. It is therefore evident that the dynamic, or retarding effect of the field is proportional to the speed, and therefore to the load in the elevator car, hence good stops under all conditions are easily obtained.

To meet the demands in districts where alternating current is in use, the same apparatus described is furnished except that the direct current motor and controller give place to an alternating current motor and controller.

The alternating current machines are made in two classes also, single and double screw. The cut, Fig. 384, represents a double screw machine designed for basement installations. The brake is slightly different in appearance but performs the same functions as does the direct current brake.

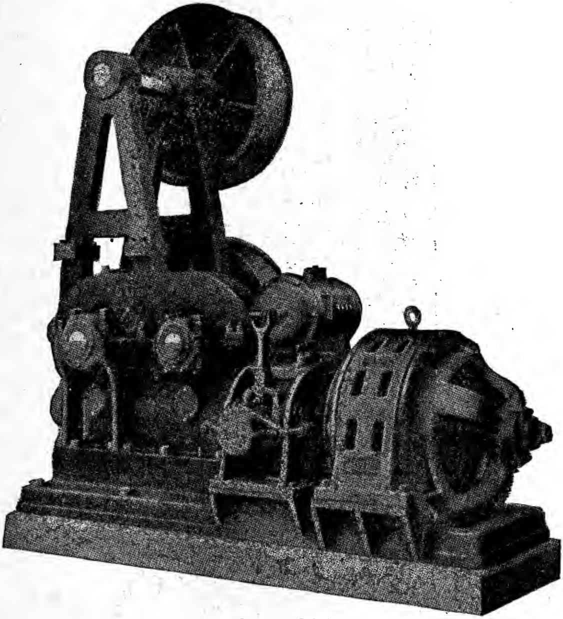


FIG. 384

OTIS ALTERNATING CURRENT DOUBLE SCREW TRACTION MACHINE

Designed for Basement Installations

The safeties used on the Otis Traction Elevators are found on the geared traction elevators. The main difference between the two machines being the ability to use on the latter a small high speed motor with gearing, instead of the large, slow speed and more expensive motor of the Otis Traction Elevator.

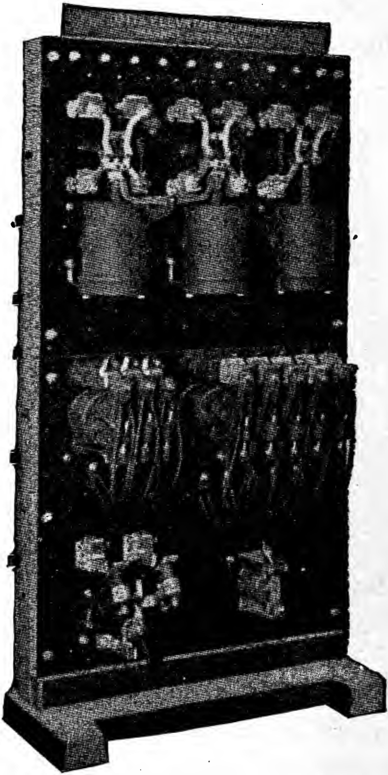


Fig. 385

MAGNET CONTROLLER

Fig. 385 shows the Otis electric magnet controller, and Fig. 386 shows the standard car switch. With this operating device the current is automatically and gradually admitted to the motor, enabling the operator to start and stop the car without shock or jar. This controlling device is constructed to secure the motor against damage by any overload, or excess of current; these features are automatic in their operation, are independent of the operator in the car, and are designed to prevent more current being admitted to the motor than is required to do the maximum work of the elevator.

Fig. 386
OTIS LEVER CAR SWITCH

Electro magnets are employed throughout, thereby eliminating the use of all rheostats, sliding contacts, or other easily deranged devices. The contacts and wearing parts in the controlling mechanism are of ample dimensions to meet the severe conditions, and exacting requirements of elevator operation and control.

Careless Operation.—The waste of power caused by the careless operation of electric elevators is well worth consideration. The following timely suggestions are quoted from an article by C. M. Ripley in the September, 1909, issue of Power:

"An electric passenger elevator driven by a 30-horsepower motor on a 220-volt circuit is generally fused for 150 amperes. Assuming that it requires four seconds for the car to gain its maximum speed, and that electric service costs 10 cents per kilowatt-hour, the cost of merely starting the elevator will figure out as follows:

150×220×4=132,000 watt-seconds;
132,000÷3600=36.6 watt-hours or
0.0366 kilowatt hour;
0.0366×10=0.366 cent, or over a third
of a cent.

"In a building with, let us say, one elevator, serving six floors continually for eight hours, this waste in power would be considerable if the operator had to make one unnecessary start on each trip, or two unnecessary starts for each round trip. If this car made 84,000 round trips in a year, the power waste would cost over $60. And if this average held good in buildings with ten elevators instead of one, with 24-hour service instead of 8-hour service, and with 20 stories instead of six stories, the loss would amount to something over $3,000. The wear and tear on switch contacts, controller contacts, controller magnets, commutator, armature, steel worm, bronze gear or gears, thrust plates, ball bearings, armature bearings, drum-shaft bearings, the car cables, the counterweight cables and the back-drum cables are all materially increased also by increased starting."

Table 49 gives some interesting and instructive data regarding the starting and running current, fuse capacity, etc., of various sized motors for Otis elevators.

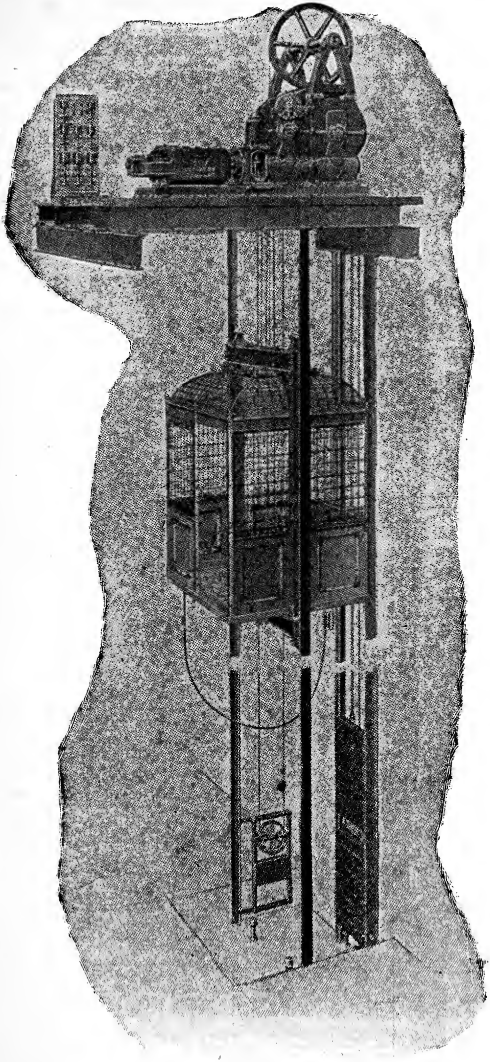


FIG. 387

DOUBLE WORM AND GEAR ELECTRIC ELEVATOR, OVERHEAD INSTALLATION

TABLE 49

No. of Motor.	R. P. M.	H. P.	Running Amperes.		Starting Amp.		Torque, Pound-feet.	Fuse Capacity.	
			220V.	500V.	220V.	500V.		220V.	500V.
2	800	7.5	25.5	11	35	15.4	120	50	15
2½	800	10	34	14.7	45	19.8	140	50	25
2	1000	10	34	14.7	45	19.8	120	50	25
3	800	15	51	22	60	26.5	240	75	50
3½	800	17.5	59.3	25.7	75	33	250	75	50
4	800	20	68	29.5	100	44	330	100	50
4½	800	22	74.5	32.5	110	48	360	125	50
4	1050	25	85	36.7	110	48	330	125	50
5	800	30	102	44.2	125	55	375	125	75
5½	800	30	102	44.2	135	60	375	150	75

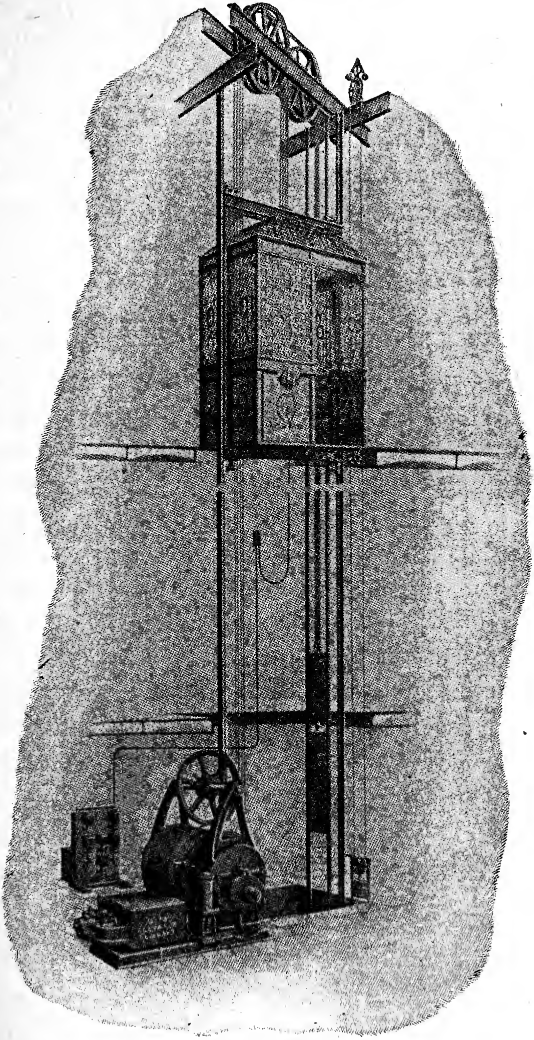


FIG. 388

SINGLE WORM AND GEAR ELECTRIC ELEVATOR, BASEMENT INSTALLATION

In addition to the waste of power caused by unnecessary starts, there is the tremendous strain to which the apparatus and cables are subjected when the car is suddenly stopped on the down trip; there is also the liability of burning out armatures by hasty reversals. Most elevator controllers are designed now so that the current cannot be sent through the motor in the reverse direction until the armature has ceased revolving. But there are many controllers still in use which are not so equipped, and motors operated with such controllers can easily be damaged by suddenly reversing the car switch before the motor has stopped revolving. If an elevator operator reverses his switch to the "down" position before the motor has fully ceased rotating in the "up" direction, the effective voltage at the armature terminals will be practically the sum of the line voltage and the counter electro-motive force of the armature, instead of the difference between the line voltage and the counter electro-motive force, or almost twice the line voltage, with nothing to oppose it but the very low resistance of the armature winding and connections. This would result in a flow of an enormous current—sufficient to burn up the armature in short order—if the safety fuses did not melt promptly.

HYDRAULIC ELEVATORS.

The mechanism of a hydraulic elevator consists of a cylinder and piston, the piston being connected by one or more piston rods to a cross-head which carries the sheaves over which run the lifting cables from which the car is suspended. By means of suitable valves, and controlling mechanism operated from the car, water, under pressure from compression, or gravity tank systems, or

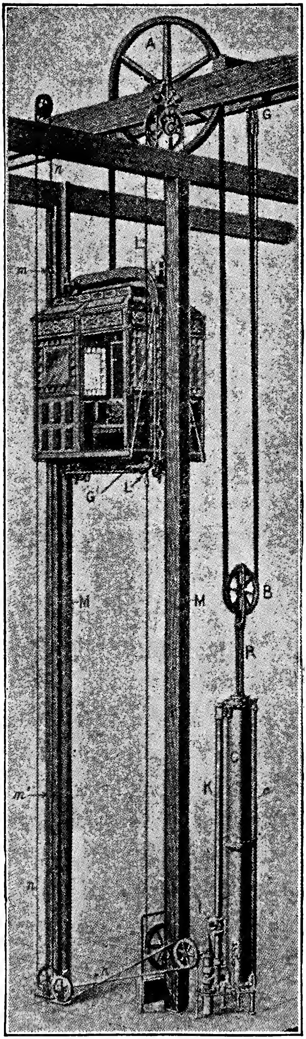


Fig. 389

from street mains where sufficient pressure is available, is caused to flow into, and out of the cylinder, thus causing the piston to move from one end of the cylinder to the other, and back again. This motion of the piston and cross-head to and fro imparts motion to the lifting cables which pass over sheaves at the top of the elevator hatchway, and which hold in suspension the car, thus moving it up or down, according as the water flows into or out of the water cylinder.

The motion of the piston transmitted to the cable is multiplied to a greater or less degree, according to the design of the elevator, by being caused to pass over sheaves designed for that purpose.

Thus the ratio of increase in speed may be anywhere from 2 to 1, to 12 to 1, to meet the requirements due to the nature of the service, whether freight or passenger. The height of the building also controls in a large measure the speed, for instance in very tall buildings the elevators may be geared as high as 12 to 1.

The cylinders of hydraulic elevators are made either vertical, or horizontal depending upon local conditions. If the floor space is restricted, vertical cylinders are used, but in cases where space above the basement floor for the accommodation of vertical machines cannot be easily obtained, it is the usual practice to place horizontal cylinders in the basement. Vertical cylinders are usually geared three and four to one, although ratios of from two to one, up to six to one are quite common.

Fig. 389 presents a view of a low pressure vertical cylinder hydraulic elevator geared two to one. The cut shows the general arrangement of the mechanism, from basement to top sheave. This type of hydraulic elevator is operated by the movement of the hand rope n, which passes around a sheave at the side of the valve chamber, and moves the valve by means of a rack and pinion gear.

Rope n then passes under two small sheaves at the bottom of the elevator hatchway, and from thence up to the top of the hatchway, and over another small sheave. One side of this hand rope passes through the car, and by pulling this side up the operator causes the car to descend, and by pulling the rope down the car will ascend. Near the top, and bottom of the hatchway two balls m and m′ are placed upon the hand rope. They are large enough to prevent their passing through the openings in the floor, and roof of the car through which the hand rope passes. When the car ascending strikes the upper ball m, the latter is carried up with the car, thus pulling up the hand rope, and moving the control valve back to the stop position. Should the car fail to stop, the valve will be carried past the stop position, which will connect both ends of the cylinder, and the car will start to descend. If, however, every part is properly adjusted, this reversal of the motion of the car cannot occur, because under such conditions, the car will stop when the valve is closed. If by any mishap the car should run away, and go beyond the normal limit of its travel, the control valve would be slightly opened in the opposite direction, just sufficient to develop a retarding force and thus stop the car. The action is the same when the car approaches the bottom, as it will then strike ball m′, which will be carried down, thereby closing the operating valve. Balls m and m′ are in fact automatic top and bottom limit stops, and constitute one of the most valuable safety devices with which elevators are equipped.

Another valuable device is the speed limit, which usually consists of stops mounted at some convenient point in the hatchway, and set above and below balls m and m′, so as to limit the distance through which the latter can be moved.

In some cases additional stop balls are used, on account of its not being convenient to place stops to act directly upon m and m′. The positions of these stops which limit the amount of opening of the valve, are determined experimentally when the elevator is installed. The movement of the car is kept steady by guides M, M, Fig. 389. In the construction shown in Fig. 389 these guides are made of hard wood. At the top of the car adjustible shoes are

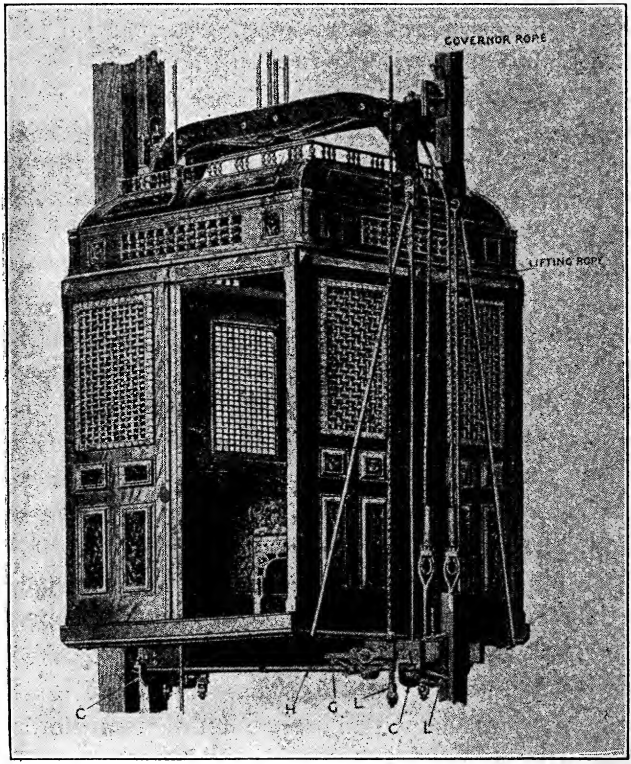


Fig. 390

provided, which slide freely against the guides. At the bottom the car is guided by jaws formed in a safety device, or "safety" as it is termed. It is made of hard wood blocks, the dimensions varying from 4 inches thick by 11 inches wide in the smaller sizes, to 5 in. x 15 in. in the larger sizes. The jaws of this safety are reinforced with massive iron castings, and on one side are provided with a wedge that can be adjusted in position by means of screws, and on the opposite side with another wedge that can be forced between the guide and the jaw to stop the car if one of the lifting ropes breaks, or the car attains an excessive velocity from any cause.

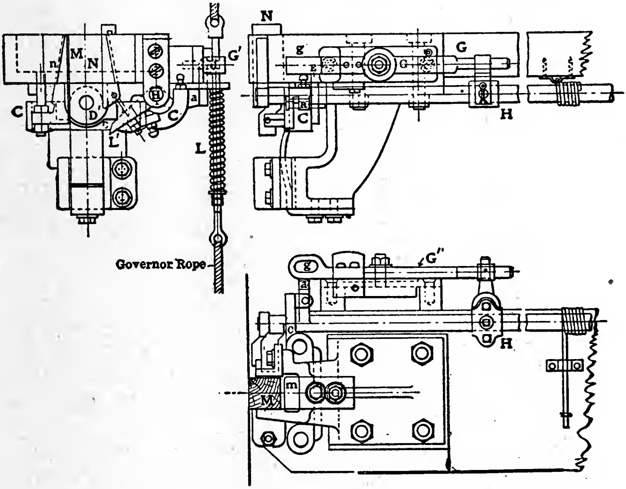


FIG. 391

By reference to Fig. 390, and also to Fig. 391, which shows one end of the safety device, its construction and operation will be clearly understood.

In Fig. 391 the governor rope rod L is shown only in the end elevation. Referring to Fig. 390 it will be seen that the two lifting ropes that run down to either side of the car are connected with the ends of a rocking lever C. This lever C, as shown in Fig. 391, is pivoted at D′, hence if either one of the lifting ropes breaks, the end of the lever it is attached to will drop down. The shaft H which extends under the car from one side to the other, carries at its ends a lever L′ which, when raised lifts the wedge N and forces it into the space between the guide M and the side of the jaw of the safety plank. Whichever way the lever C may be tilted by the breaking of one of the lifting ropes, it will rotate shaft H and lever L′ in the proper direction to throw up wedges N, thereby locking the car against the stationary guides M.

The levers on shaft H are sufficiently long to strike the guides M, when raised high enough, and are sharp at the ends so that they will cut into the guides.

It might be thought that if the wedge N is only raised far enough to catch in the space between the guide M and the safety-plank jaw it would be forced upward so tightly as to stop the car without further assistance. This would be the case if the wedge had a sufficiently long taper, but if it were so proportioned, it would require an enormously strong jaw to resist the bursting strain; moreover, the car would be so tightly wedged that it would require a greater force to release it than could be easily obtained.

With the wedges of the proportions used, it is necessary to make the lever that lifts the wedge so that it will dig into the guide, and as the car moves down through, say, a foot or two in coming to a stop, the lever shaves the side of the guide, thereby not only forcing the wedge tighter against the guide, but producing an additional retarding force. When a car is caught by the safety, all that is necessary to release it is to start in the upward direction, and the force exerted by the lifting cylinder is enough to overcome the friction of the wedges against the guides.

In the foregoing it is shown how this safely acts, providing one of the ropes breaks. Elevator cars, however, seldom drop when one of the ropes breaks, but frequently attain

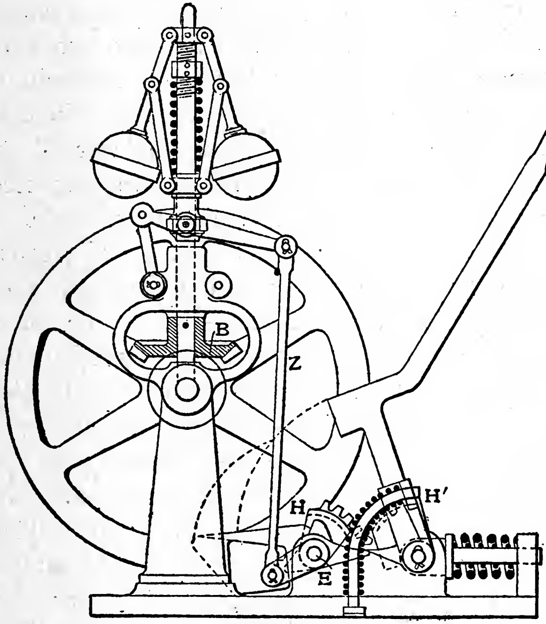


Fig. 392

a very high velocity when the ropes do not break, and on that account it is necessary to arrange the safety so that it will act when the speed reaches a certain stage regardless of the cause of increased velocity. This is accomplished by means of the Otis safety governor, shown mounted on one of the overhead beams in Fig. 389, and in detail in Fig. 392. This device is driven by the rope L, which is made fast to one end of lever G′ as shown in Fig. 389. The spring that holds G′ is strong enough to keep the lever in its normal position and rotate the safety governor at a velocity proportional to the speed of the car. Referring to Fig. 392 it will be seen that the governor may be adjusted by means of the spring on the spindle, to act at any desired velocity. The governor driving rope passes through the clamping jaws H H′, and when the governor speed becomes great enough to lift the rod Z and throw the jaws together, the rope will be clamped. Then, as the rope cannot move, the outer end of the lever G′ on the safety plank will be held stationary as the car descends; hence, the shaft H will be rotated, throwing the safety wedges N into action to stop the car. It is evident that the car can descend only as far as the upward movement of the end of lever G′ and the compression of the spring on L will permit, before the rope will be compelled to slide through the clamps H, H′ of the governor. As the distance through which the spring can be compressed, plus the movement of the end of G′ is only a few inches, it is evident that unless the car is stopped very short, the rope L must break if it cannot slide through clamps H, H′. The distance in which the car will stop is always considerably more than the compression of the spring plus the movement of the end of G′; hence, while it is necessary for H H′ to clamp the rope tight enough to move G′, the pressure must not be so great as to prevent the rope from slipping. For the same reason, in order to make the safety governor reliable it is necessary that the operating rope shall be in just as good condition as the elevator lifting ropes. The failure to inspect this rope properly, and make sure that it is at all times in perfect condition has been a prolific cause of accidents.

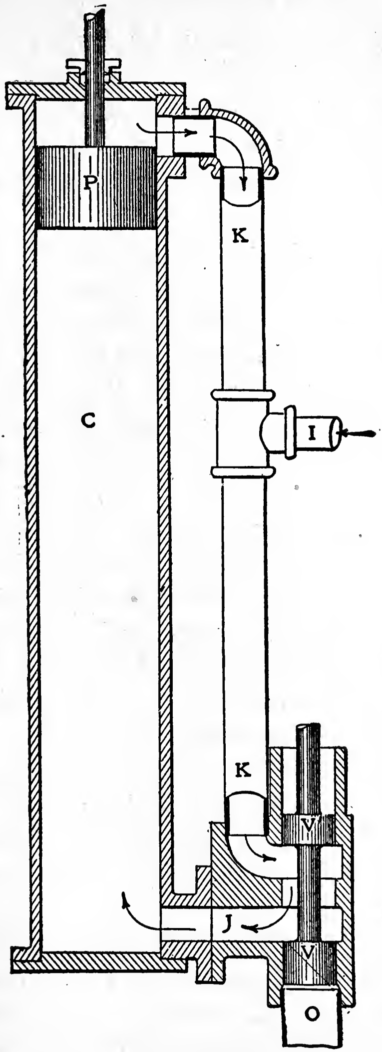


Fig. 393

The jaws of the safety plank and the wedge N should be kept clean and in proper adjustment at all times. As the guides M have to be kept well lubricated, it can be easily seen that if the safety jaws are neglected they will soon become clogged with a mixture of grease and dust, and this may give a considerable trouble by causing the wedge to stick to the side of the guide and thus go into action when everything else is running properly. The wedge N, and the adjusting wedge on the opposite side of the guide, will gradually wear away. For this reason the latter should be set up as often as required to keep the proper amount of clearance between the guide, and the safety jaw. If the clearance is too great, the wedge N is liable to not catch firmly when called into action, and if the clearance is too small, the safety is liable to act when not required.

The operating valve shown in Fig. 389 is the same in principle as the one shown in section in Fig. 393, but it has several details of construction not shown in the latter. Its design is shown more in detail in Fig. 394, which is a sectional elevation of the valve, and casing. The casing is made in three parts marked 7, 8 and 9. Part 7 forms the top, and provides a dome, into which the rack 6 on the end of the valve rod can rise as the valve is lifted by the rotation of the pinion on the end of the shaft A. This shaft carries at its outer end the hand rope sheave shown at the side of the valve in Fig. 389. The parts 7 and 8 are divided at the center of the shaft A, and form a bearing for the latter.

The lower part 9 which is the valve casing proper, has ports 10 and 11 for connection with the lower end of the circulating pipe, and the lower end of the cylinder, in the manner indicated in Fig. 393. That portion into which the circulating pipe is connected forms a separate casting in Fig. 389, and the casing 9 is bolted to it. Port 12 in part 9 of the valve casing is for the purpose of connecting

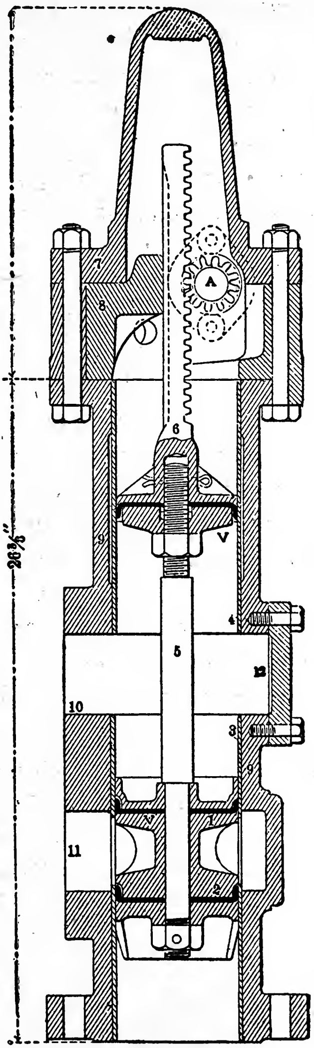


FIG. 394

with the pressure-water supply if for any reason it is not desired to have this connection made in the circulating pipe. The valve casing is lined with brass tubing 4 and 3. Lining 4 is simply for the purpose of providing a smooth surface for the cup packing of V′ to slide against. Lining 3 is provided for the purpose of making ports of such a character that the cup packings of V may be able to slide over them freely.

If the ports were large openings, the packings could not pass over them, because on the up movement they would be caught by the edges of the ports. With the brass linings this trouble is overcome by perforating the brass with a large number of small holes, about one-quarter of an inch in diameter. The combined area of the holes is much larger than would be required in a single port, this increase in opening being provided so as to reduce the friction of the water running through the holes by reducing the velocity of flow.

The pressure of the water tends to force the valve piston V′ up, and the other piston V down, and as both pistons are the same in diameter, the valve is balanced. Nevertheless the force required to move the valve is considerable, owing to the friction of the cup packings, caused by the pressure of the water acting upon the entire surface of the leather in contact with the brass linings of the valve casing.

On this account the pinion on the shaft A, through which the valve is moved, is made very small, while the hand rope sheave is large—about 20 inches in diameter—so that while the valve travels a few inches in either direction the hand rope has to be pulled through a distance of from two to four feet, according to the size of the valve and the speed of car. For high car speeds the hand rope movement is increased, so that the automatic top and bottom stops may be able to arrest the movement of the car without making the stop abruptly. Reference to Fig. 394 will show that the lower head that clamps packing 2 is made tapering. This is done in order to prevent too quick a closure of the outlet from the lower end of the cylinder when the valve is moved down to stop the car on the up trip; otherwise the stop would be too abrupt. Even with this precaution it is possible for the operator to close the valve too quickly; therefore a check valve is inserted in the passage connecting the valve casing with the cylinder.

This check is directly under the lower end of the circulating pipe, so that if the operator closes the valve too suddenly the descent of the piston within the cylinder will not be arrested instantly, but the piston will slowly continue its movement and gradually force the water under it to pass through the relief check valve, into the circulating pipe, and thus into the top end of the cylinder. If the operator moves the hand rope so quickly on the down trip as to produce a violent stop, the piston will continue to rise in the cylinder, and the water above it which cannot pass to the lower end of the cylinder on account of the valve being closed, will be forced back through the inlet pipe I to the pressure tank. In this case, as no water can pass into the lower end of the cylinder, the continued upward movement of the piston causes it to leave the water, and thus a vacuum is formed underneath it.

This vacuum together with the tank pressure on top of the piston soon arrests the movement of the car, but the stop is not so sudden. One objection to having the connection from cylinder to pressure tank through the inlet pipe I is, that if for any reason the pressure in the tank should drop to zero, owing to the starting of a bad leak, the water in the top end of the cylinder could immediately

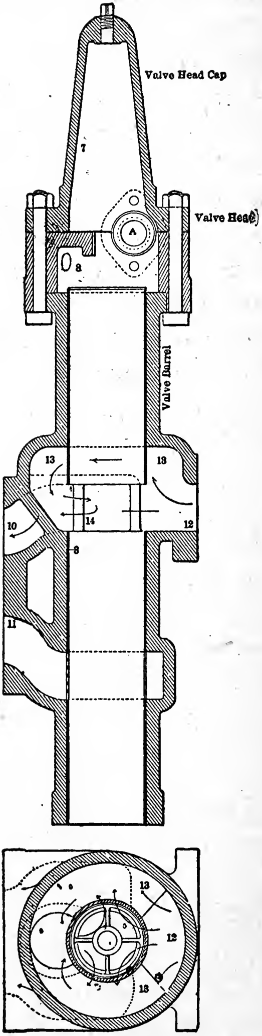

Valve Head Cap
7
Valve Head
A
8
Valve Barrel
13
13
14
12
10
8
11
13
12
13
8

Fig. 395

run out with such freedom that if the car should happen to be at, or near the top of the hatchway it would attain a dangerous speed by the time it reached the bottom. But by locating the pressure tank on the roof of the building the danger from this source is obviated, for the reason that the flow of the water from the cylinder would then be against a pressure due to the elevation of the tank, and to this may be added the pressure of the atmosphere, for the reason that the valve being closed, no water can pass into the lower end of the cylinder, and as the piston moves up, a vacuum is formed under it thus tending to retard its motion.

The result is that the combined pressures are sufficient to hold the car within safe speed limits. When the pressure tank is located in the basement, the danger above referred to is avoided by using a valve of the type shown in Figs. 395 and 396. Fig. 395 shows the casing, and Fig. 396 the valve.

The difference between this valve and that of Fig. 394 is that it is provided with an additional piston V″, see Fig. 396, which is called the throttle valve. When this valve is used, the inlet pipe from the pressure tank is attached to the port 12. When the elevator is stopped, the throttle valve V″ is directly opposite the port 12, and thus obstructs the flow of water from the port 10. It will be seen that a groove is turned in V″ at the center line. In addition the valve is not made a perfect fit in the casing, and the clearance thus afforded is sufficient to permit water to pass by in as large an amount as may be required to prevent a too sudden stoppage of the car should the operator close the valve too quickly. Another advantage is, that in case the tank pressure should fail, the flow of water past this clear-

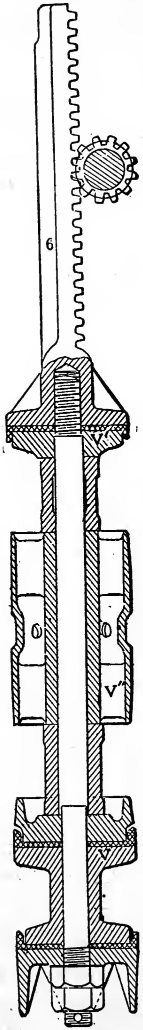


Fig. 396

ance is retarded sufficiently to prevent a dangerous speed in the descent of the car.

When the valve is moved in either direction to set the car in motion, water passes from port 12 to port 10 through side ports 14. A portion of this water passes directly from 12 to 14, and the other portion passes around the upper lining 4, through circular passages 13, and thence down into 14, as indicated by the arrows. In this way sufficient opening around the throttle valve is afforded even when the port of the operating valve piston V is only slightly open. The passages 13 and the connection between the ports 14 and 10 are not easily made out from Fig. 395, but

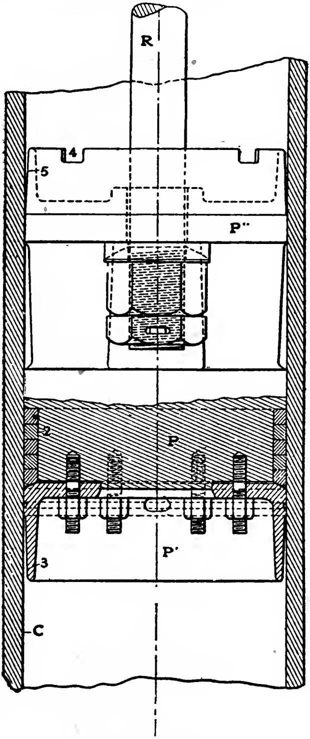


FIG. 397

the arrows indicate the course of the water, and these make the construction more easily understood. The lower cross section through the passages 13, taken at right angles to Fig. 395 will serve to illustrate more fully the construction.

The pistons used in vertical hydraulic elevators are made in several designs, some being arranged so as to be packed from the upper end, and others so as to be packed from the lower end. Fig. 397 shows one of the latest designs of pistons arranged to be packed from the lower end of the cylinder, which appears to be the favorite type now. The drawing shows a section through the complete piston, with packing in place, also a section of the cylinder C.

Ordinary square packing is used, and this is held in position by a follower secured by six bolts. Fig. 398 shows the body of the piston only. The parts P and P″ are made to fit the cylinder, but the intervening section is cut away on opposite sides, so as to afford space for the ends of the piston-rods and their fastening nuts. The top and bottom parts of the piston are connected by the pillars I and I.

In packing these pistons it is necessary to be careful not to press the packing in too tight, as there is danger of bursting the cylinder by so doing, and even if this much damage is not done, the friction caused by the excessive pressure may be so great as to prevent the car from attaining its full velocity. If a hard packing is used, and this is forced into place dry and very tight, the chances are that when it becomes well soaked it will expand enough to burst the cylinder. Bursting hydraulic-elevator cylinders is not a very rare occurrence, and when it does occur it is due to too great pressure of the piston packing against the sides of the cylinder.

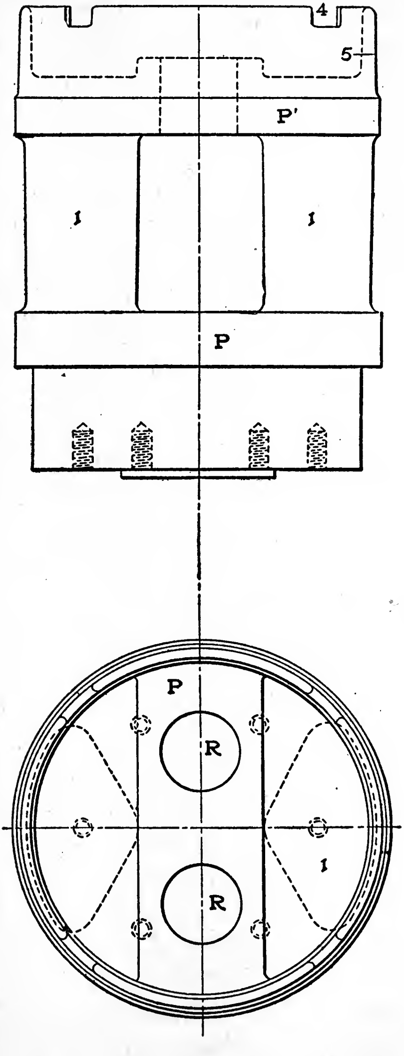


Fig. 398

Referring to Fig. 389, it will be noticed that there are two piston rods, R.

This construction was adopted in the early days of hydraulic elevators partially to increase the safety of the apparatus, but principally to prevent the traveling sheave B from twisting around. The ropes tend to hold the sheave from twisting, but they will not prevent slight movements, while the double piston-rods will. Now and for several years past, however, the frame of the traveling sheave has been made in the form of a crosshead running in stationary guides, thus effectually preventing any side movement of the sheave. With this construction the main benefit of the double piston-rods is additional safety; while it is possible for one rod to break or become loose, it is practically impossible for both to give way at the same time.

The arrangement of the cylinder C, the circulating pipe K, and the valve V, in Fig. 389, is the same as in the diagram Fig. 393, even the inlet I being similarly situated. The small pipe c is for the purpose of carrying off the drip from the upper side of the top cylinder head, ordinarily, and also for the purpose of draining the water from the upper end of the cylinder, in cases where it is necessary to run the piston to the top of the cylinder to renew or adjust the packing. Some cylinders are arranged to be packed from the upper end and others from the lower end, the latter design being the one generally used in modern machines. As will be noticed, the pipe c connects at the bottom of the cylinder with other pipes that connect to the valve chest and the lower end of the cylinder. All these pipes are either to carry off the drip or to draw water from the various parts of the cylinder and valve chest when desired. Globe valves are placed in the drainage pipes so as to keep them closed normally.

Counterbalance.—Generally a portion of the counterbalance is placed on top of the piston, so that in such machines the counterbalance weight is divided into three parts, one being within the cylinder, one in the traveling sheave frame, and one constituting the independent counterbalance.

Operating Devices.—In order if possible to avoid the uncertainty of operation in connection with the hand rope in high speed elevators, lever, and wheel operating devices have been developed, and to make these devices operative and reliable, the operating valves have been somewhat modified in design. The main valve, controlling the flow of water into, and out of the cylinder, varies in diameter from 3 inches in small machines, to 7 or more inches in the large sizes. Fig. 399 shows the lever device for operating, a modern high speed hydraulic elevator. The lever L is shown located in the car. The movement of this lever to one side or the other rocks the horizontal lever M, and this motion causes the sheave P mounted on the frame I to rotate through a small angle. The rotation of P is transmitted to P′ through the rope k, and the rotation of P′ actuates the valves in a manner that will be presently explained.

Ropes m m, n n pass around sheaves N N N N located at top and bottom of the elevator hatchway, as is clearly shown. The ends m m are fastened to the ends of the lever M but the sides n n are not connected with it, although in the illustration they look as if they were. The side n that runs up from the right-hand side N sheave at the bottom passes over the N sheave at the left-hand side at the top of the elevator hatchway. These two N sheaves at the top are mounted upon a frame I which is arranged so as to hold the sheaves firmly in the horizontal position, but

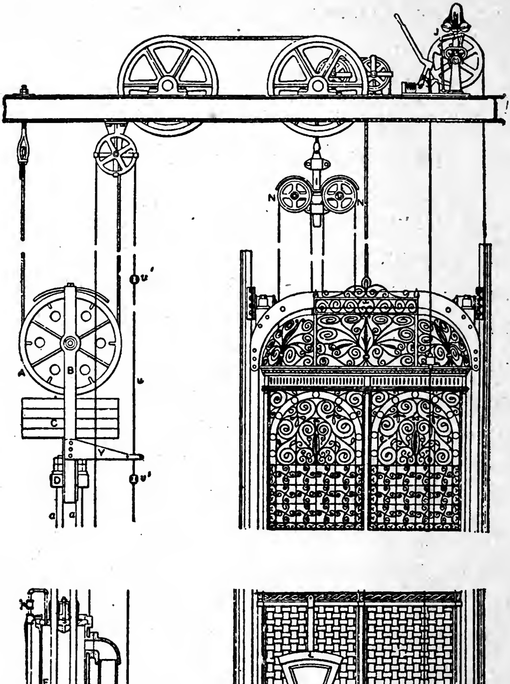

J
N
N
u'
A
B
u
C
V
D
u'
a
a
E
G
F
S
Q
R
i
P'
f
T
h
f
g
H
V
X
W
v
PRESSURE
P
N
N
M
m
n
n
m
p
r
K
I

FIG. 399

allows them to revolve freely around the studs upon which they are mounted. The frame I is suspended from a rope that passes over the two small sheaves resting on top of the overhead beams. The end of this rope extends downward, outside of the elevator hatchway, and has a weight suspended from it so as to hold the ropes m m, n n, with the proper tension.

Upon the larger sheave P are mounted the lower N N sheaves. If the right-hand end of lever M is depressed, the right-hand loop formed by the rope n m will be lowered, while the left side end will be raised, and as a consequence the right side lower N sheave will swing downward while the left side one will swing upward. Thus the rope k will be pulled with the upper side moving from left to right, and sheave P′ will be rotated in the direction in which the hands of a clock move.

This arrangement of ropes for transmitting the motion of lever L to sheave P′ is called the running rope system. There is another way of accomplishing the result with stationary ropes, the upper ends of these being attached to the upper frame I and the lower ends to the sides of sheave P, or to the ends of a lever secured to this sheave. In this arrangement the rope that is fastened to the right-hand side of sheave P is secured to the left side of the upper frame I. The sheaves N N N N are placed upon the ends of lever M and each rope passes over one sheave at one end, and under another sheave at the other end of M. This is the standing rope system. For both systems there are several modifications, but the results are the same in each case, viz., to transmit the motion of lever L to sheave P′.

Valve v controls the flow of water into and out of the hydraulic cylinder. This valve is actuated by a piston T located in the enlarged portion of the valve chamber, and which is larger in diameter than valve v; consequently if water under pressure is admitted to the space between T and v, the pressure of the water upon the larger area of piston T will cause it to move up, provided there is no pressure on its top side. If water under pressure is admitted to both sides of piston T, it will be balanced and will exert no force to move the valve in either direction. Valve v will, however, have the pressure acting upon its upper side, while the only pressure acting against its lower side will be atmospheric pressure, or that of the tank into which the water is discharged. Consequently the valve will move downward. Water is admitted to the space above piston T through a small pilot valve at h which is connected with the pressure pipe through pipe g, while pipe f connects it with the space above T.

When the car is at rest, pilot valve h is in a position to close the ports connected with pipes g and f, and also prevents the escape of water into the larger pipe connecting the lower end of the pilot valve chamber with the main discharge pipe. Under these conditions, the water in the main valve chamber above piston T cannot escape unless valve h leaks. When sheave P′ is rotated in a clockwise direction, the crank on the end of the shaft will draw down the connecting rod j, and as valve h can move much easier than main valve v and piston T the latter will remain stationary, while h will be depressed. This movement of h will uncover the ports connecting with pipes g and f, thus establishing a through connection between the pressure pipe and the space above T and the latter will be forced downward, carrying with it throttle valve V which will uncover the port connecting with pipe G, and also move the main valve v far enough down to uncover the upper edge of the port connecting with the lower end of the cylinder, thus opening a communication between the two ends of the main cylinder. Under these conditions the weight of the elevator car which acts to pull piston F upward will set the latter in motion, and the water in the upper end of the cylinder E will be forced down through pipe G and through the valve chamber, around valve V into the lower end of the cylinder. The pipe G is called a circulating pipe, as one of its objects is to provide a path through which the water may circulate between the top and the bottom of the cylinder E.

As the action just explained takes place when the elevator car descends, it will be seen that, for the down trip, no water is drawn from the pressure tank. To run the car upward, the sheave P′ is rotated counter clockwise by swinging the car lever L in the opposite direction. When P′ is so rotated, the crank on the end of the shaft will push connecting rod j upward, and thus pull on rod i and thereby lift the pilot valve h. The upward movement of h uncovers the port that connects with pipe f, but keeps that connecting with pipe g closed, so that the water confined in the valve chamber above T can now escape through pipe f, and the lower end of the pilot valve chamber into the discharge pipe. In this way the pressure acting on the top side of T is removed, and the pressure acting on the bottom side forces the valves up, owing, as has been already explained, to the difference in area between T and valve v. The upward movement of valve v opens communication between the port running to the lower end of the hydraulic cylinder, and the discharge pipe, thus permitting the water in the lower end of the cylinder to escape through the discharge pipe. This upward movement of the valves also raises throttle valve V and allows the water in the pressure pipe free access to the port connecting with pipe

G, thus admitting a new supply of water under pressure to the space above the piston in the hydraulic cylinder. Under these conditions the water acting upon the top side of piston F in conjunction with the vacuum formed under the piston by the escape of the water into the discharge pipe, provides the force that depresses the piston and thereby lifts the car.

Upon the rate of flow with which the water can enter, or pass out of the cylinder will depend the velocity with which the piston will move, and this rate of flow is evidently dependent upon the extent to which the valves are opened. If the operator in the car desires to run at a slow speed, he moves lever L a short distance from the central position; for a higher speed, he moves it further from the center, and for the highest velocity, he moves it as far as it will go.

Now suppose L is moved a short distance only, then sheave P will be rotated through a short angle, imparting a correspondingly small movement to connecting rod j. Suppose j is depressed, thus opening the connection between pipes g and f—water will begin to flow into the space above T as soon as pilot valve h moves down far enough to uncover the ports connecting with pipes g and f and draw down the end S of lever Q. As j will now be stationary, it will act as a fulcrum, and R will be lifted. This movement will continue until pilot valve h is raised sufficiently to cover the ports connecting with pipes g and f, which will stop the flow of water into the space above T. It will thus be seen that, after pilot valve h has been moved by the rotation of the sheave P′, main valve v, and piston T also begin to move, and as they move, the pilot valve is returned to stop position. If pilot valve h is moved but a short distance from stop position piston T and valve v will have a correspondingly short distance to move to return the pilot valve to stop position. The amount of opening given to pilot valve h depends upon the distance the car lever L is moved. If for a short distance, the opening will be but a small fraction of its travel, and the main valve will open a correspondingly short distance, and vice versa. As water is practically incompressible, it is apparent that if lever L be too quickly moved to the central position when the car is moving at a high rate of speed, the motion will be arrested with a violent jerk. In order to prevent such action, means are provided whereby the water may find an outlet, if the valve is closed too suddenly. If the sudden stop occurs on the downward trip of the car, which is the up-stroke of piston F, the water will leak by the throttle valve V and flow back into the pressure pipe, and will continue to flow until the car has come to a stop.

If the throttle valve V were not provided, the water would escape too freely, back into the pressure pipe, and as a result the car could not be stopped in a very short distance; hence, the object of valve V is to provide means to prevent a too sudden stop of the car on the down trip, and at the same time not to permit the car to run farther than is necessary to make a gradual stop. Valve V is not water-tight, as has already been explained (see Fig. 396), and its throttling action begins gradually.

Should the car be stopped too suddenly on the up-trip, the water in the lower end of cylinder E will be forced through valve d at the bottom of pipe G, and the momentum of the moving parts will be expended in compressing the spring that holds valve d to its seat. Fig. 399 has been reduced in length, but it shows in detail all of the mechanism of a modern type vertical cylinder hy-

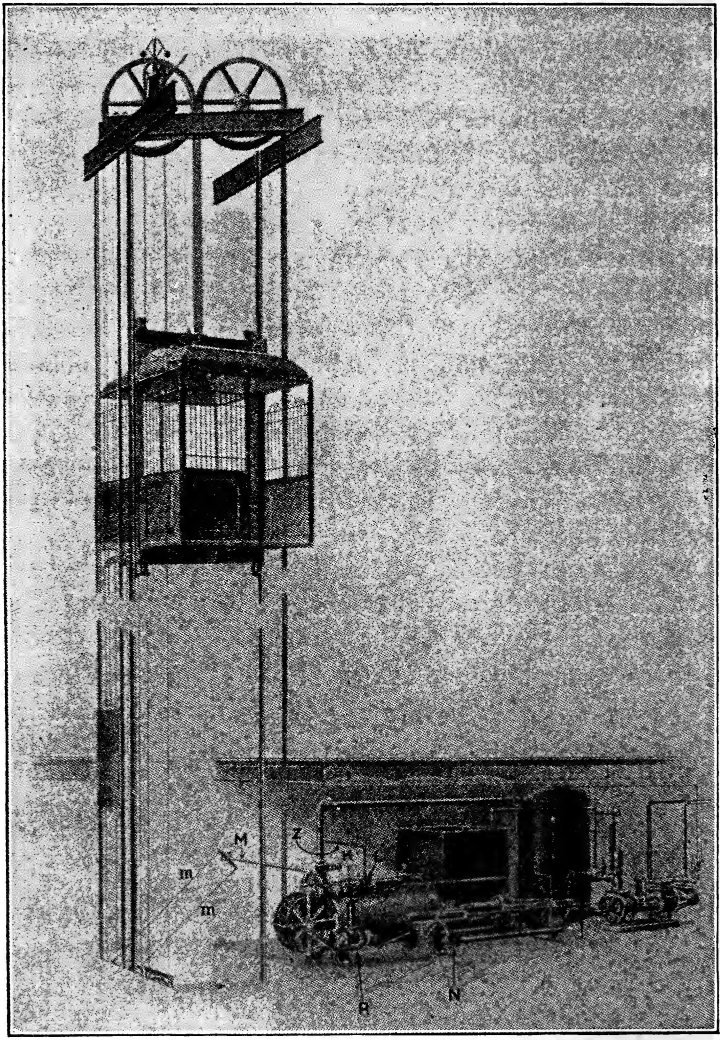


FIG. 400

draulic elevator, with running rope or standing rope control. Other methods of control besides those already described are in use, mainly in private dwellings and other places where an operator is not employed. These consist of magnetic controllers for operating the pilot valve by means of push buttons, the magnets being operated by current from the incandescent light circuit, or if such a circuit is not available, the current is derived from primary, or storage batteries.

Horizontal Cylinder.—The principal difference between the vertical, and the horizontal cylinder types of hydraulic elevators lies in the fact that in the one type the cylinder stands in a vertical position, while in the other it is placed horizontally. The principles governing the operation of the valve mechanism are practically the same in both cases, outside of a few details which will be explained. Fig. 400 shows the general arrangement of a horizontal cylinder hydraulic elevator, including pump and pressure tank. The type here illustrated and described is the Crane pushing type elevator, there being two distinct classes of horizontal hydraulic elevators, viz., the pushing and pulling types. Referring to Fig. 400, the stationary sheaves and rear end of the cylinder will be seen close to the hatchway. The main valve which controls the admission and release of the water to and from the cylinder is located at K, and is automatically operated by the movement of the pilot valve L, the latter being actuated by the rocking of shaft M, which is done by means of rods m m connected with a running rope system operated by the lever in the car. An automatic stop valve is located at R similar in design to that described in connection with vertical cylinder machines. This valve is actuated by the mechanism at N, which is set in motion by the movement of the crosshead.

Figs. 401, 402 and 403 show the apparatus in detail.

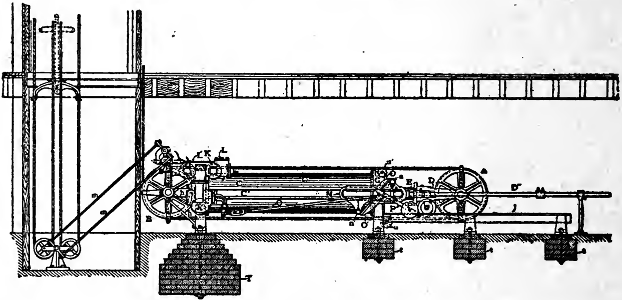


FIG. 401

In Fig. 401, which is a side elevation, it will be seen that if lever S is moved in either direction, the rods m m will cause shaft M to rock, thus moving the pilot valve by means of valve rod L′. Moving the pilot valve will either open or close main valve K, which will allow the water to flow into, or out of the cylinder, depending upon what direction lever S is moved.

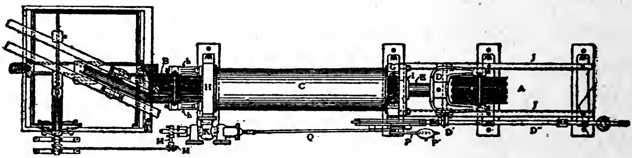


FIG. 402

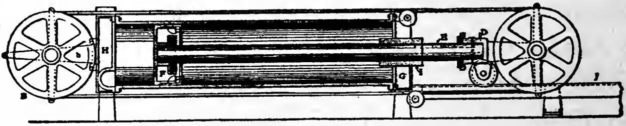


FIG. 403

If the operator fails to return lever S to stop position when the car reaches the top of the hatchway, the frame N will be carried to the right by the motion of the crosshead, and the projecting arm D′, Fig. 402, will strike the stop mounted on rod D″ connected to the end of the frame. This movement of N will cause a roller at n′ to strike lever o′, which will move to the right, and pull rod Q with it, and this action will close stop-valve R, which will stop the flow of water into the cylinder, and the car will come to a stop.

Should the car be descending, the main piston will be moving to the left, and if lever S is not returned to stop position at the proper time, the automatic stop will act in precisely the same way, except that frame N will be moved to the left instead of to the right.

Referring to Fig. 403, which is a sectional elevation of the cylinder, piston, sheaves and connecting parts, it will be seen that there is a rubber ring around the piston end of the plunger E, and a similar ring in the crosshead D. A strong buffer frame I is attached to front cylinder head G. The function of these parts is to act as cushions in case the car travels past its normal position at either end. These parts should be adjusted so as to prevent the car, or counterbalance weight from striking the overhead beams in case the automatic stop valve fails to act.

Pulling Type.—Fig. 404 shows a view of a pulling type of horizontal cylinder hydraulic elevator. This machine is made by the Whittier Machine Company, and its action is as follows: G is the main operating valve, and the pilot valve is located directly above it at J. The automatic stop valve is at H, and is actuated by stop balls N mounted on rope L. These stop balls are moved by coming in contact with an arm attached to the crosshead, which also carries

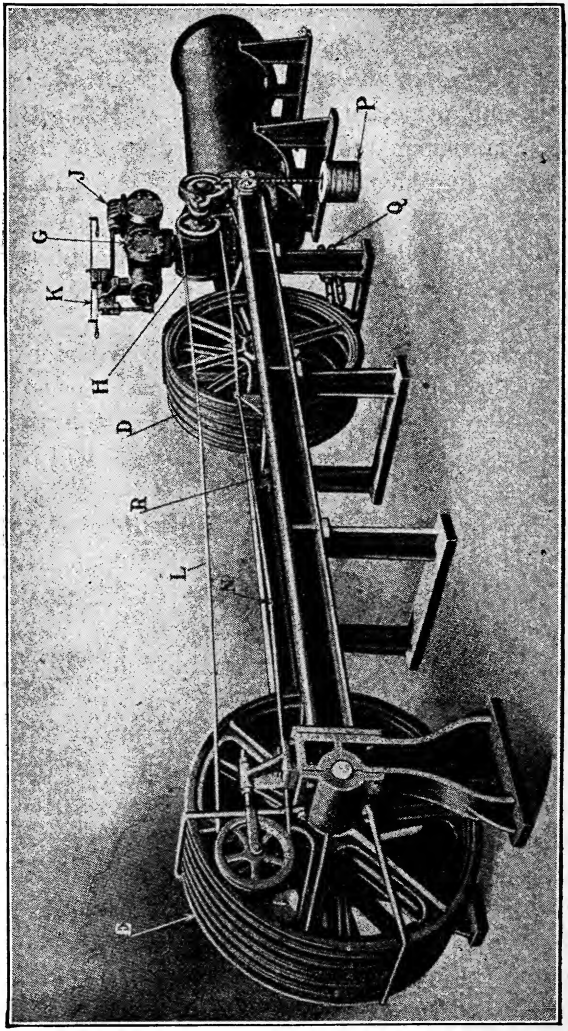


Fig. 404
THE WHITTIER PULLING MACHINE

the traveling sheaves D, and shoes R on the crosshead slide within the side guides.

The weight P suspended from the chain that travels between two small guide sheaves located just below the valve casing, is for the purpose of bringing the automatic stop valve to central position as soon as the piston moves away from either end of the cylinder. The shackle bolts for the ropes are shown at Q.

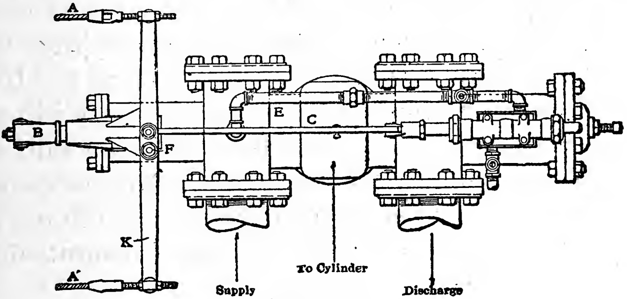


FIG. 405

The main and the pilot valves of the Whittier machine are shown in detail in Figs. 405 and 406, the first being a plan view and the second a sectional side elevation. Referring to Fig. 405, it will be seen that the operating lever K is pivoted at the point F, so that when actuated by the operating ropes AA′ it imparts an end movement to the pilot valve rod C. The ropes AA′ are connected with the

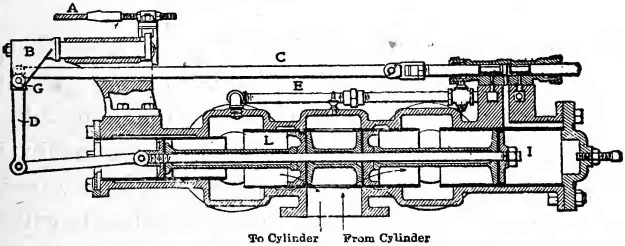


FIG. 406

operating lever in the car by either a running, or a standing-rope arangement identical with those used for vertical-cylinder elevators.

In Fig. 406 the pilot valve rod C is shown connected with the top end of lever D, the latter being pivoted at G. The part B, which holds the pivot G is actuated by the lever K. The supply pipe is connected with the right-hand end of the pilot-valve chamber through the pipe E. If the rod C is moved to the left, high-pressure water will pass through the pilot valve to the end I of the main valve and force the latter to the left, thereby connecting the cylinder with the discharge pipe, when the water will run out and the elevator car descend. The forward movement of the main valve will carry the lower end of the lever D to the left and the upper end to the right, until the pilot valve is returned to the closed position. If the pilot-valve rod C is moved to the right, the end I of the main valve will be connected with the discharge and the water will escape, then the pressure acting on the piston L will force the valves to the right and connect the supply pipe with the cylinder, which will fill with water from the pressure tank and the car will be forced upward. The movement of the main valve to the right will carry the lower end of the lever D in the same direction and the upper end to the left, and return the pilot valve to the central position.

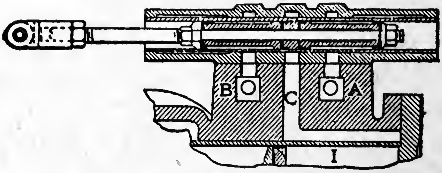


FIG. 407

The pilot valve shown in Fig. 406 is provided with stuffing-boxes at each end to insure tight joints with the valve-rod, but this construction is not used in all the Whittier elevators; in some of them the pilot valve is made as shown in Fig. 407, where the escape of water at the ends is prevented by the use of cup packings. The pressure water enters through the port A, the discharge being through the port B; consequently, the cups are set so as to oppose the pressure which is exerted in both directions from the port A.

Another design of the pulling-type elevator is presented in Figs. 408, 409 and 410. This is called a "double-decked" machine, and is made by Morse, Williams & Co., of Philadelphia. Why it is called double-decked can be understood from Fig. 408, which is a side elevation and shows two machines placed one over the other. In buildings where floor space is limited, this construction is often adopted, in some cases three and four machines being installed one over another. Fig. 409 is a top view of Fig. 408, and Fig. 410 is an end view seen from the right side. In these machines there is but one piston rod, as at B., Fig. 408. The crosshead is similar to that in the Whittier machine, except that the sides of the end bars are square with the side frames, instead of in line with the traveling-sheave shaft, as at J, Fig. 410. The guides F are set so that the crosshead shoes a, slide on top of the upper flange, not between the flanges.

At the stationary-sheave end of the guides there are shorter guides U, which carry a shaft provided with small rollers b, the function of which is to support the ropes running over the upper sides of the sheaves. In Fig. 408 the upper machine is shown with the traveling sheaves close to the stationary sheaves, caused by the car being at

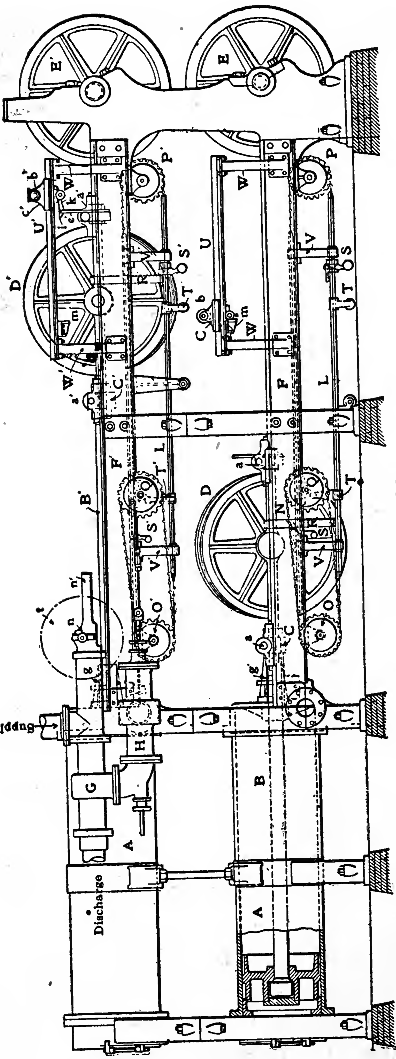


FIG. 408

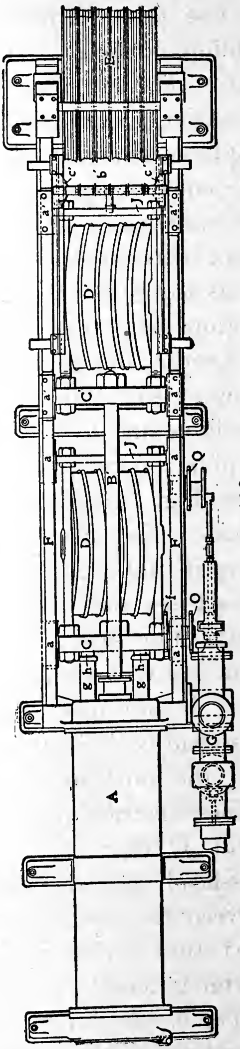


FIG. 409

the lower floor of the building. In this machine the supporting rollers b′ are at the extreme right-hand end of the guides U′. In the lower machine sheaves D are close to the cylinder, as they will be when the elevator car is at the top floor. In this case the supporting rollers b are at the extreme left-hand end of guides U and midway between the sheaves D and E, the better to support the ropes at the central point. On the upper machine in Fig. 408 a hook l mounted on a shaft carried by the guide shoes c′ engages a piece e, secured to the part J′, as shown in Fig. 510, at the center. At one end of the shaft which carries

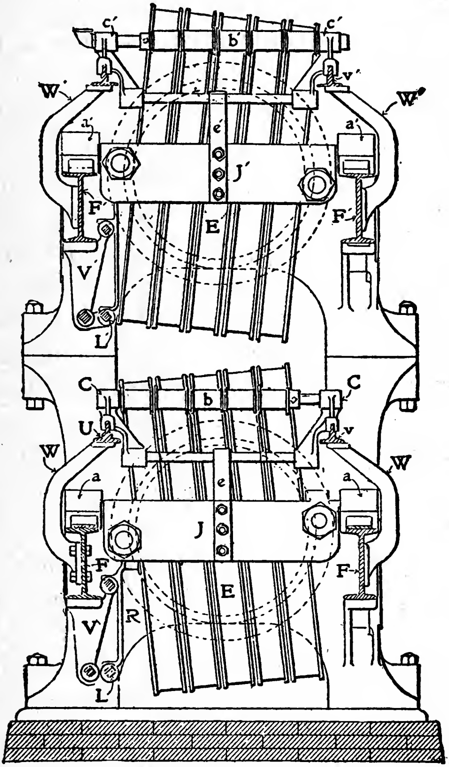


Fig. 410

hook l there is a lever k. When the sheaves D′ move toward the cylinder, the hook l being engaged with lever e, the supporting rollers b′ are carried along with the hook l until lever k reaches an inclined plane m, up which the rollers slide, causing the shaft to be rotated and hook l to be pulled up out of the way of the lever e, the rollers being left in the position of those shown on the lower machine. The supporting roller shaft is kept in line, notwithstanding that it is carried along by the part e acting at the central point, by reason of the guide-shoes c being provided with grooves that fit over the guides U, as clearly shown in Fig. 410. When the traveling sheaves move forward, the piece e engages hook l when the latter is reached, and the roller shaft is carried forward to the end of the guides, as shown at b. These supporting rollers relieve the ropes of considerable strain when the stroke is long, and the traveling sheaves are near the cylinder, but they are of little service in short-stroke machines. The movement of the roller shaft is equal to one-half the stroke of the machine.

The Stop and Main Valves.—In a machine of the pulling type the piston is forced toward the back end of the cylinder on the upward motion of the car. If the automatic stop-valve is properly adjusted, it will begin to close at the right time to stop the car even with the upper floor; but if it is improperly adjusted, the car is likely to run into the overhead beams, therefore buffers g g, faced with rubber cushions h h, are provided. In the machine illustrated in Fig. 408 the automatic stop-valve does not fit perfectly, and if the main valve is not closed when the car reaches the upper floor, the car will not stop but will slowly move upward until the crosshead brings up against the buffer cushions h h. On the downward trip, if the main valve is not closed when the car reaches the lower floor, the car will settle gradually until it rests on the bumpers, or the piston strikes the front cylinder head.

In Fig. 408 the main valve is located at G and is actuated by a pinion at n which meshes with a rack in the neck-bearing n′. The automatic stop-valve is contained within the casing H and is actuated by a rod connecting with a crank-pin on a crank-disk mounted on the shaft with the sprocket-wheel Q, Figs. 408 and 409. The sprocket-wheel Q is rotated by means of a sprocket O mounted on the shaft with sprocket f, Fig. 409, which latter is operated by a chain, the ends of which are affixed to the ends of two square rods, the lower of which is shown at L. Another chain around the sprocket P is connected with the opposite ends of these two rods. To stop the movement of the piston, the stop-valve is actuated to the left. If the traveling sheave is moving toward the cylinder the actuating bar R attached to the crosshead will strike the stop N and move it to the left, which will set up a counter-clockwise rotation of the sheaves O and Q, and this will move the crank-pin and the stop-valve to the left. If the traveling sheave is moving away from the cylinder, the lower end of bar R will strike the stop N on the square rod L and, by carrying the latter to the right, rotate sheaves O and Q counter-clockwise in the same direction. The stops N are hook-shaped; they slide over the side projections on bar R, Fig. 410, and lock with it, with the result that when the elevator is started on the return trip the movement of the crosshead carries the stop N with it, and the automatic stop-valve H is pulled open. When the elevator is started it moves very slowly for a few inches, as only the water that leaks by the automatic stop-valve is available to move it, but as the movement of the

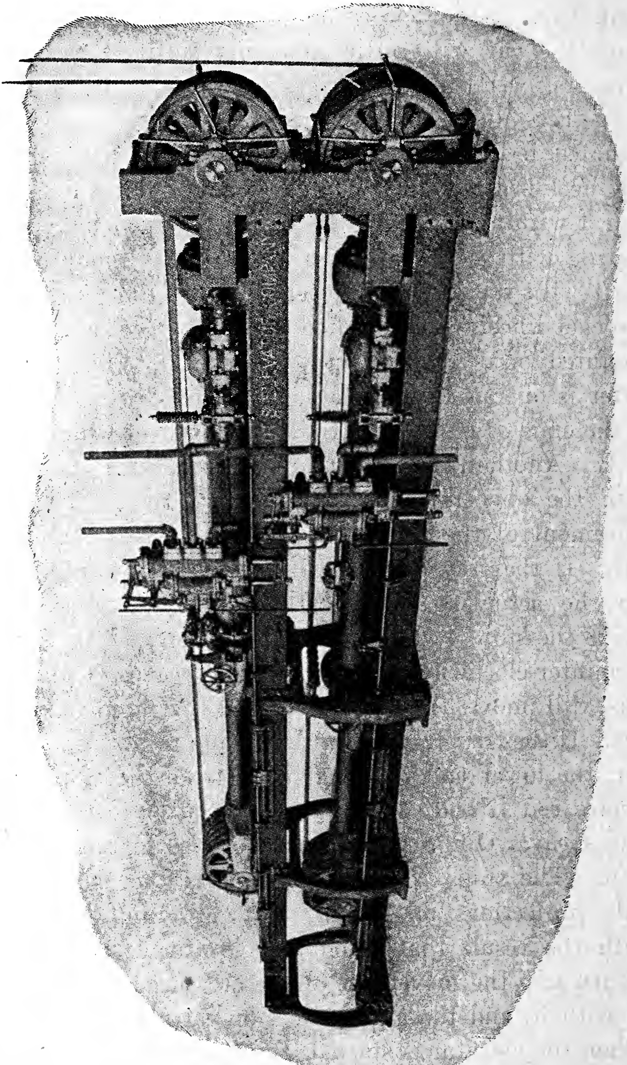


FIG. 411

crosshead also operates the valve, the opening of the latter is rapidly increased and the car speed correspondingly accelerated.

When the bar R has carried the stop N as far as the stop T the releasing lever S strikes the latter and the hook on the stop N is raised so that the bar R may slide by and leave the stop N adjoining the stop T, ready to be struck by the bar R on the next stroke. The actuating stops T are not held on the rod L but on a rod directly in front of it (see Fig. 410), and this rod is secured, so it will not move endwise, in the frame V.

Fig. 411 shows a double-deck arrangement of two separate machines. This grouping of horizontal elevator engines is often resorted to for the purpose of economizing space, the machinery for operating two cars occupying the same floor area as that ordinarily required for one.

High Pressure Elevators.—The types of elevators hitherto discussed belong in the low pressure class, the water pressures used in operating them not exceeding 200 lbs. per square inch, the average being about 150 lbs. But the increase in the height of modern office buildings, and the demand for a high car speed have resulted in the development of high pressure elevators, operating under pressures as high as 700 lbs. per square inch, and even higher in some cases.

The reduction in the size of the machine and piping that can be effected by using this pressure is much greater than would be supposed by those who have not investigated the subject. To give a general idea of how great the reduction actually is, suppose a low-pressure elevator has a cylinder 16 inches in diameter and works with a pressure of 100 pounds. For such a machine the supply pipe would probably be not less than 6 inches in diameter. Substitute for this a high-pressure machine working with 800 pounds pressure per square inch; then, if everything else remains unchanged, the area of the cylinder will be reduced to one-eighth, and this will make the diameter a trifle under 5¾ inches, as compared with the low-pressure cylinder of 16 inches diameter. This is not all the gain that can be made; there can also be effected a great reduction in the size of the supply pipe, for as only one-eighth of the quantity of water is required, the size of the pipe can be reduced to the same degree as that of the cylinder, provided the water is to run through it at the same velocity. This reduction would cut the pipe down from 6 inches to a trifle over 2 inches in diameter.

These reductions are not exactly what would be made in actual practice, because the frictional loss in the small high-pressure cylinder would not be as great as in the large low-pressure cylinder, and the velocity of the water through the supply pipe could be made greater for the same percentage of loss; this would permit a farther reduction in the size of the pipe. In practice the gain in this direction is utilized in part to reduce the size of the apparatus, and in part to reduce the loss of energy in forcing the water through the pipes. As a result, the loss of energy due to the friction of the water passing through the pipes, lifting cylinder and valves is reduced to about 5 or 6 per cent, whereas in low-pressure machines it runs from, say, 10 to 30 per cent. The change of pressure from 100 to 700 or 800 pounds brings about other changes in the construction of the machine and apparatus and also in the general arrangement of the system.

The arrangement of the various parts of a high-pressure system is indicated by the diagram, Fig. 412. This diagram shows a machine geared six to one. The cylinder is shown at C, the plunger at P and the traveling sheaves below it; the cylinder is inverted, the plunger being forced downward by the pressure of the water. This construction is used because the small size of the cylinder makes it impracticable to use a piston and piston-rod, therefore a solid plunger is provided and the pressure acts to push it out of the cylinder.

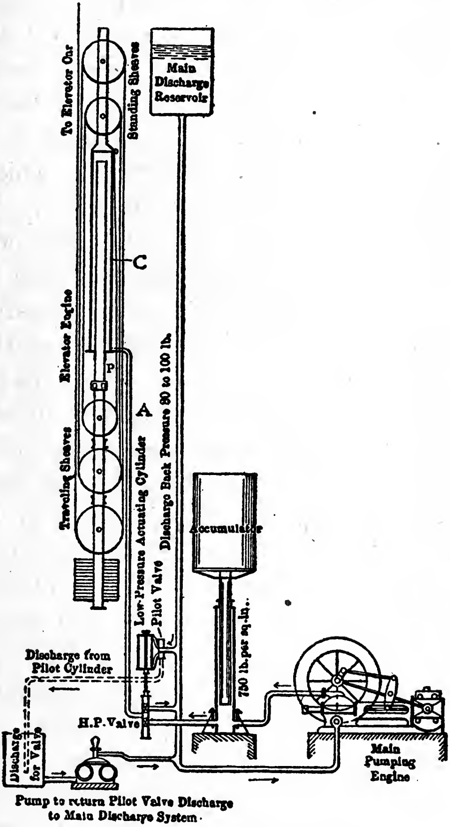


FIG. 412

In Fig. 412 the pump forces water into the lower end of the accumulator, from which a pipe runs to the main valve, through which it passes to the pipe A and thence to the lifting cylinder. On the return stroke the water passes out of the cylinder through the pipe A and through the upper end of the main valve to the discharge pipe, which runs up to a tank placed on or near the roof of the building. The object of this arrangement is to provide a low pressure to operate the pilot valve, which is shown in the diagram just above the main valve. In the first high-pressure elevators made, the pilot valve was operated with water at the same pressure that was used for the lifting cylinder, but these valves were not successful, owing to the fact that they had to be very small and the packings would not withstand the wear due to the pinhead jets of water striking them at terrific velocities; in addition, the small holes through which the water passed were soon enlarged so that the valve would not work satisfactorily. With the low-pressure pilot valve there is no trouble. A small tank is provided to receive the discharge from the pilot valve and its actuating cylinder, and this water is returned to the roof tank by means of a small pump as shown in Fig. 412.

The Accumulator.—The accumulator takes the place of the pressure tank of the low-pressure system. A pressure tank cannot be used with the high-pressure system, owing to the fact that it is troublesome and expensive to pump air against a high pressure, and it is necessary to do this so as to replenish the air that gradually leaks out of the pressure tank. Even if there were no difficulty in pumping air into a high-pressure tank, the accumulator would be preferable, because with it the pressure depends upon the weight on top of the plunger, not on the height of the water in the cylinder. With a pressure tank the pressure drops as soon as water is drawn out, and it runs up as soon as the outflow stops, consequently the pressure is continually varying.

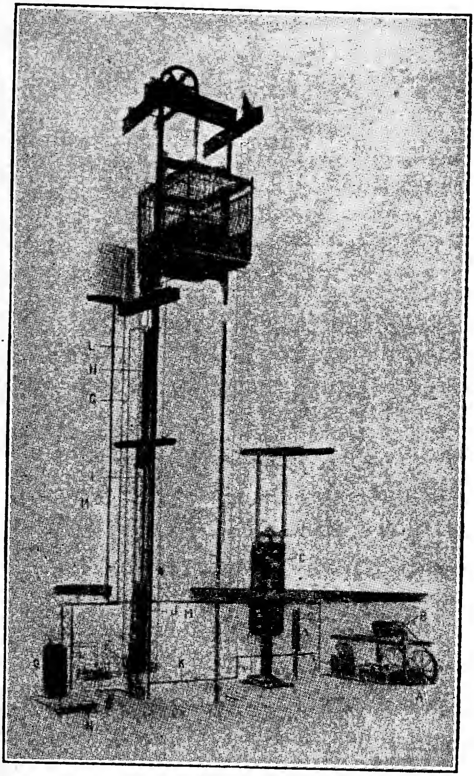


FIG. 413

The arrangement of the entire apparatus of an Otis high-pressure vertical elevator is shown in Fig. 413. This illustration shows several parts not represented in the elementary diagram, Fig. 412. The main pump is at A and at B is shown the prime mover, which in this case is an electric motor, although in practice steam power is almost always used. The accumulator is shown at C and the main valve, and pilot valve are at D. From the main valve the water passes to the lifting cylinder through pipe E, passing first through an automatic stop-valve F, thence through pipe G to cylinder H. The plunger is shown at I, and the traveling sheaves at J.

The high-pressure water from the accumulator reaches the main valve through pipe K and is discharged from the valve through pipe L which runs up to the tank at the top of the building. Through pipe M, the water returns to the pump A. An air chamber is provided at Q to smooth out any pulsations of the pump that its own air chamber does not subdue. The small pump to return the water discharged from the pilot valve to the roof tank is also shown.

It will be noticed in Fig. 413 that the machine proper of a vertical high-pressure elevator is not very elaborate.

Fig. 414 shows a sectional, and also a plan view of the main and pilot valves.

The pilot valve is at A, and the main valve at C; B is a motor cylinder, the piston of which moves the main valve. In this construction, the pilot valve is not much smaller in diameter than the main valve, and the motor piston is very much larger than the main valve. The difference in the proportions of these parts as compared with the valves described in connection with low-pressure machines is due to the fact that in the high-pressure system the motor piston is actuated by low-pressure water, so a to make it possible to use a pilot valve of large enoug size to be durable. As is shown in Fig. 413, the tank int which the lifting cylinder discharges is placed high enoug to give enough pressure to operate the motor piston, and from this tank water passes through the pilot valve A to the cylinder B. If the motor piston were operated by the high-pressure water, the pilot valve and its port holes would have to be so small that the parts could not be made sufficiently substantial. For this reason water at a pressure of about 80 pounds per square inch is used to operate the motor piston.

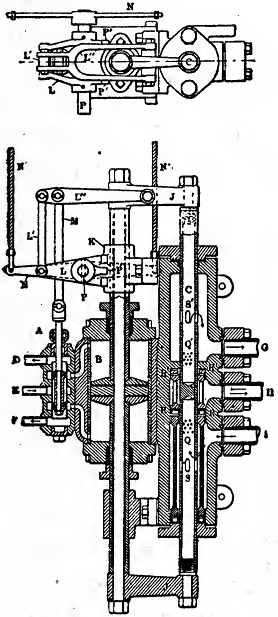


Fig. 414

It might be thought that having to discharge the water in the lifting cylinder against a back pressure of 80 pounds would cause considerable loss, and make the high-pressure system objectionable on the score of low efficiency, but this is not the case because the main pump draws water from this same discharge tank; therefore, the back pressure against the lifting cylinder acts to help the pump, so that in reality all the work the pump has to do is to force water against a pressure equal to the difference between the pressure of the accumulator and that of the discharge tank. The net result is that if the accumulator pressure is 750 pounds, and that of the discharge tank is 80 pounds, the actual pressure against which the pump acts is 750—80 =670 pounds, and the pressure that acts in the lifting cylinder to raise the elevator car is 670 pounds, not taking into account the losses due to friction of the water through the pipes and valves on its way from the accumulator to the cylinder.

Operation of Main and Pilot Valves.—The operation of the main and pilot valve in Fig. 414 is as follows: If the operator desires to run the car upward he moves the car lever so as to pull up the rope N′ on the right side, thus tilting the rock lever N in a counter-clockwise direction. The levers N and L are secured to the shaft P; hence, the end of L will move down and through the connecting rod L′ will pull down the lever L″; and the latter, through M, will depress the pilot valve. The center pipe E is connected with the upper discharge tank; hence, water will flow in and through the lower end of the pilot-valve chamber, pass to the lower end of the motor-piston cylinder B, and raise the piston, the water above the latter passing out into the pilot-valve chamber above the valve, and thence to the pipe D. As the motor-piston rod is connected at both ends by arms J J with the ends of the main valve C, the upward movement of the piston will lift the main valve, and then the water from the accumulator coming through the pipe I will pass into the center of the main valve through the port S. The port Q will be above the packing R, so that the water will pass out into the central pipe H and thence to the lifting cylinder, and by pushing the plunger out of the latter will lift the elevator car. If the rock lever N is tilted in the opposite direction, the pilot valve will be raised, and then water will pass to the upper end of the motor cylinder and depress the piston, thus moving the main valve down so that the water in the lifting cylinder may escape through the ports Q′ into the upper end of the main valve and thence through the ports S′ to the upper discharge pipe G; from there it passes to the discharge tank near the top of the building.

Cylinder and Plunger.—Figs. 415 and 416 show the construction of the plunger, cylinder, and sheaves of the Otis high pressure vertical cylinder elevator.

Fig. 415 gives external and sectional views of the cylinder, the upper end of which is seen at A and the lower end at B. To shorten up the drawing the cylinder is broken at C C. The plunger is indicated by D. Above the cylinder are shown the stationary sheaves held between side frames made of channel iron G, to the lower end of which the cylinder is bolted, as shown at G′. The channel frames G are bolted to a rod H at the upper end, and this is held between beams I that are secured to the wall or floor framing of the building. The traveling sheaves are carried in a crosshead attached to the lower end F of the plunger.

The internal construction of the cylinder is shown in the vertical section, which is taken at right angles to the exterior view. The upper end of this drawing shows the way in which the bearings of the stationary sheaves are held between the side frame channel beams G G, and in like manner the lower end shows the construction of the cap F that forms the end of the plunger and the support

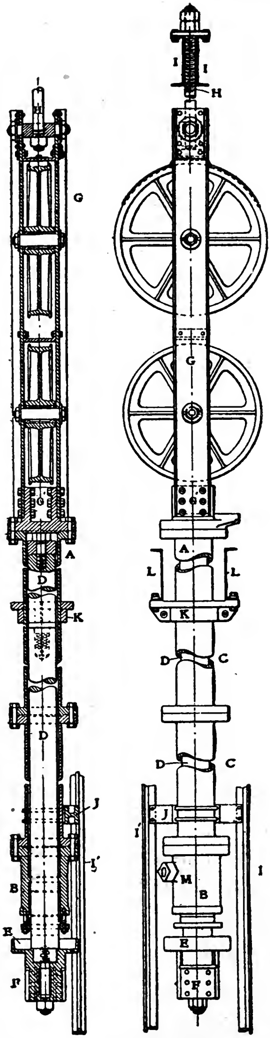


FIG. 415

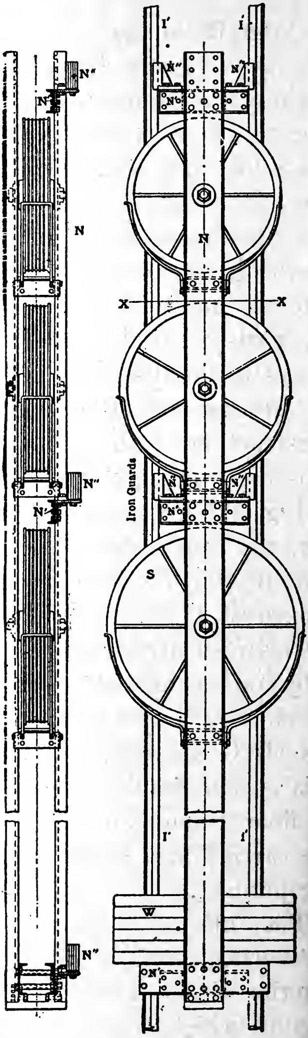


FIG. 416

for the traveling-sheave frame. This cap is constructed cup-shaped on its upper side to receive the drip from the cylinder. The plunger, it will be noticed, does not fit the cylinder throughout its entire length, but only for a short distance at the lower end, where the stuffing-box is located. The cylinder is held up by the rod H, and is sustained against side displacement by means of one or more rings K and the frame J, the construction of both of which can be readily understood from the drawings.

The outlet M in Fig. 415 is the pipe connection through which the actuating water enters and passes out of the cylinder. T-bars I′ I′ to which the frame J is bolted form the guides for the crosshead of the traveling sheaves, and the cylinder is held true with these by means of the frame J so as to keep the plunger and the crosshead guides in line.

Fig. 416 shows side, and edge views of the crosshead, the guides, and the traveling sheaves.

Fig. 417 shows the speed regulator used in connection with the Otis high pressure type of elevator. This device will not allow the car to attain an excessively high speed under any conditions, for the reason that it depends for its action upon the velocity of the current of water passing through it, and not upon the pressure. The device is connected in the piping so that the water that flows into or out of the lifting cylinder passes through it. If, when the car is ascending, the water enters through port, C, and passes out through D, then on the descending trip the water will enter through D and pass out through C. In either case, the water will have to pass through the openings, E, in the valve piston, this passage causing a certain amount of loss in pressure dependent entirely upon the velocity of the water through the holes, E.

Suppose that, when the car is running at 400 feet per minute, the loss of pressure suffered by the water in

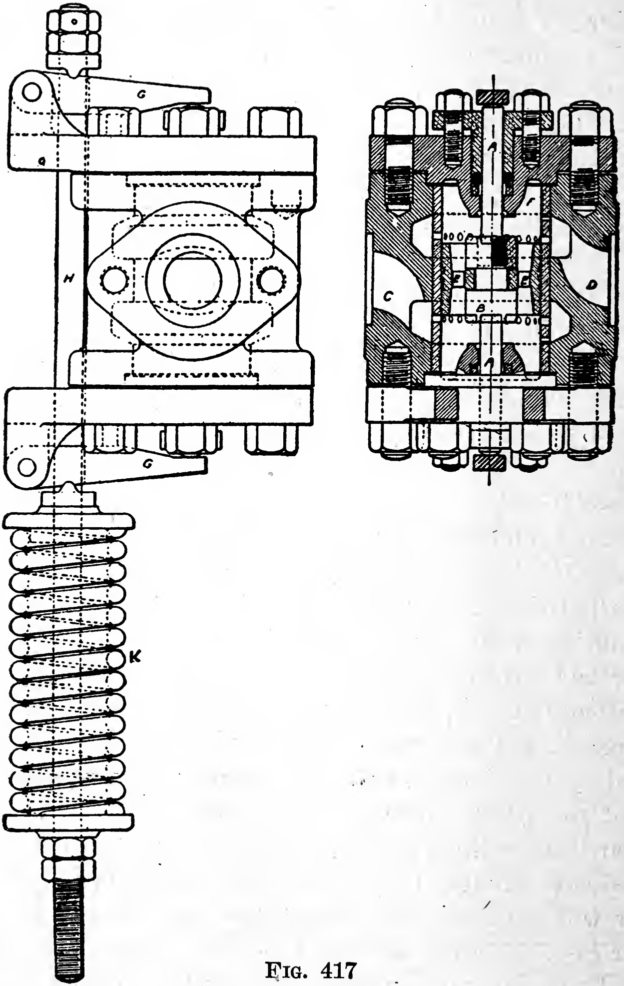


FIG. 417

passing through the piston holes, E, is 20 pounds; then, if the car is running up, and the pressure of the water when it reaches one side of B is 800 pounds, it will be, on the other side, 780 pounds. If the car is running down and the water is discharging into the delivery tank, a pressure of 100 pounds on the cylinder side of B will correspond to 80 pounds on the tank side of B; that is to say, in either case the difference in pressure between the two sides of B will be 20 pounds.

From the construction of the device, it will be seen that the force with which the piston rod, A, is moved endwise by the difference in the pressure on the opposite sides of B is resisted by the spring, K, so that by properly adjusting this spring, the car can be made to run at any desired speed with the main valve wide open, regardless of the magnitude of the load or whether it is running up or down. Thus it will be seen that, when this speed regulator is provided, the car cannot attain an excessive velocity, even if the operator becomes confused and opens the main valve too wide.

In passing from either of the inlets, C or D, into the interior of the cylinder, the water must flow through the small holes in the casing, F. These holes are drilled on spiral lines so that, when B moves in either direction, it covers the holes one at a time, thus gradually closing the outlet. The end movement of B is transmitted to one, or the other of the levers, G, through rod, A, and the movement of either lever will compress spring, K.

Direct Acting Plunger Type.—A direct acting plunger elevator consists of a cylinder set vertically in the ground directly under the car, and of length a few feet greater than the travel of the elevator car. In this cylinder is a plunger of the same length, carrying a car on its upper end. The bottom of the plunger is supported by an incompressible body of water, and the car cannot descend faster than the water is forced out.

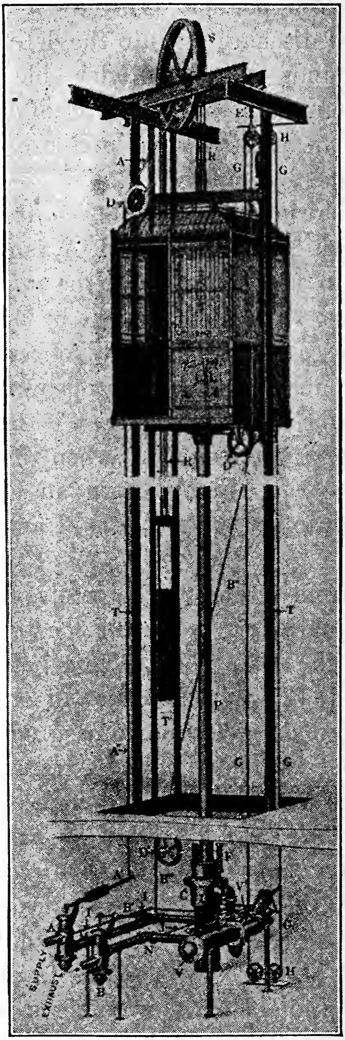


Fig. 418

DIRECT ACTING PLUNGER ELEVATOR

The success of this elevator depends largely upon the merits of the operating mechanism. In the installation of this type of hydraulic elevator it is necessary to sink the hole for the reception of the cylinder to a depth equal to the height of the building. Fig. 418 shows the general arrangement of the Otis direct acting plunger elevator. This illustration is broken at a point between the elevator car and the bottom of the elevator shaft in order to reduce its length, but the part broken away would only show the continuation of the guides, plunger, operating ropes, etc.; all the operating parts of the outfit are shown in the illustration.

In plunger elevators, as the full pressure on the end of the plunger acts to lift the car, the diameter of the plunger is much smaller than in the geared types of elevators. The pressure used varies from about 140, to 200 pounds per square inch and the diameter of the plunger may be from 5 to 7 inches. The cylinder is made of steel pipe about 2 inches larger in diameter than the plunger, and the hole in the ground is a couple of inches larger than the cylinder. It will thus be seen that the hole in which the cylinder is placed is not very large, so that it can be bored in a manner similar to that employed for driving pipe wells. If the subsoil is earth, a steel pipe lining is provided which is large enough to receive the cylinder. If the hole is drilled in rock, no lining is required.

For the cylinder, a number of lengths of steel pipe are turned true on the ends, threaded in a lathe, and joined by sleeve couplings. The upper end of the cylinder is screwed into a cast-iron section which is bored to fit the plunger, and is provided with a stuffing-box and a pipe connection through which the water enters and passes out of the cylinder. The lower end of the cylinder is closed by means of a suitable cap. The cylinder is coated with a protecting paint and when in position, the space between it and the sides of the hole is filled with sand.

For the plunger, a number of lengths of steel pipe are turned true and well polished. The sections are joined by means of long internal sleeves which are so proportioned that the transverse strength of the plunger at the joint is as strong as at any other point.

As the elevator car can rise only as high as the plunger travels, it follows that when the rise is 300 feet, the cylinder must extend down into the earth several feet more than 300, because when the car is at the top of the elevator hatchway the bottom end of the plunger must be some distance below the top end of the cylinder. Furthermore, it is necessary to provide sufficient length of plunger to carry the car a short distance above the upper floor, say, two feet, in order to avoid running the bottom of the plunger too high up in the cylinder if the elevator should overrun the upper limit of travel.

The plunger passes through a stuffing-box at the upper end of the cylinder, and is provided with guide shoes at the lower end to keep it in line and central.

Referring to Fig. 418, the car rests upon the upper end of the plunger P, and the latter runs down into the cylinder C, the upper end of which projects above the ground floor. From the top of the car a number of cables R extend upward and over a sheave S and thence down to a counterbalance W. This counterbalance serves to reduce the pressure required to raise the elevator, and also to reduce the compression stress to which the plunger is subjected.

The pipe of which the plunger is made weighs about 22 pounds per foot, so that a plunger 200 feet long will weigh about 4,400 pounds; this is more than the car is likely to weigh, the latter ranging between 3,000 and 4,000 pounds. If the car weighs, say, 3,600 pounds, and the plunger 4,400 pounds, the two combined will weigh 8,000 pounds, and with no counterbalance this weight would have to be raised in addition to the load. Consequently the plunger would be subjected to a compression stress of 3,600 pounds plus the load at the upper end, and 8,000 pounds plus the load at the bottom, the stress increasing from top downward at the rate of 22 pounds per foot. With a counterbalance weighing 5,000 pounds, the weight raised will be reduced to 3,000 pounds plus the load, and as the counterbalance exceeds the weight of the car by 1,400 pounds, it will actually hold up about one-third of the plunger, from the upper end downward, when the car is empty.

When the car is at the bottom of the shaft the plunger is immersed in the water in the cylinder, consequently a portion of its weight is balanced by the water it displaces. When the car is at the top of the shaft the plunger is out in the air and its weight is not counterbalanced to any extent by the water. This being the case, the weight lifted will be less when the car is at the bottom of its travel than when at the top, the difference being equal to the weight of water displaced by the plunger. By properly proportioning the weight of the cables R, the load lifted can be made equal at all points, for when the car is at the bottom of the shaft these cables will hang above the car, and thus will offset a portion of the counterbalance W, while when the car is at the top of the shaft the cables will hang above the counterbalance W and balance a portion of the weight of the car.

The main valve for controlling the movement of the car is shown at V, and the pilot valve at V′. The two valves A and B are the automatic stop or limit valves, A being the top limit and B the bottom. The valve A is actuated by the rope A″ which pulls up the lever A′ and thereby closes the valve. This rope moves the lever A′ through the motion of the elevator car. Looking at the illustration, it will be seen that the rope A″ runs over a sheave D mounted on top of the elevator car, and it can also be seen that when the car approaches the upper limit of travel, D begins to put a bend in A″ and thereby draws up the lever A′; by the time the car reaches the upper floor, A′ will be raised enough to close the valve A. By this arrangement the valve is closed gradually and the car is as gradually brought to a state of rest.

The valve B is actuated by the rope B″ in precisely the same manner that A is operated by the rope A″. The rope B″ passes over the stationary sheave D′ and under the sheave D″ located under the car, and when the latter descends near enough to the lower floor, the bend put in the rope B″ by the sheave D″ will raise the lever B′ and gradually close the valve B.

The pressure water enters through the valve A; hence, at the top landing the automatic stop arrests the movement of the car by shutting off the supply water. When the elevator car descends, the discharge water passes out through the valve B; hence, the bottom limit valve stops the descent of the car by stopping the escape of water from the cylinder.

Construction of Cylinder.—The construction of the upper end of the cylinder is shown in Fig. 419. This drawing, which is a vertical sectional elevation of the top of the cylinder and plunger, also shows the way in which the plunger is fastened to the under side of the car, as well as the construction of the plunger. For the purpose of

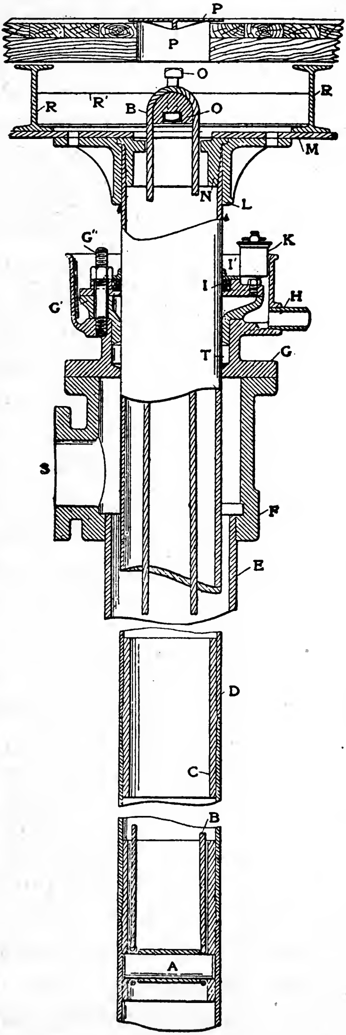


FIG. 419

reinforcing the plunger, a steel cable B is strung inside, both of its ends fastened to a pin A, located some distance below the center of the plunger, and the loop or bight, at the top of the plunger, is passed around a tightening block O; this block is arranged so as to be drawn up by the bolts O′ to put the desired tension on the rope B. The plunger D is made of as many lengths of piping of the proper size as may be necessary, these being connected by means of long internal sleeves C. The plunger sections are turned true and highly polished, and the screw threads at the ends are made with great accuracy, so as to hold the sections in perfect alignment when connected. The threads are also made extra long, so that the joints may be as strong as the other parts of the pipe. For the purpose of making the pipe sections come together perfectly central when joined, the center portion of the sleeve is turned true, and the ends of the pipe are bored to fit this portion; when the parts are screwed up, the turned central portion of the sleeve slides into the bored-out ends of the pipes and brings them into line, so that there is no point around the joint where one part projects over the other.

The top of the cylinder is finished off with a casting F screwed to the top of the upper section of the cylinder barrel E. On top of the cylinder cap F is mounted a stuffing-box casting G, containing the usual packing space T and fitted with a gland G′. The latter is constructed so as to form a space surrounding the plunger to hold oil which is fed in from the oil cup K. Above this oil reservoir is a recess in which babbitt metal wiping rings I are placed for the purpose of scraping the oil off the plunger as it moves up, and retaining it in the space in gland G′. In Fig. 418 it will be noticed that buffers F are provided for the car to rest upon when at the lower floor. Similar buffers are also provided for the counterbalance W to rest upon, this to prevent running the car up against the overhead beams. The construction of the car buffers is shown in Fig. 420, which is an external view of the upper end of the cylinder taken at right angles to Fig. 419. The buffer consists of a plunger P made of pipe, provided with a cast cap P′ and a rubber cushion P″. The plunger P slides within a cylinder C, also made of pipe. Within this cylinder there is a spring that is compressed by the plunger, the lower end of the latter being provided with a flat head to press against the top of the spring. The cylinder C is held in position by a side extension F, formed on the top cylinder casting F. The nuts F′ F″ are screwed on the

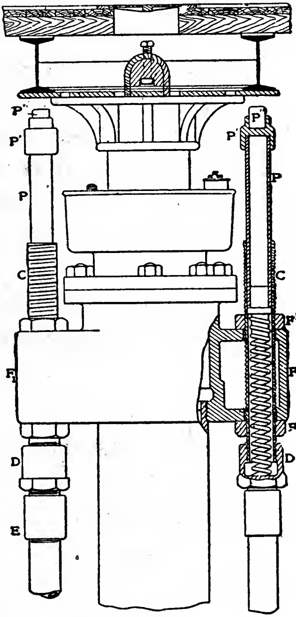


Fig. 420

cylinder C, the latter being threaded, and by this means the height of the buffer is adjusted. To furnish additional support, so that the buffer may not be pushed down, and the thread of the nut F′ stripped if the car should come down unusually hard, a pipe extension E is provided, extending down to the floor, or some other firm support. These buffers are set so as to be struck and compressed every time the car comes down to the lower floor, acting to stop the motion gradually. If the car descends at the normal speed, the buffer is compressed slightly, just a trifle more than is necessary to hold the unbalanced portion of the weight of the car, but if the car speed in approaching the floor is excessive, the buffers will be compressed farther, and the car will run a few inches below the floor.

Boiler Power for Elevators.—The following very able discussion of this subject is presented by Charles L. Hubbard in *Power*:

"The power necessary to operate an elevator depends upon its size, the method of construction and counterbalancing, the speed, and the efficiency. Placing these conditions in the form of an equation:

$$H.P. \frac{(W+u)S}{e\times 33,000}$$

in which

W=weight of *live load,*
u=unbalanced weight of car,
S=speed in feet per minute,
e=efficiency.

The elevators in most general use for passenger service are of the hydraulic and electric types; for freight work, some steam and belted elevators are in commission, the latter being connected directly with the line shaft in shops and factories. The general method of computing the power is the same for both hydraulic and electric elevators, although they differ to some extent in detail, making it advisable to consider them separately.

The live load for a passenger elevator is usually figured on a basis of from 60 to 80 pounds per square foot of floor space, and the weight of the elevator itself from 100 to 125 pounds per square foot, which also includes the safety device. These figures will be found ample for cars of ordinary construction, but may be exceeded somewhat in the case of metal cars of especially massive design.

Hydraulic Elevators.—It is common practice with elevators of this type to counterbalance up to about three-fourths of the weight of the car. The speed varies from, say 200, to 600 feet per minute, 400 feet being about the average for office buildings of medium size. The efficiency is in the vicinity of 60 per cent.

In computing the boiler power, it is usually assumed that probably all of the elevators will not be running at one time at their maximum capacity; it must be remembered also that power is required only on the upward trip, as the weight of the car causes it to descend under the control of a suitable braking device. When there is no definite information at hand, it is customary to compute the power necessary to operate all of the elevators at one time under full load, and base the boiler power on two-thirds of this result.

Example.—An office building has four hydraulic elevators, each having a floor space of 30 square feet. What boiler power should be provided, using the following average data: Live load, 70 pounds per square foot of floor space; weight of elevator, 100 pounds per square foot of floor space; speed, 400 feet per minute; efficiency, 60 per cent; steam consumption of pumps, 65 pounds per hour per horse-power.

From the foregoing,

$$W=30\times 70\times 3=6300;$$

$$u=30\times 100\times 3\times 0.25=2250.$$

Then for a continuous upward movement with a full load the required horse-power would be:

$$\frac{(6300+2250)\ 400}{0.60\times 33{,}000}=172 \text{ horse-power.}$$

but, of course, under actual conditions one-half of the time is occupied by the downward trips, and the power required is therefore only one-half of this, or 86 horse-power. Making allowance for stops at the various floors and for the time that part of the elevators are idle, it may be assumed that it will be sufficient to provide for 70 per cent of the full time, or 0.70×86=60 horse-power. The steam consumption under the conditions stated would be 60×65=3,900 pounds per hour.

Assuming 30 pounds of steam per boiler horse-power, which may be taken with sufficient accuracy when the pressure and feed-water temperature are not given, the required boiler horse-power will be 3,900÷30=130. The boiler horse-power required for running a pump is computed in a similar manner to that for an engine.

The rating, or capacity of a pump, however, is usually expressed in gallons of water per minute raised to a given height, instead of horse-power, as in the case of an engine.

The weight of water in pounds per minute multiplied by the height in feet to which it is raised, divided by 33,000, will give the useful, or delivered work of the pump in horse-power. The friction of the water flowing through the passages and valves is so great under ordinary working conditions that not much more than 50 per cent of the indicated horse-power of the steam cylinders is represented by the net useful work. This calls for a large amount of steam in proportion to the work done, as shown by the table herewith, which gives the average steam consumption of the ordinary duplex pump.

TABLE SHOWING AVERAGE STEAM CONSUMPTION OF DUPLEX PUMPS.

Type of Pnmp	Pounds of Steam per hour per delivered horse-power
Simple non-condensing	120
Compound non-condensing	65
Triple non-condensing	40
High-duty non-condensing	30

The head against which a pump works is the vertical distance between the surface of the water in the suction reservoir and that in the discharge reservoir. If the pump is delivering against a pressure, as in feeding a boiler, the pressure may be reduced to "feet head," by dividing the pressure per square inch by 0.43.

Electric Elevators.—The type of electric elevators mostly used is the drum. The speeds at which this type commonly runs may be taken as 300 and 500 feet per minute, respectively, for single, and double-drum machines; for regular work, speeds above 400 feet are not usually found necessary for the average building.

So far as the necessary power is concerned, the single drum and duplex machines may be considered together. The efficiency of these is ordinarily from 50 to 70 per cent, although theoretically the former is the more efficient type. In practice it is not customary to count on much more than 50 per cent, which gives results on the side of safety.

The method of balancing the electric elevators of the drum type differs from that applied to the hydraulic, in that the entire weight of the car plus from 40 to 50 per cent of the maximum live load is counterbalanced. From this it is evident that with no load the power required to pull the car down is that necessary to raise the excess counter-weight, which may be taken as equal to one-half the maximum live load, and to overcome the friction of the machine. When the car is half loaded it is balanced, and the power required is that to overcome friction only. At full load the conditions are the same as for an empty car, except the power is required during the upward trip instead of the downward. It is evident that power may be required for both the upward and downward trips, depending upon the number of people in the car, but it will never be as great at any one time as in the case of the hydraulic elevator.

Example.—Taking the same conditions as in the preceding example, what boiler power will be required to operate electric elevators of the drum type, having an efficiency of 50 per cent and a speed of 300 feet per minute?

In this case u, the unbalanced weight of the car, disappears, and the maximum live load is equal to only one-half the weight of the people in the car, the other half being counter-balanced, so that:

$$W=30\times70\times3\times0.5=3150 \text{ pounds,}$$

from which

$$H.P.\frac{3150\times300}{0.50\times33,000}=57.$$

If the full load was carried on both upward and downward trips, or sufficient of it on the downward trip to overbalance the counter-weight and the friction of the car, the conditions would be the same as in the case of the hydraulic elevator, that is, power would only be required on the upward trip.

This condition, however, does not hold, especially in the case of office buildings, where during the morning hours the maximum loads are on the upward trips, with empty or nearly empty cars coming down. Under these conditions the power is practically the same on both trips, owing to the necessity of raising the counter-weight when the car is descending. This makes it necessary to treat the problem the same as though the machine were raising a continuous load.

Assuming, as before, that a certain amount of time is required for passengers to enter and leave the car, and that all of the cars will not be running at one time, we may take 70 per cent of the above, or $57 \times 0.7 = 40$, as the maximum horse-power to be delivered continuously by the motor.

Assuming efficiencies of 80, 90 and 85 per cent for the motor, generator and engine, respectively, the required indicated horse-power of the engine will be

$$\frac{40}{0.80 \times 0.90 \times 0.85} = 62 \text{ horse-power.}$$

The boiler power will, of course, depend upon the water ate of the engine. Assuming that a simple non-condensng engine is employed, requiring 30 pounds of steam per ndicated horse-power per hour, the boiler power will be ractically the same as that of the engine, that is, 62 orse-power. The power required to operate duplex elevators is practically the same, except a higher speed may be allowed."

The method of balancing a screw machine is practically the same as for the hydraulic type. The efficiency of this machine may be taken as about 70 per cent. The horsepower for driving elevators of this type is calculated the same as for the hydraulic, except for the higher efficiency. After the power of the motor has been computed, the boiler power may be determined as in the preceding example.

Freight elevators are computed in the same way, except they are run at lower speeds, and are built especially to carry the desired load in each particular case. When applying these methods of computation to any particular case, the engineer should obtain all the data possible regarding the type of machine to be used, the probable speed, efficiency, etc., before proceeding; but if any of the data are lacking, the average figures already given may be used with approximate results.

QUESTIONS AND ANSWERS.

661. What are the essential parts of the Otis traction elevator?

Ans. A traction motor driving sheave, and a pair of electrically released brake shoes.

662. What type of electric motor is used in the Otis traction elevator?

Ans. A slow speed shunt-wound motor.

663. What is the principal function of the armature shaft besides carrying the armature?

Ans. To support the load.

664. How, then, is the drum, or sheave driven?

Ans. By means of projecting arms from the armature, that engage with similar arms projecting from the drum.

665. Describe the system of safety devices with which this elevator is equipped?

Ans. There are two groups of switches located respectively at top and bottom of the shaft, each switch in series being opened one after the other by the car as it passes. This retards the speed and finally brings the car to stop, applying the brake, independent of the operator in car.

666. Are there any other safeties besides this?

Ans. Yes—speed governors, wedge clamps for gripping the guides, and potential switches.

667. Describe in general terms the construction of the Otis geared traction elevator?

Ans. A multi-grooved driving sheave around which the cable works. The sheave is mounted upon a shaft driven by geared wheels actuated by a right and left hand worm cut on the armature shaft.

668. What advantage is gained by the use of the double screw, or worm?

Ans. The elimination of all end thrust.

669. With what kind of brake is this machine equipped?

Ans. A mechanically applied, and electrically released brake.

670. What type of motor is used?

Ans. Compound-wound—speed 800 R. P. M.

671. When is the series field of this motor used?

Ans. Only at starting.

672. Why?

Ans. To obtain a highly saturated field in the shortest possible time.

673. How is a gradual slowing down of speed of car obtained with this elevator?

Ans. By throwing a low resistance field across the armature, thus providing a dynamic brake action.

674. What kind of current is used for operating electric elevators?

Ans. Either alternating, or direct current.

675. How is the transmission of current to the motor of an electric elevator controlled?

Ans. By means of an electric magnet controller operated through the switch in the car.

676. How may considerable power be wasted in the operation of electric elevators?

Ans. By careless handling—making unnecessary stops and starts, or too sudden stops or starts.

677. Briefly, of what does the mechanism of a hydraulic elevator consist?

Ans. A cylinder and piston with one or more rods connected to a crosshead which carries the sheaves over which run the lifting cables from which the car is suspended.

678. What moves this piston?

Ans. Water under pressure admitted by means of suitable valves causes the piston to move from one end of the cylinder to the other, and back again.

679. How is this motion transmitted to the elevator car?

Ans. By means of the sheaves mounted on the crosshead which carry the lifting cables.

680. In what position is the cylinder placed?

Ans. Either vertical alongside the hatchway, or horizontal in the basement of the building.

681. How are the valves of a hydraulic elevator operated?

Ans. In some cases by a hand rope passing through the car and over small sheaves at the top and bottom of the hatchway, and connected with the main valve in the basement. By pulling this rope down the valve is opened, and the car will ascend, while pulling the rope up will cause the car to descend.

682. What safety devices are attached to this type of elevator?

Ans. Two balls are attached to the hand rope, one near the bottom, and the other near the top. These balls come in contact with the top, or bottom of the car, according as it is going up or coming down, and being carried along they, of course move the cable, thus actuating the valve, bringing the car to a stop.

683. Is this device safe, and automatic?

Ans. It is.

684. Mention another safety device connected with hydraulic elevators.

Ans. Safety clamps under the control of a speed limit centrifugal governor which causes the clamps to grip the guides and thus hold the car.

685. How is this safety governor operated?

Ans. By means of a small cable connected with the car and moving with it, which passes over the sheave pulley of the governor.

686. Why are some elevator pistons fitted with two piston rods?

Ans. To prevent the piston, and crosshead from turning or twisting, and also to strengthen the construction.

687. What other methods are used for manipulating the water valve, besides the one already described?

Ans. Running ropes, and standing ropes, either of which may be operated by means of a lever, or wheel in the car.

688. Do these devices directly operate the main valve?

Ans. No. They operate a small valve called the pilot valve.

689. What is the function of the pilot valve?

Ans. When opened it admits the pressure water to a small cylinder with piston connected to the main valve stem. This actuates the main valve, which in turn, by its movement, closes the pilot valve.

690. Upon what does the amount of opening given the pilot valve, and consequently the main valve depend?

Ans. Upon the distance the lever in the car is moved from central position.

691. What is meant by central position of lever?

Ans. That position in which there is no flow of water either into or out of the cylinder, and the car is moving only by its momentum.

692. What is the result of moving the lever too quickly to central position when the car is moving at a high rate of speed?

Ans. The motion of the car will be arrested with a sudden jerk.

693. How many kinds of horizontal hydraulic elevators are in use?

Ans. Two. One is the pushing, and the other the pulling type.

694. Describe the action of the pushing type?

Ans. The car being at the bottom, the pressure water is admitted behind the piston which then moves, pushing the crosshead and cable sheave and lifting the car.

695. Describe the action of the pulling type?

Ans. It is the opposite of that just described.

696. Is there much difference in the valve mechanism of the horizontal, and vertical types of hydraulic elevators?

Ans. Very little except a few minor details.

697. What is meant by a double-deck machine?

Ans. Where the floor space is restricted two, and sometimes three or four machines are mounted one above the other.

698. What water pressure is usually carried in operating the types of hydraulic elevators that have hitherto been described?

Ans. Pressures not exceeding 200 lbs., the average being 150 lbs. per square inch.

699. Are any higher pressures than this being used for operating hydraulic elevators?

Ans. Yes. Pressures of 700 to 800 lbs. and higher.

700. Why are such high pressures used?

Ans. Owing to increased height of buildings, and the demand for high car speed.

701. What advantage, other than high speed, is gained by the use of high pressure elevators?

Ans. A reduction in the size of the valve mechanism, piston areas and piping.

702. Mention another advantage in connection with the high pressure system?

Ans. A reduction in the loss by friction of the water passing through the pipes, owing to reduced areas.

703. What is the percentage of loss due to this cause?

Ans. In low pressure machines from 10 to 30 per cent, and in high pressure machines from 5 to 6 per cent.

704. Describe in general terms the construction of the cylinder and piston of a high pressure machine.

Ans. The cylinder area is reduced to about one-eighth that of the low pressure type, and the piston is a solid plunger.

705. How is the pressure maintained?

Ans. The pump forces water into the lower end of the accumulator, an air-tight tank, which is also weighted. From the accumulator a pipe runs to the main valve.

706. Describe in general terms the construction and operation of the direct-acting plunger elevator.

Ans. A cylinder is set vertically in the ground under the center of the car, and the length of it is slightly greater than the travel of the car. In this cylinder is a plunger of the same length, which carries the car. Water under pressure is forced into the cylinder and thus lifts the car, and allowed to run out at the top when the car descends. The cylinder is about two inches larger in diameter than the plunger, and is always full of water.

707. What is the usual diameter of the plunger?

Ans. 6½ to 7 inches.

708. How is it constructed?

Ans. Of lengths of highly polished steel pipe, joined together with an internal sleeve, and having its lower end closed.

709. What pressure is ordinarily used on this type of elevator?

Ans. 150 to 200 lbs. per square inch.

710. How is the top of the cylinder arranged?

Ans. With a packing gland through which the plunger moves up and down.

711. What types of elevators are in general use for passenger service?

Ans. Electric and hydraulic.

712. How is the capacity of a pump usually expressed?

Ans. In gallons of water per minute raised to a given height.

713. What is meant by the head under which a pump works?

Ans. The vertical distance between the surface of the water in the suction reservoir, and that in the discharge reservoir.

Electricity for Engineers

Electricity is an invisible agent, the exact nature of which is not very well known, although the laws governing its action, the methods of controlling it, and the effects produced by it are becoming well known. It is necessary to assume in the start that it is of such a nature as to be susceptible of possessing quantity. We may, and do use terms to designate definite and definable quantities of electricity without being able to say just what is meant by the word itself. For instance, referring to an electric current, it is the transfer of definite quantities of electricity along a conductor, just as in a current of water, gallons, or cubic feet are transferred through a pipe. But, the idea of large quantities of electricity being stored up in receptacles for future use, in a similar manner to water, cannot be followed except in a limited sense, as for instance, in the case of storage batteries. One of the most, if not the most important generalizations ever made in physical science is the doctrine of the conservation of energy, or as it is sometimes called, the doctrine of the indestructibility of energy. This doctrine teaches that the total quantity of the energy in the universe is unalterable; that is, if energy is expended or disappears in one form, it must reappear in another form. A simple analogy will serve to make this matter plain: Suppose a man, by means of a rope passing over a pulley, raises a 100-pound weight one foot above the surface of the earth, which means 100 foot pounds of work, or energy. Now, the man has exerted, or put forth that amount of energy, and so far as he is concerned, he no longer possesses it. Apparently it has been blotted out of existence—annihilated. But this annihilation is only apparent for the reason that energy is capable of existing in two forms, viz., kinetic, and potential or stored energy. While the muscular force of the man is being expended in actually doing work raising the 100-pound weight, it is in a condition called kinetic energy. While the weight is held in position at a distance of one foot above the earth, it is producing a stress, or pull on the rope, and is in the condition of stored or potential energy. If the rope is suddenly loosed, the weight will descend, and during this descent will put forth an amount of kinetic energy exactly equal to the 100 pounds of work or energy that was expended in raising it one foot from the ground.

Much of the mystery that exists in the minds of many persons concerning electricity will be unraveled and made clear when it is understood that, like all other natural forces, electricity is only one of the many forms in which energy manifests itself. Like all other forms of energy, electric energy, or the power that electricity possesses of doing work, is fixed and determinate.

An electric source, whether it be a voltaic cell, or a dynamo, is capable, under given conditions, of producing a certain quantity of electricity. In the case of the dynamo being operated by the steam-engine, the heat energy stored in the fuel by the sun's rays, is made to do a certain amount of work, through the medium of the boiler, the steam, and the engine, and this work or energy is simply changed by the dynamo into the form of electric energy, and passes on out through the circuit to do useful work in the way of power, lighting, etc.

When electricity is caused to flow between any two points in a circuit, the amount of work it can perform is equal to the amount of electricity that passes, multiplied by what is called the difference of potential through which the electricity falls or moves.

When work is done on a quantity of water by forcing it into a reservoir at a higher level than that from which the water has been raised, the amount of work done can be measured in foot-pounds by the quantity of water in pounds so raised, multiplied by the difference in level through which it is raised in feet. While it is not the intention to suggest that electricity is a fluid, yet it possesses many of the properties of a fluid, so that the amount of work electricity is capable of doing depends on the quantity of electricity moved, as well as on the difference of the electric level or potential through which it has been raised.

The unit of quantity of a water current may be taken as a cubic foot or a cubic inch. In electricity the practical unit of quantity is a certain quantity of electricity called a coulomb. In measuring this quantity of electricity, reference must be had to certain other electrical units, i. e., the ampere, the volt and the ohm.

The ampere is the name given to a practical unit of electric current, and is such a rate of electric flow as is capable of transmitting a quantity of electricity equal to one coulomb per second. A current of electricity equal to one ampere will flow through a circuit whose resistance is one ohm, when acted on by an electromotive force or pressure of one volt. An ampere is approximately such a current of electricity that is capable of depositing 1.118 milligrammes of silver per second from a specially prepared solution of silver nitrate.

The volt or practical unit of electromotive force is an electromotive force or pressure that is capable of causing the flow of an electric current of one ampere through a circuit, the electric resistance of which is equal to one ohm.

The ohm is the practical unit of electric resistance. It is the resistance that would limit the flow of electricity under an electromotive force of one volt to a current of one ampere, or to a discharge of one coulomb per second. It is equal to the resistance of a column of pure mercury one square millimetre in area of cross section and 104.9 centimetres in length.

A coulomb is the practical unit of electric quantity. It is the quantity of electricity that would pass in one second through a circuit carrying a current of one ampere.

Electric energy can be measured in terms of electric power or rate of doing work. A careful distinction should be made between work, or the product of force by the distance through which the force acts, and power or rate of doing work. As we have already seen, the unit of work is called the foot-pound. The unit of power or rate of doing work, or, as it is sometimes called, the unit of activity is equal to the foot-pound per second, or foot-pound second.

The amount of work electricity is capable of doing is equal to the quantity of electricity that flows, multiplied by the difference of level or potential through which it flows. This is the volt-coulomb or joule. The amount of electric activity or work per second is equal to the volt-ampere or the watt.

THE WATT.

The volt-ampere or watt is equal to the power developed when 44.25 foot-pounds of work are done per minute, or 0.7375 foot-pounds per second.

If the ampere is replaced by the symbol C, the volt by the symbol E, the watt by the symbol W, and resistance by R, then, $C \times E = W$, and $C^2 \times R = W$.

The square of the current multiplied by the resistance equals watts; and the square of the voltage divided by the resistance equals watts, thus: $E^2 \div R = W$, expressed in figures as follows:

First. An electromotive force or pressure of 10 volts and a current of 20 amperes equals,

$$10 \times 20 = 200 \text{ watts.}$$

Second. A current of 10 amperes and a resistance of 30 ohms equals,

$$10 \times 10 \times 30 = 3000 \text{ watts}$$

Third. An electromotive force of 10 volts, and a resistance of 20 ohms equals,

$$10 \times 10 \div 20 = 5 \text{ watts}$$

MAGNETS.

The *natural* magnet is a mineral consisting of a combination of iron and oxygen, and its composition is indicated by the chemical formula $Fe_3\ O_4$. The mineral is called magnetite, and it is attracted by the magnet just as iron is, only not so powerfully.

Some samples of magnetite attract iron. These are natural magnets known to the ancients as the lodestone.

The *permanent* magnet is a piece of steel which has been charged with magnetism, and retains it. It attracts iron, its ends having the strongest attractive power, it tends to point north and south, the same end always tending towards the same pole. The poles of the magnet are thus determined, and are designated the north pole, and the south pole.

The north poles of two magnets tend to repel each other, and the south poles influence each other in the same manner. But the north pole of one magnet attracts the south pole of another; like repels like, and unlike attracts unlike.

There are various methods of charging magnets. One process is as follows: Lay a bar of steel on a table, and with one pole of a permanent magnet, stroke the steel bar from center to end, always lifting the magnet clear of the bar on the return stroke. This is repeated a number of times, and then the same operation is applied with the other pole of the magnet to the other half of the bar. The end of the bar stroked with the north pole of the magnet will be a south pole, and vice versa. The stroking may be done for both halves of the steel bar by using two magnets at the same time. The north pole of one magnet and the south pole of the other are brought almost together at the center of the bar, and simultaneously moved out to the ends, always lifting them clear of the bar on the return stroke, and the stroking is repeated.

The U-shaped Magnet, or as it is usually called, the horseshoe magnet, may be charged or magnetized by stroking with another horseshoe magnet from near the bend to the ends, or from the ends to the bend. A piece of iron should be laid across the ends during the process.

The Electro-Magnet.—If a bar of iron be surrounded by a coil of wire through which an electric current is passing, it will become charged magnetically, and will attract iron.

LINES OF FORCE.

The passing of a current of electricity produces a condition of more or less strain, or whirl in the ether, and unless distorted in some way the locus or locality of the condition is symmetrical with respect to the current. This locality is called the field of force. It affects iron, and is traced, and may be located by its effects upon the needle of the compass, or upon iron filings. It is by virtue of the field of force that every dynamo electric generator, and every electric motor works. A needle held near a magnet is attracted because of the field of force. In the case of the mariner's compass, the needle is influenced by the earth's field of force. A coil of wire rotated within any artificial field of force, will generate electromotive force, and it is due to this principle that the revolving armature of a dynamo, or more properly speaking, a generator, produces currents and potential capable of doing work of various kinds. We can thus see that the electric current in its effects is a very real and tangible thing, although in theory it is somewhat imaginary. The magnet is the most familiar producer of lines of force, and the polarity, or direction of these lines is fixed by assuming that they pass through the steel of the magnet from its south pole to its north pole, and issuing from the latter, curve around through space and return to the south pole. The direction taken by the electric current is fixed by assuming that when produced by a galvanic battery, it starts from the copper electrode, and passes through the outer conductor, to the zinc plate, and the lines of force

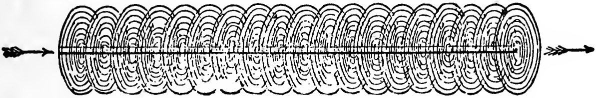


FIG. 421

LINES OF FORCE SURROUNDING AN ACTIVE CONDUCTOR surrounding the conductor will be in planes at right angles to it, and will form closed lines around it. These lines may be circular or otherwise, and their polarity, or in other words, their direction of rotation, may be expressed by saying that it is opposed to the motion of the hands of a watch or clock, assuming that the current is coming toward a person, and corresponds to the motion of the clock hands when going away from the person. In the first case, the polarity is anti-clockwise, and in the second case, it is clockwise. Figs. 421 and 422 will serve to illustrate the principle governing the action of these lines, the arrows in Fig. 421 indicating the direction of the current, while Fig. 422 may be called an "end view."

FIG. 422

LINES OF FORCE SURROUNDING AN ACTIVE CONDUCTOR

The smoke rings often produced from the smoker's pipe are good representations of the whirling motion of these lines of force. A conductor that is swept through a field of force in such a direction as to cut the lines of force, has electromotive force impressed upon it, and if the ends of the conductor are connected so as to form a closed circuit, a current of electricity will pass through it. The electric current may therefore be considered as electricity in motion, and the line of force with absolutely fixed direction may be assumed to have a whirling motion around its axis, which latter does not change, see Figs. 421 and 422.

When a current passes through a spiral conductor, as shown in Fig. 423, in the direction indicated by the small arrows, the direction of the lines of force produced will be as indicated by the large arrow; but if, instead of passing through the spiral conductor, the current should pass through a conductor occupying the position of the large arrow, then the lines of force would follow the direction of the small arrows.

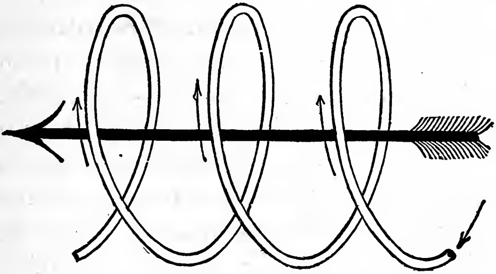


Fig. 423

DIRECTION OF LINES OF FORCE PRODUCED BY A CIRCULAR CURRENT

There are, then, surrounding a conductor carrying a current of electricity, an infinite number of lines constituting in fact a volume of force, and the strength of this volume, or field, varies with its nearness to, or distance from the conductor.

In practice, the field near the conductor is the only portion strong enough to play any part in useful work, and this strength or density is estimated by the relative number of lines of force in a given cross-sectional area of the field.

THE MAGNETIC CIRCUIT.

A fundamental difference exists between the electric, and the magnetic circuit. By a constant electric current passing upon its circuit, energy is developed, and energy must be expended to maintain it; but the lines of force are maintained in their circuit without the expenditure of energy. The entire course taken by lines of force must be a closed curve, either a circle, or an ellipse. In the field of force maintained by the horseshoe magnet, or other shaped magnets, the lines of force pass through the magnet, and also through the space surrounding it, and their path may approximate a circle, or an ellipse, or be a combination of lines and curves, but this path must be continuous. A straight line of force, or a line of force extending into space without limit, is impossible. For the passage of an electric current, a conductor forming a closed circuit is required. This conductor may be any form of matter, although a distinction is to be made between good and bad conductors. For the passage of the magnetic circuit or lines of force no such arbitrary requirement exists, although a distinction is also to be made, as, for instance, air, or a vacuum are the worst conductors, while iron is the best. There is in fact very little difference in substances as regards their ability to pass lines of force, with the exception of iron which has over three hundred times the power of passing lines of force that air has. The electric current passes through a conductor in intensity proportional to the electromotive force urging it. The magnetic circuit passes through air or a vacuum in proportion to the magneto-motive force urging it.

In order to create new lines of force, or in other words to build up a field of force, new energy must be expended;

but when the field of force is once built up, no energy is required to maintain it, as the full current passing through the circuit unopposed, except by resistance, maintains the field of force without the expenditure of energy. This condition is similar to the carrying of a weight up a flight of stairs. Energy is expended in carrying the weight to the top of the stairs, but when there it is maintained there without requiring the expenditure of energy, and the energy exerted in bringing the weight up-stairs would seem to have disappeared, or to have been annihilated. But this is not the case. On the contrary, the energy is stored in the weight, and will be again expended when the weight is taken down. So also the energy expended in building up a field of force is stored there in the form of electric potential, and may be expended in the production of kinetic electric energy when the field goes out of existence. This disappearance of the field occurs when the electric current ceases, the lines of force disappearing at a more or less rapid rate, and in doing so they develop forward electromotive force of the same polarity as the original current, thus forcing additional current through the line.

The leading characteristics of the field of force may be summed up under the following general headings:

First. Energy is expended in building up a field of force.

Second. No energy is expended in the maintenance of a field of force.

Third. Energy is expended in the destruction of a field of force.

Fourth. A field of force, then, must be, and is the location of potential energy.

Electro-Magnetic Induction.—If we take a coil of wire, Fig. 424, and rapidly thrust a magnet into it, we shall observe a certain deflection of the galvanometer needle shown with it. This deflection continues only while the magnet is in motion. After we have inserted the magnet and it has come to rest the galvanometer needle will return to its normal position. When we withdraw the magnet the deflection of the needle will be in the opposite direction. If the magnet is inserted or withdrawn with a very quick motion, the deflection will be considerable. If the magnet is very slowly inserted, or withdrawn the deflection will hardly be noticeable. The same phenomena will occur if instead of moving the magnet, we hold it stationary and move the coil, or if both of them be moved towards or from each other. The deflection of the compass needle indicates that a current of electricity is passing along the wire, and the experiments above described show exactly how currents of electricity are produced in dynamos.

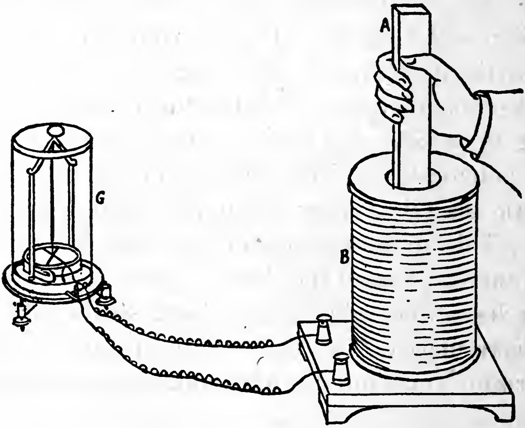


Fig. 424

While a natural magnet will maintain a field of force indefinitely without the expenditure of energy, it is necessary that energy be indirectly expended in maintaining the field of a dynamo, for the reason that an electro-magnet is preferred to a natural magnet in such a machine, because by its use the dynamo may be made much smaller and lighter.

An electro-motive force is induced by rapidly cutting lines of force, that is, by moving either a magnet over a wire or a wire over, or near a magnet. The current in turn is the result of this electro-motive force acting in a closed circuit. A bar of iron becomes an electro-magnet if we wind about it a few turns of wire and cause a current of electricity to flow along the wire, Fig. 425. The magnetism is conceived to consist of lines of force, which leave the bar at one end and enter it at the other, the direction of these lines depending upon the direction in which the current circulates about the bar of iron. The number of these lines of force depends upon the number of ampere turns in the iron bar and on the diameter, length, and quality of the iron bar.

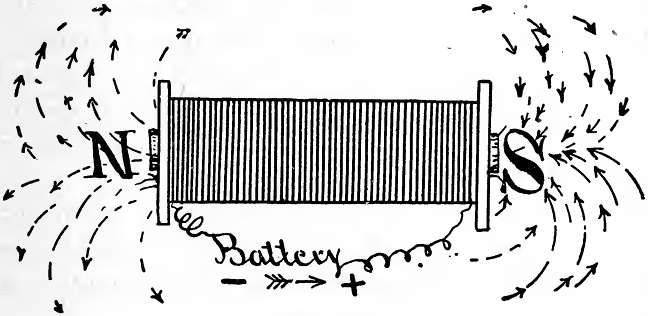


Fig. 425

The meaning of the word ampere as used in electric practice has already been defined.

Ampere turns is a term used to indicate the magnetizing force; it is the number of turns of wire on a magnet multiplied by the current in amperes flowing through these turns of wire.

Haskins, in *Electricity Made Simple,* explains it in this manner: "If, for instance, we have a current of one ampere flowing through a single turn of wire around a bar of soft iron, and we have developed enough magnetism to lift a keeper or other piece of iron, weighing one ounce, then with one-half the amount of current and two coils around the bar, we would obtain the same result, and with three turns of wire we would require but one-third the current to develop the same lifting power in the bar or magnet."

The law of magnetic flow is very much the same as the law of current flow. If the iron bar is of low magnetic resistance, the flow will be quite great; if of high resistance, the flow will be small.

Lines of force can also be shunted just as a current of electricity can; that is, they will follow the path of lowest resistance just as a stream of water or a current of electricity will.

Faraday's law of induction is as follows: "When a conductor is moved in a magnetic field so as to cut the lines of force, there is an electro-motive force impressed on the conductor in a direction at right angles to the direction of the motion, and at right angles also to the direction of the lines of force."

Foucault or Eddy Currents.—If a conductor should be so moved in a magnetic field that the number of lines of force passing through it at an angle with its direction of motion vary, a current will be produced within it. This current will circle, or eddy around within the conductor, and will absorb energy, and expend it in heating the metallic body of the conductor. These local currents are called Foucault or eddy currents, and are a hindrance, rather than a help to the generation of useful currents.

DYNAMO-ELECTRIC GENERATORS.

The dynamo is a machine for transforming mechanical energy into electrical energy—mechanical energy is required to operate the mechanism for changing field and armature relations, and this energy is absorbed by the dynamo, and electric energy is produced in its stead. The easiest way to comprehend the principles of the dynamo is to follow up its construction from the most simple type, to one of the more complicated forms. Dynamos are classified into two grand divisions, viz., alternating (A. C.) dynamos, and direct current (D. C.) dynamos. The A. C.

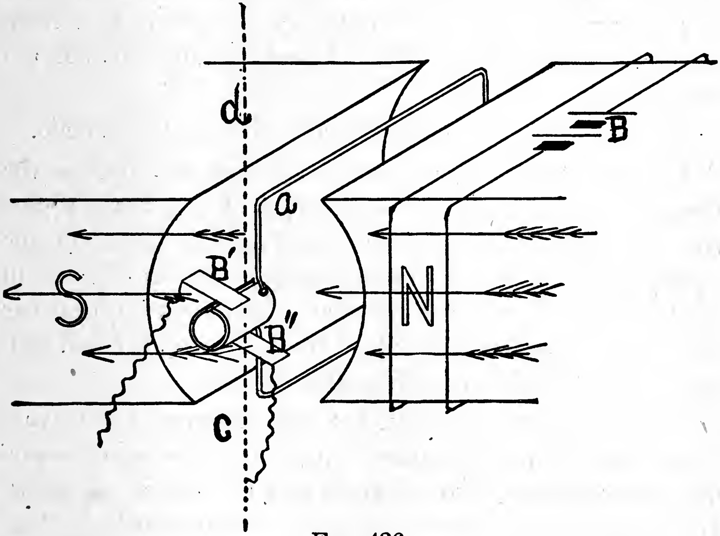


Fig. 426

dynamo produces a current that reverses its direction of flow periodically, in practice from twenty times and upward per second. The D. C. dynamo produces a current of unchanging direction.

The principal constituent parts of a dynamo are the armature, consisting of a core and windings, the field consisting also of core and windings, the collecting rings, or commutator, and brushes. The armature and field vary in construction, their windings vary in system, and from these variations, many different varieties of dynamos are constructed.

Fig. 426 is an elementary sketch of a D. C. dynamo.

The wire a represents the armature, and we have also the iron bar, and the coil of wire wound on it and, for the present, we may consider the battery B as the source of the current which produces the magnetism or lines of force in the iron bar. The battery current magnetizes the iron bar (which in dynamos is known as the field magnet) and produces the lines of force indicated by arrows.

These lines of force leave the field magnet of the dynamo at the north pole marked N, and pass through the air-gap, and armature into the south pole marked S. As we begin to move the wire or armature, it cuts through these lines of force and begins to generate an electro-motive force, which in turn will cause the current to flow if the circuit is closed through a lamp or other device.

This current reverses in direction as the wire *a* passes from the influence of the south pole into that of the north pole, and the brushes B′ and B″, which transmit the current to the outside wires, are so set that they change the connection of the wire *a* at the time that it passes from one pole to the other. By this means the current in the external circuit is kept constant in direction, although it alternates in the armature.

The faster we turn the wire or armature, the greater will be the electro-motive force generated. Instead of using only one wire, as in Fig. 426, we may take many turns before bringing the end out, and in so doing obtain the well known drum armature, or, by a slightly different method of winding, the gramme ring armature, Fig. 427.

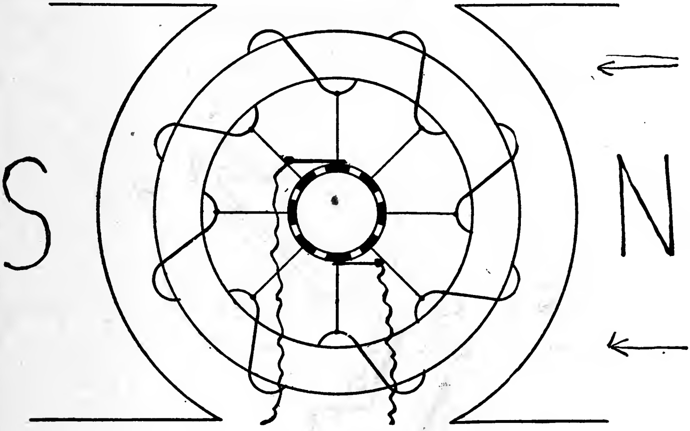


Fig. 427

Here we have many wires cutting the lines of force at once and the electro-motive force with the same number of revolutions of the armature is correspondingly increased, and the more turns of wire we arrange to cut those lines of force per second the greater will be the E. M. F. Instead of providing more wire or increasing the speed of the armature we can increase the magnetism, or number of lines of force, by sending more current through the fields, that is increasing the ampere turns.

If we wish to reverse the current flow we can do so by revolving the armature in the opposite direction, or by reversing the current through the fields.

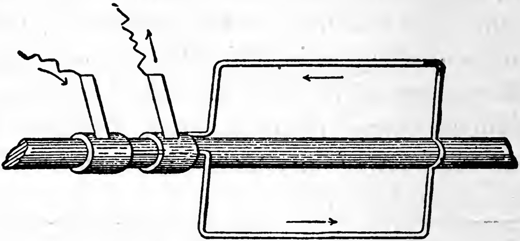


FIG. 428

USE OF COLLECTING OR SLIP RINGS

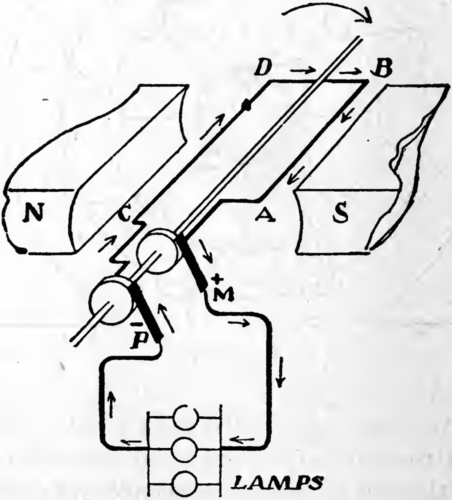


FIG. 429

THE SIMPLE ALTERNATING CURRENT DYNAMO. BRUSH M IS POSITIVE

Elementary Idea of an Alternating Current Dynamo.—If instead of the brushes B′ and B″ as shown in Fig. 426, we collect and transmit the current to the outside circuit by means of collector rings as shown in Fig. 428, we will then have an alternating, instead of a direct, or constant current as before mentioned.

In Figs. 429 and 430 are shown two positions of the loop on the armature of an alternator. The collector rings are insulated from the shaft and each other by mica. The terminals of the loop are soldered or riveted (sometimes both) to the rings, and current is led to the external circuit containing the lamps by stationary strips of copper which form a sliding contact with the rings.

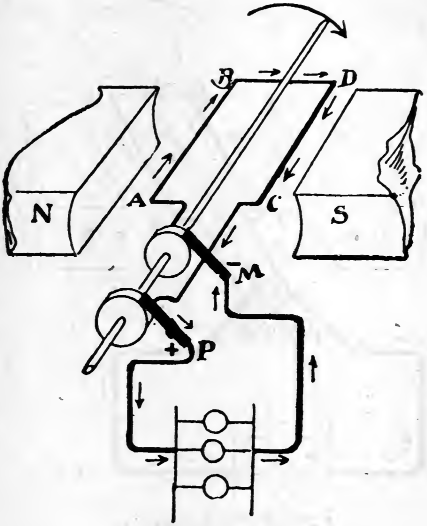


Fig. 430

THE SIMPLE ALTERNATOR, SHOWS COIL AT ONE-HALF A REVOLUTION FROM FIG. 429. BRUSH M IS NOW NEGATIVE

Referring to Fig. 429 it will be seen that during the first half of the revolution of the loop ABCD, the direction of the electro-motive force in AB is from B to A, and in CD is from C to D.

The current flows from the brush M to the lamps so that M is positive.

Reference to Fig. 430 shows that the wire in front of the S-pole is still positive, but that it is now the wire CD instead of AB, so P is the positive brush for the second half of the revolution. There are two reversals of the current per revolution.

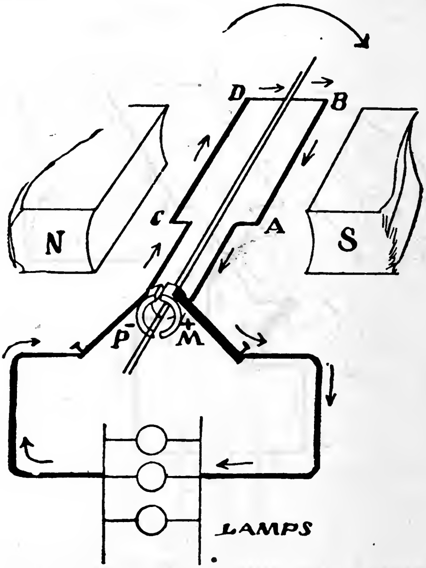


FIG. 431

SIMPLE D. C. GENERATOR. AT THIS INSTANT THE BRUSH M IS POSITIVE

The number of *alternations per minute* is the speed in revolutions per minute multiplied by the number of poles. The number of cycles is found by multiplying the speed in revolutions per second by the number of pairs of poles. The number of cycles is usually spoken of as the *frequency* of the alternator.

The usual frequencies are for power 25, for motor circuits, and arc lamps 66, and for incandescent lighting 133.

The Direct Current Generator.—In Fig. 431 is shown a loop and a two part commutator of a direct current generator.

Since the wire AB is moving down past a S-pole, the current flows from B to A and out of the brush M, which is called the positive brush. In wire CD the current flows from C to D, making P the negative brush.

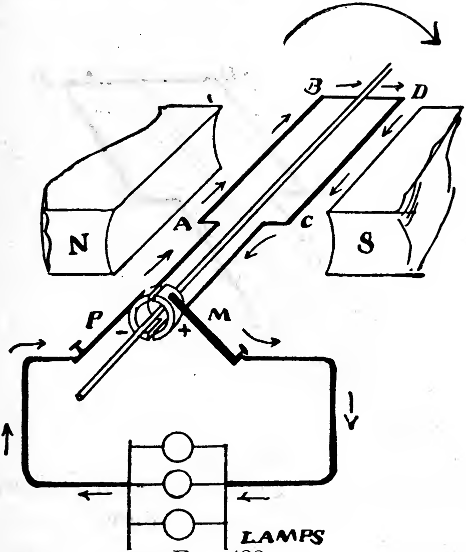


FIG. 432

SIMPLE D. C. GENERATOR. THE ARMATURE HAS MADE HALF A REVOLUTION, BUT BRUSH M IS STILL POSITIVE

After half a revolution the wire CD is over where AB was, and is now delivering the current towards the external circuit instead of away from it; *but CD is now connected through its commutator bar to brush M instead of to P so that the brush M is still positive.* (See Fig. 432.)

This arrangement of commutator bars and brushes performs the duty of connecting the brush M to that part of the winding, and only that part which is moving down in front of a S-pole. As long as the wire AB moves up in front of a N-pole the commutator connects it to brush P, but as soon as it moves down in front of a S-pole it is immediately disconnected from P, and a connection made with M.

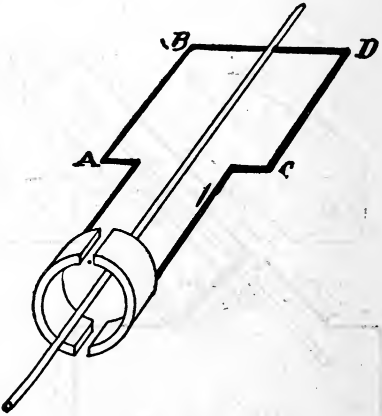


FIG. 433

AN ARMATURE COIL CONNECTED TO A TWO-PART COMMUTATOR, SO AS TO DELIVER DIRECT CURRENT

The two brushes are placed as shown in Fig. 434. In this case the alternating electro-motive force will be reversed or commuted at the proper instant, and there will be a one direction electro-motive force impressed on the outside circuit. The split ring is called a commutator, and is formed of alternate sections of conducting and non-conducting material, running parallel with the shaft with which it turns. It is placed on the shaft of the armature so that it rotates with it, as shown in Fig. 437. The brushes press upon its surface and collect the current from the bars. (See Fig. 438.) The function of the commutator as before stated, is to change the connections of the armature coils from the + or positive to the negative or — side of the circuit at the time at which the coil connected to the bar under the brush passes from the influence of one pole piece into that of the other. This is the time at which the current in the coil reverses in direction, and is called the neutral point. If we consider, for the sake of simplicity, an armature having only one turn of wire on it, as Fig. 426, there will be a time while the coil is in the position indicated by dotted lines at c and d when no current is being generated. The brushes on any dynamo should always be set at this point, for this is the point of least sparking. In actual practice all commutators have quite a number of bars and it is impossible to avoid, in passing under the brushes, that at least two of them are in contact with a brush at the same time. If a brush did leave one bar before it touches another, the current would be entirely broken for that length of time, and much sparking would result. The nature of all armature windings is such that while the brush is in contact with the commutator bars it short circuits that coil between them. This is the main reason why the brushes must be kept at a point at which the coil which is short circuited generates no current.

FIG. 434

CROSS SECTION OF SIMPLE COMMUTATOR. BLACK REPRESENTS COPPER; WHITE SPACE IS MICA INSULATION

Although the electro-motive force generated in one coil of a dynamo is very weak, the resistance of the "short circuit" formed by the dynamo brush is also very weak and therefore the current may be quite strong. This current is the main cause of sparking in dynamos. The number of bars constituting a commutator depends upon the winding of the armature, and the number of coils grouped thereon. By increasing the number of coils and commutator sections the tendency to spark at the brushes is decreased, and the fluctuations of the current are also decreased. However, there are many reasons against making the number of bars on a commutator very great. Increasing the number of bars in a commutator increases the cost of manufacture, and in smaller dynamos, if the number of bars be increased beyond a certain extent, each bar becomes so thin that a brush of the proper thickness to collect the current from the commutator would lap over too many bars of the commutator at one time. Each commutator bar should be of the size that will present sufficient metal for the carrying capacity of the current generated in the coil to which it is connected. Different builders of dynamos have different ideas as to the number of amperes that may be carried per

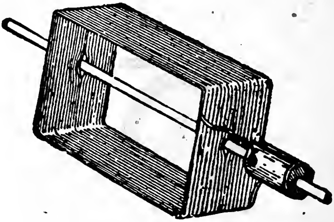


Fig. 435

A SINGLE COIL ARMATURE OF MANY TURNS

square inch in a commutator bar, but where a commutator is made of 95 per cent. copper it is usual to allow for each 100 amperes a commutator bar surface of 1½ sq. in.

The method of electrical connection between the commutator bar and the coil of the armature varies in different designs. Some builders solder the terminals of the coils to the commutator bars; others bolt the terminals of the coils to the bars; and some makers use hard drawn copper

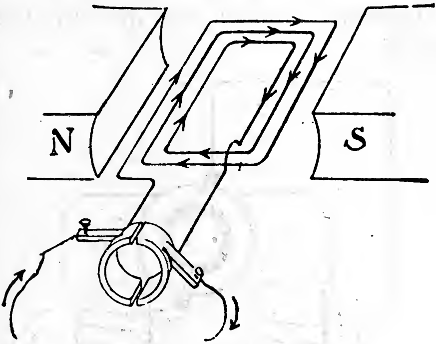


FIG. 436

AN ARMATURE COIL OF MANY TURNS SHOWING HOW THE INDUCED E. M. F. OF EACH TURN ADDS ITSELF TO THAT OF OTHER TURNS

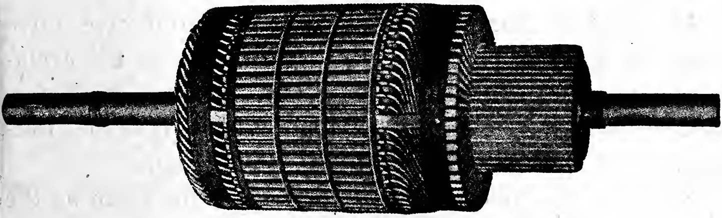


FIG. 437

and "form" the armature coil in such a manner that both ends of the coil become commutator bars, making the coil continuous from one end of the commutator bar to the end of the diametrically opposite commutator bar.

To increase the electro-motive force. The greater the field strength, and the higher the speed the greater the electro-motive force.

When the speed has been raised until the surface of the armature is traveling at the rate of 3,000 ft. per minute* no further increase is made, lest the bursting stresses become too great.

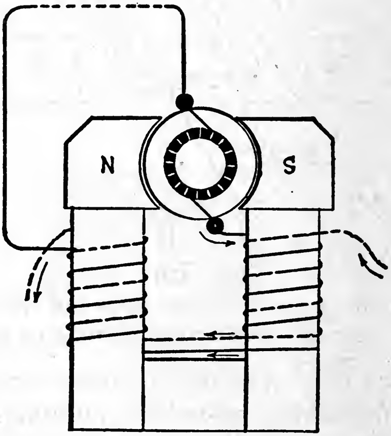


FIG. 438

SEPARATELY AND SELF-EXCITED SERIES DYNAMO.

In order to further increase the electro-motive force more *turns* or *loops* of wire must be wound on the armature. A coil of 16 turns as in Fig. 435 will give an electromotive force 16 times as great as a coil like Fig. 426. Reference to Fig. 436 will serve to make this plain.

Suppose the direction of rotation to be the same as the

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*This is called the Peripheral Speed of the armature and is calculated by this rule:

P. S. equals 3.1416 x D x R. P. M. where D is the diameter of armature in feet and R. P. M. is the revolution of the armature per minute.

hands of a watch when viewed from the commutator end of the machine; then the electro-motive forces induced in the successive portions of the wire will be as shown by the arrows, and will add to each other impressing a high electro-motive force on the brushes. These turns of wire are said to be in series.

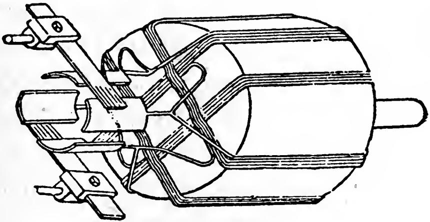

FIG. 439

DRUM WINDING ON A DRUM CORE. FOUR COILS AND FOUR COMMUTATOR BARS. FOR DIRECT CURRENT

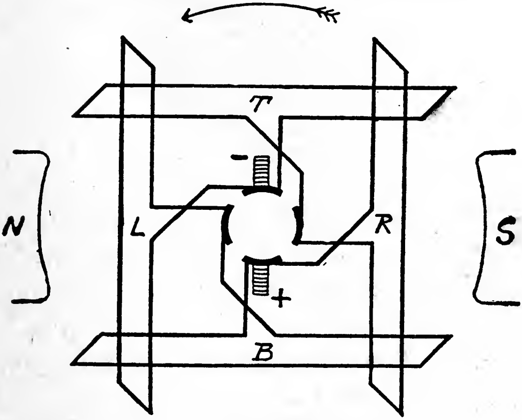

FIG. 440

DIAGRAM OF FIG. 439

Any betterment of the magnetic conductivity of the frame of the machine will increase the electro-motive force; by producing a greater flux per pound of copper on the field magnets. Hence the winding of the armature inductors (wires) on a core of very softest iron is an economic necessity, resulting in either a higher electro-motive force or a reduction of the expense for copper in the field coils.

These cores are called *Drum cores* when the central hole is just large enough for the shaft and the insulation around it (Fig. 439); and are named *Ring cores* when the internal diameter of the ring is much larger than the shaft. (Fig. 441.) The armature in Fig. 442 has a ring core, but the end plates being in position, the large hole is concealed.

These cores are built up of a great many punchings of soft iron from 15 to 40 mils thick, pickled so as to rust them a little. Every tenth one is varnished or tissue paper pasted on. The rust, varnish and paper are all insulators and when the punchings are assembled in a core, prevent *Eddy currents* from flowing from one end of the armature to the other and heating it.

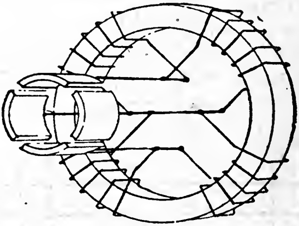

FIG. 441

SIMPLE GRAMME RING WINDING

These cores are sometimes *smooth,* but more frequently are *slotted* with the wires laid in the slots.

About 10 to 15% of the length of the core is insulation, and about 50% of the surface is slotted, containing the inductors (wires.)

Continuous Electro-Motive Force.—While a single coil of many turns produces a high electro-motive force, which by a two part commutator is always applied to the external circuit in the same direction, yet this coil passes through all the changes in voltage mentioned in connection with Fig. 426. Fig. 441 shows the construction of the Gramme ring, so named from the inventor, Gramme. The winding is on a ring coil made up of soft iron punchings 25 mils thick. The wires on the outer surface are active, having electro-motive force induced in them, and called armature inductors. Fig. 443 shows the same winding with eight coils, and eight commutator bars. In Fig. 442 the armature as diagramed in Fig. 443 is shown completed with its four bands. These bands are from 12 to 25 convolutions of phosphor-bronze wire in sizes varying from No. 20 up to 14, laid on tightly over a mica insulation and sweated with solder all the way round.

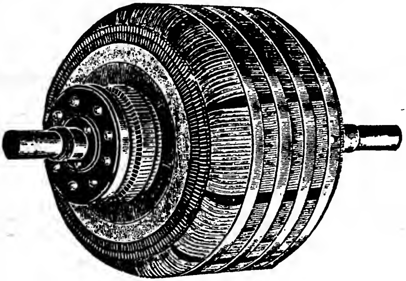

Fig. 442

EIGHT SECTION EIGHTY COIL RING WINDING ON A SMOOTH RING CORE, WITH EIGHTY BAR COMMUTATOR. FOR DIRECT CURRENT

Referring to 443 it will be seen that the complete winding can be divided into two parts, one influenced by the N-pole, the other by the S-pole standing at the commutator end. The N-pole side moving upwards has its electro-motive force in direction from back to front of armature *through the inductors*; the S-pole side has electro-motive force in direction from back to front of armature *through the dead wire.*

In winding the armature the wire is laid on in a continuous spiral as shown. This makes the electro-motive force in each half of the armature in series, and allows the current to flow from one coil to another, except at the points where the N-half and S-half of the armature meet. Here the electro-motive forces oppose and if wires were connected for an instant to the winding, as shown in the cut, the two opposing electro-motive forces would both force electricity out into the wire at the top of the armature, and draw it in at the bottom as shown by the arrows on these wires. This will cause a current to flow in the external circuit.

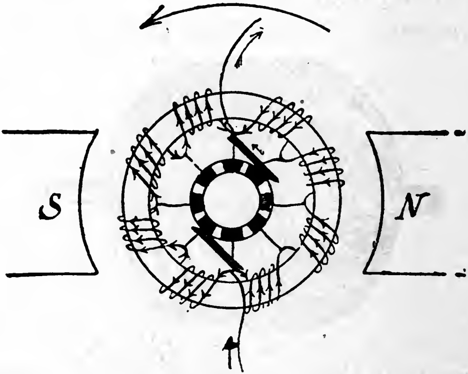

Fig. 443

EIGHT COIL GRAMME RING WINDING, WITH EIGHT PART COMMUTATOR

If the junctions of the coils are connected to eight commutator bars, (one bar per coil), and connect the ends of the external circuit by brushes to the commutator bars which are midway between the N- and S-poles, then each half of the armature separately generates an electro-motive force, and delivers current to the external circuit.

Suppose the armature to be revolving at the highest safe speed. Each inductor will move past the magnet poles at a speed of 3,000 feet a minute. With pole pieces 5 x 8 inches and a *flux density* of 90,000 lines per square inch, the *total flux* will be 5 x 8 x 90,000 or 3.6 million lines.

The armature may be 9 inches in diameter which gives it rotative speed 1,270 (nearly).

For R. P. M.*=P.S.†÷(3.1416×diameter).

$$=\frac{3000\times12}{3.1416\times9}=1270 \text{ nearly}$$

and R.P.S.‡=21 nearly.

An inductor therefore cuts 3.6 million lines of magnetism twenty-one times a second, which is equivalent to cutting 75.6 millions once per second.

Since the cutting of 100 million lines per second by an inductor induces 1 Volt pressure, each inductor on this armature revolving in this field will produce 75.6÷100 or ¾ of a volt approximately.

The 4 coils of 4 inductors each (Fig. 443) on the N-half of the armature being in series produce 3 volts per coil or a total of 12 volts *which is the electro-motive force of the generator.*

The S-half of the armature also generates a pressure of 12 volts, which is not added to the pressure of the N-half, being in parallel with it. An inspection of Fig. 443 shows that they oppose rather than add to each other; but an outlet being provided they turn aside through it, and send cur-

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*Revolutions per minute.

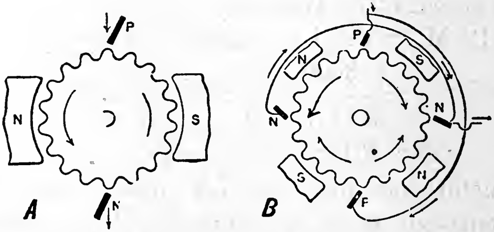
†Peripheral speed.

‡Revolutions per second.

§American Wire Gauge.

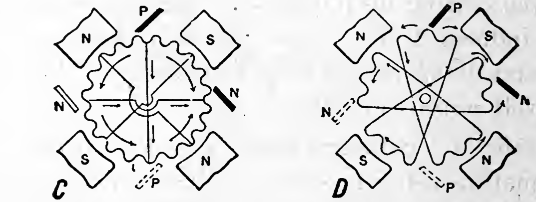
rents separately and independently towards the outside circuit.

If the armature is wound with No. 10 wire A.W.G.§ the diameter of which is 0.102 inch or 102 mils, its area is 102 squared equal to 10,404 c. m. Allowing 700 c. m. per ampere, it will carry 15 amperes, without too much heating.



Two Pole, Two Circuit

Four Pole, Four Circuit, Four Brushes In Multiple.



Four Pole, Four Circuit, Cross Connected Two Brushes or Four Brushes, In Multiple.

Four Pole, Two Circuit Ring Two Brushes or Four Brushes, In Multiple.

FIG. 444

SHOWING THE NUMBER AND POSITION OF BRUSHES ON DIFFERENT ARMATURE WINDINGS

The black brushes are the ones actually used, the dotted ones being dispensed with on account of the particular winding.

Since each side of the armature delivers its own current to the brushes, the safe current output of this generator is 30 amperes.

Suppose there are 250 ft. of this No. 10 wire on this armature. The resistance of the wire according to the wiring table is 1.02 ohms per 1,000 ft.

The resistance of *all the wire* on the armature is 0.255 ohm, and the resistance of the wire on each *half* of the armature is 0.128 ohm.

But the two halves are in parallel so *the resistance of* the armature as measured from brush to brush will be one-half of 0.128 or 0.064 ohm. The drop, or loss of pressure in the armature will be C x R or 30 x 0.064=1.92 or say 2 volts. This machine being a shunt generator, the main current does not pass through the fields, and there is no further voltage lost.

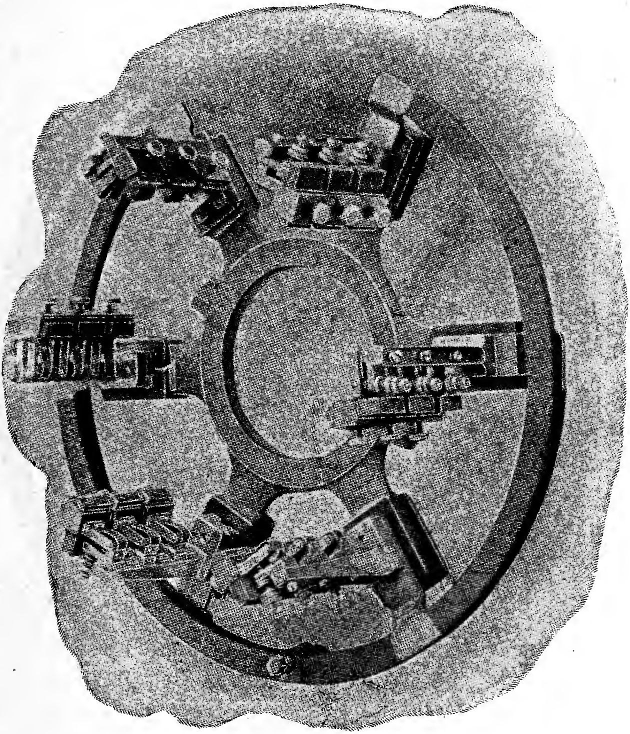


FIG. 445

The electro-motive force of this dynamo is 12 volts, and its voltage is 10 volts.

Its output in watts will be 10×30=300 watts or 0.3 K.W. This is the rating of the machine, and it will carry this load 22 hours a day without getting more than 90° Fahr. hotter than the surrounding atmosphere. A properly proportioned machine will stand a 25 per cent overload for half an hour, rising an extra 30° in temperature,

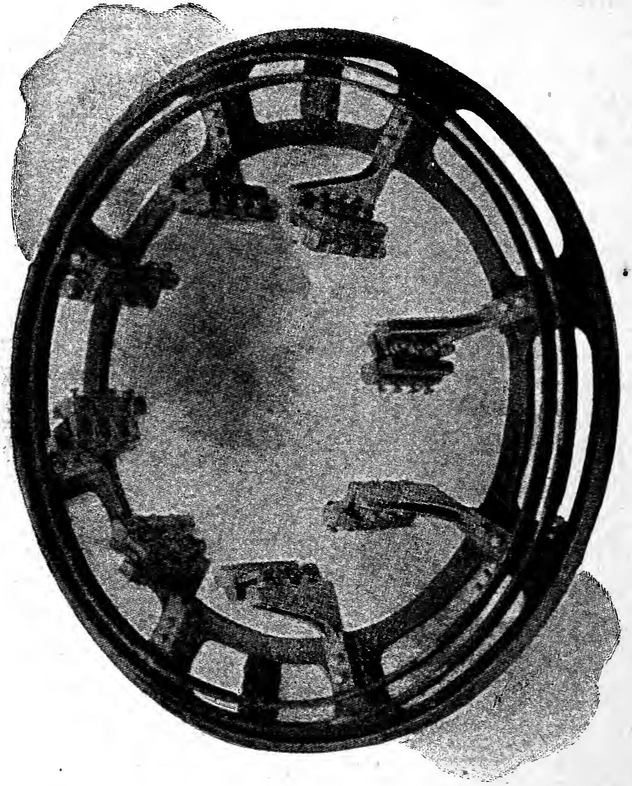


FIG. 446

and it will stand a 50 per cent overload for one minute without being damaged by the heat.

Drum Winding.—The extra labor involved in passing the dead wire through the bore of a ring core is avoided by going back to first principles again, and placing on the core, (either drum or ring) a number of coils shaped as in Fig. 435, producing a winding as shown in Fig. 439. It is to be noted that the inductors lie entirely on the outer surface of the core, and that the percentage of dead wire is less than in Fig. 441. For a long, small diameter armature, drum winding uses the least wire, while for a short, large diameter core, the ring winding will require fewer pounds of copper. In order to make the diagram in Fig. 440 clear it has its proportions wrong. The dead part of the wire is drawn very long and the active part very short. The reverse is true of an actual winding.

Referring to Fig. 439, and using Fig. 440 as a guide, the left side of the armature is the N-pole side and the right the S-pole side; and the armature is revolving anticlockwise (otherwise the upper brush would be positive).

The electro-motive forces on the N-side and S-side of coil T, as in Fig. 436, are in series and add up, producing a current flow towards the lower (positive) brush. The current passes through the inactive (dead) coil R in order to get to the positive brush.

At the same time the electro-motive forces in coil B add up and passing through the dead coil L, drive current out of the lower brush.

The value of the electro-motive force is eight times that which one inductor can produce. For the active coil T has 4 loops, i. e., 8 inductors in series, as also has the coil B. Suppose T produces 8 volts, the two coils T and B are in parallel and do not add their electro-motive forces.

The coils L and R are dead, L being in series with B and R in series with T, but they produce no electro-motive force. At the present instant they are but a wasteful resistance; their value, however, will be soon seen.

When the armature has moved about ⅛ of a revolution, T is cutting flux slantingly and R, which is in series with it, is beginning to cut flux also. T is only ¾ active, producing say 6 volts, and R is not totally dead but ¼ active, producing 2 volts. Hence the voltage of the machine is still 8.

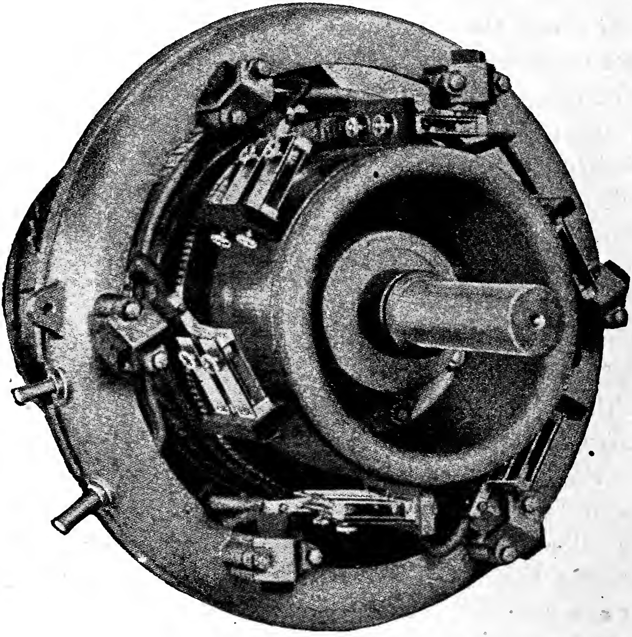


FIG. 447

At ¼ revolution R is doing full work and B is dead and in series with it, while T is dead and L in series with it is at full activity. Now R and L produce the electro-motive force.

The current enters the armature through the upper brush, splits and passes through the armature by two parallel circuits, one containing T and R in series and the other containing L and B. During a revolution these coils interchange places, but two coils are always in each circuit.

When 6 amperes flow in the external circuit the No. 16 wire of the armature is not overheated, as it has but 3

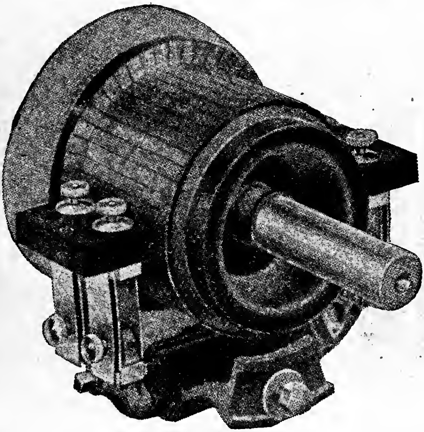


Fig. 448

amperes to carry. It has 2583 circular mils, which is more than 3×700 C. M.

Self-excitation of a Dynamo.—When a dynamo is standing idle the field magnets are weakly magnetic, due to residual magnetism.

Let the armature revolve, and in a shunt, or compound machine open, and in a series generator close the external circuit.

A few volts will be generated and cause a current to flow though the fields, hence the magnetism will increase and more voltage will be induced. This voltage will send increased current through the shunt field, and cause more volts to be induced.

The machine is now "building up."

As more and more magnetism is put into the fields, it becomes harder to get any more in as the iron is approaching *saturation* and there is more and more *leakage.*

Hence at a certain point, depending on the design of the machine, the difficulty of increasing the magnetism being added to the effect of the leakage just balances the tendency of the voltage to be increased. If nothing else is done the voltage of the dynamo will remain constant.

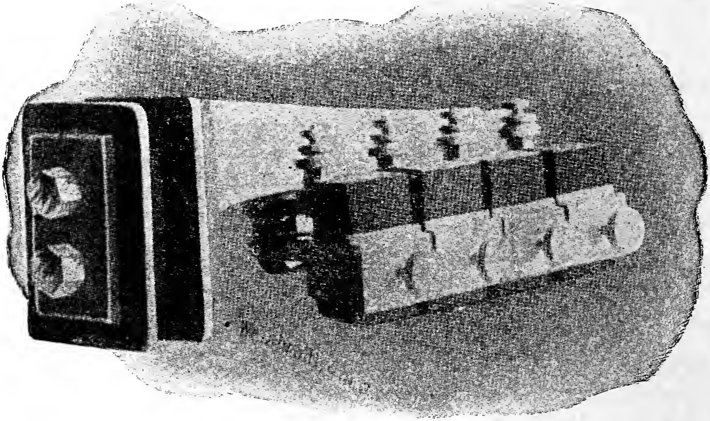


Fig. 449

In the series field, is passing all the current drawn from the machine, and the field strength and voltage tend to increase. This increase is opposed by the C. R. loss in armature and field, and the effect of the increasing field density. The net result is a *building up* of the voltage and if the load is not changed the voltage of the machine will remain constant.

Regulation.—If now in the shunt generator the external circuit is closed, an extra current (very large in proportion to the field current) is drawn from the armature and causes a C.R. loss.

A lower voltage is thus impressed on the external circuit, also on the field. Hence the field weakens, and the added results of C.R. loss and weaker field is a considerable drop in voltage for each increase in load.

Resistance must be cut out of the field as load increases.

When in the series generator the load increases, a shunt should be placed around the field to weaken it, if a constant potential is desired.

Position of the Brushes.—In order that one set of brushes may take away from, and the other set deliver current to the generator in a bipolar machine these sets are on opposite sides of the commutator.

In some dynamos when the inductors come out of the slots, one goes straight on to a commutator bar, and the other is bent over to its proper bar. This puts the brushes in line with part of the coil, and they will be found half way between the pole tips.

It is usual to bend both inductors as they leave the slots and connect to bars half way between the slots. Then the brushes will be found opposite the middle of the pole piece.

In dynamos and non-reversing motors the brushes are a little distance away from the points mentioned, but in reversing motors are exactly at these points.

The alternate brushes are of the same polarity, and there is usually a set of brushes for each field magnet.

The placing of the brushes on the commutator with a certain relation to the winding is necesary as a reference to Fig. 444, or to the diagram of any winding will show that the brush while collecting current is at the same time *short circuiting* one of the coils.

In order that an excessive current may not be generated in this short circuited coil it must be out in the interpolar space at the time the brush touches the two bars belonging to it.

Brushes and Commutators.—Figs. 445 to 449 show different arrangements of modern brushes and brush-holders. These are used to take the current from the commutator and deliver it to the outside wires in the case of a dynamo, and for the opposite in the case of a motor.

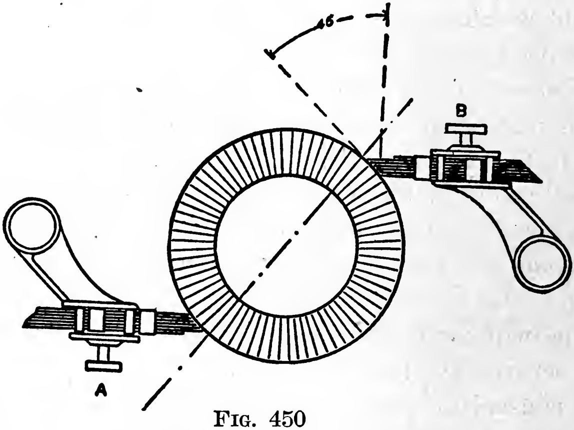


Fig. 450

There are many different designs and constructions of brushes and brush-holders, and these designs are brought about by the various ideas of different builders in their attempt to produce various advantageous results, but the electrical connections and underlying principles remain the same whether a copper or a carbon brush be used.

In any construction of brush holding device, if great care is not exercised in keeping it thoroughly clean, trouble is sure to be the result, and trouble of this nature increases so rapidly that unless the attendant immediately sets about to right it, a burned out armature is almost sure to be the consequence sooner or later. In alternating current dynamos, where brushes rest on collector rings instead of commutators, it is much easier to keep out of trouble, because the brushes in this case merely collect the current from the rings, and do not commutate or rectify it.

The brushes and commutator of a dynamo or motor are probably the most important parts with which the engineer has to deal. Great care should be taken that the brushes set squarely on the commutator, and that the surface of the brushes and commutator are as smooth as possible. It is a good plan, and in some cases the brush-holders are so made, that the brushes set in a staggering position, that is to say, in a position so that all the brushes will not wear in the same place over the circumference of the commutator and cause uneven wear across the length of the commutator bars. In most machines the armature bearing is arranged so that there is more or less side motion, which, when the

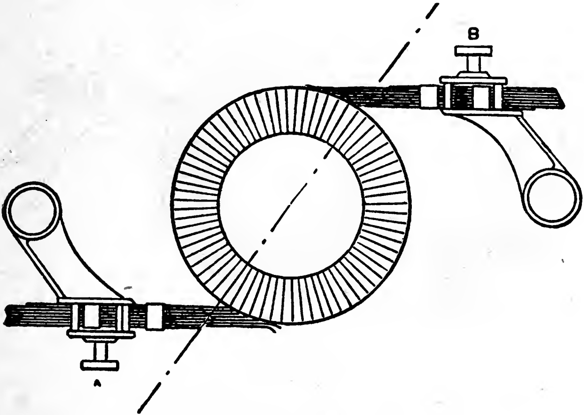


Fig. 451

armature is running, causes a constant changing of the position of the brushes and commutator.

Whatever style of brush is used, the commutator should be kept clean and allowed to polish or glaze itself while running. No oil is necessary unless the brushes cut, and then only at the point of cutting. A cloth (not cotton waste) slightly greased with vaseline and applied to the surface of the commutator while running is best for the purpose of preventing the commutator from cutting. Should the commutator become rough, it should be smoothed with sandpaper, never using emery cloth, because emery is a conductor of electricity, and the particles of emery are liable to lodge themselves between the commutator bars in the mica and short circuit the two bars, thereby burning a small hole wherever such a particle of emery has lodged itself. The emery will also work into the brushes and copper bars and wear them down; it being almost impossible to remove all the emery.

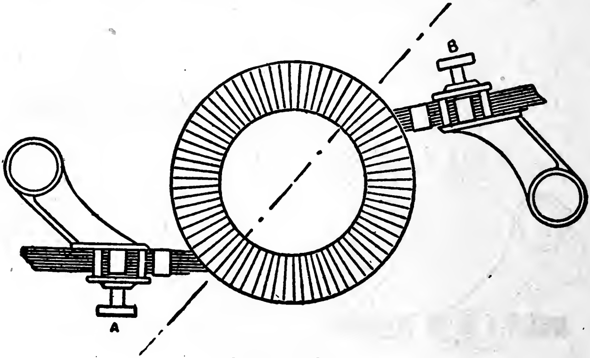


FIG. 452

In the end-on carbon brushes, Fig. 449, the contact surface of the brushes should be occasionally cleaned by taking a strip of sandpaper, with the smooth side of the paper to the commutator, and the sanded side toward the contact surface of the brush, and then by leaving the tension of the brush down on the sandpaper, it is an easy matter to move the sandpaper to and fro and thoroughly clean off the glazed and dirty surface from the carbon, leaving it with a concave that will exactly fit the commutator.

The advantages of carbon brushes are many. Among the cardinal points are: The armature may run in either direction without it being necessary to alter the brushes; the carbon can be manufactured with a quantiy of graphite in its construction, thereby lowering the mechanical friction of the brushes on the commutator; they do not cut a commutator so much by sparking; the commutator has a longer life, the wear being more evenly distributed.

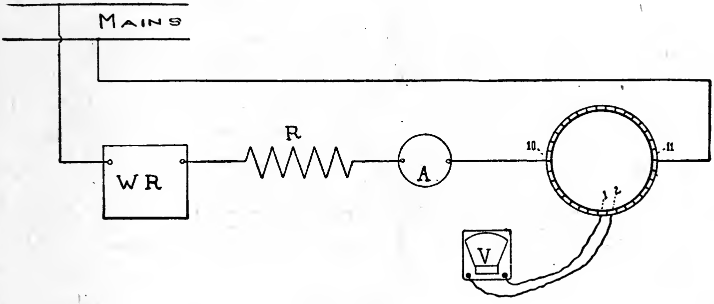


FIG. 453

Carbon brushes, due to their rather high resistance, will often heat up considerably, but, although this heat is objectionable, their resistance tends to cut down the sparking. The brushes are sometimes coated with copper to reduce their resistance. Often a carbon brush will be found which is very hard. As a rule such a brush should be thrown away, as it will heat abnormally and at the same time wear the commutator.

In Fig. 450 we have one of the various so-called old styles of leaf brush-holders. The end-on brushes are more generally used in modern practice, because their contact surface area is not increased or decreased by wear. Consequently the brushes always remain in a diametrically opposite position. With the old style brush-holding device, where the brushes rest on the commutator at a tangent, great care should be exercised not to allow the brushes to wear in a position so that their points will be out of diametrical opposition. Fig. 450 shows the correct setting of this type of brush, and Figs. 451 and 452 show the incorrect setting.

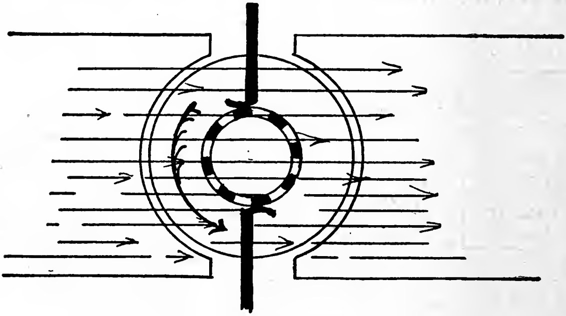


Fig. 454

By remembering that each one of the commutator bars is the end of a coil, and then just mentally tracing the current through the coils from one brush to the other, we can readily understand what the results are when the brushes are neglected and left in a relative position, as shown in these figures.

Sparking is the usual result of brushes allowed to wear to such an extent. Overloading of a dynamo or motor will also cause serious sparking, and no amount of care can prevent damage to armature, commutator or brushes, if a machine is permitted to be overloaded.

Sometimes the commutator will contain one or more bars which, as the commutator gets old and wears down, will wear away either too fast or too slow, due to the metal being harder or softer than the rest of the bars forming the commutator. This causes a roughness of the commutator, and results in the flashing of the brushes and heating of both the commutator and brushes. About the only satisfactory method of remedying this evil is to take out the armature, and have the commutator turned down in a lathe.

A short-circuited coil in the armature, or a broken armature connection, will also cause considerable sparking. Either of these conditions can be located by means of a Wheatsone bridge, or by what is known as the fall of potential method. To make a test with this latter method, connect in series with the armature to be tested some resistance capable of carrying the necessary current, also an ammeter. Some apparatus for varying the current strength, such as a water rheostat, or lamp rack, must be connected in the circuit, a diagram of which is shown in Fig. 453.

In the diagram, WR is the water rheostat or lamp rack, R the known resistance, A the ammeter and M the armature to be tested. By means of the water rheostat regulate the current passing over the apparatus until it is of such strength that a deflection can be obtained on a voltmeter when it is connected to two adjacent bars on the commutator. Suppose the armature coil between bars 1 and 2 on the commutator were broken. The voltmeter connected across these two bars would give the same reading as when connected across the two points 10 and 11. If the voltmeter were connected between any other two points on the commutator on the same side as the broken coil no deflection would be obtained, while connecting the voltmeter between any two adjacent bars on the other side of the commutator would give practically the same reading irrespective of which bars were used. The resistance of one or more sections of the armature winding could also be found by using Ohm's law, $R=E/C$, or the resistance would be equal to the voltage divided by the current as shown on the ammeter. It must be remembered that this latter will be true only when there is an open coil in one side of the armature, for in this case only will the whole current flow through the one side. If the coil between bars 1 and 2 were short circuited, the voltmeter would show practically no reading between these bars; while between any other bars some deflection would be obtained. An open circuit, or short circuit will nearly always be found by examination, as the trouble usually happens very close to the commutator connections in the case of an open circuit, and may very often be found between the commutator bars themselves, in the case of a short circuit. If the trouble is not at these places it will usually be in the windings, in which case the only remedy is to have it re-wound. Temporary repairs may be made in the case of an open circuit by short circuiting the

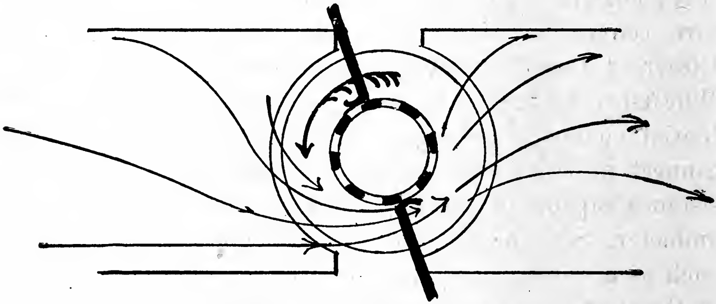


FIG. 455

commutator bars around the open circuit, but this method should only be used in emergency, as the sparking will in time destroy the commutator.

With many dynamos, especially of older types, it is necessary to shift the brushes with every change of load. The current produced by the armature makes a magnet out of it, and the magnetism of the armature opposes that of the fields. In Fig. 454 the armature is working with a very light load and the lines of force of the field magnets are only slightly opposed by those of the armature. In Fig. 455 we assume a heavy load on the dynamo and consequently the magnetism of the armature opposes that of the fields. This changes the location of the neutral point (when the coils under the brush generate no current) and it becomes necessary to shift the brushes accordingly, or great sparking would result. The amount of shifting necessary with changes of load varies in different dynamos. If the field is very strong compared to the armature, it will be but little. If the armature (as in some arc dynamos)

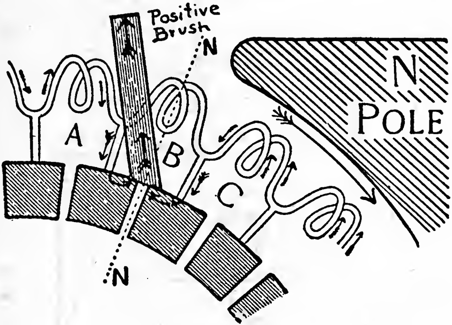


Fig. 456

SHOWING POSITION OF BRUSH FOR SPARKLERS. COLLECTION OF CURRENT is very strong compared to the field, it will be considerable.

In dynamos, with increasing load, the brushes should be shifted in the direction of rotation, and in the opposite direction when the load decreases.

Never allow a dynamo or motor to stand in a damp place uncovered. Moisture is apt to soak into the windings and cause a short circuit or ground when started. Great care should also be used should it ever be found necessary to use water on a heated bearing. If the water is allowed to reach the armature, or commutator, it is bound to cause trouble. Water should only be used in case of emergency, and then sparingly.

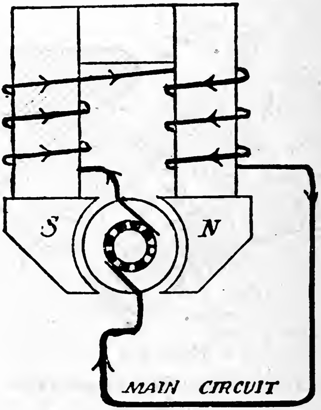


Fig. 457

CIRCUITS IN A SERIES DYNAMO OR MOTOR

Sparking.—When a current is broken there is always a spark, which is greater the more turns in the wire, and the more iron within these turns. That is, the more *inductive* the current the worse the spark.

The conditions are right for excessive sparking in a machine, for the circuit is *inductive* and, although the circuit is not actually broken, the current being merely shifted, yet the result is equivalent to it.

Looking at Fig. 456 and considering the line N N to be about midway between the pole pieces. The coil B is short circuited but has no current in it because:

1. The field is very weak and the coil is moving parallel to it, so no electro-motive force is generated in the coil.

2. The currents from the N- and S-side of winding enter the brush without going through the coil B.

Coil B has therefore no *current* in it, but being connected to A and C whose potential is high, B is *charged* with electricity, and it is full of *coulombs,** which are at rest.

When the armature revolves as shown and the toe of a copper brush leaves bar 3 the current from C must instantly change over going through B to reach the brush. The coulombs in B which are at rest should instantly move at full speed becoming a part of the armature current.

It being impossible to set the coulombs in B into motion instantaneously, it is evident that the current from C encounters *more* than the *ohmic resistance* of the coil B. This extra opposition is called *reactance.*

The path through B being momentarily practically nonconducting, the circuit is broken by the bar moving away from the brush, and a spark or arc formed.

The circuit being *inductive* (having turns containing iron), the spark is persistent and holds until the *reactance* of coil B decreasing, it begins to conduct and diverts enough current into the proper path, and the arc goes out for lack of current to maintain it.

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*A coulomb is a certain quantity of electricity. When a coulomb passes a given point every second a current of one ampere is said to flow.

This *sparking* is avoided in the following way:

1. Carbon brushes of high resistance are used which, as the part of the brush touching a bar gets narrower, due to the high resistance, throttle the current, gradually forcing it over to the coil B. Hence B does not have to instantly carry *all* the current.

2. Move the brushes of a dynamo in direction of rotation until they are nearer the pole shoe, exactly as is shown in Fig. 456.

The short cicuited coil B is now under the *fringe* from the pole piece; and is moving obliquely through a stronger field. A small electro-motive force is generated in it.

From the illustration it will be seen that a current in the same, as in C (for B and C are under influence of same pole piece) flows around through B, the bars 2 and 3 and the brush.

By *shifting* the brushes a little to and fro the correct strength of field can be selected, and the obliquity at which it is cut adjusted, so that a current will be made to flow in B not only of *the same direction as that in C*, but also of exactly the *same value*.

Hence when the toe of the brush slips from bar 3 the current in C instead of running against the *impedance* (the sum of the resistance and reactance) of coil B, finds itself merely falling in behind the flow already established, and there is no tendency to spark.

In a motor the brushes are shifted in opposite direction to the rotation to get the no sparking position. Hence the positions for sparkless forward or backward running are some distance apart.

It is a mere matter of first cost to produce a machine with absolutely *sparkless commutation* under any conditions. It is the skill of the designers which has (without prohibitive cost) so reduced the distance between these two points that it may be spanned by a thick carbon brush.

TYPES OF DYNAMOS.

Dynamos are divided into different types with reference to the manner in which their fields and armature are interconnected.

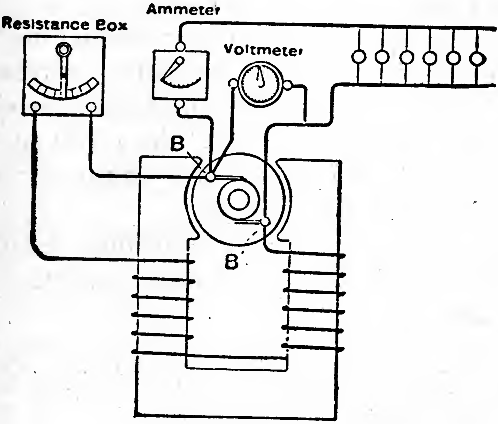


FIG. 458

CIRCUITS OF A SHUNT DYNAMO WITH INSTRUMENTS AND A LOAD OF LAMPS

The series dynamo.—Fig. 457. The same current traverses the field, armature and main or external circuits. The conductors in these circuits are about the same size. The circuits are all in *series.*

This dynamo is used for arc lighting and, as a booster for increasing the pressure on a *feeder* carrying current furnished by some other generator.

The characteristic of this type is to furnish power at an increased voltage as the load increases. If sufficient current is drawn to overload the machine, the voltage will drop.

The shunt dynamo.—Fig. 458. Here the field circuit is arranged as a shunt circuit. The armature and external circuits are in series. The armature current is the sum of the external, and field currents. The conductors on the field are very much smaller than those on the armature, as they carry only 2 to 5 per cent as much current. The shunt dynamo is used for incandescent lamp lighting, and mill and factory power.

The leading characteristic of the shunt generator is to allow the voltage to fall, as the load is increased. It is evident that only by a combination of these two classes into a *compound* dynamo, Fig. 459, can a generator be produced which will deliver any power within its rated capacity, and still hold a steady voltage.

The armature is similar to the armature of the shunt dynamo, but the fields have two distinct windings, one shunt and the other series.

The series dynamo is often called a *constant current* generator because its tendency is that way, and with a regulator it will furnish a constant current.

The shunt dynamo is similarly termed a *constant potential* generator. For with a regulator it will keep to a constant voltage.

If a compound wound dynamo is supplying a circuit at a constant potential it may be almost self regulating. Suppose that the resistance of the external circuit be diminished. This will send more current through the series coil, thus increasing the intensity of the field. But the reduction of the resistance in the outer circuit reduces the current in the shunt winding. This action tends to reduce the intensity of the field.

If the two exciting coils, viz. shunt and series, are properly proportioned, the intensity of the field may be maintained practically constant, even though the resistance of the external circuit is increased or diminished. The armature being kept at a constant speed of rotation, in a constant field of force, by the engine, or other source of power, it will impress upon the circuit a constant voltage. This applies of course to an accurately arranged winding.

Over compounding.—The result of such even action is the maintenance of a constant voltage at the terminals of the machine. In electrical work, all sorts of conditions must be met. A very usual one is that on a circuit a constant voltage is required, not at the generating plant, but in the heart of the district several miles distant. In an over-compounded dynamo the series coil is given a certain number of turns in proportion to the turns in the high resistance shunt coil, and the influence of the series coil overbalances that of the shunt coil. The result of over-compounding is to cause the voltage at the terminals of the machine to rise with the increase of current. The proportional increase of voltage with increase of current can be accurately regulated by the relative sizes of the coils. It is only necessary to follow what has been said regarding the

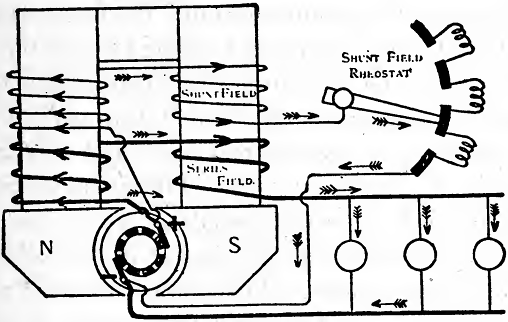


FIG. 459
CIRCUITS IN A COMPOUND DYNAMO

series dynamo, and to regard the compound wound machine as a series dynamo greatly reduced in its characteristic action. Over-compounding makes it possible to maintain a constant voltage at any point within a district. The resistance of the mains between the dynamo in the central station, and the given point in the district is known. The drop in voltage due to that resistance varies with the current. The over-compounding of the machine can be regulated to give the same increase in voltage with the increase in current, and thus the voltage at any desired point in the district can be kept constant, following Ohm's law. Suppose that the resistance of a single lead of the mains is 0.01 ohm. Then the resistance of the two leads is 0.02 ohm. Assuming a maximum current of 500 amperes is needed, the drop due to the specified resistance and current will be $RI=E$, or $0.02\times500=10$ volts. This is an extreme case, but the dynamo by over-compounding can be made to vary its voltage at the terminals in this, or in any other desired proportion to the current. With the resistance given above, and the variation in voltage for the current as calculated above, which variation is at the terminals, a constant voltage would be maintained at the outer portion of the leads. The series field coils of a dynamo can only be excited by the working current, or by a portion of it. When the machine is compound wound, the series coils are taken care of by the machine, but the shunt coils may receive their current from other sources. But in order to make the dynamo self regulating, the shunt coil should be fed from the machine proper. This practice also makes the dynamo self-contained. In some cases the terminals of the shunt coils are connected to the leads, or bus bars of the main circuit, and if several dynamos are operated, and a constant potential maintained in the circuit at all times, a new element is introduced in the excitation of the field, for the reason that the current in the shunt coil is independent of the speed of the dynamo, and the shunt coils continue to excite the field to a certain extent, and this excitation is never reduced to zero until the connection with the bus bar, or main connection is broken. This is a case of under-compounding, and the advantage of it is that it makes it possible to excite the field before starting the dynamo. The field is not only excited, but the correct polarity is established before the armature begins to revolve. The capacity of the shunt coil is considerable, and it cannot with safety be disconnected by a simple opening of a switch. A bank of lamps is generally mounted in series with it, and the field break switch is placed between the lamps and the main circuit. When it is opened the resistance of the lamps prevents undue sparking. The shunt coil may also be excited by an entirely independent source of electric energy, as a storage battery, or an exciting dynamo. The exciting ma-

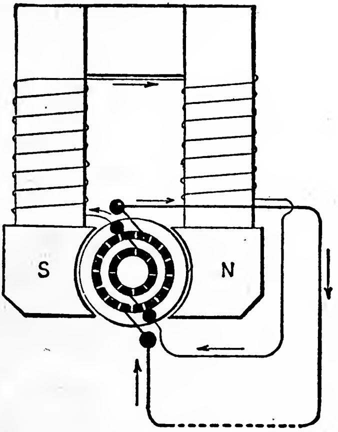


Fig. 460
SEPARATE-CIRCUIT DYNAMO

chine may be run at a constant voltage, thus passing an absolutely constant current through the excited shunt coils.

The separately excited dynamo resembles the magneto in its action, as the field strength does not directly depend upon the current generated. *The separate circuit dynamo* has either two separate armatures in the field space, or it may have two sets of coils. Whichever it is, one armature or coil set is used to excite the field, and the other to supply the current to the circuit. Fig. 460 shows such a dynamo with two commutators, one for supplying the main circuit, and the other the field magnet current.

OPERATION OF DYNAMOS.

Constant Potential Dynamos.—In order to thoroughly explain the operation of dynamos, let us assume that we have the task of starting a new shunt dynamo, one that has never generated any current. Our first step is to open

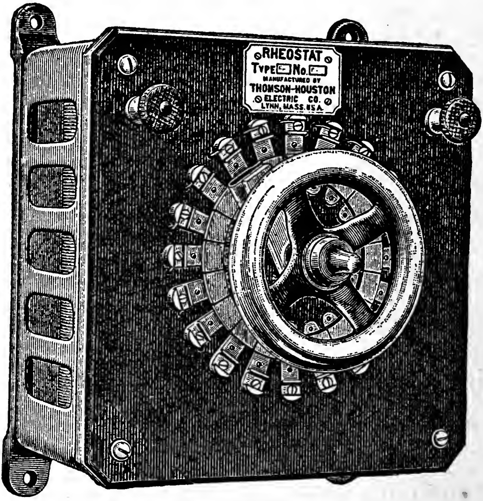


Fig. 461

the main switch and turn the rheostat or field resistance box so that all the resistance is in circuit. A rheostat consists of a number of resistances, Figs. 461 and 462, so arranged that they can be cut in or out of the circuit without opening the circuit. By reference to Fig. 462, it will be seen that the current enters at the handle, and from there passes to the contact point upon which the handle happens to rest. If the handle is at 1 the current must pass through all the wire in the box; if it is at 2 it simply passes through the handle and out.

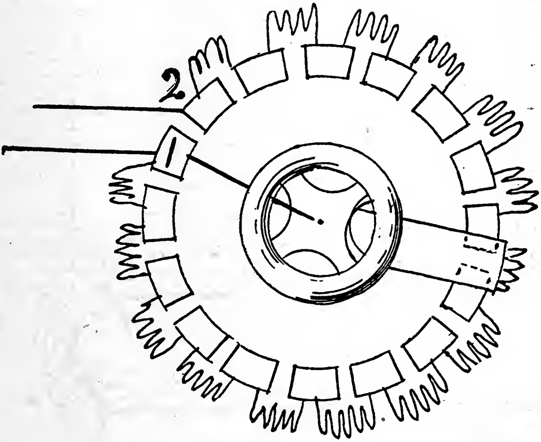


Fig. 462

Rheostats for the shunt circuit of a dynamo should have sufficient resistance, so that when it is all inserted, the voltage of the dynamo will slowly sink to zero. This method of stopping the action of a dynamo is perfectly safe, and should be followed wherever possible.

We are now running our dynamo with all resistance in the shunt circuit. This is simply as an extra precaution because we know nothing about this particular dynamo. When it is known that the dynamo is in good order, the engineer or attendant usually cuts out all the resistance, and as the generator builds up or, in other words, generates current, he proceeds, by the aid of the resistance box, to cut down or diminish the flow of electricity around the field magnets of the dynamo, and thereby diminish the magnetic density of the field magnets, and the electro-motive force of the dynamo.

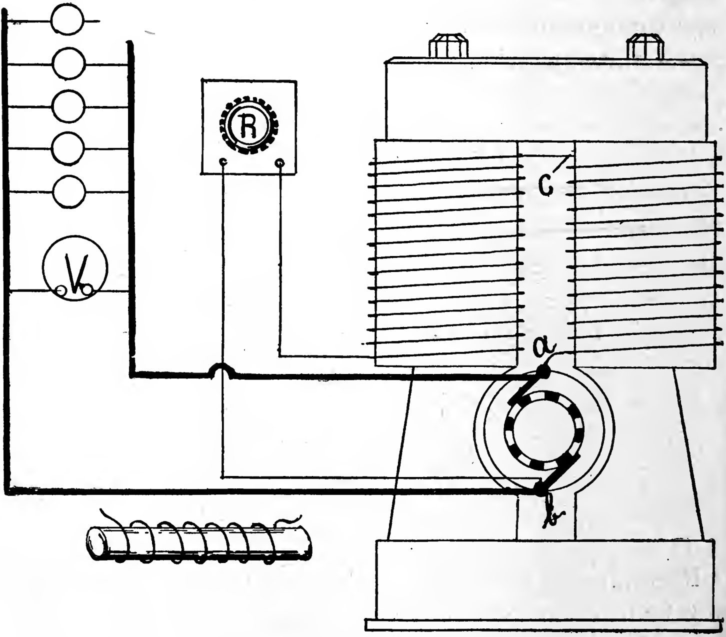


FIG. 463

We must now gradually turn our rheostat so as to cut out resistance, and watch the voltmeter, which is connected as shown at V in Fig. 463, and receives current whenever the dynamo is operating. Suppose that the voltmeter indicates nothing, and we find that the dynamo will not generate. On examination of all the connections we find everything correct, and we now discover that the dynamo field magnets do not contain what is termed "residual magnetism" sufficient to start the process of generating current.

Before an armature can generate current it must cut lines of force, that is, is must revolve in a magnetic field. If the dynamo has been generating current it is likely that the iron cores of the field magnets will retain sufficient magnetism to start the generation of current again. This magnetism which remains in the iron is known as residual magnetism. It will make itself manifest by attracting the needle of a compass, or if strong, a screw driver or a pair of pliers. If we find no magnetism in the iron core of the field magnets, we may take the ends of the shunt winding on the field magnets and pass current over them from a battery. This current will produce sufficient magnetism to cause the generator to build up; in other words, if we disconnect these batteries, and connect the wires back again from where we got them, we will find that we can generate current with the machine.

When the machine begins to generate, we watch the voltmeter, and cut resistance in or out of the circuit according whether we need to lower or raise the voltage. If we have only one dynamo we may close the main switch before we begin generating, or after we have attained full voltage.

Again referring to the pole pieces on the dynamo, it is possible that there is a sufficient quantity of residual magnetism in the pole pieces, and that the polarity of both field magnets, between which the armature is revolving, is the same. This would also cause the dynamo to fail in generating current. If sending battery current through the coils does not make one field a north pole and the other a south pole, one of the fields must be connected wrong and we must make some changes in the connection.

Referring to Fig. 463, *a* and *b* are the terminals of the shunt winding on the fields. If the winding of the fields is correctly put on it will be as in the little sketch at lower corner; that is, if both field magnets were taken out of their places and put together, the winding should run as one continuous spool. But if the winding on one field is wrong, we need simply change its connection, as, for instance, transferring *c* to *a* and *a* to *c*.

In order that a dynamo may excite itself, it is necessary that the current produced by the residual magnetism shall flow in such a direction as to strengthen this residual magnetism. If the current poduced by the residual magnetism flows through the field coils in the opposite direction, it will tend to weaken the residual magnetism, and consequently to reduce the current which flows.

For this reason if the first attempt to start a dynamo with battery current fails, the battery should be applied with the opposite poles so that the magnetism it produces in the fields will be in the opposite direction.

The magnetism, the fields, and all parts of the dynamo may be in perfect working order, and yet a short circuit in any part of the wiring will prevent the dynamo from building up. This short circuit will furnish a path of such low resistance that all current will flow through it and none can flow through the fields to induce magnetism. Often dynamos fail to generate because of broken wires in the field coils, poor contacts at brushes, or loose connections. Sometimes also part of the wiring may be grounded on the metal parts of the dynamo frame. A faulty position of the brushes may also be a cause for the machine not generating. In some machines the proper position for the brushes is opposite the space between the pole pieces, while in other machines their proper position is about opposite the middle of the pole piece. If the exact position is not known, a movement of the brushes will sometimes cause the generator to build up.

If there are several dynamos to be started great care must be taken to see that the second machine is operating at full voltage before the switch is closed connecting it to the switch board. The voltage should be exactly the same as that of the first machine and the rheostat worked to keep it so. If it is less, it is possible that the first machine will run the second as a motor; if it is more, the second machine may run the first as motor, the machine having the higher voltage will always supply the most current.

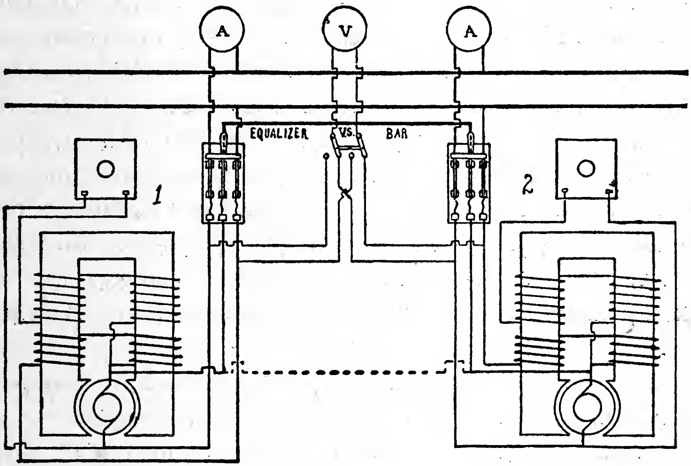


Fig. 464

It is also necessary before throwing in the second machine (connecting it to the switch board) to see that its polarity is the same as that of the machine with which it is to be run. By reference to Fig. 464 it will be seen that the + poles of both machines connect to the same bar, and if one of these machines is running and we wish to connect the other with it, we must first be sure that the wire of the second machine which leads to the top bus-bar is of the same polarity. That is, if the top bus-bar is positive, or sends out current, the wire of all dynamos connected to it must also be positive. The simplest way to find the positive pole of a dynamo is with a cup of water. Take two small wires and connect one to each of the main wires of the dynamo and then insert the bare ends of both wires into the water, small bubbles will soon be seen to rise in the water from one of the wires. That wire which gives off the bubbles is the negative wire. Take care that in making this test you do not get the ends of the small wires together or against the metal of the cup or you will form a short circuit. The polarity of both dynamos must be tested and wires of same polarity connected to the same bus-bar.

Where several machines are to be operated in parallel, compound dynamos are generally used, because it is troublesome to keep two shunt machines working in harmony.

The starting of a compound wound dynamo is the same as that of a plain shunt dynamo, but in connecting a compound wound dynamo to its circuit it is necessary to be sure that the shunt coils and series coils tend to drive the lines of force around the magnetic circuit in the same direction. If the series coil is connected up in the opposite direction to the shunt coil the dynamo will build up all right, and will work satisfactorily on very light loads. When, however, the load becomes even, five or ten per cent. of full load, the voltage drops off very rapidly, and it is impossible to get full voltage with even half the load on. This is because the ampere turns due to the series coils decrease the total ampere turns acting on the magnetic circuit instead of increasing them as the load comes on. This lowers the magnetic flux and of course lowers the resulting voltage. In such a case it will be necesary to reverse either the field or series coils.

Fig. 464 shows connections for two compound wound dynamos run in parallel. When two or more compound wound dynamos are to be run together, the series fields of all the machines are connected together in parallel by means of wire leads or bus-bars which connect together the brushes from which the series fields are taken. This is known as the equalizer, and is shown by the line running to the middle pole of the dynamo switch. By tracing out the series circuits it will be seen that the current from the upper brush of either dynamo has two paths to its bus-bar. One of these leads through its own fields, and the other, by means of the equalizer bar, through the fields of the other dynamo. So long as both machines are generating equally there is no difference of potential between the brushes of No. 1 and No. 2. Should, from any cause, the voltage of one machine be lowered, current from the other machine would begin to flow through its fields and thereby raise the voltage, at the same time reducing its own until both are again equal. The equalizer may never be called upon to carry much current, but to have the machines regulate closely it should be of very low resistance. It may also be run as shown by the dotted lines but this will leave all the machines alive when any one is generating. The ammeters should be connected as shown. If they were on the other side they would come under the influence of the equalizing current and would indicate wrong, either too high or too low. The equalizer should be closed at the same time, or preferably a little before the mains are closed. In some cases the middle, or equalizer, blade of the dynamo switch is made longer than the outside to accomplish this.

The series fields are often regulated by a shunt of variable resistance.

To insure the best results compound machines should be run at just the proper speed, otherwise the proportions between the shunt and series coils are disturbed.

GENERAL RULES.

1. Be sure that the speed of the dynamo is right.

2. Be sure that all the belts are sufficiently tight.

3. Be sure that all connections are firm and make good contact.

4. Keep every part of the machine and dynamo room scrupulously clean.

5. Keep all the insulations free from metal dust or gritty substances.

6. Do not allow the insulation of the circuit to become impaired in any way.

7. Keep all bearings of the machine well oiled.

8. Keep the brushes properly set, and see to it that they do not cut, or scratch the commutator.

9. If the brushes spark, locate the trouble and rectify it at once.

10. The durability of the commutator and brushes depends on the care exercised by the person in charge of the dynamos.

11. At intervals the dynamos must be disconnected from the circuit and thoroughly tested for leakage and grounds.

12. In stations running less than twenty-four hours per day, the circuit should be thoroughly tested and grounds removed (if any are found) before current is turned on.

13. Before throwing dynamos in circuit with others running in multiple, be sure the pressure is the same as that of the circuit; then close the switch.

14. Be sure each dynamo in circuit is so regulated as to have its full share of load, and keep it so by use of resistance box.

15. Keep belting in good order; when several machines are operating in parallel and a belt runs off from one, the others will run this machine as a motor.

16. In the same way if you shut down an engine driving a generator, the other generators will run the generator and the engine.

Constant Potential Switchboard.—Fig. 465 illustrates the usual type of switchboard employed to connect, or switch various dynamos, and to feed various circuits from. These types, sizes and arrangements of switchboards vary, and depend entirely on the type and size of the plant, the number of dynamos used and the number of circuits to be controlled. The switchboard in this cut has three dynamo panels, and one load panel. At the left of the board and near the top is the voltmeter, while on the three left panels are the dynamo main switches and their respective ammeters. On the lower part of these three machine panels will be noticed the protruding hand wheels of the field resistance boxes, which are hidden back of the board. The meter at the top of the right hand panel is the load ammeter and registers the total number of amperes that are being supplied to the circuits whose several switches are just below the meter.

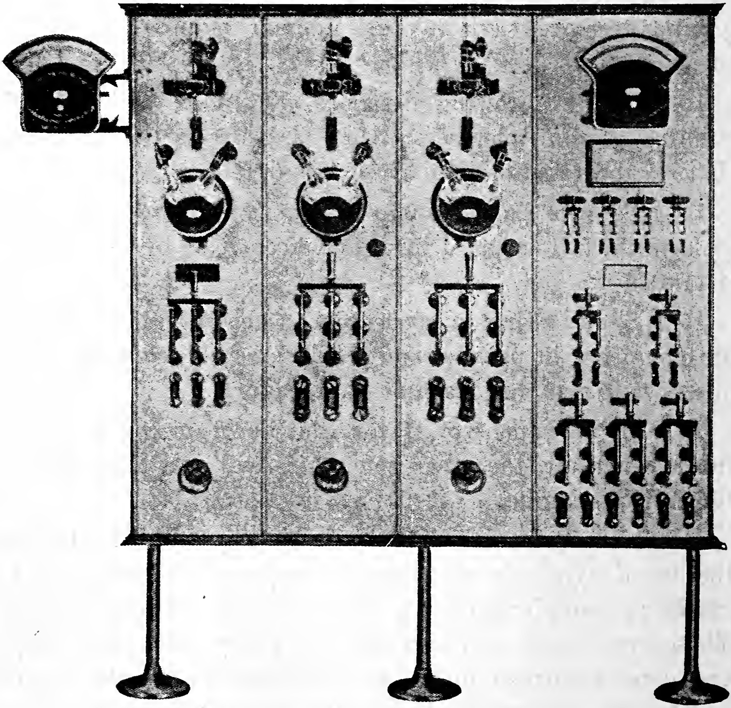


Fig. 465

Fig. 466 shows diagrammatically the reverse side of a similar switchboard. Below all of the switches there are installed fuses in each wire. The object of these fuses is to protect the wires and also the dynamos. These fuses consist of an alloy which melts at a comparatively low temperature. If, for instance, a short circuit occurs in any line, the current will suddenly become very strong and will generate considerable heat. This heat will cause the fuse to melt and open the circuit. If the fuse did not melt, the current would continue and overheat the wires, causing considerable damage and perhaps fires. The fuses should always be chosen of such a size that they will melt before the current rises enough to do any damage.

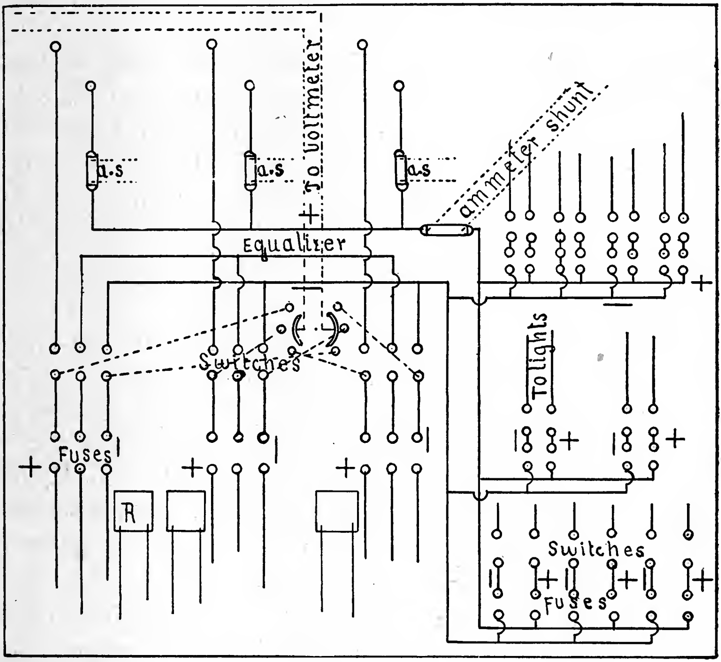


FIG. 466

Operation of Constant Current Dynamos.—Constant current dynamos differ from constant potential dynamos mainly in the higher voltage for which they are usually constructed. Such machines are always more or less dangerous to life, and great care must be taken not to touch any of the current-carrying parts with bare hands.

When such parts must be handled, rubber gloves are very convenient and useful if kept dry. High voltage machines should always be surrounded by insulating platforms of dry wood, or rubber mats, so arranged that one must stand on them in order to touch any part of the machine. By reference to Fig. 467 it will be seen that the constant current dynamo is not equipped either with a voltmeter or a field rheostat; but an ammeter should always be used. The troubles encountered with these dynamos are much the same as those of constant potential dynamos. Most of them are referred to in the following descriptions and instructions for different systems and to avoid repetition need not be mentioned here.

The type of dynamo generally used with constant currents is shown in Fig. 467 and is series wound; that is, the same current that passes through the lights and outer circuit also passes through the fields and excites them. The fields of this dynamo are connected with a short circuiting switch S, which is generally used when the machine is to be shut down. When this switch is closed it forms a path of much lower resistance than do the fields of the dynamo, and all current passing through it and the dynamo loses its magnetism and stops generating. A constant potential dynamo will not begin generating if there is a short circuit anywhere in the wiring connected with it, but with the constant current dynamo it is often necessary to provide a short circuit in order to start it. If there is very much resistance in the line, or if it is entirely open the dynamo will fail to generate.

In order to start generation a small wire may be attached to one of the terminals of the dynamo and the other end brought in contact with the other terminal for a fraction of a second or the shortest possible instant. If the circuit happens to be arranged somewhat as shown in Fig. 467, the plug may be inserted so that the dynamo is started through only one lamp. When this lamp is burning properly the plugs may be suddenly withdrawn

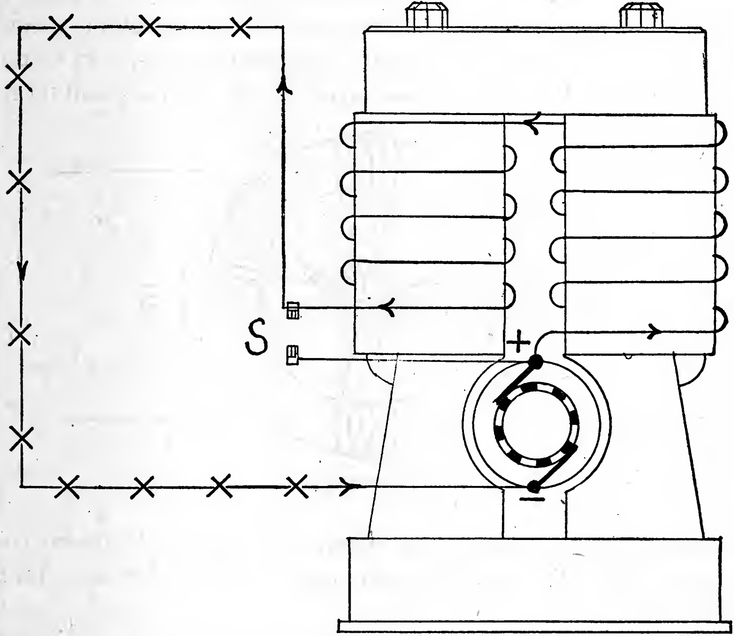


Fig. 467

and the current will now force itself through the other lamps. This process is known as "jumping in" and should be used only in an emergency, as much damage may be caused, especially if a dynamo is already running a large number of lamps and is then "jumped into" a bad circuit. This is also often done, but is just as dangerous as it would be to attempt to start a heavy steam engine by opening up the throttle valve with a quick jerk.

Constant current dynamos are, or should be always equipped with automatic regulators, and before the dynamo is started special attention must be given the regulator to see that it is in proper working order.

Often it may be desirable and even necessary to run two dynamos in series, as, for instance, if a circuit has been extended beyond the capacity of one machine. In such a case the regulator of one machine is cut out, and that machine set to operate at about its highest electromotive force, and the variations are taken care of by the other dynamo.

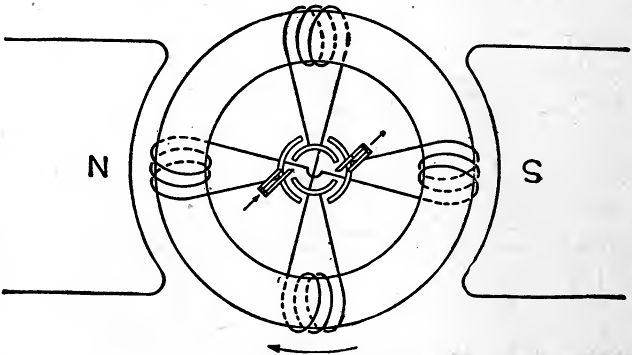


Fig. 468

The Brush System.—The brush arc dynamo is quite distinct from other constant current dynamos in general use. The brush arc generator is of the open coil type, the fundamental principle of which is illustrated in Fig. 468. Two pairs of coils, placed at right angles on an iron core, are rotated in a magnetic field. The horizontal coils represented in the diagram are producing their maximum electromotive force, while the pair of coils at right angles to them is generating practically no electromotive force. The brushes are placed on the segments of the four-part commutator, so as to collect only the current generated by the two horizontal coils. The other coils are open circuited or completely cut out of the circuit.

Such a machine will generate current, continuous in direction, but fluctuating considerably in amount. These fluctuations will be diminished by the addition of more coils to the armature.

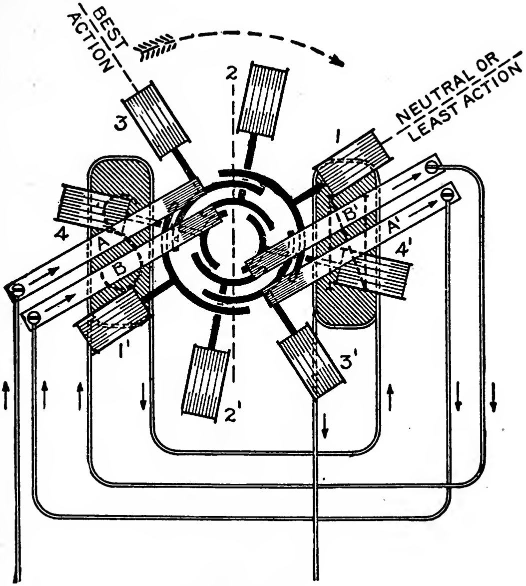


FIG. 469

Fig. 469 shows the connections of an eight-coil brush arc generator. Each bobbin is connected in series with the one diametrically opposite. The connection is not shown on the diagram. It will be noticed that of those coils connected to the outer ring on which the brushes A and A^1 bear, only 3, 3^1 are in circuit, 1, 1^1 being entirely cut out; while on the inside ring all coils 2, 2^1 and 4, 4^1 are in circuit, the two pairs being parallel; 4, 4^1 are coming into the field of best action; in other words, they are approaching that part of the field in which there is most rapid change of magnetic flux, while 2, 2^1 are approaching that part in which the flux is uniform. In 4, 4^1 there is an increasing electro-motive force being generated, and the current is rising; while in 2, 2^1, the electromotive force is decreasing and the current falling. Unless 2, 2^1 were cut out of the circuit a point would soon be reached where the electromotive force in 2, 2^1 would be zero, and consequently 4, 4^1 would be short circuited through 2, 2^1. Just before this occurs, however, 2, 2^1 have passed from under the brush, and the small current still flowing draws out the spark seen on the commutator of all open coil machines.

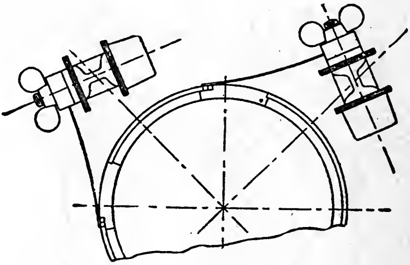


Fig. 470

Setting the Brushes.—A pressure brush should always be used over the under brush in the same holder, as it improves the running of the commutator and secures better contact on the segment. The combination is referred to as the "brush." The brushes should be set about 5⅛ in. from the front side of the brass brush-holder.

In setting the brushes, commence with the inner pair and set one brush about 5⅛ in. from the holder to tip of the brush, then rotate the rocker or armature until the tip of the brush is exactly in line with the end of a copper segment, as shown in Fig. 470. The other brush should be set on the corresponding segment 90° removed (the same relative position on the next forward segment); but if the length of the brush from the holder is less than 5⅛ in., move both brushes forward until the length of the shorter brush from the holder is 5⅛ in. Now set the two extreme outer brushes in the same manner, clamping firmly in position, and by using a straight edge or steel rule, all the brushes can be set in exactly the same line and firmly secured. The spark on one of the six brushes may be a trifle longer than on the others. In this case, move the brush forward a trifle so as to make the sparks on the six brushes about the same length. Equality in the spark lengths is not essential, but it gives at a glance an indication of the running condition of the machine.

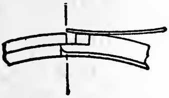


FIG. 471

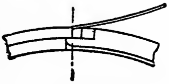


FIG. 472

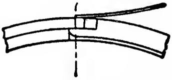


FIG. 473

Brushes should not bear on the commutator less than ⅛ in. from the point of the brush, or, as illustrated in Fig. 471, they will tend to drop into the commutator slots and pound the copper tip of the wood block, causing the fingers of the brushes to break off. If, on the other hand, the bearing is too far from the end, or the brushes are set too long, as in Fig. 472, the point of the brush will not be in contact with the segment, thereby prolonging the break, and allowing the spark to follow the tip with consequent burning of the segments and brushes.

Fig. 473 shows correct setting with the tip of the brush nearly tangential and stiff on the segment as it leaves.

Care of Commutator.—If the commutator needs lubrication, oil it very sparingly. Once or twice during a run is ample. If the oil has a tendency to blacken the commutator instead of making it bright, wipe the commutator with a dry cloth. Too much oil causes flashing.

The machine, of course, generates high potential, and the cloth, or whatever is used to oil the commutator, should therefore be placed on a stick so that the hand is not in any way between the brushes.

A rubber mat should be provided for the attendant to stand on when working around the commutator or brushes.

One hand only should be used, and great care exercised not to touch two brush clamps or brushes at the same time; never with switches closed.

As soon as current is shut off from the machine the commutator should be cleaned. A piece of very fine sandpaper held against the commutator under a strip of wood for about a minute before the machine is stopped, will scour the commutator sufficiently. The brushes need not be removed. An effort should be made to have the machine cleaned immediately after it is shut down. Five minutes at that time will give better results than half an hour when the machine is cold. Never use a file, emery cloth or crocus, on the commutator. New blocks will sometimes cause flashing, due to the presence of sap in the wood. The machine should be run for a few hours with a slightly longer spark, say ½ in., and the commutator then thoroughly cleaned with fine sandpaper.

All constant current arc machines require an automatic regulator to increase the voltage as more lamps are cut into the circuit, and decrease it as lamps are cut out.

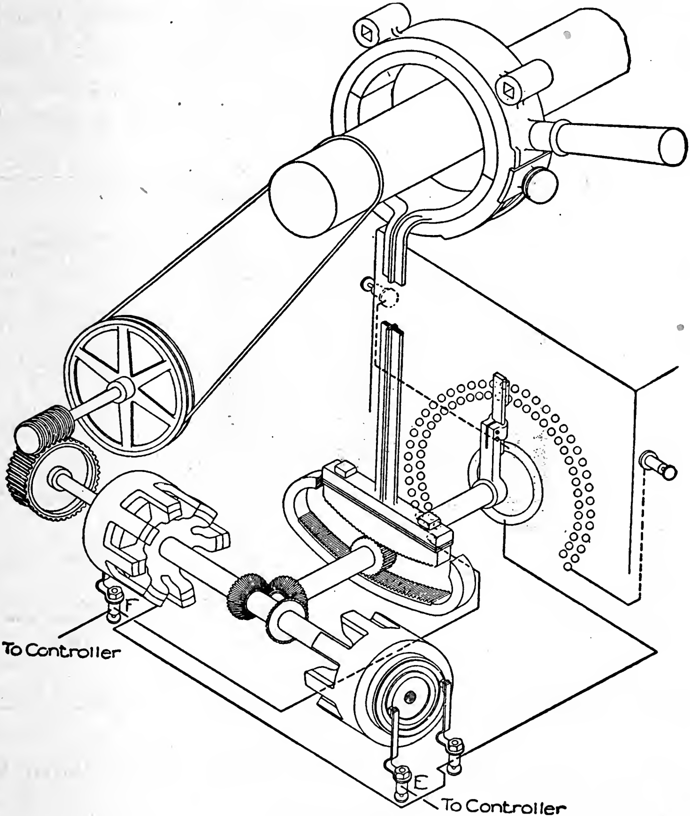
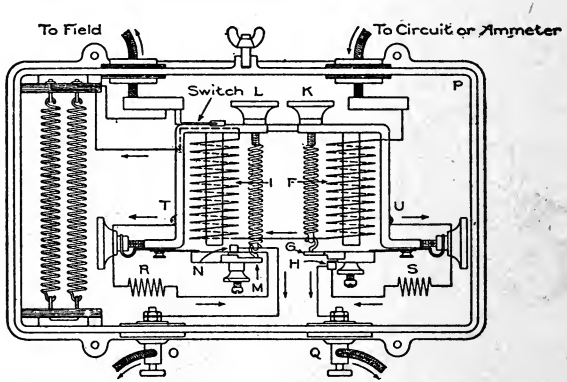


FIG. 474

We will give only one of the several forms of regulators used with this system.

The form 1 regulator is placed on the frame of the machine beneath the commutator, and a constant motion is imparted to its main shaft through a small belt running around the armature shaft. (See Fig. 474.) By means of magnetic clutches and bevel gears, a pinion shaft is rotated, which moves the rack and the rocker arm and so shifts the brushes on the commutator to maintain a spark of about 3/8 in. on short circuit and 1/8 in. at full load; at the same time the rheostat arm is moved over the contacts to cut resistance in, or out of the shunt around the field circuit.

CONNECTIONS OF BRUSH CONTROLLER



To Clutch at F for Clockwise.
To Clutch at E for Counter Clockwise.

To Clutch at E for Clockwise.
To Clutch at F for Counter Clockwise

Changed 6 June '98.

FIG. 475

The current for the magnetic clutches is regulated by the controller.

The controller consists principally of two magnets which are energized by the main current, and act when the current is too high or too low by sending a small current to one of the clutches.

A careful examination of the controller (see Fig. 475). in connection with Fig. 474, will give a clear idea of its regulating action. It is generally advantageous to make the yoke which carries the brushes on the machines, and the arm moving the rheostat, rather tight. As the magnetic clutches act with considerable force, it is not necessary to adjust these moving parts so loosely that they will move without considerable pressure on the rocker handle. Less difficulty will then be experienced in adjusting the controller.

For shunt lamps, the controller may be adjusted to permit a variation of .4 ampere above or below normal; for differential lamps, the variation above and below normal should not exceed .2 ampere. The limits given in the following instructions are for differential lamps, and may be extended .2 ampere above or below for shunt lamps.

If the controller is out of adjustment and fails to keep the current normal, do not try to adjust the tensions of both armatures at the same time. For example, suppose the current is too high, either one of the two spools may be out of adjustment. The left-hand spool I may not take hold quickly enough, or the spool F may take hold too quickly. To make the adjustment, screw up the adjusting button K on the right hand spool, increasing the tension. This will have a tendency to let the current fall much lower before the armature comes in contact with H, to cause the current to increase. By simply tapping the armature G quickly with a pencil or piece of wood, forcing it down to its contact, and at the same time watching the ammeter, the current may be brought up to 6.8 amperes if 6.6 amperes is normal, or to 9.8 if 9.6 amperes is normal. With the current at 6.8 amperes, which is .2 amperes high, the adjusting button L should be turned to increase the tension on this spring until the armature M comes in touch with contact N, which will force current down through O.

The clutch which pulls the brushes forward and rocks the rheostat back for less current will thus be energized. Repeat this adjustment two or three times, but do not touch the adjusting button K; adjust L until it is just right.

At the side of the armature M a little wedge is screwed in by means of an adjusting button, and increases or decreases the leverage on this armature. See that this wedge is fairly well in between the core or frame of the spool and the spring of the armature. The armature M may have to be taken out and the spring slightly bent. It is advisable to have the screw which passes through the adjuster button L about half way in, to allow an equal distance up and down for adjusting this lighter spring after the wedge shaped piece is in the right position to give the necessary tension on the spring which is fastened to the armature M.

In the right-hand corner P, a small bent piece of wire is placed for tightening up the screw which fastens the spring to the frame of the spool. As the contact made by the spring and the frame of the spool held together by a screw and button is a part of the magnetic circuit, it will be almost impossible to get this spring back to exactly the same tension after once removing it. Therefore, the adjusting buttons of the controller must be turned slightly in order to bring it back to its proper adjustment. This, however, is an after consideration, and care should be taken to have the screw which holds the spring and frame together always tight.

Having adjusted the spool I so that the current will not rise above 6.8 amperes (or 9.8 amperes), move the armature M up to contact N with a pencil or piece of wood, causing the current to be reduced to about 6.2 (or 9.2). After the current settles at this point, decrease the tension on the spring which is fastened to armature G, allowing this armature to fall down to contact H. Current will then flow through Q, which will rock the brushes back and also move the rheostat arm for more current. As the spool I has been adjusted for 6.8 (or 9.8) amperes, the current cannot rise above that amount no matter how the spool F is adjusted.

With very little practice in moving the armature of one spool with a pencil, the other can be adjusted much more readily than if an attempt is made to adjust the screws K and L at the same time.

The two small shunt coils R and S, are connected around the two contacts simply to decrease the spark between the silver and platinum contacts. If they should become short circuited in any way, so that their resistances become diminished, sufficient current may pass through either of them to operate the regulator. If unable to locate the trouble disconnect these coils at points T and U, when a thorough examination can be made. M and G need not move more than just enough to open the contact; $\frac{1}{32}$ in. is ample.

In starting the machine, the lower switch, which short circuits the field, should be opened last.

The switch in the left-hand corner of the controller, Fig. 475, cuts out the two resistance wires which are used to force the current through wires O and Q to the clutches. Open this switch, which leaves the automatic device of the controller in circuit, so that it will move the brush rocker. Unclamp the brush rocker from the rheostat arm rocker. Move the brushes by hand to give the proper spark, allowing the rheostat arm, however, to be moved by the controller. After the switches are opened, the rheostat arm will go clear around to a full load position, and then, as the current rises, the controller takes hold and brings the arm back. In the meantime, rock the brushes forward or backward and keep the spark about the proper length, say 1/8 in., at full load to 3/8 in., on short circuit. Gradually the rheostat arm will settle, the spark will become constant, and the machine will give its proper current. Then clamp the rocker and rheostat arm together and let the machine regulate itself.

This method is much better than opening the switches on the machine, and allowing the wall controller to take care of the machine from the start. By allowing the controller to start the machine, a trifle longer spark is obtained than by the other method, unless the machine is run from the beginning on a very full load.

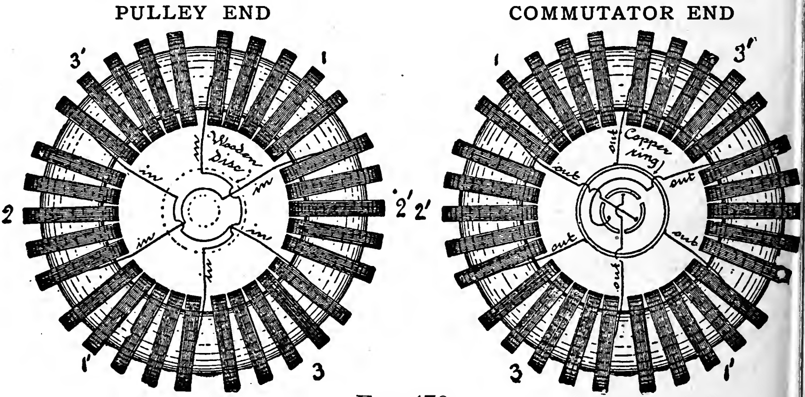


Fig. 476

The machine will require a trifle longer spark on light load, or on bad circuits, than when running at full load. This fact shuld be borne in mind in wet weather, when trouble with grounds is experienced.

A reliable ammeter should always be connected in the circuit of an arc generator, so that the exact current may be read at a glance. It should be connected into the negative side of the line where the circuit leaves the regulator.

The Thomson-Houston System.—The Thomson-Houston dynamo differs from other arc dynamos principally in the nature of its armature winding. This is shown in Fig. 476. One end of each of the three coils is connected to a copper ring common to all. The other end of each coil terminates at one of the three commutator segments.

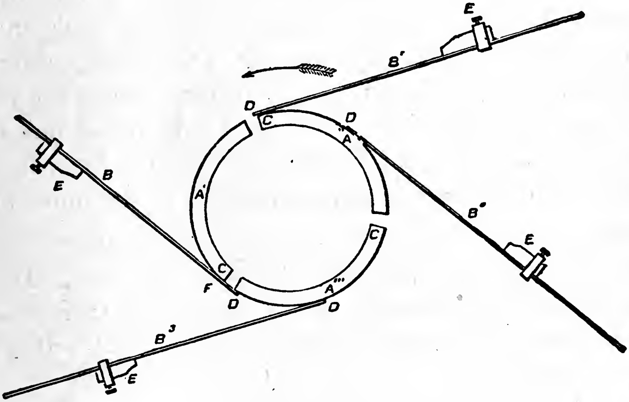


FIG. 477

The following instructions regarding the management, and operation of this machine may prove useful:

Setting the Cut-out.—After the brushes are in position the cut-out must be set. This is done by turning the commutator on the shaft in the direction of rotation (if the commutator is set in position the whole armature must be revolved) until any two segments are just touching the primary brush on that side, as segments A′ and A‴ touch brush B^4 in Fig. 477.

Under these conditions brush B¹ should be at the left-hand edge of upper segment. Then turn commutator until the same two segments are just touching brush B², when the end of Brush B³ should just come to the right-hand edge of the lower segment. If the secondary brush projects beyond the edge of the segment the regulator arm should be bent down; if it does not come to the edge of the segment, the arm should be bent up.

Care must be taken that the regulator armature is down on the stop when the cut-out is being set. These adjustments by bending regulator arm are always made in the factory before testing the machine, and should never be made on machines away from the factory, unless the regulator arm has been bent by accident. If it becomes necessary to make any adjustments they should be made by means of the sliding connection attached to the inner yoke.

Always try the cut-out on both primary brushes. If it does not come the same on both, turn one over. If the brush-holders are correctly set by the guage, there should be no trouble in getting the cut-out set properly after one or two trials.

To set the commutator in the proper position on a right-hand machine, with a ring armature, find the leading wire of No. 1 coil, Fig. 476. It is the custom in the factory to paint this lead red, also to paint a red mark on the center band between two groups of coils, namely, the last half of No. 1 coil and the first half of No. 3 coil. The first half of a coil is that group from which the lead comes. The last half is diametrically opposite the first half, and the lead wire belonging to it is connected with the brass ring on the outside of the connection disk on the commutator end.

In Fig. 478, the first halves of the three coils are represented by 1, 2 and 3, and the last halves by 1′, 2′ and 3′.

A narrow piece of tin with sharply pointed ends is bent up over the sides of the middle band at the center of the red mark so that the points are opposite each other.

When the red mark and red lead have been found, turn the armature until the last half of No. 1 coil has wholly disappeared under the left field and until the left-hand edge of the first coil to the right of the red mark (No. 3 in Fig. 478) is just in line with the edge of the left field. The red lead will then be in position shown in Fig. 478 and the armature is in proper position to set the commutator.

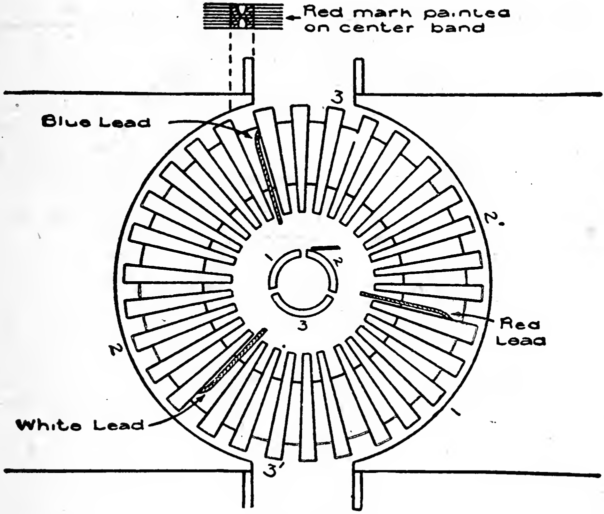


Fig. 478

In the case of the right-hand drum armature, the leading wire of the first coil should be found. This lead may be recognized from the fact that it is more heavily insulated than the rest, and is found in the center of the outer coil, on the commutator end. With this wire turned underneath, rotate the armature forward, or counter-clockwise, until the pegs on the right-hand side of this coil just disappear under the left field. (See Fig. 479.)

The position of the red lead and the red mark on the band are the same on all armatures, but their positions in the fields of the machines called left-hand (clockwise rotation), should be as shown in Figs. 480 and 481 when setting the commutator.

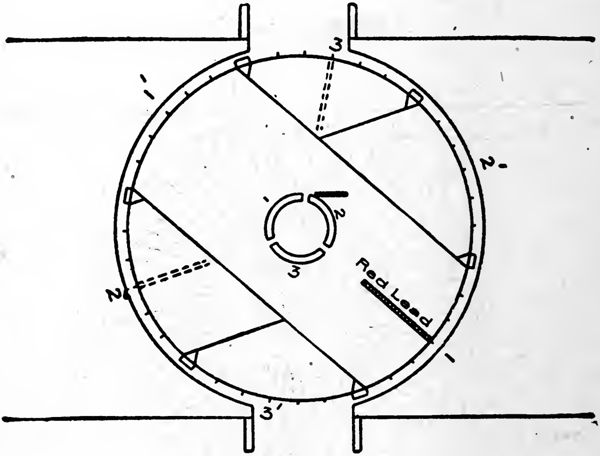


Fig. 479

When the armature of a right-handed machine is in position, the commutator is turned on the shaft until segment No. 1 is in the same relative position as the last half of No. 1 coil; segment No. 2 should correspond with the last half of No. 2 coil, and segment No. 3 with the last half of No. 3 coil, as shown on Figs. 478 and 479.

For left-hand machines, see Figs. 480 and 481.

The distance from the tip of the brush, which is on top, to the left-hand edge of No. 2 segment on a right-hand machine, or to the right-hand edge of No. 3 segment in a left-hand machine is called the lead, and should be made to correspond with the following table.

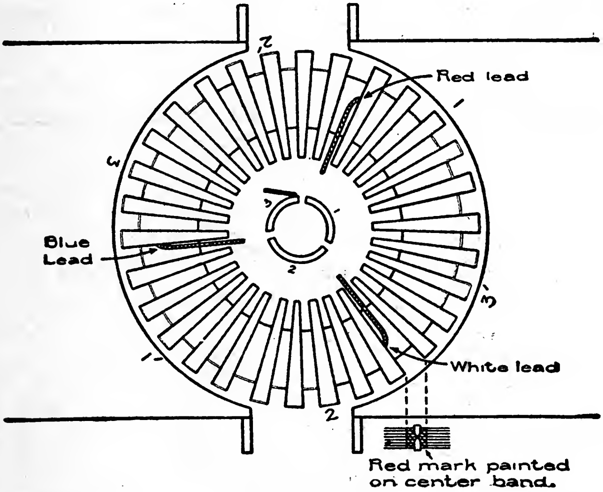


FIG. 480

TABLE OF LEADS.

DRUM ARMATURES.	
C^{12}	¼ inch positive
C^{2}	⅜ inch positive
E^{12}	$\frac{7}{16}$ inch positive
E^{2}	¼ inch positive
H^{12}	¼ inch positive
H^{2}	¼ inch positive

RING ARMATURES.	
K^{12}	$\frac{3}{16}$ inch positive
K^{2}	⅛ inch positive
M^{12}	¼ inch negative
M^{2}	½ inch negative
LD^{12}	¼ inch positive
LD^{2}	⅛ inch positive
MD^{12}	$\frac{13}{32}$ inch positive
MD^{2}	$\frac{13}{32}$ inch positive

Place the screws in the binding posts at the lower ends of the sliding connections, and put on the dash pot connections between the brushes, with the heads of the connecting screws outward. In every case the barrel part of the dash pot is connected to the top brush-holder, and plunger part to the bottom brush-holder.

See that the field and regulator wires are connected and that all connections are securely made.

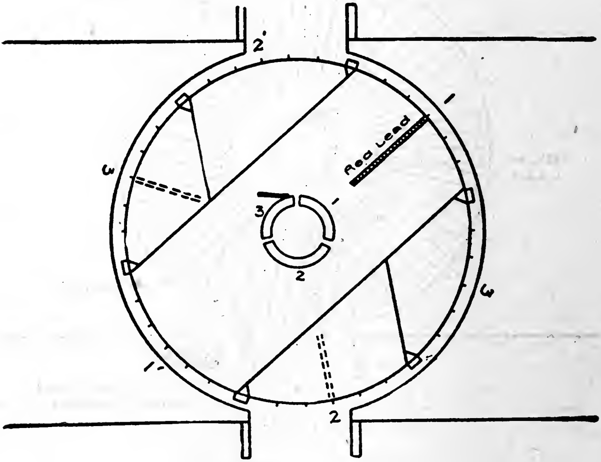


Fig. 481

When all connections have been made, make a careful examination of screws, joints and all moving parts. They must be free from stickiness, and bind in any position.

To determine when the machine is under full load, notice the position of the regulator armature, which should be within ⅛ in. of the stop. At full load the normal length of the spark on the commutator should be about 3/16 in. If it is less than this, shut down the machine and move the commutator forward or in the direction of rotation until the spark is of the desired length. If the spark is too long, move the commutator back the proper amount.

A general view of the complete dynamo is given in Fig. 482, and will help explain the regulator used with this system.

The regulator is fastened to the frame of the machine by two short bolts. On the right-hand machine its position is on the left-hand side, as shown in Fig. 482. On the left-hand machine, *i. e.*, one which runs clockwise, its position is on the opposite side. Before filling the dash pot D with glycerine, see that the regulator lever and its connections, brush yokes, etc., are free in every joint, and that the lever L can move freely up and down. Then fill the dash pot D with concentrated glycerine. The long wire

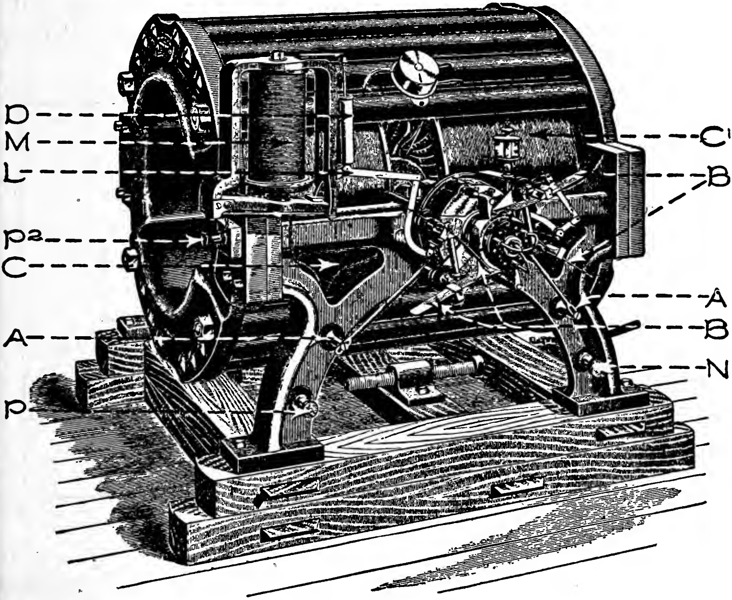


FIG. 482

from the regulator magnet M is connected with the left-hand binding post P of the machine, and the short wire with the post P^2 on the side of the machine. The inside wire of the field magnet, or that leaving the iron flange, of the left-hand field should be connected into post P^2 also, as shown in Fig. 482. The electric circuit (see Fig. 483) should be complete from post P^1, on the controller magnet, through the lamps to the post N on the machine, through the right-hand field magnet C, to the brushes B^1B^1, through the commutator and armature to the brushes B B, through the left-hand field C, to posts P^2 and P, thence to posts P^2 and P on the controller magnet, through the controller magnet to P^1. The current passes in the direction indicated by the arrows.

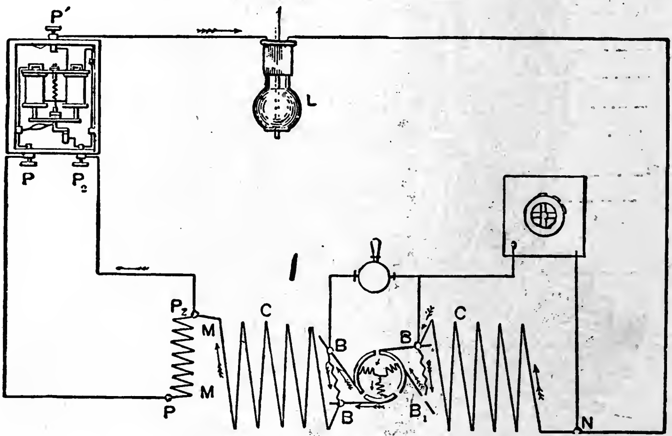


FIG. 483

When an arc machine is to be run frequently at a small fraction of its normal capacity, the use of a light load device is advisable to secure the best results in regulation.

The rheostat for this purpose (see Fig. 484) is connected in shunt with the right field of the generator. Facing the rheostat with the right binding posts at the bottom, the contact on the right side or No. 1 gives open circuit and throws the rheostat out of use. Point No. 2 gives a resistance of 44 to 46 ohms and Point No. 3 gives a resistance of 20 to 22 ohms.

This rheostat with a 75-light machine allows the following variations: Point 1, 75 to 48 lights; Point 2, 48 to 25 lights; Point 3, 25 lights or less. For use with other sizes of generators, the adjustment of the rheostat must be made to suit the conditions.

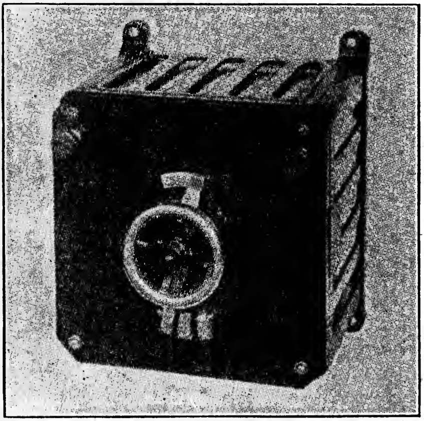


FIG. 484

When the rheostat is in use, the sparks at the commutator will be somewhat larger than normal, but will not be detrimental.

The controller magnet (see Fig. 485) is to be fastened securely by screws to the wall or some rigid upright support, taking care to have it perfectly plumb. It is connected to the machine in the manner shown in Fig. 482, i. e., the binding Post P^2 on the controller magnet is connected to the binding post P^2 (see Fig. 482) on the end of the machine, and likewise the post P on the controller to the post P on the leg of the machine; the post P^1 forms the positive terminal from which the circuit is run to the lamps and beck to N.

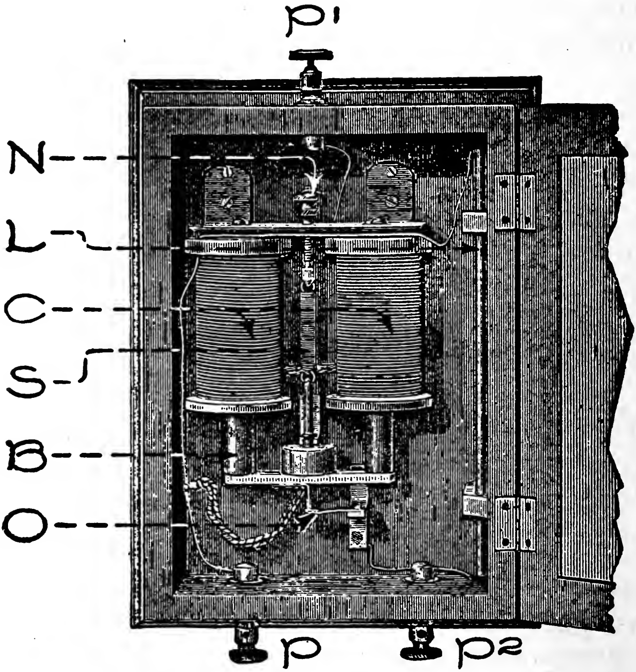


FIG. 485

Great care should be taken to see that the wires P P and P^2 P^2 are fastened securely in place; for if connection between P and P should be impaired or broken, the regulator magnet M would be thrown out of action, thus throwing on the full power of the machine, and if the wire P^2 P^2 should become loosened, the full power of the magnet M would be thrown on, and the regulator lever L, rising in consequence, would greatly weaken or put out the lights.

The wires leading from the controller magnet to the machine should have an extra heavy insulation.

Care should be taken in putting up the controller magnet that the following directions are followed:

1. The cores B of the axial magnets C C must hang exactly in the center, and be free to move up and down.
2. The screws fastening the yoke or tie pieces to the two cores must not be loosened.
3. The contacts O must be firmly closed when the cores are not attracted by the coils C C, which is the case, of course, when no current is being generated by the machine, and when the cores are lifted, the contacts must open from 1/64 in. to 1/32 in.; a greater opening than 1/32 in. has the effect of lengthening the time of action of the regulator magnet. This tends to render the current unsteady, and in case of a very weak dash pot, or short circuit might cause flashing. Adjustment must be made if necessary by bending the lower contact up or down, taking care that it is kept parallel with the upper contact, so that when they are closed, contact will be made across its whole width. If this adjustment is not properly made there will be destructive sparking on a small portion of the contact surfaces.
4. All connections must be perfectly secure.
5. The check nuts N must be tight.
6. The carbons in the tubes L must be whole. These carbons form a permanent shunt of high resistance around the regulator magnet M, and if broken will cause destructive sparking at contacts O, burning them and seriously interfering with close regulation of the generator. In case

a carbon should become broken, temporary repairs may be made by splicing the broken pieces with a fine copper wire.

To keep the action of the controller perfect the contacts O should be occasionally cleaned by inserting a folded piece of fine emery cloth and drawing it back and forth.

The amount of current generated by each machine depends upon the adjustment of the spring S. If the tension of this spring is increased, the current will be diminished, if the tension is diminished the current will be increased.

In starting these dynamos when the armature has reached its proper speed, the short circuiting switch on the frame should be opened. This method allows the generator to take up its load gradually, and is a very important point in the handling of the machine.

ELECTRIC MOTORS.

The doctrine of the conservation of energy already referred to in this volume, may safely be regarded as the corner stone of engineering science, and in nothing is it better illustrated than in the reversibility of the dynamo, and motor. When the armature of a dynamo is caused to revolve within the field of force, by mechanical power, resistance will be encountered if the circuit is closed, and the result is that the mechanical energy is absorbed, and converted into electrical energy, the presence of which is easily detected by the heating the wires, and other means. Energy is conserved.

In the electric motor, this action is exactly reversed. Electrical energy is absorbed, and mechanical energy is supplied by it. In engineering practice an electric machine (dynamo or motor), often automatically changes from motor to dynamo, or the reverse, and in some cases serious trouble results, if the change is not detected in time.

Any dynamo may be used as a motor and consequently we have as many types of motors as there types of dynamos. The pull of a motor depends upon the repulsion and attraction between the lines of force, or magnetism of the wire, and core of the armature, and that of the fields. We have seen that in a dynamo, as we force a wire through a magnetic field, current is generated. The more current there is generated, or flowing in such a wire, the greater will be the expenditure of power necessary to force such a wire through a magnetic field; in other words, the currents flowing in the wires of a dynamo armature, always tend to drive the armature in a direction opposite to that in which it is being driven.

If, then, instead of revolving a dynamo armature by machanical means, we connect it to a source of electricity and allow a current to flow through it we must obtain motion, and the direction of this motion will depend upon the direction in which the current flows, so long as this current does not alter the magnetism of the fields.

The electric motor is built exactly like a dynamo; consequently, as its armature revolves it not only does useful work, such as turning whatever machinery it is belted to, but it also generates an electromotive force. For instance, if a motor, running at full speed and receiving current from a dynamo (Fig. 486), were suddenly disconnected by opening the main switch, it would at once begin acting as a generator and sending out current. This can be easily seen with any motor equipped with a starting box, such as shown; for the current from the motor will continue to energize the fields, and the little magnet M so as to hold the arm of the starting box until the motor has nearly come to rest. If it were not for the current generated by the motor, this arm would fly back the instant the switch is opened.

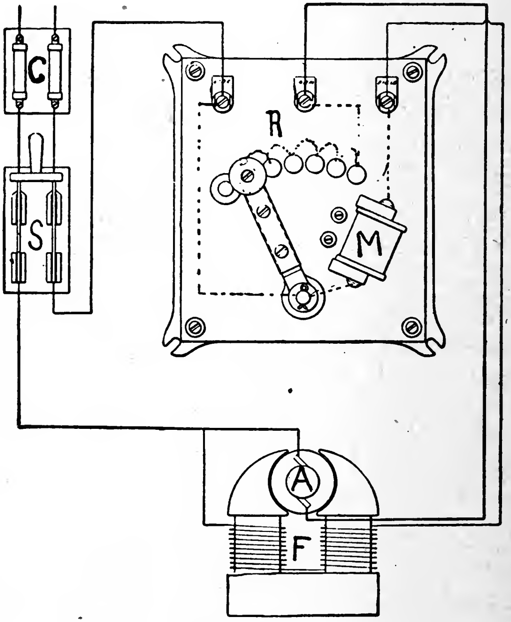


Fig. 486

The electromotive force set up by a motor always opposes that of the dynamo driving it; that is, the current which the motor tends to send out would flow in the opposite direction to that which is driving it.

This may be compared, and is somewhat similar, to the back pressure of the water which a pump is forcing into a tank. If the check valves were removed and the steam pressure shut off, the water would tend to force the pump backward.

This electromotive force is called the counter electromotive force of the motor. The counter electro-motive force of the motor varies with the speed of the motor, and also limits the speed of the motor, for it is obviously impossible that a motor should develop higher counter E. M. F. than the E. M. F. of the dynamo driving it.

The highest possible speed of a motor is, then, that speed at which its counter E. M. F. becomes equal to the E. M. F. of the dynamo supplying the current, and this is the speed which would be obtained were the motor doing no work and running without friction. This condition is impossible in practice, and the counter E. M. F. of the motor is always less than the E. M. F. of the dynamo. To speed up a motor it must run faster in order to develop an E. M. F. equal to that of the dynamo. This may be done by lessening the number of turns of wire on the armature, or by lessening the magnetism of the fields. In doing so, however, the capacity of the motor for performing work is also lessened.

The power that can be obtained from an electric motor depends upon two things: the current flowing in its armature coils, and the strength of magnetism developed in the fields.

Assuming the fields as remaining constant, the power of the motor must then vary as the current flowing through it. Suppose we have a motor being driven by an E. M. F. of 110 volts and it is doing no work; it will be running at full speed and its counter E. M. F. will therefore also be very near 110 volts. If now a load be thrown on this motor, it must get more current in order to develop the necessary power to carry the load.

Throwing on the load will decrease the speed of this motor, and consequently its counter E. M. F. will fall, say to 100 volts. The E. M. F. of the dynamo being 110 and the counter E. M. F. of the motor 100, there will be considerable current forced through the armature of the motor, so that it can now handle the load.

The current in the armature at all times will equal $\frac{E - E'}{R}$ where E is the electromotive force of the dynamo, E′ the counter electromotive force of motor, and R the resistance of the motor armature. In order that a motor should keep a nearly uniform speed, for varying loads, the resistance of its armature should be very low, for then a slight drop in counter E. M. F. will allow considerable current to flow through the armature. The above applies particularly to the shunt motor shown in Fig. 486. In this diagram C is a double pole fuse block, S the main controlling switch, R the starting box, or rheostat, M the magnet, which holds the arm of the starting box in place when it is brought over against it, F the fields, and A the armature of the motor.

The current enters, say at the right hand fuse, and passes to the starting box and along the fine wires shown in dotted lines through the fields of the motor and coil M to the other fuse. The fields of the motor and the little magnet M are now charged, but as yet there is no current passing through the armature and no motion. We now slowly move the arm on the starting box to the right; this admits a little current, limited by the resistance in the starting box, to the motor armature and it begins to revolve, and as we continue to move the arm to the right, the armature gains in speed because we admit more current to it by cutting out more and more resistance. When the armature attains full speed, the arm comes in contact with the little magnet M, and is held there by magnetism. The whole object of the starting box is to check the inrush of current, while the armature is developing its counter E. M. F. or back pressure.

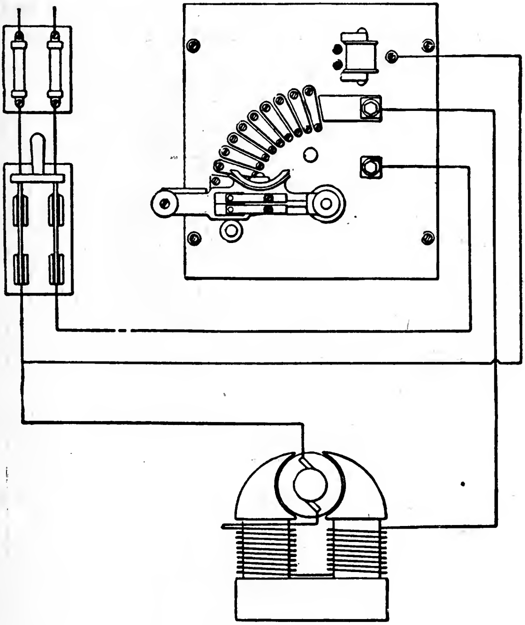


Fig. 487

When the armature has attained its normal speed, the starting box is no longer in use. If for any reason the current ceases to flow, the little magnet M loses its magnetism and releases the arm, which (actuated by a spring) flies back and opens the circuit so that, should the current suddenly come on again, the sudden inrush will not damage the armature.

In Fig. 487 are shown the connections of a series wound motor with an automatic release spool on the starting box of a sufficiently high resistance so that it can be connected directly across the circuit. This becomes necessary since the field windings are in series with the armature.

The speed of a series motor may be decreased by connecting a resistance in series with the motor, and may be increased in speed by cutting out some of the field windings. In electric railway work where two motors are used on one car, they are usually connected in series with each other in starting up, and then in parallel with each other while running at full or nearly full speed. The series motor is well adapted to such work as electric railway work, or for

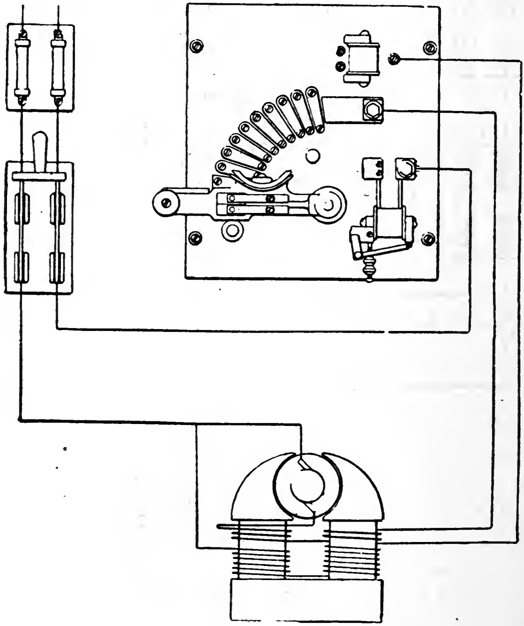


FIG. 488

cranes and so forth, because it will automatically regulate its speed to the load to be moved, exerting a powerful torque at a low speed while pulling a heavy load. Such a motor, however, requires constant attendance when the load becomes light, as it will tend to "run away" unless its speed is checked.

In Fig. 488 we have a diagram of a compound wound motor connected with a type of starting box that cuts out the armature when current has been cut off the lines supplying the motor, as before explained. In addition to this there is another electro magnet which is traversed by the main current on its path to the armature. Should the motor be overloaded by some means, the current flowing to the armature would exced the normal flow. The magnetism thus produced would overcome the tension of a spring on the armature of the so-called "overload magnet" and cause it to short circuit the magnet which holds the resistance lever, and allow it to fly back and open the armature circuit. By so doing the liability of burning out the armature due to overload is reduced to a minimum.

The compound motor may be made to run at a very constant speed, if the current in the series winding of the fields is arranged to act in opposition to that of the shunt winding. In such a case an increase in the load of a motor will weaken the fields and allow more current to flow through the armature without decreasing the speed of the armature, as would be necesary in a shunt motor. Such motors, however, are not very often used, since an overload would weaken the fields too much and cause trouble.

If the current in the series field acts in the same direction as that of the shunt fields, the motor will slow up some when a heavy load comes on, but will take care of the load without much trouble. Fig. 489 shows a starting box arranged as a speed controller. It differs from other starting boxes only in so far that the resistance wire is much larger, and that the little magnet will hold the arm at any place we desire, so that if we leave the arm at any intermediate point the motor will run at reduced speed. This sort of speed regulation can be used only where the load on the motor is quite constant. If the load varies, the speed will vary. Another and a better way of varying the speed of motors consists in cutting a variable resist-

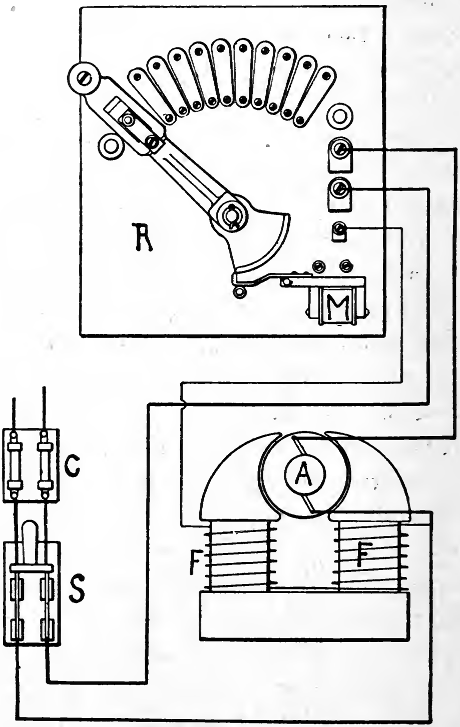


FIG. 489

ance into the field circuit, because as more resistance is cut into the circuit the fields become weaker and the motor speeds up. If possible, motors should be so designed that they can operate at their normal speed, and they will then cause little trouble.

Motors have much the same faults as dynamos, but they make themselves manifest in a different way. An open field circuit will prevent the motor from starting, and will cause the melting of fuses or burning out of an armature. The direction of rotation can be altered by reversing the current through either the armature or the fields. If the current is reversed through both, the motor will continue to run in the same direction. A short circuit in the fields, if it cuts out only a part of the wiring, will cause the motor to run faster and very likely spark badly. If the brushes are not set exactly opposite each other, there will also be bad sparking. If they are not at the neutral point, the motor will spark badly. Brushes should always be set at the point of least sparking. If it becomes necessary to open the field circuit, it should be done slowly, letting the arc gradually die out. A quick break of a circuit in connection with any dynamo, or motor is not advisable, as it is very likely to break down the insulation of the machine.

The ordinary starting box for motors is wound with comparatively fine wire and will get very hot if left in circuit long. The movement of the arm from the first to the last point should not occupy more than thirty seconds, and if the armature does not begin to move at the first point the arm should be thrown back and the trouble located.

Alternating Current Motors.—By a proper combination of two phase or three phase currents it is possible to produce a rotating magnetic pole. By placing inside of the apparatus which produces this rotating magnetic pole, a suitable short circuited armature, this armature will be dragged around by the rotating pole in much the same way that a short circuited armature in a direct current machine would be dragged around if the fields were revolved. Such a machine is called an induction motor. The armature will revolve without any current entering it from the external circuit. This does away with commutators, collector rings, brushes, brush-holders, and in fact many of the parts which are so necessary in direct current machines.

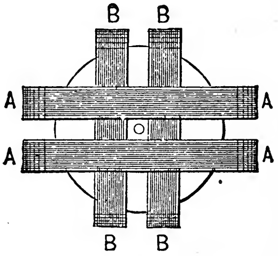


Fig. 490

ROTARY FIELD COILS

The rapidity of the alternations in the external circuit determines the speed of the motor.

Synchronous Motors.—Some alternating current motors are known as "synchronous" motors. What is meant by synchronous is, occurring at the same time, or in unison. As an example, suppose two clocks are ticking just alike so that the pendulums start and stop at the same time; we would hear but one tick. These two clocks would then be in synchronism. If an alternating current generator has 32 field coils and revolves at the rate of 60 R. P. M., then a synchronous motor with only 4 field coils would revolve at the rate of 480 R. P. M. This motor would operate in synchrony with the generator, and yet would make 480 R. P. M. while the generator made 60 R. P. M.

The production of the rotary field is the main reason for the generation of polyphase currents.

Fig. 490 shows four coils of wire. Assume that the coils B B receive an alternating current, and the coils A A receive another current in quadrature with the first. Then when the current in B B is at maximum, the current in A A will be at minimum, and as the current in B B decreases, the current in A A will increase.

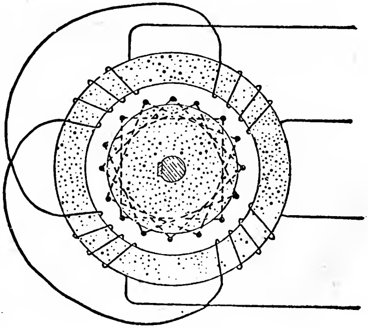


Fig. 491

TWO PHASE ROTATING FIELD COIL AND ARMATURE

When the B current is at maximum, there will be established N and S magnet poles on a horizontal axis passing through the center of the B coil. The A coils when active will establish poles on an axis perpendicular thereto.

Poles at intermediate points will also be established when current is passing through all four coils. The result of this arrangement is that north and south poles are kept traveling around the circle by the alternating currents acting in quadrature with each other, meaning that the angle of lag and lead between the two current waves is 90° or a quarter circle.

Currents of this kind constitute a two phase alternating current and the changes occur about 100 times per second. Fig. 491 shows a cylindrical laminated core wound with a re-entrant coil, and mounted on bearings within the field. This core will rotate because the alternating currents passing through the field coils will induce currents in its wires, owing to their rotary field of force.

In order to establish in the core the polarity above described, the lines of force must be cut by its windings. Consequently it lags behind, and its revolutions per minute are from 5 to 10 per cent slower than those of the rotary field. If it were made to synchronize with the field it would have no induced polarity, and no pull or torque would be exerted upon it. Therefore, it constantly falls behind, and the amount of this drop is termed its slip. Fig. 492 is a diagrammatic view of the generation of a three-phase current, and the operation by it of an induction motor. Following the lines and numbers will show that the stator of the motor receives the same currents that are induced in the stator of the generator.

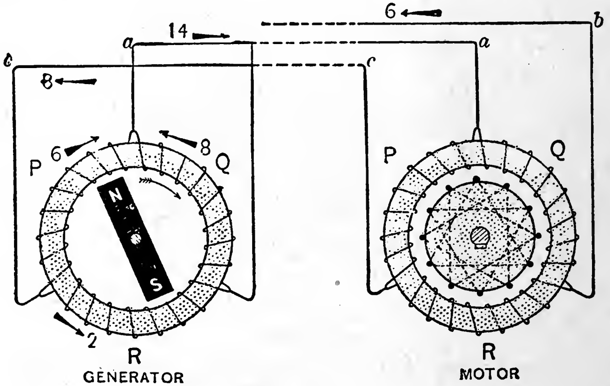


Fig. 492

THREE PHASE GENERATOR, AND INDUCTION MOTOR

But the poles of the generator travel around it, the result being that a rotary field is produced in the stator of the generator. Fig. 493 represents a four-pole, three-phase generator driving such a motor.

There are 12 armature coils, three sets marked A, B, C, for each pole of the generator, thus giving a three-phase current. They are connected in Y combination. The generator is shown on the left, the field being the rotor.

The motor is shown on the right of the diagram, and it also has 12 coils marked as in the generator, and Y connected. The generator and motor are connected by the three wires a, b, and c, the fourth wire being omitted, as it would have no load to carry. The large letters on the armature indicate the course of the windings. The three-phase current produces a rotary field, on the same general principle as does the two-phase current. The lag of the currents behind each other acts to cause the poles resulting from the combined action of the coils, to rotate around the field. Motors constructed upon this principle are termed induction motors, and the coils on the armature (which is the rotor), are self-contained, having their ter-

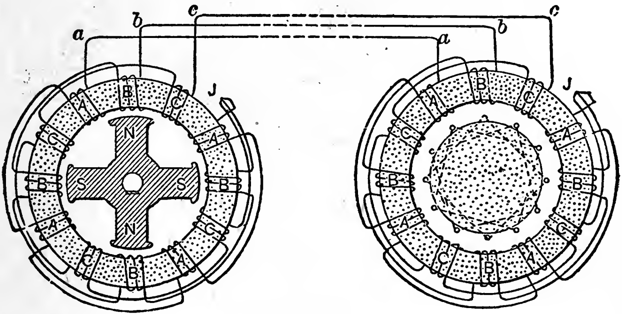


Fig. 493

FOUR-POLE THREE-PHASE GENERATOR AND INDUCTION MOTOR minals connected so that the winding is re-entrant, and has no outside connection whatever. Fig. 494 shows such a motor complete. The rotary field referred to in the foregoing description should not be confounded with the revolving field. In the rotary field the rotary action is purely electrical, the poles simply rotating around the circle, there being no rotation of any part of the mechanism. But a re-

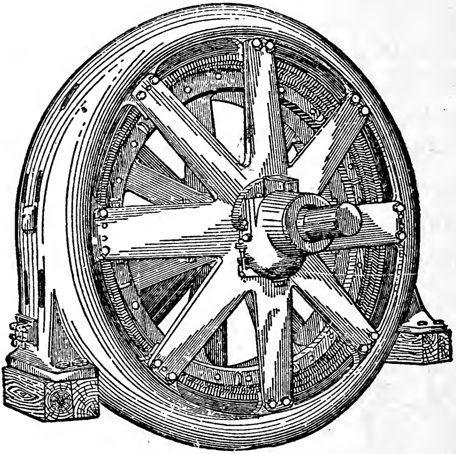


Fig. 494

INDUCTION MOTOR WITH SQUIRREL CAGE ARMATURE

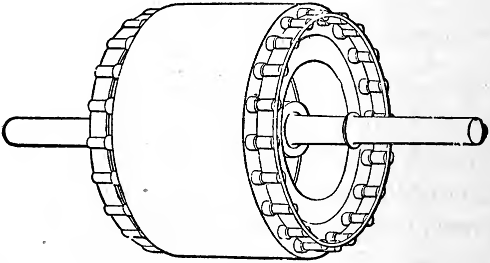


Fig. 495

SQUIRREL CAGE ARMATURE

volving field is entirely different. It revolves on an axis like a wheel. The student should remember this, as there is danger of confusion in the use of the two terms. A combined rotary, and revolving field may be obtained by a simple modification of the mechanical structure, in which the field is mounted on journals, and the armature is stationary. Fig. 495 shows the squirrel-cage armature of an induction motor, the core being laminated, and having straight conductors of copper lying in the longitudinal grooves close to its surface. The ends of these conductors are connected to two rings of copper.

QUESTIONS AND ANSWERS.

714. What is electricity?

Ans. Electricity is an invisible agent. Its exact nature is not very well known, although the laws governing its action, the methods of controlling it, and the effects produced by it are becoming well known.

715. Is it correct to use the term quantity with reference to electricity?

Ans. It is. We may use terms to designate definite quantities of electricity, passing through a conductor, in the same way that we speak of gallons of water flowing through a pipe.

716. Is it proper to assume that there are large quantities of electricity stored for future use, in a manner similar to water?

Ans. It is not, except in a limited sense, as in storage batteries.

718. Define the doctrine of the conservation of energy.

Ans. The total quantity of energy in the universe is unalterable. When energy is expended, or disappears in one form, it must reappear in another form.

719. In accordance with this doctrine, what would be the proper term to apply to electricity with reference to the physical requirements of man?

Ans. It is a useful agent for the rapid transmission of stored up energy in fuel, water falls, etc.

720. What is the practical unit of quantity used in speaking of electricity?

Ans. The coulomb. It is that quantity of electricity that would pass in one second through a circuit carrying a current of one ampere.

721. What is an ampere?

Ans. It is the unit of volume, or rate of flow. A current of one ampere will flow through a circuit whose resistance equals one ohm, when the electro-motive force, or pressure behind it equals one volt.

722. What is a volt?

Ans. The volt is the unit of electro-motive force, and represents a pressure that will cause the flow of one ampere through a circuit in which the resistance equals one ohm.

723. What is an ohm?

Ans. The ohm is the practical unit of electrical resistance. It is that amount of resistance that would limit the flow of electricity under an electromotive force of one volt, to a current of one ampere, or to a discharge of one coulomb per second. It equals the resistance of a column of mercury one sq. millimetre in area of cross section, and 104.9 centimetres in length.

724. What is the unit of work?

Ans. The foot pound.

725. What is the unit of power, or rate of doing work?

Ans. The foot pound, per second.

726. How is the amount of work that electricity is capable of doing, measured?

Ans. By the volt-coulomb, or Joule. The amount of electrical work per second is equal to the volt ampere, or watt.

727. What amount of power developed is represented by the watt?

Ans. 44.25 foot-lbs. of work per minute, or 0.7375 foot-lbs. per second.

728. What is a magnet?

Ans. A mineral consisting of a combination of iron and oxygen.

729. What is the chemical formula of a magnet?

Ans. Fe^3O^4.

730. What is a permanent magnet?

Ans. A piece of steel that has been charged with magnetism, and retains it.

731. What is meant by the poles of a magnet?

Ans. All magnets tend to point north and south, the same end always pointing in the same direction; hence the end pointing north is called the north pole, and the end pointing south is termed the south pole.

732. What peculiar characteristic attaches to the poles of magnets?

Ans. The north poles of two magnets tend to repel each other, and the same is true of the south poles. But the north pole of one magnet attracts the south pole of another, like repels like, and unlike attracts unlike.

733. What is an electro magnet?

Ans. A bar of iron surrounded by a coil of wire through which an electric current is passing.

734. What are lines of force?

Ans. They are certain imaginary lines passing through the steel of the magnet from its south pole to its north pole, and issuing from the latter they curve around through space and return to the south pole.

735. What is the magnetic circuit?

Ans. It is the path of these lines of force, around and through the magnet. It resembles a closed curve, either a circle, or an ellipse.

736. Explain the difference between the magnetic circuit and the electric circuit.

Ans. The magnetic circuit, or field of force, that surrounds a magnet is maintained without the expenditure of energy, while on the other hand an electric current passing upon its circuit develops energy, and energy must be expended to maintain it.

737. Are there any other points of difference between the two circuits.

Ans. Yes, the electric current passes through a conductor in intensity proportional to the electro-motive force urging it, while the magnetic circuit passes through air, or a vacuum in proportion to the magneto-motive force urging it.

738. What is meant by the term potential as applied in electric practice?

Ans. Voltage or pressure.

739. What is the law of induction?

Ans. When a conductor is moved in a magnetic field of force so as to cut the lines of force, there is an electromotive force impressed on the conductor in a direction at right angles to the direction of motion, and at right angles to the direction of the lines of force.

740. What is a dynamo?

Ans. A machine for transforming mechanical energy into electrical energy.

741. How is the field of force maintained in a dynamo?

Ans. By means of electro-magnets.

742. Does not this require the expenditure of energy?

Ans. Yes; a certain amount of energy is indirectly expended.

743. How are dynamos classified?

Ans. Into two grand divisions, viz., direct current dynamos and alternating current dynamos.

744. What is direct electrical current?

Ans. A current of unchanging direction.

745. What is an alternating current?

Ans. A current that reverses its direction of flow, periodically, from 20 times and upward per second.

746. Name the principal constituent parts of a dynamo.

Ans. The armature, the field, the collecting rings, or commutator, and the brushes.

747. How is electro motive force or current induced in a dynamo?

Ans. By rapidly changing field and armature relations by means of mechanical energy.

748. How is the output of a dynamo stated?

Ans. In Kilowatts equal to 1,000 × volts × amperes.

749. How is the output of a motor stated?

Ans. In horse power, equal to Watts intake ÷ 746 × efficiency expressed decimally. (Not as a percentage.)

750. What is the voltage of a dynamo? of motor?

Ans. It is the pressure that the generator or alternator delivers at its own terminals. The voltage of a motor is the voltage which should be applied to its terminals in order to develop full horse power.

751. What is full load current of dynamo? of motor?

Ans. Full load current of a dynamo is that current which may be drawn steady for 24 hours without causing any part of the machine to exceed a safe temperature, i. e., 150° Fahr. This applies to factory motors.

752. What is meant by the rating of a dynamo? Of a motor?

Ans. The product of full load current multiplied by the voltage expressed in Kilowatts is rating of a dynamo. The actual mechanical horse power developed at the pinion of the motor as tested in shop.

753. What is the armature core?

Ans. The sheet iron body which carries the armature winding, and conducts the flux from pole piece to pole piece.

754. What is the armature spider?

Ans. The casting consisting of hub and arms which supports armature core.

755. What are binding wires?

Ans. They are narrow bands of phosphor bronze wire placed around the armature every three or four inches to help bind the winding to the core. They rest on strips of mica, and are sweated with solder all around.

756. What are commutator segments?

Ans. The commutator segments or bars are the copper pieces of which the commutator is built.

757. What are commutator leads?

Ans. They are the ends of the armature winding extending from the core to the lug of the commutator bar.

758. What are pole pieces?

Ans. The end of the magnet core nearest the armature. Usually larger than the core.

759. What are magnet cores?

Ans. The iron inside the field coil.

760. What is the yoke?

Ans. The part of magnetic circuit connecting the magnet cores.

761. What is the pitch of an armature winding?

Ans. It is the number of teeth between the two sides of a formed coil plus one tooth.

Example: The two sides of a coil are in slots number 3 and 17, then pitch is 14.

762. Is there insulation between winding and core?

Ans. Yes. Mica or fuller board; there is also the tape on coil.

763. What insulation is there between conductors of winding?

Ans. The double cotton covering of each wire makes four thicknesses between conductors.

764. What is the air gap?

Ans. It is the air space between armature and pole pieces. In dynamos it is made as small as possible for efficiency.

In motors it is not made too small because this tends to make the machine spark due to the weak field. In D. C. series motors it is from ⅛ to ¼ of an inch, in A. C. series motor it is smaller, say 1/10 to ⅛ inch.

The larger the air gap of a motor the more the bearings may wear before there is danger of the armature rubbing against the lower pole pieces.

765. What are field spools?

Ans. The brass shells on which the field coils are wound.

766. What is the commutator?

Ans. It is a series of copper bars placed parallel to the shaft, insulated from each other and from the frame of the machine. Each is connected to the winding and current flows from the winding through them to the brushes. It at the same time reverses the connections between the brushes and the winding at the proper times so that the brush always collects current.

767. What is a collector or slip ring?

Ans. A collector consists of two or more rings of copper placed around the shaft and insulated from it, and each other. Each is connected to a part of the winding. The brushes rest on the rings.

They are used to collect current from a revolving armature style of alternator, to feed current into armatures of rotary converters, or the revolving fields of alternators.

The collector has no corrective influence and passes on the A. C. or D. C. current exactly as it receives it.

Single phase machines have two rings; two, three, and six phase machines have three rings.

768. Is there a difference between no load and full load voltage of dynamos?

Ans. Yes. A shunt dynamo gives highest voltage at no load and lowest at overloads; the series dynamo gives lowest at no load and highest at full load. The compound dynamo is a combination of series and shunt, and gives same voltage at all loads.

An alternator acts like a shunt dynamo.

769. What is a field rheostat?

Ans. It is a resistance in the field circuit which can be varied to change the current, and hence the field strength. This alters the voltage of the dynamo.

770. What are commutated fields?

Ans. In some motors the field coils are arranged in sections so that they may be arranged in parallel, or series, or in combinations.

All coils in parallel give the greatest current and hence slowest speed of motor; all coils in series give the weakest field and the fastest speed.

771. What relation has field strength to the speed oi motor?

Ans. The weaker the field the faster the speed, for the motor must revolve fast to generate its proper counter E. M. F.

772. What relation has armature strength to the speed of motor?

Ans. The greater the armature current the higher the speed.

773. What effect on the power of motor does field, and armature strength have?

Ans. The greater the field and armature current the greater the power.

774. What is a ring winding?

Ans. One which passes over and under around the core, a space being left between the shaft and core to accommodate the winding.

775. What is a drum winding?

Ans. One where all winding is on the outer surface of the core.

776. Upon what does sparkless commutation of current depend?

Ans. (1) The more commutator bars the better, there being less voltage and therefore tendency to spark between bars. The average railway motor has from 100 to 125 bars on commutator.

(2) The fewer the ampere turns on the armature in comparison to the ampere turns on the field the less sparking.

(3) The more turns short-circuited by the brush when touching two or more bars at once, the greater the tendency to spark.

777. What is a shunt field?

Ans. One whose coils are placed as a shunt across the brushes. It carries a small current.

778. What is a series field?

Ans. One which carries the main, or nearly all the main current, and is placed in series with the armature. A small strip of resistance metal is used sometimes to divert a portion of the main current from the series field.

779. What are Foucault, or eddy currents?

Ans. Local currents set up within the armature, and acting as a hindrance to the generation of useful current.

780. How may the electro-motive force be increased?

Ans. By increasing the speed, or by adding more turns or loops of wire to the armature winding.

781. What is meant by self excitation of a dynamo?

Ans. When the dynamo is standing still, the field magnets become weakly magnetic, but when the armature begins to revolve a few volts of electric current will be sent through the field coils, gradually increasing the magnetic strength until full voltage is reached.

782. What is a series dynamo?

Ans. One in which the same current that travels the main circuit also traverses the field.

783. Explain the action of the shunt dynamo.

Ans. The field circuit is a shunt, and only a portion of the main current passes through it.

784. How are the fields of a compound dynamo excited?

Ans. The fields have two distinct windings; one shunt, and the other series.

785. What advantage pertains to the compound wound dynamo?

Ans. It is practically self-regulating.

786. What is the difference between the dynamo and the electric motor?

Ans. Practically none in the principles governing the design of the machines. Any dynamo may be used as a motor, and vice versa.

787. State the difference in their functions.

Ans. The dynamo converts mechanical energy into electrical energy, while the motor converts electrical energy into mechanical energy.

788. Upon what does the power to be obtained from a motor depend?

Ans. Two things, viz., the current flowing in its armature coils, and the strength of magnetism developed in its fields.

789. How is the speed of motors controlled?

Ans. By a starting box or rheostat.

790. How may the direction of rotation of a motor be reversed?

Ans. By reversing the current through either the armature or the fields.

791. Upon what principle does the alternating current motor act?

Ans. Upon the principle of induction, having for its main accessory the rotary field.

792. How is a rotary field produced?

Ans. By the use of polyphase currents.

793. Explain the meaning of the term rotary field.

Ans. In a rotary field the rotary action is purely electrical, the poles simply rotating around the circle. There is no rotation of the mechanism of the field.

794. What then is a revolving field?

Ans. A field that revolves around an axis like a wheel.

Electric Currents

Reference having been frequently made in the foregoing pages to different kinds of electric currents, such as direct, alternating, two and three phase, etc., it is now in order to give a short explanation of their leading characteristics. *The direct current* is in a measure explained by its title direct, meaning that it travels in the same pressure direction straight from the generator to the locality where it does work, and then back again to the generator, over the return wire. The natural tendency of the current generated in all dynamos is to alternate, that is it starts at a value of zero, rises to a maximum of one polarity, descends to a value of zero again, and changing in direction of pressure, attains a maximum of opposite polarity, from whence it returns to zero again, these alternations being constantly repeated over and over again. In the direct current generator the alternating electro-motive force producing this current is reversed or commuted at the proper instant by means of the commutator, and brushes, and the result is that a one direction electro-motive force, having a constant fixed potential or voltage, is impressed upon the external circuit.

The alternating current. In order to get a clear conception of the true nature of the alternating current it is absolutely necessary that the student should comprehend, and bear in mind the meaning of the different terms used in alternating current practice, such as volts, amperes, frequency, phase, and power-factor. These will be taken up and discussed in their logical order, with reference to their practical meaning, omitting as much as possible all theoretical, and mathematical deductions. The voltage, or pressure in an alternating current does not have a constant fixed value, as in the direct current system, but is continually changing in amount, and alternating in the direction of pressure at equal, regular intervals of time. Reference to Fig. 496 will serve to explain the action of the alternating electro-motive force within the generator, and also the action of the alternating current produced by it. The horizontal line having degrees from 0 to 360 marked upon it represents the line of zero values or no voltage. The lengths of the vertical lines correspond to the distance of points of the curve from the horizontal or zero line. The left hand quadrant of the generating circle is divided into angles of 22½° or one sixteenth of a circumference. For each angle lines are drawn, such as M P. On the zero line, divisions corresponding to the angles are laid off, and ordinates erected upon them. Each sine determines the length of the ordinate corresponding to its angle, as for instance the sine M P of 45° determines the length of the ordinate M P erected on the second (or 45°) of the sixteen divisions of the zero line.

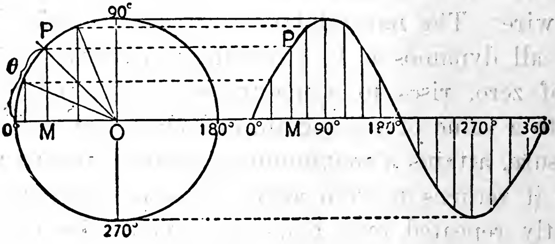


FIG. 496.
SINE CURVE OF GENERATING CIRCLE.

The sines as drawn in Fig. 496 represent the values of the E M F from zero to 90° or one quarter of the generating circle, and the length of the ordinate erected upon the 90° point of the zero line corresponds to the highest voltage value of the current wave above the zero line. The portion of the wave above the line may be assumed to represent the positive pole, and the portion below the line the negative pole.

It will easily be seen that if sines are drawn in each quadrant of the circle, the lengths of the ordinates for the remaining parts of the wave curve may be determined from them, and thus a true representation of one complete wave, or cycle, be obtained.

In the alternating current dynamo the current is sent to the line exactly as it is generated in the armature, flowing out one wire, and back on the other and then reversing, and flowing out on the wire on which it has just flowed in, and back on the wire on which it had formerly flowed out. An illustration which will more fully explain this action can be found by supposing the two ends of the cylinder of a piston pump were connected by means of a pipe and then, having done away with all the valves except the suction valves, the pump was started. At the beginning of the stroke, water would be forced out one side of the cylinder around the pipe into the other side of the cylinder, and after the piston had reached the end of the stroke and started back, the water would then take a return course back to where it had started. In this case the pump could be likened to the dynamo, and the pipe to the wires, and the current to the water flowing back and forth. As the water pressure in the pipe will fluctuate, reaching maximum at one point in the stroke, and zero at another point, so also when the alternating current wave reaches its point of highest voltage or pressure the whole circuit is affected, and when it reaches zero value, the whole circuit is at zero. The expression wave should be clearly understood. It means that the whole circuit passes simultaneously through the values of the cycle represented in the wave curve. The number of waves per second is called the frequency of the current, therefore when we speak of a frequency of 60 we mean that it requires one-sixtieth of a second for the voltage to pass through a complete cycle, or in other words 60 cycles are completed in one second. By alternations is meant simply the change in direction of pressure, or voltage, of the current, and it will be seen by reference to Fig. 497 that two alternations occur in each complete cycle, one at C, and the other at E, (assuming that we start at zero value of A). Alternations are usually expressed in terms of the number per minute, as for instance 7,200 alternations means 60 cycles per second; for since there are two alternations per cycle, the number of cycles per minute will be 7,200÷2= 3,600, and the cycles per second, or frequency will be

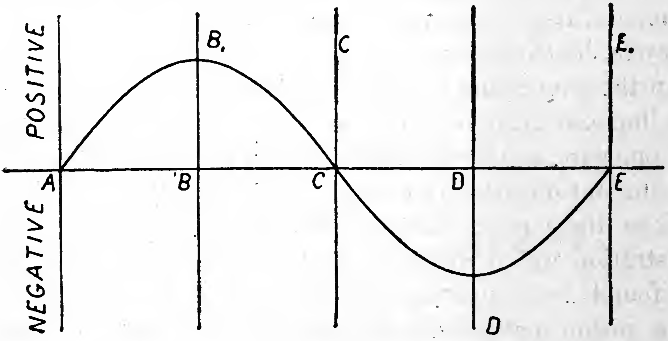


FIG. 497
CHANGES IN AMOUNT AND DIRECTION OF PRESSURE

3,600÷60=60. The following table gives the alternations corresponding to the usual commercial frequencies:

Frequency.	Alternations.
25	3,000
50	6,000
60	7,200
133	16,000

The action of the alternating current as represented in Figs. 496-497 can be considered as continuing indefinitely in the same regular order, and in the same intervals of time. Referring to Fig. 497, the curved line AB′, CD′ E represents the alternating voltage as it rises at A to a positive maximum value at B′, then falls to zero at C, where the direction of pressure is reversed, and the same maximum value of the voltage in the negative direction is reached at D′ when it again falls to zero at E. The word "period" is sometimes used to designate the time in seconds or fractions of a second required to pass through a complete cycle, and the number of periods per second is termed the frequency. We have so far considered only the voltage wave but in actual practice the volt-meter does not indicate the peak of the voltage wave, but rather that of the current wave, which is usually about 0.707 or roughly speaking .7 of the maximum voltage. For instance, when the volt-meter reading is 110 volts, the maximum value at the peak of the wave will be 155 volts, nearly. The pressure indicated by the volt-meter is the effective voltage, and it is with this voltage value that the engineer is concerned in every-day work.

The maximum voltage is important to the station man only in testing insulating materials, and in the design of line insulators on high tension transmission lines. As in the case of the volt-meter, the ordinary alternating ammeter measures about 70.7 per cent of the maximum value of the amperes at the peak of the current wave. The ammeter reading of effective current produces the same heating effect, gives out the same available energy as a direct current of the same amount. When there is no apparatus with an iron magnetic circuit connected to an alternating current system, such as induction motors, arc lamps, etc., the current wave will begin to rise with the voltage wave, reach its maximum value at the same instant as the voltage does,

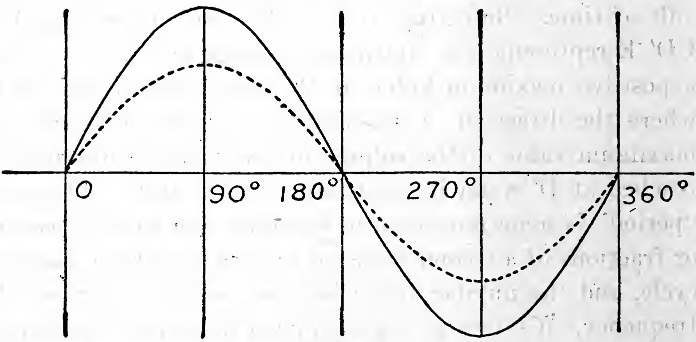


FIG. 498

VOLTAGE AND CURRENT WAVES

and complete the cycle in exact time relation with the voltage. Fig. 498 shows both the voltage and the current waves, the zero line being divided into 360° as in Fig. 496. The full line represents the voltage wave, and the dotted line the current wave. In commercial alternating current work the choking action or "inductance" as it is called which results from the presence of the iron magnetic circuit, caused by the connection of the electrical apparatus with the main circuit, and in which apparatus there is more or less iron surrounded by, or enclosing coils, causes the current wave to lag behind the voltage wave, that is the zero, maximum, and all intermediate values of the current will follow a certain interval of time, or a certain number of electrical degrees, behind the corresponding values of the voltage.

Phase, Lag, and Lead.—The term phase is employed to denote the relative position of a current wave with respect to the wave of electro-motive force producing it. Fig. 498 shows voltage and current in phase, that is the waves of both are in unison, both starting at zero, and reaching their maximum values at the same instant. If however the current lags behind the voltage, as shown by Fig. 499, it is said to be out of phase, and the amount of this lag in degrees is called the angle of lag, and depends upon the nature of the load, being greatest for a load of induction motors, and series arc lamp.

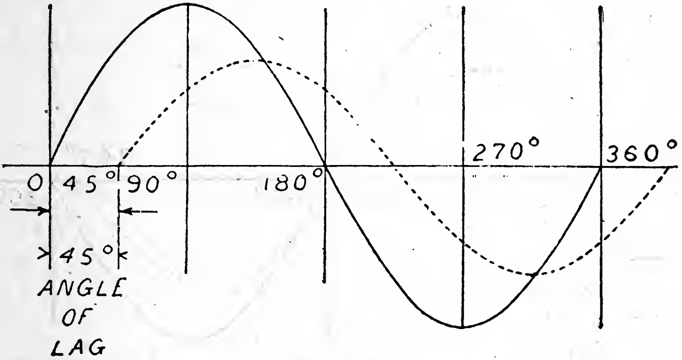


FIG. 499

CURRENT LAGGING 45 DEGREES BEHIND THE VOLTAGE

In Fig. 499 the current wave (dotted line) is shown as lagging 45 electrical degrees behind the voltage wave (full line), and in this case the angle of lag is 45°.

In some cases, especially in the operation of rotary converters, and synchronous motors, the current wave may be ahead of, or lead the voltage wave. This is caused by an action directly the opposite of inductance, called capacity, and is illustrated in Fig. 500, where a current lead of 15 electrical degrees is shown, and in which the angle of lead is 15°. In the alternating current-generator the field coils occupy about 50% of the surface of the field bore, because when their inner edges are tight together, their outer edges are apart, due to the larger circumference at the pole pieces, and because some interpolar space must be left to prevent excessive leakage from pole to pole.

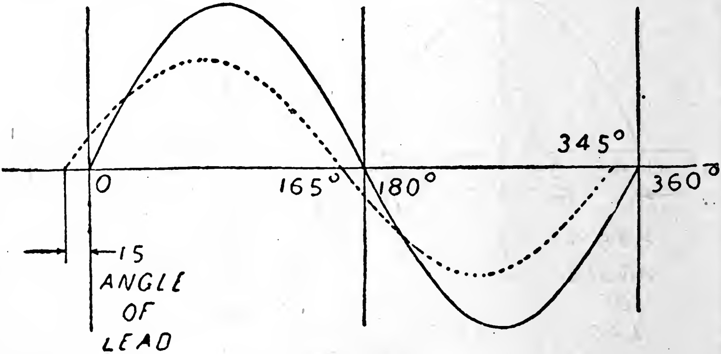


FIG. 500

SHOWING A CURRENT LEAD OF 15 DEGREES

Only 50% of the armature bore is wound, for otherwise the coils would be so wide that they would extend over into the field of a wrong pole piece. If one side of a coil is under a N-pole the other side should be under a S-pole. Then the two electro-motive forces induced, add together. Should the coil be so wide as to extend over to the next N-pole any electro-motive force induced by that pole would be subtracted.

There is then on the ordinary alternator half of the armature empty. Such a machine is called a Single Phase Alternator.

Two and Three Phase.—It occurred to some inventor that an entirely separate winding could be put on between the coils of the original winding, and be connected to its own collector. The current was to be led to a different circuit, but it soon became evident that it was better to make of the four wires from the alternator, a three-wire circuit by joining two of them inside the armature and leading out three wires to the switchboard. Such an alternator is a Two Phase Alternator.

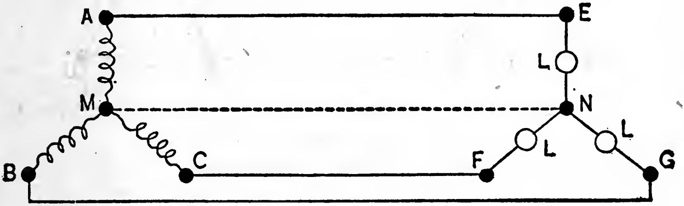


FIG. 501
3-PHASE Y CONNECTION

Of course the capacity of the machine is not doubled, because from a single phase alternator is drawn enough current to heat it to the safe limit. From a two phase alternator we do the same thing. The reason we gain in capacity is because in a single phase machine the heating is concentrated, while in the two phase machine it is evenly distributed all over the armature.

Even in a two phase alternator there is a portion of the armature not used for winding, and there was still a desire to reduce the number of line wires. This led to the Three Phase Alternator.

The three armature windings of the alternator are connected together at one point, and the other ends to the three collector rings, or the three windings are connected in series and the three points where they are joined are connected to the three collector rings.

The former winding is called a Y winding and is shown in Fig. 501. The latter is a Δ (Delta) winding and is shown in Fig. 502. The European names are respectively Star and Mesh windings.

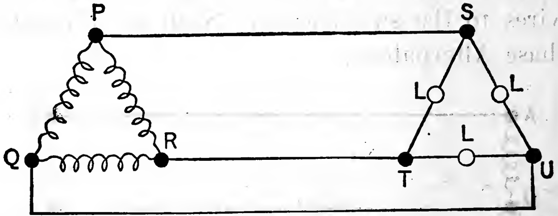


Fig. 502
3-PHASE DELTA CONNECTION

The three wires of a three phase system each act as a main wire, and a return wire for one of the others at the same time. The actual current in the wire is the difference of the two currents: in and outgoing.

If the same three phase armature is connected first as a Y and then as a Δ winding these differences will be noticed.

The Y armature will give the higher voltage and have less current capacity. The Δ will give a lower voltage and have greater current capacity. Power that can be drawn from each is the same.

Transformers and other apparatus are wound two, and three phase, and also Y and Δ, for use with the correspondingly wound alternator.

By a peculiar connection of coils, rotary converters are wound for six phase currents; it having been discovered that it is possible to do so with the result of increased output for a given sized machine.

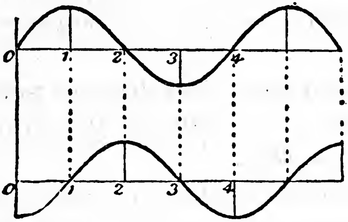


Fig. 503
WAVES IN QUADRATURE

Two, three and six phase machinery is often grouped under name of polyphase.

Waves in quadrature.—Fig. 498 shows waves in phase. In Fig. 503 are shown waves in quadrature, that is the angle of lead is 90° which is a quarter of a circle. When the angle of lag, or lead is 180° the waves are said to be in opposition. This is illustrated in Fig. 504.

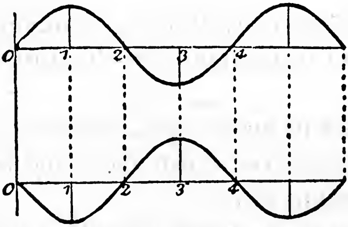


Fig. 504
WAVES IN OPPOSITION

QUESTIONS AND ANSWERS.

795. What is the leading characteristic of the direct current?

Ans. It travels in the same direction of pressure.

796. What is the tendency of the current generated in all dynamos?

Ans. It is alternating in voltage or pressure.

797. Explain the meaning of the term alternating as used in this connection.

Ans. The current starts at a value of zero, rises to a maximum of polarity, descends to a value of zero again, and changing in direction of pressure, rises to a maximum of opposite polarity, from whence it drops to zero again.

798. How then is direct current produced from this alternating current?

Ans. By means of the commutator and brushes on the direct current generator.

799. What is the leading characteristic of the alternating current?

Ans. Its voltage is continually changing at regular intervals from zero to maximum in the direction of opposite polarity.

800. How is this action best represented?

Ans. By wave curves drawn above and below a horizontal line representing zero.

801. In what manner does the action of the alternating current affect the circuit through which it travels?

Ans. The whole circuit passes simultaneously through voltage values of the cycle represented by the wave curve.

802. What is meant by the frequency of an alternating current?

Ans. The number of waves or cycles per second.

803. What does a frequency of 60 mean?

Ans. It means that the voltage values pass through a complete cycle in one sixtieth of a second, that is 60 cycles per second.

804. What is meant by alternations?

Ans. The number of reversals per minute in the direction of pressure.

805. How many alternations would there be in a current having a frequency of 60?

Ans. 7,200.

806. What is meant by a "period?"

Ans. The time in seconds or fractions of a second required to pass through a complete cycle.

807. What is meant by current wave?

Ans. It means the actual values of the current as shown by the volt-meter and ammeter.

808. Do these equal the values of the theoretical wave curve?

Ans. They do not, reaching about 70 per cent.

809. Why is this?

Ans. It is due to the influence of the iron magnetic circuit caused by the connections of induction motors, arc lamps, and other electrical apparatus.

810. What is meant by effective current?

Ans. The voltage and volume as shown by the volt-meter and ammeter.

811. In what respect is the maximum voltage as shown by the calculated wave curve useful?

Ans. It is useful in testing insulating materials.

812. What is meant by phase in electric practice?

Ans. It denotes the relative position of a current wave, with respect to the wave of electro-motive force producing it.

813. When is a current in phase?

Ans. When the two waves just mentioned start at zero and reach their maximum values at the same instant.

814. What is meant by lag?

Ans. When the current wave lags behind the voltage wave.

815. What is meant by lead?

Ans. When the current wave is ahead of, or leads the voltage wave.

816. What is the meaning of two and three phase currents?

Ans. When the winding of the armature is such that two or three electro-motive forces in quadrature with each other are simultaneously produced by the generator the currents thus produced may be distributed over four or six conductors, a pair for each current.

817. Is it necessary to have a pair of conductors for each current in two and three phase current work?

Ans. No. By means of the Y winding it is possible to distribute the current over three wires, each wire acting as a main, and return wire for one of the others.

Armature Design and Construction*

Economy of construction demands that an armature be run at a high rate of speed. In any armature the output in volts can be increased by simply increasing the speed; the output in amperes cannot be so increased unless at the same time larger wires are used. If, however, in any armature we should increase the size of the wires, so that fewer turns would be upon it, we can compensate for the consequent loss in voltage by increasing the speed, and thus, with the same armature, also increase the output in amperes. It will be seen that speed is an important item in the construction of any armature. To operate at a high rate of speed requires the very best workmanship and mechanical construction.

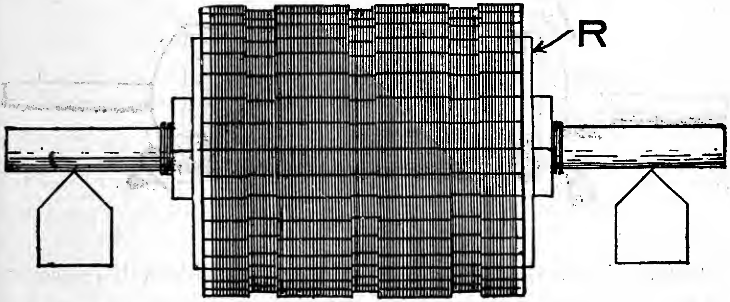


FIG. 505

Whenever a high speed is to be used it is of the utmost importance to see that the armature is well balanced. Any

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*From "Armatures and Armature Winding," by Horstman and Tousley.—

rotating piece of machinery is said to be out of balance when one side is heavier than the other. This condition of being out of balance will manifest itself by a more or less severe jarring, and shaking of the frame upon which it rests when running.

Whether an armature is in balance while at rest can be easily determined by placing it upon two knife edges, as shown in Fig. 505. If these edges are perfectly level, the armature will roll to one side or the other until the heavier part is at the bottom. If the diameter of the armature is small compared to its length, this test will not be very sensitive. If the diameter is great as compared to its length a small excess of weight on one side will cause it to roll over. If a very good balance for high speed is to be obtained this method must not be relied upon. In such a case the armature should be placed in bearings and run at its proper speed. If there is much jarring or shaking the armature is out of balance, and this must be rectified.

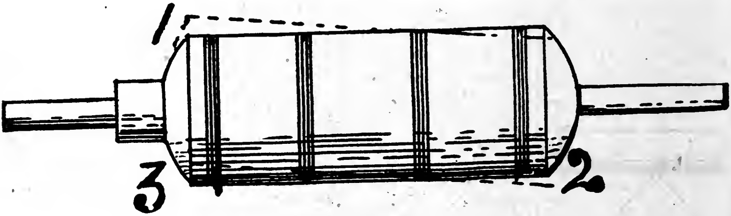


FIG. 506

It is obvious that this had best be done before any wire is placed on the core. How it may come about that the armature may be perfectly balanced statically and yet almost unfit for the work while in operation at a high rate of speed can be seen from Fig. 506. If there is an excess of weight at 1 this may be perfectly balanced for a state of rest by the addition of a similar weight at 2. If, however, the armature is revolved at a high rate of speed there will be a tendency to strain the shaft as indicated by the dotted lines.

An armature out of balance is rectified by adding weights at different places until the proper amount is found. This will make itself evident by the smooth running. If possible, the weights should now be removed and an equal weight of metal removed from the armature at the side opposite to that at which it was found necessary to add weight. If. for instance, it was found necessary to add one pound at 3, Fig. 506, the same result can be obtained by removing one pound at 1.

In speaking of high speeds is must be understood that it is not, necessarily, a great number of revolutions that are required to produce a certain E. M. F. What is required is that a certain number of conductors shall cut through the lines of force passing between the pole-pieces in a given length of time. As these conductors are always located on the periphery of the armature, it is the speed of this part that counts. The greater the diameter of the armature, therefore, the lower the speed of the shaft. Other things being equal, the capacity of an armature is directly proportional to its length. We may therefore choose whether we shall increase the capacity of a machine by increasing the length of the armature, or the diameter.

If the length of the armature is too great there is some danger that the shaft will bend, not only from centrifugal force to which it is subject, but also from the magnetic attraction of the pole pieces if it is not well centered.

The *centering of an armature* is an important point. It rests between two powerful magnets. If it is exactly in the center, the attraction of one pole piece will neutralize that of the other; but if it is the least bit out of center, there will be a strong attraction to one side and this will greatly add to the friction. The bearings and pole pieces should be in such relations to each other that they can be truly centered, and that there will be no likelihood of their becoming loosened. The bearings should have sufficient surface so that the wear will be a minimum. Bearings should, furthermore, not be of iron or steel. If the shaft is constructed of the same material there may be some magnetic attraction between the shaft and the bearing which would increase the friction, and cause heating. Bearings should also be out of line of the magnetic circuit, as such magnetization will cause the shaft to generate Foucault currents, which will heat it, and in turn heat the bearings. The shaft should also be protected by shields, which will prevent oil from running along it and getting into the wires on the armature. The lateral play which is essential to the smooth running of the shaft can be obtained by lining up the shaft after the belt is put on. This lateral play also tends to distribute the wearing surface of the brushes over the surface of the commutator, thereby giving a more uniform contact surface. It is quite evident that if the armature was made to run without this lateral movement the brushes would always bear on the same part of the commutator and a ridge would soon appear on it.

The inexperienced mechanic should be warned not to skip lightly over any part of the work. While, of course, there is no visible connection between the armature and the pole pieces of the machine, and while it seems to be turning free and easy, it must be borne in mind that the force exerted upon the armature is, nevertheless, just as great as though a friction clutch of the capacity of the armature were applied to the periphery of the armature.

Furthermore, in the case of a sudden overload, or short circuit, or too rapid starting in the case of a motor, the force applied is almost as severe as the blow of a hammer.

MECHANICAL CONSTRUCTION OF THE ARMATURE.

All good armatures are made up of a number of punchings similar to those shown in Figs. 507-508-509. These punchings are made of soft iron or steel. The figures illustrate the different forms of slots used in connection with armatures. Into these slots the wires are wound, as will be hereafter explained. The punchings are usually made of thin iron with some form of insulation provided between them to reduce the Foucault, or eddy, currents. This insulation is obtained by inserting layers of thin paper between the sheets of metal, or by coating the punchings themselves. Paper, and similar materials used for this purpose will in time char from the heat of the armature and work out and tend to loosen the armature. Care should also be exercised in the use of an insulating varnish, as some of these varnishes soften from the heat of the armature, and are thrown out on the pole pieces.

FIG. 507

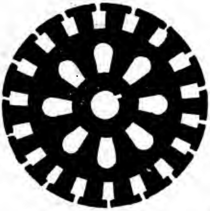


FIG. 508

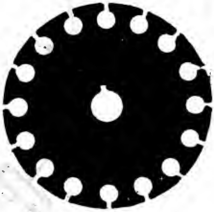


FIG. 509

As many of the punchings as are necessary are slipped upon the shaft of the armature as indicated in Fig. 505, and fastened together with clamps shrunk upon the shaft, or with large nuts screwed on the shaft. Bolts extending through the punchings are often used. These bolts must be insulated from the punchings; otherwise there will be a flow of current through the shaft, the body of the armature and the bolts. It is well to remember in laying out the armature and the means of fastening it to the shaft that the Foucault currents will flow according to the principles of any other electrical circuit, so that to keep these currents to a minimum, no electrical paths should be provided through the armature core.

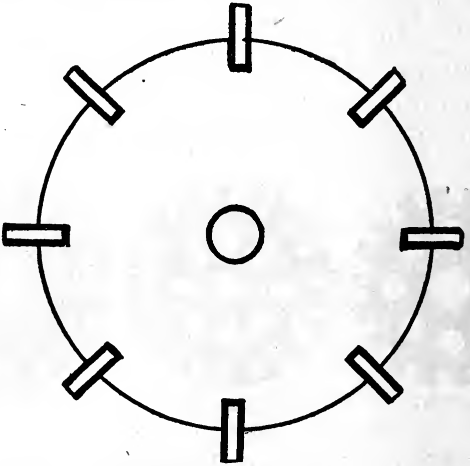


Fig. 510

Where an armature is slotted as indicated in Fig. 505, some of the punchings are often made of smaller diameter than the rest, or are afterward turned down as indicated in the figure. This is to allow room for the binding wires which are put on after the winding is completed. Sometimes the punchings are not slotted, but are milled out, and narrow bars of metal or wood inserted in the grooves as shown in Fig. 510. These bars are for the purpose of keeping the wires from slipping. If of metal, they must be insulated from the punchings for the same reason as was explained with the use of bolts.

In some cases the slots are made partially closed as shown. This makes it a little more difficult to insert the wires, but they are then held securely in place. Often these slots are made wedge shape, and the tops closed by means of wood or fiber strips after the wires have been put in place. In some cases the slots containing the wires are entirely closed.

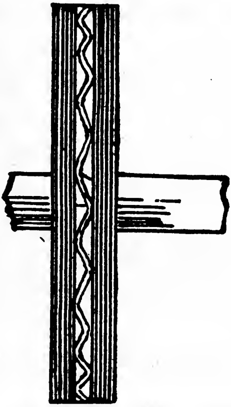


Fig. 511

In slotted armatures, especially if the slots are deep, when the punchings are forced together, that part of the punchings which projects beyond the ring R, Fig. 505, is likely to bulge out. In order to prevent this a few pieces of extra heavy metal are obtained and used at the ends. One punching of insulating material is also generally used at each end.

For small armatures the punchings are generally left solid. With diameters of 18 inches or so, openings are left. These openings lighten the armature, and are also useful in ventilating it to reduce the heating. With very large armatures, opportunities for radial ventilation must also be given. For this purpose some of the punchings are corrugated, or otherwise arranged, so that they allow air to pass from the center outward. When such pieces (see Fig. 511) are used in connection with the openings shown in the punchings, the air drawn in at the sides escapes radially, and thus helps to keep the armature cool.

The punchings are preferably made of metal ranging from 10 to 30 mils in thickness. The thinner the better, so long as the metal can be easily handled. Punchings should be made as accurate as possible. Where it is necessary to turn down an armature to obtain perfect roundness, the Foucault current losses are greatly increased. This is due to the fact that the cutting tool of a lathe has a tendency to bend over the edges of the thin punchings, and cause an electrical contact which allows current to flow. If it is necessary to smooth down an armature this work is best done with a sharp file.

ARMATURE WINDING.

Armature windings are divided into three general classes, viz.:

1—Ring wound armatures.
2—Drum wound armatures.
3—Disk wound armatures.

The winding of each of these classes is again subdivided into what is known as open coil winding, where the winding is part of the time on open circuit; and closed coil winding, where the winding forms a closed circuit.

The ring and drum windings are in most general use, the disk winding not having had any extensive application in this country. On direct current machines, windings of the closed coil type are generally used, although the open coil type of armature is employed on some constant current arc light generators. This type of armature is open to the serious objection that the sparking at the brushes is excessive, and some special means must always be provided to reduce it.

Gramme Ring.—The ring wound armature, or as it is more commonly called, the Gramme ring armature, comprises an iron core made in the form of a ring around which are wound the conductors which are to convey the current.

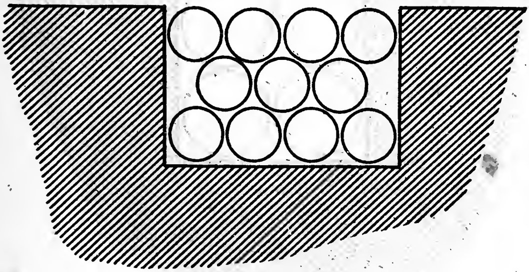


Fig. 512

The various coils are wound on separately, the wire being carried over the outside of the iron core, then through the center opening and again around the outside of the core, this operation being repeated until all the wire for that individual section is wound on. The adjacent coil is then wound on in the same manner, the ends of each coil being brought out to the commutator side of the armature.

There are various advantages, and disadvantages, to this class of winding and, the conditions under which the machine is to be used must be taken into consideration in determining whether it is the best form to use.

As only those conductors which cut lines of force are active in the production of current, it is evident that those conductors which lie on the inner side of the iron ring serve no useful purpose so far as the generation of current is concerned. Numerous attempts have been made to utilize this part of the winding by making the pole pieces extend around the ring in such a manner that lines of force will pass to the inside of the ring; also by arranging an additional pole piece on the inside of the armature but mechanical considerations have shown these methods to be impractical.

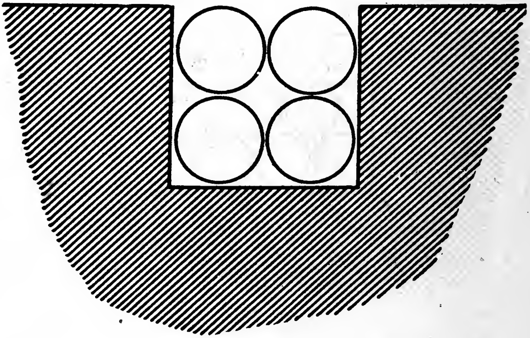


Fig. 513

The dead wire on the inside of the armature constitutes one of the greatest disadvantages of this class of winding, and this is especially the case where the armature carries heavy currents. In arc lighting machines, where a comparatively small current is used, this loss is not of so great importance, and is entirely outweighed by the several advantages, as will appear after further consideration. In laying out ring armatures it is well to remember, that, where the armature coils consist of only a few turns of fairly heavy conductor, the losses become proportionately less as compared with the drum armature, as the cross connectors on drum armatures also form an inactive part of the circuit.

In Fig. 514 is shown a simple ring wound armature with a bi-polar field. The end of one coil is connected to the beginning of the next, and the winding therefore forms a continuous spiral, encircling the iron ring core. Taps taken off at the point of connection of the various coils are carried to segments of the commutator, brushes being provided, to either conduct the current from, or convey it to the commutator as the case may be. It will be seen that with an armature of this kind each individual coil is generating an electromotive force which is proportional to the number of lines of force being cut by the coil. Assuming for the present that we have a uniform field, it is plain that the volt-meter connected across the ends of coil 13, or 5 would indicate a certain difference of potential, and the potential readings over the other coils would show a gradually diminishing difference of potential, until we reach the point of brush contact, where

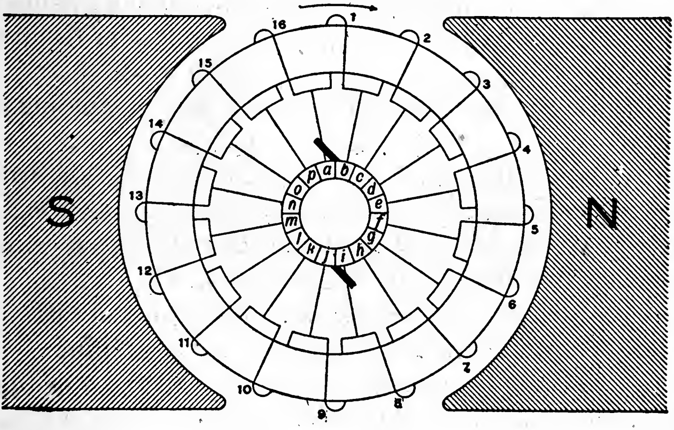


Fig. 514

the difference of potential would be practically nothing. It is also evident that at no place in the winding is there any great difference of potential between adjacent wires, or between adjacent commutator segments. By greatly increasing the number of coils and, also the number of commutator segments, the difference of potential between adjacent coils and commutator segments can be still further reduced.

A further inspection of the drawing will show that there are no crosses between wires of opposite polarity on the taps extending to the commutator segments. Herein lies one of the great advantages of this style of winding over the drum winding.

Other advantages pertaining to this class of winding are as follows:

(a) As it is possible to increase the diameter of the armature without greatly increasing its weight, a much higher velocity can be obtained in the moving conductor, with a corresponding increase in the induced E. M. F.

(b) A defective coil can be easily detected, and easily replaced without disturbing the balance of the winding.

(c) In case of emergency a defective coil can sometimes be cut out, and the machine still operated.

(d) Better ventilation due to the open style of construction.

Its disadvantages in addition to those already mentioned are:

(a) The resistance of the magnetic circuit is increased, owing to the shape of the armature.

(b) A ring armature requires more work in the winding as each coil has to be wound by hand, and is therefore more expensive.

While ring armatures are all wound in practically the same manner, i. e., each coil wound separately, a number of different connections between the coils, and the commutator segments are employed. A development of the faces of the pole pieces, together with the armature conductors, will show in a plainer manner the relations existing between the coils and their connections. The development of the armature in Fig. 514 is shown in Fig. 515, and is that view which would be obtained were a person to take a position corresponding to that occupied by the armature shaft and make a complete revolution, thus bringing into view consecutively all the pole piece faces, and the armature conductors.

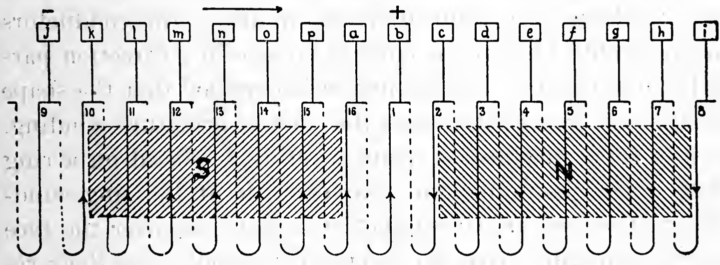


Fig. 515

In the figure the full lines denote the active conductors, and the dotted lines the inactive conductors on the inside of the armature ring. The small squares at the top represent the commutator segments, and the shaded cross sections the pole pieces. The arrows indicate the direction of flow of the induced current.

By an examination of the figure it will be seen that there are two commutator segments, one at which the current in both wires connected to it has a tendency to flow in a positive direction, or toward it, and the other where the current tends to flow away from it, or in a negative direction. These are obviously the proper locations for the brushes. It will be seen further that the end of one coil connects to the beginning of the coil next to it.

While the figure represents a simple armature of sixteen coils, it is apparent that the number of coils could be greatly increased or, instead of a coil having but one turn, it could consist of a number of turns of wire.

Drum Windings.—The drum wound armature varies primarily from the ring wound armature in the shape of the core. While with the latter the core is in the shape of a ring or hollow cylinder, the conductors being wound spirally around the ring, with a drum-wound armature the core is in the shape of a solid cylinder, or drum, the conductors being wound around the outside surface in a direction parallel to the shaft. It must not be understood that the shape of the core alone determines the class of armature winding, for in some machines a drum winding is placed on a ring core. The distinguishing characteristic of the ring winding is, that the active conductors, which pass over the face of the armature from the front to the back, have their return conductor pass through the opening in the center of the ring from the back to the front, this part of the conductor being inactive in the production of current. With a drum winding the conductors, in returning from the back to the front of the armature, also pass over the face of the armature, where they can cut lines of force and are also active in the production of current. It will thus be seen that in the ring armature considerable of the wire is not only inactive in the production of current, but at the same time is the cause of a loss of energy, due to its resistance, with a resultant heating of the armature. This objectionable feature is to a great extent overcome in the drum winding. Less wire therefore has to be used on a drum-wound armature, other conditions being equal, than on a ring-wound armature of the same capacity, and the armature has a lower resistance.

At first glance the winding of a drum armature appears a quite difficult matter, but with a little study it will be found that it is not very much unlike that of the ring armature.

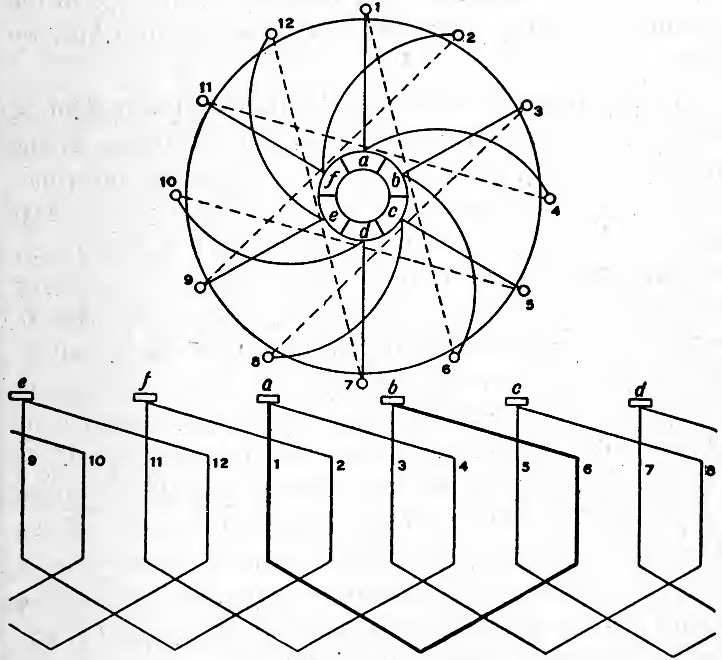


Fig. 516

A simple case of drum winding is shown in Fig. 516. There are 12 conductors on the armature face, and 6 commutator segments. Suppose we take a wire and connect it to segment *a* of the commutator. Now start to wind around the armature, passing along 1 to the rear and returning by way of 6 to the front where we loop back to commutator segment *b*. Now make another turn around the armature by way of 3 and 8, returning to segment *c* of the commutator. Repeat this procedure, gradually turning the armature to the left. When the last turn 11, 4 has been made, we come back to commutator bar *a*, the one from which we started. This operation can be considered as simply winding a wire spirally around the drum, and bringing down loops to the commutator segments, ending at the point from which we start.

The first question which presents itself to the student is, Why does not the wire which passes over 1 return in the diametrically opposite position, or 7? Consider for a moment the armature shown in Fig. 516. Suppose we start our wire at segment *a* of the commutator, pass to the rear of the armature along 1, and return to the front end along the diametrically opposite position 7. Now loop back to segment *b* of the commutator and from there make another turn around the armature by way of 3 and 9 and back to segment *c*. From segment *c* make another loop around the armature by way of 5 and 11 and return to segment *d*. It will now be seen that we have made a complete revolution of the armature, but have made connection to only half the commutator segments. In order to keep up the winding in a regular manner, the wire from commutator segment *d* should pass to the rear of the armature along space 7, but this space we find already occupied by the return of 1. If we were to continue with our winding from this point, we would have to carry the wire from segment *d* to position 6 or 8, but this would result in an unbalanced winding.

It is plain that, in order to keep the winding symmetrical, the conductors in passing from the front to the rear of the armature must occupy the positions 1, 3, 5, 7, 9, 11, and the even numbered positions will then serve as the returns for these wires.

It will be noticed that in the example shown there are 6 coils, comprising 12 conductors and 6 commutator segments. If the armature was so designed that we had an uneven number of coils, for instance 7 coils, in which case there would be 14 conductors, and 7 commutator segments, the rear connections could be made directly across a diameter as shown in Fig. 517. This gives a perfectly symmetrical winding. Only one coil will be short-circuited at a time for, with the brushes set across a diameter of the commutator when one brush is in such a position that it laps across two segments, the other brush is in the center of a segment.

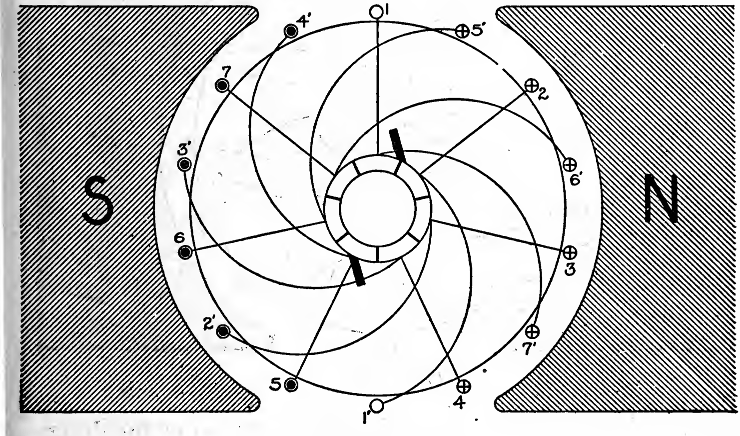


Fig. 517

Fig. 518 shows the connections of a drum-wound armature having 8 coils comprising 16 conductors and 8 commutator segments. While in the example shown each coil consists of only a single loop with two conductors, a coil may consist of a number of turns of wire, in which case the drawing indicates merely the connections for the beginning and end of each coil.

As has been previously explained, the conductor which passes from the front to the rear of the armature along space 1 cannot be brought back to the front of the armature if the winding is to be perfectly regular along the diametrically opposite space, 9, but must return along one of the

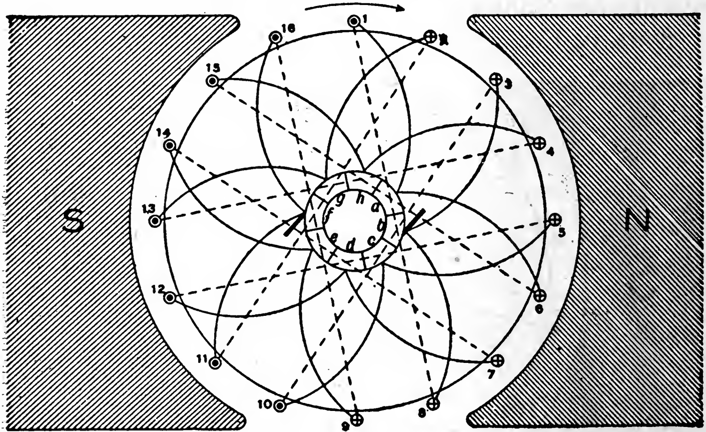


FIG. 518

spaces to the right or left of 9. The expression for determining the proper spacing for the return conductor is:

$$y=\frac{2}{n}\left(\frac{z}{b}\pm 1\right),$$

where y=spacing or pitch,
n=number of poles,
z=number of conductors,
b=number of conductors to a coil.

The symbol $\pm$ means simply, plus or minus, that it is optional with us whether we add 1 to, or subtract 1 from the number found by the operations indicated in the formula.

In Fig. 518 $n=2$, $z=16$, $b=2$, therefore

$$y=\frac{2}{2}\left(\frac{16}{2}-1\right)=7.$$

Each conductor is connected at the rear of the armature to one 7 spaces in advance of it; as 1 to 8, 3 to 10, etc.

In winding an armature according to the plan shown where each coil consists of a number of turns of wire, we would start with the wire connected to commutator segment *a*, and wind along space 1 to the back of the armature, thence across the back of the armature to space 8, returning to the front of the armature along space 8 and across the front to space 1, continuing until all the wire of this coil is wound on. The end of the wire would now be brought to segment *b* of the commutator. The second coil is now wound on, starting from segment *b* and winding to the back of the armature along space 3, across the back to space 10, to the front along space 10 and across the front to space 3, continuing in this manner until this coil is also wound on. The end of this coil is now brought to commutator segment *c*. The remaining coils are wound on in the spaces indicated.

In the actual winding of an armature the commutator is generally left off during the process of winding, the beginning and end of each coil being brought out and connected to the commutator after the armature is completely wound. A winding table which shows the several steps just described and which is very convenient both for winding and connecting is given below:

a-1-8-b
b-3-10-c
c-5-12-d
d-7-14-e
e-9-16-f
f-11-2-g
g-13-4-h
h-15-6-a

This table shows both the position of each coil and the commutator connections; for instance, segment *b* is connected to the end of coil 1-8 and to the beginning of coil 3-10.

The development of the armature winding, Fig. 519, will show in a plainer manner the various connections made, also the direction of flow of the induced current in the various conductors. Following out the direction of current it will be seen that at commutator segment *f*, the current in both conductors flows toward the segment, while in segment *b* the current flows away from the commutator. These two positions are the proper points for the brush contacts.

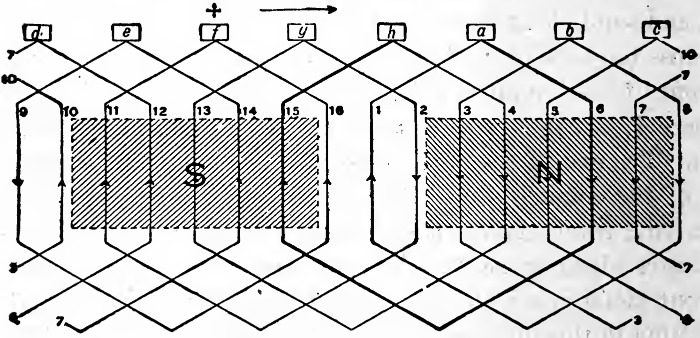


FIG. 519.

With the armature connected, as shown, the brushes lie in an almost direct line, between the pole pieces, and the connections on the front of the armature are symmetrical. It is quite evident that we could, without changing the order of the winding, turn the commutator through an angle of 90°, thus bringing the brushes in a line with the spaces between the pole pieces. The front connections would not then be symmetrical, one connection to each coil being shortened, and the other being lengthened. The design of some machines is such that locating the brushes in a line with the pole pieces brings them in an inaccessible position, and the commutator is therefore shifted as described.

There are two circuits through the armature from brush to brush and in the position shown these circuits are as follows:

$$-\left\{\begin{array}{l}\text{b-3-10-c-5-12-d-7-14-e-9-16-f}\\ \\ \text{b-8-1-a-6-15-h-4-13-g-2-11-f}\end{array}\right\}+$$

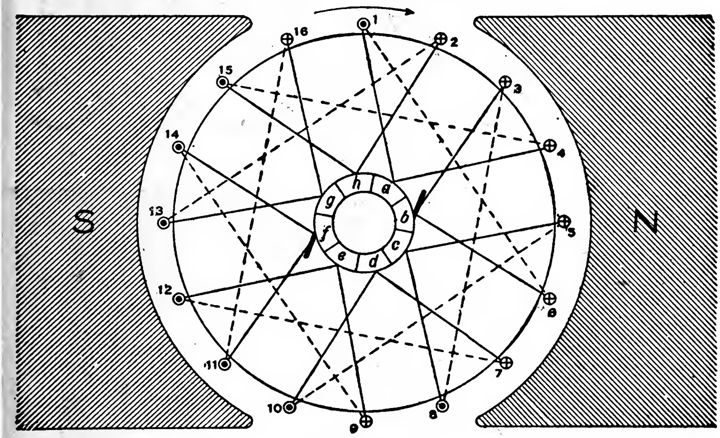


Fig. 520

As the armature revolves in the direction shown by the arrows, the positive brush will short-circuit commutator segments e, and f, and the negative brush segments a, and b. The two coils e-9-16-f and b-8-1-a will therefore be short-circuited, and the full difference of potential of the machine will exist between them. As these coils are adjacent with each other, in a smooth face armature where the coils consist of a number of turns of wire, they will be placed side by side, and the question of insulation between them therefore becomes of considerable importance.

Following out the paths on the development of the winding, it will also be seen that there are numerous crosses between wires of greatly different potentials. Compare with the ring armature winding shown in Fig. 514.

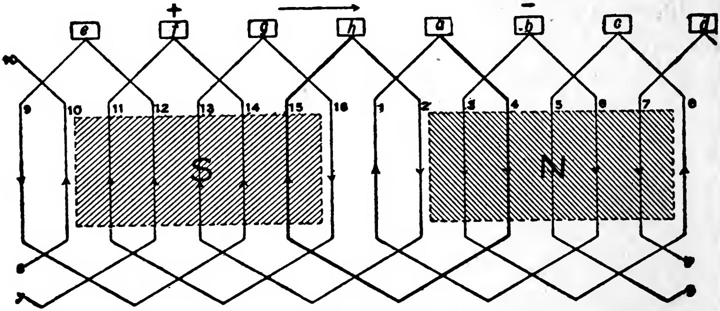


FIG. 521

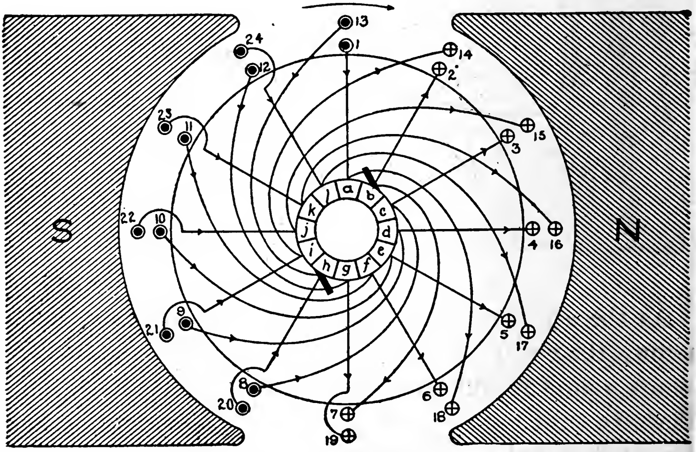


FIG. 522

To obviate some of the objectionable features of the winding just described, the method shown in Fig. 520 is used. The value of y is in this case 5, each conductor at the rear of the armature being connected to another conductor 5 spaces ahead of it. The coils short-circuited by the brushes are now separated, and there are fewer crosses between conductors at the ends of the armature. Tracing out the circuits it will be seen that the current induced in some of the conductors is in opposition to that of the remainder of the circuit. This has the effect of decreasing the demagnetizing effect of the armature.

The armatures which have so far been considered have had but one layer of wire. Fig. 522 shows an armature with 24 conductors and 12 commutator segments with the wire placed on in two layers. The development of this winding is also shown in Fig. 523. The winding table is given below:

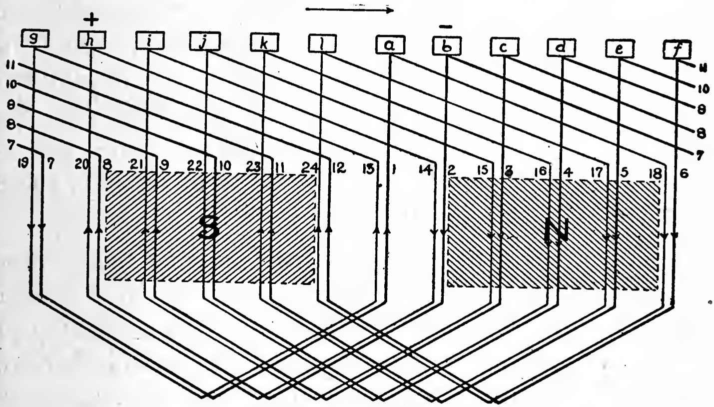


FIG. 523

a-1-7-b
b-2-8-c
c-3-9-d
d-4-10-e
e-5-11-f
f-6-12-g

g-19-13-h
h-20-14-i
i-21-15-j
j-22-16-k
k-23-17-l
l-24-18-a

One of the first points which will be noted is, that each conductor in returning from the back of the armature to the front passes through the diametrically opposite space; coil 1-7, for instance. The rear connections are not shown, as they would complicate the drawing. If we start to wind this armature from commutator segment *a,* winding coil 1-7, returning to segment *b* and continuing our winding from segment *b,* coil 2-8, segment *c,* to coil 3-9, segment *d* to coil 4-10, segment *e* to coil 5-11 and segment *f* to coil 6-12 it will be seen that we have made a complete revolution of the armature and have only made connection to half the commutator segments. We can complete the winding by continuing with the outer layers. It is evident that the outer layer of coils will have a greater resistance due to their increased length and will also travel at a greater speed than the coils of the inside layer.

The two paths through the armature, from the positive to the negative brush vary between the coils in the outer layer, and those in the inner layer, and in one position of the armature one of the paths from brush to brush is through the coils of the inner layer exclusively, and the other path through the coils of the outer. This results in a constant variation between the electro-motive forces induced in the two halves of the armature.

The two paths through the armature from brush to brush are

$$-\left\{\begin{array}{l}\text{b-2-8-c-3-9-d-4-10-e-5-11-f-6-12-g-19-13-h}\\ \\ \text{b-7-1-a-18-24-1-17-23-k-16-22-j-15-21-i-14-20-h}\end{array}\right\}+$$

As the armature moves forward from the position shown, coil 1-7 is short-circuited by the negative brush and coil 13-19 by the positive brush. It will thus be seen that a considerable difference of potential exists between the inner and outer layers of wire, and they will have to be well insulated from each other. It will also be seen that no great difference of potential exists between adjacent coils. The two short-circuited coils lying as they do, one above the other, are both in the neutral point of the field at the point of commutation. This can be considered as an advantage over the previous type where the short-circuited coils are somewhat separated, and are therefore not commutated at the exact neutral point.

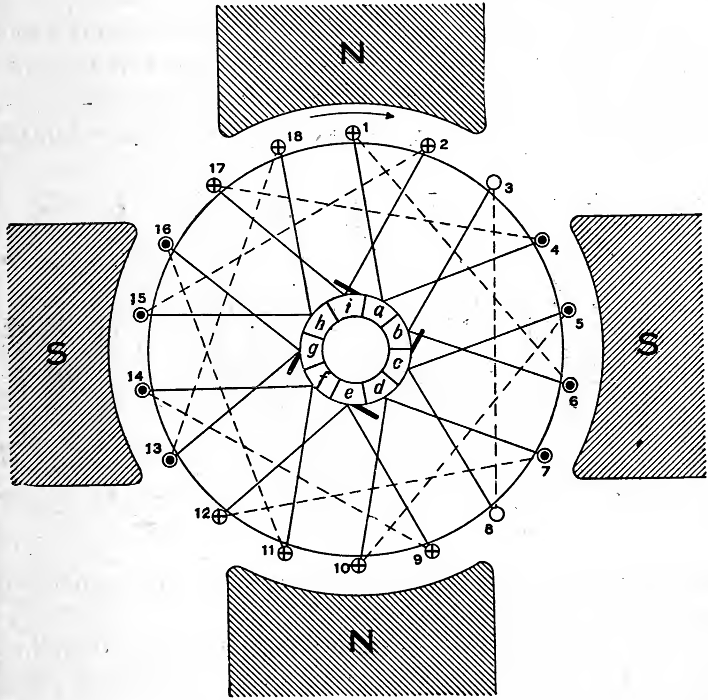


FIG. 524

In the previous examples of drum windings we have considered only the methods of winding used with bi-polar fields. As has been explained elsewhere there are many conditions where the use of a bi-polar field is not advisable, and numerous advantages are gained by using a multi-polar field, or a field consisting of more than one pair of poles.

The same general principles apply to multi-polar windings as apply to bi-polar windings, and these various applications will be described. We will investigate only those methods in general use, there being a number of other schemes of winding which are in the main only extensions of the principles here shown.

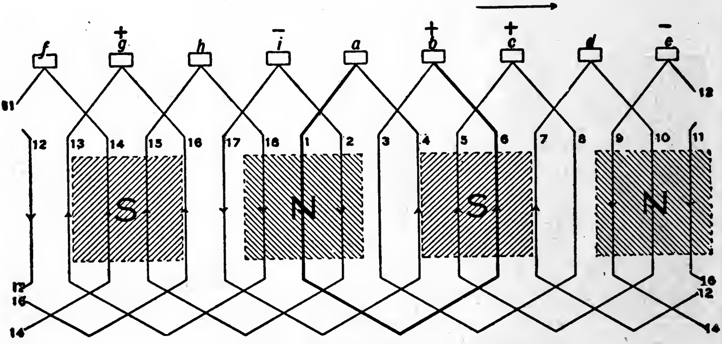


FIG. 525

Fig. 524 shows an armature winding, with its development, Fig. 525, consisting of 18 conductors and a 4-pole field. Following out the circuits from one commutator segment to the next or the developed winding, Fig. 525, it will be seen that the winding after making a turn of the armature, laps back to the commutator segment next to the one from which it started, and is therefore called a lap winding. Tracing out the winding from commutator segment *a*, we find it follows the path a-1-6-b, b-3-8-c, c-5-10-d, etc., until it arrives at coil i-17-4-a, where it returns to the starting point. A complete revolution of the armature has been made, and every conductor has been passed through, and each one only once, forming what is termed a single re-entrant winding.

Observing the end connections of coil a-1-6-b, for instance, it will be seen that the value of y for the rear connection is 5, each conductor at the rear of the armature connecting to one five spaces beyond. The value of y for the front connection is —3, each conductor being connected to a conductor three spaces back from it. The average spacing is therefore 4, and the difference between the front and rear spacing is 2.

In connecting up the armature for a bi-polar field, in order that the induced currents would flow in the same direction in all conductors connected in series, we found it necessary to connect together at the rear of the armature, the conductors lying under a north pole with those lying almost directly opposite it under a south pole. So, in the case of a four-pole field, each conductor at the rear of the armature is connected in series with a conductor which lies in a field of opposite sign which, in this case, is not across a diameter, but one-fourth the distance around the armature. The value of y, the spacing, should therefore be nearly equal to the total number of conductors divided by the number of poles, or $z \div n$ where $z =$ the number of conductors and $n =$ the number of poles. As explained under the section on bi-polar armatures, this spacing may be either greater or less than the value just given. If the spacing is greater than $z \div n$, the cross connections will be longer, with a resulting increase in armature resistance. With the spacing less than $z \div n$ the cross connections will be correspondingly shortened, and the armature resistance lessened, and the conductors lying between the pole pieces will then oppose each other.

In Fig. 524 it will be noticed that there are an even number of conductors, and that the spacing at the rear is 5 and at the front—3. In all lap windings, with multi-polar fields, there must be an even number of conductors, and the spacings at the front and rear must be odd and must differ by 2.

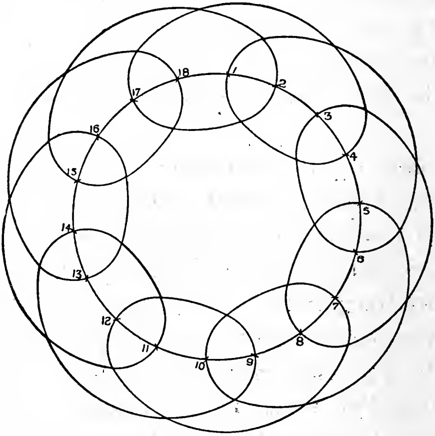


FIG. 526

A simple plan by means of which the student may investigate these several conditions, consists in drawing roughly a circle, subdividing it with as many intersections as there are conductors on the armature, and then drawing a series of connecting lines through the various points. These lines will then represent the armature conductors, and their connections, the lines on the outside of the circle representing the rear connections, and the lines on the inside of the circle the front connections.

Fig. 526 shows this scheme worked out for the armature shown in Fig. 524. That the armature must have an even number of conductors can be seen by figures similar to that shown in Fig. 527. Here 17 conductors are shown with a rear spacing of 5 and a front spacing of —3. The line from 13 should connect to a conductor 5 spaces beyond, or conductor 1, but this conductor is already connected.

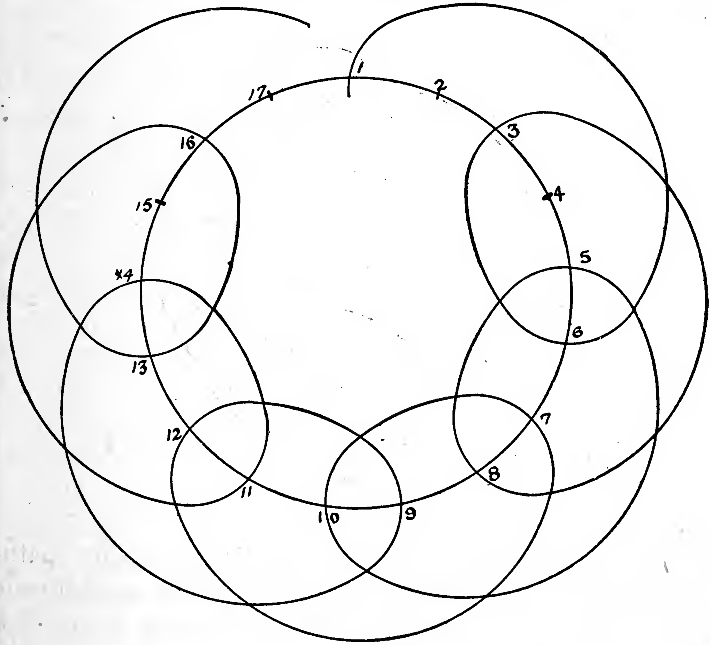
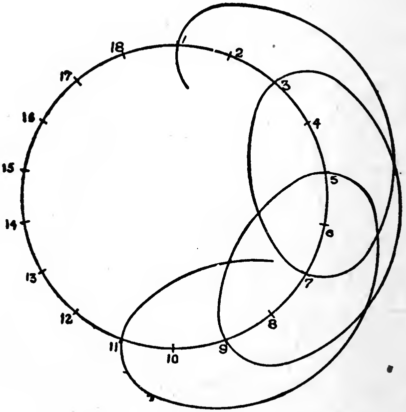


FIG. 527

With a bi-polar field, and a one-layer winding, it will be remembered that adjacent commutator segments were connected to every other conductor, the even numbered conductors being taken as returns for the odd numbered conductors. Similarly in a multi-polar armature, our spacing must be such that only every other conductor is connected to a commutator segment. The front and rear spacings must therefore differ by 2.

That the front and back spacings must be odd can be easily determined with the scheme previously described, Fig. 528 showing an armature with 18 conductors, and a spacing at the rear of 6 and at the front 4. We see here that the loops close on themselves and would form a short-circuited winding.



2"

Fig. 528

With a lap-wound armature there are as many paths through the armature, and as many brushes as there are poles. This can be seen from the development of Fig. 524, the paths through the armature being

i-2-15-h-18-13-g
i-17-4-a-1-6-b
e-12-7-d-10-5-c
e-9-14-f-11-16-g

These paths are unequal in length, as will be noticed from the drawing, when the brush which bears on the commutator segments b, and c, has moved from this position. In order to make all the paths of equal length, the number of coils must be a multiple of the number of pairs of poles. For example, 16 conductors (8 coils) with a four-pole field (2 pairs of poles), would give uniform paths, each containing an equal number of coils. The objection to this arrangement lies in the fact that four coils would be short-circuited at the same time. An examination of Fig. 524 where the number of coils is not a multiple of the number of pairs of poles, will show that four coils are not short-circuited at the same time. Where the number of coils is comparatively large the objection to the unequal length of the paths is not of so great importance. Where slotted armatures are used, the same conditions as just stated apply. It is quite evident that instead of having the conductors placed around the outside of the periphery of the armature, these conductors could be arranged in suitable slots. For instance, in Fig. 528 each pair of conductors such as 1 and 2, 3 and 4, etc., could be placed in separate slots, in which case the same diagrams would apply, it being customary to consider the even numbered conductors as lying in the lower layer, and the odd numbered conductors as lying in the upper layer. As the number of conductors must be even, it is plain that there can be either an even or odd number of slots, but the number of conductors per slot must be such that the total number of slots, times the number of conductors per slot, must be an even number.

In Fig. 529 is shown an armature similar to the armature previously shown in Fig. 524. There are exactly the same number of conductors and commutator segments. The conductors are placed on in the same positions, and the connections on the back of the armature are identical with those of the previous figure. The distinguishing feature of this armature lies in the method of connecting the various coils to each other, and to the commutator segments at the front of the armature. Where, in the previously described armature connection, each coil after making a turn of the armature, was carried back to a commutator segment adjacent to the one from which it started; in the present case the end of each armature coil is connected by means of a commutator segment, to a coil some distance in advance of it.

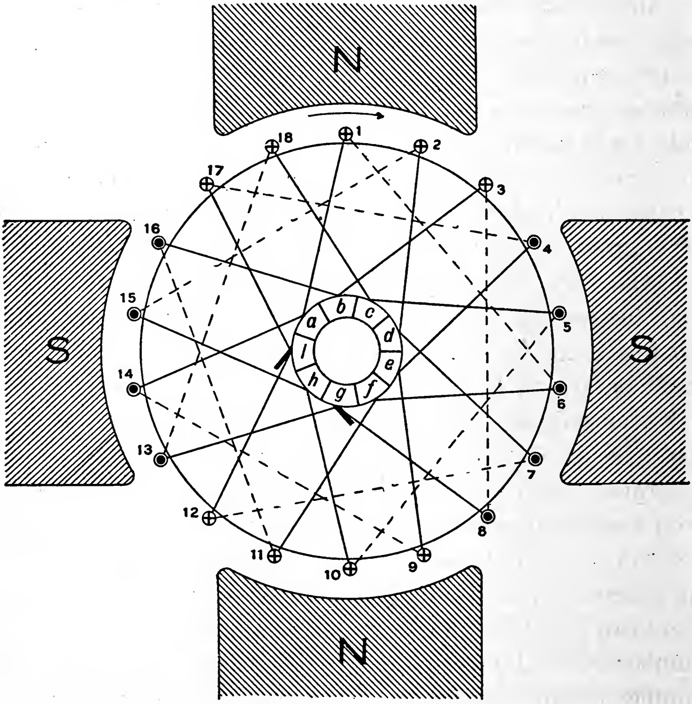


Fig. 529

The developed winding clearly shows the manner in which this connection is made. It will be seen that the conductors are so connected that the current induced in each is in the same direction as that in the remaining conductors of the series. It will also be noticed that the developed winding of each element forms a sort of wave and this winding is therefore known as a "wave" winding.

The scheme previously described may be employed to get a clearer understanding of this winding. This consists in drawing a circle, and dividing it with as many intersections as there are conductors on the armature, and then drawing a series of connecting lines through the various points, as shown by the winding table. The lines on the outside of the circle are to be considered as the rear connections of the armature, and the lines inside the circle, the front connections, or those connections running to the commutator segments. Tracing out the winding (or its development, Fig. 530), it will be seen that, starting from any one point and following out the winding circuit, every conductor is passed over once, and the winding finally returns on itself.

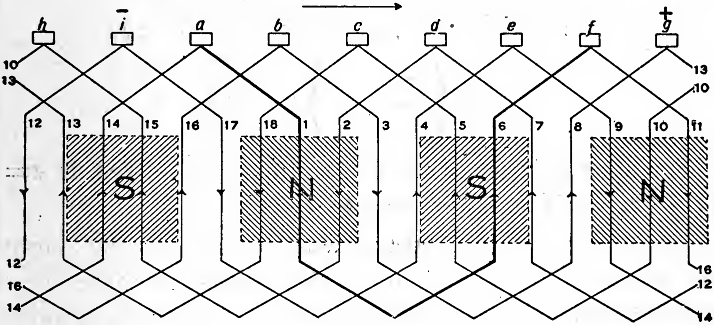


FIG. 530

The spacing or pitch for the rear is 5, being the same as that used for the lap winding, the conductor passing to the rear of the armature along 1, and returning along space

6. The spacing at the front of the armature differs from that of the lap winding in that it is not carried back, but advances 5 spaces forward. The formula previously used for determining the number of conductors and the spacing may be applied in the present case.

$$y=\frac{2}{n}\left(\frac{z}{b}+1\right)$$

In Fig. 529.

n, the number of poles=4;
z, the number of conductors=18;
b, the number of conductors to a coil=2.

$$y=\frac{2}{4}\left(\frac{18}{2}\pm 1\right)=4 \text{ or } 5.$$

For four-pole machines this formula simplified is $z=4y\pm 2$. In Fig. 529 $z=4\times 5-2=18$.

While the front and back spacings in the drawing shown are alike, i. e., 5 and 5, it is also possible to have these spacings differ. It is evident that the average spacing must be approximately equal to the total number of conductors divided by the number of poles, as the winding in passing around the armature from one commutator segment to the one next to it, comes under each pole piece. In the example shown in Fig. 529 $\frac{z}{n}$ is equal to 4½, the average spacing may, therefore be taken as 4, in which case the front spacing could be 5, and the rear spacing 3.

The pitches at the front and rear of the armature must be odd, for, as has already been explained, the even numbered conductors are considered as returns for the odd numbered conductors.

The winding table for this armature is

a-1-6-f
f-11-16-b
b-3-8-g
g-13-18-c
c-5-10-h
h-15-2-d
d-7-12-i
i-17-4-e
e-9-14-a

The two paths from the — to the + brush are:

$$-\left\{\begin{array}{l}\text{i-17-4-e-9-14-a-1-6-f-11-16-b-3-8-g}\\[1em]\text{i-12-7-d-2-15-h-10-5-c-18-13-g}\end{array}\right\}+$$

It will be seen that one path contains one more coil than the other and that, with narrow brushes, only one coil is short circuited at a time.

We have thus far been studying armature winding from a theoretical standpoint.

It is now in order to devote a space to the practical side. In the applicaton of the wire, the first thing in order is the proper insulation of the slots wherein the wire is to rest. The most suitable materials for this purpose are

Shellaced paper, or cloth,
Shellaced cardboard,
Thin fibre,
Mica.

After the slot has been carefully insulated we may begin to apply the wire. Figure 531 illustrates two methods of doing this. In the first method shown at *a* the winding is begun in one corner of the slot, and continued in regular order, progressing first from left to right, until one layer is finished, and then from right to left until the second layer is complete. By this method we can see, by referring to the figure, that the last turn of the second layer comes in very close contact with the first turn of the first layer. The same condition will exist with every other layer in the same coil. The result of this is a great liability to abrasion in the first place, further a great liability of the insulation being pierced, should the coil be wound with a great number of turns, so that a great difference of potential would exist within it. We must bear in mind that the insulation of armature wires is very thin, economy of space being a great consideration in all cases.

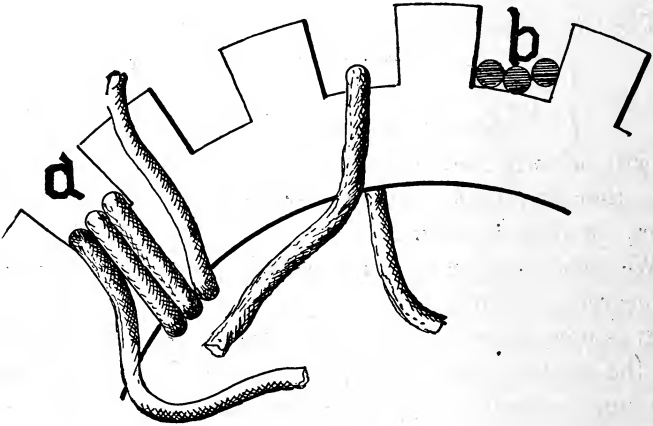


FIG. 531

By the above method of winding another great disadvantage is introduced. The lowest coil of wire being so tightly hemmed in, and at the same time there being considerable necessity for handling the wire, the end of which is projecting, there is much risk of breaking it off short. If this occurs it becomes necessary to unwind the whole coil in order to get at this wire for repairs.

In order to avoid these elements of trouble, the method now to be described is extensively used. Take of the wire that is to be wound upon the armature, sufficient to make one coil; the amount required can best be determined by winding one coil temporarily, and then unwinding it and using it to measure the other coils with. Take one of the wires so obtained and mark the center of it and place it exactly in the center of the slot as shown in Figure 531. Now begin winding from the center, to one side until that side is filled, next begin winding the other side in the same way and continue winding the second layer in the same way, half from each side, until the slot is filled. By this method if the number of layers is even, the two ends of the coil will finish side by side in the center; if there is an uneven number of layers the two ends of the coil will be at opposite sides. It will make no particular difference which is the case.

The full difference of potential of the coil will exist between the two wires of the last layer which lie side by side, and a difference of potential of a lesser degree between the two middle wires of each layer. It might, therefore, be advisable, where the coil consists of a number of turns, to provide an insulating layer between the two halves of the coil.

When the last layer is placed on the armature great care should be exercised to see that it finishes off smooth. If possible avoid the condition of wires shown in Fig. 531. The wire at the right is likely to work down in time, and thus leave a loose wire above it that may work down and cause trouble.

A wire in the position of the one shown in Fig. 531 exerts a leverage on the other wires, and will gradually force its way down.

If the armature to be wound, has no slots, a few clamps (Fig. 532) will serve to hold the wire in place while a coil is being wound.

Before starting the winding, tape should be laid on the armature, leaving it long enough so that it can be used to tie the coils together when the clamps are removed. Each wire should go to its proper place, and by no means cross any other wire below it so as to form a bulge. The strain on the wires of an armature, whether dynamo or motor, is at times very severe, and if there is any flaw it will surely show itself.

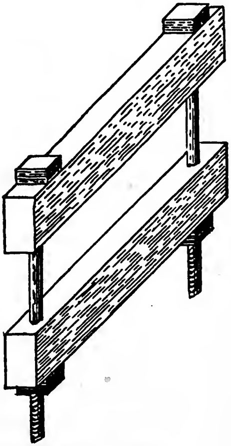


Fig. 532

In the case of fine windings, each layer as it is put in place should be thoroughly soaked with shellac. No current, except of a very low potential from a small battery, should be used either for testing or any other purpose until this shellac is dry. Shellac until dried is a conductor and may be pierced by the current and thus leave a gap, through which at a later time current may leak. An armature of this kind is usually baked at a high temperature for 24 hours.

As an illustration of the great care that is advisable in the insulation of armature wires, we may state that some manufacturers place the magnet windings into tanks from which the air can be exhausted. After the air is withdrawn from the coils, the insulating compound is allowed to flow into the tank until the coil is submerged. This allows the insulating compound to enter into the most minute openings that may exist between the wires. Air pressure is afterward applied to make certain that the interior of the coil is reached by the fluid.

As each coil is finished it may be tested for correctness of winding by a battery of two or three cells, and a small galvanometer. The battery if always applied in the same way must always produce the same deflection on the galvanometer (see Fig. 546); if it does not do this the coil in question has been wound wrong. It is not always necessary to unwind the coil to correct this; frequently all that will be necessary is to connect the terminals of the coil in the opposite way from the rest. As this, however, often necessitates a crossing of the wires it is sometimes objectionable.

When all of the coils have been wound upon the armature the end of each coil is to be fastened to the beginning of the next. Both are then fastened to their respective commutator bars. It is well to tape the two wires together; this leaves them stronger to resist mechanical interference, and also occupies less space. This latter is an important consideration where there are many coils.

The commutator sections are sometimes provided with screws to hold the wire, but oftener the wires are soldered directly to the commutator segments. This latter is the safest method but may cause some trouble should it be desired to remove the commutator for repairs.

The next step is the placing of the binding wires. These are to hold the wires of the armature in place and must always be used, unless the slots on the armature are of the nearly enclosed type. The binding wires are wound upon the finished armature as shown in Figure 533. After placing a band of insulating material, such as mica, where the wires are to go, begin by taking one or two turns of wire around the armature with the spool; draw these as tight as possible and solder as indicated by arrow in the drawing.

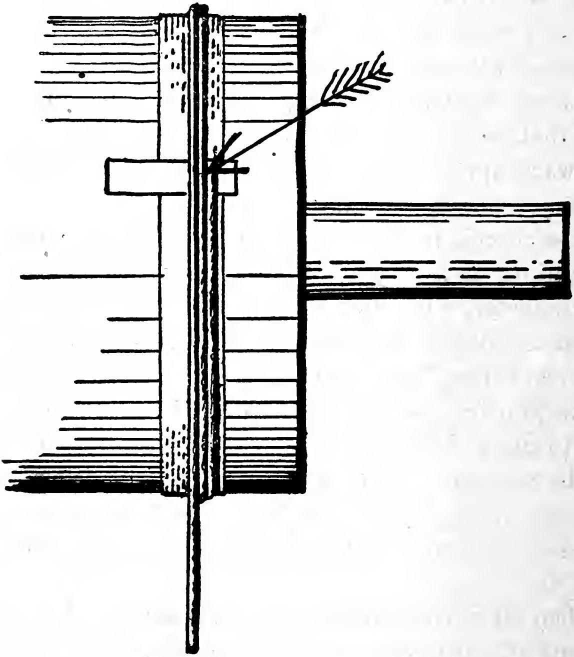


FIG. 533

Now proceed, and put the balance of the necessary turns in place by revolving the armature and holding the spool with the wire stationary. In this way the winding can be placed very accurately and close together. After a sufficient number of turns have been placed they are all soldered together over the whole circumference to avoid possibility of any of the wires breaking loose and causing damage.

Where the winding begins and ends a thin piece of brass should be laid under the wire before it is wound on. After the winding is finished this is bent over and soldered. Iron and steel should not be used for binding wires; although the section may not be large, they would always increase the magnetic leakage that would to some extent lessen the E. M. F. of the machine. The size of the binding wires used ranges from number 20 to number 10. The latter is used for the larger machines and the first for the smaller. Usually about one-third of the armature is covered by such wires.

The student of drum armature winding will save himself considerable worry, and mental tribulation if he will, at the beginning, construct for himself out of a large spool or some similar circular object a little imitation armature, upon which he can wind with strings such coils as are herein described as being in use on armatures. These little experiments will be more realistic if, for this purpose the armature of some old fan motor can be procured. Such an armature should preferably be of the slotted kind; if the wooden spool above referred to is used its periphery should be divided off into the proper number of spaces by inserting suitable nails thereon. Much can be learned in this way regarding armature winding that can never be fully grasped in any other way.

QUESTIONS AND ANSWERS.

818. Can the properties of a dynamo be accurately calculated from any of the formulas given for that purpose?

Ans. No. The accurate design of a new type of dynamo, and an armature as well, is as much a matter of experiment as it is of calculation.

819. Why is this?

Ans. There are so many factors involved in the calculation that cannot be accurately determined until a machine of the exact dimensions of the one under consideration has been built.

820. What are the principal factors that are so troublesome to determine?

Ans. The permeability of the iron, the resistance of the magnetic circuit, the tendency to leakage of the lines of force, the exact proportion of the dead wire, the reaction of the armature, the losses due to *Foucault* currents.

821. Are not the causes of all these losses well understood?

Ans. They are, and it is easy enough to tell what must be done to lessen any or all of them. It is merely their exact value which is indeterminate until the machine in question is in operation.

822. What is the chief precaution which must be taken on this account.

Ans. It is necessary to leave some part of the controlling influences so that they can be readily varied and thus adjust the machine so that it will be exactly right when it is finally finished.

823. How can this best be done?

Ans. Since it is manifestly very troublesome to rewind an armature, if perchance too great or too small a number of wires have been placed upon it, the proper factors to be arranged to be variable are: the speed, and the strength of the field. In some cases the speed, even, is not changeable, and the whole duty of compensating for misjudgment in the calculations falls upon variations of the field strength.

824. Can the whole regulation be accomplished in this way?

Ans. It can, and in most cases this is the method relied upon. It is very easily accomplished by this method if we arrange to have the fields magnetized to only a low degree of saturation. By doing this, however, we are led to provide field magnets whose capacity is far in excess of what we believe to be necessary and, therefore, more expensive. So that again in the last consideration it behooves us to experiment before we definitely determine the exact proportion of our dynamo or motor.

825. Are there any formulæ that can be used in determining the exact proportions?

Ans. There are, and they are given below. These will materially assist the student in forming an idea how the different parts can be adjusted to bring about the desired final result. For the following formulæ we shall adopt the attached set of symbols:

Let F=the total number of lines of force, or flux,
V=the number of volts to be generated,
S=the number of slots in the armature,
R.P.S.=the number of revolutions per second,
W=the number of wires per slot.

Then, to find the number of wires necessary per slot where the speed and flux are fixed:

$$W = \frac{10^8 \times V}{F \times S \times R.P.S.}$$

To find the necessary speed where the number of wires, and the flux, are fixed:

$$\text{R. P. S.}=\frac{10^8\times V}{F\times S\times W}$$

To find the necessary strength of field, where the wires and speed are fixed:

$$F=\frac{10^8\times V}{S\times \text{R. P. S.}\times W}$$

To find the volts generated:

$$V=\frac{F\times S\times W\times \text{R. P. S.}}{10^8}$$

826. Are these formulæ used in actual practice to determine the size of wire, speed, etc.?

Ans. These formulæ are of value principally in checking up the actual calculations made.

827. How is an armature actually designed?

Ans. In actual practice whenever a new dynamo or motor is to be constructed it is, so to speak, built up around the armature. That is to say, the armature must first be designed, and the other parts made to fit around it.

828. What is the principal consideration to be taken into account?

Ans. In order to deliver a certain current, the number of poles, etc., being fixed, which is with rare exceptions the case, we must use a certain size wire.

829. Is there no choice whatever in the size of wire for a given current?

Ans. There is some choice. In most cases the heating of the wire on the armature determines the size of wire to be used; in other cases it is the drop in potential at the terminals of the armature that governs.

830. How does the size of wire affect the heating, and the loss of potential?

Ans. Both of these losses, and the troubles occurring from them, are lessened by selecting wires of greater diameter.

831. How do you proceed to calculate the necessary size of wire?

Ans. The number of wires, and the dimensions of the armature for any given purpose can be found by trial calculations only. By this we mean that, unless we are very lucky, we shall have to make a number of calculations, using, perhaps, different dimensions and wires before we get the result that suits us best.

832. Give an example.

Ans. As an example let us take an armature 8 inches in diameter and 8 inches in length and see what it will do for us. Such an armature has a cross-section of 64 sq. inches and, assuming a flux of 30,000 lines of force per square inch, we have a total flux of 1,920,000 lines through the armature. We first find how often one wire must cut this number of lines of force to generate, say, 110 volts. To do this we first divide 110×100,000,000 (which is the total number of lines to be cut per second) by the total flux, 1,920,000, and obtain as the result 5728. Next, to get the necessary number of wires to be placed upon the armature, we must divide this quotient (5728) by the number of revolutions the armature makes per second. If our armature revolves at the rate of twenty revolutions per second (1,200 per minute) we shall need one-twentieth of 5,728 wires placed upon it. This amounts to 286. As our armature, 8 inches in diameter, has a circumference of 25.12 inches, this gives us a wire running about 11 per inch. If there is to be but one layer, this gives a number

12 wire. As the two sides of the armature are in parallel we have a capacity of 2 times 14.31 amperes according to Table 50. If we decide to use two layers, we can take a No. 6 wire, 5.5 per inch, and obtain a capacity of 56.55 amperes. It may be stated in explanation of the calculations here made that each wire in the course of one revolution of the armature cuts the total flux two times; but as the two halves of the armature are in parallel, each side must produce the full voltage by itself.

833. How much radiating surface is usually allowed per watt of energy used up?

Ans. That depends very much on the work for which the armature is intended. If it is for a railway motor, which is entirely enclosed, and almost constantly in use, it is much more than, for instance, an elevator in a private residence where there is but very little use, and only at long intervals, so that the armature has time to cool off between one run and another. Table 50 is based upon the requirement that there shall be three square inches of radiating surface for each watt of energy expended in the coils.

834. What radiating surface is allowed for each watt expended in the case of an armature?

Ans. This amount varies in different machines, being as low as 1 square inch per watt, and as high as three square inches per watt. About 1.75 square inches per watt expended can be considered as a fair average for armatures and about 3 inches per watt expended for field coils.

835. How is the table referred to (Table 50) made up?

Ans. This table is figured from the formula,

$$I = \sqrt{\frac{RS}{3 \times R}}$$

R S being the radiating surface, and R the resistance of a unit of length of the wire under consideration. This formula gives the current allowed where the wire is wound in one layer. As we add more layers we must, with each successive layer, reduce the current, so that the square of the current multiplied by the resistance (which equals the watts) shall remain always the same, because increasing the depth of the winding does not affect the radiating surface of the coil.

836. The table gives the carrying capacity only to a depth of six layers; how is the carryng capacity of a greater number of layers to be found?

Ans. To do this we refer to Table 50 and select from the column headed I^2 the number pertaining to the wire in question. This number represents the square of the current permissible with one layer of wire. Divide this number by the number of layers it is intended to use, and extract the square root of the number so found. The result will be the carrying capacity of the wire in question, wound to a depth of that number of layers. As a general guide we may bear in mind that, as we multiply the number of layers by 4, 16, 64, 256, we, each time, decrease by one-half the carrying capacity of the wire. From this we can see that the capacity of the wires after a certain number of layers have been considered, decreases very slowly, though very fast with the first few layers.

837. Is there need of very great accuracy in these calculations?

Ans. Great accuracy is not necessary in these calculations. We can always lengthen our armature a little by adding a few punchings, should the potential be insufficient, and we can always vary the speed and strength of field con-

TABLE 50

TABLE SHOWING CURRENT CARRYING CAPACITY OF DIFFERENT WIRES AT DIFFERENT DEPTHS OF WINDING, 3 SQ. IN. RADIATING SURFACE PER WATT.

B. & S. Gauge.	Diameter bare.	Resistance per foot 140° F.	Diameter D. C. C.	Amperes at different depths of winding layers.						Number of wires per inch.	12
				1	2	3	4	5	6		
4	.2043	.000283	.224	56.28	39.74	32.42	28.12	25.15	22.97	4.45	3166
5	.1819	.000357	.200	47.30	33.46	27.33	23.66	21.16	19.31	5.00	2240
6	.1620	.000450	.180	40.00	28.28	23.08	20.00	17.88	16.34	5.5	1600
7	.1413	.000567	.158	33.40	23.60	19.28	16.67	14.93	13.63	6.3	1114
8	.1285	.000715	.144	28.35	20.04	16.37	14.17	12.68	11.57	7.0	805
9	.1144	.000902	.130	24.00	16.97	13.85	12.00	10.72	9.74	7.7	576
10	.1019	.001137	.117	20.27	14.31	11.70	10.14	9.05	8.24	8.6	411
11	.0907	.001436	.106	17.19	12.12	9.69	8.60	7.68	7.00	9.6	295
12	.0808	.00181	.093	14.31	10.09	8.24	7.14	6.40	5.83	10.7	205
13	.0719	.00228	.084	12.12	8.54	7.00	6.08	5.38	4.89	11.9	147
14	.0640	.00288	.075	10.19	7.21	5.91	5.09	4.58	4.12	13.3	104
15	.0570	.00362	.067	8.60	6.08	4.95	4.30	3.87	3.50	15.0	74
16	.0508	.00458	.059	7.14	5.04	4.12	3.57	3.19	2.91	17.0	51
17	.0452	.00575	.053	6.08	4.30	3.5	3.04	2.64	2.47	19.0	37
18	.0403	.00727	.048	5.09	3.60	2.94	2.54	2.28	2.08	21.0	26
19	.0358	.00916	.044	4.36	3.08	2.52	2.18	1.97	1.78	22.7	19
20	.0319	.01153	.040	3.74	2.64	2.16	1.87	1.67	1.52	25.0	14
21	.0284	.01454	.036	3.14	2.22	1.81	1.57	1.39	1.28	28.0	9.9
22	.0253	.01845	.033	2.66	1.87	1.54	1.33	1.19	1.09	30.3	7.1
23	.0225	.0231	.030	2.28	1.61	1.30	1.14	1.01	.94	33.3	5.2
24	.0201	.0295	.028	1.94	1.37	1.14	.97	.86	.80	35.7	3.8
25	.0179	.0365	.026	1.70	1.18	.98	.85	.80	.74	38.4	2.9
26	.0159	.0461	.024	1.41	1.00	.82	.71	.63	.57	42.0	2.0
27	.0142	.0603	.022	1.18	.78	.68	.59	.52	.47	45.5	1.4
28	.0126	.0744	.021	1.04	.72	.60	.52	.47	.42	48.0	1.1
29	.0112	.0925	.020	.92	.65	.52	.46	.42	.38	50.0	.86
30	.0100	.1181	.018	.77	.54	.44	.38	.35	.31	56.0	.61

TABLE 51

TABLE SHOWING CURRENT CARRYING CAPACITY OF DIFFERENT WIRES AT DIFFERENT DEPTHS OF WINDING, 1 SQ. IN. IN RADIATING SURFACE PER WATT.

B. & S. Gauge.	Diameter bare.	Resistance per foot 140° F.	Diameter D. C. C.	Amperes at different depths of winding layers.						Number of turns per inch.	12
				1	2	3	4	5	6		
4	.2043	.000283	.224	97.36	68.75	55.88	48.64	43.50	39.73	4.45	9498
5	.1819	.000357	.200	81.82	57.88	47.27	40.87	36.60	33.40	5.00	6720
6	.1620	.000450	.180	69.20	48.92	39.92	34.60	30.93	28.28	5.5	4800
7	.1413	.000567	.158	57.78	40.82	33.35	28.91	25.86	23.60	6.3	3344
8	.1285	.000715	.144	49.04	34.66	28.37	24.57	21.97	20.07	7.0	2416
9	.1144	.000902	.130	41.52	29.37	24.00	20.76	18.60	16.97	7.7	1728
10	.1019	.001137	.117	35.06	24.81	20.27	17.54	15.71	14.35	8.6	1233
11	.0907	.001436	.106	29.74	21.02	17.17	14.86	13.30	12.12	9.6	885
12	.0808	.00181	.093	24.79	17.52	14.31	12.40	11.09	10.09	10.7	615
13	.0719	.00228	.084	21.00	14.86	12.12	10.50	9.38	8.54	11.9	441
14	.0640	.00288	.075	17.66	12.49	10.19	8.83	7.88	7.21	13.3	312
15	.0570	.00362	.067	14.89	10.53	8.60	7.44	6.66	6.08	15.0	222
16	.0508	.00458	.059	12.40	8.77	7.21	6.20	5.56	5.09	17.0	154
17	.0452	.00575	.053	10.53	7.44	6.08	5.26	4.71	4.30	19.0	111
18	.0403	.00727	.048	8.88	6.28	5.12	4.44	3.97	3.63	21.0	79
19	.0358	.00916	.044	7.54	5.34	4.35	3.76	3.37	3.08	22.7	57
20	.0319	.01153	.040	6.49	4.58	3.74	3.24	2.89	2.64	25.0	42
21	.0284	.01454	.036	5.38	3.80	3.11	2.68	2.40	2.19	28.0	29
22	.0253	.01845	.033	4.58	3.24	2.64	2.28	2.04	1.87	30.3	21
23	.0225	.0231	.030	4.00	2.82	2.30	2.00	1.78	1.64	33.3	16
24	.0201	.0295	.028	3.37	2.38	1.94	1.67	1.51	1.37	35.7	11.4
25	.0179	.0365	.026	2.93	2.07	1.67	1.44	1.30	1.18	38.4	8.6
26	.0159	.0461	.024	2.49	1.76	1.44	1.22	1.09	1.00	42.0	6.2
27	.0142	.0603	.022	2.07	1.44	1.18	1.04	.94	.84	45.5	4.3
28	.0126	.0744	.021	1.78	1.26	1.04	.89	.78	.71	48.0	3.2
29	.0112	.0925	.020	1.61	1.14	.94	.79	.71	.65	50.0	2.6
30	.0100	.1181	.018	1.34	.95	.78	.64	.60	.55	56.0	1.8

siderably. Adding to any of these would tend to increase the E. M. F. of the armature, but not its capacity in amperes.

838. If the capacity of the armature is not sufficient, how do we proceed?

Ans. Take the next larger wire, or such a wire as will give the desired capacity, and from the diameter of this wire figure out a new armature. By using the same number of wires of a larger diameter, a greater cross-section of armature is obtained.

839. Do these considerations apply equally well, whether an armature is slotted, or not?

Ans. The only difference is that with a slotted armature it is necessary to take into consideration the length of the winding space in the slots only, not the total circumference of the armature. There is also considerable loss of flux through the teeth of the armature so that the flux must be assumed less. A great flux is obtainable, however, with the same field winding, as the magnetic circuit of a dynamo with a slotted armature has less resistance.

840. How do you proceed in the case of a slotted armature?

Ans. If we have an armature provided with slots of a fixed size we can but arrange to accommodate ourselves to it as best we may. It may be that the slots are of such size that the wire we have selected through our calculation will not fill out the slot well, and we must, therefore, try some other size wire. In this case it will be preferable to select a larger size wire if practicable. This had best be tried by actual experiment. As the wire often will not fill out the slot quite fully, calculations are not exactly reliable. Any deficiency can, of course, be made up by filling in with insulation. The number of wires per slot is found by dividing the total number of wires by the number of slots.

841. How can the size of a slot capable of holding a certain number of wires be determined?

Ans. The approximate depth of the slot can be obtained by multiplying the diameter of the wire to be used by .86 and this by the number of layers placed over each other. The result will be exact if the wires lie as shown in Figure 512. The width of the slot can be found by multiplying the diameter of the wire by the number of turns per layer. It will be seen from the figure that each alternate layer will contain one turn less than the first.

842. Can slots be proportioned so that they will accommodate any number of wires?

Ans. The slots must be proportioned to the number of wires to be used, and the number of wires per slot must be carefully considered. If the number of turns per slot are few, the wires should be placed as shown in Figure 513. If there are many, according to Figure 512. Which of these two methods is to be used will have a bearing on the number of wires per slot. The total number must be a multiple of the number of layers.

843. After we have selected our wire, and determined the number of wires to be used, can we form some idea of what the losses in the armature will be?

Ans. We can easily figure the approximate loss of voltage in the armature from the size of wire to be used. To do this we first find from Table 50 the resistance per foot of the wire in question, and then measure the length of wire in one coil and multiply the resistance by the number of feet. If we have a bi-polar armature we again multiply this by half the number of coils (the two sides being in parallel). Since the loss in voltage is equal to the amperes multiplied by the resistance, we need but to multiply the resistance so found by half the total current to find the loss in voltage that will occur. This loss is, of course, in direct proportion to the current. This loss is not of much importance in ring armatures, or in drum armatures either, when they are working with small currents, or on constant current work such as arc lighting; but with heavy, and variable currents it is a very important matter, and the lower the losses can be kept, the better.

844. Are there any special considerations to be borne in mind while winding the different coils?

Ans. It is quite important to see that each coil contains the same number of turns, and that these fill out the same relative space.

845. Why is this so important?

Ans. We have already seen that the two halves of the armature are generating in parallel, that is, the currents from the two sides meet at the positive brush and flow out to the line, and return by the negative side to the armature. If now there are fewer turns of wire on one side than on the other, or if there is one weak coil in the armature, one side or the other will always be generating a greater E. M. F. than the other and consequently current from the high pressure side will flow through the winding of the low side. To see this more clearly refer to Figure 514. On the armature there shown, there are 16 coils. If this armature is to generate 40 volts, each coil will be called upon to produce 5 volts. Now suppose one of the coils to be cut out of the circuit entirely. It is clear that at all times except when the dead coil is at the neutral points, there are 8 coils generaing on one side against 7 on the other; i. e., 40 volts against 35. In order to find the current that would flow in such an armature while on open circuit, subtract the low voltage from the high, which leaves an active voltage of 5. If the resistance of the armature were .1 ohm a current of 50 amperes will be circulating a great part of the time.

846. Why would this not be a constant current?

Ans. For the reason that this current would be constantly changing in direction, because the strong side of the armature would be first on one side, and then on the other, of the fields. On open circuit a perfect armature would generate no current whatever; with an armature as described the current mentioned would always be flowing toward the coil which is cut dead.

The current would be changing in strength, because during the time the dead coil is short circuited by a brush it would be balanced by another coil under the opposite brush which for the moment is also dead. Consequently during that time the armature would not be generating at all.

847. How would this inequality of generation manifest itself if the dynamo were generating current?

Ans. If the dynamo were generating current this condition would greatly reduce its capacity. The current flows only in obedience to the pressure, and as this would be variable the current would of course also be variable.

848. Are differences in potential between different parts of an armature caused by any other conditions in the armature?

Ans. Such differences are sometimes caused by the location of the wires of different coils. Other things being equal the E. M. F. generated by any coil varies with its distance from the center of the armature. It can readily be seen that the farther a wire is from the center, the greater will be the area enclosed and therefore the greater the number of lines of force cut by it.

849. What other cause is there for inequality of generation?

Ans. Another cause for inequality of generation between different coils lies in a difference of resistance.

850. Does this affect the generation on open circuit?

Ans. It does not. We have already seen that the loss in potential in any circuit is proportional to the current flowing, multiplied by resistance of the circuit in which it flows. Therefore the drop in potential in any coil is in proportion to the current being taken from it. If one coil therefore has a much higher resistance than the others its potential will fall much more, and the side of the armature on which it happens to be will be of lower E. M. F. than the other, and there will be the same tendency to a vacillating current as in the case of coils of uneven number of turns. The variations will, however, not be near so great, for an excessive current flow from the strong side will reduce the pressure on that side, and the checking of the current on the low side will raise the pressure there, so that a balance will be obtained without any great current flow. The main danger of introducing inequality in the resistance of the winding lies in the winding of the inside of the coil with Gramme ring armatures. The space for the winding at this point is necessarily of a different shape than that on the outside, and there are also the spokes of the armature to contend with.

851. How many methods of armature winding are in general use?

Ans. The methods of armature winding are very numerous. For the present we shall confine ourselves to the methods used with hand winding on cylinder armatures.

852. Which is the most simple of these windings?

Ans. The simplest one of these windings is that shown in Figure 534, and we shall take this one for the purpose of demonstration. It will be noticed that in this figure there are 12 slots in the armature and 6 commutator sections, indicated by the wires twisted together.

853. Is it necessary that this proportion of slots and armature coils exist?

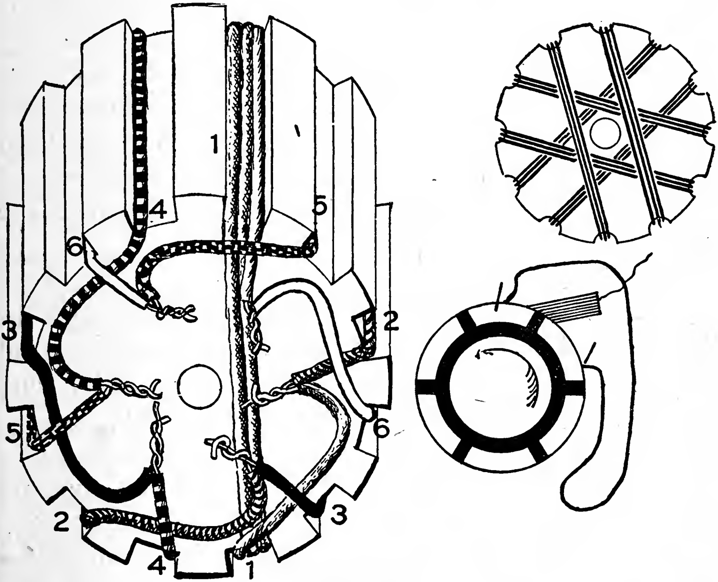


Fig. 534

Ans. It is not; in fact it is not at all desirable that this proportion should exist, but this proportion is very convenient for winding, as we shall see.

Begin winding by selecting two of the slots located opposite each other, as shown in the figure, and starting at 1 wind into those slots as many turns of wire as has been determined there should be and bring the last end of the coil to the commutator section next the one from which we started.

854. Should this be to the one in front of, or behind the section from which the winding started?

Ans. This is immaterial. In actual practice there should not be any commutator sections in place while winding. They would be very much in the way. Instead, tie the two ends of the coil together and properly mark the beginning and end.

855. Are all coils wound in the same way?

Ans. They are; but in this case we must skip one slot at each subsequent coil, in order to make them come out right in the end. That is to say, if the first coil is wound into 1, 1, the second must be wound into 2, 2, the third into 3, 3, etc.

856. Why is this?

Ans. As each coil fills out two slots, we have with the third coil finished half of the armature. If we were to wind the slots in consecutive order, the connections for the commutator would all come on one side, and we could do nothing with the armature. As we now continue in the order we have started we finally complete the entire winding and have the beginning and end of one coil opposite each commutator section. We can now fasten the beginning of the first coil to its proper commutator section, and the end of it to the next one. It will be immaterial whether this be to the section ahead, or behind the starting section, but, whichever way we start, we must be sure to continue in the same way.

857. This being the most simple method of armature winding, why are not all armatures wound in this way?

Ans. The great objection to an armature wound in this way is that the coils become too large.

858. Why are large coils objectionable?

Ans. In order to understand why large coils are objectionable we refer to the commutator shown at the right of Figure 534. Here a brush is shown bridging two commutator sections and short circuiting the coil connected to them. The coil indicated by the black line is the same one shown in the slots 1, 1, and the connections are identical. It can readily be seen that all of the coils will in turn become short circuited in the same way in the course of every revolution of the armature.

Now in the first place assume that the coil when thus short circuited is in an entirely dead part of the field. When a brush short circuits such a coil it takes all the current away from it. When the brush leaves the forward section of the commutator this short circuit must be broken, and current must be again established through the coil. As every coil possesses some inductance (which acts for an instant like a very high resistance), there is a tendency for the current in that half of the armature to jump across the insulation between the commutator sections, rather than pass through the coil. If this occurs there is destructive sparking. The greater the number of turns of wire in any coil, the greater will be the likelihood of this taking place.

859. Is this the main reason why the coils on an armature should be made up of few turns of wire?

Ans. It is not. The most important reason for this is the following: If the coil is not in an entirely "dead" part of the field there is always some current generated in it during the time the brush is in the position discussed above. This current circulates in the coil during the time the brush holds it on short circuit, without appearing in the outer circuit, and is therefore a dead loss. It furthermore tends to heat the coils. Because two of the coils are nearly always on short circuit in this way, the loss and the heating are considerable when the coils are large. When these currents are broken by the commutator section sliding from under the brush, they also make themselves evident by severe sparking, if the coils are large.

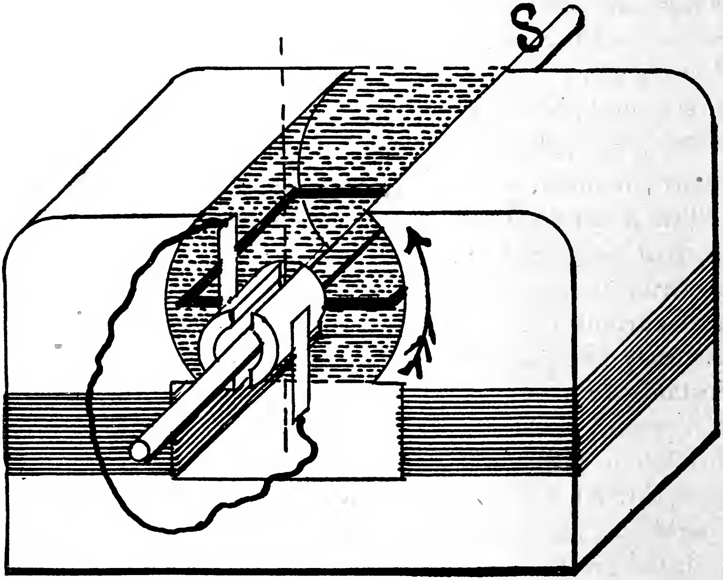


Fig. 535

860. Are there any more reasons why large coils are objectionable?

Ans. Another reason why large coils in an armature are objectionable can best be understood by reference to Fig. 535. A simple dynamo such as is depicted in this figure delivers a current graphically illustrated by Fig. 536. It will be seen that this is really an intermittent current. This is because the dynamo has but one coil, and while this is at the neutral points, nothing is being generated. The current therefore fluctuates from 0 to its maximum. If we add one more coil the current line becomes as shown in Fig. 537, and the greater the number of coils the smaller becomes the percentage of non-generating coils, and the nearer does the current line approach a straight line showing a steady value.

861. Why cannot small coils be wound in the manner shown in Fig. 534.

Ans. It is desirable to make the coils as small as possible. The ideal coil would consist of only one turn. Now as long as we wind only one coil into one slot we shall have the coils needlessly large. The number of coils is limited by the number of commutator sections, and unless we wind two coils into each slot (as we can see from Fig. 534) we can have but half as many commutator sections as there are slots. In order to get a small coil it is therefore necessary to get two coils into each slot.

Fig. 536

Fig. 537

862. Can this be done in more than one way?

Ans. This can be done according to any of the plans shown in Fig. 538. In this figure the black and white circles respectively represent the wires of the two different coils wound into the same slot.

We have already seen under ring armatures, that wires of different coils should all be of the same distance from the center of the armature, so as to cut the same number of lines; it follows, therefore, that the plan showing one coil wound over the other should not be used where it can be avoided.

863. How do you manage to place two coils in one slot?

Ans. In order to understand exactly how this is done let us consult Fig. 539. This figure is a duplicate of Fig. 534 with the exception that now we have as many commutator sections as there are slots in the armature. The black circles represent the wires of one set of coils, and the light those of the other.

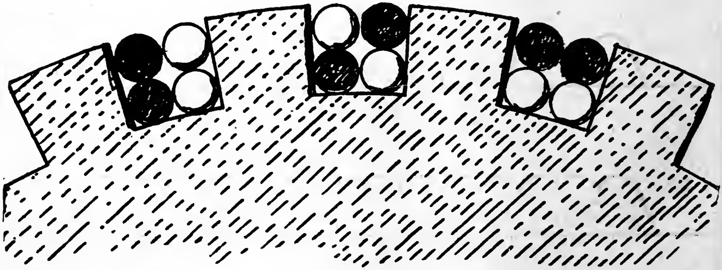


Fig. 538

The simplest method of winding two coils into one slot is, first to wind one coil complete, filling half the slot, then turn the armature half way round and wind the second coil over the first. As this, however, gives two coils of different lengths and resistance, and also cutting a different number of lines of force, such a winding is seldom used. A better way is the following: Cut two wires of sufficient length so that each will make one coil, place the armature upon two crossbars of convenient height so that it can be easily turned over when required. Mark all of the slots with appropriate numbers according to the plan of wiring selected, so there may be no confusion when the work is started. A very good plan is shown in Fig. 534. This plan gives the smallest head of any because there are always two coils running parallel to each other across the ends of the armature. Thus we have three layers of coils crossing over each other, while with any of the others we should have six. But in order to get the advantage of this smaller head, we cannot wind the coils in the order given in the explanation of this winding. It becomes necessary to wind completely, at the same time, the two coils that are running parallel with each other across the ends. To do this requires more experience and forethought, than the way previously described.

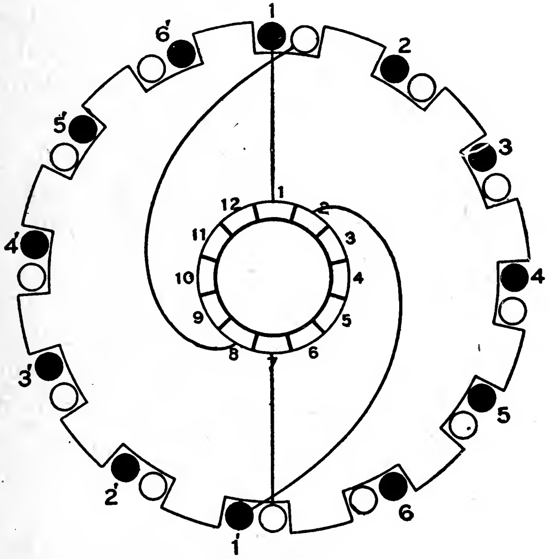


FIG. 539

Begin the winding with the coil marked 1, and make one complete turn and fasten the two ends of the wire together temporarily if more turns are to follow, or fasten each to its proper place on the commutator, if there is to be but one turn. Now turn the armature half way round and wind the other wire in the same way. If there are to be more turns, continue to wind the second turn. After this is finished turn the armature back to its original position and wind the first wire again. Repeat in this manner until the desired number of turns in both coils have been obtained. By reference to Fig. 539 we note that the windings do not skip slots as in Fig. 534. This is easily explained when it is noticed that each slot contains two conductors and that at each step we skip one conductor as before.

It is not necessary in actual practice to turn the armature around as above suggested. This was suggested merely as a beginning to make the principle more plain. The same result can readily be obtained if the armature is left stationary. The windings need merely to be so arranged that they will come right for connection to the commutator as shown in the cut.

It is well enough to use care that all of the coils are wound in the same direction, but it will not materially affect the operation, if one part of the coils are wound left hand, and the others right hand. The essential point is to see that they are so connected that the magnetism resulting from a current flow through the coil will be the same in all. If it is different in one coil from the others it can easily be rectified by simply changing the end connections of the coil in question.

864. Are all armatures hand wound?

Ans. Hand winding is customary with the smaller drum, and ring armatures only. It is the only method that can be used with ring armatures, and also with drum armatures where the wire is to encircle the whole armature. The larger dynamos are now made mostly multipolar, and in these the coils do not return at nearly, or wholly, diametrically opposite points as they do in those machines we have so far had under consideration. With multipolar machines the armature is divided into as many sections as there are poles. While it is possible to work any regularly wound drum, or ring armature in connection with many poles, it is not customary to do so. In general the coil wound on a multipolar armature has its return winding spaced about as far from the first turn, as it is from the center of one pole piece to the center of the next one.

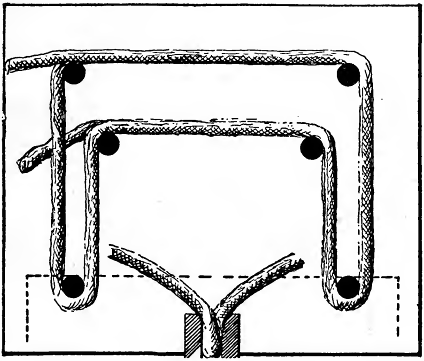


FIG. 540

865. How does this affect the winding?

Ans. This gives us a winding of much lower resistance than could otherwise be obtained, and the magnetic circuit is also much better. Furthermore, it makes possible the use of so-called "former coils."

866. What is a former coil?

Ans. A former coil is one that is wound upon a former, i. e., one that is wound complete before it is placed upon the armature.

867. How are such coils made up?

Ans. Figs. 540 and 541 show two styles of former coils, and the manner in which they are wound. In Fig. 540 the black circles represent strong pins fastened into a piece of plank, or other suitable material. The wire is wound around these pins as indicated in the figure, as many turns being taken as it has been decided to allow for each coil. When the coil is thus completely wound it is taken from the pins, and the lower ends placed in a suitable clamp, as indicated by the broken line in the lower center of the figure. After this clamp is fastened onto the coil the two halves of the coil are spread apart, one being pulled toward the operator and the other pushed away from him at

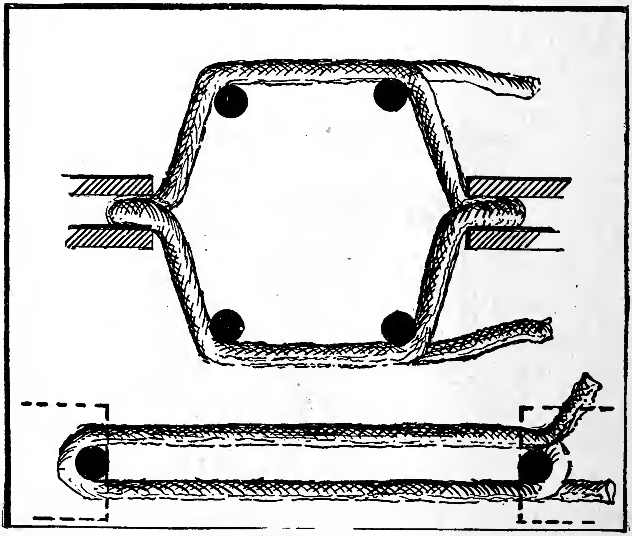


FIG. 541

right angles to the clamp. In this way the coil is made to assume the shape illustrated in Fig. 542. Before winding a coil in this manner it is of course necessary to know exactly what length it must be, and a pattern coil must therefore first of all be prepared, from which the spacing of the pins can be taken, so that the completed coil will fit into the slots for which it is intended.

868. How are such coils placed upon the armature?

Ans. Begin placing the coils at any convenient slot, and lay them in, as indicated in Fig. 542. It is necessary to mark the beginning, and end of each coil, so that there may be no wrong connection when the wires are finally connected to the commutator.

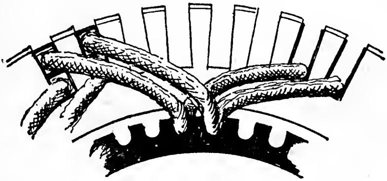


FIG. 542

Before placing the coils the slots must of course be insulated as explained previously. We now continue to lay in coils until the whole armature is full, but when nearly full, the forward ends of the coils we are placing require to be brought under the first coils put in place. To do this it is merely necessary to raise up the first six coils, (in this case) and place the forward ends of the last six under them in the regular order.

869. By what name is this winding known?

Ans. This is known as the "evolute" winding. It will be noticed that when this winding is completed, the wires of the outer portion entirely conceal those of the inner, and thus give this style of winding its characteristic appearance.

870. What other manner of winding multipolar armatures is there?

Ans. Another method of forming coils is illustrated in Fig. 541. In this case the coil is first wound around two pins, as shown at the top of the figure. The ends are then placed in clamps, as indicated by the dotted lines at the top and shaded lines in the center of the figure. After these clamps are fastened, the coil is turned one-fourth around, and the wires spread over the four pins, as indicated in the figure.

871. How is this coil placed upon the armature?

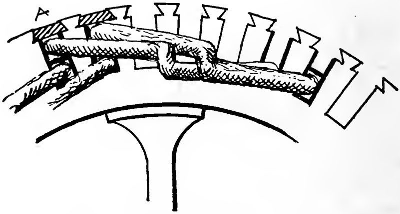


FIG. 543

Ans. The coil formed in the manner above assumes the shape shown in side view in Fig. 543 and is placed upon the armature as there indicated, the manner of placing being the same as that of the previous coil.

872. What name is given to this style of winding?

Ans. This is termed a "barrel" winding and its characteristic appearance can be seen from the figure.

873. Is it necessary to carry out the same kind of winding on both sides of an armature?

Ans. There is nothing to prevent one from using one of these windings on one side of the armature, and the other on the opposite side. They cannot, however, be combined on the same side. The windings of large machines very often are made up of bars of copper made of special sizes to suit. These are often arranged as shown in Figs. 544 and 545. Sometimes such bars are bare and laid into the slots with insulation loose on the sides and bottom and between the different bars of a slot. Such winding is often held in place by pieces of wood inserted into the slots as indicated in Fig. 543, the slots being specially prepared to admit of this. Where no such provision has been made the wires are held in place by the usual binding wires.

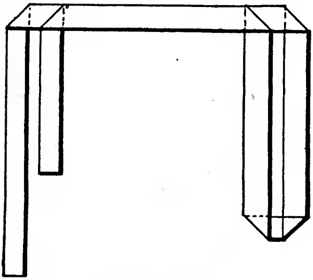


Fig. 544

MOTOR ARMATURES.

874. Is there any difference between the armature of motors and dynamos?

Ans. Theoretically there is no difference between the armature of a dynamo and motor. In fact, many machines are placed in conditions in which their functions change, perhaps a hundred times per day, from that of generator to that of motor.

875. Are there any special provisions necessary to make them operate thus?

Ans. No. This change takes place automatically, and the operation is so smooth that the observer will have no idea in which capacity the machine may be operating from moment to moment. It is also no unusual thing for a dynamo working in parallel with other generators to become reversed, and instead of delivering current to the line, it will be drawing from it and running as a motor.

876. What should one principally have in view in the design of a motor armature?

Ans. Motor armatures must be designed to produce a certain counter E. M. F. just as dynamo armatures are designed to produce E. M. F. In the case of a dynamo the power is measured by the product of the E. M. F. and the current, so in the motor the power is proportional to the product of the counter E. M. F. and the current.

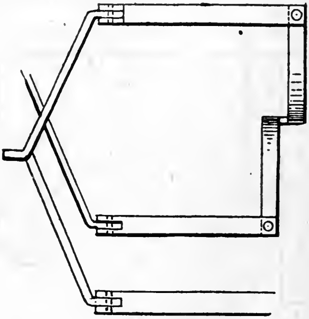


FIG. 545

877. How do you proceed to calculate the winding for a motor armature?

Ans. In the same way as with a dynamo except that the E. M. F. should not be figured as high. The current passing through a D. C. motor equals $\frac{V-v}{R}$, where V is the volume of the line that supplies it; v the counter E. M. F. of the armature, and R its resistance. It is apparent that in order to get more power out of a given motor, its counter E. M. F. must be reduced in order that a greater current can flow.

878. How is this brought about?

Ans. With a motor in operation this counter E. M. F. is reduced when the speed reduces, on account of a heavier load. More current is thus allowed to flow until the power of the motor becomes equal to the work required of it, but if the load exceeds the capacity of the motor it will take too much current, and burn out the armature. If a motor is to be designed to operate at a certain speed, all of these facts must be taken into consideration, and the wires so selected that when running at the required speed, the necessary counter E. M. F. will be generated.

For illustration, take the same armature that was considered in the previous section. In this case a No. 12 wire was required. This gave 11 turns per inch, and its carrying capacity was 14.3 amperes. The dimensions of the armature were 8″x8″, requiring about 770 feet of wire. With this quantity of No. 12 the resistance is 1.39 ohms.

Only one-half of this, however, is on one side, and only 14.3 amperes pass on one side, so that the total E. M. F. to drive this current through the armature is 14.3×.697, which is 9.96. In order that this motor may allow the 14.3 amperes to pass, its counter E. M. F. must fall to 9.96 volts less than the E. M. F. of the line. If this is 110, the speed must slack off about 9 per cent in order that the motor may develop its full power.

It is easily seen from this that, in order that the motor may operate at a fairly constant speed, the resistance of the armature should be made as low as possible. In practice it is generally made so low that a reduction of 1 per cent in speed wll bring about the required lowering of counter E. M. F. to cause the proper current to flow.

ARMATURE TROUBLES.

879. How do armature troubles manifest themselves?

Ans. Either by excessive sparking at the commutator, or by abnormal heating of the armature.

880. What are the causes of such troubles?

Ans. They may result from any one of the following causes: There may be a wrong connection of one, or more of the coils. Some of the coils may be grounded. There may be an open circuit. There may be a short circuit. The brushes may be improperly set. The brushes may not make sufficient contact with the commutator. The commutator may be rough or worn. The fields may be of uneven strength.

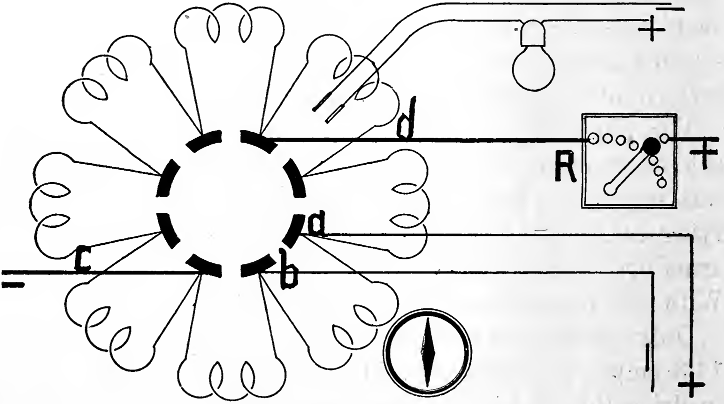


FIG. 546

881. How can a wrong connection of the coils be tested for?

Ans. In order to see how this test can be made let us consider Fig. 546 for a moment. This figure shows the wiring of an armature connected to the commutator segments exactly as it would be if it were taken off, and the coils separated without detaching from the commutator, instead of being placed in an orderly manner upon the core of the armature. In other words, the connections are exactly as in an armature. If we should now take the two wires of some supply of current capable of delivering a few amperes, and connect these two wires to two adjacent commutator segments, as shown at *a,* and *b,* it is clear that current would flow through the coil connected between these two sections, and also through the other coils. The current has two paths: one through the single coil, the other through the remaining seven coils in series.

The current in the two coils flows in opposite directions, with the result that a field of force is set up in the vicinity of the single coil. A suitable galvanometer placed at this point will be deflected in a certain direction. By revolving the armature and applying the test to each succeeding pair of commutator sections, a number of deflections of the needle will be obtained.

If all the coils are correctly connected these deflections will all be in the same direction. If one of the coils is connected wrong, a different deflection will be obtained. If one of the coils has been wound on in the wrong direction, it is not necessary to rewind it; the connections can simply be reversed.

882. What is meant by a "ground"?

Ans. An electrical connection between some current carrying part of the armature, and the metal armature frame. A "ground" is often caused by the insulating covering of the wire breaking down, thus allowing the wire to come in contact with the iron core.

883. How do you test for this condition?

Ans. The simplest method of testing for a ground consists in taking a lamp or voltmeter and connecting it as shown in Fig. 546. Place one of the wires in contact with the iron core, and the other in contact with the wire on the armature. If the lamp lights, there is a connection between the wire and the core, and this should be removed.

884. How is an open circuit located?

Ans. Referring to Fig. 546, connect the commutator as shown by the horizontal lines *c. d.* to some source of supply. A rheostat is needed to adjust the current strength until a suitable deflection of the needle is obtained between adjacent commutator segments. Now, take two wires of the voltmeter and test the voltage between the various adjacent commutator segments. A reading will be obtained between each two segments on one side of the commutator, but on the side which contains the open coil no reading will be obtained until connection is made between the two segments to which the open coil is connected. At this point the voltmeter will show practically the full voltage of the supply current.

885. How do you locate a short circuit?

Ans. If the short circuit has come on while the armature was in use, it will locate itself by a burned out coil. To test a new armature for short circuits we can proceed in the same way as for open circuit, the only difference being that, when we come to the short-circuited coil, we shall obtain either none, or at least a reduced deflection.

886. What effect does an improper location of the brushes have?

Ans. An improper location of the brushes will manifest itself by a more or less severe sparking. If the brushes are of the right dimensions the trouble can be remedied by simply shifting them to the proper location, which is that of least sparking. Brushes should be of such length, and set at such an angle, that they come in contact with diametrically opposite points on the commutator, with all bi-polar machines.

887. How must the brushes be set in connection with multipolar machines?

Ans. This depends on the manner in which the armature is wound. With a lap winding there are as many brushes as there are pole pieces, and they must be equally spaced around the periphery of the commutator. Provision must also be made so that they can be shifted to the point of least sparking. In wave wound armatures there may be only two brushes, these being so spaced that they are separated by an angle equal to the angle of separation of two adjacent pole pieces; for instance, with a four-pole field they would be separated by an angle of 90°.

888. Is much shifting of the brushes necessary?

Ans. This depends very much on the design of the machine. With some of the older machines constant shifting of the brushes is required with changes in the load, but with the newer, and better machines this is reduced to a minimum.

889. What is the ordinary size of a carbon brush?

Ans. It should be of such size that not more than 25 to 40 amperes per square inch of carbon are ever required to flow through it.

890. How does inequality in field strength affect an armature?

Ans. Wherever this exists there will be more lines of force cut by the armature on one side than on the other, thus causing a higher potential to be generated on one side than on the other. The brushes will have to be set uneven distances apart around the commutator, and useless currents will be set up in the armature windings, which will not only cause a loss of power, but which will tend to overheat the armature.

SWITCHBOARDS.

Switchboards are made up of panels of slate on a frame of angle iron. Each panel is designed for certain work so that a description of the different kinds of panels is sufficient.

The first board to consider is the D. C. outgoing line board, served from D. C. generators.

D. C. Generator Panels.

Fig. 547 shows three generator panels, each of which is regularly equipped, from a capacity of 250 to 6,500 amperes with

1 Carbon break or magnetic blow-out circuit breaker, with telltale.

1 Illuminated dial ammeter with shunt.

1 Hand wheel and chain for operating rheostat.

1 Receptacle for voltmeter plug

1 S. P.-S. T. field switch.*

1 S. P.-S. T. main switch.

1 Recording Watt-hour meter.

A rear view of these panels is shown in Fig. 552.

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*S. T. means single throw.

D. T. means double throw, i. e., the switch has two sets of clips and can be thrown into either of them.

S. P. means single pole.

D. P. means double pole, i. e., opens both sides of circuit

T. P. means triple pole, i. e., opens every conductor of a 3-phase system.

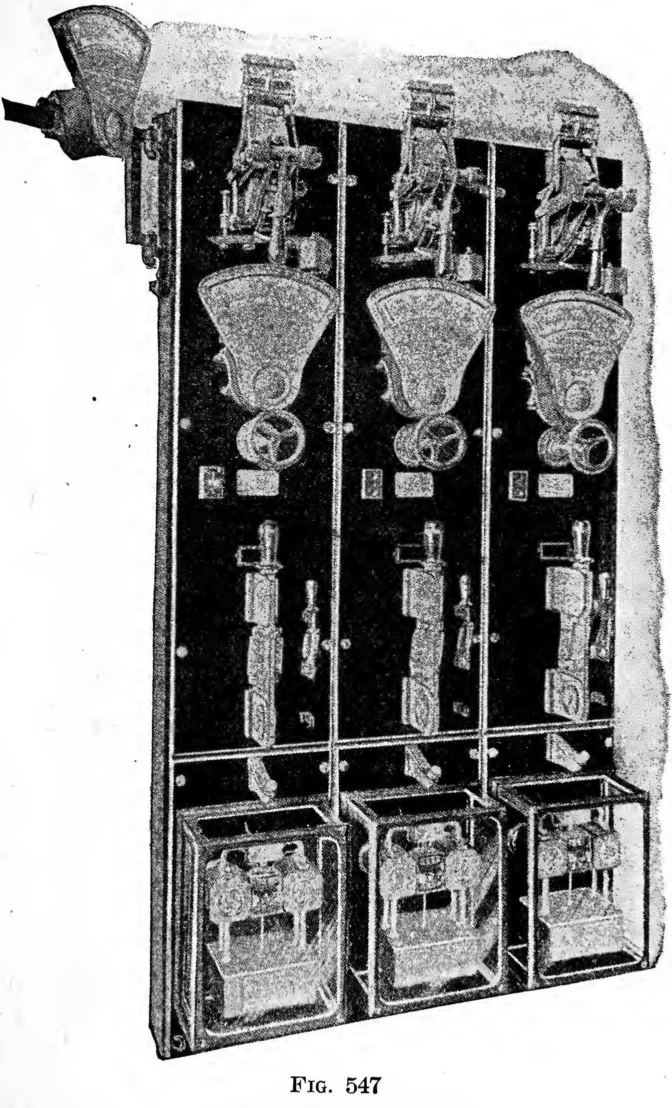

FIG. 547
D. C. GENERATOR PANELS

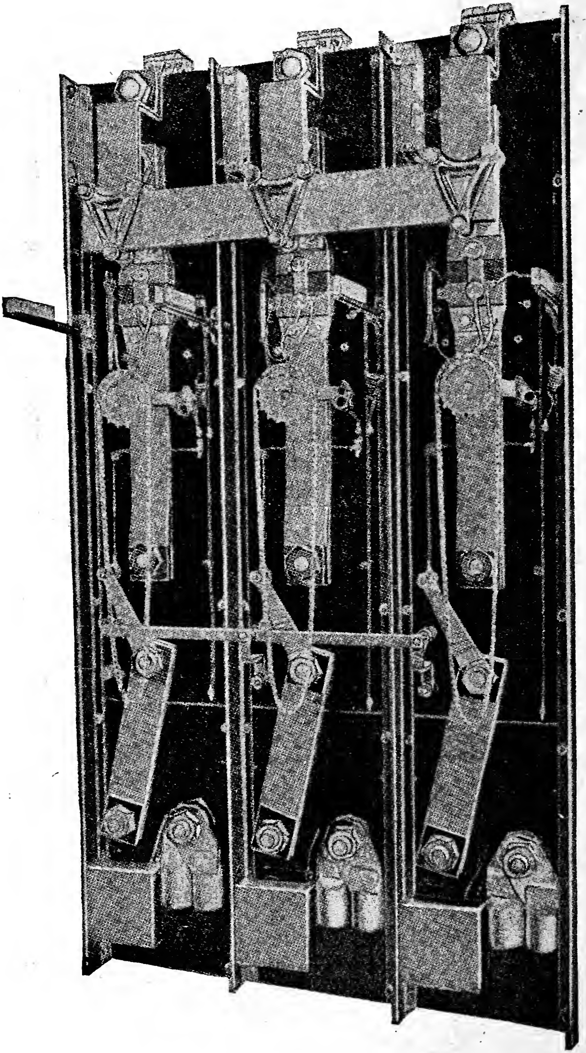

FIG. 548
REAR VIEW OF FIG. 547

The best practice puts a main switch at the machine, so that the cables from machines to board may be cut off from generator. It is also good practice to run the equalizer cable along in ducts from machine to machine without carrying it to the board.

This equalizer connects the junctions of series field and brush on all machines as shown in Fig. 549; the shunt coils being omitted to simplify diagram.

It is best to place the main switch and equalizer switch on a pedestal panel as shown in Fig. 550 for moderate capacity and in Fig. 551 for 4,000 ampere (and larger) machines. The upper switch being the main switch. The rear view of these large capacity pedestals is shown in Fig. 556.

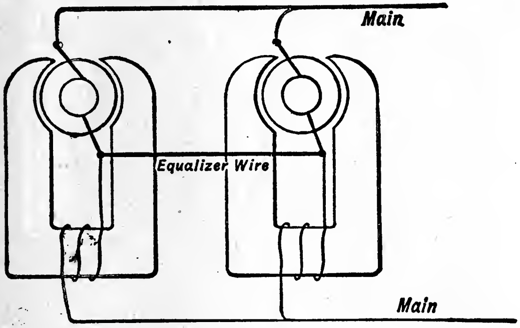

FIG. 549
EQUALIZER

A better view of the 4,000 ampere toggle operated main switch is given in Fig. 553. The quick-break S. P.-S. T. switch is illustrated in Fig. 554.

The field switch, Fig. 555, has a carbon break. Just before the switch opens it makes contact with an extra clip which puts a resistance on as a shunt around the field coils.

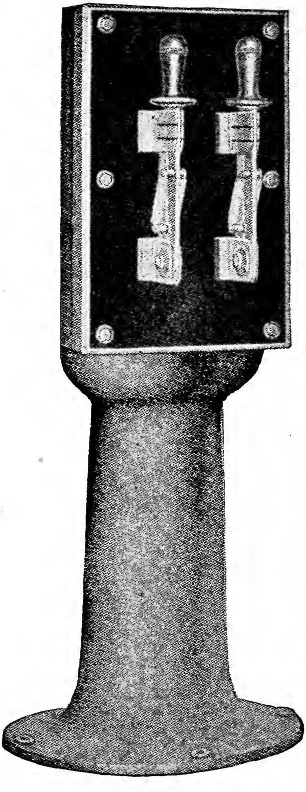

Fig. 550.

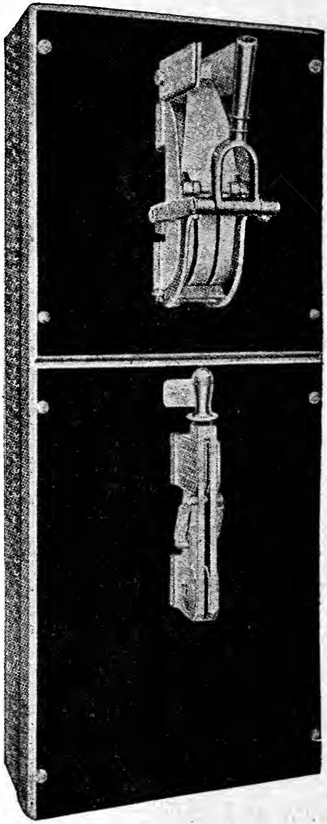

Fig. 551

FIG. 550

PEDESTAL PANEL FOR MAIN AND EQUALIZER SWITCHES
SMALL CAPACITY

FIG. 551

MAIN AND EQUALIZER SWITCHES FOR LARGE CAPACITY

If this were not done the fields would act like a kicking, or spark coil and their insulation be damaged.

In Fig. 556 is seen the diagram of the panel shown in Figs. 557 and 558 when capacity is 800 K. W. or under.

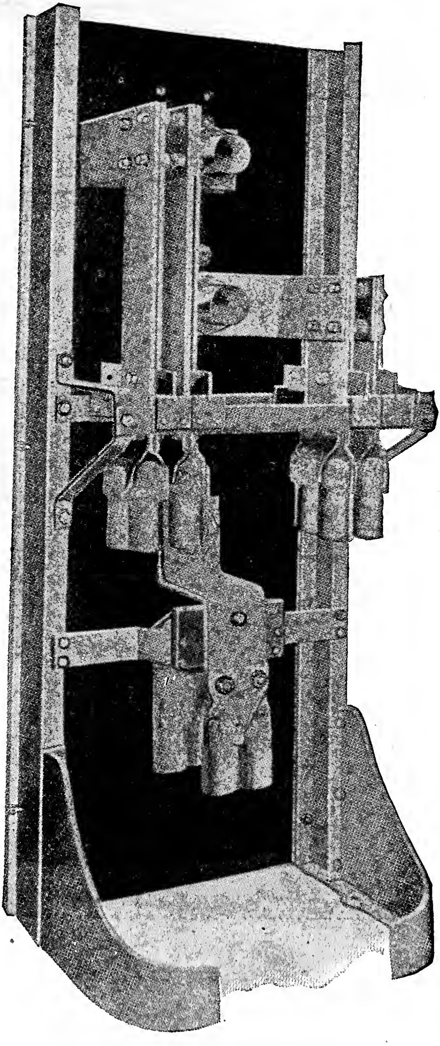

FIG. 552
REAR VIEW OF FIG. 551

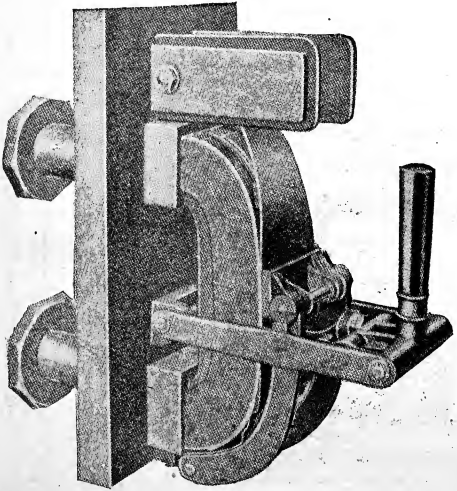

FIG. 553

4,000 AMPERE TOGGLE OPERATED SWITCH. LAMINATED MAIN CONTACT, CARBON SECONDARY CONTACT WITH MAGNETIC BLOWOUT.

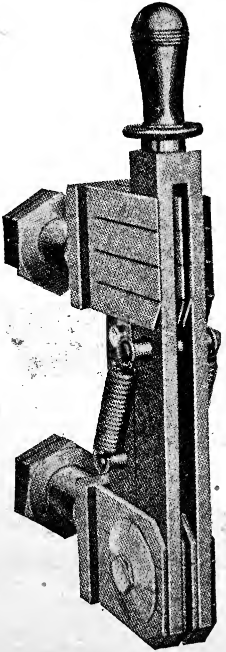

FIG. 554

3,600 AMPERE QUICK BREAK SWITCH.

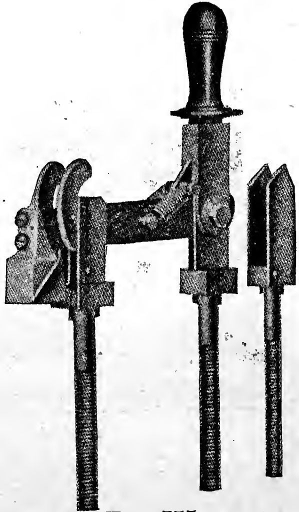

FIG. 555

FIELD DISCHARGE SWITCH.

Fig. 557 shows the same panel when capacity is larger. The panel at left is for 1,000 and 1,200 K. W., the next for 1,500 K. W. and over. The cuts on right side show the back and side view of the 1,500 K. W. panel.

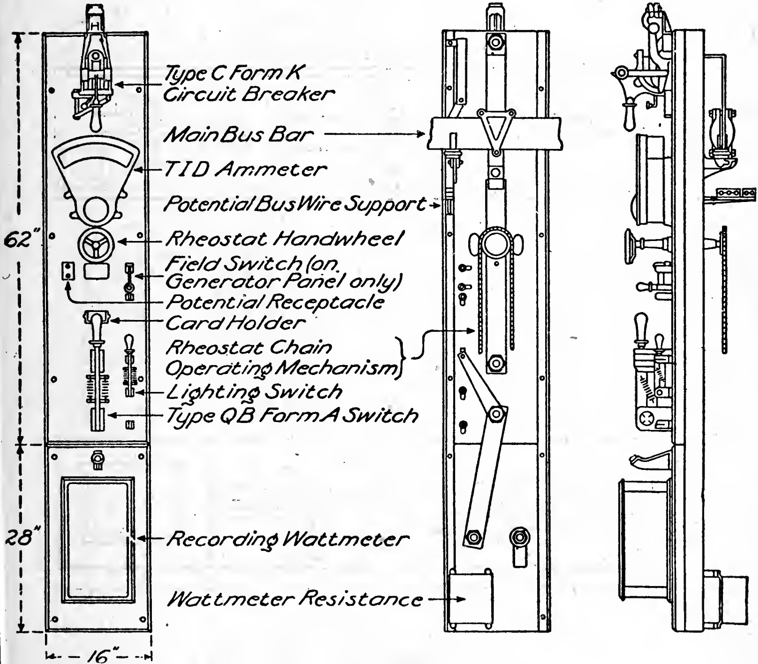

FIG. 556

CONSTRUCTION OF FIG. 547 FOR SMALL CAPACITY

The scheme of electrical connections for panel of Fig. 547 is shown in Fig. 558.

D. C. Feeder Panels.

A set of feeder panels for one feeder each is shown in Figs. 559 and 560, a panel for two feeders with separate switches and one ammeter reading sum of both currents is

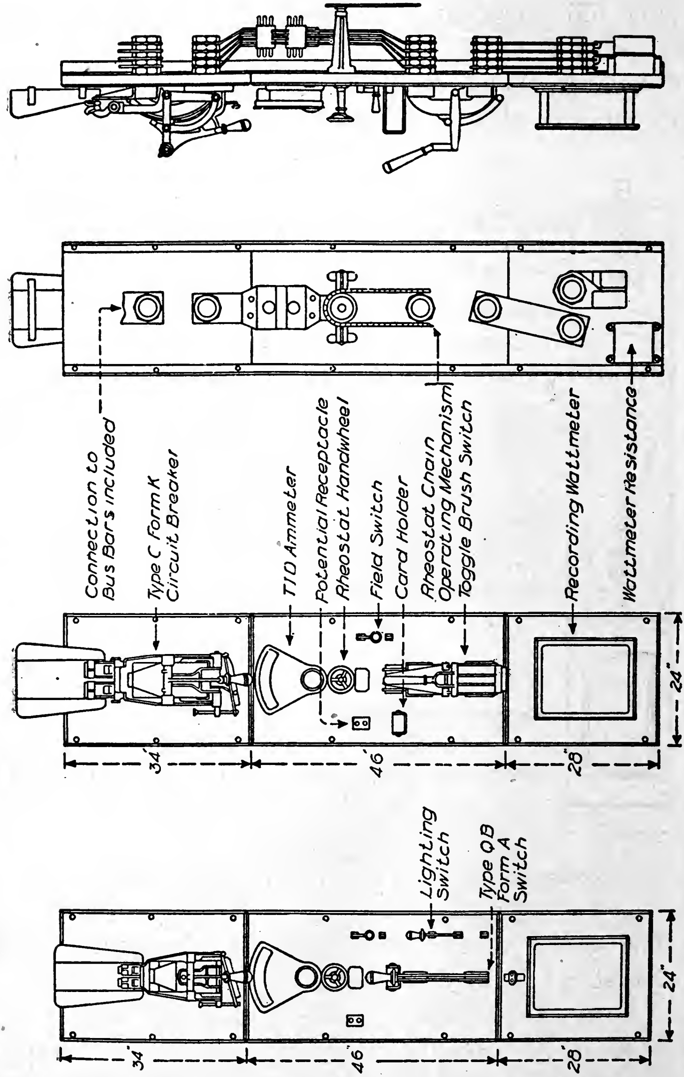

FIG. 557

CONSTRUCTION OF FIG. 547 FOR LARGE CAPACITY shown in Fig. 561, while Fig. 562 has an instrument and switch for each circuit.

Fig. 563 gives the diagram of these feeder panels and Fig. 564 gives the electrical connections.

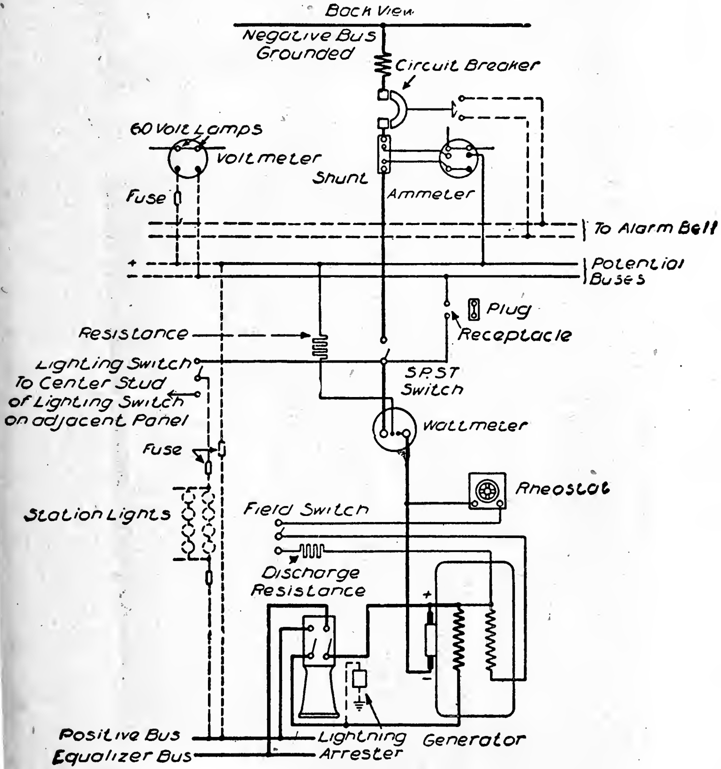

FIG. 558

D. C. GENERATOR PANELS

With panels as described the way to throw a generator in parallel with other generators already running, the following procedure should be followed:

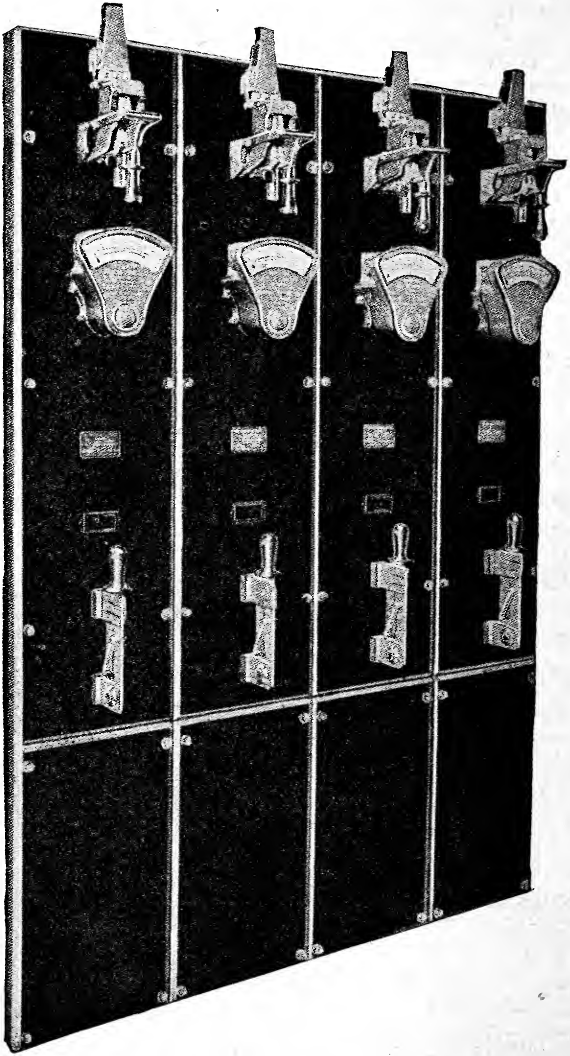

FIG. 559
D. C. FEEDER PANELS

First—Close main and equalizer switches (on pedestal or panel near machine).

Second—Close field switch (on panel).

Third—Close circuit breaker.

Fourth—Insert potential plug in receptacle and regulate voltage.

Fifth—When the proper voltage is obtained, close the other main switch (on panel).

All the above applies to the distribution of the output of rotary converters, but as they have some peculiarities they will be considered later.

A. C. Generator Panel.

The panel in Fig. 565 contains:

1 Horizontal edgewise balanced three-phase indicating wattmeter, arranged for reading both the kilowatts output and the wattless component.

1 Horizontal edgewise ammeter.

1 Horizontal edgewise volt-meter.

1 Balanced three-phase induction recording wattmeter.

1 D. P. D. T. potential reversing switch for the indicating wattmeter.

1 Four-point receptacle for synchronizing connections.

1 Hand-wheel and chain operating mechanism for field rheostat.

1 S. P. S. T. carbon break field switch with discharge clips.

1 D. P. D. T. engine governor control switch.

1 T. P. S. T. oil switch.

1 Current transformer for instruments.

2 Potential transformers for instruments.

The functions of the instruments are to indicate the current, voltage and kilowatts output of the generator, and the wattless component of the output. For indicating the

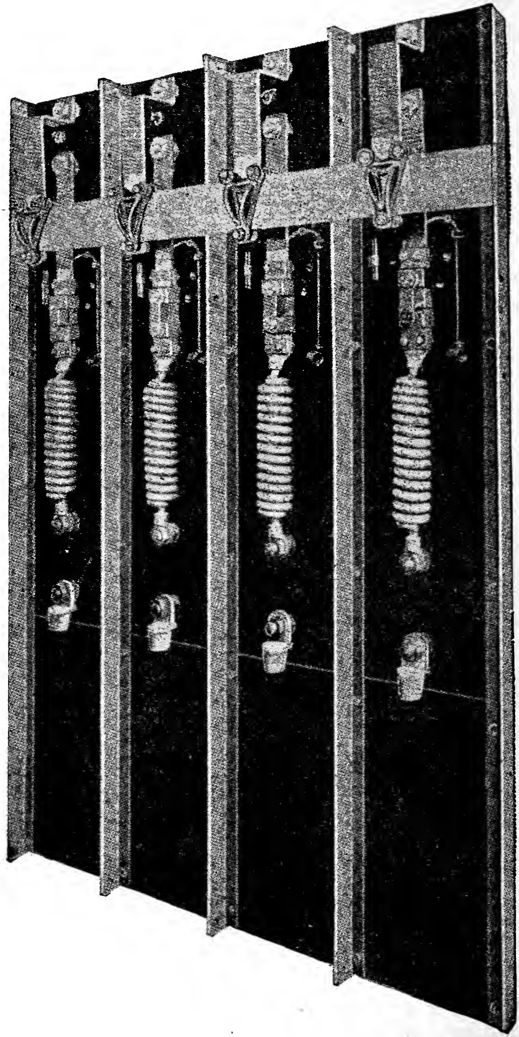

FIG. 560
REAR VIEW OF FIG. 559

wattless component, the potential coil of the indicating wattmeter is wired to the potential reversing switch, which is normally held by a spring so as to connect the instrument up as a wattmeter. By throwing the switch against the spring into the other position the potential coil is reversed, and the instrument reads the wattless compotent, giving a ready means of detecting any currents flowing between the alternators which are operating in parallel.

The engine governor switch is to operate the motor which temporarily controls the governor on engine, or turbine when their speeds are being altered to bring two alternators into synchronism, or adjusting the division of load when operating in parallel.

The generator oil switch has no automatic overload release, as it is important to keep the generator in service during heavy short circuits caused by trouble on the transmission lines. When such short circuits occur, the generators are immediately relieved by the opening of the automatic line switches.

The diagrams for connecting up generator panels according as transformers are, or are not used will be found in Figs. 566 and 567.

A. C. Outgoing Panel.—The panel on left of Fig. 568 contains:

3 Horizontal edgewise ammeters.
1 T. P. S. T. oil switch, with overload release.
3 Current transformers.

Three ammeters—one for each phase—are furnished for each line, to facilitate the detection of unbalancing due to open circuits or leakage. With balanced loads, the ammeter pointers should show equal deflections under normal conditions. As the ammeters are arranged in a perpendicu-

FIG. 561

TWO FEEDER D. C. PANEL

FIG. 562

1,200 D. C. AMPERE, RAILWAY FEEDER PANEL FOR TWO CIRCUITS

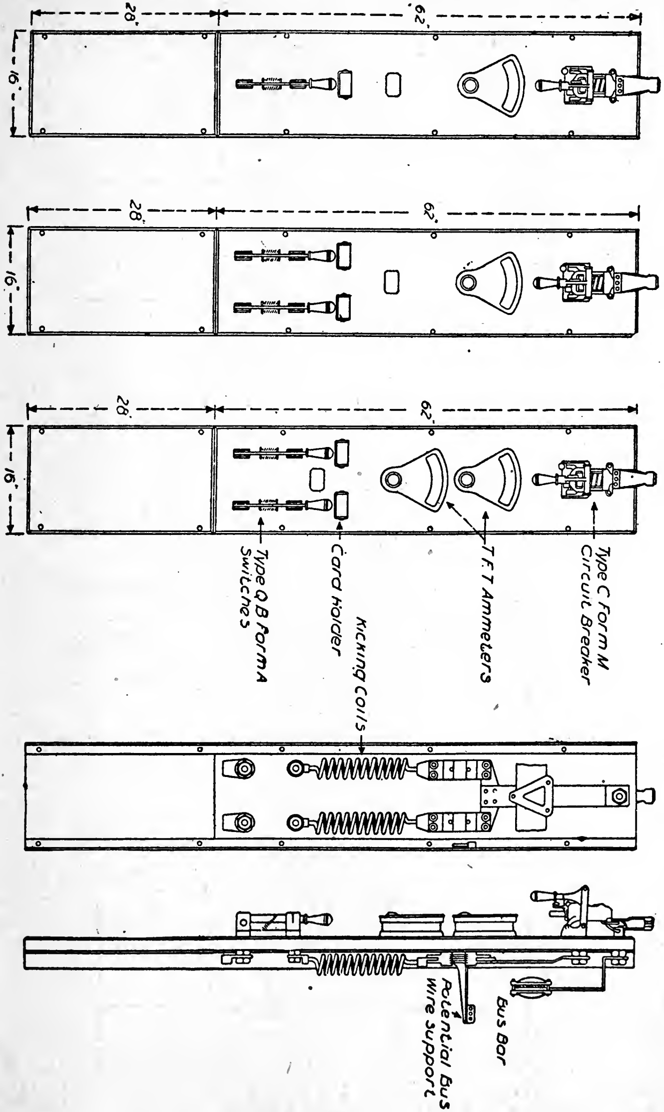

FIG. 563
CONSTRUCTION OF FIGS. 559 AND 562

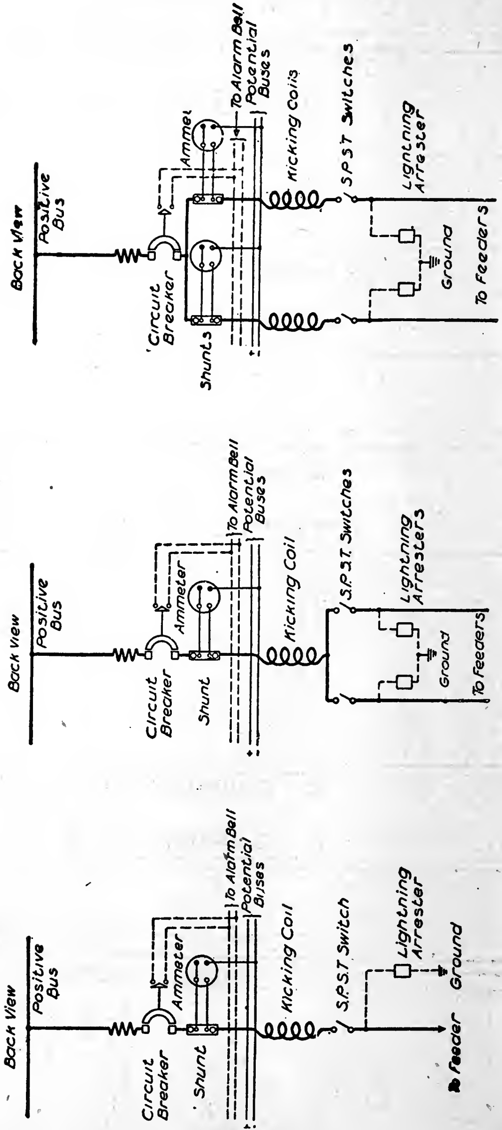

Fig. 564

THREE STYLES OF D. C. FEEDER PANELS

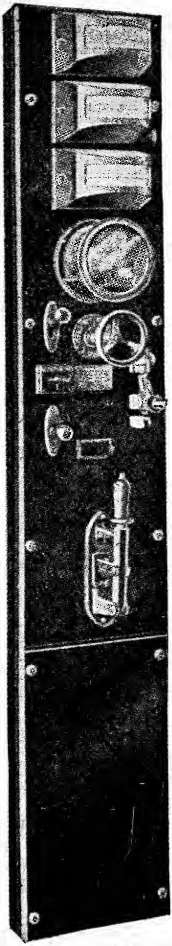

FIG. 565

A. C. GENERATOR PANEL

lar row any variation in the deflection of the pointers is readily detected.

The current transformers serve to operate the ammeters and the automatic release on oil switches.

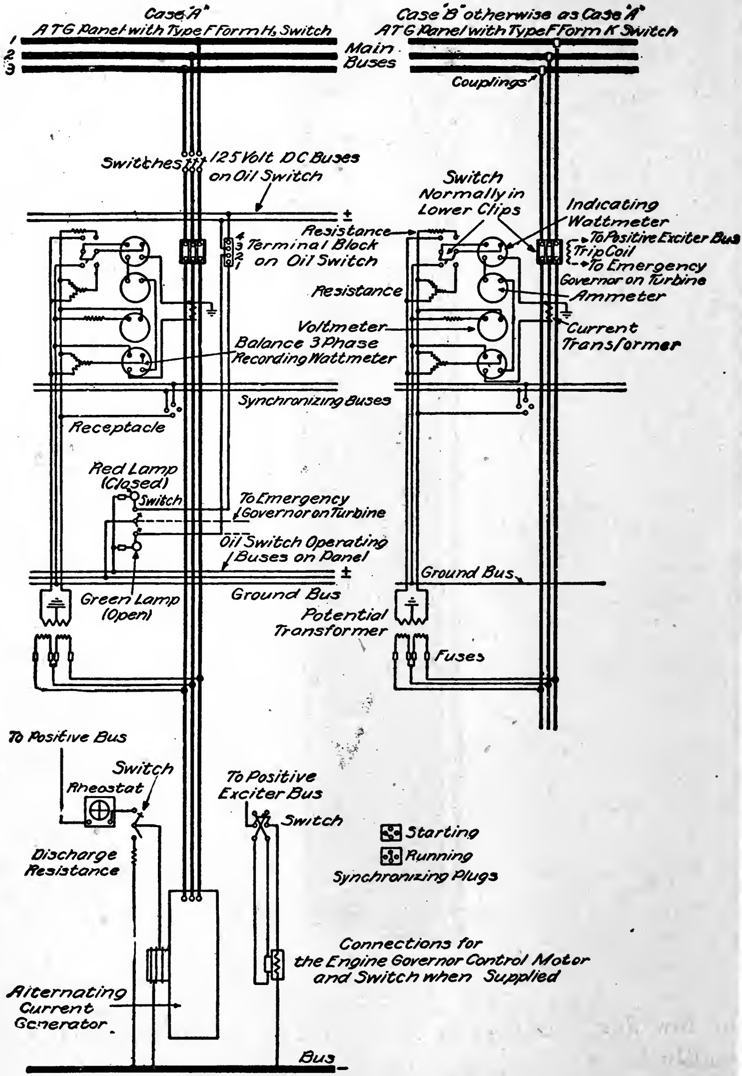

FIG. 566

A. C. GENERATOR PANEL WITHOUT STEP-UP TRANSFORMERS

The panel on right of Fig. 568 has but one ammeter and merely has the handle for operating the oil switch. The actual switch being in a brick compartment at rear of panel. The overload relay (3-pole) which trips the oil switch is at base of panel.

Fig. 569 gives the electrical connections of panels in Fig. 568.

The swinging bracket of Fig. 570 contains a synchronism indicator, two lamps for synchronizing (practically a duplicate set of synchronizers) and a voltmeter for the station exciter generator.*

To use the synchronism indicator put one plug in on panel of a generator which is running, and the other plug in the panel of the generator which is starting.

Fig. 571 shows a complete switchboard of one generator panel in center, a panel for one outgoing line on the right, an exciter panel on left, with the swinging bracket on extreme left.

Such a switchboard would be extended towards the right indefinitely, as more lines were put on the station, by the addition of more outgoing line panels.

Exciter Panel.—Each exciter panel is equipped with:

1 Thomson feeder type ammeter.

1 Hand-wheel for operating rheostat.

1 Two-point potential receptacle connected to voltmeter.

1 S. P. S. T. positive lever switch, with fuse mounted back of panel.

One Exciter Panel in every switchboard is furnished with the following additional switches: (as in Fig. 572.)

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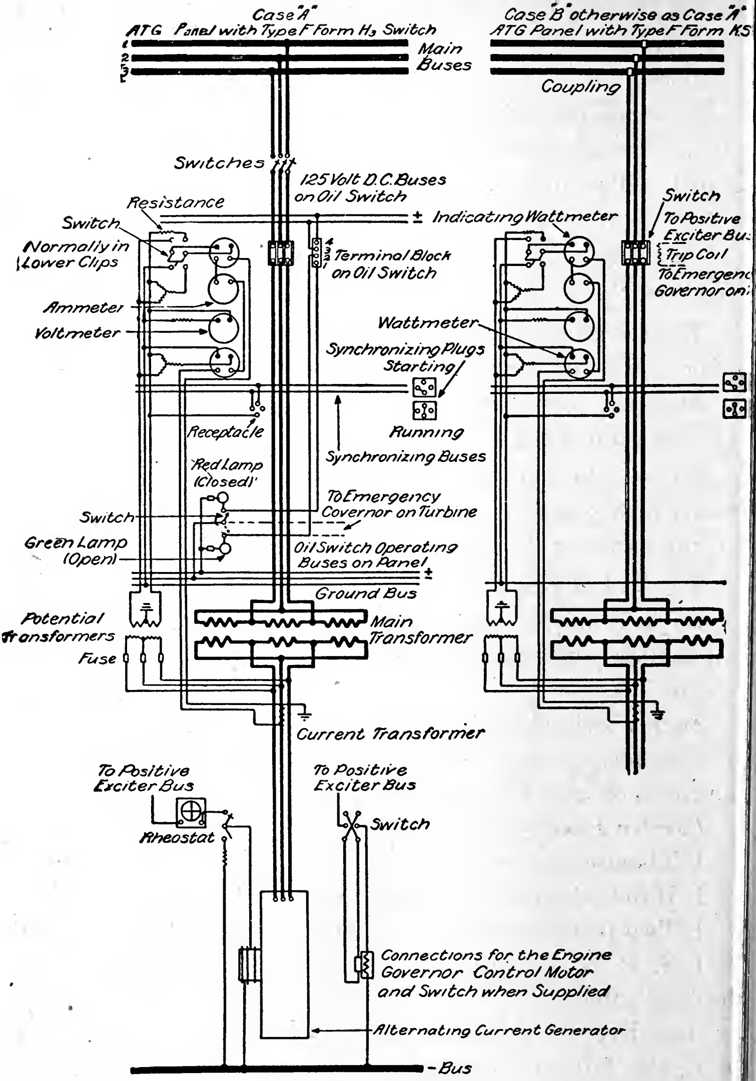
*D. C. Generator furnishing current for field of alternator.



ALTERNATING CURRENT GENERATOR PANEL FOR GENERATOR WITH STEP-U TRANSFORMER

FIG. 567

A. C. GENERATOR PANEL FOR GENERATOR WITH STEP-UP TRANSFORMER

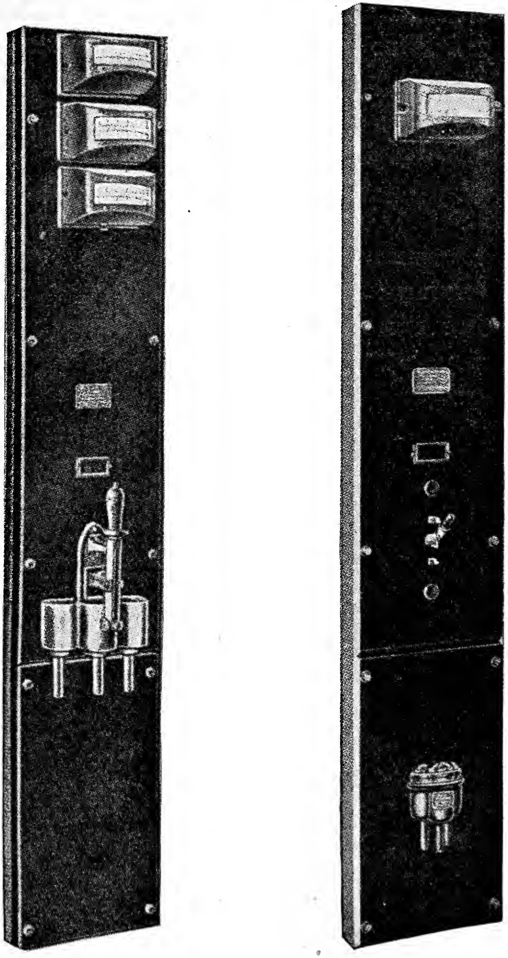


Fig. 568

A. C. OUTGOING LINE PANELS

2 S. P. S. T. lever switches, with fuses back of panel, for the control of station lighting and auxiliary circuits.

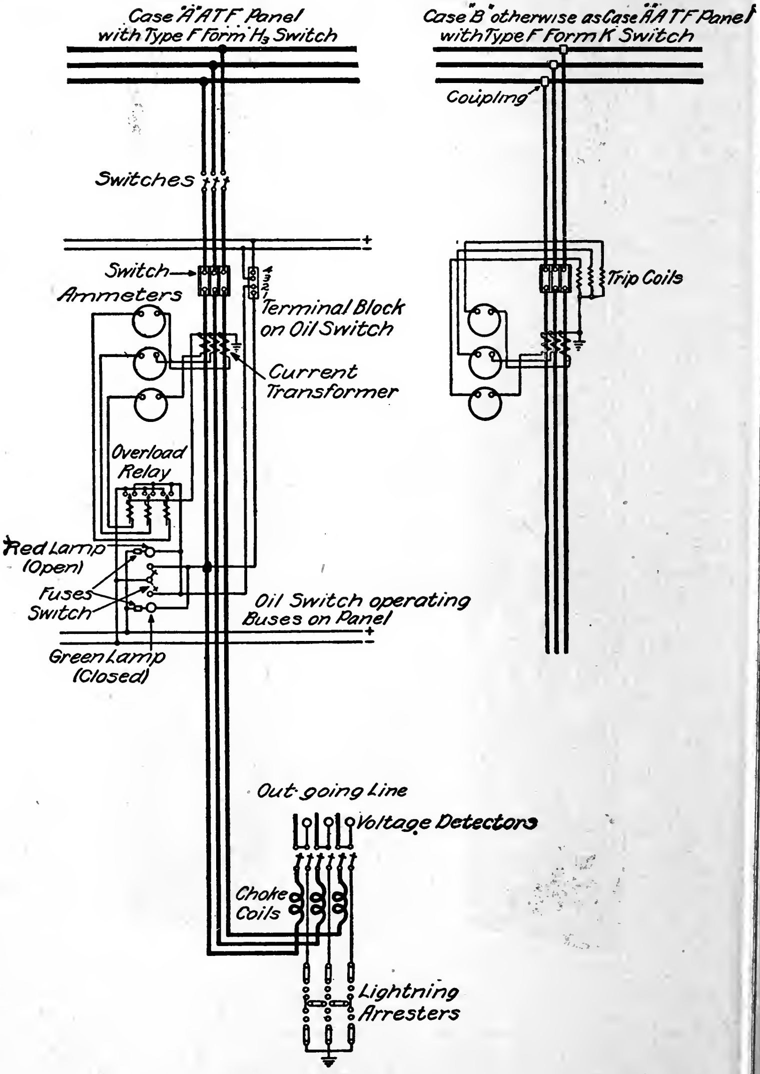


FIG. 569

A. C. OUTGOING LINE PANEL

On the frame of each exciter there are required the following switches, mounted on a common slate base:

1 S. P. S. T. negative lever switch.

1 S. P. S. T. lever switch for equalizing.

The exciter panels are designed single pole, *i. e.,* only the positive leads of the generators are connected to the switch-board panels and only the positive bus-bar is mounted back of them. The negative and equalizer leads are connected through their switches to the negative and equalizer bus-bars, which are placed under the floor near the exciters. With the bus-bars of opposite polarity so widely separated there is practically no chance of short circuit of the exciter connections. The positive field leads of the alternators are carried to the panels, while the negative field leads are permanently connected to the negative exciter bus-bar.

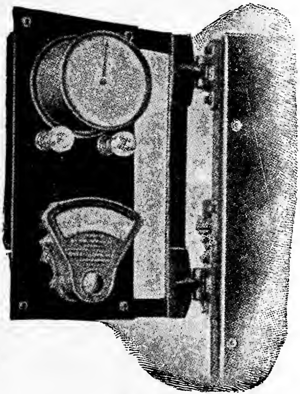


Fig. 570

SYNCHRONISM INDICATOR AND EXCITER VOLTMETER ON SWINGING BRACKET

Fig. 573 will give the electrical connections of an exciter panel.

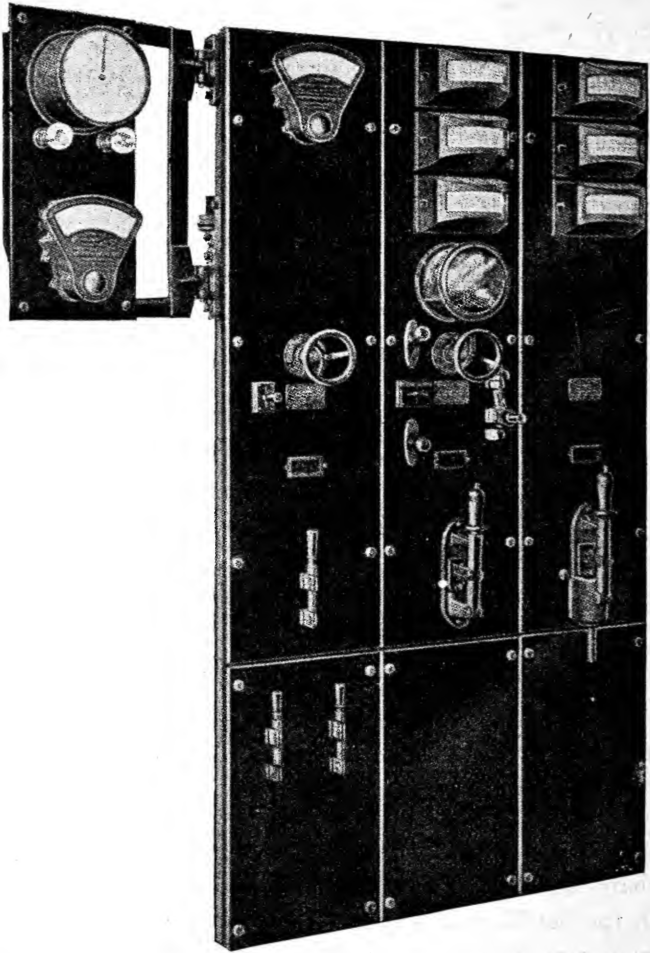


FIG. 571

MAIN STATION SWITCHBOARD FOR ONE A. C. GENERATOR AND ONE OUTGOING LINE

The blower motors running the blowers which cool transformers are of the 3-phase induction type, or D. C. shunt motors.

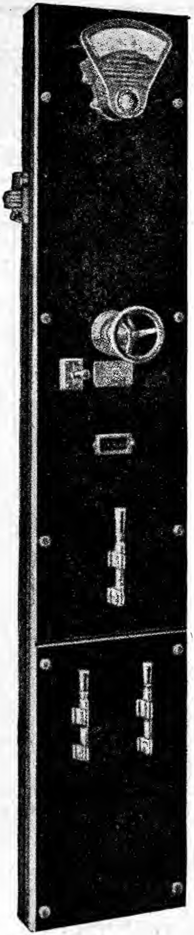


FIG. 572

EXCITER PANEL AUXILIARY LIGHTING SWITCHES ON SUB-BASE

The D. C. motors are started by the regular starting box, Fig 574.

The current to an induction motor is controlled by a switch like Fig. 575. if from auxiliary low voltage buses,

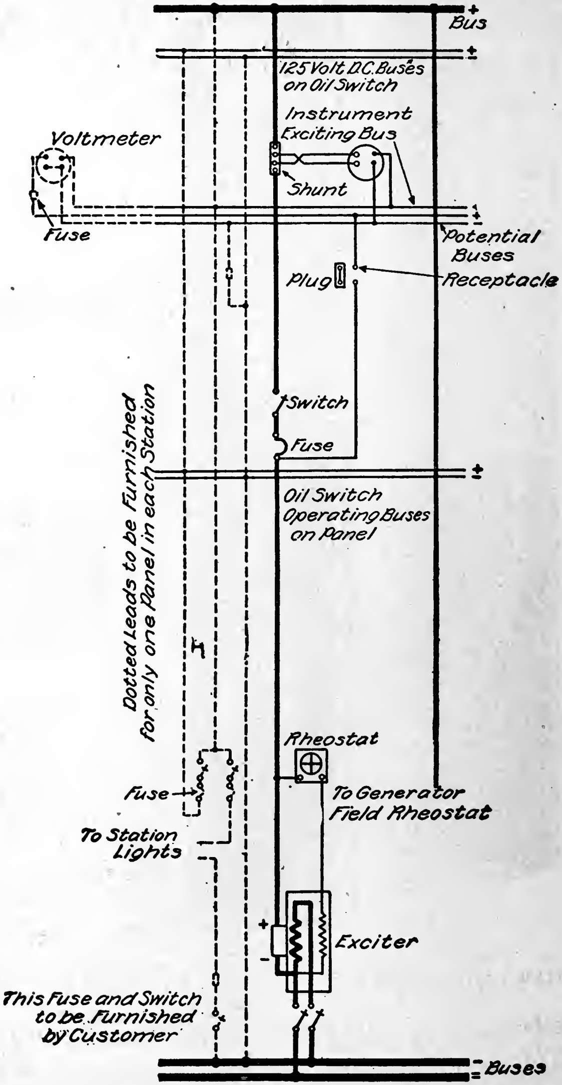


FIG. 573
EXCITER PANEL

or from an oil switch on a panel like Fig. 576, if full station voltage is used.

The actual starting is done by a switch as in Fig. 577, which is between secondaries of transformers or reactance coils and the induction motor.

Fig. 578 shows connections of an induction motor to main buses, using an oil switch and a starting switch.

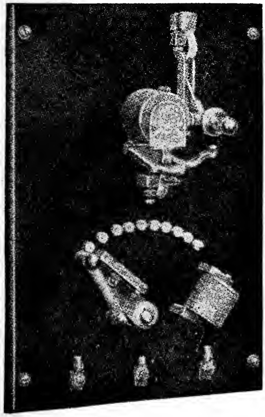


Fig. 574

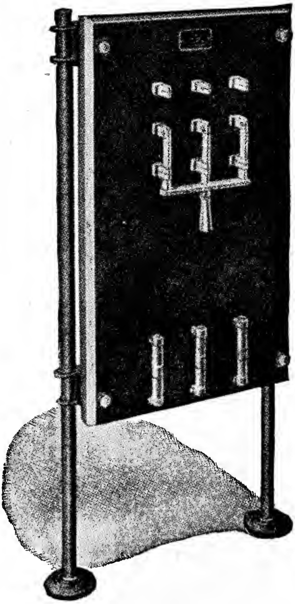


Fig. 575

FIG. 574

STARTING PANEL FOR D. C. BLOWER SET

FIG. 575

MAIN SWITCH PANEL FOR A. C. BLOWER SET

The operation of several sub-stations on a single line is generally recognized as good practice.

To insure continuity of service in the event of line trouble, it is expedient to sectionalize the line at every sub-

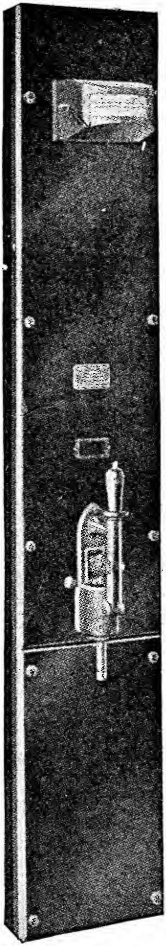


Fig. 576

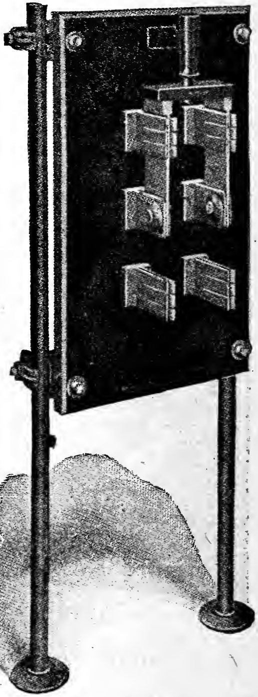


Fig. 577

Fig. 576

OIL SWITCH A. C. PANEL FOR INCOMING LINE

MOTOR DRIVING EXCITER OR A. C. SIDE OF ROTARY

Fig. 577

INDUCTION MOTOR OR ROTARY STARTING PANEL station that is located at an intermediate point of the line. This sectionalizing is accomplished at each intermediate station by carrying the incoming line to the bus-bars through the air brake disconnecting switches which are installed in connection with the arresters, and by carrying the outgoing line through an oil switch. In case of line trouble, this arrangement allows all sections of the line between the generating station, and any section on which the trouble occurs to be operated continuously. The power is automatically cut off from the section in trouble by an oil switch in the outgoing line panel equipment of the sub-station at the generating station end of the section, so that the air brake disconnecting switches in the sub-station at the other end of the section need never be opened under load.

When duplicate transmission lines are used, two incoming line panels and two outgoing line panels are recommended for each intermediate sub-station. The installation of these individual panels facilitates the disconnection of either line of any section and the continuance of the service over the other line of the section without any interruption.

Arc Switchboards.—Fig. 579 shows a general view of the Thomson-Houston plug switchboard. A rear view of the same board is given in Fig. 580.

In a standard panel the number of horizontal rows of holes equals one more than the number of generators. The vertical holes are always twice the number of generators. The positive leads of the generators are attached to the binding posts on the left-hand ends of the horizontal conductors. The negative leads are connected to the corresponding binding posts at the right-hand end of the board.

The positive line wires are connected to the vertical straps

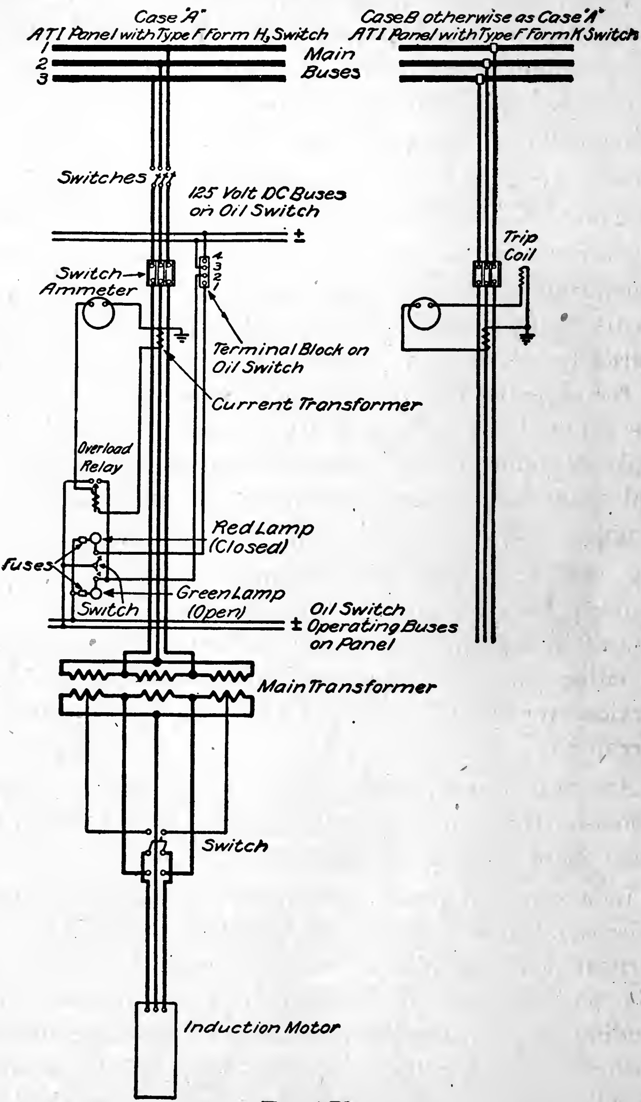


FIG. 578

INDUCTION MOTOR PANEL

on the left, and the negative wires to the similar straps on the right of the center panel.

If a switchboard plug be inserted in any of the holes of the board, it puts the corresponding generator lead and the line wire in electrical connection, but as the positive line wires are back of the positive generator leads only, it is not possible to reverse the connection of the line and the generator accidentally, though any other combinations of lines and generators can be made readily and quickly.

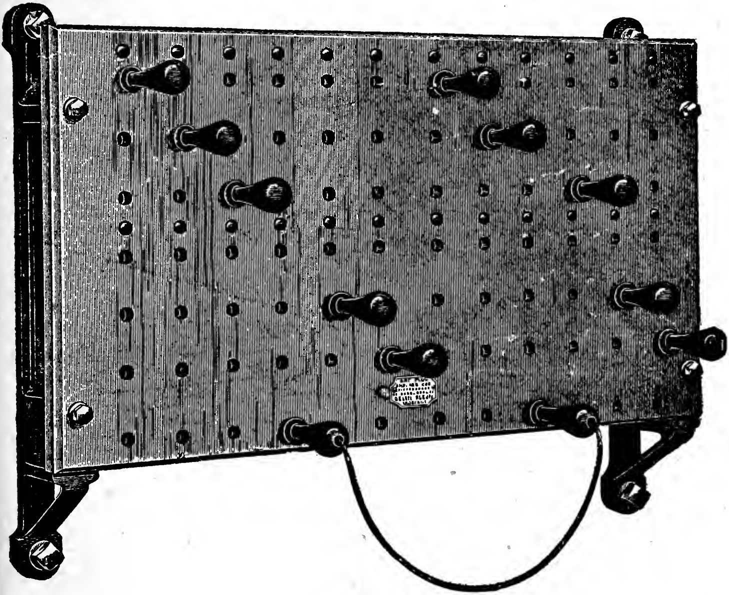


FIG. 579

The holes of the lower horizontal rows have bushings connected with the vertical straps only. Plugs connected in pairs by flexible cable and inserted in the holes put the corresponding vertical straps in connection as needed, and normally independent lines may be connected when one generator is required to supply several circuits.

Lines and generator leads may be transferred, while running, by the use of these cables, without shutting down machines or extinguishing lamps.

The standard boards are arranged for an equal number of generators and circuits, but special boards for any ratio of circuits to generators can be built.

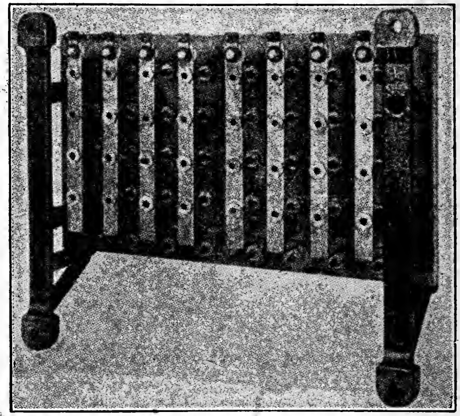


Fig. 580

As it is sometimes convenient, even in small plants, to interchange lines and generators without shutting down machines, a special transfer cable with plugs has been devised. This serves the same purpose as the regular transfer cable, but the plugs may be used in any of the holes of the switchboard, as they are insulated, except at the tip, and when inserted connect with the line strips only.

The transfer of circuits from one generator to another gives trouble to dynamo tenders who are not familiar with the operation of these plug switchboards. Fig. 581 illus-

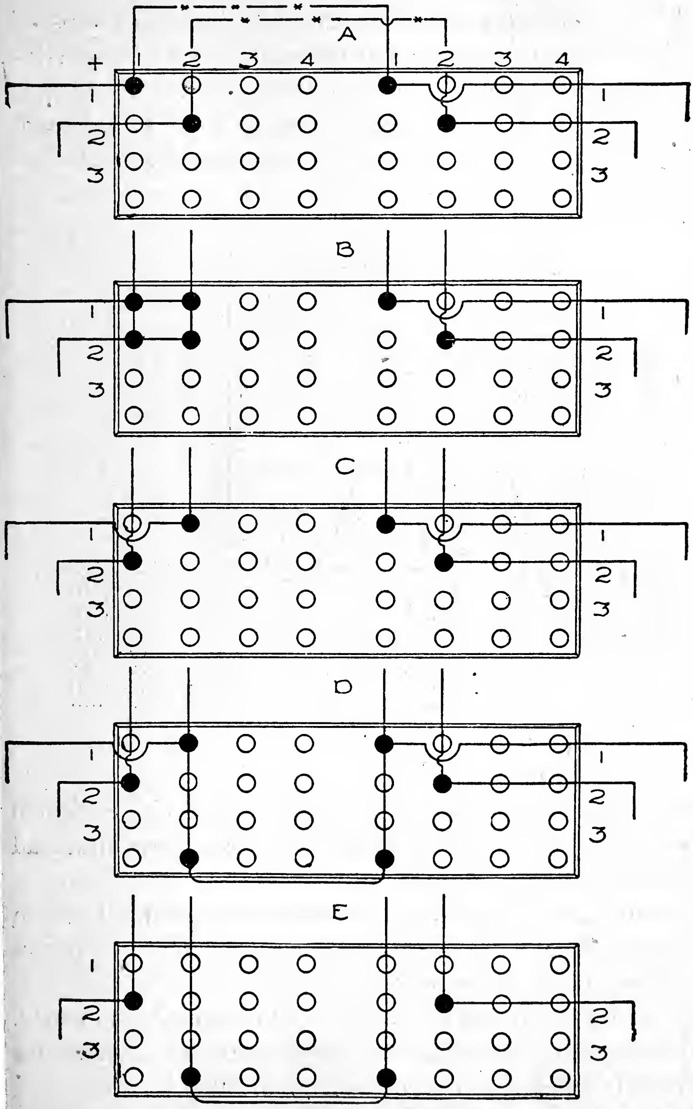


FIG. 581

trates the successive steps for transferring the lamps of two independent circuits from two generators to one without extinguishing the lamps on either circuit.

This process is a very simple example of switchboard manipulation, but illustrates the method used for all combinations.

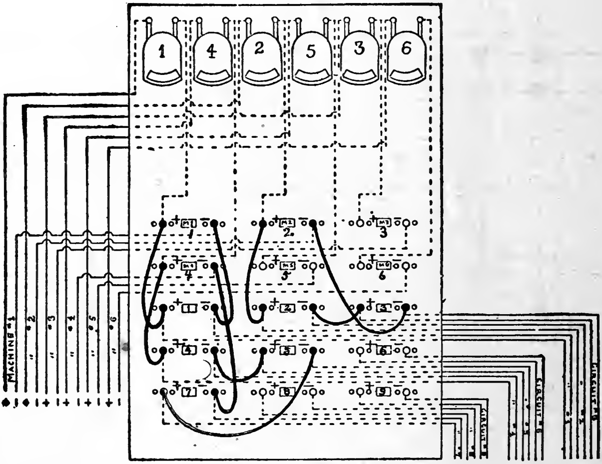


FIG. 582

The location of plugs is shown by the black circles, which indicate that the corresponding bars of the horizontal and vertical rows are connected.

Circuits No. 1 and No. 2, running independently from generators No. 1 and No. 2, respectively, are to be transferred to run in series on generator No. 2.

In A, Fig. 581, are two circuits running independently. In B the positive sides of both generators and circuits are connected by the insertion of additional plugs.

At C both generators and circuits are in series.

Next insert plugs and cables as shown in D. Then withdraw plugs on row corresponding to generator No. 1, and the circuits No. 1 and No. 2 are in series on machine No. 2, and machine No. 1 is disconnected as at E.

Similar transfers can be made between any two circuits or machines, and by a continuation of the process additional circuits can be thrown in the same machine. The transfer of the two circuits to independent generators is accomplished by reversing the process illustrated.

Fig. 582 shows the wiring and connections of the Western Electric Co.'s series arc switchboard. At the top of the board are mounted six ammeters, one being connected in the circuit of each machine. On the lower part of the board are a number of holes, under which, on the back of the board, are mounted spring jacks to which the circuit and machine terminals are connected. For making connections between dynamos and circuits, flexible cables terminating at each end in a plug, are used; these are commonly called "jumpers." The board shown has a capacity of six machines and nine circuits, and with the connections as shown, machine 1 is furnishing current to circuit 1, machine 2 is furnishing current to circuits 2 and 3, and machine 4 is furnishing current to circuits 4, 5 and 7. In connecting together arc dynamos and circuits the positive of the machine (or that terminal from which the current is flowing) is connected to the positive of the circuit (the terminal into which the current is flowing). Likewise the negative of the machine is connected to the negative of the circuit. Where more than one circuit is to be operated from one dynamo, the negative of the first circuit is connected to the positive of the second. At each side of the name plate (at 3, for instance) there are three holes. The large hole is used for the permanent connection, while the smaller holes are used for transferring circuits, without shutting down the dynamo. Smaller cables and plugs are used for transferring. If it is desired to cut off circuit 5 from machine 4, a plug is inserted in one of the small holes at the right of 4, the other plug being inserted in one of the holes at the left of 7. Circuit 5 would now be short-circuited, and the plug in the + of 5 can now be transferred to the permanent connection in the + of 7, and the cords running to 5 removed. If it is desired to cut in a circuit, say circuit 6 onto machine 2, insert a cord between the — of circuit 2 and the + of 6 and another between the — of 6 and the + of 3. Now pull the plug on the cord connecting the — of 2 and the + of 3 and insert the permanent connections. In cutting in circuits, if they contain a great number of lights, a long arc may be drawn when the plug between 2 and 3 is pulled, and it is sometimes advisable to shut down the machine when making a change of this kind.

TRANSFORMERS.

When a current passes through a conductor it creates around it a field of force. If a second wire, or conductor lies parallel to the first during the time that the field of force is being built up, electromotive force will be impressed upon it, and will be of such polarity that the current produced by it will be in a direction opposite to the direction of the original current. The transformer contains two coils of wire insulated from each other.

In Fig. 583 is shown the principle upon which the transformer used in alternating current work operates. Two separate coils of wire are wound on a ring of laminated iron. One of the coils contains a number of turns of fine wire, while the other contains only a few turns of large wire. When an alternating current is sent around the coils of fine wire, generally called the primary, a current will be induced in the coil of heavy wire, or secondary. The amount of current induced in the larger wire will be relatively greater in amperes, and less in potential than that of the fine wire circuit. This ratio is almost entirely dependent upon the relative number of turns existing between the large and the small wires. To illustrate, suppose we had a current of 10 amperes at a pressure of 1,000 volts in the primary, and there were ten times as many turns of wire in the primary coil as in the secondary, then we would get a current of 100 amperes at a pressure of 100 volts in the secondary coil. This same relation would hold true whatever the ratio between the number of turns on the two coils might be. In Fig. 584 is shown a core of iron having on one end a primary coil connected to a battery. On the other end of the core is another coil connected to the ends of which is an incandescent lamp. By making and breaking the battery circuit the lamp may be made to flash

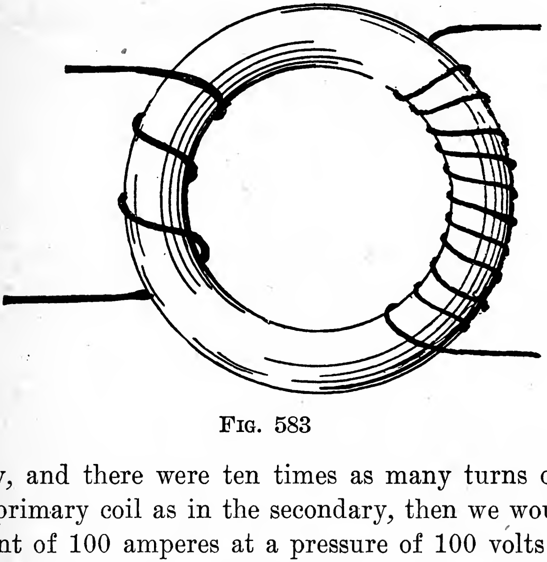


Fig. 583

up, due to the great voltage induced in the secondary coil. This is a good thing to remember when working with a dynamo or motor. Do not quickly break the shunt field connection, as the increased voltage due to the current induced by the field magnet when the circuit is broken is liable to puncture the insulation and necessitate the rewinding of the field coil.

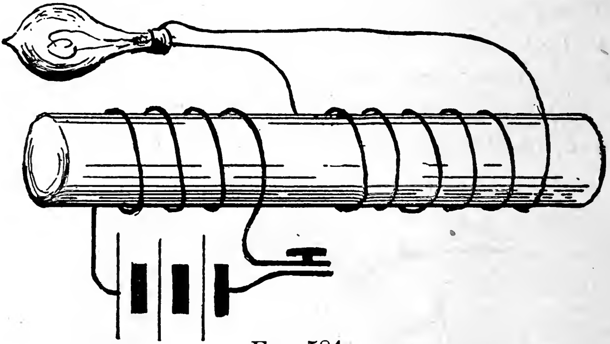


FIG. 584

Referring to Fig. 585, A represents the alternator, B its brushes and D and E the mains to the transformer H. This transformer consists of a core of iron C on which are two windings. The coil P is called the primary, and is connected to the main from alternator. The other coil S is called the secondary, and to it the load is connected.

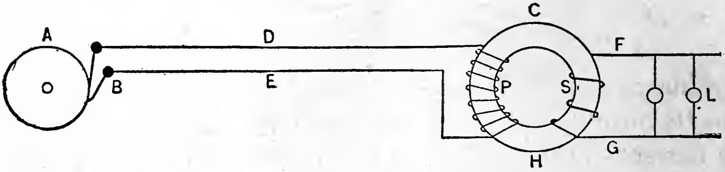


FIG. 585
DIAGRAM OF ALTERNATOR, LINE, TRANSFORMER, AND SECONDARY CIRCUIT

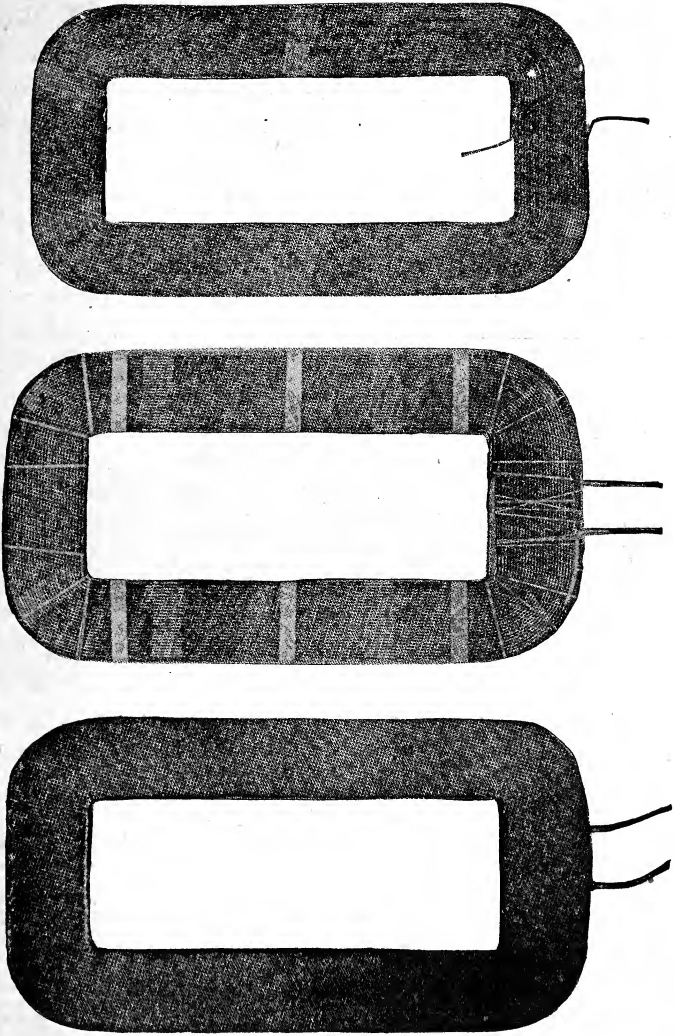


FIG. 586

TRANSFORMER COILS IN WOUND, BOUND AND TAPED STAGES OF COMPLETION

Whatever the voltage of alternator A, that of the secondary circuit F. L. G. will be three-eighths of it because there are eight turns on the primary and three turns on the secondary. The power in the secondary circuit is practically the same (minus the losses) as is given out by the alternator, hence the primary current is low and wire is small. The secondary current is large and the wire is large.

Since one kilowatt can be a combination of a large current and small pressure, or small current and large pressure, it is evident that the transformer simply transfers the power, and transforms the voltage, and indirectly the current.

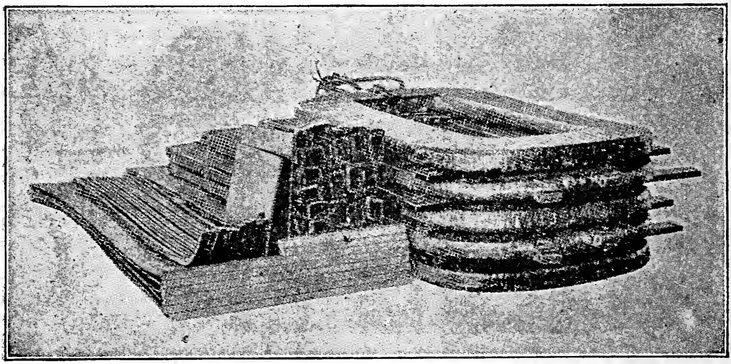


Fig. 587

COILS, AIR DUCTS AND SEPARATORS FOR TRANSFORMER

This transformer (Fig. 585) lowers the voltage and is called a step down transformer.

When the secondary is connected to the alternator, the transformer raises the voltage and is called a step up transformer.

The coils of a transformer must be very well insulated. After winding they are bound, to keep them in shape, and then wound with linen tape, or varnished cambric cloth. Fig. 586 shows a coil in the three stages of completion.

In Fig. 587 is shown a set of completed coils, together with the ventilating ducts and mica barriers sufficient for one leg of a transformer.

Fig. 588 shows the two legs of a transformer, which form its iron core, each over half filled with coils. The coil is made of sheets of soft iron.

Fig. 589 shows the manner in which the coils are sometimes bound up to be placed in transformer as one coil.

Exciting Current.—The Exciting Current, being also called by various other names, such as leakage current, open circuit current, and magnetizing current, is a very important factor.

In order that a transformer may be ready to do its work it is always connected to the line. This means that the primary coil is always magnetizing the core, if no current is drawn from the secondary.

This steady flow of current to excite the primary is the price we have to pay for having the transformer continually ready for service.

A transformer should therefore never be left on a line unless it is needed.

Efficiency of Transformers.—The losses in transformers are less than any other piece of electrical machinery or apparatus; 98 per cent of the intake being delivered in the larger sizes as used in railroad sub-stations or power houses, when fully loaded. Unfortunately they lose about the same amount of power at all loads.

A. 100 K. W. transformer loses 2 K. W. at full load, its efficiency is then 98÷100=0.98. At half load it loses 2 K. W., but is only carrying 50 K. W., so (its losses are

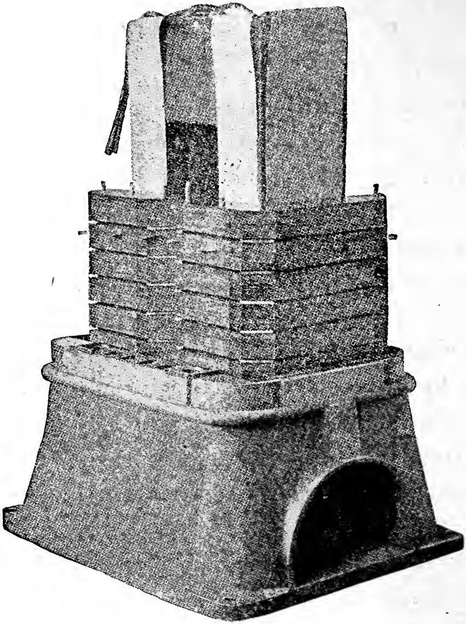


FIG. 588

INTERIOR CONSTRUCTION OF AN AIR BLAST TRANSFORMER

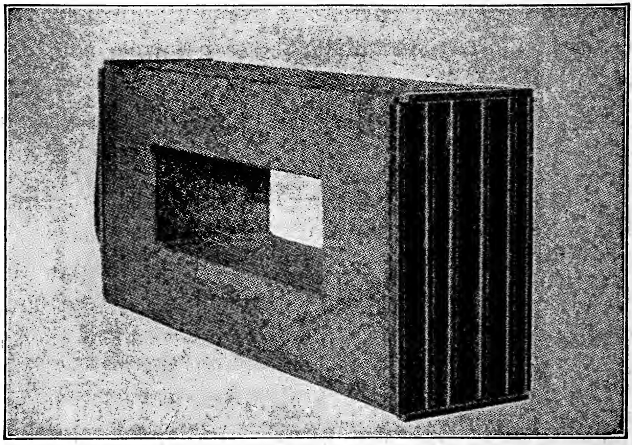


FIG. 589

SET OF COILS MADE UP READY TO BE PLACED IN TRANSFORMER now equivalent to 4 K. W. on a 100 K. W.) its efficiency is 48÷50=0.96.

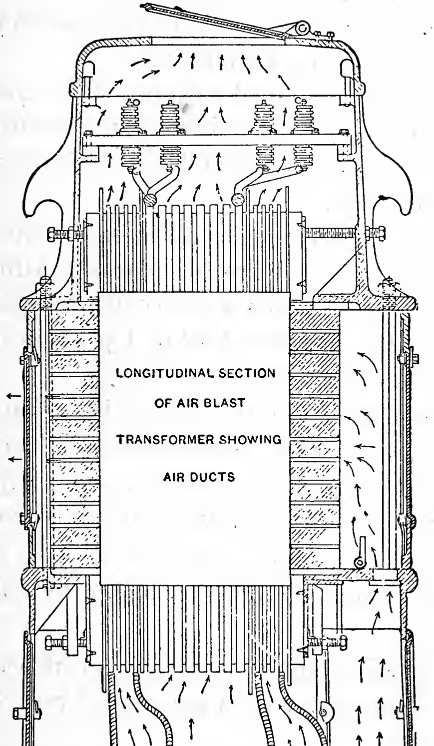


FIG. 590
AIR BLAST TRANSFORMER

At quarter load it takes in 25 K. W., loses 2 K. W., so its efficiency is 23÷25=0.92.

By clever designing transformers are built to be most efficient at three-quarters load. They are a little less efficient at half, and full loads, and still less at quarter load, and quarter overload, but never fall below 95 per cent.

Cooling Transformers.—Small transformers hung up on poles are cooled by surface radiation only.

Medium sized ones are filled with oil. This conducts the heat to the iron case, and also acts as an insulator.

The oil will also flow in and fill a break in the cloth, or mica after a puncture.

Air blast avoids the danger of oil in case of fire or flame due to short circuits. They are cheap as a transformer may be much more heavily loaded when cooled by the air blast, and the blower only consumes 1-10 of 1 per cent of the full load output of transformer.

Fig. 590 shows the interior construction of an air blast transformer and Fig. 591 shows how they are installed.

Water cooled. These are the smallest and cheapest transformers to build, but not so cheap to run as is the air blast.

The cases are filled with oil which absorbs heat from coils. Pipes are run through the oil, in which cold water is circulated.

In a water power plant where the head of water would render pumps unnecessary the water cooled type would certainly be the best.

Auto-Transformers.—These are only applicable to certain cases.

The idea is shown in Fig. 592. The same coil of wire A to B is used as primary and secondary, the whole being the primary, and portions as C to D, D to E, or C to E being used as secondary.

They are only used where the primary voltage is fairly low and the secondary voltage is not less than one-fifth of the primary voltage.

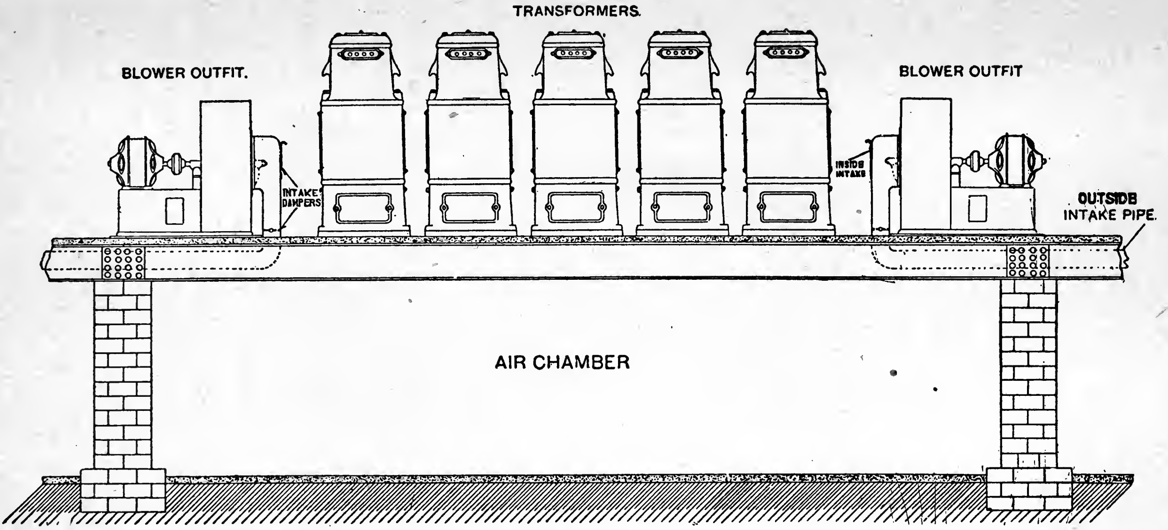


FIG. 591

INSTALLATION OF AIR BLAST TRANSFORMERS

They are used instead of resistances to start A. C. motors.

Allis-Chalmers Power Transformers.—Transformers for use on power transmission lines are made by Allis-Chalmers Company in three different types, depending on the method used for cooling. These types are as follows: oil-filled self-cooled (O. F. S. C.); oil-filled water-cooled (O. F. W. C.) and air-blast. In the first the heat is carried off by radiation, and conduction from the case; in the second by the circulation of water through coiled pipes immersed in the oil; and in the third by currents of air forced through the transformer. Oil-insulated transformers are used in the great majority of cases, and the question as to whether they shall be self-cooled or water-cooled is determined largely by the size of the units, and the available supply of cooling water.

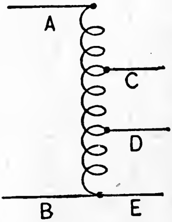


Fig. 592

DIAGRAM OF AUTO-TRANSFORMER OR COMPENSATOR

Self-cooled transformers are built in sizes up to 250 K. V. A. (kilovolt-amperes). Above this size the external surface of the case is not sufficient for the effective radiation of the heat unless the case is made abnormally large. Fig. 593 shows a standard transformer of this type.

Water-cooled transformers, Fig. 594, are made in sizes from 100 K. V. A. up. Water is circulated through a coil of seamless copper tubing immersed in the oil in the upper part of the tank, and the heat is effectively carried off. Wherever water is available and not expensive this method is preferable to air cooling, even for comparatively small transformers, as it permits operation at lower temperatures, and allows more margin for overloads.

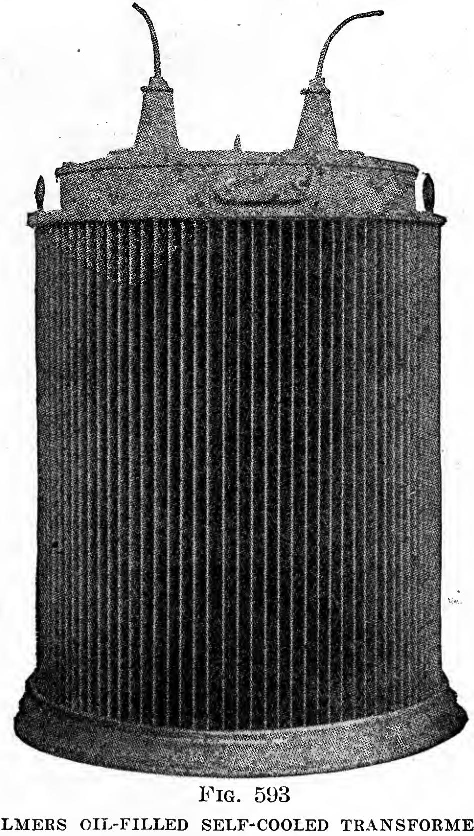


FIG. 593

ALLIS-CHALMERS OIL-FILLED SELF-COOLED TRANSFORMER, 60 CYCLE, 170 K. W., 20,000 TO 2,300 VOLTS

Air-blast transformers are made in sizes from 75 K. V. A. up. Cooling is effected by placing the transformer over

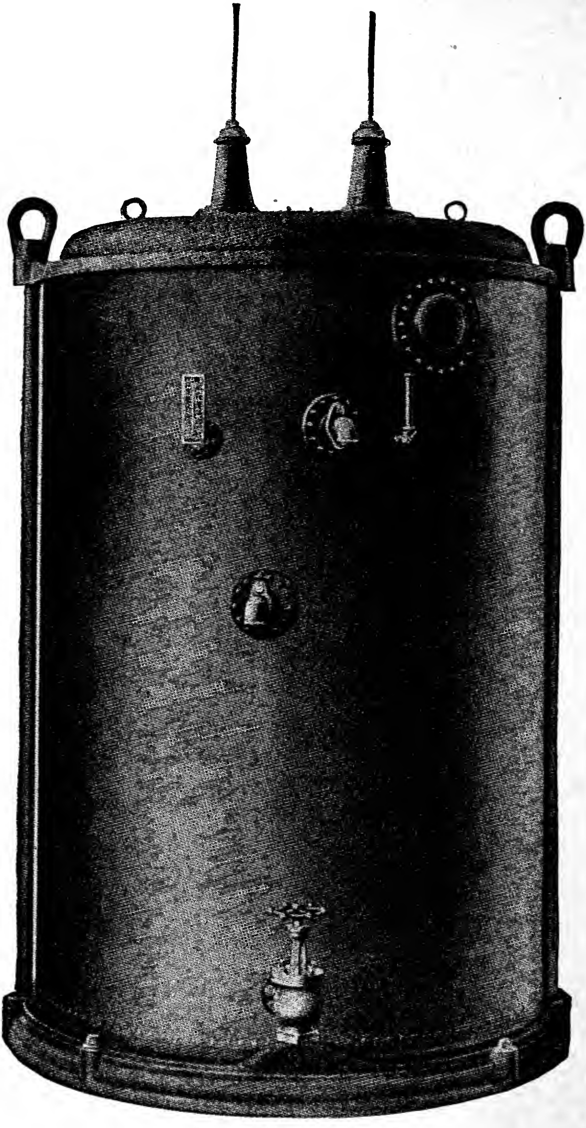


Fig. 594

ALLIS-CHALMERS OIL-FILLED WATER-COOLED TRANSFORMER, 25 CYCLE, 500 K. W., 20,000 TO 375 VOLTS an air chamber in which a pressure of air is maintained by motor driven fans; currents of air passing up around the transformer carry off the heat. In this type oil cannot be used for insulating purposes, and 25,000 volts is the highest pressure for which it is advisable to build them.

Much has been written about the relative fire risks of air-blast and oil-filled transformers, but this is a matter that depends as much on surrounding conditions, and the location of the transformers as upon the construction. The air-blast transformer contains a small quantity of inflammable matter as compared with the oil-filled transformer, but this material is much more easily ignited. A breakdown in an air-blast transformer is usually followed by an electric arc that sets fire to the insulating materials, and the flame soon spreads under the action of the forced circulation of air. Although the fire is of comparatively short duration, it is quite capable of ignitng the building unless everything near the transformers is of fire-proof construction.

The chance of an oil-filled transformer catching fire on account of any short circuit in the windings is extremely small, because oil will burn only in the presence of oxygen, and, since the transformer is completely submerged in oil, no air can get at it. Moreover, the oil used in transformers is not easily ignited; it will not burn in open air unless its temperature is first raised to about 400° F. In fact, the chief danger of fire is not that the oil may be ignited by any defect or arc within the transformer, but that a fire in the building in which the transformers are installed may so heat the oil as to cause it to take fire.

General construction.—The general construction of the coils and core is much the same in all three types, regardless of the method of cooling. All transformer coils are

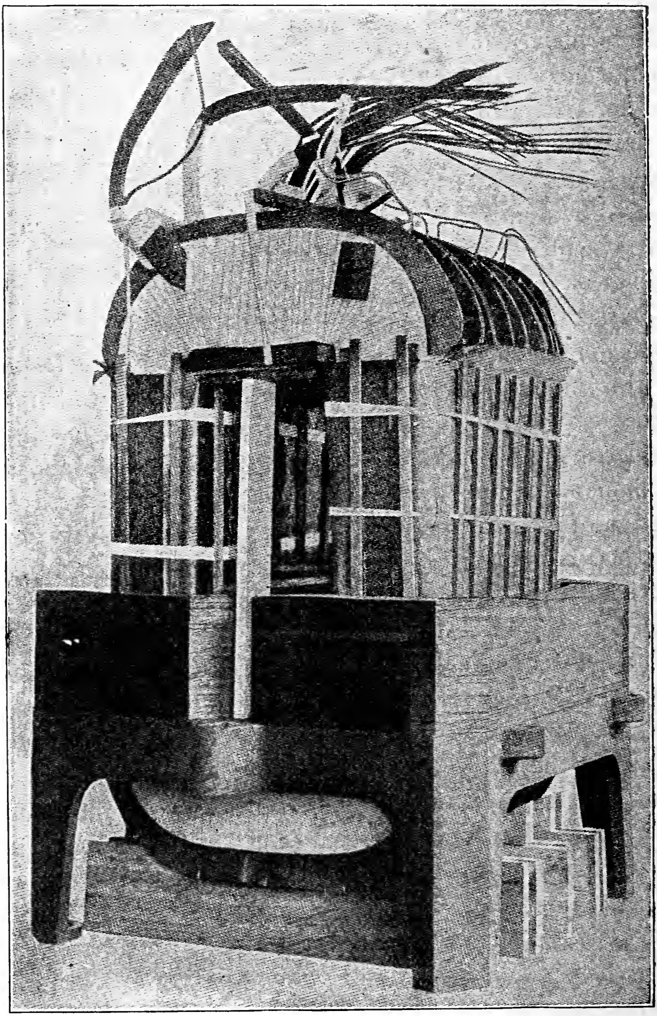


FIG. 595
PARTLY ASSEMBLED 25 CYCLE, 500 K. W., 20,000 TO 375 VOLT TRANSFORMER

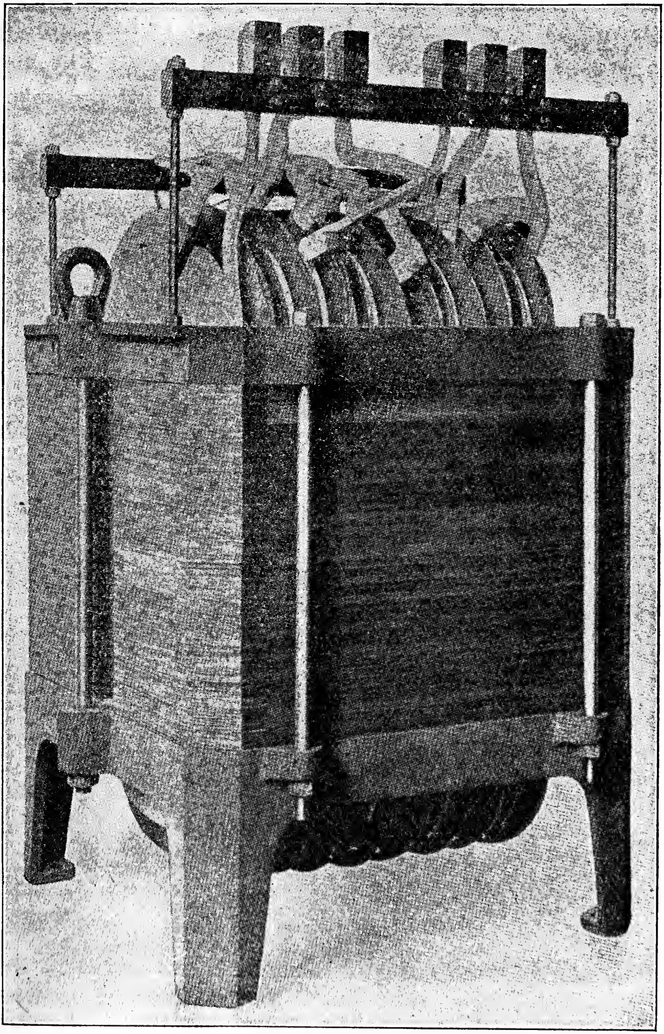
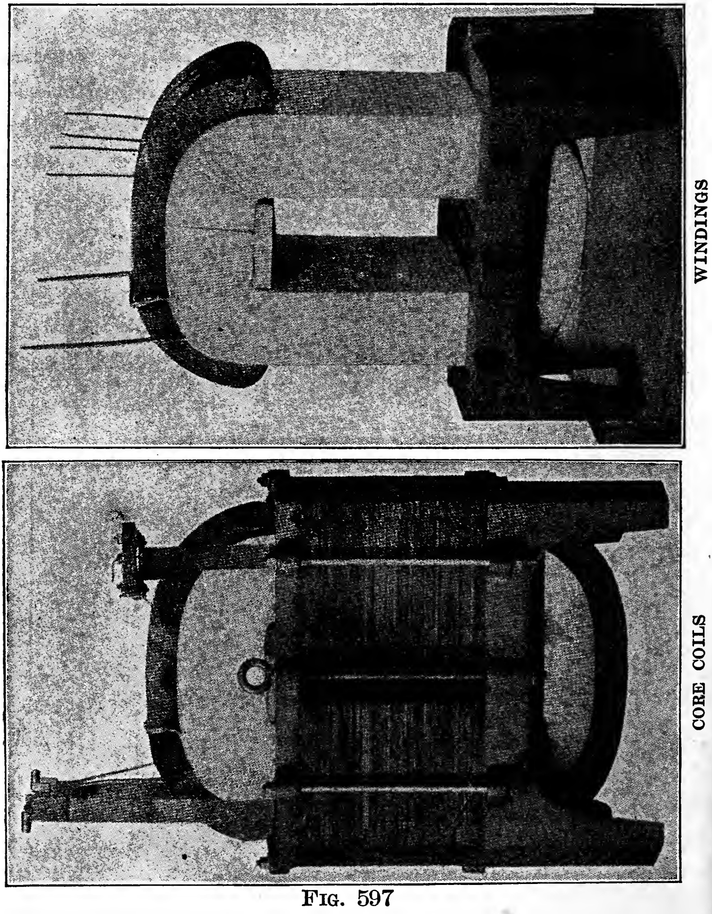


FIG. 596

CORE AND COILS, 500 K. W., 20,000 TO 375 VOLT TRANSFORMERS wound with double cotton covered strip copper, one turn per layer, with fullerboard insulation, in addition to the cotton covering, between turns. Exceptions to this construction are made only when the size of the conductor is such as to render the use of copper strip impracticable, and in such cases the coils are wound with round, double-cotton



WINDINGS

CORE COILS

Fig. 597

covered wire with few turns per layer, so that the voltage between the layers is kept within safe limits. The core is built up of steel sheets 0.0014 inch thick. In the larger sizes, space blocks are placed every few inches in the core, thus providing ducts through which oil can circulate and carry off the heat. Also, in assembling the coils, spaces are formed between the coil sections, and between the coils and core, so that all parts are in contact with a free circulation of oil. Fig. 595 shows a core partly built up and Fig. 596 core and coils completely assembled. Fig. 597 shows the windings and core for a transformer of smaller output.

ROTARY CONVERTERS.

Perhaps one of the greatest objections to the use of direct current is the inability to change its voltage without the use of moving machinery.

There is but one way to transform direct current and that is by a motor and generator.

This motor-generator set usually consists of a direct current motor driven by current at the pressure of the incoming line. This motor drives a direct current generator which furnishes current at the desired pressure.

By altering the strength of the field of the generator we regulate the outgoing pressure to suit the requirements.

The motor and generator are built on the same shaft, and set on a long cast iron base, making them mechanically one machine.

When the incoming and outgoing voltages can have the same ratio to each other always, a cheaper form of machine can be used called **a** Dynamotor.

This is a direct current motor running on the incoming voltages. On the same armature core is a separate winding connected to its own commutator at the other end of armature. The one set of field magnets serves for the motor winding and the generator or dynamo winding.

The Rotary Converter.—Combines in a single machine the functions of the two machines just described. In one sense it may be regarded as an alternating-current synchronous motor driving a direct-current generator, or if the machine be inverted, it may be considered a direct-current motor, driving an alternating-current generator.

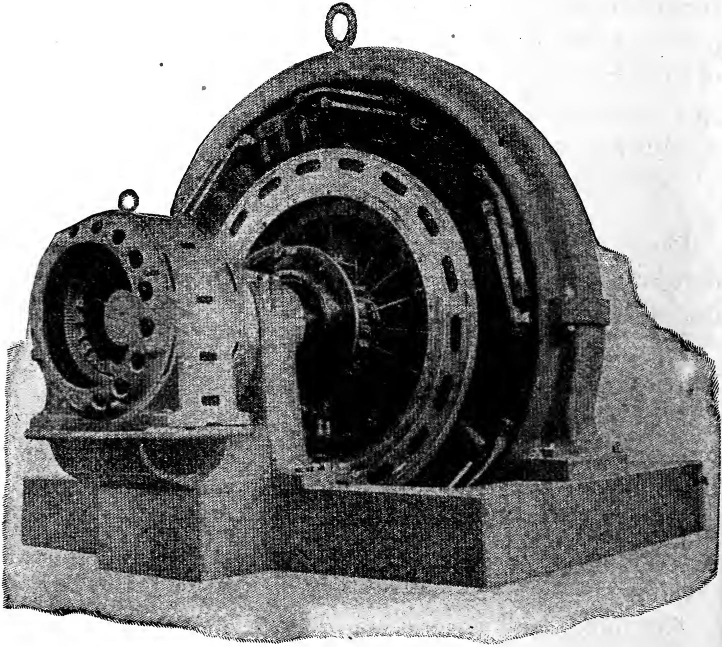


Fig. 598

WESTINGHOUSE 1,500 K. W. ROTARY CONVERTER

As direct current cannot readily be generated at, or transformed to a high voltage, which economical distribution dictates, alternating current is almost invariably used for all except very small electrical power transmissions. Wherever direct current is used, as in direct current railway lines, the alternating current must be transformed into direct current. While, of course, this can be accomplished by means of a motor-generator set, consisting of an alternating current motor connected to a direct current generator, the higher efficiency and lower cost of the rotary converter accounts for the almost universal practice of using it in preference to the motor-generator on low frequencies.

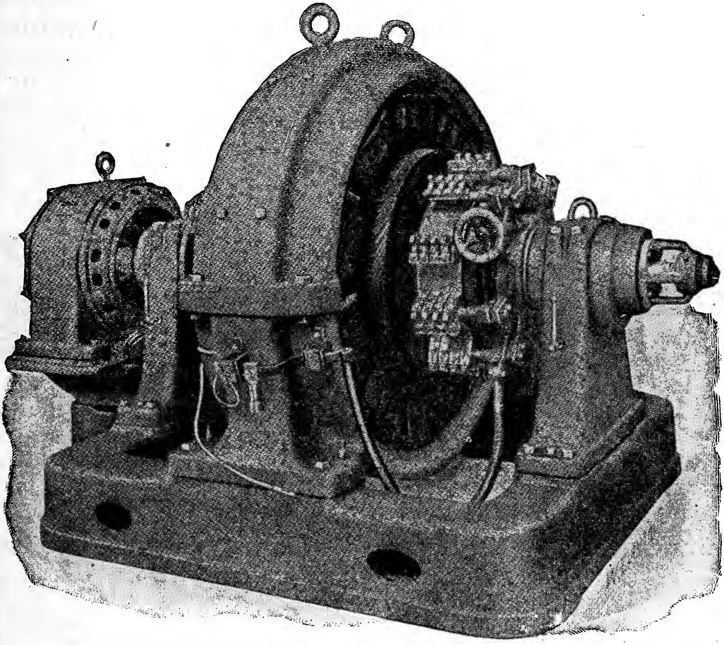


FIG. 599

WESTINGHOUSE 300 K. W. ROTARY CONVERTER, 600 D. C. VOLTS, 500 D. C. AMPERES, THREE-PHASE, 60 CYCLES

Rotary converters have many of the features which distinguish the most modern direct-current machines; the only material difference being the addition of collector rings connected to certain points of the armature winding. The number of such connections depends upon the number of poles and phases.

The machine is built for single-phase, two-phase, three-phase or six-phase circuits, although single-phase and six-phase converters are seldom desired. A two phase converter is provided with four collecting rings, and a three-phase converter is provided wth three collecting rings. As it is usually found expedient to transmit the alternating current at high pressure, transformers must be employed for lowering the potential to secure the proper direct voltage. Where the converter is operated from direct, to alternating current, transformers are usually employed to raise the voltage for transmission.

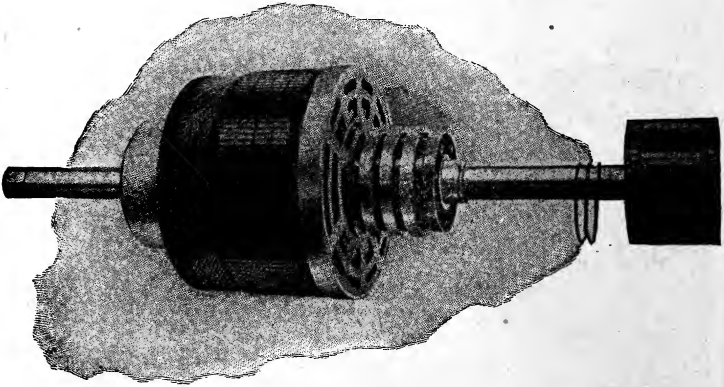


FIG. 600

WESTINGHOUSE ROTARY CONVERTER ARMATURE FROM THE COLLECTOR SIDE, 300 K. W., 550 VOLTS, THREE-PHASE

A rotary converter may be separately excited, but it is usually shunt wound, or compound wound, depending upon the nature of the service. When the load is variable, as in railway service, the machine is compound wound, which tends to maintain the direct current voltage constant, by compensating for the drop in the supply circuit as the load comes on. The ratio between the alternating and direct current voltages of a rotary converter depends upon the number of phases, upon the wave form of its alternating current, upon the lead given to the direct current brushes, and to a slight extent upon the field excitation. In any given converter, therefore, the direct current voltage depends practically upon the voltage of the alternating current applied. To a smaller extent it depends upon the armature drop, which diminishes the voltage ratio in slight proportion with the load when running A. C. to D. C. and increases the ratio when running D. C. to A. C. This will be easily seen by referring to a saturation curve.

With a sine wave the ratios of conversion are approximately as follows:

Single Phase,	Two Phase,	Three Phase,	Six Phase,
.71	.71	.61	.71 or .61

Thus if the D. C. voltage be 550 volts, the A. C., if two-phase, will be .71×550=390 volts, and if three-phase, it will be .61×550=335 volts. The ratio of conversion in the six-phase is .71 with the star connection, or .61 with the double delta connection.

The variations from these figures with wave forms in commercial use are taken into account in the ratios of the transformers used in connection with the rotary converters.

The rotary converter built by the Westinghouse Company presents in its frame the same mechanical features as are found in its well-known line of direct current machines. The machine is of the multipolar type, havng laminated steel poles, cast, or bolted to its iron yoke, and carrying easily removable field coils. If the windings are compound, the series, and shunt coils are insulated separately. The armature is of the slotted drum type, with either a two circuit, or multiple type of winding. The number of poles in a rotary converter is dependent upon the speed of the armature and the frequency, as is the case with all alternating current machinery.

This feature accounts for the difficulty in designing rotary converters for high frequencies, as the maximum armature speed is limited by the maximum safe speed of the periphery of armature and commutator. With a given speed, however, the number of poles is proportional to the frequency, and with a given maximum speed of armature and commutator periphery, the distance between adjacent poles, and therefore adjacent brush holders, is inversely proportional to the frequency. With high voltage 60-cycle converters, these facts necessitate high commutator speeds, short distances between poles, and between brush holders,

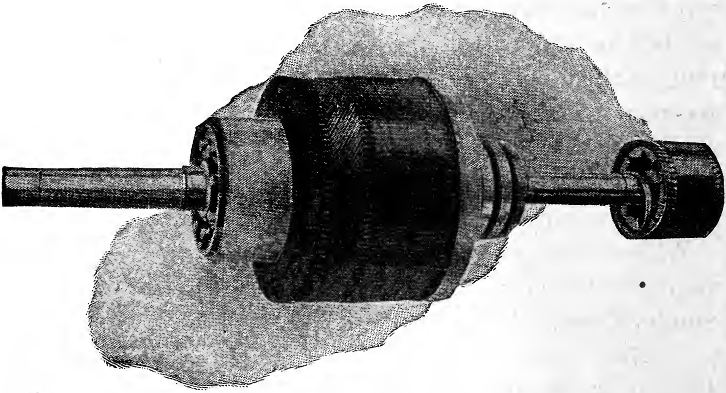


Fig. 601

WESTINGHOUSE COMPLETE ROTARY CONVERTER ARMATURE FROM THE COMMUTATOR SIDE, 300 K. W., 550 VOLTS, THREE-PHASE narrow commutator segments, and a high voltage between adjacent segments; resulting in a tendency to flashing over between brushes at sudden overload.

This should always be borne in mind when choosing the frequency of a system on which rotary converters are to be used, and it applies particularly to 500 and 600 volt railway rotary converters, which are required to withstand much more severe service than is ever experienced on lighting systems.

In the erection of a rotary converter the following considerations should, as far as possible, be observed:

First. It should not be located in a position where it would be exposed to moisture, as drippings from pipes, or escaping steam.

Second. It should not be exposed to dirt or dust, especially from coal.

Third. It should be located in as cool and well ventilated a place as possible. The temperature of the machine depends upon the temperature of the air surrounding it.

Fourth. It should be so located as to allow easy access to the alternating current brushes, and also to the commutator. These are the parts requiring special attention. Rotary converters should be set on substantial foundations in order to prevent vibration when running.

The following list of instructions refer more particularly to Westinghouse machines, but much of it will apply to others.

Insulation of Frame.—Whether the frame should be insulated from the ground is a matter to be determined by the engineer in charge of the plant, but rotary converters are usually not insulated. However, the following remarks which apply to alternating practice, may not be amiss: Generally speaking, the strain on the insulation of the windings will be decreased, and the danger to the attendant increased by insulating the frame. When, however, it is considered advisable to insulate the frame, the foundation should be capped with a strong wooden frame bolted down. The bolts which hold this frame to the masonry should not come in contact with those which hold the machine to the frame, nor should any metal, or electrical conductor unite the two sets of bolts.

The wooden insulating frame under the machine may also be covered with some insulating waterproof paint or compound.

Erection of Machine.—When placing the parts of a machine in position the following points should be observed:

(1) Set the lower half of the field in position and place the armature in its bearings, having first carefully examined the bearings and oil wells to be sure that they are clean and free from dirt. Be sure that the oil rings are in place and in good running order.

(2) Clean the contact surfaces of both halves of the field and file off the burs, if any exist, to secure perfect magnetic joints at the division of the yoke.

(3) Set the upper half of the field in position and secure it to the lower half by means of the field bolts and feather keys.

(4) Note that the machine is to be perfectly level along the axis of the shaft, except that when an oscillator is attached the machine is placed slightly out of level, as will be pointed out later.

Armature.—Never try to support any of the weight of an armature by the commutator or collector rings. Do not allow these parts to rest on any blocking, and do not pass a rope around them for the purpose of lifting. When handling the armature always support it with a rope slung about the shaft, and be careful not to mar or scratch the shaft, as any roughness would cause it to cut the bearings and so produce heating when the machine is running.

In putting the armature in the field be careful not to scratch the bearings, nor to bend the oil rings.

Coils. Assembly or field coils.—The field coils of the larger machines are shipped separately. The coils are held on the poles by the dampers, which should be bolted to the pole pieces. The coils on each of the separate halves of the field should be properly connected before the machine is set up.

Each pole piece has a number stamped with steel stencil and also painted in red, and a red line is drawn parallel and near to one edge of the pole. This line and number correspond to similar marks inside the coil. In erecting, place the coils on the poles so that the marks coincide.

If a rotary converter has been exposed to dampness it may be dried out by employing one of the following methods:

(1) Short-circuit the field and apply to the collecting rings about 10 per cent of normal alternating current voltage, which may usually be obtained from the lowering transformers. During this application the D. C. brushes must be raised and the rotary must be at a standstill. The standard Westinghouse transformers are usually provided with taps, between which a low voltage may be obtained.

(2) Run the rotary converter, driving it by a suitable motor, and short-circuit the armature on the direct current side with very weak field excitation. If shunt wound, separate excitation at very low voltage must be used. If the converter be compound wound, the armature may be short-circuited through the series field coils. As rotary converters are usually very sensitive as series machines this

method should be undertaken only by those who are thoroughly experienced, as there is danger of excessive current.

(3) Dry the field coils from a source of separate excitation, with about two-thirds of the normal D. C. voltage. This will also dry the armature somewhat. While drying out, the temperature of the accessible parts should be watched closely, and not be allowed to exceed 75° C.

In drying out with current there is always danger of overheating the windings, as the inner parts may get injurously hot because they cannot quickly dissipate the heat generated in them. Coils containing moisture are more easily injured by overheating than those which are already dry. Several hours, or even days, may be required for thoroughly drying out.

Repairs to Armatures.—The instructions pertaining to armature troubles, and repairs to commutators and other parts of electric generators, will also apply in the case of rotary converters.

Bucking.—Bucking is the expressive name given to the action of the rotary converter when arcing occurs between two adjacent brush holder arms, thereby short-circuiting the machine. Bucking is, in general, due to abnormally high voltage, or a path of low resistance over the commutator surface, or to abnormal commutation conditions. The poorer the commutation, the more liable will the machine be to buck whenever these abnormal operating conditions occur. Some of the particular causes for bucking are the following:

a) Rough or dirty commutator. A drop of water falling on the commutator has been known to cause the machine to buck.

(b) Excessive voltage due to increase in A. C. voltage.

(c) Excessive voltage due to static disturbances from lightning arrester short-circuits.

(d) Excessive voltage due to static discharge from or through lowering transformers. When bucking is due to this cause, it will usually occur when switching is done in the high tension circuits.

(e) Bucking may be caused by fluctuations in the voltage, due to the removal of a short-circuit.

In multiple wound rotary converters, balancing rings or cross-connections are employed as in direct current generators. These rings connect together points of equal potential around the commutator.

By this means the same field strength is obtained under each pole.

Oscillators.—The armature of a rotary converter revolving with its horizontal shaft will take up normally a fixed position relative to its bearings, and the frame of the machine, and revolve without any tendency to move or oscillate in the direction of its length. This is detrimental to its best operation as the brushes are liable to wear grooves in the commutator, and collector. It therefore becomes necessary to provide a means of producing a periodic movement of the armature in the direction of its length, and this function is performed by the oscillator.

There are two classes of oscillators, viz.: mechanical and magnetic. The mechanical oscillator employed by the Westinghouse Co. is described as follows:

This device is self-contained and is carried over one end of the shaft. The operating part consists of a steel plate grooved by a circular ball race in which travels a hardened steel ball. The steel plate is not quite parallel to the face of the end of the shaft. The normal position of the ball is at the lowest point of the circular race. The steel plate is backed by a spring.

The machine is leveled so that the armature is slightly inclined toward the oscillator. The steel plate is then adjusted so that when the ball is at its bottom position it just comes in contact with the shaft end. As the armature revolves the ball is carried up the race, and owing to the inclination of this race, compresses the spring. The reaction of the spring drives the shaft away. Thus the armature receives an impulse, which moves it toward the other limit of its travel, and it continues to move until the opposing forces bring it to rest and start it back to its normal position, where it again comes in contact with the ball, and the operation begins over again. Fig. 602 shows a diagrammatic view of the Westinghouse magnetic oscillator, of which

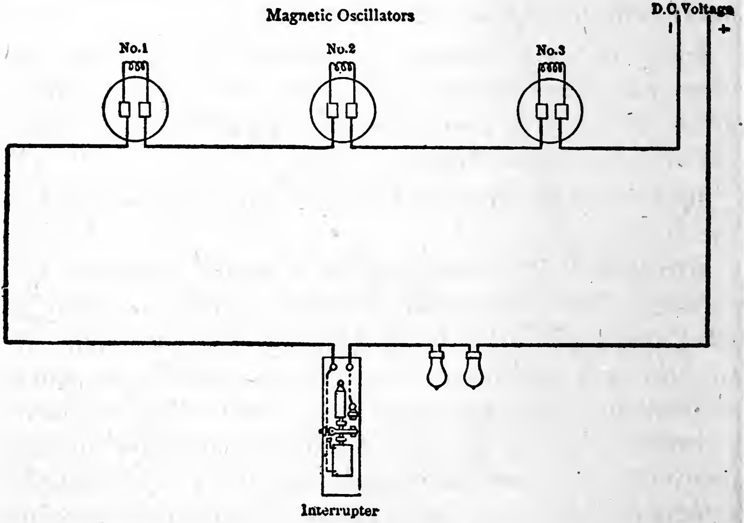


FIG. 602

DIAGRAM OF CONNECTIONS FOR MAGNETIC OSCILLATOR the following is a description. A magnet is mounted upon one of the bearing housings of the rotary converter in such a manner as to attract the end of the shaft. When the circuit is closed the magnet draws the shaft toward it and when the circuit opens, the armature tends to resume its normal position which is determined by the leveling of the converter. The magnet has in series with it a make and break device called an interrupter which is controlled by a dash-pot to secure the proper frequency of action.

As the dash-pot offers an adjustable resistance, the frequency of the impulses is adjustible. When there are a number of rotary converters in the same sub-station, the magnetic oscillators are connected in series, and controlled by a single interrupter.

Under certain conditions the commutator, and collector surfaces of machines provided with oscillators may be worn in irregular wavy grooves.

When this occurs it will then be necessary to turn down the commutator and collector.

QUESTIONS AND ANSWERS.

891. What is the function of a transformer?

Ans. To transform the current from a higher, to a lower voltage, or vice-versa.

892. What principles govern the action of a transformer?

Ans. The principles of electro-magnetic induction.

893. What is a step up transformer?

Ans. A transformer that raises the voltage.

894. What is a step down transformer?

Ans. One that lowers the voltage.

895. How are transformers cooled?

Ans. Small sizes by surface radiation. Larger sizes by oil; also by air blast. Some of the smaller sizes are cooled by water circulating through surrounding coils.

896. How is direct current transformed from one voltage to another?

Ans. By means of a machine called a motor-generator.

897. Describe in brief a motor-generator.

Ans. It consists usually of a D. C. motor driven by current at the voltage of the incoming line. This motor in turn drives a D. C. generator that furnishes current at the desired voltage.

898. How is the outgoing voltage regulated?

Ans. By altering the field strength of the generator.

899. In case the incoming and outgoing current can bear the same ratio to each other constantly, what kind of an apparatus is used?

Ans. A machine called a dynamotor.

900. Describe the operation of a dynamotor.

Ans. It is a D. C. motor running on the incoming voltages. On the same armature core is a separate winding connected to its own commutator at the other end of the armature. One set of field magnets serves for the motor winding and the generator or dynamo winding.

901. Describe in general terms a rotary converter.

Ans. It combines in a single machine the functions of a motor-generator, and a dynamotor.

902. Why are rotary converters and transformers necessary?

Ans. Because it is more economical to transmit alternating current at high voltages and transform, or convert it to the lower voltage at which it is used.

903. Give another reason for using rotary converters.

Ans. For the purpose of transforming alternating current into direct current when direct current is used.

904. What is the chief point of difference between a rotary converter and a direct current generator?

Ans. The rotary has collector rings connected to certain points of the armature winding.

905. What governs the number of such connections?

Ans. The number of poles and phases.

906. Describe the different types of rotaries.

Ans. They are built for single-phase, two-phase, three-phase or six-phase.

907. How many collecting rings has a two-phase converter?

Ans. Four collecting rings.

908. How many collecting rings has a three-phase converter?

Ans. Three collecting rings.

909. When alternating current is transmitted at high pressure, what means are employed for lowering the potential?

Ans. Transformers.

910. When the incoming current is direct and the outgoing current alternating, how is the voltage raised?

Ans. By step up transformers.

911. Describe the winding of a rotary converter.

Ans. It is usually shunt wound, or compound wound, although sometimes separately excited.

912. How are rotaries in railway service usually wound?

Ans. Compound, owing to variations in the load.

913. What advantage is gained by this method of winding?

Ans. It tends to maintain the D. C. voltage constant.

914. Upon what does the ratio between the A. C. and D. C. voltages of a rotary depend?

Ans. Upon the number of phases, the lead given the D. C. brushes, the wave form of its alternating current, and upon the field excitation.

915. Does the armature drop affect this ratio to any extent?

Ans. It does by decreasing it slightly when running A. C. to D. C. and increasing it when running D. C. to A. C.

916. What are the ratios of conversion approximately?

Ans.

Single-phase	.71
Two-phase	.71
Three-phase	.61
Six-phase	.71 or .61

917. Give an example illustrating above.

Ans. If D. C. voltage is 550 volts, the A. C., if two-phase will be 500×.71=390 volts, or if three-phase it will be 550×.61=335 volts.

918. What precautions should be observed in the erection of a rotary converter?

Ans. First—It should be protected from moisture. Second—It should be protected from dust or dirt. Third—It should be in a well ventilated room and kept as cool as possible.

919. Should the frame of the machine be insulated?

Ans. Generally speaking the strain on the winding insulation will be decreased, and danger to attendant increased by insulating the frame.

920. If a rotary has been exposed to dampness how may it be dried out?

Ans. By running it with about 10 per cent of the normal A. C. voltage, while at same time observing certain precautions noted in the text of this book under head of rotary converters.

921. What method should be pursued in caring for the commutator?

Ans. Wipe it off with a piece of canvas—never use waste. Lubricate it with a very small quantity of vaseline, or oil applied with a piece of cloth. See that none of the segments is at all loose.

If it gets out of true turn it down.

922. If a commutator gets hot while carrying only a normal load what should be done?

Ans. Heating under such conditions is an indication that the commutator is worn out, and should be replaced by a new one.

923. Give some of the causes of sparking at the brushes.

Ans. Brushes may not have proper lead.
Brushes may not fit commutator.
Brushes may be burned on end.
Commutator surface may be rough.

924. What is meant by a rotary bucking?

Ans. When arcing occurs between two adjacent brush holder arms, thus short circuiting the machine.

925. Name a few of the principal causes of bucking.

Ans. Rough or dirty commutator.
Excessive voltage.
Fluctuations in the voltage.

926. What is an oscillator, and what is its function?

Ans. An oscillator is a device operated either magnetically, or by mechanical means, and its function is to produce a slight, periodic movement of the armature shaft endwise.

927. Why is this endwise movement of the shaft necessary?

Ans. In order to prevent the wearing of grooves in the commutator.

928. What is meant by the hunting of a rotary converter?

Ans. It is a slight change of the speed of the armature.

929. What is the cause of hunting?

Ans. Irregularities in the speed of the generator delivering current to the rotary, thus causing a slight difference in the relative positions of the armature of the two machines, resulting in a change in the phase positions of the generator E. M. F. and the counter E. M. F. of the converter.

930. What are the usual methods of starting rotary converters?

Ans. First—By a separate A. C. starting motor.

Second—By applying direct current to the commutator. This starts the converter as a shunt motor.

Third—By applying alternating current directly to the collector rings. This starts the converter as an induction motor.

931. What is meant by synchronizing a rotary converter?

Ans. Bringing it to the same frequency, the same phase, and the same voltage as the generator from which it is receiving current.

932. What method is employed to determine when the machines are in synchronism?

Ans. There are several methods, the most common one being by means of incandescent lamps connected in series with the two machines.

933. What is a synchroscope?

Ans. It is an instrument for determining when electrical machines are in synchronism.

934. What is an automatic synchronizer?

Ans. It is a device that will automatically synchronize two electrical machines; also connect a synchronized machine with the main by means of an electrically operated switch.

935. Name two important points to be looked after before starting a rotary converter.

Ans. First—See that both the A. C. and D. C. brushes are properly adjusted and that every thing is clear about the converter. Second—See that the switches on board are open on both the A. C. and D. C. sides, and that the resistance of the rheostat is all cut in the field circuit.

Oil Switches

As considerable space has been devoted to oil switches, the subject will be continued still further by a brief explanation of the construction and operation of this type of switches, and also of oil circuit breakers. The principle of construction is shown in Fig. 603. On the right and left hand are two metallic rods which descend through insulating blocks, and carry springs at their lower end projecting therefrom. Another metallic rod descends between these two, and carries a cross-piece at its lower end, having beveled carbon contacts C. C. facing upward. This rod moves up and down through an insulating block, and it is connected to one lead of the circuit, while both side rods are connected

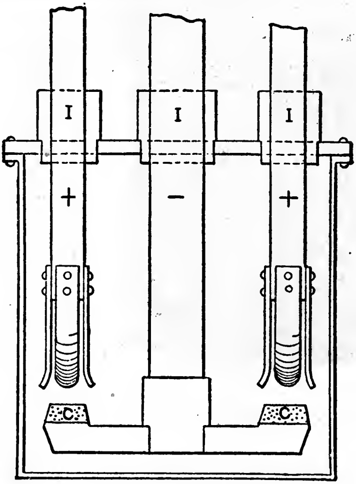


FIG. 603

to the other. When the central rod is raised the carbon blocks C. C. enter between the springs and make the contact, closing the circuit. When lowered it opens the circuit. Thus far the action of the switch is similar to the ordinary switch, but in order to prevent the formation of arcs, and to insure definite action in the opening or closing of the circuit, the lower portion of the mechanism is immersed in oil contained in a tank which is shown in section in the diagram

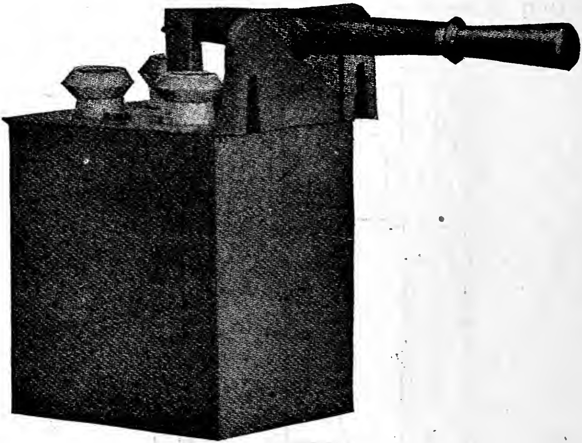


Fig. 604

TYPE I WESTINGHOUSE OIL SWITCH

Fig. 603. Oil switches are made in many different styles, but the one feature of the complete submersion of all live parts in oil, governs all. They are also as a rule held in the open position, either by gravity or by special locking mechanism consisting of a safety catch that holds the switch open until released by pressure of a button in the end of the operating handle.

The development of the oil switch, and circuit-breaker has produced what is probably the most valuable addition to high-potential line apparatus made during the last ten years. It is indeed likely that the development of high-tension transmission of power would have been very seriously hampered but for the invention of the oil switch.

This use of oil has made it possible to rupture easily and safely, circuits carrying heavy currents at high voltage and, further, to open these circuits under conditions of short circuit. The possibility of opening high-tension circuits under conditions of heavy overload has made possible the development and application of the present system of relays.

Fig. 605
TYPE D WESTINGHOUSE OIL SWITCH

By means of these relays, used in connection with oil circuit-breakers, perfect protection can be secured for the apparatus to which they are applied.

The term "switch" is given to those pieces of apparatus in which the contacts are similar to the ordinary switch, and are opened and closed by hand. Devices in which the contacts tend to separate, and are only held in a closed position by means of triggers and toggles are called "circuit-breakers."

The Westinghouse oil switches are essentially knife switches immersed in oil, the blades being connected to a common operating lever by specially treated wooden rods. The knife-blade contacts are used, as they give the most perfect contact and therefore the lowest temperature rise.

Fig. 604 shows a Westinghouse type I oil-switch for switchboard use only. Fig. 605 shows the type D Westinghouse oil-switch for outdoor service, the casing being moisture proof, and the leads brought out underneath through sealed bushings as shown. Fig. 606 shows the same switch with the oil tank removed. Fig. 607 shows the Westinghouse type B oil circuit-breaker, designed for potentials from 3,300 to 22,000 volts, and currents from 300 to 1,200 amperes. This device is a double-break, oil circuit-breaker. It may be automatic or non-automatic, and may be placed on the back of the switchboard, or arranged for distant control through rods and levers.

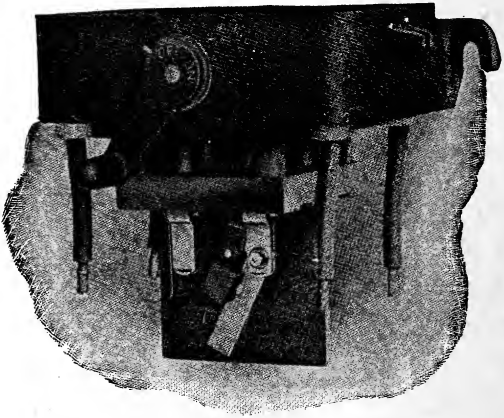


Fig. 606

Through a very simple system of levers, the operating handle is connected to a cast-iron cross bar, to which are fastened the movable contact arms. To the lower end of the wooden arm is fastened a metal yoke with a conical contact on either end. When the circuit is closed these contacts engage with two stationary contacts, forming one pole of the breaker. Each stationary contact is supported by a porcelain insulator, rigidly secured to the frame. The leads are brought to the terminals of the stationary contact within the insulator, forming an unbroken and continuous

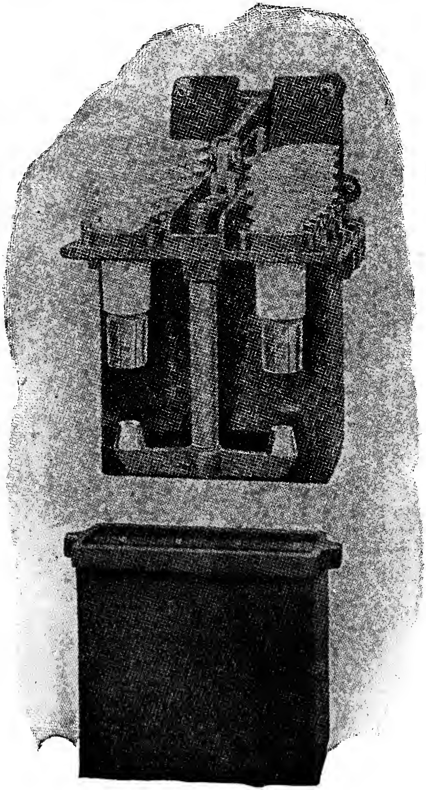


FIG. 607

TYPE B WESTINGHOUSE OIL CIRCUIT BREAKER

insulated conductor between the circuit-breaker, and the bus-bar or line. Each pole of the circuit-breaker has a tank in which its live metal parts are immersed in oil, each tank being entirely independent of the adjacent one.

These tanks have a lining so formed as to reduce the quantity of oil required and which serves as a barrier between the two stationary contacts, yet allowing ample space for the movement of the wooden arm and its contacts. The lining serves as an insulation, and reduces to a minimum all danger of the arc communicating through the oil. Any one of the tanks may be removed without interfering in any particular with the others. Fig. 608 shows the type E

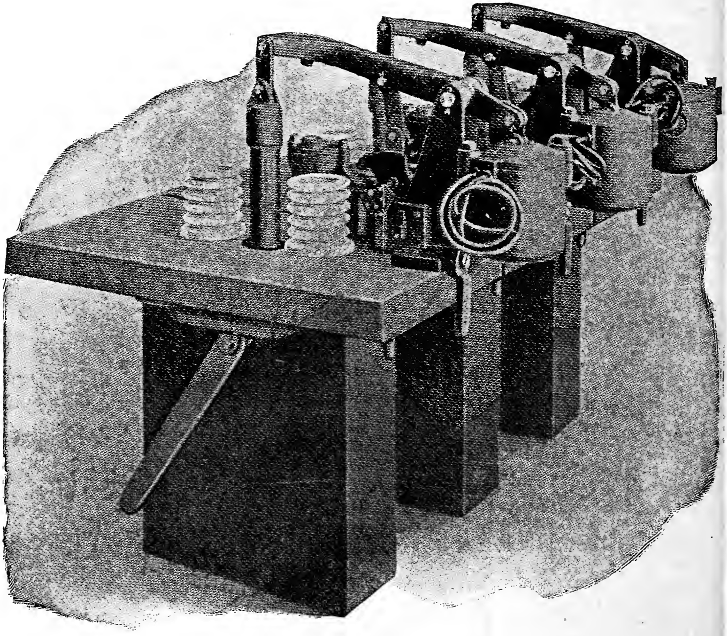


Fig. 608

TYPE E WESTINGHOUSE OIL CIRCUIT BREAKER

Westinghouse oil circuit-breaker, electrically operated. This circuit-breaker is also designed for high potentials, and heavy currents.

A simple system of toggles and levers is mounted on the top of the breaker, and a powerful electro-magnet is arranged with its movable core attached to the lever system, so that when it is drawn into the coil, the circuit-breaker will be closed. A small single-pole, double-throw switch is mounted on the breaker, and is operated by the motion of the levers in opening or closing the circuit; it controls the tell-tale indicator, and lamp which are mounted in view of the operator. These circuit-breakers are operated by 125 volts direct-current, and are calibrated for 3,000 alternations.

ELECTRO-METERS.

Galvanometers.—An electric current passing near a magnetic needle deflects the needle, and if the current is passed first over the needle and then back under it in an opposite direction, the needle will be still further deflected.

An instrument consisting of a coil of wire carrying the current to be tested, and a magnet; the two being so arranged that one can be deflected, is called a galvanometer.

There are two types, the Thompson and the D'Arsonval.

The Thompson type has the coil of wire stationary, and the light magnetic needle suspended by a silk thread. These can be made more sensitive than the other type, but are not portable, and external fields have a great influence on them. causing them to give false indications. This is prevented by thick soft iron cases, much too heavy to be carried around.

The silk suspension makes the needle sensitive to vibration.

It is a fine laboratory instrument, and with modified construction has been used in the workshop and field, but for this work the D'Arsonval is much better.

The D'Arsonval type has a very small, light coil of wire suspended by a fine bronze wire between the poles of a stationary magnet. Since the movable part is not a magnet except during the actual instant of the test, outside magnetic fields have no influence on its motion. To shield it during test, a thin soft iron or steel case is put on the instrument which does not affect its portability. These covers are usually copper, brass or nickel plated for appearance sake, but the actual material is iron for the purpose of shielding the instrument.

These D'Arsonval galvanometers are not so sensitive as the other type, which for ordinary work is a great advantage.

Both of these types have the needle swinging over a circular scale divided into degrees, or may have a small mirror attached so that the deflection may be read by the motion of a spot of light moving along a long ruler supported about a yard away from galvanometer.

As mentioned before, twice the current does not give twice the deflection, but by sending known currents through a galvanometer, and marking a scale with pen and ink we could make an ampere meter. This is called Calibration.

Ammeters and Voltmeters.—The ammeters and voltmeters of commercial work are all special adaptations of the D'Arsonval galvanometer or, for the least accurate work such as on switchboards; they are of the magnetic vane type.

The Weston instruments are D'Arsonval galvanometers.

Fig. 609 shows an instrument with the cover removed. A large permanent magnet of U shape is supported by a gun-metal casting screwed to the ends of the limbs, and

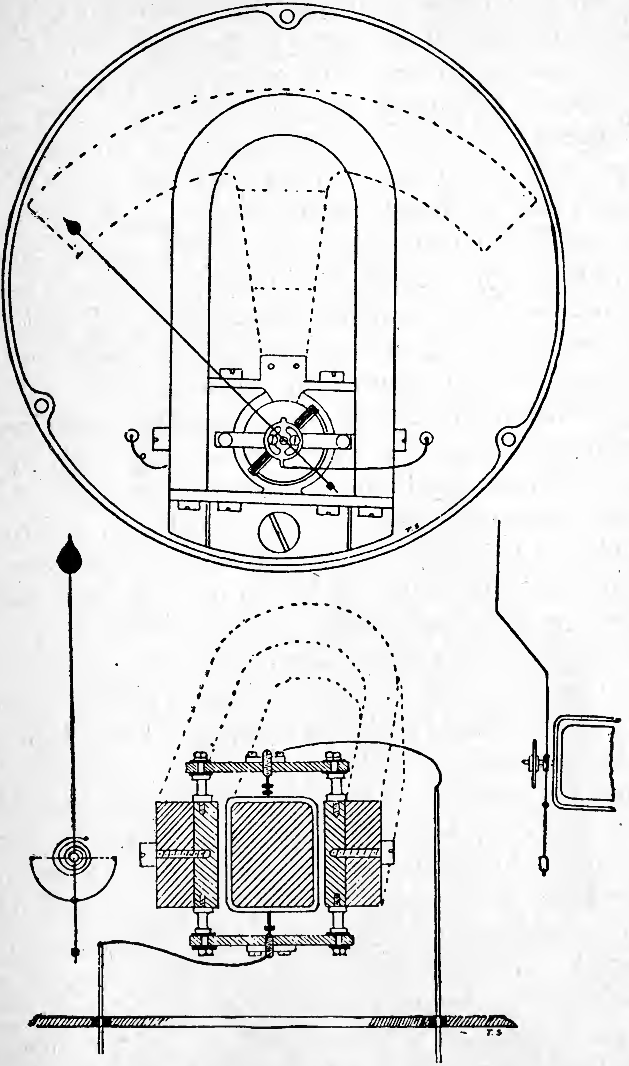


FIG. 609
INTERIOR OF WESTON INSTRUMENT

the whole of the working part is built up on this magnet independent of the case, so that the movement can be removed bodily from the case by simply taking out one screw which holds the gun-metal casting in place. The inside polar faces of the magnet are surfaced up so as to come closely into contact with wrought-iron pole pieces which are bored out to about 1 in. diameter, and fixed rigidly in their place with screws passing through the limbs of the magnet. To these pole pieces a second gun-metal casting is screwed, which forms a support for a soft iron cylinder ¾ in. diameter inside the bored out pole pieces, and also a support for the scale. The soft iron cylinder fills up most of the space between the pole pieces, allowing an air space at either side of ⅛ in., and in this space a fairly strong, uniform, magnetic field exists. A coil of fine insulated copper wire of about twelve turns is wound on a thin brass frame, large enough to embrace the soft iron cylinder, with freedom to move in the space between it and the pole pieces. This is pivoted in jeweled bearings which are screwed to the pole pieces, but insulated from them, forming little bridges across, and the ends of the coil are connected to these bridge pieces by spiral springs, one at the top and the other at the bottom of the coil, the springs being wound in opposite directions, so that when one is wound up by a movement of the coil the other is unwound. This arrangement corrects for any variation in temperature, for the effect on one spring would be counteracted by the opposite effect on the other. The coil normally lies at 45° to the line joining the poles of the magnet, and consequently the magnetic field created by a current in the coil will be displaced relatively to the field of the horseshoe magnet as shown in Fig. 610, and the lines twist the coil through a certain angle against the action of the spiral

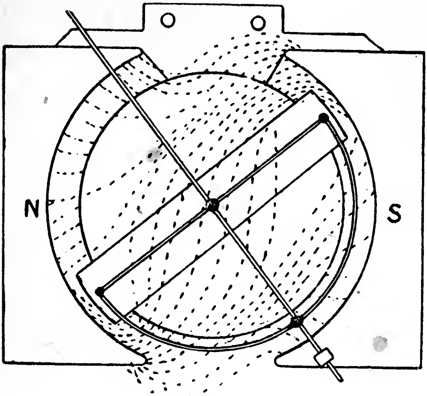


FIG. 610
DIAGRAM OF MAGNETS, FLUX, COIL AND INNER CORE OF WESTON INSTRUMENT

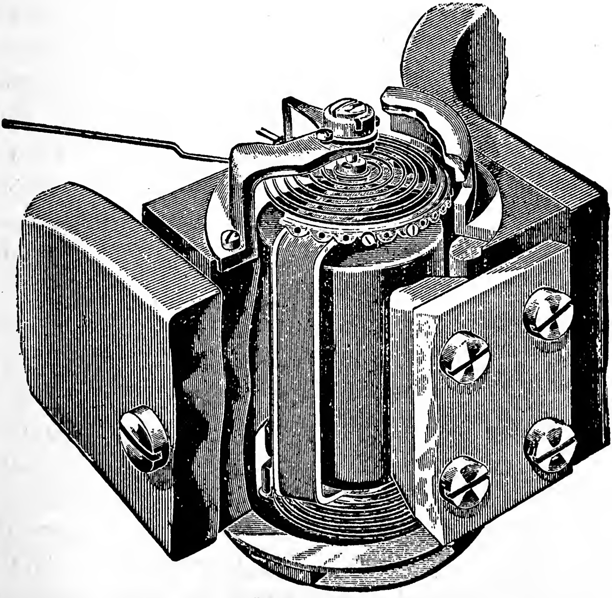


FIG. 611
VIEW OF MOVEMENT OF WESTON INSTRUMENTS

springs, the angular movement of the coil depending on the strength of the current in the coil and the strength of the field in which it is placed.

To the coil is attached a pointer of aluminum, the whole being balanced so that the instrument can be read in any position, and the pointer and scale are bent up so as to come near the front of the case.

A perspective view of the movement is shown in Fig. 611.

In this instrument the whole current does not go through the coil, but only a small fraction of it. The main part of the current crosses from one terminal to the other by a broad strip of metal under the base of the instrument, while the coil is placed as a shunt across the terminals, or as a conductor in parallel with the metal strip (Fig. 612), and consequently the ratio of the currents in the strip and in the coil will be inversely proportioned to their resistances. Now with a given strength magnetic field due to the magnet and a given elasticity of the spiral springs, it will require a certain number of ampere turns in the coil to produce the full deflection on the scale. This can be secured by adjusting the resistance of the strip connecting the terminals so that the same movement will do for any instrument. Thus, suppose the instrument were required to read to a maximum of 10 amperes, and we required 1 ampere in the coil to give the maximum deflection, then the resistance of the coil must be 9 times that of the strip, so that the current will divide at the terminals, 9/10 going through the metal strip and 1/10 through the coil. If the instrument is required to read to a maximum of 100 amperes, then the metal strip must have 99 times less resistance than the coil, and the current will then divide at the terminals, 99/100 going through the strip and 1/100 going through the coil, which will give a reading to the full range of the scale as before. By the arrangement of the pole pieces, and wrought iron cylinder the field due to the permanent magnet is practically uniform over the range of movement of the coil, and so the scale readings are the same size throughout. Should the permanent magnet vary in strength, the instrument would not read correctly, but the magnets are so treated that the falling off in strength over a number of years is inappreciable.

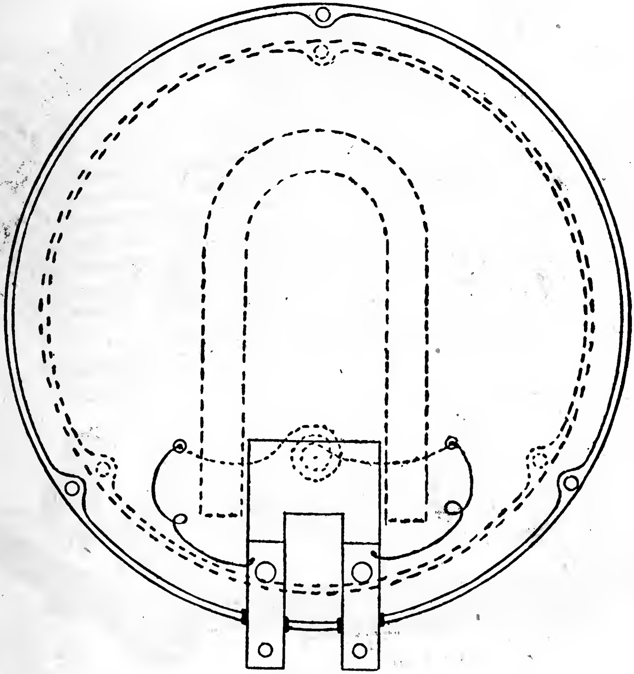


FIG. 612

MAGNET AND SHUNT OF WESTON AMMETER

The strip or shunt for portable instruments is always inside the case, while for switchboard instruments the shunt is too large (Fig. 613) and is placed separately on the back of the board. Leads are run along the board to the meter terminals which project through holes in the board from the meter which is in front.

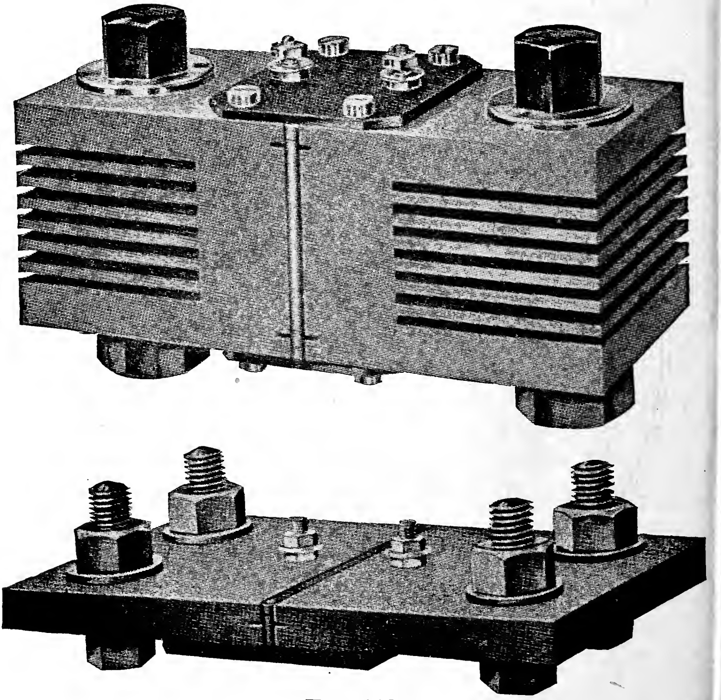


Fig. 613

EXTERNAL SHUNTS FOR AMMETERS. 1000 AND 5000 AMPERE SIZES

Such a switchboard instrument is shown in Fig. 614 and Fig. 615.

A Voltmeter is made by removing the metal strip or shunt connecting the terminals and placing a resistance coil in series with the moving coil.

As it takes 1/100 amperes to swing the pointer over full scale for every volt the instrument reads, it must have 100 ohms in the resistance coil.

A 500 volt instrument will have 500,000 ohms resistance, and hence 1/100 amperes will flow through the moving coil.

The moving coil is wound on a copper, or aluminum frame, which when it swings has current induced in it by the magnets and stops vibrating very quickly; in fact, you cannot detect any vibration. The needle seems to move to a certain spot and stop dead. This is called a "dead beat" needle.

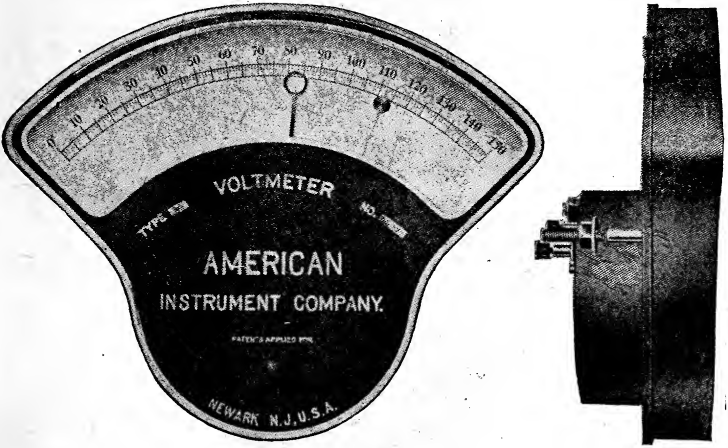


Fig. 614
SWITCH BOARD INSTRUMENT

Some instruments have electro-magnets instead of permanent magnets. The Thomson Astatic instruments are of this type. Two of these instruments are shown in Figs. 615 and 616. This latter has a scale or dial of opal glass with an electric light behind it. This makes the instrument easily read from a distance or at night. These are called "illuminated dial instruments."

Fig. 615

SWITCH BOARD AMMETER

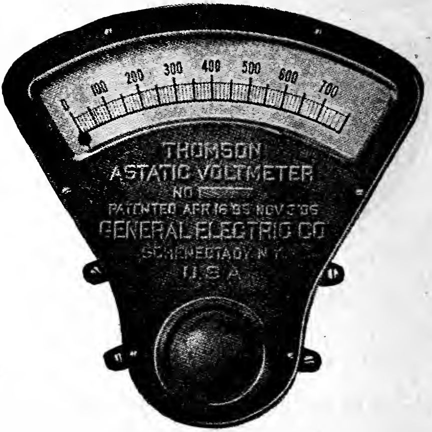


Fig. 616

ILLUMINATED DIAL INSTRUMENT

The instrument shown in Fig. 614 has an extra hand ending in a ring. This can be set at the voltage it is desired to maintain. The most hasty glance will then show whether the voltage is too high or too low.

In order to save space on switchboards some instruments are made thin and broad and are set horizontally or vertically.

Fig. 617 shows the exterior and interior of a Thomson Edgewise Ammeter.

The Thomson Inclined Coil instruments as shown in Fig. 618 are portable instruments used for alternating current only. In an emergency they can be used to measure direct current by reading, then reversing current, reading again, and averaging results.

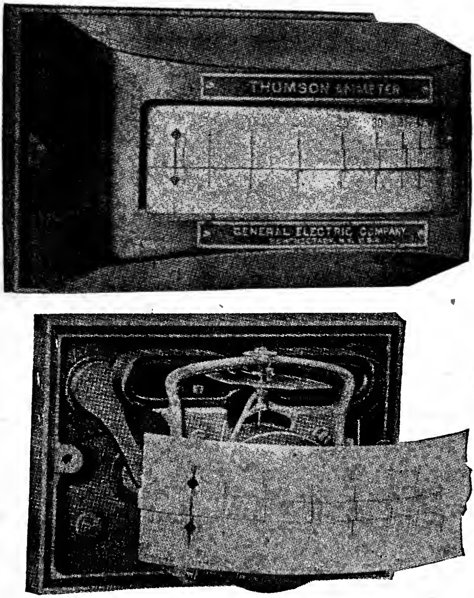


FIG. 617

THOMSON HORIZONTAL AMMETER

The action of the magnetism of the inclined coil is to twist the inclined sheet iron vane "a" around to the dotted line position.

The Weston instruments described are for direct current only. The company makes an alternating current voltmeter but no ammeter. Thomson Astatic instruments are for direct current. The Thomson Inclined Coil in portable, or edgewise switchboard form is for alternating current.

Wattmeters.—By combining two coils, one movable, the other stationary, one attached as a voltmeter with series resistance, the other attached as an ammeter, with a shunt, we get an instrument whose needle indicates power or watts. These are called indicating wattmeters.

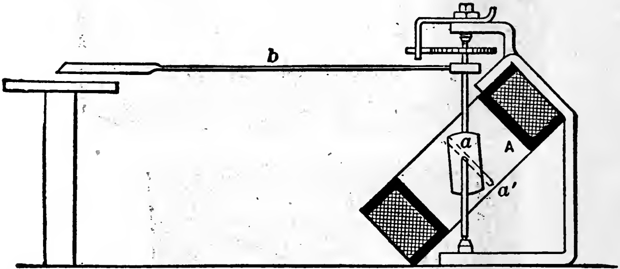


FIG. 618

THOMSON INCLINED COIL INSTRUMENT

The recording wattmeter records watt-hours. A watt-hour is one watt of power used for an hour, or any combination like one-quarter of a watt for four hours, etc.

The Thomson Recording Watt-Hour Meter is used for direct, or alternating current. It is shown with dust-proof case removed in Fig. 619. The connections made to it are shown in Fig. 620. By "lights" in the figure must be understood any load at all.

The meter consists of an electric motor whose armature A, Fig. 620, is supplied with current from the mains through a high resistance P in the back of the instrument, and a small field coil on right-hand side.

This armature is in shunt across the circuit, hence its current is proportional to the voltage.

The main current passes through the field F, hence the strength of the field is proportional to the current.

The speed of the motor is therefore proportional to both current and voltage, that is to the power, or watts.

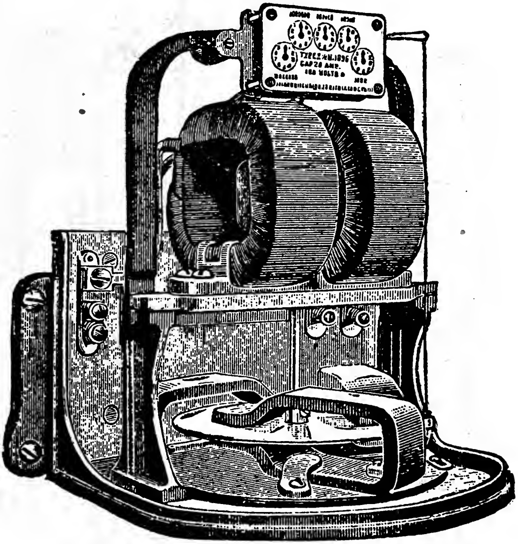


FIG. 619

THOMSON RECORDING WATT-HOUR METER

The armature shaft goes on past the commutator, to a cyclometer with dials like a gas meter. The revolutions are here recorded as watt-hours.

The auxiliary field is just strong enough to nearly overcome the friction in the bearings and cyclometer, so that the smallest current through the mains will produce rotation.

At the bottom of the armature shaft is an aluminum disc revolving between the poles of permanent magnets.

This device prevents the meter from running at too great a speed and gives an adjustment for accuracy.

The further out the magnets are swung the faster is the motion of the metal passing between their poles, and the greater a retarding effect they produce.

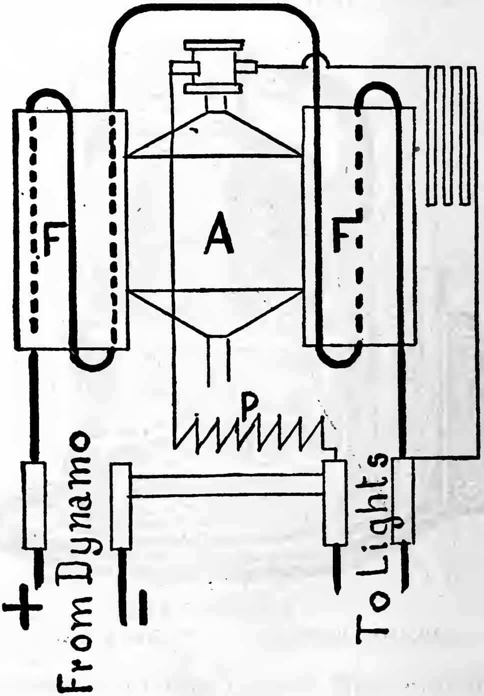


FIG. 620

DIAGRAM OF CONNECTIONS. THOMSON RECORDING WATT-HOUR METER

A meter running too slow from age, or dirty bearings could be brought up to proper speed by swinging the magnets in a little.

For heavy currents the appearance of the meter is quite different, as is shown in Fig. 621. The retarding device is enclosed in a case, and the whole instrument is enclosed in a dust-proof glass case.

Switchboard Maintenance.—The increasing relative cost of switchboard apparatus in power plants justifies more thorough inspection on the part of attendants than at present obtains in many installations. There is a feeling in some quarters that if a switchboard is blown out every day with compressed air, and the instruments wiped with a dust cloth, nothing further in the way of inspection need be done until something goes wrong.

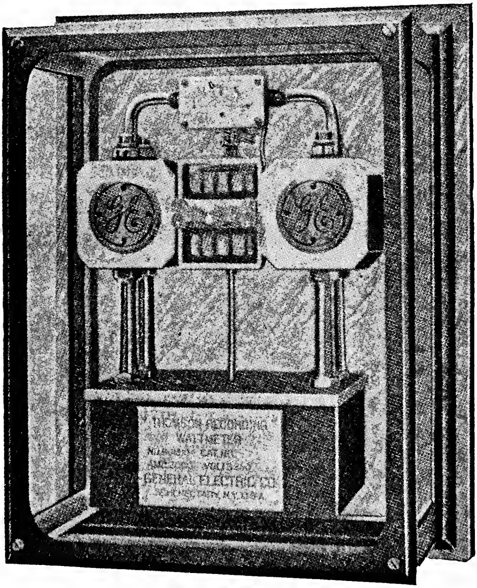


FIG. 621

LARGE CAPACITY THOMSON RECORDING WATT-HOUR METER

There are more moving parts on a modern switchboard than one would at first suppose, and a certain amount of attention is an essential of continuous reliable service. In addition to the indicating and recording instruments there are time limit relays, circuit-breaker controls, oil switch mechanisms and other contacts to look after, while the possibility of overheated parts of switches and coils is always present. Oil switches in operation should be inspected for overheating at least three times a day during the heaviest part of the load, and the binding posts of potential transformers, regulators and instruments should be looked after every two or three weeks with an eye to their becoming loose.

The oil tanks on oil switches ought to be dropped certainly once in three months, and the contacts carefully examined to locate any broken or bent springs, burned contacts or loose connections. When these contacts are cleaned with a file or in any way where there is a chance of personal connection with the wiring system, the utmost care is essential that current should be cut off, and high-potential contacts avoided. Knife switches for simple disconnecting work are worth many times their cost.

The solenoid equipment of time-limit relays are often neglected for long periods. The adjustment of these devices should be tested every two or three months and the contacts cleaned with the finest sandpaper or emery cloth. There is a tendency sometimes to forget that these relays are delicate apparatus. The adjustment of spring tension to hold contact pieces in place and the varnishing of solenoid plungers need to be carefully done. No little trouble can arise by careless varnishing of plungers so that they stick in one position and do not respond to the load variations above normal. Another point likely to be neglected is the care of the leather diaphragm on the relay bellows. This should be dressed with neatsfoot oil every two or three months to prevent it from becoming stiff and hard. Lightning arresters should always be examined and placed in condition after a storm; rheostat contact points, fixed and movable, carbon brakes and copper feeder and switch jaws all need regular inspection just as much as commutators, brushes and bearings.

LIGHTNING ARRESTERS.

Ordinarily a lightning discharge, which is an equalization of potential between the earth, and either clouds or saturated atmosphere above the earth, will take place through the path of least resistance, but, as pointed out by Rowland, there is a certain factor somewhat resembling inertia which causes the lightning, once started, to follow sometimes an irregular path, similarly, for instance, as when a piece of paper is suddenly torn. Transmission lines and buildings of ordinary height surrounded by trees are not peculiarly subject to damage from lightning, because they cover a comparatively small portion of the earth, and are surrounded by objects of greater height, which offer a better path for the lightning discharge to the earth. They do, however, receive some discharge, and the damage which might be done can be very great. It is therefore, necessary to provide ample protection.

Generally speaking, the severe manifestations of lightning are confined to a relatively small area, which rarely exceeds in extent an area of about one square mile. It may be concluded from this that protective apparatus situated at certain points along the line will afford no protection to remote points.

Generally speaking, the broad requirements for lightning protection consist in supplying paths to ground for any charge which might accumulate on lines, or machinery from any cause whatever. The ideal arrester will cause excessive potential differences to be relieved instantaneously, and stop the flow of current, as soon as the potential has fallen to safe limits for the line. No one type of lightning arrester fulfills all requirements, and accordingly it is found expedient to use different types and combinations, in different situations, and under different conditions.

For the protection of electric circuits, grounded guard wires are best, and when the cost over the whole system would prove prohibitive, they should be confined to such localities as are peculiarly liable to suffer destructive discharges. Three ground wires are required for the best practicable protection. One of these should be placed on top, and in the middle of the line, and should be a heavy galvanized steel cable, and the other two, which should be heavy telegraph wires, are placed outside, and above the top side conductors. The ground wires should be earthed at every pole for the first 10 or 12 poles from the building, and at every second pole on the rest of the line. Graded resistance, or aluminum type lightning arresters should be installed on every feeder issuing from the station, and on the primary and secondary of every transformer, and a surge protector in the station, but choke coils having a large number of turns should not be used in the station, as they represent a possible source of danger.

Where from internal causes, such as flashing over a bushing or insulator, the arcing ground sends a series of oscillations through the circuit, it is necessary to provide an arrester which will continue to discharge the abnormal voltage for a sufficient period to permit the operator to locate and isolate the trouble. Half an hour is generally found to suffice for the period of an arrester, as this will give time to discover the point of trouble, where this is remote from the station.

Horn arresters placed along the line at various places will do much to protect insulators from puncturing or arcing across. These horn arresters should be adjusted to arc at something below the wet arc-over voltage of the insulators, and should be connected to earth direct. Only one phase per pole should be protected by a horn arrester, so that in the event of two horns arcing simultaneously, the earth resistance can be utilized to limit the discharge. Ground wires should not be grounded at poles carrying horn arresters.

Lightning rods above wooden poles are an advantage. Graded resistance multigap, or aluminum arresters should be used on outgoing and incoming lines. Choke coils should be in the circuit just back of the arresters, which, in turn, are placed quite near the passages and are provided with disconnecting switches.

Multigap Arresters.—The general theory of the multigap arrester is as follows: When voltage is applied across a series of multigap cylinders, the voltage distribution is not uniform. The voltage distributes according to the capacity of the cylinders, both between themselves and also to ground, and the capacity of the cylinders to ground, results in the concentration of voltage across the gaps nearest the line. Fig. 622 shows the theoretical voltage gradient along an arrester. The voltage across the end gaps reaches a certain value. They arc across, passing the strain back to the other gaps, which in turn arc over until the spark has passed entirely across. The arrester in this manner arcs over at voltage much lower than would be required if the voltage distributed evenly. When the arrester has arced over, and current is flowing the voltage then does distribute evenly between the gaps, and is for this reason too low to maintain an alternating current arc. The arc, therefore, lasts only to the end of a half cycle, and then goes out. The maximum voltage per gap at which the arc will extinguish at the end of the half cycle depends to a great extent upon the metal of the cylinders. Thus some metals are more efficient than others in extinguishing the arc.

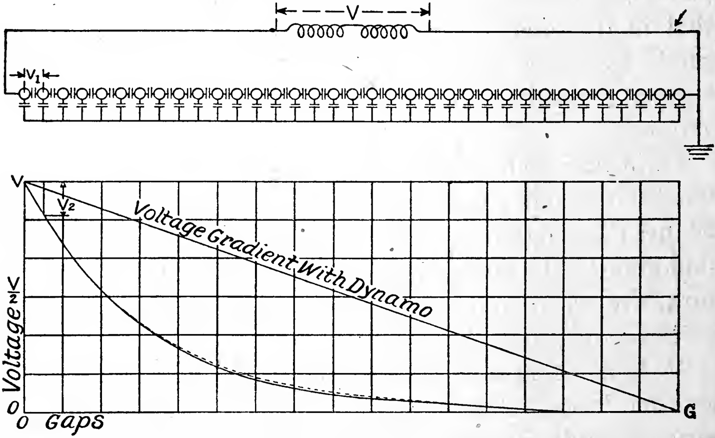


FIG. 622

LIGHTNING ARRESTER

When the voltage of an alternating current passes through zero, of course no current flows. Before the current flows in the reverse direction the voltage must again break through the dielectric. The voltage required to do this depends upon how much the dielectric has been weakened by the passage of the arc. The cooler the arc, the less the dielectric is weakened, and the higher will be the voltage required to reverse the arc. As the temperature of the arc depends upon the boiling point of the cathode metal, in very much the same way as the temperature of steam depends upon the boiling point of the water, metals with low boiling points are used for the lightning arrester cylinders, in order to keep down the arc temperature.

The use of resistance in a lightning arrester needs very careful consideration. Lightning does not readily pass through resistance, especially when in series with multigaps, and therefore series resistance should not be used. At the same time it is very desirable in some way to limit the current. This problem has at last been solved by use of a low shunt resistance, shunting a part of the gaps and so proportioned to divert the current from the gaps, after the discharge has passed the ground. Shunt resistance has been

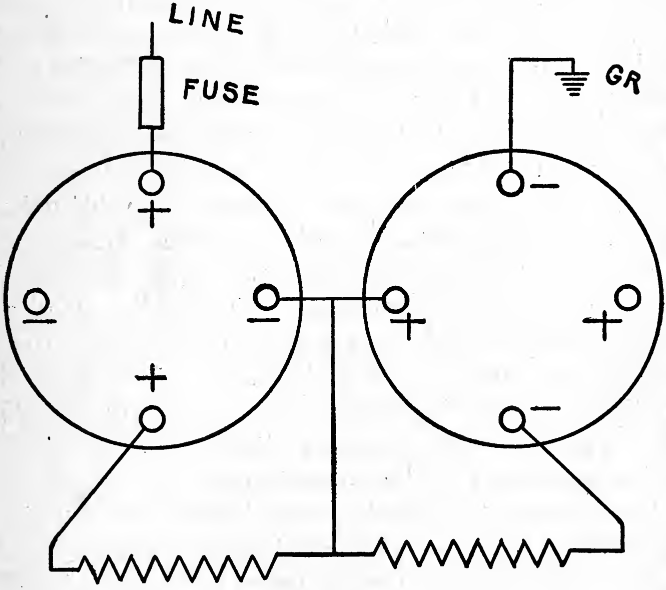


Fig. 623
STATION ARRESTER

used before, but never for this purpose, and was never made low enough to divert the arc in this way.

It is obvious, of course, that a discharge taking place through a high resistance will not relieve the line except in a case of the static. What happens, however, is something like this: When a surge of dangerous voltage rises, and before it reaches a danger point, the series gaps arc over. The series gaps then being practically short-circuited by the arc the voltage concentrates across the lowest division of the shunted gaps, and these at once also break down. The current is then limited by the medium resistance, and the voltage is concentrated across the second division of the arrester. If these gaps break down, the discharge is limited only by the low resistance, which should take care of most cases. If necessary, however, the voltage can "break back" in this way, and cut out all resistance. The number of gaps to rectify depends largely on the current that flows. In this arrester the number of gaps discharging increases as the limiting resistance decreases. The arrester will, therefore, operate and extingush the arc at the end of the half-cycle no matter which path the current takes.

Instructions for Installing 600 *Volt D. C. Aluminum Lightning Arresters.*—The principal elements of this arrester are two cells, each consisting of two concentric aluminum plates immersed in an electrolyte contained in a glass jar.

The outside plate of each cell should be the positive, and the inner one the negative, as indicated by the marking of the four studs on the porcelain cover, two studs supporting each plate.

In addition, station arresters are fitted with a balancing resistance in shunt with each cell and a series fuse; car arresters, with a series fuse as connecting link between the two cells. A diagram of connections is shown in Fig. 624.

To Fill the Arrester.—Unscrew the metal rings at the top of the jars and lift off the porcelain covers, with the aluminum plates attached, without removing the connection between the two units. Pour enough electrolyte into the jars to bring the level to about one inch from cover. Add 1/8 pint of oil to each jar.

In transferring the electrolyte, or oil from the carboy, or other container used for shipping, employ nothing but clean aluminum, or glass vessels and funnels. Take every precaution to prevent any dust or other material from getting into the electrolyte.

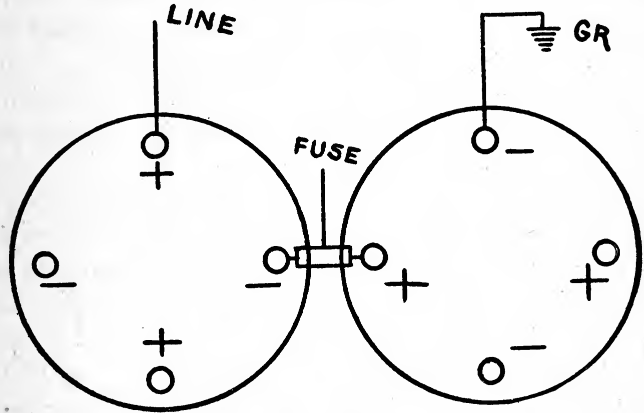


FIG. 624
CAR ARRESTER

Before connecting permanently to the circuit it is advisable to connect the arrester in series with five 120 volt incandescent lamps across the 600 volt circuit. The lamps will burn brightly for an instant and then rapidly diminish to darkness, thus indicating that the film is all right. If the lamps are dark at first, the circuit should be opened and closed, and a small snappy spark at the contact point will show that the circuit is complete and the film in proper condition. The lamps should then be removed and the cells connected directly to the circuit.

Connections.—These should be as short as possible between line and ground, and only to those points on which the terminals are placed when shipped. Use only the style of terminal furnished, as they afford no chance for a short circuit by swinging against the opposite terminal. In the case of pole arresters the test with series lamps, as described above, should be made before making the last connection, otherwise there may be a considerable flash due to an instantaneous current rush. The ground connection of these line arresters should be made directly to the ground bus, and driven pipe ground.

Operation.—If the arrester has stood assembled in its electrolyte for a month or more, when reconnected there will be a momentary rush of current which may amount to several hundred amperes. To avoid this current rush, use lamps in series as explained above.

It is preferable, however, when an arrester is to be left out of service for some time, to pour out the electrolyte and oil, wash the plates and jars with clean water and put the plates back in the jar. When replacing in service, make the usual test with lamps.

After operating for some time, arresters without balancing resistance, may divide the voltage unequally between cells, which is indicated by sparkling of the plates in one cell. In such cases the arrester should be removed from the circuit, and connected to a test circuit with a bank of five lamps in shunt with each jar; that is ten lamps from line to line with the middle point connected between cells. After operating this way for several hours remove the lamps. If sparkling has ceased, the arrester is ready to be placed in service.

After the arrester has been in operation for a short time, the electrolyte may become dark in appearance, but this condition is normal.

Inspection should cover answers to the following questions:

1. Are there any loose connections?
2. Is the level of the electrolyte at the proper height?
3. Are the positive plates worn off at the surface of the electrolyte?
4. Are the connecting leads as short as possible?
5. Does either cell sparkle?

Multigap Lightning Arresters for Alternating Currents.—These arresters, designed upon an elaboration of Prof. Elihu Thomson's fundamental patents, consist of a series of spark gaps shunted by graded resistances, but without series resistance. The advantages possessed by them are:

1. Uniform voltage discharge over a wide range of frequency due to graded resistance.
2. Shunting the dynamic current through resistance.
3. The "breaking back" action on low frequency surges.
4. Fuse in ground leg of non-grounded neutral systems.
5. Adjustable gap in each leg shunted by a fuse.
6. Metallic resistance rods of improved composition.
7. Durable knurled cylinders of special alloy.
8. General Electric standard multiplex connection.

When properly installed they will perform the following functions:

First. Prevent excessive rise of potential of a transitory nature between lines, as well as between lines and ground.

Second. Restrain the flow of electric current across the gaps, and extinguish the arc when normal potential is restored.

Third. Discharge high potentials covering a wide range of frequency.

The essential elements of the arrester are, a number of cylinders spaced with a small air gap between them and, placed between line and ground, and between line and line. In operation the multigap arrester discharges at a much lower voltage than would a single gap having a length equal to the sum of the small gaps.

In explaining the action of multigaps, there are three things to consider:

1. The transmission of the static stress along the line of cylinders.
2. The sparking of the gaps.
3. The action and duration of the dynamic current which follows the spark, and the extinguishment of the arc.

A spark may be defined as conduction of electricty by the air, and an arc as conduction of electricity by vapor of the electrode.

Distribution of Static Stress Along Cylinders.—The cylinders of the multigap arrester act like plates of condensers in series. This condenser function is the essential feature of its operation. When a static stress is applied to a series of cylinders between line and ground (Fig. 625), the stress is instantly carried from end to end. If the top cylinder is positive it will attract a negative charge on the face of the adjacent cylinder, and repel an equal positive charge to the opposite face, and so on down the entire row. The second cylinder has a definite capacity relative to the third cylinder and also to the ground; consequently the charge induced on the third cylinder will be less than on the second cylinder, due to the fact that only part of the positive charge on the second cylinder induces negative electricity on the third, while the rest of the charge induces negative electricity to the ground. Each successive cylinder, counting from the top of the arrester, will have a slightly smaller charge of electricity than the preceding one. This condition has been expressed as a "steeper potential gradient near the line."

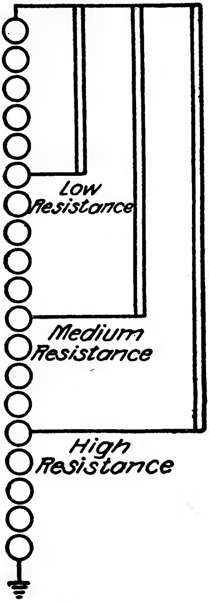


Fig. 625

ARRANGEMENT OF RESISTANCES

Sparking of the Gaps.—The quantity of electricity induced on the second cylinder is greater than on any lower cylinder, and its gap has a greater potential strain across it as shown by Fig. 626. When the potential across the first gap is sufficient to spark, the second cylinder is charged to line potential, and the second gap receives the static strain and breaks down. The successive action is similar to overturning a row of nine-pins by pushing the first pin against the second. This phenomenon explains why a given length of air gap concentrated in one gap requires more potential to spark across it, than the same total length made up of a row of multigaps. As the spark crosses each successive gap, the potential gradient along the remainder readjusts itself.

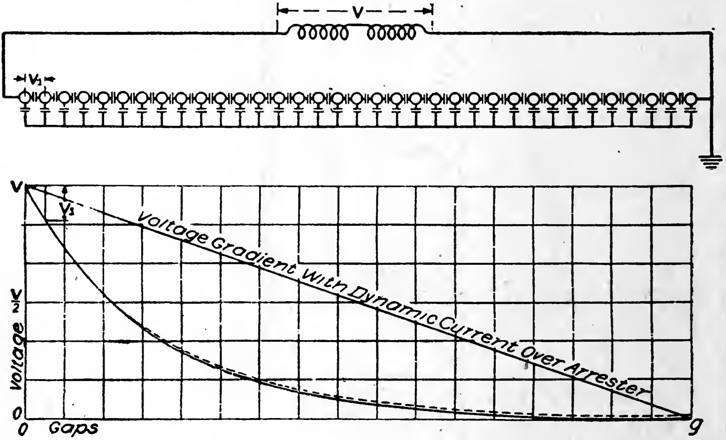


FIG. 626

DIAGRAM SHOWING CONDENSER ACTION OF CYLINDERS AND POTENTIAL GRADIENT FOR STATIC STRESS

How the Dynamic Arc is Extinguished.—When the sparks extend across all the gaps the dynamic current will follow if, at that instant, the dynamic potential is sufficient. On account of the relatively greater current of the dynamic flow, the distribution of potential along the gaps becomes equal, and has the value necessary to maintain the dynamic current arc on a gap. The dynamic current continues to flow until the potential of the generator passes through zero to the next half cycle, when the arc-extinguishing quality of the metal cylinders comes into action. The alloy contains a metal of low boiling point which prevents the reversal of the dynamic current. It is a rectifying effect, and before the potential again reverses, the arc vapor in the gaps has cooled to a non-conducting state.

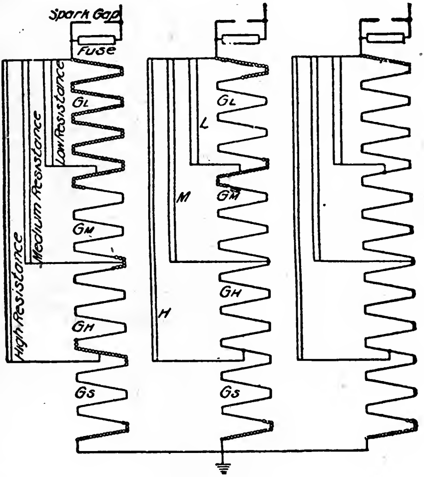


FIG. 627

CONNECTIONS FOR 33,000-VOLT Y SYSTEM WITH GROUNDED NEUTRAL

The Cumulative or Breaking Back Effect.—The graded shunt resistances (Figs. 627 and 628) give a valuable effect not brought out in the previous description, where the arrester is considered as four separate arresters. This is the cumulative or breaking back action.

When a lightning strain between line and ground takes place, the potential is carried down the high resistance, H, to the series gaps, GS, and the series gaps spark over. Although it may require several thousand volts to spark across an air gap, it requires relatively only a few volts to maintain the arc which follows the spark. In consequence, when the gaps GS spark over, the lower end of the high resistance

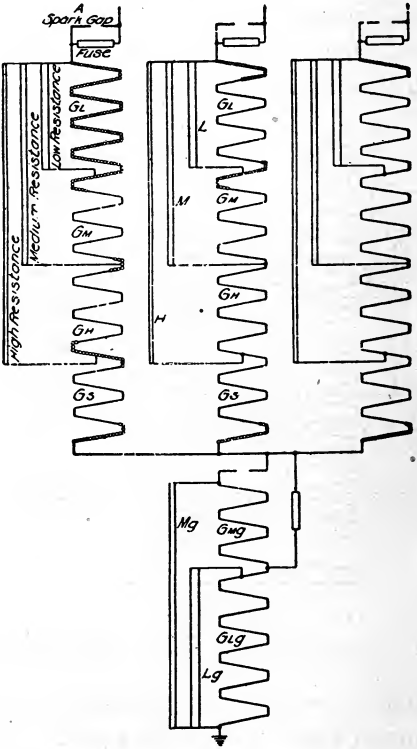


FIG. 628

CONNECTIONS FOR 33,000-VOLT DELTA OR UNGROUNDED Y SYSTEMS

is reduced practically to ground potential. If the high resistance can carry the discharge current without giving an ohmic drop sufficient to break down the shunted gaps GH, nothing further occurs—the arc goes out. If, on the contrary, the lightning stroke is too heavy for this, the potential strain is thrown across the shunted gaps, GH, equal in number to the previous set. In other words, the same voltage breaks down both of the groups of gaps, GS and GH, in succession. The lightning discharge current is now limited only by the medium resistance, M, and the potential is concentrated across the gaps, GM. If the medium resistance cannot discharge the lightning, the gaps GM spark, and the discharge is limited only by the low resistance. The low resistance should take care of most cases, but with extraordinarily heavy strokes and high frequencies, the discharge can break back far enough to cut out all resistance. In the last step the resistance is relatively low in proportion to the number of shunt gaps, GL, and is designed to cut out the dynamic current instantly from the gap, GL. The illustration (Fig. 631) of the 2,200 volt arrester shows that the low resistance actually performs this function. This breaking back effect is valuable in discharging lightning of low frequency, in a manner better than has been obtained before.

FIG. 629

"V" UNIT OF MULTIGAP LIGHTNING ARRESTERS

After the spark passes, the dynamic arcs are extinguished in the reversed order. The low resistance, L, is proportioned so as to draw the dynamic arcs instantly from the gaps, GL. The dynamic current continues in the next group of gaps, GM, until the end of the half cycle of the generator wave. At this instant the medium resistance, M, aids the rectifying quality of the gaps, GM, by shunting

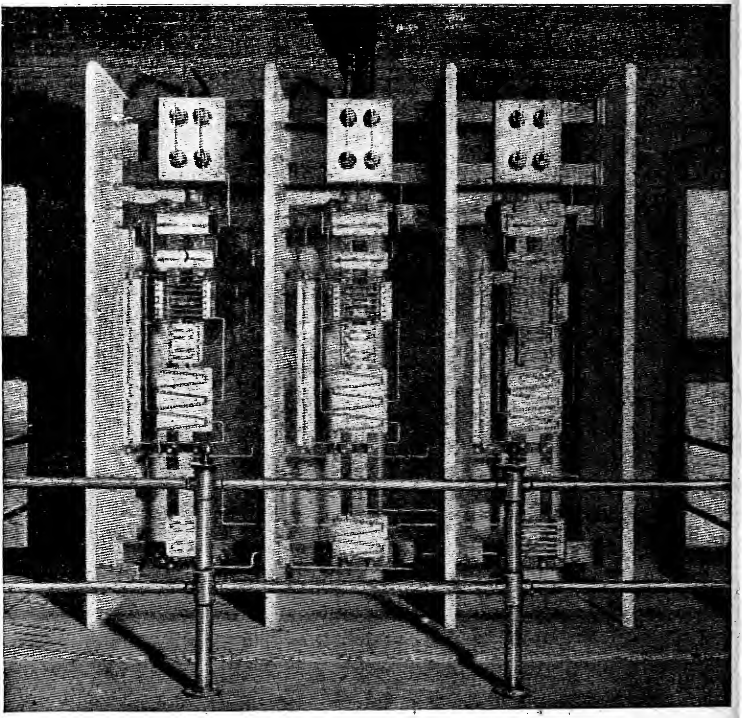


Fig. 630

INSTALLATION OF A 12,000-VOLT, THREE-PHASE, MULTIGAP LIGHTNING ARRESTER IN THE GARFIELD PARK SUB-STATION OF THE WEST CHICAGO PARK COMMISSION out the low frequency dynamic current of the generator. On account of this shunting effect the current dies out sooner in the gaps, GM, than it otherwise would. In the same manner, but to a less degree, the high resistance, H, draws the dynamic current from the gaps, GH. This current now being limited by the high resistance, the arc is easily extinguished at the end of the first one-half cycle of the generator wave.

"V" Unit for Multigap Arresters.—The High-voltage Multigap Arrester is made up of "V" units (see Fig. 629), each unit consisting of gaps between knurled cylinders, and connected together at their ends by short metal strips. The base is of porcelain, which thoroughly insulates each cylinder, and insures the proper functioning of the multigaps.

Cylinders.—The cylinders are made of an improved alloy that contains metal of low boiling point which gives the rectifying effect, and metals of high boiling point which cannot vaporize in the presence of the one of low boiling point. The cylinders are heavily knurled. As the arc plays on the point of a knurl it gradually burns back and when the metal of low boiling temperature is used up, the gap is increased at that particular point. The knurling therefore, insures longer life to the cylinder, by forcing successive arcs to shift to a new point. When worn along the entire face, the cylinder should be slightly turned.

Resistance Rods.—The low resistance section of the graded shunt is composed of rods of a new metallic alloy. These rods have large current-carrying capacity, and practically zero temperature coefficient up to red heat.

The medium and high resistance rods are of the same standard composition previously used. The contacts are metal caps shrunk on the ends; the resistances are permanent in value and the inductance is reduced to a minimum. The rods are designed with a large factor of safety, and have sufficient heat absorbing capacity to take the dynamic energy following transitory lightning discharges. They are glazed to prevent absorption of moisture, and surface arcing.

DIFFERENCE BETWEEN ARRESTER FOR GROUNDED Y AND NON-GROUNDED NEUTRAL SYSTEMS.

The connection for a three-phase arrester, 33,000 volts between lines, are shown in the illustrations (Figs. 627 and 628). One illustration (Fig. 627) shows the design for a thoroughly grounded Y system and the other for a non-grounded neutral system. The latter (Fig. 628) includes delta, ungrounded Y, and Y systems grounded through a high resistance.

The difference in design lies in the use of a fourth arrester leg between the multiplex connection and ground, on ungrounded systems. The reason for introducing the fourth leg is evident. The arrester is designed to have two legs between line and line. If one line became accidentally grounded, the full line potential would be thrown across one leg, if the fourth or ground leg were not present. On a Y system with a grounded neutral, the accidentally grounded phase causes a short circuit of the phase, and the arrester is relieved of the strain by the tripping of the circuit breaker. Briefly stated, the fourth or ground leg of the arrester is used when, for any reason, the system could be operated, even for a short time, with one phase grounded.

Multiplex Connection.—The multiplex connection consists of a common connection between the phase legs of the arrester above the earth connection, and provides an arrester better adapted to relieve high potential surges between lines than would otherwise be possible. Its use also economizes greatly in space and material for delta and partially grounded or non-grounded Y systems.

Fuse Auxiliaries.—The practice of introducing an auxiliary adjustable gap between each line wire and its corresponding leg of the arrester has been discarded in the new design, with marked increase in the *sensitiveness* of the arrester. As the gap is necessary, under certain abnormal conditions, it is left on the arrester, but short circuited by a fuse so that it comes into service only when the fuse blows on account of an arc between phase and ground, or some similar extremely severe continued strain. The sensitiveness is also greatly increased by the addition of a similar shunting fuse around the adjustable gap in the ground leg of the arrester. The ground leg is necessary only when there is an accidental ground of a phase and, ordinarily the increased sensitiveness is maintained continually.

Location.—Ample wall space should be provided and plenty of room in front should be left for the operator. The arresters should be placed as near as possible to where the lines enter the buildng. The following minimum separation distances have proved entirely satisfactory.

TABLE GIVING PROPER SPACE BETWEEN LIGHTNING ARRESTERS AND SETTING OF ADJUSTABLE GAP.

Max. Volts	Distance in Inches Between Live Parts of Adjacent Phases	Minimum Distance Between Centers (See Note)	Inches of Gap
7,600	8″	28″	¼
12,250	8″	28″	⅜
13,500	8″	33″	⅜
17,000	10″	35″	⅜
22,000	12″	37″	½
27,000	18″	48″	½
32,000	22″	52″	⅝
37,000	26″	56″	¾

NOTE—If barriers are used the width of barriers should be added to distances given.

It is advisable to locate arresters in a dry place, and before assembling them the wooden supports, insulators, etc., should be thoroughly dried of all moisture which may have collected during transportation.

The adjustable spark gap on these arresters is shunted by a fuse. This fuse blows under certain conditions and cuts in the added protection of the gap. The settings of this gap for the various arresters should be as already explained.

Voltage Range of Arresters.—Lightning arresters of the form described have been designed for voltages from 5,700 to 37,000. For lower voltages, down to 300 volts, alternating current, the arresters are of slightly different design, havng only two resistance rods. For 300 volts and less no resistance is necessary, as the voltage is so low that the arc cannot hold. These arresters, therefore, consist simply of spark gaps.

LOW VOLTAGE ARRESTERS—FORMS F1 AND F2.
300 TO 5,700 VOLTS.

The 2,200-volt (Figs. 631 and 634) arrester consists of one unit having fourteen cylinders, nine of which are shunted by a low resistance and eleven by a high resistance. As in the case of the high voltage arresters, the grading of resistance provides *selective paths* for discharges. Its action and advantages are therefore similar to those of the high-voltage arrester. Accumulated static charges pass off across the high resistance, and two gaps. High frequency discharges pass across all the gaps; discharges of moderate frequency across the low resistance, and four gaps. The low resistance is so proportioned to the number of shunted gaps that the high frequency discharge across these gaps is not followed by the dynamic current; the dynamic shunting at once to the low resistance. The discharge takes place over all the gaps, but the arcs between the gaps shunted by the low resistances are very small compared with the bright arcs between the last four gaps. The static discharge passes through all the gaps, while the half wave of dynamic current following the static is shunted part of the way by the resistance.

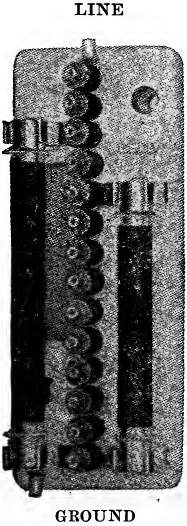


FIG. 631

FORM F1, 2,200-VOLT MULTIGAP ARRESTER FOR STATIONS

An oscillogram of this phenomenon is shown in Fig. 632. The only current in the shunted gaps is the current of static discharge. It should be noted, however, that the current shown is not a measure of the true current, as the oscillograph cannot respond to currents of such high frequency.

It should be here explained that the oscillograph is a device consisting of a galvanometer of strong field and high frequency of vibration, and is used for recording waves of alternating current.

This arrester is designed to operate across 2,200 volts. It is used, however, from each line to ground, giving, thus connected, sufficient protection, and being always able to handle a discharge when one line is grounded. It is built to be used single-pole, but by placing two or three in the same box, becomes double-pole or triple-pole.

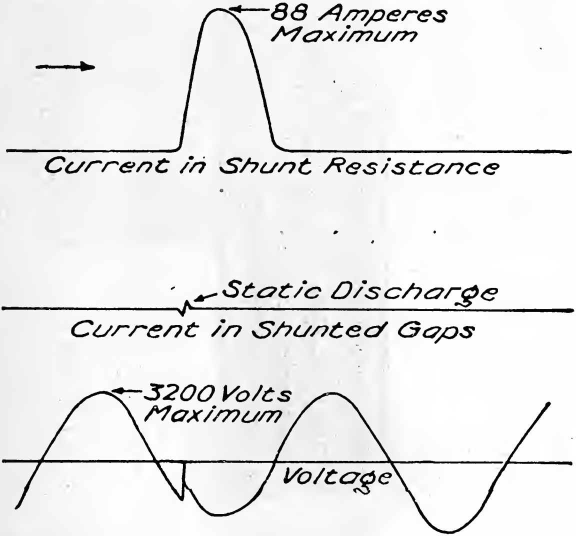


Fig. 632

OSCILLOGRAPH CURVES SHOWING LIGHTNING ARRESTER ACTION

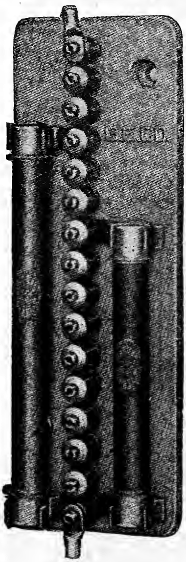
The 1,000-volt arrester is the same in design, but has only one gap between the high resistance rod and line.

The 3,000-volt arrester (see Fig. 633) is based on the same general principle as the 2,200-volt arrester, differing from it mainly in having two additional gaps to take care of the higher voltage.

The 2,200-volt arrester (Fig. 634) is used in various combinations to form arresters of higher voltage.

Low-Voltage Lightning Arresters.—For low-voltage, alternating-current circuits up to 300 volts the lightning arrester shown in Fig. 635 is used. This type meets the requirements for the protection of low voltage circuits such as transformer secondaries, motors, series arc lamps, etc. These arresters are made in single, double and triple-pole units.

LINE



GROUND

FIG. 633

FORM F2, 3,000-VOLT MULTIGAP ARRESTER FOR STATIONS

Protection of Cable Systems.—It is frequently necessary, and desirable for circuits to dip underground when passing through cities, under rivers, etc., and in these cases some form of metal covered cable is generally used. Resonance invariably produces high potentials at the junction of overhead, and underground lines, and these potentials are often of sufficient value to break down the insulation of the cables, and also the insulation of apparatus installed on the system.

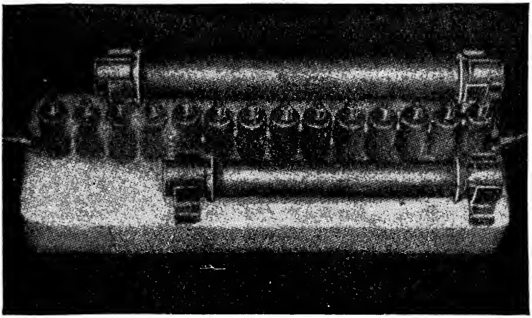


FIG. 634
2,200-VOLT, FORM F1, LIGHTNING ARRESTER, DISCHARGING AND SHUNTING THE DYNAMIC CURRENT

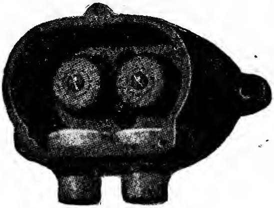


FIG. 635
SINGLE-POLE ARRESTER

Whenever lines contain both inductance, and capacity in appreciable quantities, high voltages, which endanger the insulation of the whole system, and which it is impossible to detect on ordinary switchboard instruments may exist. Abnormal voltages are therefore often found in circuits containing a combination of underground, and overhead circuits and in underground transmission lines.

Constant Current Arresters.—For constant current lighting circuits, horn arresters with resistances are recommended. It is advisable to place these arresters in the station on each outgoing line. When cables are used, the arrester should be placed on the pole where the cable joins the overhead wires. Fig. 637 shows the appearance of a horn lightning arrester.

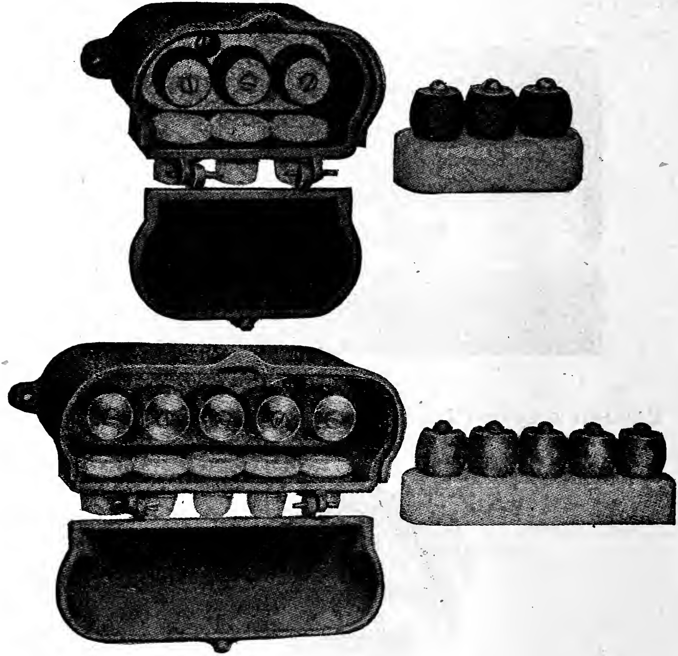


Fig. 636

DOUBLE-POLE AND TRIPLE-POLE 300-VOLT ARRESTERS

Disconnecting Switches.—Lightning arresters with disconnecting switches are desirable in order that they may be disconnected from the line for proper inspection, adjustment, cleaning, etc., without opening the line circuit.

The disconnecting switches, except the 2,500-volt switches, are of the post insulator type. The 2,500-volt switches are single-blade, front connected, and are mounted directly on marble bases. The post insulator switches are arranged for mounting on flat surfaces.

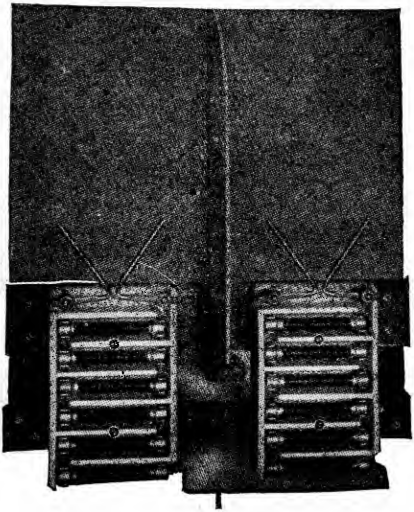


FIG. 637

HORN ARRESTER FOR CONSTANT CURRENT CIRCUITS

Choke Coils.—The proper selection of choke coils is an important feature of lightning protection. Choke coils should be used with lightning arresters except, when the arresters are used to protect cable systems.

Three types of choke coils are shown in Figs. 639 and 640. The 4,600-volt coil is made of insulated wire, wound on wooden core supported by iron feet. The 6,000-volt coil is made of insulated wire and is mounted on marble base. For voltages above 6,000 the "hour glass" type with air insulated turns is used. With this type the coil is mounted on a wooden, slate or marble base.

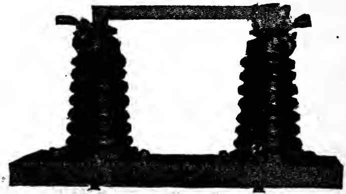


Fig. 638
POST TYPE INSULATOR DISCONNECTING SWITCH

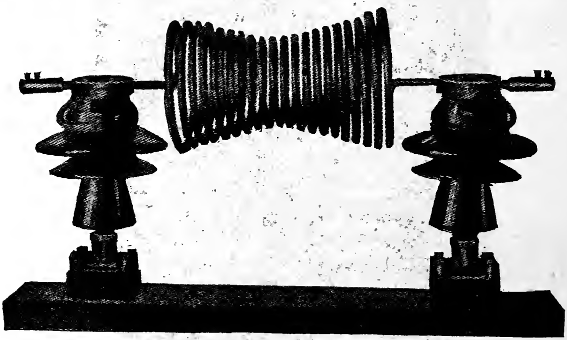
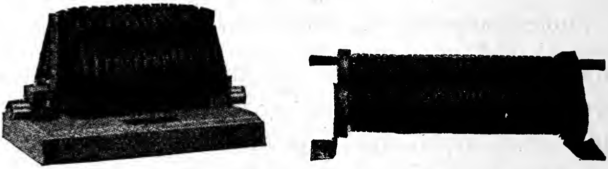


Fig. 639
HOUR GLASS TYPE—CHOKE COIL 15,000-35,000 VOLTS



6,000 VOLTS

4,600 VOLTS

Fig. 640
LOW VOLTAGE CHOKE COILS

The "hour glass" type has the following advantages on high voltages.

1. Should there be any arcing between adjacent turns, the coils will reinsulate themselves after the discharge.
2. They are mechanically strong, and sagging is prevented by tapering the coils toward the center turns.
3. The insulating supports can best be designed for the strains that they have to withstand.

In providing lightning arresters the following points should be considered:

1. What is the normal line to line voltage?
2. How many sets of transmission lines are there?
3. Is the system single-phase, two-phase, or three- phase; or three-phase, four wire?
4. Is the system delta connected; Y connected, neutral non-grounded; or Y connected, neutral grounded?
5. If single-phase, is the neutral grounded?
6. Are switches to be furnished with the arrester?
7. If so, are they to be double-blade or single-blade?
8. If double-blade switches are required, state the current-carrying capacity of the line switch.
9. Are choke coils to be furnished? If so, state their ampere capacities and the number desired.
10. The number of switch hooks to be furnished.
11. If the line is partly overhead, and partly underground, submit a rough sketch that shows where the underground portion is located with reference to the stations and the remainder of the line.

DIRECT CURRENT LIGHTNING ARRESTERS.

The Type M Form D-2 arrester (Fig. 641) has been the standard for direct current circuits for several years, and is furnished for lighting and power circuits of from 60 to 375 volts, and for railway and power circuits of from 250 to 1,800 volts.

The present form of arrester is somewhat longer and narrower than the earlier types, and the spark gap, and non-inductive resistance are in a straight line, thus forming a direct path for the discharge, and reducing to a minimum the possibility of short circuit in the box in case of excessively heavy lightning discharges. One of the valuable features of the MD-2 arrester is the fact that all parts can be readily inspected on removing the cover of the porcelain enclosing box (Fig. 642) and a glance will show if the arrester is in proper condition for the next storm. The gap is surrounded by a strong electro-magnet, which immediately blows out the dynamic arc through the chute after the lightning discharge has passed.

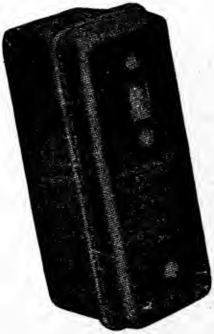


FIG. 641
DIRECT CURRENT ARRESTER, TYPE M, FORM D-2

The gaps on arresters up to 850 volts are adjusted to .025 inch, and on higher voltages to .094 inch. These arrangements have been found to afford excellent protection to the insulation of the equipments, due to the low breakdown points.

The spark gap terminals are threaded, and attached to the lid of the box, thus affording a ready method of adjustment, positive grip on the terminals, and easy access for examination.

Ground Connections.—In all lightning arrester installations it is of utmost importance to make perfect ground connections, as a large majority of lightning arrester troubles can be traced to the lack of this precaution. It has been customary to ground a lightning arrester by means of a large metal plate buried in a bed of charcoal, at a depth of six or eight feet in the earth.

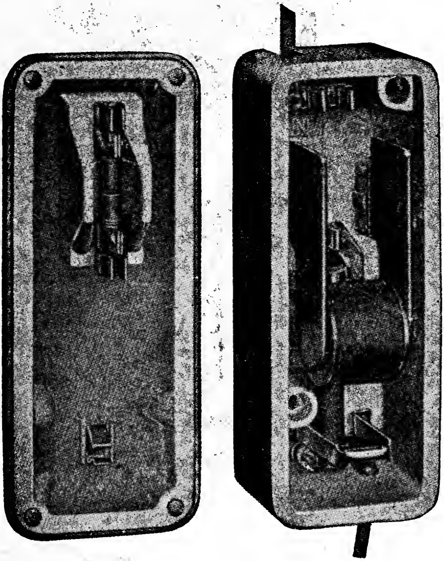


FIG. 642

DIRECT CURRENT LIGHTNING ARRESTER—INTERIOR

A more satisfactory method of making a ground is to drive a number of 1-inch iron pipes six or eight feet into the earth at several points about the station, connecting all these pipes together by means of copper wire or preferably copper strip. A quantity of salt should be placed around each pipe at the surface of the ground and the ground thoroughly moistened with water. It is advisable to connect the pipes to the iron frame work of the station,

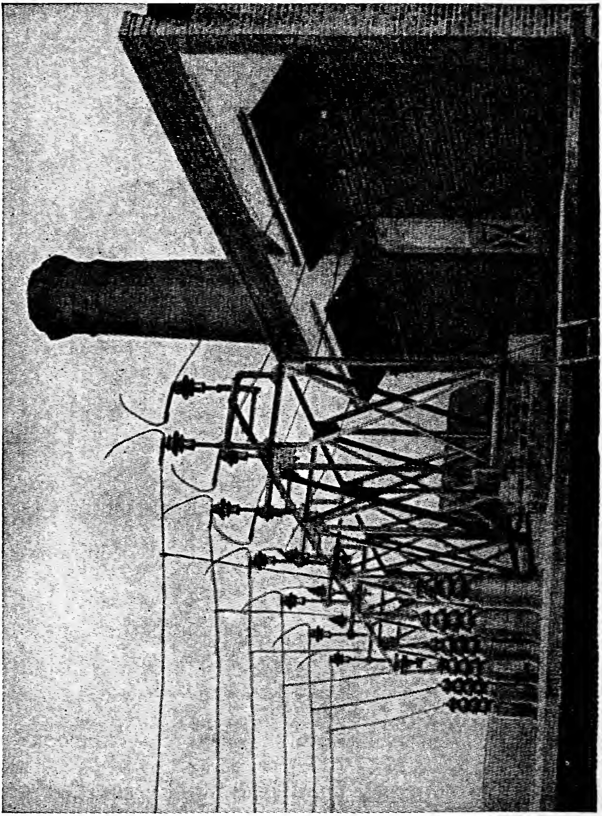


FIG. 643

HORN GAP INSTALLATION FOR 35,000 VOLT ALUMINUM LIGHTNING ARRESTERS, SCHENECTADY POWER CO., SHOWING ROOF ENTRANCES TO STATION AND WALL ENTRANCES TO LIGHTNING ARRESTER TOWER. ONE SET OF ARRESTERS DISCONNECTED and also to any water mains, metal flumes, or trolley rails that are available.

For the station of ordinary size the following recommendation is made. Place three earth-pipes equally spaced near each outside wall, making twelve altogether, and place three extra pipes spaced about six feet apart at a point nearest the arrester.

When plates are placed in streams of running water, it is much better for them to be buried in the mud along the bank, than to lie in the stream. Streams with rocky bottoms are to be avoided except as a last resort.

Whenever plates are placed at any distance from the arrester it is advisable to drive a pipe in the earth directly beneath the arrester, thus making the ground connections as short as possible. Earth plates at a distance cannot be depended upon. Long ground wires in a station cannot be depended upon, unless a lead is carried to the multiple pipe-earths described above.

In view of the fact that it is advisable to occasionally examine the ground connections to see that they are in proper condition, it is desirable to lay out the exact plans of the location of the ground plates, ground wires, or pipes, with a brief description of them, so that at any time the data may be referred to.

From time to time the resistance of the ground connections should be measured to determine their condition. This is very easily done when pipe grounds are installed, as the resistance of one pipe can be accurately determined, when three or more pipes are used. The resistance of a single pipe ground in good condition has an average value of about 15 ohms. A simple and satisfactory method of keeping account of the condition of the earth connections is to divide the pipe-earths into two groups, and connect each group to the 110-volt lighting circuit, with an ammeter in series. If there is a flow of about 20 amperes the conditions are satisfactory, provided the pipe-earths are properly distributed around the station.

ALUMINUM LIGHTNING ARRESTERS.

The design of the aluminum arrester is based on the characteristics of a cell consisting of two aluminum plates on which has been formed a film of hydroxide of aluminum, immersed in a suitable electrolyte. This film is formed on the aluminum plates by a series of chemical and electrochemical treatments at the factory.

Valve Action.—Up to a certain critical voltage this hydroxide film has the property of insulating, or rather opposing the flow of current and is, therefore, closely analogous to a counter-electromotive force. Up to this critical voltage only a small leakage and charging current can flow, but during any rise above this voltage the current flow through the cell is limited only by the actual resistance of the electrolyte, which is very low. The action is comparable to that of the well-known safety valve of a steam boiler by which the steam is confined until the pressure rises to a given value, at which point the valve opens and releases the excess pressure. This action of the aluminum cell is also closely analogous to that of a storage battery on direct current. Up to about two volts per cell, impressed, the storage battery, when charged, opposes an equal counter-electro-motive force, shutting off the flow of current; but for voltage above this value the current is limited only by the internal resistance of the cell. This characteristic makes the aluminum cell ideal as a means of discharging abnormal potentials, or surges in electric circuits. It practically prevents the flow of current at operating voltages, but instantly short circuits such abnormal portions of a potential wave, or surge, as would be dangerous to the insulation of the system.

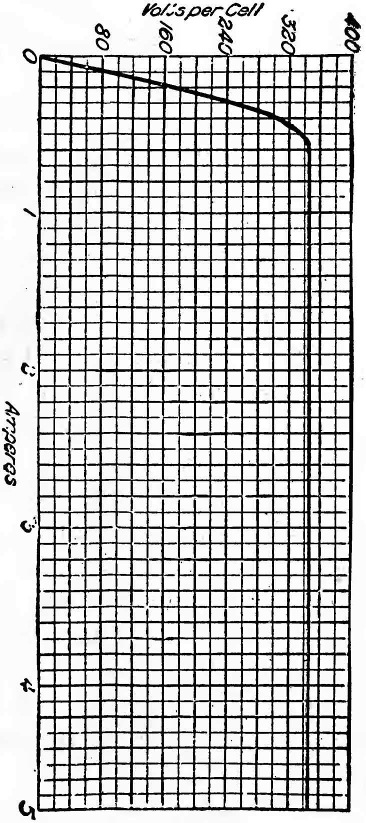


FIG. 644

VOLT-AMPERE CHARACTERISTIC CURVE OF ALUMINUM CELL

A volt-ampere-characteristic-curve of the aluminum cell on alternating current is shown in Fig. 644. The data for this curve was taken with an oscillograph. It should be noted that the critical voltage, alternating current, is slightly above 340 volts. This cut gives the discharge rate only up to 5 amperes, in order to better illustrate the normal and critical voltage points. Above this value the discharge rate depends almost entirely upon the internal resistance of the electrolyte. This resistance is such that at double the normal operating voltage, or 600 volts per cell, the current discharge is six hundred, to one thousand amperes for a brief time. This rate of discharge represents a quantity of electricity several times greater than the quantity liberated by an ordinary induced lightning stroke.

Condenser Action.—Besides the valve action described above there is another characteristic of the cell of great importance. The thin insulating film of aluminum hydroxide between the conducting aluminum and the conducting electrolyte acts as a dielectric and the cell, therefore, is an elecstatic condenser. A condenser of this type makes an ideal path for high frequency lightning discharges. With these arresters, for instance, 10,000 cycles, which is not an unusual frequency for lightning disturbances, would discharge almost 100 amperes without any rise in voltage.

Due to this capacity, these aluminum arresters cannot be connected permanently across alternating voltage. The charging current at normal frequency (about .5 amp.) would in time heat the electrolyte. In every case, therefore, spark gaps set to arc over at slight increase of voltage, insulate the arrester from the line.

Film Dissolution.—Another characteristic of the aluminum cell is the dissolution of a part of the film when the plates stand in the electrolyte, and the cell is disconnected from the circuit. The film is presumably composed of two parts; one part is hard and insoluble, and apparently acts as a skeleton to hold the more soluble part. When a cell, which has stood for some time disconnected, is reconnected to the circuit, there is a momentary rush of current, which replaces the part of the film which has dissolved. All electrolytes dissolve the film, the extent of the dissolution depending upon the length of time the film is in the electrolyte, the electrolyte used, and its temperature. It is neces-

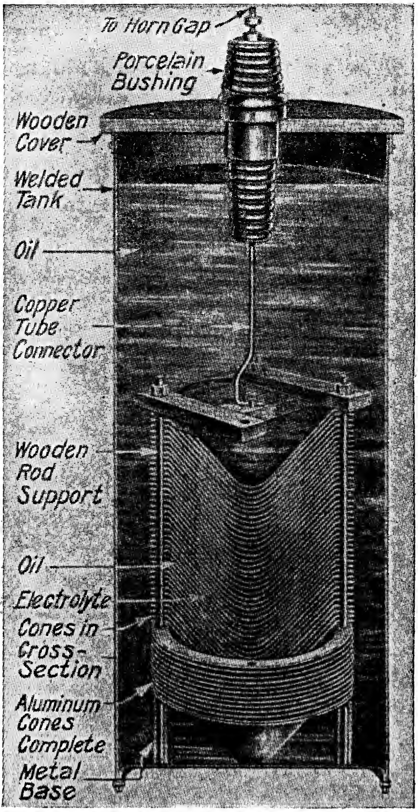


FIG. 645
CROSS SECTION OF ALUMINUM LIGHTNING ARRESTER

sary to charge the cells from time to time to prevent the initial rush of dynamic current causing trouble. By keeping the films formed at all times, the initial rush of current is prevented, and the ultimate temperature rise in case of continued discharge of the arrester is minimized. The ability of the arrester to take care of discharges lasting for any considerable length of time, therefore, depends upon the conditon of the arrester film. When the cells, in commercial use, are allowed to stand for not more than a day or two, the film dissolution, and initial current rush is negligible. Suitable means are provided with the arresters for connecting them directly across the line. This is a very simple operation, and thus the film is kept in good condition.

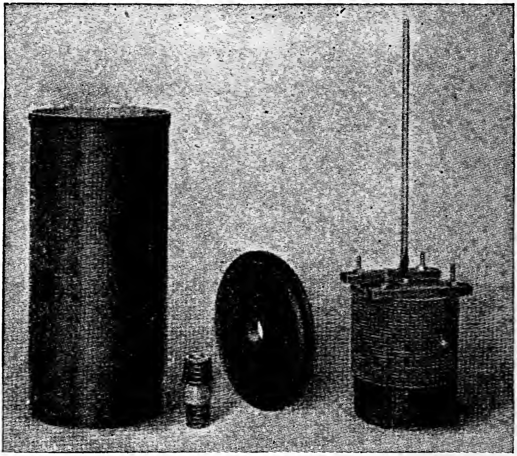


Fig. 646

PARTS OF 15000 VOLT ALUMINUM LIGHTNING ARRESTER

In very warm climates it is sometimes advisable to take special precaution to keep the cells normally cool.

Design.—The aluminum lightning arresters for alternating current circuits from 1,000 to 110,000 volts consist essentially of inverted aluminum cones, placed one above the other in stacks, and insulated with a vertical spacing of about .3 inch. An electrolyte partially fills the space between adjacent cones, so forming aluminum cells connected in series. The stack of cones with the electrolyte between them is then immersed in a tank of oil. The electrolyte being heavier than the oil remains between the

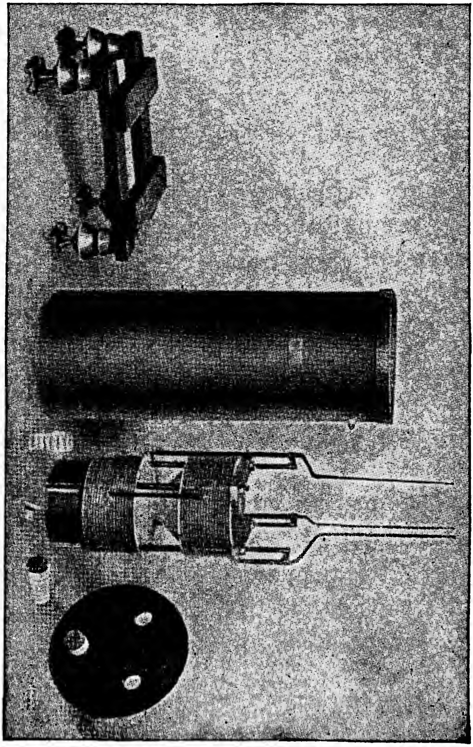


FIG. 647

PARTS OF 4600 VOLT THREE-PHASE ALUMINUM LIGHTNING ARRESTER aluminum cones. The oil improves the insulation between cones, prevents evaporation of the solution and, due to its heat absorbing capacity, enables the arresters to discharge continuously for long periods, a very valuable feature of these arresters. The tanks are of steel with welded seams.

The general arrangement of the cells is shown in Figs. 645, 646 and 647.

QUESTIONS AND ANSWERS.

935. How are switchboards made up?

Ans. They are built up of panels of slate or marble supported by frames of angle iron.

936. How are the different panels designated?

Ans. Some are for motor control, others for dynamo running, others for operating the outer circuit, and others for charging storage batteries.

937. Is a knowledge of switchboards an important matter?

Ans. It is, and every engineer should especially study those in his own station.

938. What is the regular equipment of a D. C. switchboard having a capacity of from 250 to 6,500 amperes?

Ans. One carbon-break or magnetic blow-out circuit breaker with telltale.

One illuminated dial ammeter with shunt.

One hand wheel and chain for operating rheostat.

One receptacle for voltmeter plug.

One S. P. S. T. field switch.

One S. P. S. T. main switch.

One recording watt-hour meter.

939. What is meant by the abbreviations S. P. S. T.?

Ans. Single Pole Single Throw.

940. What does D. P. D. T. mean in speaking of switchboards?

Ans. Double Pole Double Throw.

941. What is meant by T. P.?

Ans. Triple pole. It opens every circuit of a three-phase system.

942. Is it good practice to place a main switch at the machine?

Ans. It is best.

943. Why?

Ans. So that the cables from generator to board may be cut off at the generator.

944. What is an equalizer?

Ans. It is a cable running along from machine to machine, and connecting the functions of series field and brush on all the machines, but does not connect with switchboard.

945. What kind of a break has the field switch?

Ans. A carbon break.

946. Describe the action of a field switch.

Ans. Just before it opens it makes contact with an extra clip, and puts a resistance on as a shunt around the field coils.

947. If this were not done what would be the consequences?

Ans. The fields would act as a spark-coil and the insulation be damaged.

948. When it is desired to throw a generator in parallel with other generators already running what is the proper method of procedure?

Ans. First. Close main and equalizer switches near the machine.

Second. Close field switch on panel.

Third. Close circuit breaker.

Fourth. Insert potential plug in receptacle and regulate voltage.

Fifth. When proper voltage is obtained close the other main switch on panel.

949. What is meant by voltage?

Ans. Electric pressure, or potential.

950. What is a volt?

Ans. The unit of pressure.

951. What is a voltmeter?

Ans. An instrument that indicates the voltage.

952. What is an ohm?

Ans. The unit of resistance.

953. Give a brief definition of Ohm's law?

Ans. The electromotive force equals the resistance multiplied by current intensity.

954. What is an ampere?

Ans. It is the unit of volume, or quantity-time unit for measuring the rate of flow of an electric current.

955. What is a coulomb?

Ans. It is an ampere-second. A coulomb equals the flow of an ampere of current past a given point each second of time.

956. What is an ammeter?

Ans. An apparatus for measuring current rate.

957. What is the meaning of the word watt as used in electrical work?

Ans. A watt is the unit of work. It equals volts × amperes.

958. What is the function of the wattmeter?

Ans. To record the watt-hours of work.

959. What is a kilo watt (K. W.)?

Ans. 1,000 watts.

960. Expressed in mechanical horse-power, what is one K. W. equal to?

Ans. 1000÷746=1 1/3 H. P.

961. What is a field rheostat?

Ans. An apparatus for controlling the current output.

962. What is the function of a transformer?

Ans. To transform the current from a higher to a lower voltage, or from A. C. to D. C.

963. What is meant by synchronism of electric machines?

Ans. When the maximum value of the E. M. F. in each machine occurs at exactly the same instant of time, the machines are in synchronism.

964. What is meant by the exciter panel of a switchboard?

Ans. It is the panel that is equipped with the necessary switches, etc., for connecting the small exciter dynamo with the other generators in the station.

965. What is a sub-station?

Ans. It is the connecting link between the transmission line, and the trolley wire or third rail.

966. When A. C. is generated at the power station, and D. C. is used on the line, how is it accomplished?

Ans. The A. C. is changed to D. C. by rotary converters at the sub-station.

967. What is meant by frequency?

Ans. The number of times the current reverses per second.

968. What is the usual frequency for railway motors?

Ans. 25 is the standard.

969. What is a frequency changer?

Ans. A machine which receives current at one frequency and delivers it at another frequency.

970. What apparatus is used in an A. C. to D. C. substation?

Ans. Step down transformers, rotary converters, and A. C. incoming and D. C. outgoing switchboards.

971. What is the proper procedure for placing rotary converters in service?

Ans. After the machine has been started from the A. C. ends, and builds up with the proper polarity, first close the equalizer switch (on machine)—second, close circuit breaker on panel—third, insert potential plug in receptacle and regulate voltage—fourth, when the proper voltage is obtained, close positive switch (on panel).

972. What will be the result if the rotary builds up with polarity reversed?

Ans. The voltmeter will swing back of zero.

973. How may the polarity be corrected?

Ans. By means of the four-pole, double-throw field break-up reversing switch mounted on the converter.

974. Describe an oil switch.

Ans. It is a switch similar in its action to other switches, with the exception that its mechanism is immersed in a small tank of oil.

975. What advantage is gained thereby?

Ans. Reliability of action in opening or closing a circuit.

976. Mention another advantage gained by the use of the oil switch and oil circuit breaker.

Ans. It has made safely possible the transmission and use of high-tension currents of electricity.

977. What is a circuit-breaker?

Ans. It is a switch so designed as to be capable of frequently opening the circuit carrying its full current without any damage to itself.

978. What is a galvanometer?

Ans. An instrument consisting of a coil of wire carrying the current to be tested, and a magnet, the two being arranged so that one can be deflected.

979. Describe the Thompson type of galvanometer.

Ans. The coil of wire is stationary, and the light magnetic needle is suspended by a silk thread.

967. Describe the D'Arsonval galvanometer.

Ans. In this type the small light coil of wire is suspended by a fine bronze wire between the poles of a stationary magnet.

968. How are the readings taken from these instruments?

Ans. From a circular scale, over which the needle of the instrument swings.

980. What is a lightning discharge?

Ans. An equalization of potential between the earth, and either clouds, or saturated atmosphere.

981. What path does the discharge generally follow?

Ans. The path of least resistance.

982. What are the general requirements for protection of electric stations from lightning?

Ans. The supplying of paths to ground for any charge which might accumulate on lines or machinery.

983. What is the general theory of the multi-gap lightning arrester?

Ans. When voltage is applied across a series of multigap cylinders, the voltage distribution is not uniform, but is governed by the capacity of the cylinders, both between themselves, and also to ground, which results in the concentration of voltage across those gaps nearest the line.

984. What are the principal elements of a 600 volt D. C. aluminum lightning arrester?

Ans. Two concentric aluminum plates immersed in an electrolyte contained in a glass jar, the outside plate of each cell being positive, and the inner one negative.

985. Describe the multigap lightning arrester for A. C.

Ans. It consists of a series of spark gaps shunted by graded resistances, but without series resistance.

986. Describe briefly the aluminum lightning arrester.

Ans. It consists of two aluminum plates on which has been formed a film of hydroxide of aluminum, immersed in a suitable electrolyte.

Current Distribution

Divided Circuits.—Currents of electricity, although they have no such material existence as water or steam, still obey the same general law; that is, they flow and act along the lines of least resistance. If a pipe extending to the top of a ten-story building had a very large opening at the first floor, it would be impossible to force water to the top floor. All the water would run out at the first floor. If the opening at the first floor were small only a part of the water would escape through it, some would reach the top of the building. The flow of water in each case is inversely proportional to the resistance offered to it by the different openings.

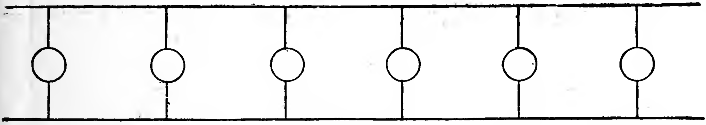


FIG. 648

The same thing is true of currents of electricity. Where several paths are open to a current of electricity the flow through them will be in proportion to their conductivities, which is the inverse ratio of their resistances. As an illustration, the current flow through all of the lamps, Fig. 648, is the same, because each lamp offers the same resistance. But if we arrange a number of lamps as in Fig. 649, the lamps in series will offer twice as much resistance as the single lamps, and will receive but half the current of the single lamp. In Fig. 650 we have still another arrangement. The lamp A limits the current which can flow through B and C, and that current which does flow divides between B and C in proportion to their conductivities. If B has a resistance of 110 ohms and C 220 ohms, then B will carry two parts of the current and, C only one. The combined resistance of all lamps, Fig. 648, equals the resistance of one lamp divided by the number of lamps. The combined resistance, Fig. 649, equals the sum of the resistances of the two lamps at A multiplied by the resistance of B and divided by the sum of all the resistances. If the resistance of each of the lamps were 110 ohms, the problem would work out thus:

FIG. 649

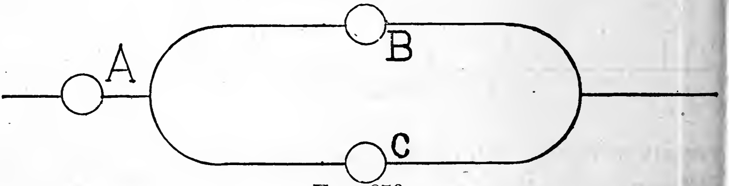


FIG. 650

$$\frac{110+110\times110}{110+110+110}=73\ 1/3.$$

In Fig. 650 the total resistance is

$$\frac{110\times220}{110+220}+110=183\ 1/3.$$

One practical illustration of the above law may be found in the method of switching series arc lamps, Fig. 651. As long as the switch S is open the arc lamp burns, but as soon as the switch is closed the lamp is extinguished because the resistance of the short wire and the switch S is so much less than that of the arc lamp that practically all the current flows through S.

Wiring Systems.—The system of wiring which is most generally used for incandescent lighting and ordinary power purposes is called the two-wire parallel system. In this system of wiring the two wires run side by side, one of them being the positive and one the negative. The lamps, motors and other devices are then connected from one wire to the other. A constant pressure of electricity is maintained between the two wires, and the number and size of lamps, or other apparatus, connected to these two wires, determine how many amperes are required. Each lamp or motor is independent of the others and may be turned on or off without disturbing the others.

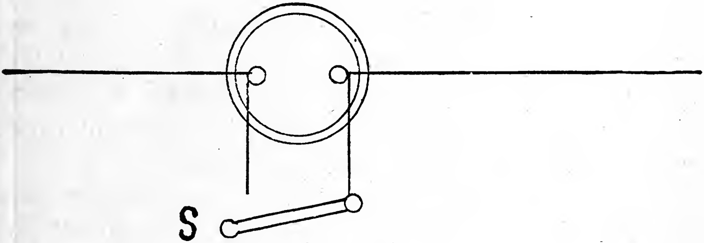


Fig. 651

A diagram of such a system is shown in Fig. 652.

In this system the quantity of current varies in proportion to the number of devices connected to it. Suppose that we are maintaining a pressure or potential or electromotive force of 110 volts on such a system, and that we have connected to the system ten 16 candle power incandescent lamps, consuming one-half ampere each. The total quantity of current to supply these lamps would be 5 amperes. If we should now switch on ten more lamps the quantity of current would be 10 amperes, and the pressure would remain 110 volts. This system is also known as the "constant potential system," or multiple arc system, and among the numerous devices used in connection with it are the constant potential arc lamp, the shunt motor, the compound wound motor, the series motor, incandescent lamps, etc. Electric street railways are also operated on this system. The current supplied through this system of wiring may be either direct or alternating current.

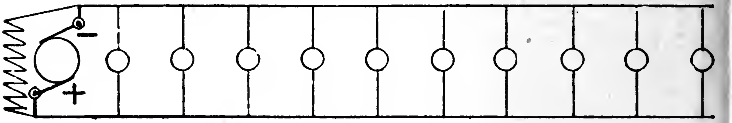


Fig. 652
TWO-WIRE PARALLEL SYSTEM

The series arc system, Fig. 653, is a loop; the greatest electrical pressure being at the terminal, or terminal ends of the loop. The current in such a system of wiring is constant, and the pressure varies as the lamps or other apparatus are inserted in or cut out of the circuit. This system is also called the constant current system. The same current passes through all of the lamps, and the different lamps are also independent of each other.

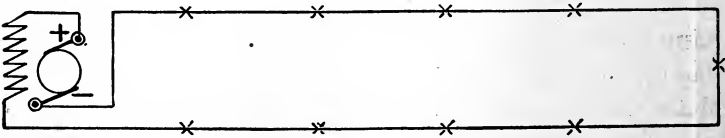


Fig. 653
SERIES ARC SYSTEM

At the present time the series system is used mostly for operating high tension series arc lamps. The use of motors with it has been almost entirely abandoned.

The series multiple system, Fig. 654, is simply a number of multiple systems placed in series. This method of wiring was at one time employed to run incandescent lights from a high tension series arc light circuit, but on account of the danger connected with the use of incandescent lamps, operated from a high tension arc lamp circuit, the system has been abandoned. It is not approved by insurance companies, and consequently is not often used.

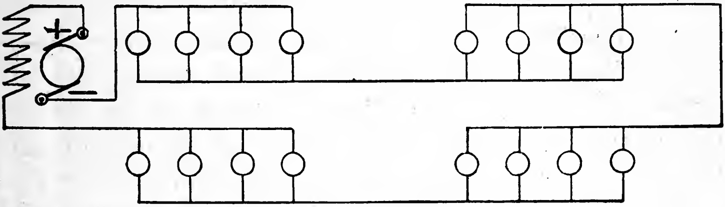


FIG. 654

SERIES MULTIPLE SYSTEM

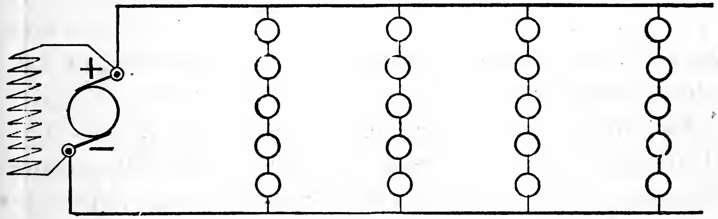


FIG. 655

MULTIPLE SERIES SYSTEM

The multiple series system consists of a number of small series circuits, connected in multiple, as shown in Fig. 655. This system of wiring is used on constant potential systems, where the voltage is much greater than is required by the apparatus to be used, as, for instance, connecting eleven miniature lamps, whose individual pressure required is 10 volts, into a series, and then connecting the extreme ends of such a series to a multiple circuit whose pressure is 110 volts.

The three wire system, Fig. 656, is a system of multiple series. In this system, as its name implies, three wires are used, connected up to the machines in the manner shown in the diagram. Both machines are in series when all lights are turned on, but should all lights on one side of the neutral or center wire be turned off the machine on the other side alone would run the other lights.

One of these wires is positive, the other is negative, and the remaining one or center wire is neutral. In ordinary practice from positive to negative wire, a potential of 220 volts is maintained, while from the neutral wire to either of the outside wires a potential of 110 volts exists. The advantages of such a system are many, principally among them is the use of double the voltage of the two wire system; this reduces the current one-half and allows the use of smaller wires. This system only requires three wires for the same amount of current that would require four in the other system. Motors are supplied at 220 volts, while lights operate at 110. Incandescent lighting circuits can be maintained from either outside wire to the neutral wire. The saving in copper by dispensing with the fourth wire

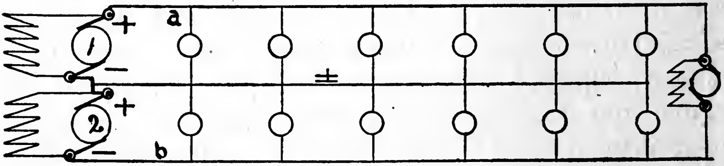


FIG. 656
THREE WIRE SYSTEM

is not the only advantage in the saving of conductors. The neutral wire may be much smaller than the outside wires because it will seldom be called upon to carry much current.

Inside of buildings, however, where overheating of a wire is always dangerous, the neutral wire should be of the same size as the others. By tracing out the circuits in Fig. 656, it will readily be seen that, so long as all lamps are burning, the current passes out of dynamo 1 into the positive wire and from there through the lamps (always two in series) to the negative or — wire, returning over it to the — pole of dynamo 2. So long as an equal number of lamps is burning on each side of the neutral, no current passes over the neutral wire in either direction. But if the positive or + wire should be broken, say at *a*, dynamo 1 will no longer send current and the lamps between the positive and neutral wire will be out.

Dynamo 2 will now supply the lamps between the neutral and the negative wire and for the time being the neutral wire will become positive. Should the negative wire break at *b*, the lamps connected to it would be out and dynamo 1 would supply the lights on its side, the neutral wire becoming negative. When motors of one or more horse-power are used on this system, it is usual to connect them to the outside wires using 220 volts. It is important also to arrange the wiring so that an equal number of lights are installed on each side of the neutral. When the lights and motors are so arranged, the system is said to be "balanced." It is also very important to arrange so that the neutral wire cannot readily be broken. Should the neutral wire be opened while, for instance, fifty lamps were burning on one side and say ten or twenty on the other, the ten or twenty would be broken by the excess voltage. Grounded wires ordinarily cause more trouble than anything else on electric light or power circuits, but with the three wire system, the neutral wire is often grounded. Grounds on this wire are less objectionable than on other wires, because it carries very little current, and that current is constantly varying in direction, so that no great amount of electrolysis can occur at any one place.

Feeders.—(See Fig. 657), as the name implies, is a term used to designate wires which convey the current to any number of other wires, and the feeders become a part of the multiple series, multiple and three wire systems.

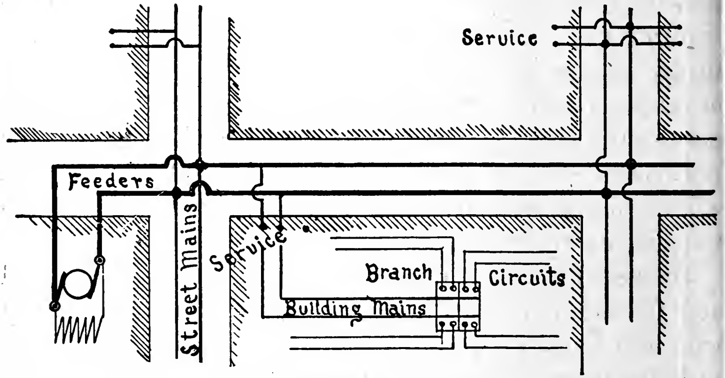


Fig. 657

Distributing mains are the wires from which the wires entering buildings receive their supply.

Service wires are the wires that enter the buildings.

The center of distribution is a term used for that part of the wiring system from which a number of branch circuits are fed by feeder wires. In most buildings the tap lines are all brought to one point, and terminate in cut-out boxes. These cut-out boxes are supplied by the main. Each floor of the building may have a cut-out box, or each floor of the building may have several cut-out boxes of the above description.

Calculation of Wires.—If we desire to transmit or deliver a certain quantity of liquid through a pipe, we estimate the size of the pipe and the comparison of sizes in the pipes by squaring the diameter, in inches, and multiplying the result by the standard fraction .7854. By way of explanation we will dwell upon the above method for a short time. In Fig. 658 we have a surface which measures one inch on all four sides, and which has an area of one square inch.

Now in a circle which is contained in this figure, and which touches all four sides of the square, we would only have .7854 of a square inch. If the diameter of this circle is 2 inches instead of 1, you can readily see by Fig. 659 that its area is four times as great or 2×2=4. We then multiply by the standard number .7854 in order to find the area contained in the two-inch circle; and if the diameter were 3 inches, then 3×3=9, and 9×.7854 would be the area in square inches contained in the three-inch circle.

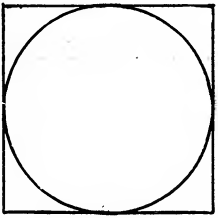


FIG. 658

Again, if we had a square one inch in area, like Fig. 660, and we took one leg of a carpenter's compass and placed it on one corner of this square, striking a quarter-circle from one adjacent corner to the other adjacent corner, the area inscribed by the compass would again be .7854 of a square inch.

The above will explain to the reader the relation between the circular and square mil. The circular mil is a circle one mil ($\frac{1}{1,000}$ of an inch) in diameter. The square mil is a square, one mil long on each side. In the calculation of wires for electrical purposes, the circular mil is generally used, because we need only multiply the diameter of a wire by itself to obtain its area in circular mils. If we used square mils we should have to multiply by .7854.

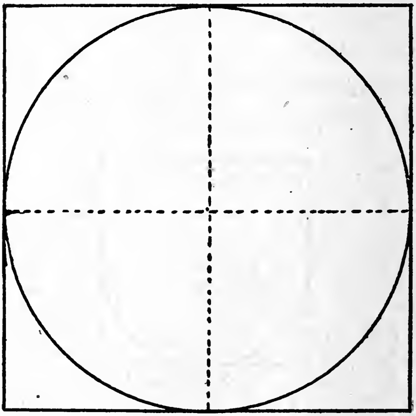


Fig. 659

The resistance of a conductor (wire) increases directly as its length, and decreases directly as its diameter is increased. A wire having a diameter of one mil and being one foot long has a resistance at ordinary temperature of 10.7 to 10.8 ohms. 10.8 ohms is the resistance usually taken. If this wire were two feet long, it would have a resistance of 21.4 ohms, but if it were two mils in diameter and one foot long, it would have a resistance one-fourth of 10.7, or about 2.67.

Every transmission of electrical energy is accompanied by a certain loss. We can never entirely prevent this loss any more than we can entirely avoid friction. But we can reduce our loss to a very small quantity simply by selecting a very large wire to carry the current. This would be the proper thing to do if it were not for the cost of copper, which would make such an installation very expensive. As it is, wires are usually figured at a loss of from 2 to 5 per cent.

The greater the loss of energy we allow in the wires, the smaller will be the cost of wire, since we can use smaller wires with the greater loss.

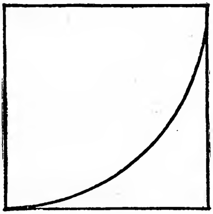


FIG. 660

In long distance transmission and where the quality of light is not very important, a loss of 10 or 20 per cent is sometimes allowed, but in stores, residences, etc., the loss should not exceed 2 or 3 per cent, otherwise the candle power of the lamps will vary too much.

Where the cost of fuel is high the saving in first cost of copper is soon offset by the continuous extra cost of fuel to make up for the losses in the wires.

To determine the size of wire necessary to carry a certain current at a given number of volts loss, we may proceed in the following manner: Multiply the number of feet of wire in the circuit by the constant 10.7, and it will give the circular mils necessary for one ohm of resistance. Multiply this by the amperes, and this will give the circular mils for a loss of one volt. Divide this last result by the volts to be lost, and the answer will be the number of circular mils diameter that a copper wire must have to carry the current with such a loss. After obtaining the number of circular mils required, refer to table 53 and select the wire having such a number of circular mils.

The formula is as follows:

$$\frac{\text{Feet of wire} \times 10.7 \times \text{amperes}}{\text{Volts lost}} = \text{circular mils.}$$

By simply transposing the above terms we obtain another formula, which can be used to determine the volts lost in a given length of wire of a certain size, carrying a certain number of amperes.

The formula is as follows:

$$\frac{\text{Feet of wire} \times 10.7 \times \text{amperes}}{\text{Circular mils}} = \text{Volts lost.}$$

And again, by another change in the terms we obtain a formula which shows the number of amperes that a wire of given size and length will carry at a given number of volts lost:

$$\frac{\text{Circular mils} \times \text{volts lost}}{\text{Feet of wire} \times 10.7} = \text{Amperes.}$$

In computing the necessary size of a service or main wire, to supply current for either lamps or motors, it is necessary to know the exact number of feet from the source of supply to the center of distribution. When the distance of center of distribution is given it is well to ascertain whether it is the true center or not. It may be only the distance from a cut-out box that has been given, when it should have been the distance from the point at which the service enters the building or, perhaps from the point at which the service is connected to the street mains. For when the size is determined it is for a certain loss which is distributed over the entire length of the wire to be installed. The transmission of additional current on the mains in the building increases the drop in volts in the main, and likewise in the service. Most buildings are wired for a certain per cent loss in voltage, estimated from the point where the service enters the building. All additions should be estimated from that point.

In using the formula for finding the proper size wire to carry current, the first thing to be determined is the length of the wire; remember that the two wires are in parallel, and therefore the total length of the wire is twice the total distance from the commencement to the end of the circuit. If the proposed load on this circuit is given in lamps, you may reduce it to amperes, and if the proposed load is given in horse-power, you may reduce it to amperes. The voltage on the circuit is known in either case. You take the loss of the voltage and divide the product of amperes, multiplied by the length, as found, and 10.7 by it; this answer will be the size in circular mils of a wire necessary to carry the amperes.

Example.—What is the size of wire required for a 50-volt system, having 100 lamps at a distance of 100 ft., with a 4 per cent loss?

Answer.—The load of 100 lamps on a 50-volt system is 100 amperes, and a 4 per cent loss of 50 volts is 2 volts. Multiply the total length of the wire, which is twice the distance, or 200 feet, by the 100 amperes of current; this gives us 20,000. Then multiply this by the constant, which is 10.7; this gives us 214,000. Divide this by 2, which is the loss in volts, and you have 107,000 circular mils diameter of wire required.

When determining the size of wire to be used it is always necessary to consult the table of carrying capacities, and this will very often indicate a wire much larger than that determined by the wiring formula, especially if a somewhat high loss is figured on.

When estimating the distance it is not always correct to take the total distance.

To illustrate: Suppose one lamp is 100 feet from the point at which the distance is determined, and the farthest lamp is 400 feet, the remaining lamps being distributed evenly between these two points, we would average the distances between the first and last lamp, which would be 200 feet. It is necessary to use judgment in estimating the mean or average distance, as the lamps or motors are bunched differently in each case.

In a series system the loss in voltage makes considerable difference to the power, but does not affect the quality of the light as much as in a multiple arc or parallel system. In a parallel system the lamps require a uniform pressure, and this can only be had by keeping the loss low. In a series system the lamps depend upon the constant current and the voltage varies with the resistance, in order to keep the current constant. This is accomplished by a regulator on the dynamo, which is designed to compensate for the changes of resistance in the circuit and to increase or decrease the pressure as required.

In estimating the size of wire for a series system you consider the total length of the loop. There is no average distance as the total current travels over the entire circuit. We will assume that you have an arc light circuit of a No. 6 Brown & Sharp gauge wire, and want to find what loss there is in this circuit. You have the area of a No. 6 wire, which is 26,250 circular mils, and the length of the circuit, and from this we will figure the loss in this manner: Assuming the circuit to be 10,000 feet long, and the current 10 amperes, we will multiply 10,000 feet by 10 amperes, and this by 10.7, which gives us 1,070,000, and divide this by 26,250. The answer is 40 volts, lost in the circuit.

Such a circuit would operate at perhaps 2,000 or 3,000 volts, and a loss of 40 volts would not be excessive. It would be wasting a little less energy than is required to burn one large arc lamp.

The *multiple series system* is a number of small wires connected in multiple, and is the same as the multiple arc or parallel system. The wire is figured in the same way as for the multiple arc system.

The *series multiple system* is a number of small parallel systems, and these are connected in series by the main wire. The wire is figured the same as for the series system.

The *Edison three-wire system* is a double multiple, and the two outside wires are the ones considered when carrying capacity is figured. When this system is under full load or balanced, the neutral wire does not carry any current, but the blowing of a fuse in one of the outside wires may force the neutral wire to carry as much current as the outside wire and it should, therefore, be of the same size. The amount of copper needed with this system is only three-eighths of that required for a two-wire system.

Wiring Tables.—On the following pages are presented wiring tables 55, 56 and 57 for 110,220 and 500 volt work. These tables are used in the following manner: Suppose we wish to transmit 60 amperes a distance of 1,800 feet at 110 volts and at a loss of 5 per cent. We take the column headed by 60 in the top row and follow it downward until we come to 1,800, or the number nearest to it. From this number we now follow horizontally to the left, and under the column headed by 5 we find the proper size of wire, which is 500,000 c. m. The same current, at a loss of 10, would require only a 0000 wire, as indicated under the column at the left, headed by 10.

Before making selection of wire, always consult table 53 of carrying capacities. This table is taken from the rules of the National Board of Fire Underwriters, and is in general use.

The first three of the following tables are wiring tables for the three standard voltages, 110, 220, 500. From these tables can be found the sizes of wire required to carry various amounts of current (in amperes) different distances (in feet) at several percentages of loss, or the distance the different sizes of wire will carry various amounts of current at several percentages of loss can be found.

These tables are figured on safe carrying capacity for the different sizes of wire. The distances in feet are to the center of distribution.

TABLE 53

CARRYING CAPACITY OF PURE COPPER WIRES.

(Underwriters' Rules.)

B. & S. G.	Table A. Rubber Insulation. Amperes.	Table B. Other Insulations. Amperes.	Circular Mils.
18	3	5	1,624
16	6	8	2,583
14	12	16	4,107
12	17	23	6,530
10	24	32	10,380
8	33	46	16,510
6	46	65	26,250
5	54	77	33,100
4	65	92	41,740
3	76	110	52,630
2	90	131	66,370
1	107	156	83,690
0	127	185	105,500
00	150	220	133,100
000	177	262	167,800
0000	210	312	211,600
Circular Mils.			
200,000	200	300	
300,000	270	400	
400,000	330	500	
500,000	390	590	
600,000	450	680	
700,000	500	760	
800,000	550	840	
900,000	600	920	
1,000,000	650	1,000	
1,100,000	690	1,080	
1,200,000	730	1,150	
1,300,000	770	1,220	
1,400,000	810	1,290	
1,500,000	850	1,360	
1,600,000	890	1,430	
1,700,000	930	1,490	
1,800,000	970	1,550	
1,900,000	1,010	1,610	
2,000,000	1,050	1,670	

The lower limit is specified for rubber-covered wires to prevent gradual deterioration of the high insulations by the heat of the wires, but not from fear of igniting the insulation. The question of drop is not taken into consideration in the above tables.

TABLE 54

DIMENSIONS OF PURE COPPER WIRE.

No. B. & S.	Diam. Mils.	Area.		Weight and Length. Sp. Gr. 8.9.		
		Circular Mils.	Square Mils.	Lbs. per 1000 feet.	Lbs. per mile.	Feet per pound.
0000	460.000	211600.0	166190.2	640.73	3383.04	1.56
000	409.640	167805.0	131793.7	508.12	2682.85	1.97
00	364.800	133079.0	104520.0	402.97	2127.66	2.48
0	324.950	105592.5	82932.2	319.74	1688.20	3.13
1	289.300	83694.5	65733.5	253.43	1338.10	3.95
2	257.630	66373.2	52129.4	200.98	1061.17	4.98
3	229.420	52633.5	41338.3	159.38	841.50	6.28
4	204.310	41742.6	32784.5	126.40	667.38	7.91
5	181.940	33102.2	25998.4	100.23	529.23	9.98
6	162.020	26250.5	20617.1	79.49	419.69	12.58
7	144.280	20816.7	16349.4	63.03	332.82	15.86
8	128.490	16509.7	12966.7	49.99	263.96	20.00
9	114.430	13094.2	10284.2	39.65	209.35	25.22
10	101.890	10381.6	8153.67	31.44	165.98	31.81
11	90.742	8234.11	6467.06	24.93	137.65	40.11
12	80.808	6529.94	5128.60	19.77	104.40	50.58
13	71.961	5178.39	4067.07	15.68	82.792	63.78
14	64.084	4106.76	3225.44	12.44	65.658	80.42
15	57.068	3256.76	2557.85	9.86	52.069	101.40
16	50.820	2582.67	2028.43	7.82	41.292	127.87
17	45.257	2048.20	1608.65	6.20	32.746	161.24
18	40.303	1624.33	1275.75	4.92	25.970	203.31
19	35.890	1288.09	1011.66	3.90	20.594	256.39
20	31.961	1021.44	802.24	3.09	16.331	323.32
21	28.462	810.09	636.24	2.45	12.952	407.67
22	25.347	642.47	504.60	1.95	10.272	514.03
23	22.571	509.45	400.12	1.54	8.1450	648.25
24	20.100	404.01	317.31	1.22	6.4593	817.43
25	17.900	320.41	251.65	.97	5.1227	1030.71
26	15.940	254.08	199.56	.77	4.0623	1299.77
27	14.195	201.50	158.26	.61	3.2215	1638.97
28	12.641	159.80	125.50	.48	2.5548	2066.71
29	11.257	126.72	99.526	.38	2.0260	2606.13
30	10.025	100.50	78.933	.30	1.6068	3286.04
31	8,928	79.71	62.603	.24	1.2744	4143.18
32	7.950	63.20	49.639	.19	1.0105	5225.26
33	7.080	50.13	39.360	.15	.8015	6588.33
34	6.304	39.74	31.212	.12	.6354	8310.17
35	5.614	31.52	24.753	.10	.5039	10478.46
36	5.000	25.00	19.635	.08	.3997	13209.98
37	4.453	19.83	15.574	.06	.3170	16654.70
38	3.965	15.72	12.347	.05	.2513	21006.60
39	3.531	12.47	9.7923	.04	.1993	26487.84
40	3.144	9.88	7.7635	.03	.1580	33410.05

1 mile pure copper wire $\frac{1}{16}$ in. diam.=13.59 ohmns at 15.5° C. or 59.9° F.
1 circular mil. is .7854 square mil.

TABLE 55 WIRING TABLE FOR 110 VOLTS.

Top Figures in Each Column the Percentage of Loss; Those Below the Size of Wire B. & S. Gauge.						The Top Figures in Each Column are the Number of Amperes; Those Below the Distance in Feet.																		
2	3.15	5	6.3	8	10	2	4	6	10	15	20	25	30	40	50	60	80	100	125	150	200	250	300	350
......	......	......	......	......	500000	127315	63657	42438	25463	16975	12731	10185	8487	6365	5092	4243	3182	2546	2037	1697	1273	1018	849	727
......	......	......	......	500000	400000	101850	50925	33950	20370	13580	10185	8148	6790	5092	4074	3395	2546	2037	1629	1358	1018	815	679	...
......	......	......	500000	400000	300000	76380	38190	25460	15276	10184	7638	6111	5092	3819	3055	2546	1910	1527	1222	1018	763	611	...	...
......	......	500000	400000	300000	0000	53880	26940	17960	10776	7184	5388	4311	3592	2694	2155	1796	1347	1077	862	718	538	....	...	...
......	......	400000	300000	0000	000	40410	20205	13470	8082	5488	4041	3233	2744	2020	1616	1372	1010	808	647	538	....	....	...	...
......	500000	300000	0000	000	00	33885	16942	11295	6777	4517	3388	2711	2258	1694	1355	1129	822	677	542	452	....	....	...	...
......	400000	0000	000	00	0	26880	13440	8960	5377	3584	2688	2151	1792	1344	1075	896	672	537	430	....	....	....	...	...
500000	300000	000	00	0	1	21310	10655	7103	4262	2841	2131	1705	1420	1065	852	710	532	426	341	....	....	....	...	...
400000	0000	00	0	1	2	16900	8450	5633	3380	2253	1690	1352	1126	845	676	563	422	338	....	....	....	....	...	...
300000	000	0	1	2	3	13400	6700	4466	2680	1786	1340	1072	893	670	536	447	335	....	....	....	....	....	...	...
0000	00	1	2	3	4	10605	5302	3535	2121	1413	1060	848	706	530	424	353	....	....	....	....	....	....	...	...
000	0	2	3	4	5	8430	4215	2810	1686	1124	843	675	562	422	337	281	....	....	....	....	....	....	...	...
00	1	3	4	5	6	6685	3342	2228	1337	890	668	535	445	334	267	....	....	....	....	....	....	....	...	...
0	2	4	5	6	7	5300	2650	1766	1060	706	530	424	353	265	212	....	....	....	....	....	....	....	...	...
1	3	5	6	7	8	4220	2110	1406	844	562	422	338	281	211	....	....	....	....	....	....	....	....	...	...
2	4	6	7	8	9	3330	1665	1110	666	444	333	266	222	....	....	....	....	....	....	....	....	....	...	...
3	5	7	8	9	10	2640	1320	880	528	352	264	211	....	....	....	....	....	....	....	....	....	....	...	...
4	6	8	9	10	11	2095	1047	698	419	278	209	....	....	....	....	....	....	....	....	....	....	....	...	...
5	7	9	10	11	12	1660	830	553	333	221	....	....	....	....	....	....	....	....	....	....	....	....	...	...
6	8	10	11	12	13	1320	660	440	264	176	....	....	....	....	....	....	....	....	....	....	....	....	...	...
7	9	11	12	13	14	1045	522	348	209	....	....	....	....	....	....	....	....	....	....	....	....	....	...	...
8	10	12	13	14	15	830	415	276	166	....	....	....	....	....	....	....	....	....	....	....	....	....	...	...
9	11	13	14	15	16	655	327	218	....	....	....	....	....	....	....	....	....	....	....	....	....	....	...	...
10	12	14	15	16	......	525	263	175	....	....	....	....	....	....	....	....	....	....	....	....	....	....	...	...
11	13	15	16	......	......	412	206	137	....	....	....	....	....	....	....	....	....	....	....	....	....	....	...	...
12	14	16	......	......	......	330	165	111	....	....	....	....	....	....	....	....	....	....	....	....	....	....	...	...
13	15	......	......	......	......	263	131	87	....	....	....	....	....	....	....	....	....	....	....	....	....	....	...	...
14	16	......	......	......	......	206	103	68	....	....	....	....	....	....	....	....	....	....	....	....	....	....	...	...
15	......	......	......	......	......	165	82	55	....	....	....	....	....	....	....	....	....	....	....	....	....	....	...	...
16	......	......	......	......	......	131	65	43	....	....	....	....	....	....	....	....	....	....	....	....	....	....	...	...

One 16-Candlepower 55 Watt Incandescent Lamp=½ ampere. One Horsepower=6.78 amperes.
One 2000-Candlepower Constant Potential Arc Lamp=5 amperes.

TABLE 56 WIRING TABLE FOR 220 VOLTS

Top Figures in Each Column the Percentage of Loss; Those Below the Size of Wire B. & S. Gauge.						The Top Figures in Each Column are the number of Amperes; Those Below the Distance in Feet.																		
2	3.15	5	6.3	8	10	2	4	6	10	15	20	25	30	40	50	60	80	100	120	160	200	250	300	350
......	......	......	......	......	500000	254630	127315	84877	50926	33950	25463	20370	16975	12731	10185	8487	6366	5092	4243	3183	2546	2037	1697	1455
......	......	......	......	500000	400000	203700	101850	67900	40740	27160	20370	16295	13580	10185	8147	6790	5092	4073	3395	2546	2036	1629	1357	....
......	......	......	500000	400000	300000	152775	76387	50924	30550	20370	15275	12222	10183	7637	6111	5091	3819	3055	2546	1910	1528	1222	....	....
......	......	500000	400000	300000	0000	107780	53890	35926	21556	14370	10778	8622	7185	5389	4311	3592	2695	2155	1796	1348	1077	....	....	....
......	......	400000	300000	0000	000	85450	42725	28483	17090	11393	8545	6836	5696	4272	3418	2848	2136	1709	1424	1068	....	....	....	....
......	500000	300000	0000	000	00	67745	33872	22581	13549	9032	6774	5420	4516	3387	2710	2258	1679	1355	1129	839	....	....	....	....
......	400000	0000	000	00	0	53770	26885	17923	10754	7170	5377	4302	3585	2688	2151	1792	1344	1075	896	....	....	....	....	....
500000	300000	000	00	0	1	42620	21310	14206	8524	5682	4262	3410	2841	2131	1705	1420	1065	852	710	....	....	....	....	....
400000	0000	00	0	1	2	34055	17027	11351	6811	4540	3405	2724	2270	1702	1362	1135	851	681	....	....	....	....	....	....
300000	000	0	1	2	3	26570	13285	8856	5314	3542	2657	2125	1771	1328	1062	885	664	....	....	....	....	....	....	....
0000	00	1	2	3	4	21255	10627	7085	4251	2834	2125	1700	1417	1062	850	708	....	....	....	....	....	....	....	....
000	0	2	3	4	5	16855	8427	5618	3371	2247	1685	1348	1123	842	614	562	....	....	....	....	....	....	....	....
00	1	3	4	5	6	13365	6682	4455	2673	1782	1336	1050	891	668	525	....	....	....	....	....	....	....	....	....
0	2	4	5	6	7	10560	5280	3520	2112	1413	1060	848	706	530	424	....	....	....	....	....	....	....	....	....
1	3	5	6	7	8	8405	4202	2801	1681	1120	840	672	560	420	....	....	....	....	....	....	....	....	....	....
2	4	6	7	8	9	6665	3332	2221	1333	888	666	533	444	....	....	....	....	....	....	....	....	....	....	....
3	5	7	8	9	10	5275	2637	1758	1055	703	527	422	....	....	....	....	....	....	....	....	....	....	....	....
4	6	8	9	10	11	4190	2095	1396	838	558	419	....	....	....	....	....	....	....	....	....	....	....	....	....
5	7	9	10	11	12	3325	1662	1108	665	443	....	....	....	....	....	....	....	....	....	....	....	....	....	....
6	8	10	11	12	13	2635	1317	878	527	351	....	....	....	....	....	....	....	....	....	....	....	....	....	....
7	9	11	12	13	14	2090	1045	696	418	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
8	10	12	13	14	15	1655	827	551	331	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
9	11	13	14	15	16	1315	657	438	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
10	12	14	15	16	......	1050	525	350	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
11	13	15	16	......	......	828	414	276	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
12	14	16	......	......	......	657	328	219	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
13	15	......	......	......	......	526	263	175	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
14	16	......	......	......	......	414	207	138	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
15	......	......	......	......	......	329	164	109	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
16	......	......	......	......	......	265	132	88	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....

One 16-Candlepower 55 Watt Incandescent Lamp=¼ ampere. One Horsepower=3.39 amperes.
One 2000-Candlepower Constant Potential Arc Lamp=2½ amperes.

TABLE 57. WIRING TABLE FOR 500 VOLTS.

Top Figures in Each Column the Percentage of Loss; Those Below the Size of Wire B. & S. Gauge.						The Top Figures in Each Column are the Number of Amperes; Those Below the Distance in Feet.																
2	3.15	5	6.3	8	10	2	4	6	10	15	20	25	30	40	50	60	80	100	120	150	170	200
......	......	......	......	......	500000	578700	289350	192900	115740	77160	57870	46296	38580	28935	23148	19290	14467	11574	9645	7716	6800	5787
......	......	......	......	500000	400000	460645	230322	153550	92129	61420	46064	36852	30710	23032	18426	15355	11516	9213	7677	6142	5420	4606
......	......	......	500000	400000	300000	347220	173610	115740	69444	45296	34722	27777	22648	17361	13888	11324	8680	6944	5662	4629	4085	3472
......	......	500000	400000	300000	0000	244950	122475	81650	48990	32660	24495	19595	16330	12247	9797	8165	6123	4898	4082	3266	2882	2449
......	......	400000	300000	0000	000	194215	97107	64738	38843	25895	19421	15537	12947	9710	7768	6473	4855	3884	3236	2589	2285	....
......	500000	300000	0000	000	00	154025	77012	51341	30805	20536	15402	12322	10268	7701	6161	5134	3850	3080	2567	2054	....	....
......	400000	0000	000	00	0	122210	61105	40736	24442	16293	12221	9775	8146	6110	4887	4073	3055	2443	2036	....	....	....
500000	300000	000	00	0	1	96405	48202	32135	19281	12854	9640	7712	6427	4820	3856	3213	2410	1928	1606	....	....	....
400000	0000	00	0	1	2	76565	38282	25521	15313	10208	7656	6125	5104	3828	3062	2552	1914	1531	....	....	....	....
300000	000	0	1	2	3	60915	30457	20305	12183	8122	6091	4873	4061	3045	2436	2030	1522	....	....	....	....	....
0000	00	1	2	3	4	48310	24155	16103	9662	6441	4831	3864	3220	2415	1932	1610	....	....	....	....	....	....
000	0	2	3	4	5	38282	19140	12760	7656	5104	3828	3062	2552	1914	1531	1276	....	....	....	....	....	....
00	1	3	4	5	6	30457	15228	10152	6091	4061	3045	2436	2030	1522	1218	....	....	....	....	....	....	....
0	2	4	5	6	7	24155	12077	8051	4831	3220	2415	1932	1610	1207	966	....	....	....	....	....	....	....
1	3	5	6	7	8	19140	9570	6380	3828	2552	1914	1531	1276	957	....	....	....	....	....	....	....	....
2	4	6	7	8	9	15229	7614	5076	3045	2030	1522	1218	1015	....	....	....	....	....	....	....	....	....
3	5	7	8	9	10	12077	6039	4026	2415	1610	1207	978	....	....	....	....	....	....	....	....	....	....
4	6	8	9	10	11	9570	4785	3190	1914	1276	957	....	....	....	....	....	....	....	....	....	....	....
5	7	9	10	11	12	7639	3819	2546	1527	1018	....	....	....	....	....	....	....	....	....	....	....	....
6	8	10	11	12	13	6039	3019	2013	1207	805	....	....	....	....	....	....	....	....	....	....	....	....
7	9	11	12	13	14	4785	2392	1595	957	....	....	....	....	....	....	....	....	....	....	....	....	....
8	10	12	13	14	15	3819	1910	1273	763	....	....	....	....	....	....	....	....	....	....	....	....	....
9	11	13	14	15	16	3019	1510	1005	......	....	....	....	....	....	....	....	....	....	....	....	....	....
10	12	14	15	16	......	2392	1195	797	......	....	....	....	....	....	....	....	....	....	....	....	....	....
11	13	15	16	......	......	1910	950	636	......	....	....	....	....	....	....	....	....	....	....	....	....	....
12	14	16	......	......	......	1510	755	503	......	....	....	....	....	....	....	....	....	....	....	....	....	....
13	15	......	......	......	......	1195	597	398	......	....	....	....	....	....	....	....	....	....	....	....	....	....
14	16	......	......	......	......	950	475	316	......	....	....	....	....	....	....	....	....	....	....	....	....	....
15	......	......	......	......	......	755	377	252	......	....	....	....	....	....	....	....	....	....	....	....	....	....
16	......	......	......	......	......	597	298	199	......	....	....	....	....	....	....	....	....	....	....	....	....	....

One Horsepower=1.49 amperes. When lights are used the lamps are put in series.

Table 58

SIZES, WEIGHTS, AND RESISTANCE OF PURE COPPER WIRE.

Size B. & S. Gauge.	Diam. Mils.	Area		Weather-Proof Wire						Bare Wire			Resistance at 75° F.			
				Double Braided			Triple Braided									
		Circular Mils.	Square Mils.	Pounds per 1000 feet.	Pounds per mile.	Feet per pound	Pounds per 1000 feet.	Pounds per mile.	Feet per pound.	Pounds per 1000 feet.	Pounds per mile.	Feet per pound.	R. Ohms per 1000 feet.	Ohms per mile.	Feet per ohm.	Ohms per pound.
....	707 160	500000.0	392700	1680	8870	.59	1744	9208	.57	1562	8247	.64	.02079	.10978	48290	.00001322
....	632 455	400000.0	314160	1343	7091	.74	1405	7418	.76	1209	6489	.81	.02589	.13723	38630	.00002063
....	547 722	300000.0	235620	1055	5570	.94	1112	5873	.90	941	4968	1.06	.03465	.18297	28980	.00003656
0000	460 000	211600.0	166190	700	3718	1.42	746	3940	1.34	639.33	3375.7	1.56	.04904	.25891	20392.9	.00007653
000	409 640	167805.0	131790	565	2983	1.77	599	3161	1.67	507.01	2677.0	1.97	.06181	.32649	16172.1	.00012169
00	364 800	133079.0	104520	460	2433	2.17	493	2600	2.03	402.09	2123.0	2.49	.07797	.41168	12825.4	.00019438
0	324 950	105592.5	82887	371	1963	2.69	397	2095	2.52	319.04	1684.6	3.14	.09827	.51885	10176.4	.00030734
1	289 300	83694.5	65733	281	1483	3.56	299	1572	3.35	252.88	1335.2	3.95	.12398	.65460	8066.0	.00048920
2	257 630	66373.2	52130	231	1219	4.33	248	1310	4.03	200.54	1058.8	4.99	.15633	.82543	6396.7	.00077784
3	229 420	52633.5	41339	193	1018	5.18	207	1091	4.84	159.03	839.68	6.29	.19714	1.04090	5072.5	.0012370
4	204 310	41742.6	32784	152	802	6.58	162	855	6.17	126.12	665.91	7.93	.24858	1.31248	4022.9	.0019666
5	181 940	33102.2	25998	123	650	8.12	134	710	7.45	100.01	528.05	10.00	.31346	1.65507	3190.2	.0031273
6	162 020	26250.5	20617	104	550	9.60	112	595	8.87	79.32	418.81	12.61	.39528	2.08706	2529.9	.0049723
7	144 280	20816.7	16349	....	....	.....	....	....	....	62.90	332.11	15.90	.49845	2.63184	2006.2	.0079078
8	128 490	16509.7	12966	66	352	15.00	74	387	13.65	49.88	263.37	20.05	.62849	3.31843	1591.1	.0125719
9	114 430	13094.2	10284	....	....	.....	....	....	.....	39.56	203.88	25.28	.79242	4.18400	1262.0	.0199853
10	101 890	10381.6	8153.2	48	250	21.11	52	271	19.50	31.37	165.63	31.38	.99948	5.27726	1000.5	.0317946
11	90 742	8231.11	6467.0	....	....	.....	....	....	.....	24.88	137.37	40.20	1.2692	6.65357	793.56	.0505413
12	80 808	6529.94	5128.6	31	160	33.00	33	172	30.36	19.73	104.18	50.69	1.5890	8.39001	629.82	.0803641
13	71 961	5178.39	4067.1	....	....	.....	....	....	.....	15.65	82.632	63.91	2.0047	10.5798	499.06	.127788
14	64 084	4106.76	3225.4	23	118	44.74	24	125	42.24	12.41	65.525	80.38	2.5266	13.3405	395.79	.203180
15	57 068	3256.76	2557.8	....	....	.....	....	....	.....	9.84	51.956	101.63	3.1860	16.8223	313.87	.323079
16	50 820	2582.67	2028.6	14	76	69.47	15	80	66.00	7.81	41.237	128.14	4.0176	21.2130	248.90	.513737

Correcting Dynamo Troubles.—Inasmuch as the use of small direct current electric dynamos is becoming very general, and since they are frequently in operation under the supervision of users who are not as a rule familiar with electrical machinery, a few simple pointers relative to the care and maintenance of an electric dynamo may help some user to avoid considerable annoyance.

Electrical machinery, even though it has been largely shrouded in mystery, is, nevertheless, comparatively simple apparatus in its operation and maintenance. To a considerable degree it is a delicate piece of mechanism, by which is meant that it cannot be handled with the same treatment as one would expect to give a clumsy, crude, or inexpensive device. However, there are a few underlying principles which govern such dynamos as are ordinarily used in small isolated plants, which, if they are observed, will enable practically any operator to maintain and keep in perfect running condition any well constructed machine. When the dynamo is received from the factory it should be carefully examined to see if it is in apparently good condition, or whether it shows evidence of having been injured by rough handling in transit. If this inspection points to its having arrived in good condition, its installation should be considered in a general way along the lines similar to those which would be observed for the installation of any piece of machinery. Care should be taken to see that the bearings are properly supplied with oil; that the dynamo stands perfectly level on its foundation; that the belt is of good quality and free from bumps or improper lacing. It may be noted that the dynamo does not necessarily require an independent foundation, which is demanded by some classes of apparatus. Because of the fact that its vibration is very slight, any rigid or substantial floor will answer for this purpose.

In starting up a dynamo, only two things which might be termed "electrical" need be specially considered. The first is the direction of rotation, because each dynamo as shipped from the factory is so connected as to run in only one direction and will not generate current if the direction of rotation is reversed. It is an easy matter to change the connections on a machine so that a reversed direction is possible, and a sheet of instructions furnished with the dynamo usually covers instructions for this modification, but it should be remembered that each dynamo as received by the user is so connected as to operate in only one direction.

The second matter for consideration is the speed of the dynamo, which should not be less than the speed given on the name plate nor greater than ten per cent above the speed. A slower speed would interfere with the building up of the voltage, while a higher speed would deliver an excessive current from the machine. It is needless to add that the directions for wiring connections furnished with the dynamo should be followed carefully.

If, after a dynamo has once been running satisfactorily, there occurs some difficulty in its operation, the probabilty is that, unless the occasion of the trouble is due to some mechanical injury or to the dynamo having become saturated with water or oil, the nature of the trouble will most frequently manifest itself in one or two ways. The first is that the dynamo will refuse to generate current, and the second is that sparking will show itself between the commutator and the brushes. Under this latter head it is worth remembering that the heating of a dynamo is generally due to some cause which, if it existed to a greater degree, would manifest itself in sparking, so that many times the heating of the machine means that trouble exists to a limited extent, which, if it occurred in a greater degree, would manifest itself in sparking. A common exception, however, to this statement is that the brushes, if pressing too firmly on the commutator, will from their friction produce heat. With the above explanation, the more frequent difficulties can be classified under the two heads, "Failure of the dynamo to generate" and "Sparking at the commutator."

If, on starting a dynamo, after its use has been discontinued for a time, it refuses to generate, which means that the operator is unable to secure electricity from it, he should first assure himself that the machine is operating at its proper speed and that there has been no speed reduction, due either to a slowing up of the motive power or to a slippage of the belt. If no such difficulty appears, the next investigation should determine as to whether or not the resistance of the rheostat remains in the field circuit. In many instances dynamos can frequently be made to generate by simply moving the handle of the rheostat to the point marked "highest voltage." The third and possibly most common cause of failure of a dynamo to generate is due to a defective contact between the commutator and the brushes. This may be caused by a lack of proper tension on the brushes, due either to their being too weak or their need of readjustment. Again the brushes and holders may have become dirty and gummy, preventing their proper action. An excessive amount of grease or dirt on the commutator occasionally (especially in cold weather) forms a scum over its surface which intervenes between it and the brushes, retarding the flow of the current. It is possible that the obstacle in the path of the current may lie elsewhere than between the brushes and the commutator; as, for instance, loose connection may exist in the wire leading from the brushes to the head post. However, the operator can look intelligently for the trouble when he realizes that the early current generated when the dynamo begins to operate is of slight intensity, and obstacles which would not interfere with the flow of the current of ordinary proportions will retard the flow of this initial current, consequently a very slight resistance or hindrance may prevent the dynamo from generating.

To these statements may be added the facts that the brushes may have become moved from their proper position or the dynamo may have lost its magnetism. The latter condition, however, is rare; and the former will not exist unless the machine has been tampered with. In a later paragraph is given information relative to the adjustment of the brushes.

This brings us up to the general manifestation of trouble, namely, sparking at the commutator, which is probably the most frequent difficulty encountered in a dynamo. A small red spark, which can be easily recognized as occasioned by dirt, is not seriously injurious, and a cleaning of the commutator and brushes will overcome it. However, a vicious, spitting spark will, in the course of a comparatively brief time, materially injure the dynamo, and when first detected, steps should be taken to overcome it without delay.

Briefly indicating the causes of sparking which do not permit of ready classification, it may be possibly occasioned by an excessive overload on the machine, due to a leakage in the wiring or to the use of too many lights. If this is responsible for the sparking, the machine will heat materially in all its parts. It may be true that an open circuit or a break in the wiring of the armature may exist. In this instance the spark will be very vicious, and an examination of the commutator will show that it has been burned on one of the mica lines across its surface. An open circuit in one of the fields may also result in sparking, but this can be determined by an unequal heating of the fields.

Coming, however, to the two most common causes of sparking: the first lies in the fact that the contact between the commutator and the brushes may not be firm and uniform. The commutator itself may be rough, or the bearing surface of the brushes may be irregular; roughness of the commutator resulting occasionally by its having been burned down or worn. Occasionally the copper wears more rapidly than the mica, leaving the mica projecting upon the surface of the commutator. If the commutator is rough, a piece of No. 2 sandpaper held firmly on its surface while it is in operation will overcome minor irregularities. If this does not correct the trouble, the armature should be taken to a first-class machine shop and the commutator turned off in a lathe.

If the brushes are so worn that they do not fit snugly on the commutator, fasten a strip of No. 2 sandpaper around the face of the commutator, the sand side out; then revolve the commutator with this strip of sandpaper attached to it until the bearing surface of the brushes will be trued up, insuring a perfect contact. Strange as it may seem, the most common cause of sparking, occasioned by an improper contact, lies in the fact that the user does not recognize that carbon brushes wear out and occasionally need to be replaced. Frequently machines are sent back to the manufacturer for repairs when the only occasion of the trouble is that the carbon brushes have been worn until they cannot rest firmly on the commutator. When the brushes become so worn that it is difficult with the mechanism of the holder to secure a firm pressure against the commutator, they should be renewed with new and longer brushes.

The last occasion for sparking which will be mentioned is that the brushes may have been shifted out of their proper position in reference to each other and to the commutator. On machines which have two-field coils the brushes should rest on the commutator at points which are exactly opposite to each other. On machines which have four-field coils these points should be exactly 90° apart. If the brushes are properly spaced in reference to each other, then their correct position on the commutator becomes a matter of locating what is known as the "neutral point." In order to locate this neutral point, move the rocker arm which carries all the brushes around with the direction of rotation, while the machine is in operation, and carrying a comparatively light load. Do this until a slight spark appears, then move the rocker arm back in the opposite direction just enough to stop the sparking; this will be the neutral point.

PRACTICAL POINTS.

Brushes and Commutators.—Brush holders and commutators will sometimes show excessive temperatures because of the heat which may come from a bearing in which the armature shaft revolves. The failure of a bearing upon a dynamo or a motor to run cool may be due to any one of a great variety of causes, some of which are mechanical and others electrical.

A common cause, and one which is not infrequently overlooked is that of lack of sufficient oil in the bearing for the purposes of lubrication. When renewing the supply of oil to a bearing care should be exercised in the choice of oil, making certain that it is free from dirt or grit, and that it is an oil of good quality for the purpose in hand. The passages or oil ducts should be carefully examined and kept perfectly clear for the free running of the lubricant. A bearing may be leaking at some point, causing the oil to run off much sooner than an attendant would think, and this kind of a defect should be carefully guarded against.

The modern dynamos and motors have their bearings so designed that they are self-oiling, *i. e.,* the oil is carried by means of chains or rings from the oil chamber beneath the bearing proper, up and over the shaft and through grooves provided for the purpose, returning to the well to be used over and over again. Gauge glasses are nearly always provided by means of which it is possible to observe at any and all times the quantity of oil remaining in the well. Oil used over and over again in this manner is quite likely to gather foreign impurities. It is good practice to remove the oil from bearings at least once a month, clean out the bearing thoroughly with gasoline, filter carefully the oil that is left and return the same to the bearing, adding a sufficient quantity of fresh oil to make up for any loss which has been the result of operation.

Gritty substances are very likely to work into bearings at different times, depending upon the use which is made of a motor or a generator. If electrical apparatus is to be placed in a space that is dirty, and cannot well be kept clean, then it is a good precaution to have the machine suitably enclosed, or else to have the bearings completely enclosed with tight-fitting plates about the shaft so as to exclude foreign substances. Whenever it is found necessary to wash out a bearing in order to remove any dirt, care should be exercised not to get any water or kerosene upon the commutator or windings of the machine.

A roughened shaft or a tight fit between the shaft and the sleeve of the bearing may cause heating. These difficulties are purely mechanical and are easily remedied, once that the source of the trouble is ascertained.

Sudden and excessive strains sometimes spring the shaft of a generator or a motor, and it not infrequently happens that with some types of bearings they are thrown out of line. Either of these causes will bring about a heating of the bearing. A bent or crooked shaft can rarely ever be straightened, the only remedy being a new one. Bearings that can be thrown out of line for the reasons mentioned are also susceptible of being properly aligned by means of the caps and screws for holding them in position.

The end thrust of a collar on the armature shaft, upon one side or the other of the machine, may cause a heated bearing. When machines are driven by belting, or when motors are connected with shafting by belting, it is an easy matter to ascertain whether the armature is running freely with respect to the belt connection. A stick placed against the end of the shaft would enable one to move the armature back and forth with very little effort. In fact, every armature should have free end play, and if a test with a stick as mentioned does not show that such a free end play does exist, then the machine should be lined up with respect to its belt, so that such end play is secured.

The bearings may wear down sufficiently in time to permit of the armature bands rubbing against the pole pieces, or stationary iron of the machine. This can often be detected by placing the ear near the frame of the machine opposite the pole piece where it is thought that the armature might come in contact. It might also be detected by turning the armature over slowly with the belt removed and with the field current turned on. It might also happen, however, that the armature will not touch any of the field poles, except when running under load with the belt on. The positive evidence of rubbing lies in an examination of the circumference of the armature itself when the bands around the armature will show whether there has been any rubbing or not. This kind of an examination can usually be made without removing the armature from the machine. If there should be positive evidences of rubbing, it must not be allowed to continue.

The pulley, the belt or other parts of the revolving armature shaft may rub against adjacent surfaces, and bring about a scraping or a rattling noise. The movement of the shaft back and forth in its bearings in one direction or another may stop the noise, in which case it will be a simple matter to locate the cause, after which it will be an equally simple matter to remedy the trouble.

Generally, in starting up a new generator or motor, the new and unused carbon brushes upon a new, and previously unused commutator will cause an unpleasant squeaking or a hissing. The sound is usually of a high pitch and is easily located. Sometimes, it may be due to but one or two new brushes. These can be located by removing one brush at a time until the noisy ones are found. Then by moistening them slightly with a light oil, the noise from that particular brush will be stopped. There should not, however, be so much oil used for this purpose so that any of it will adhere to the brush in the form of drops. It sometimes happens that the commutator has not been finished off as smoothly as it should have been and this, of course, would cause a considerable humming until the commutator surface had been worn over sufficiently to take on a polished appearance. If the commutator is rough enough to cause a hissing of the brushes, it should be polished off by hand before it is put into operation. This can be done in the manner already described, and would insure a much better commutator in service than if allowed to run along in the rough state, trusting to luck that it will assume a polished appearance as a result of operating conditions alone.

A squeak due to the slipping of a belt upon the pulley is easily located, and not confounded with any other noise which may result from operating any class of machinery. Whenever such slipping of a belt occurs, it means a loss of power, and that means expensive operation. A care for the details of operating costs will not permit of a squeaking belt at any point.

Another kind of humming is often present in motors and in some kinds of generators. This is the humming which is something of a musical sound, and is likely to be confined to the armature teeth as they pass the pole faces at high speed. It is a molecular vibration due to the magnetic reversals in the iron. If it is an objectionable feature in the operation, it may be remedied by trimming off the ends of the pole faces so that the full length of an armature tooth would not be likely to leave the pole face throughout its entire length at the same instant of time, but would shade off instead. The testing of generators and motors in the shops of the builders, however, is supposed to reveal excessive humming, and the trimming of pole faces should be done before the machine is sent to the shipping room. In general, it is always well to be certain that the noises of operation come from the electrical apparatus, and not from some other equipment which might be close by.

Transformer Oil.—Transformer oil, its proper character, treatment and use, has been much neglected by central station engineers. It forms one of the weak links in the chain of a high-tension electric-transmission system. In its dual function as insulator and cooler, it requires high dielectric strength, and high flash point, combined with great fluidity. It should be neutral so as to not dissolve the insulation of the core and coils immersed in it.

Of these qualities, the dielectric strength is the most variable, for it depends largely upon the amount of moisture present. The popular axiom that oil and water do not mix is not scientifically correct, for oil does absorb a small amount of moisture that materially lessens its dielectric strength. Instances have been known of transformer oil having broken down under 16,000 volts when wet, but which stood the test of 40,000 volts after being dried.

While oil and water do not chemically mix, they may mingle so closely as to require steam, or rheostat heating to remove the water. Every precaution should be taken to keep oil dry during shipment and in use, for it abhors dehydration even more than nature abhors a vacuum.

It should have a high fire or flash test to eliminate danger of fire. Crude oil is refined by frictional distillation, the most volatile products passing off first. These are low in gravity and in burning temperature, as is exemplified by gasoline. Kerosene for use in lamps is one of the next products, soon followed by an oil suitable for transformer purposes. This usually has a gravity of 30° Baume or less, and burns at about 300° Fahrenheit. The higher the temperature at which the product is distilled, the greater is its viscosity. Consequently, what is gained in flashing temperature is lost in fluidity. Acid introduced into the refining must be removed by adding just enough alkali to render the oil neutral. Disastrous fires have been known to result from the volatilization of the oil by an arc.

Another frequent trouble is the deposition of a thick, carbonaceous, jelly-like sludge on the cooling coils, and in the circulating ducts. The former are covered so thick that cooling is not effected, and the latter are so clogged that circulation is difficult. Such deterioration generally occurs when the oil has been overheated. The deposit is easily washed off when hot, but becomes hard and brittle upon exposure to the air, resembling bitumen in this respect. The deposits around the points of high potential allow creepage, so that a medium of high resistance may become a conductor.

But careful examinations of these troubles show that they are usually due to no inherent fault of the oil, but to the transformer design, or more particularly to the attendant's carelessness.

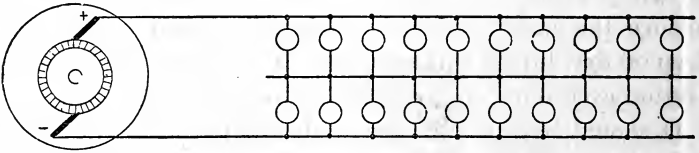


Fig. 661

Careful breakdown tests should be made not only when the oil is furnished, but at frequent intervals thereafter, once a month not being too often for main stations. Tests for acidity will avoid the destruction of the insulation by dissolving, and flash tests will often prevent fires. The carbon may be removed by occasional filtering. In case of leaky cooling coils, the water should be drawn off from the bottom until such time as the transformer can be taken out of service and properly repaired.

All this trouble occurs with both water, and self-cooling transformers. Where water is plentiful, it has been suggested that outside circulation of the oil would cause better cooling, and larger ventilating ducts would not become clogged. We attain success only by the most careful attention to the details of our work. Look after the oil, and transformer troubles will take care of themselves.

Three Wire System with One Dynamo.—When the load on one side of the middle or neutral wire exactly equals the load on the other side, as in Fig. 661, the circuit is balanced, but it is very seldom that such load conditions exist, at least for any length of time, and when there is a difference between the loads carried by the two sides, the circuit is unbalanced.

In order therefore to successfully operate a three wire system with one dynamo, it becomes necessary to provide some method of taking care of the surplus current on the lightly loaded side, and transferring it to the heavily loaded side; in other words, to balance the circuit. There are two methods by which this may be accomplished.

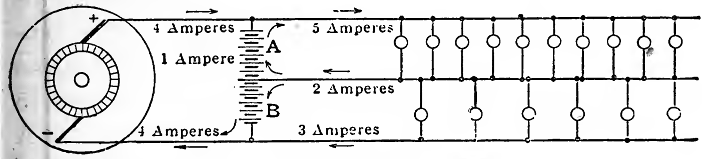


FIG. 662

The first and most simple method of compensating for unbalancing is to connect a storage battery between the two main wires, and then connect the neutral wire to the middle point of the battery, as shown in Fig. 662. Here are shown connected 10 lamps on one side, and 6 on the other. The direction of flow of the current is indicated by the arrows. Assuming that the resistance of each lamp is 220 ohms, which is the ordinary value for 110 volt lamps, the joint resistance of the group of 10 lamps would be

220÷10=22 ohms. The joint resistance of the 6 lamps on the other side would be 220÷6=36.66 ohms.

The total resistance of both groups of lamps would be 22+36.66=58.66 ohms, and the volume of current flowing through both groups would be 220÷58.66=3.75 amperes. Assuming that each lamp requires ½ ampere of current, the group of 10 will require 5 amperes, and the group of 6 requires 3 amperes. As the volume of current equals 3.75 amperes, it is evident that the 10 lamps will not get enough current, while the group of 6 will get too much, unless, as before mentioned, a balancer be provided, and right here is where the storage battery enacts its role. Under the conditions shown in Fig. 662, the A half of the battery will deliver just enough current, provided the voltages are suitably proportioned, to supply one-half of the excess or unbalanced load on the heavy side of the system. The dynamo supplies the other half of the excess current which comes in on the neutral wire, with the current supplied by the A section of the storage battery, and returns to the dynamo through the B half of the battery charging that section.

This proportion holds good for any degree of unbalancing; that is, that part of the battery on the heavily loaded side will send out one-half of the current in the neutral wire, and the other half will go through the part of the battery that is on the light load side of the neutral.

This arrangement, though apparently ideal in simplicity on paper, is not so attractive in practice, for the reason that a regulator is needed in conjunction with the battery in order to prevent it from exhausting itself when the load is heavy, or drawing too heavily from the line when it is light. Moreover, the two halves of the battery cannot be kept in equal condition, because one side would do more work than the other, unless the circuit could be unbalanced alternately, and equally on, first one side and then the other. This difficulty can be met, however, by exchanging the two sections at regular intervals, say once a week.

A more practical method of compensation is by means of what is commonly termed a "motor-balancer," but is more correctly a motor-compensator. This consists of two small motors exactly alike in all respects, their shafts rigidly coupled together and their armatures connected, one on each side of the neutral wire, as indicated in Fig. 663, where 120 lamps are represented on each side of the neutral wire. Here it is assumed that the motor armatures require one ampere to drive them, or 220 watts (110 watts each), and for simplicity the current required by their field windings is ignored. So long as the load is balanced, the two armatures will take current from the main wires only. and will revolve idly. If more load is added to one side, however, or some load taken off the other side, the equilibrium between the voltages of the two sides will be upset; the voltage at the brushes of the motor on the lightly loaded side will be higher than that at the brushes of its mate, and it will drive the latter at a speed beyond that due to the circuit voltage, making a dynamo of it, and forcing it to carry the unbalanced part of the heavier load on the circuit. This is illustrated in Fig. 664, where 120 lamps are shown on one side and 60 on the other, each of the circles representing 10 lamps, taking ½ ampere each. What causes the distribution of current shown is this: When the load in the B division is reduced the voltage rises, because the losses in the dynamo and circuit wires are reduced; the voltage between the neutral and the negative wires rises more than that between the positive and neutral, because the resistance there is higher—all the reduction of load has occurred in that division of the circuit. The armature B, therefore,

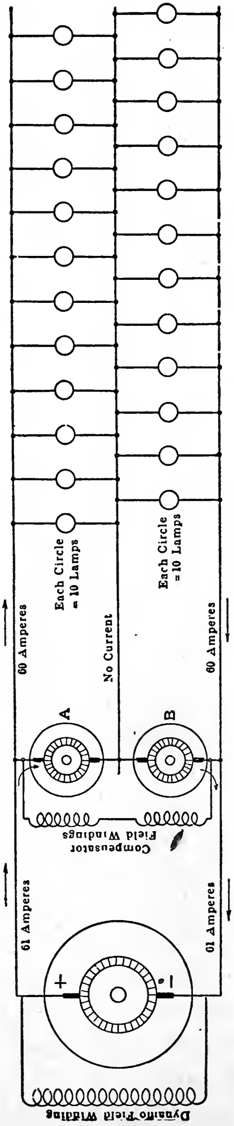


FIG. 663

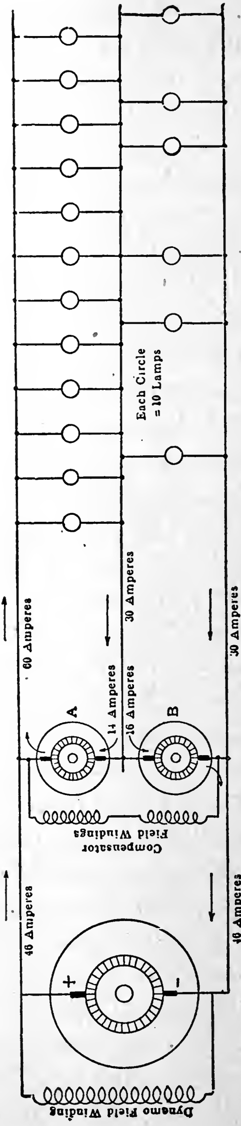


FIG. 664

speeds up, dragging the armature A with it until the voltage of the latter increases above that of its side of the circuit sufficiently to carry half of the excess load on that side, minus the power required to drive the two machines. This power was assumed to be 220 watts; the current taken by the two armatures in series in Fig. 663 being one ampere and the total voltage 220. Here, one of the armatures does all the work, so that the whole 220 watts must be applied to it, in addition to an amount of power equal to that being delivered by the armature A working as a dynamo. As the armature B takes its current now from the unbalanced current coming in on the neutral wire, it works at 110 volts and therefore requires 2 amperes to overcome the losses in the two machines (the losses in the windings are ignored to simplify the problem); the neutral wire must carry 30 amperes because the 60 lamps in the negative division will pass only 30 amperes. Deducting the 2 amperes for motor losses leaves 28 amperes, which divides between the two machines, 14 amperes supplying the motor with the energy necessary to produce 14 amperes from the armature now driven as a dynamo.

Another way to arrive at the division of current is as follows: The main dynamo must supply all of the energy represented in the circuit; all that the compensator does is to transfer the surplus energy from one side of the circuit to the other—it cannot supply any additional energy because it is driven by energy taken from the main circuit. Now the lamps take each ½ ampere at 110 volts, or 55 watts; there are 180 lamps, requiring $180 \times 55 = 9900$ watts. The compensator requires 220 watts to overcome its no-load losses, the extra losses at load being ignored for the present. The lamps and compensator together, therefore, require $9900 + 220 = 10{,}120$ watts. Ignoring line losses, the generator works at 220 volts, and in order to deliver 10,120 watts it must deliver 10,120÷220=46 amperes. Since the lamps in the positive division (A) require 60 amperes, the armature A working as a dynamo must supply 60—46=14 amperes. Consequently, of the 30 amperes in the neutral wire, 14 must have been generated in the little machine; the other 16 pass through the motor armature B to the main dynamo, as prevously explained.

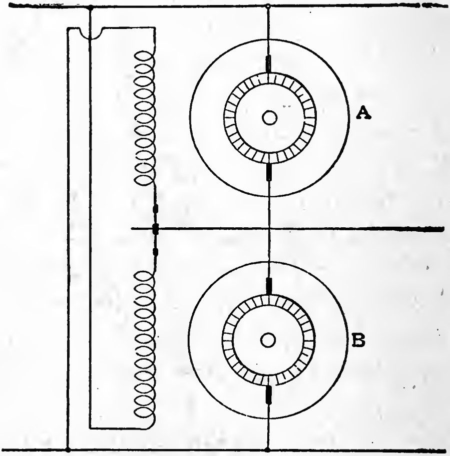


FIG. 665

The exact figures in practice would not be those here stated because the line losses, the current in the field windings of the compensator, and the losses in their armature windings affect the current distribution. The principle, of course, is not affected; the machine on the lightly loaded side of the system always runs as a motor, and drives its mate as a dynamo, the latter supplying about one-half of the difference between the two divisions of the load, minus the power required to drive the machine. The losses do affect the voltage regulation, however. If the armature windings of the compensator are of very low resistance, the voltages on each side of the neutral will be kept almost exactly equal; if the armature resistances are high, the voltage between the neutral and the main wire which carries the heavier load will be appreciably lower than that on the other side of the system.

The regulation obtained with motor compensators can be much improved by cross-connecting the field windings, as shown in Fig. 665. The result of this is that when the load on the side A, for example, is less than that on the other side, the voltage of the side A being higher than that of the side B, the field strength of the machine A will be weaker than that of the machine B, and its speed will be higher than it would be with a steady field. The machine B, on the other hand driven as a dynamo, will have its field strengthened, and will deliver a higher voltage than it would otherwise. In other words the machine that runs as a motor runs at a higher speed, thus giving its mate a higher voltage, and the latter will also have a stronger field, increasing its voltage still more, with the connections as shown, in Fig. 665, than with the arrangement shown in Figs. 663 and 664. The armature capacity of a motor balancer in amperes, must be equal to one-half of the current that will flow in the neutral wire when the system is out of balance by the maximum amount possible under operating conditions, plus the current required to overcome all losses in the two armatures at full load. The losses in small armatures range from 5 to 10 per cent at full load; therefore if the armatures of the balancer can carry 55 per cent of the maximum current that is likely to ever flow through the neutral wire they will be large enough.

ARC LAMPS.

When two rods of carbon are connected to a source of current, and their ends brought into contact with each other, and then separated a slight distance, the current will continue to pass across the interval, but an intense heat is generated, and the space between the ends of the carbon rods is filled with carbon vapor, and minute particles. The current passes over this space in a bow-shape path or arc, and it is from this fact that the lamp gets its name. The arc is constantly moving, and generally revolves around the carbon points. This can be easily seen by looking closely at a burning lamp through a smoked glass. After a lamp has been burning for some time on direct current the carbons assume the shape shown in Fig. 666, the upper or positive carbon assuming a cup shape, while the lower carbon generally burns to a point. This cup shape formation

Fig. 666

on the upper or positive carbon acts as a reflector to throw the light downward. The positive carbon burns away about twice as fast as the negative carbon, and lamps must be trimmed accordingly. Sometimes the current feeding arc lamps (on direct current systems) becomes reversed, either through the dynamo reversing its polarity or through wrong plugging of the switchboard. The lamps will now burn "upside down," or, in other words, the bottom carbon will be the positive one. In such a case, if let go, the carbon holders of the lamp will be burned and the lamp will burn for only half the time for which it was intended, owing to the fact that the lower or negative carbon is only

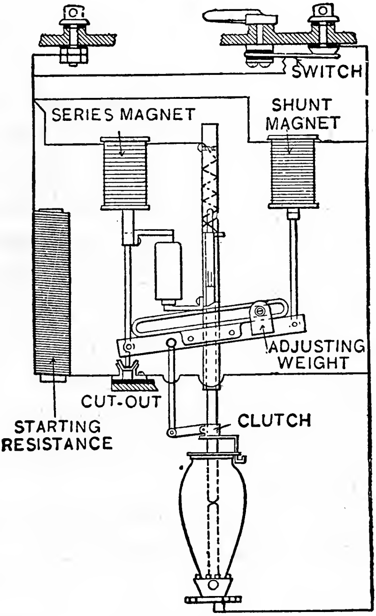


FIG. 667

DIAGRAM OF CONSTANT-CURRENT SERIES ARC LAMP MECHANISM.

one-half as long as the upper or positive carbon. Such a condition can be determined by either of the following ways: See if the light is being thrown downwards. See which carbon is burning away the faster. Raise the carbons and notice the formation of the carbon tips. When the carbons are separated it will be noticed that the tip of one carbon is considerably hotter than the other, and is heated a longer distance from the point; this is the positive carbon.

The heat of the arc is very intense, that of the positive pole being 7200° Fahr. and the negative 5400° Fahr. Fig. 667 illustrates the action of a constant current or series arc lamp. It shows the lamp inactive, the carbons in contact, and the cut-out closed. If current is turned on, it goes through the cut-out. In series with the cut-out is a coil which provides the starting resistance. Its resistance shunts sufficient current through the series magnet to cause it to attract its armature and raise the clutch. This separates the carbons, the arc strikes, and the current is shunted through the shunt magnet. This at once begins to regulate the length of the arc.

The armatures of the shunt and series magnets operate a rocker arm which is pivoted between the magnets, so that the series and shunt magnet have reverse effects on the movable upper carbon. As the shunt-magnet armature is drawn up, the clutch descends, owing to the action of the rocker arms, and the reverse action takes place when the shunt-magnet armature descends. In this way the increase of arc length, shunting more current through the shunt magnet, causes the clutch to descend and the arc shortens. The dash-pot is shown to the left of the central tube above the rocker arm. Immediately below the clutch is the tripping platform, seen extending over the top of the globe.

Adjusting Weight.—This slides back and forth upon the rocker arm attached to the two armature rods. This is fastened in any desired position by a setscrew. For variations in current exceeding 0.2 ampere above or below the rated current of the lamp, the weight must be shifted. By moving the weight toward the clutch rod the voltage is reduced, and moving at away from the clutch rod increases the voltage.

Fig. 668 shows a diagram of connections for the improved Brush arc lamp. These lamps are used on constant current, or series systems, and their action is as follows:

The carbons should rest in contact when the lamp is cut out. When the switch is opened, part of the current from the positive terminal hook P goes through the adjuster to the yoke, and thence through the carbon rod and carbons to the negative terminal hook N. The remainder of the current goes to the cut-out block, but, as the cut-out block is closed at first, the current crosses over through the cut-out bar to the starting resistance, and so to the negative side of the lamp. A part of it, however, is shunted at the cut-out block through the coarse wire of the magnets, and so to the upper carbon rod and carbons and out. This shunted current energizes the magnet, and so raises the armature which opens the cut-out, and at the same time establishes the arc by separating the carbons.

The fine wire winding is connected in the opposite direction from the coarse wire winding, and its attraction is therefore opposite. When the arc increases in length, its resistance increases, and consequently the current in the fine wire is increased. The attraction of the coarse wire winding is therefore partly overcome, and the armature begins to fall. As it falls, the arc is shortened and the current in the fine wire decreases. The mechanism feeds

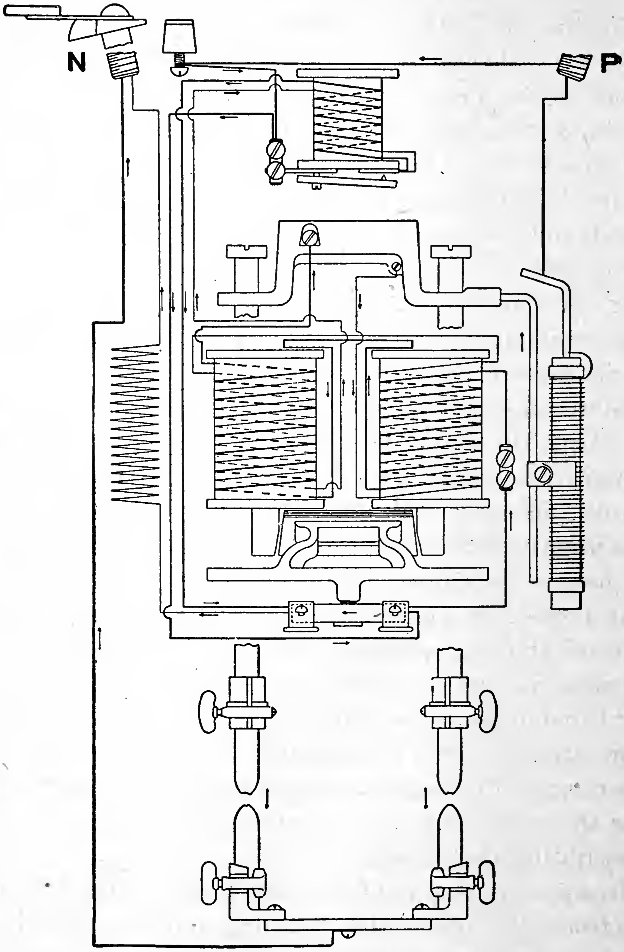


Fig. 668

the carbons, and regulates the arc so gradually that a perfect, steady arc is maintained.

The fine wire of the magnets is connected in series with the winding of a small auxiliary cut-out magnet at the top of the mechanism.

This magnet, which also has a supplementary coarse winding, does not raise its armature unless the voltage at the arc increases to 70 volts. The two windings connect at the inside terminal on the lower side of the auxiliary cut-out magnet, and the current from the fine wire of the main magnets passes through both windings and then to the cut-out block, and so to the starting resistance and out.

If the main current through the carbon is interrupted (as by breaking of the carbons) the whole current of the lamp passes through the fine wire circuit. Before this excessive current has time to overheat the fine wire circuit, it energizes the auxiliary cut-out magnet, and closes a circuit directly across the lamp through the coarse wire on the auxiliary cut-out to the main cut-out block, and thence to the negative terminal.

The auxiliary cut-out operates instantly, and prevents any danger to the magnets during the short period required for the main armature to drop and throw in the main cut-out. When the main cut-out operates, the armature of the auxiliary cut-out falls, because there is not sufficient current in that circuit to energize the magnet.

The voltage at which the auxiliary cut-out magnet operates depends on the position of its armature, which is regulated by the screw securing the armature in position. It should be adjusted to operate at not less than 70 volts.

One of the three methods of suspension may be used for Brush lamps. If chimney suspension, which is the most common, is adopted, the wire, cable or rope used to suspend the lamp must be carefully insulated from the chimney. For this purpose a porcelain insulator should be inserted between the support and the lamp, as shown in Fig. 669.

Hook suspension may be used to advantage in some places, but great care must be taken to insulate the supporting wires from any conductors, as the hooks form the terminals of the lamps.

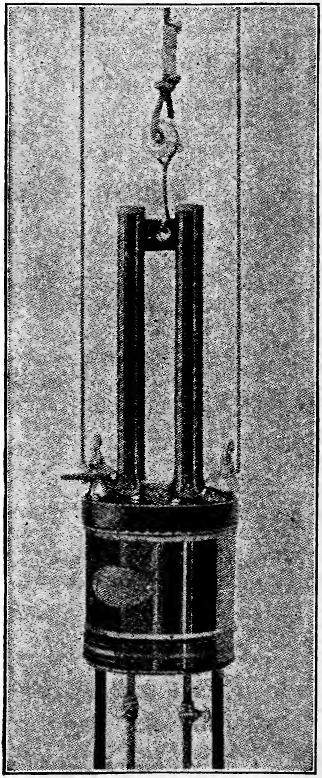


FIG. 669

The most convenient arrangement for indoor use is to suspend the lamp from a hanger board. The porcelain base of the hanger board prevents short circuits or grounds.

A protecting hood is not necessary for outdoor use, as the lamp chimney and its base are one casting and effectually exclude rain or snow.

The lamps run on circuits of 6.6 amperes for 1,200 and 9.6 amperes for 2,000 nominal candlepower. In case it is necessary to run a lamp on a circuit differing from the standard, the lamp may be adjusted by moving the contact on the adjuster. About one ampere either above, or below the normal may be compensated for by this means.

Permanent adjustment for special circuits of variation greater than one ampere is made by filing the soft iron armature. The clutch should be so adjusted that the center of the armature is $\frac{13}{16}$ in. above the plate when the trip on the first rod is touching the bushing, and $\frac{11}{16}$ in. when the trip on the second rod is in a similar position. A small gauge is convenient for adjusting the clutch. The position of the trip of the clutch determines the feeding point of the lamp.

After thoroughly repairing and cleaning the lamp, it should be run a short time before installing. Lamps should not be tested in an exposed place, as a strong draft of air will cause unpleasant hissing which may be mistaken for some internal trouble.

Lamps should not hiss or flame if good carbons are used. A voltmeter should always be used when adjusting or testing.

The lamp terminals are marked P (positive) and N (negative) and should be connected into circuit accordingly.

The carbons should be solid and of uniform quality. For the best results, the upper carbon should be 12 in. $\times \frac{7}{16}$ in., and the lower 7 in. $\times \frac{7}{16}$ in. The stub of the upper carbon may then be used in the lower holder when retrimming.

At each trimming the rod should be carefully wiped with clean cotton waste. If any sticky or dirty spots appear, which cannot be readily removed with waste, use a piece of well-worn crocus cloth, always being careful to use a piece of clean waste before pushing the rod into the lamp.

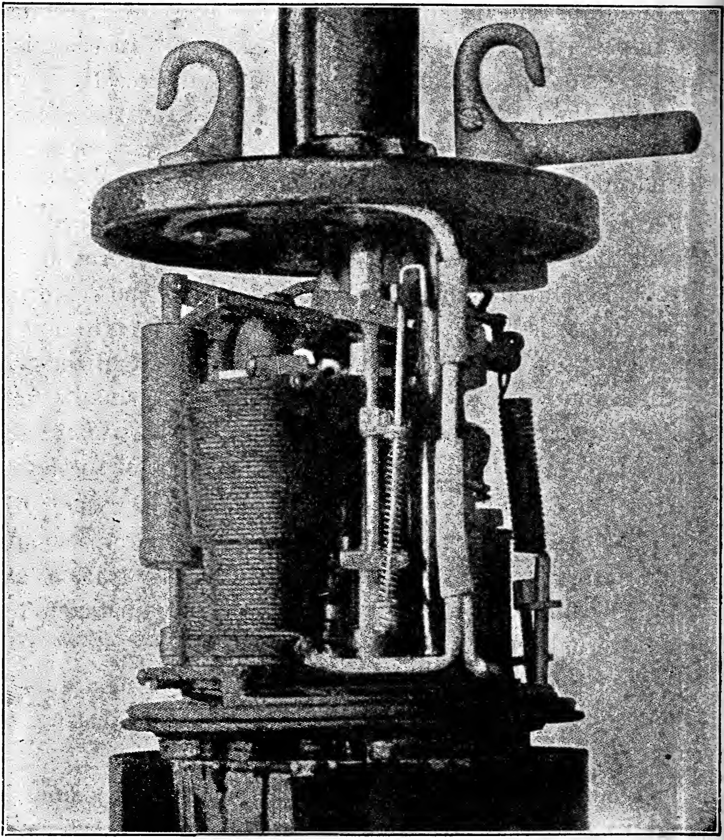


Fig. 670

It should never be pushed up into the lamp in a dirty condition.

The carbon rod may be unscrewed and removed with a small screw driver, or small strip of metal inserted in the slot cut in the rod cap. The cap will remain in the hole through the yoke when the rod is taken out.

In Fig. 670 an interior view of the Thomson-Houston arc lamp is shown. This lamp is also used on constant current systems.

The lamps should be hung from the hanger boards provided with each lamp, or from suitable supports of wire or chain.

As the hooks on the lamp form also its terminals, they should be insulated, where a hanger board is not used, from the chains or wires used to support the lamp.

When the lamps are hung where they are exposed to the weather, they should be covered with a metal hood, to prevent injury from rain and snow.

In such cases, care should be taken that the circuit wires do not form a contact on the metal hood and short circuit the lamp.

Before the lamps are hung up they should be carefully examined to see that the joints are free to move, and that all connections are perfect.

No lamp should be allowed to remain in circuit, with the covers removed and the mechanism exposed. Such practice is dangerous, and in violation of insurance rules.

The object of testing the lamps in the station is to find any defects, if such exist, and to test all the conditions of running, before delivering them to customers. The lamps should not be hung up in their respective places in the external circuit, until everything is running with perfect satisfaction.

The tension of the clamp which holds the rod is adjusted by raising or lowering the arm at the top of the guide rod. (See Fig. 671.) If the tension is too great the rod and clutch will wear badly, and the feeling will be uneven, causing unsteadiness in the lights. Too little tension will not allow the clutch to hold up the rod, and any sudden jar to the lamp will cause the rod to fall and the light to go out.

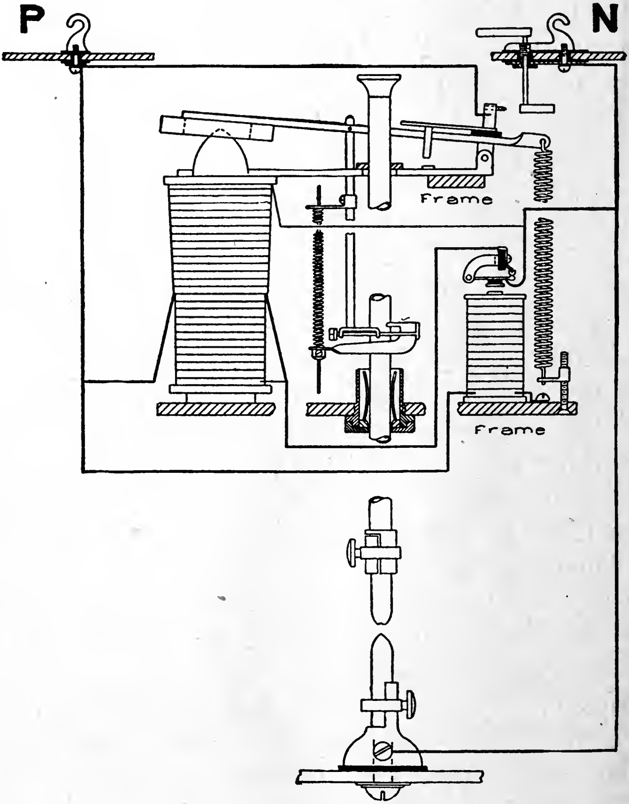


FIG. 671

The double carbon, or M lamp, should have the tension of the second carbon a trifle lighter than the first one.

When adjusting the tension, be sure to keep the guide rod perpendicular and in perfect line with the carbon rod; it should be free to move up and down without sticking.

The tension of the clutch in the D lamp should be the same as that of the K lamp. It is adjusted by tightening or loosening the small coil spring from the arm of the clutch to the bottom of the clamp stop.

To adjust the feeding point in the K lamp, press down the main armature as far as it will go, then push up the rod about one-half its length, let go the armature and then press it down slowly and note the distance of the bottom side of the armature above the base of the curved part of the pole. When the rod just feeds, this distance should be $\frac{1}{4}$ in. If it is not, raise or lower the small stop which slides on the guide rod passing through the arm of the clutch, until the carbon rod will feed when the armature is $\frac{1}{4}$ in. from the rocker frame at base of pole.

To adjust the feeding point of the M lamp, adjust the first rod as in the K lamp. Then let the first rod down until the cap at the top rests on the transfer lever. The second rod should feed with the armature at a point $\frac{1}{16}$ in. higher than it was while feeding the first rod, that is, it should be $\frac{5}{16}$ in. from rocker frame at base of pole.

The feeding point of the D lamp is adjusted by sliding the clamp stop up or down, so that the rod will feed when the relative distances of the armatures of the lifting magnet, and the armature of the shunt magnet from rocker arm frame arc in the ratio of 1 to 2. There should be a slight lateral play in the rocker, between the lugs of the rocker frame.

The armatures of all the magnets should be central with cores, and come down squarely and evenly. There should be a separation of $\frac{1}{32}$ in. between the silver contact points, when the armature of the starting magnet is down. This contact should be perfect when the armature is up. The arm for adjusting the tension should not touch the wire or frame of the lamp when at the highest point. There should be a space of $\frac{3}{32}$ in. or 1/8 in. between the body of the clutch and the arm of the clutch, to allow for wear on the bearing surfaces.

Always trim the lamp with carbons of proper length to cut out automatically, that is, have twice as much carbon projecting from the top as from the bottom holder. Always allow a space of 1/4 in., when the lamp is trimmed, from the round head screw in the rod, near the carbon holder, to the edge of the upper bushing, so that there will be sufficient space to start the arc.

The arcs of the 1,200 candlepower lamps should be adjusted to 3/64 in., with full length of carbon. Arcs of 2,000 candlepower lamps should be adjusted from $\frac{1}{16}$ to $\frac{3}{32}$ in. when good carbons are used.

The action of a lamp that feeds badly may often be confounded with a badly flaming carbon. The distinction can readily be made after a short observation. The arc of a lamp that feeds badly will gradually grow long until it flames, the clutch will let go suddenly, the upper carbon will fall until it touches the lower carbon, and then pick up. A bad carbon may burn nicely and feed evenly until a bad spot in the carbon is reached, when the arc will suddenly become long and flame and smoke, due to impurities in the carbon. Instead of dropping, as in the former case, the upper carbon will feed to its correct position without touching the lower carbon.

In a series arc lamp the shunt coil is used to regulate the voltage over the arc. With constant potential arc lamps this shunt coil is not needed, owing to the fact that the voltage over the lamp is practically constant. Fig. 672 shows a diagram of an arc lamp for use on constant potential circuits. The upper carbon is supported by means of an iron yoke which forms a core to the two solenoids M M. Current entering binding posts T passes through the windings of these two solenoids and then through the carbons and through the resistance coil R to the other terminal of the lamp. The action of the lamp is as follows: Current passing over the solenoids M M is regulated by the resistance across the arc. This current produces an electromagnetic pull on the iron core and floats, magnetically, the core and upper carbon. When the carbons burn away at the crater the distance from point to point of the carbons is increased, and a corresponding increase in resistance to the flow of the current takes place. This reduces the flow of

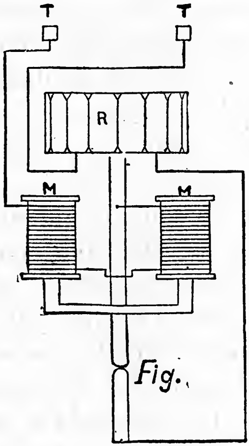


FIG. 672

current around the solenoids and correspondingly reduces the electromagnetic pull on the core; the iron core and carbon fall a slight distance by gravity. In so doing the distance at the crater is decreased and the flow of current increased, and a corresponding increase in resistance to the solenoids and drawing up the core and carbons. In this way a very nice equilibrium between gravity and magnetic pull is maintained. It will be noticed that this lamp has no automatic cut-out as has the constant current arc lamp. In a series arc lamp when the carbons are all consumed, the automatic cut-out closes the circuit from the positive and negative binding posts of the individual arc lamp, thereby maintaining a path through the arc lamp over which the current can continue to flow to supply the remaining arc lamps in the series circuit.

The series arc, as its name would indicate, is the most simple of all lighting circuits. The lamps are arranged so that all the current from the positive pole of the dynamo goes through each, and from the last on the conductor leads back to the dynamo. The series system is more generally used where it is desired to illuminate a large district, as in street lighting. It is also used to some extent in store lighting, although the series arc is fast being replaced with the constant potential arc for this purpose.

In the low tension or constant potential arc lamp the use of a cut-out mechanism is not necessary, because these lamps burn singly across the system of wiring, where a constant potential is maintained, and hence when the carbons are all consumed, current simply ceases to flow across them. In the open arc lamp the potential across the crater is usually from 45 to 50 volts, while in the inclosed arc lamp the potential across the crater is from 68 to 75 volts. This is due to the increased resistance through the crater, because of the peculiar nature of the gases emitted from the crater burning in a condition with practically no atmosphere. When such an arc lamp is connected across a 110 volt circuit, the lamp contains a resistance coil in the mechanism box over which the current must flow before producing the arc, see R. Fig. 672. This resistance coil assists to reduce the pressure from 110 volts to the pressure required by the arc or crater. If, for instance, the electromotive force across the wires supplying current to a low tension arc lamp is 110 volts, and the pressure required to maintain the arc or

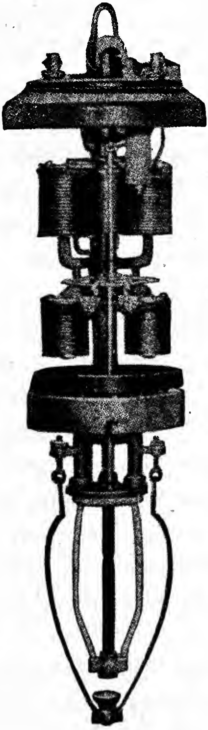


Fig. 673

crater is 70 volts, then the resistance coil chokes down the electromotive force from 110 to 70, or 40 volts. If the arc consumes 4 amperes of current then the loss is 4 (amperes) times 40 (volts), or 160 watts. This 160 watts is lost by heat radiating to the atmosphere from the wire of the resistance coil. The constant potential lamp is usually referred to as the low tension arc lamp. The high tension arc lamp generally burns with the arc in the open air, while the low tension lamp burns with the arc encased in a small glass bulb so arranged as to permit the upper carbon to slide into the bulb in a manner that will maintain, as near as possible, a condition whereby the arc burns in a gas containing no oxygen. The enclosed arc lamp has the advantage of burning a considerable number of hours without being recarboned or trimmed; but it also has the disadvantage that the bulb enclosing the arc turns black after burning for some time, caused by the gases emitted from the arc. This renders the bulb partially opaque, consequently imprisoning a considerable quantity of useful light. Enclosed arc lamps are also operated in series systems, and where they are so used the objection of loss due to the cutting down of the voltage (as in constant potential lamps) is overcome. Enclosed lamps are also operated on alternating current systems.

The operation of the alternating current arc lamp, and the mechanism in the lamp is very similar to that of the direct current arc lamp, but the magnets instead of being constructed of solid iron are laminated in a manner similar to the system of lamination explained in the construction of armatures. These laminated cores, and other parts forming the magnetic circuit in the arc lamp are necessary to avoid eddy currents. The crater has neither a cup shape on the upper carbon, nor a point on the lower carbon, because current flows through the crater alternately positive, and negative with each alternation. In the alternating arc lamp the upper and lower carbons burn away with almost equal rapidity, and the same quantity of light is projected upward as downward.

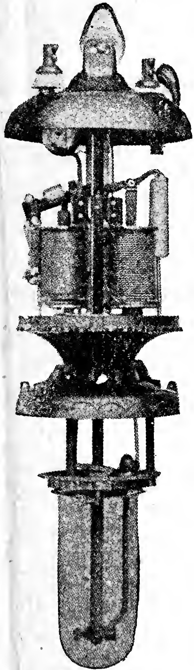


Fig. 674

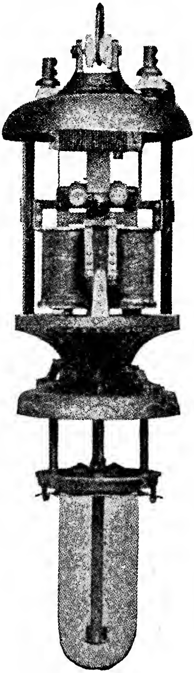


Fig. 675

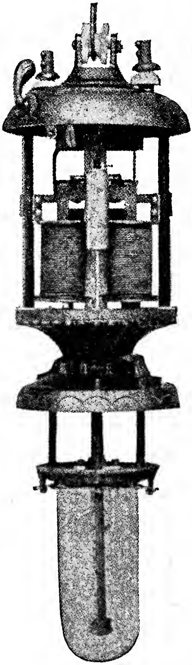


Fig. 676

In Fig. 673 is shown an arc lamp with the case removed. The two upper coils are the coarsely wound series coils, while the two lower coils are the finely wound shunt coils. This lamp is adapted for an enclosed arc bulb. The magnetically attracted cores are U shaped, and both cores are connected together mechanically by non-magnetic metal, such as brass or zinc, so that the magnetism set up in the shunt coils will not be affected by the magnetism set up by the series coils. This scheme is used in alternating current lamps, while in direct current lamps the cores are made of H shaped iron not laminated.

In Figs. 674 to 676 are shown three views of series enclosed, alternating current arc lamps of the Western Electric Company.

Fig. 674. Side view of lamp, showing one series and one shunt spool, lever movement and adjusting weight. This weight is fastened upon a threaded rod, and the finest adjustment can be obtained by screwing the weight backward or forward. Threads can be clamped in position when the correct adjustment is obtained.

Fig. 675. Front view of lamp, showing shunt spools, supporting resistance and cut-out. Note that lever carries no current when in normal working position, but that insulated bridge forms connection across two contacts, completing cut-out circuit when in position shown in cut.

Fig. 676. Rear view of lamp, showing series spool, short circuiting switch, and manner of suspending dash-pot. Note that the dash-pot is inverted, allowing such dirt as may accumulate therein to fall out, rather than in the dash-pot.

The three cuts show the manner of suspending the spools and their accessibility, it being possible to remove any spool by simply taking out the two screws which fasten it to the frame, and lifting it off the lower support.

The carbons used in arc lamps are extremely hard and dense. They are made from a mixture of powdered gas house coke, ground very fine, and a liquid like molasses, coal tar, or some similar hydro-carbon, forming a stiff, homogeneous paste. This is molded into rods or pencils of the required size and length, or other shapes, being solidified under powerful hydrostatic pressure. The carbons are now allowed to dry, after which they are placed in crucibles or ovens, thoroughly covered with powdered carbon, either lampblack or plumbago, and baked for several hours at a high temperature. After cooling, they are sometimes repeatedly treated to a soaking bath of some fluid hydrocarbon, alternated with baking, until the product is dense as possible, all pores and openings having been filled solid. Arc carbons are often plated with copper by electrolysis, to insure better conductivity.

It is said that one 2,000 candlepower arc lamp will light in open yards 20,000 sq. ft.; in railroad stations, 14,000 sq. ft.; in foundries and machine shops, 5,000 to 2,000 sq. ft. Where good, even illumination is desired, it is advisable to use a greater number of smaller lamps evenly distributed.

THE INCANDESCENT LAMP.

One of the fundamental laws of electric supply is, that the resistance in an electric circuit should be concentrated at the point where energy is to be developed, and the incandescent lamp is a good expression of this law, as the useful resistance is that which is afforded by the filaments of the lamp. The incandescent lamp comprises a carbon filament enclosed in a glass bulb from which the air has, as far as possible, been withdrawn, the carbon filament being soldered to the ends of small platinum wires entering the glass shell. Incandescent lamps can be burned either in series or in multiple; the multiple system being the most used. Series incandescent lamps are used to a considerable extent in the smaller towns for street lighting and also for the small miniature lamps burned in series on a constant potential system, and used for decorative purposes. They are also used in street car lighting.

When incandescent lamps are to be used in series, they should be carefully selected; there is quite a difference in the current consumed by different lamps, even of the same make, and when they are all limited to the same current quite a difference in candlepower may be noticeable. Some will be above their rated candlepower and others below.

The resistance of an incandescent lamp when cold is very high, varying in the ordinary 16 candlepower 110 volt lamp from 600 to 1,000 ohms. When the lamp becomes heated, as when current is passing through it, the resistance reduces considerably, being in the 16 candlepower 110 volt lamp about 220 ohms.

The current required by the various incandescent lamps varies considerably for lamps of the same voltage and candlepower, but a good average which can be used in figuring currents is ½ ampere for a 16 candlepower 110 volt lamp and ¼ ampere for the 220 volt 16 candlepower lamp. The amount of power, in watts, consumed by a lamp is equal to the voltage multiplied by the current, or $W=C\times E$. A 16 candlepower 110 volt lamp taking ½ ampere would consume $110\times\frac{1}{2}=55$ watts, while a 220 volt lamp taking ¼ ampere would consume $220\times\frac{1}{4}=55$ watts. It will thus be seen that while the current and voltage may vary, the amount of power consumed will be approximately the same for all 16 candlepower lamps. Lamps are rated at a certain number of watts per candle, the amount varying from 3 to 4 watts for 16 candlepower 110 volt lamps. The proper lamp to be used varies according to the conditions. While less power is consumed in a 3.1 watt lamp, the life of the lamp is comparatively shorter, so that the lamps will have to be renewed oftener. With a 4 watt lamp a greater amount of current is consumed, but the life of the lamp is longer. Another point of great importance in burning incandescent lamps is the voltage. The table below shows what effect variation in voltage has on the candlepower and efficiency.

An increase in voltage increases the candlepower. This increases the efficiency and shortens the life as follows:

A lamp burning at—

Normal voltage gives 100 per cent. C. P. and consumes 3.1 Watts per C. P.
1% above normal gives 106% C. P. and consumes 3. Watts per C. P.
2% above normal gives 112% C. P. and consumes 2.9 Watts per C. P.
3% above normal gives 118% C. P. and consumes 2.8 Watts per C. P.
4% above normal gives 125% C. P. and consumes 2.7 Watts per C. P.
5% above normal gives 132% C. P. and consumes 2.6 Watts per C. P.
6% above normal gives 140% C. P. and consumes 2.5 Watts per C. P.

A lamp burning at normal voltage should give its full candlepower at its rated efficiency. A 3.1 watt lamp burning below its voltage loses its efficiency and candlepower as follows:

If burned—

1% below normal it gives 95% C. P. and consumes 3.2 Watts per C. P.
2% below normal it gives 90% C. P. and consumes 3.35 Watts per C. P.
3% below normal it gives 85% C. P. and consumes 3.5 Watts per C. P.
4% below normal it gives 80% C. P. and consumes 3.6 Watts per C. P.
5% below normal it gives 75% C. P. and consumes 3.75 Watts per C. P.
6% below normal it gives 70% C. P. and consumes 4. Watts per C. P.
10% below normal it gives 50% C. P. and consumes 4.6 Watts per C. P.

By referring to the table it will be seen that with the voltage raised 3 per cent (on a 110 volt system to a little over 113 volts) the candlepower will increase 18 per cent, or in other words, a 16 candlepower lamp would be raised to nearly 19 candlepower. At the same time raising the voltage will decrease the life of the lamp. This is shown in the following table where, with an increase of 6 per cent in the voltage, the life of the lamp is reduced 70 per cent. A lamp at normal voltage has 100 per cent life.

The same lamp 1% above normal loses 18% life.
The same lamp 2% above normal loses 30% life.
The same lamp 3% above normal loses 44% life.
The same lamp 4% above normal loses 55% life.
The same lamp 5% above normal loses 62% life.
The same lamp 6% above normal loses 70% life.

To obtain satisfactory results, the voltage should be kept constant at just the proper value.

Considerable heat is generated in an incandescent lamp, so that as a general rule it is a bad plan to use paper shades which come very close to the bulb. Where lamps are hung so that there is a liability of their coming in contact with surrounding inflammable material, such as in warehouses and store-rooms, it is a good plan to enclose the lamp in a wire guard.

Table 59 will prove a handy reference for estimating the number of lamps (8 to 50 C. P.) that can be run per horsepower or kilowatt. The table is figured for theoretical values, so that the actual horsepower or kilowatts delivered must be used, or else values less than those given must be used to allow for loss in the lines.

TABLE 59

EFFICIENCY OF INCANDESCENT LAMPS.

Candlepower.	Efficiency.	Total Watts.	Per Horsepower.	Per Kilowatt.
8	3.5	28	26.6	35.7
8	4	32	23.3	31.2
16	3	48	15.5	20.8
16	3.1	50	14.9	20
16	3.5	56	13.3	17.8
16	4	64	11.6	15.6
20	3	60	12.4	16.6
20	3.1	62	12	16.1
20	3.5	70	10.6	14.2
25	3	75	9.9	13.3
25	3.1	77.5	9.6	12 9
25	3.5	87.5	8.5	11.4
25	4	100	7.4	10
32	3	96	7	10.4
32	3.1	99.2	7.5	10
32	3.5	112	6.6	8.9
50	3	150	4.9	6.6
50	3.1	155	4.8	6.4
50	3.5	175	4.2	5.7

The first column gives the candlepower. The second column gives the number of watts consumed for each single candlepower obtained, and is called the efficiency of the lamp. Multiply the total candlepower by the efficiency and you get the total number of watts consumed by the lamp. The fourth column shows the number of lamps per 746 watts, and the last column the number of lamps per 1,000 watts.

The current and watts consumed by 110 volt lamps of the different candlepowers are approximately given below.

4 candlepower	0.18 amperes,	20 watts.
8 candlepower	0.29 amperes,	32 watts.
16 candlepower	0.5 amperes,	55 watts.
32 candlepower	1.0 amperes,	110 watts.

The light given off by an incandescent lamp varies according to the position from which it is viewed. In some makes of lamps most of the light is given off directly downward, while in other lamps the maximum light is given off in a horizontal direction. The best lamp to use must be determined by the location of the lamp and the place where the light is required. By the use of suitable reflectors or shades the light can be thrown in any direction desired. A 16 candlepower lamp if placed seven feet above the floor will light up a floor space of 100 sq. ft., providing the walls are of a light color. If the walls are of a dull color, or if a bright illumination is desired more lamps should be used. Glass globes placed over the lamps reduce the light to a considerable extent, as is shown in the following table:

Clear glass	10 per cent.
Holophane	12 per cent.
Opaline	20 to 40 per cent.
Ground	25 to 30 per cent.
Opal	25 to 60 per cent.

PRIMARY BATTERIES.

There are many places where a small amount of electrical power is needed, but the amount is so small, that running a line to the point would not pay. In such cases primary batteries may be used to good advantage.

Construction.—If a piece of zinc, and a piece of copper be placed in a jar containing dilute sulphuric acid, and not allowed to touch each other below the surface of the liquid, but are connected above it, by a wire, a current of electricity will flow through the wire, and the wire will show magnetic qualities. This is one of the most simple forms of primary battery. The current flows from the copper to the zinc outside of the cell, and from the zinc to the copper in the liquid.

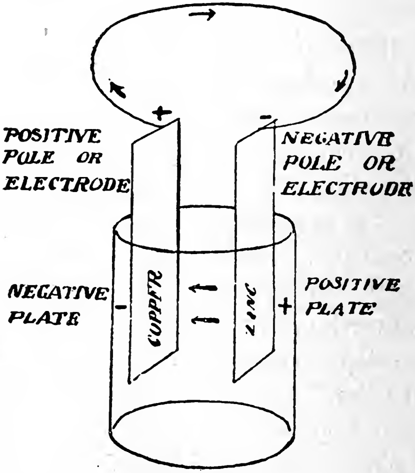


FIG. 677
NAMES OF PARTS OF CELL

Fig. 677 shows a cell such as described above giving names of the different parts. The zinc plate slowly dissolves, and more or less hydrogen gas is thereby set free, which arises in the form of bubbles. Carbon has been found to be a good substitute for copper, in the makeup of battery cells. The different types of cells are classified as follows:

Open circuit: A cell designed for intermittent work. Periods of work short, intervals of rest long. Usually designed for small currents. When not in use these cells must be left on open circuit.

Semi-closed: A cell designed for fairly steady work. Periods of work long, intervals of rest short. Often designed to produce heavy currents. When not in use these cells must be left on open circuit.

Closed circuit: A cell designed for continuous work. Periods of work long, intervals of rest very short. Usually designed for very small currents. Almost impossible to design so as to produce much current. When not in use they must be left on closed circuit.

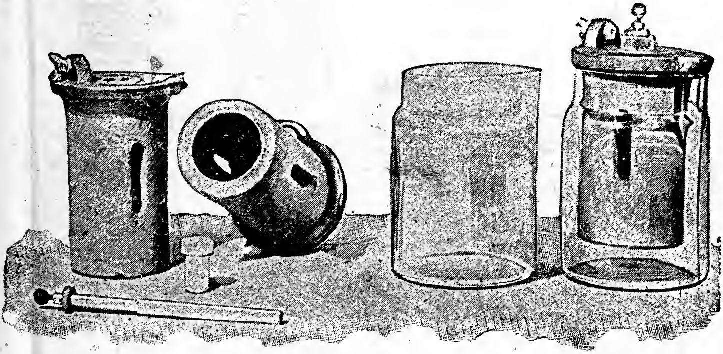


FIG. 678
CARBON CYLINDER CELL

Polarization prevented: Cell so designed that no hydrogen gas is produced by chemical action of cell.

Polarization cured: Cell produces hydrogen, but a chemical placed in the cell turns the hydrogen to water which is harmless.

Polarization delayed: Cell has very large and absorbent negative plate.

The Carbon Cylinder Cell.—These are sold under the name of Law, Samson, Hercules, etc. It is an open circuit, polarization delayed type. They give a pressure of 1.5 volts and have a resistance of 1 to 2 ohms. Two of them are shown in Fig. 678.

The carbon element is made with as large a surface as possible. Carbon and charcoal have a remarkable power of absorbing gases. A cubic inch of charcoal will condense and absorb 20 to 30 cubic inches of gas.

The zinc element is a rod and the fluid a strong solution of sal ammoniac in water. The scientific name of this chemical is ammonium chloride.

FIG. 679

CARBON CYLINDER CELL WITH DEPOLARIZER

The action of the cell dissolves the zinc, forming zinc chloride, which dissolves in the water. A little ammonia and hydrogen gases are set free. The ammonia is dissolved by the water and the hydrogen absorbed by the carbon.

In time the carbon gets soaked full of hydrogen, and to restore the cell it should be taken out and boiled in water for an hour.

These should only be used for call bells in offices or such unimportant work.

Leclanche Cell.—This is an open-circuit, polarization cured type. They are made in several forms. Voltage 1.5

and resistance 1 to 4 ohms. Uses sal ammoniac, zinc and carbon.

The carbon cylinder cell is sometimes modified to the Leclanche type by making the carbon element with a bottom and no opening in the sides. This carbon can, or bucket is filled with lumps of black oxide of manganese (manganese dioxide). The zinc is made in a cylindrical form, surrounding the carbon. This cell is shown in Fig. 679.

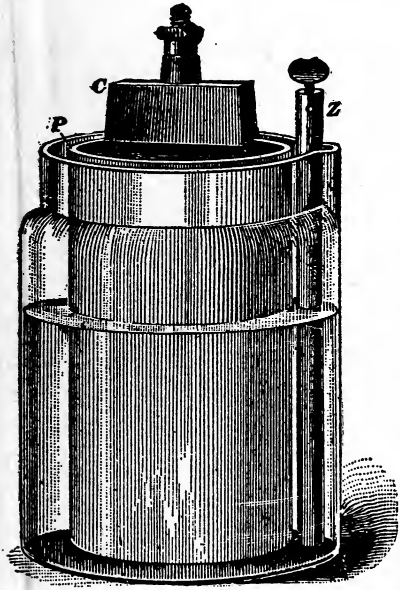


Fig. 680
ORDINARY LECLANCHE CELL

Fig. 681
ELEMENTS OF THE GONDA-LECLANCHE CELL

The hydrogen is absorbed by the carbon but the manganese dioxide, being in contact with the carbon, gives up half of its oxygen to the hydrogen forming water, while it is reduced to manganese monoxide.

This cell is useful for call bell work, operating magnets on interlocking machines, running tell-tales on interlocking boards, and such other intermittent light work.

There is an older form of Leclanche cell shown in Fig. 680, where the carbon is placed in a cup of unglazed earthen ware (like a yellow flower pot) called a porous cup. The manganese is packed around the carbon slab. This form does not give such a large current as the cell in Fig. 679 because its resistance is high, often as much as four or five ohms.

A much used form of the Leclanche cell is the Gonda cell. The elements are shown in Fig. 681.

Here the manganese is powdered, mixed with cheap molasses, then by heat and pressure formed into slabs. These are attached to the carbon plates by rubber bands.

The bother and resistance of the porous cup is avoided.

The usual charge of a Leclanche type cell is a generous quarter pound of sal ammoniac dissolved in sufficient water to fill the jar two-thirds full after elements are in place.

The Gravity Cell.—This is a closed circuit cell with polarization prevented. It is very much used for telegraph circuits, operating the electrical devices in the lock and block signals, the motors in automatic signals and generally around interlocking plants. Its pressure is 1 volt and its current capacity rather low for its resistance is 3 or 4 ohms.

This cell is made in many forms called Bluestone cell, crow-foot battery, Lockwood cell, etc.

The parts of a gravity cell are shown in Fig. 682, and the assembled cell in Fig. 683.

The glass jars should be about 7 inches high and 6 inches in diameter. The zinc is cast in a shape so as to be easily suspended from the edge of the jar. The form shown is called a crow-foot zinc. It weighs about 3 pounds.

The copper element shown on left of Fig. 682 is made of three sheets riveted together at center and then spread out as shown. The rubber covered wire must be attached to the copper element by riveting. If soldered the joint would be eaten away by electrical action.

To set up a cell of ordinary size which holds about 0.8 gallons of liquid, make two solutions, one of copper, the other of zinc.

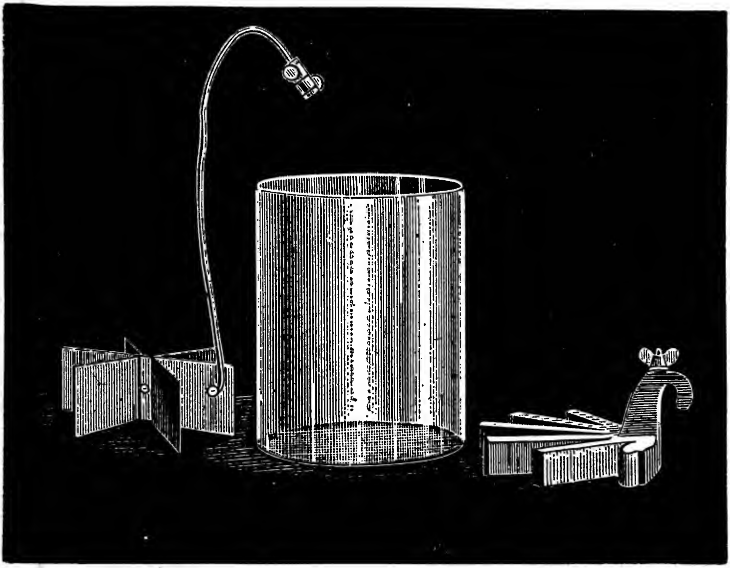


Fig. 682

ELEMENTS OF GRAVITY CELL AND JAR

Zinc solution: Pint and a half of pure soft water and 10 oz. of crystallized sulphate of zinc (white vitriol). Mix until dissolved and let it stand half a day in a glass jar.

Copper solution: Two and a half pints of soft water, 4 ozs. of crystallized sulphate of zinc, 8 ozs. crystallized sulphate of copper (blue vitriol). Mix and let stand a few hours in a glass jar.

Dip edge of battery jar for an inch in melted paraffin and let it cool.

Place the parts in jar as in Fig. 683 and pour jar nearly three-fourths full of the zinc solution. Place it at once in the spot where it is to be used and pour in the copper solution.

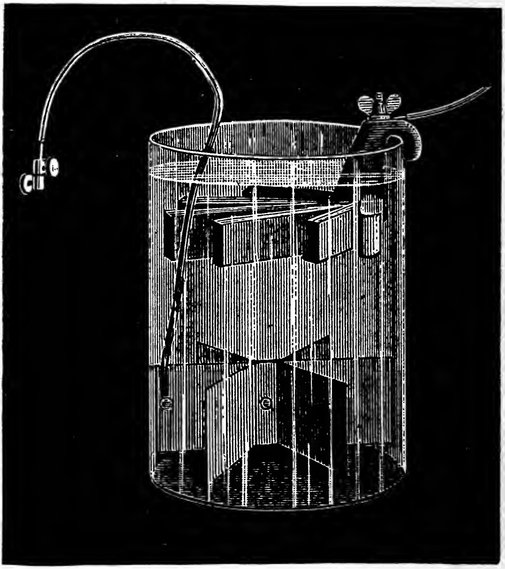


Fig. 683

GRAVITY CELL READY FOR USE

Insert a glass funnel in the top of a piece of $3/8$-inch rubber tubing. Hold funnel so that lower end of the tube will be in the middle of the jar and just a little above the bottom.

Pour in the copper solution slowly until the copper element is completely covered. Place the cell into service immediately.

This cell will show a sharply defined line between the blue copper solution and the colorless zinc solution. This separation of solutions is essential to the cell's health. Leaving the circuit open for any length of time will allow the solutions to mix and spoil the cell.

The action of the cell is such that no hydrogen is permanently formed. The zinc is steadily dissolved into the zinc solution, setting free some hydrogen. This forms with the copper sulphate, sulphuric acid and metallic copper. The sulphuric acid dissolves more zinc, while the copper plates itself on the copper element at the bottom of jar.

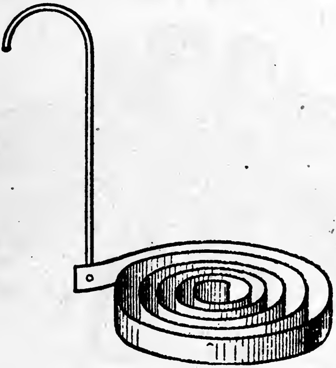


Fig. 684

LONG SERVICE COPPER ELEMENT FOR GRAVITY CELL

The zinc is consumed and the copper plate grows larger.

The effect of continued action is to increase the strength of the zinc solution so that it tends to settle to bottom of jar.

The copper being taken out, bit by bit, from the copper solution this latter gets lighter in weight and tends to rise being pushed up by the zinc solution.

If the blue solution of copper sulphate ever touches the zinc it will copper plate it at once. The cell will then have two copper elements and stop working.

Cells should be given some attention, and clever management will keep a gravity cell working continuously for an almost indefinite time.

As helps in the maintenance of cells two improvements have been made.

The form of copper element shown in Fig. 684 is better when heavy currents are not needed. It is a copper ribbon 4 feet long and ½ an inch wide, coiled like a clock spring. Zincs shaped like Fig. 685 are used until the prongs are all eaten off. A new one is then put in service and the old one jammed into the bottom of the new one as shown in Fig. 686.

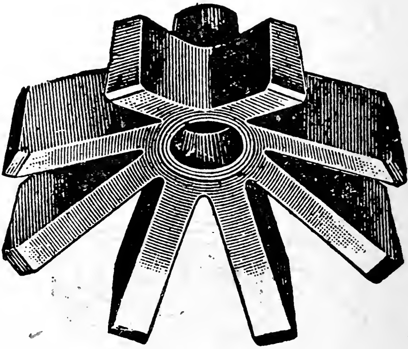


FIG. 685

D'INFREVILLES WASTELESS ZINC

These zincs are hung from a spring clip shown in Fig. 687, which lays across the top of the jar. The stud on the zinc makes a tight friction fit with the hole in the hanger, due to the springiness of the metal.

To keep cells in order a hard rubber syringe with the nozzle at right angles to barrel, holding about a pint, and a hydrometer should be obtained.

The hydrometer (Fig. 688) is a hollow glass float loaded with shot so as to float upright. The heavier a liquid the more of the stem sticks up above the surface.

These hydrometers are graduated on stem in actual specific gravities or in degrees Baume (pronounced Bomay). One with a stem about two inches long graduated from 15° to 40° Baume, or from 1.11 to 1.40 specific gravity, is best for battery work.

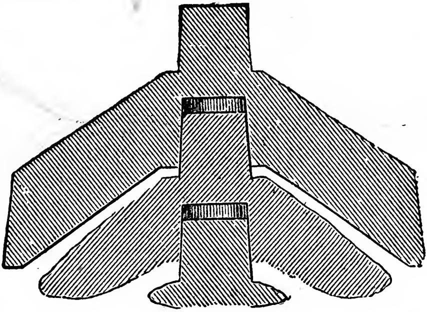


FIG. 686
USING UP OLD ZINCS

The first signs of exhaustion in the cell will be a fading of the deep blue color of the copper solution and a lowering of the line of separation between blue and white liquids.

When this occurs drop in about an ounce of copper sulphate in lumps. Be sure the lumps fall to the bottom. There will always be a lot of fine powder at the bottom of the copper sulphate barrel. Use this for making up new cells when possible. If too much accumulates for this purpose, make a saturated solution of it in water.

A saturated solution is one where the water has dissolved all it possibly can of the chemical, and leaves some yet undissolved on bottom of jar after repeated stirring.

Place this in cells showing signs of exhaustion in same way as the copper solution was placed in a newly set up cell.

The zinc solution should be tested as frequently as possible. Once in two weeks is not too often. Drop the hydrometer gently in. Should it read 1.15 draw some out with syringe and replace by fresh water.

Do not let it go below 1.10. If you have a Baume scale these numbers are 20 and 15 degrees. Throw all the removed zinc in a wooden tub, whether from working cells or from old cells, to be renewed.

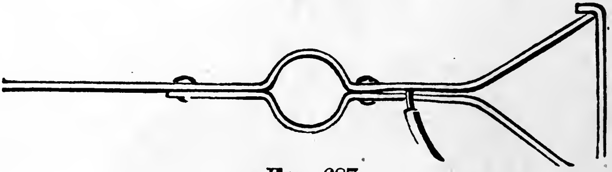


FIG. 687

Keep half a dozen pieces of metallic zinc in this tub. Any copper in this solution, mixed by cell's action, will turn to a reddish brown curd which can be filtered out. Reduce the clear liquid to 1.10 and use in making up new cells.

Watch your zinc. Should any brown hangers develop on it, detach them with a bent wire and let them fall to bottom of cell.

In time, in spite of all care, the zinc in a cell gets reddish brown all over. It is now time to give a complete overhauling.

Take the cell out of service. Syphon off zinc solution into the tub. Lift zinc out carefully and at once scrub clean with a wire brush. Wash and replace in another cell at once or dry thoroughly and keep dry until needed.

Syphon off the rest of the liquid into another wooden tub and use after filtering as copper solution to make up new cells.

Any lumps of copper sulphate in the bottom take out, rinse, and put in other cells.

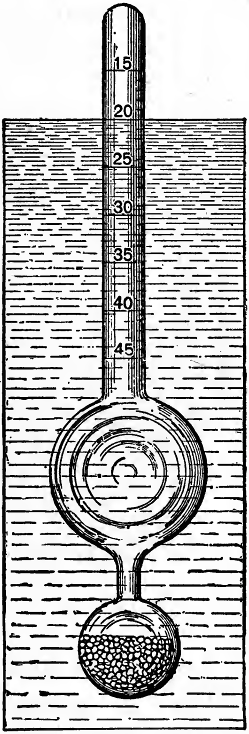


FIG. 688.

HYDROMETER WITH BAUME SCALE

The mud in bottom of cells and in the zinc solution tub should be dried and sold to brass founders as "battery mud."

The copper plates taken from cells should be kept completely covered with water, wire and all, until needed again.

When they get too heavy and cumbersome sell them, as they are an especially pure form of copper.

Never leave gravity cell on open circuit; the liquids will mix.

The Fuller Cell.—Semi-closed circuit type, for heavy duty. Long periods of work with little rest.

Polarization cured. Pressure 2 volts, resistance 0.5 ohms. Cell shown in Fig. 689.

These cells are carbon and zinc, and since the chemical which converts the hydrogen to water will attack the zinc, a porous cup is used.

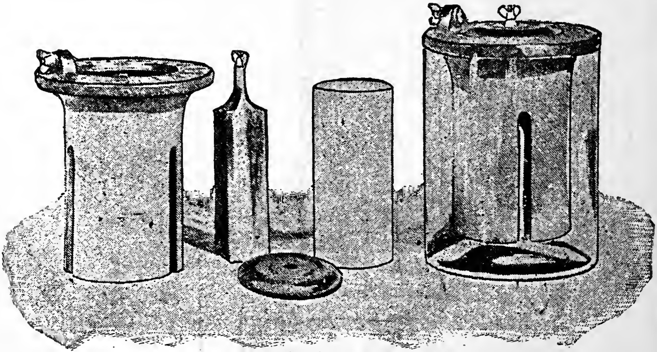


FIG. 689
FULLER CELL

The carbon or the zinc can be placed in the porous cup, but the zinc usually is. A tablespoonful of mercury is placed in bottom of porous cup, the zinc set in and the cup filled with very dilute sulphuric acid (1 acid, 50 water). The carbon is then placed in the outer jar, the porous cup being also in, and the outer jar filled three-quarters full of battery fluid or electropoin.

This is composed of 4 ozs. of bichromate of soda, 1¼ pints of boiling water, mixed and cooled; then while slowly stirring add little by little 3 ozs. sulphuric acid taken out of a carbon (not diluted). *Never pour water into acid.*

The bichromate of soda has so much oxygen in it that it will turn the hydrogen to water, changing itself to chromate of soda.

When the interior of the porous cup gets dark green colored a cup should be soaked in 1 to 50 acid for an hour and then mercury placed in bottom and zinc set in. Simply take out old cup and insert new one in its place.

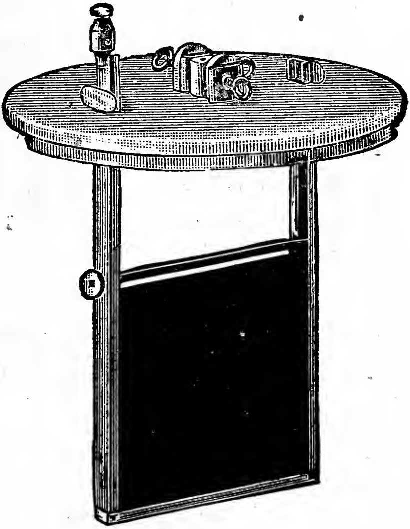


Fig. 690

OXIDE PLATE OF EDISON-LALANDE CELL

The old zinc should be cleaned, porous cup washed and then boiled in water and both placed in stock.

These cells should be left on open circuit when not in use. They are very powerful, but nasty to handle and not as cheap as the gravity cell. When the electropoin gets greenish it soon becomes exhausted, then throw it away. Cold battery rooms, or pits affect this cell less than the gravity cell.

Edison-Lalande Cell.—This is a semi-closed type with polarization cured. It has a resistance of 0.2 ohms and a very low voltage, 0.7, but is a bull dog for holding on. It will, when set up, start in to deliver a heavy current and keep at it until all its chemicals are used up. It needs no attention and is built so that you can not give any.

When it stops take out the copper and sell it, throwing everything else out. Clean up the jar and fit out again.

The cell uses zinc and oxide of copper plates immersed in a solution of caustic potash. The oxide plate is shown in Fig. 690 and the complete cell with a glass jar in Fig. 691. Porcelain jars are usually furnished.

The caustic potash comes in sticks sealed up in a tin can.

Place the elements in jar and fill with water to about one inch of the top. Take out the elements and put in the sticks of potash.

Stir constantly while dissolving, for it gets very hot and might crack the jar. Be very careful not to get caustic potash on your flesh. It not only burns terribly, but makes a wound which is very hard to heal.

If you buy potash by bulk, make the solution up to 1.33 on specific gravity scale or 38° on the Baume scale.

Place the zinc and copper oxide elements in the jar, seeing that they are properly separated by the hard rubber buffers. Pour the bottle of oil over the top of solution and place cover on.

If buying oil by bulk, get a heavy paraffin oil which will read 1.46 specific gravity or 48° Baume and pour a ¼ inch layer on each cell

These are good cells, but any sulphuric acid or caustic potash cell is a nasty thing to handle.

The action of the cell dissolves the zinc, setting free hydrogen, which is changed to water by the copper oxide, which is reduced to pure copper by giving up the oxygen in it.

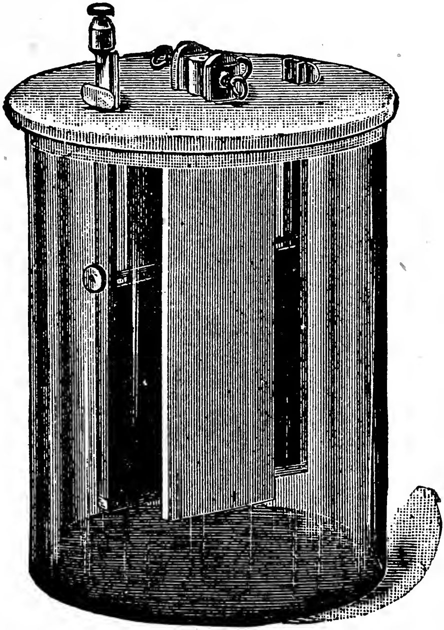


FIG. 691
EDISON-LALANDE CELL

Dry Batteries.—A dry battery is one which has its electrolyte disseminated through some solid material through which it can diffuse itself. Plaster of Paris and gelatinous compounds have been used for the solid part. The usual construction is on the basis of the plaster of Paris combination.

The outer cup is made of zinc, and acts as the positive electrode. Over it is slipped a strawboard tube. The object is to prevent the zinc of two batteries from touching each other so as to establish a wrong connection. The negative electrode is a plate of carbon. This is placed in the center of the zinc, and is so supported as not to touch it in any place. Carbon and zinc both carry binding posts. The filling varies. The following is used in the Burnley cell:

A wooden plunger or template, somewhat larger than the carbon, is inserted, and the following mixture introduced:

Fig. 692
DRY CELL

Ammonium chloride, zinc chloride, 1 part of each, plaster of Paris, 3 parts, flour 0.87 part, water 2 parts. After this has set a little, the wooden template is withdrawn, the carbon is inserted in the cavity left by its withdrawal, and the space left unfilled is filled with the following mixture. Ammonium chloride, zinc chloride, manganese binoxide, granulated carbon, flour, 1 part of each, plaster 3 parts, water 2 parts. The electromotive force of this cell is 1.4 volts, its resistance 0.3 ohm.

The Gassner dry cell has as negative a cylinder made of a mixture of carbon and manganese dioxide. The filling composition is as follows: Zinc oxide, ammonium chloride, and zinc chloride, 1 part each, plaster of Paris 3 parts, water 2 parts.

For the Meserole dry battery, there are mixed the following: Graphite, slacked lime, arsenious acid, and glucose or dextrine, 1 part each, carbon and manganese binoxide, 3 parts each. The mixture is finely pulverized and rubbed up in a saturated solution of ammonium chloride and sodium chloride (common salt) with one-tenth its volume of a solution of mercuric chloride and an equal volume of hydrochloric acid. These constituents are intimately mixed and poured into the zinc cup.

Dry batteries are sealed with pitch. A hole is sometimes left for the escape of gas.

STORAGE BATTERIES.

The storage cell is rapidly pushing the primary battery aside in signal and fire alarm work on account of:

(1) Its high voltage.

(2) Its great current capacity.

(3) The lowering of total battery expense if used for several years.

(4) Its steadiness of action.

Storage cells are used in train lighting to furnish light when train is not in motion, and to steady the supply of current.

They are used in some cases to furnish the power to operate switches on locomotives and motor cars.

In power houses they offer a reserve supply of power, and act as a steadier of the load on the generators.

The simplest storage cell would be two strips of lead immersed in dilute sulphuric acid. When current is sent through them one plate turns a dark brown color, and the other a grey color. After an hour's passage of current reverse the connection and charge the other way. The plates will change color—the grey one becoming brown and the other one grey.

If this charging first in one direction, and then in the other be kept up, you will notice that after each reversal of the current through the cell the acid is quiet but soon begins to gas or boil. This is the signal to reverse the current as the cell is charged.

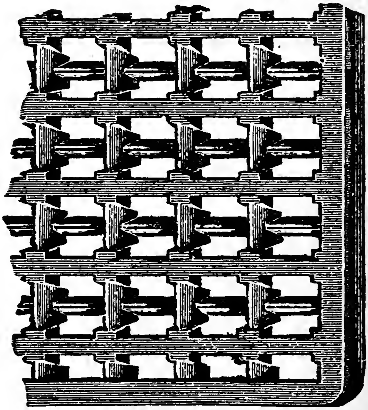


Fig. 693
LEAD GRID

When the cell takes several hours to gas it is in condition to use.

After one of the reversals continue to charge until cell has gassed about fifteen minutes. Remove the charging wires and connect to anything you wish to run. About 70% of the power you put into the cell can now be taken out.

You may now use this as a storage cell, charging it up till it gasses, and then using the accumulated electricity as you please.

You always lose 30% but you have the advantages of portability, and ability to work when engines are shut down.

In time you will notice that the lead plates become spongy and should the cell be used long enough the plates will finally crumble and break. You will notice that the more spongy the plates become the greater a charge they are capable of holding.

In fact, just before your battery goes to pieces its capacity is the greatest.

To make a commercially practical cell we would proceed thus:

The lead plates would be replaced by grids as shown in Fig. 693 or by grooved plates as in Fig. 694.

Litharge and sulphuric acid is mixed to a stiff paste and the grids or grooved plates plastered with the paste and stood up to dry. This makes a negative plate.

Using a paste of red lead and sulphuric acid the positive plates are formed in the same way.

The objection to a storage cell using these plates is that after very little use they go to pieces. The changing of the red lead to the brown oxide, and the changing of the litharge to spongy lead is accompanied by a swelling and shrinking of the material. This loosens up the pasted mass and it begins to fall out.

Most of the ingenuity of inventors has been concentrated on making plates which would hold the active materials firmly and continually.

Perhaps one of the best lead-lead (i. e. lead for both plates) is the Electric Storage Battery Company's Chloride Cell.

This cell is shown in Fig. 695. Its method of manufacture is interesting and is practically as follows:

The first thing is to get finely divided lead which is made by directing a blast of air against a stream of the molten metal, producing a spray of lead which upon cooling falls as a powder. This powder is dissolved in nitric acid and precipitated* as lead chloride on the addition of hydrochloric acid. This chloride washed and dried forms the basis of the material which afterwards becomes active in the negative plate. The lead chloride is mixed with zinc chloride, and melted in crucibles, then cast into

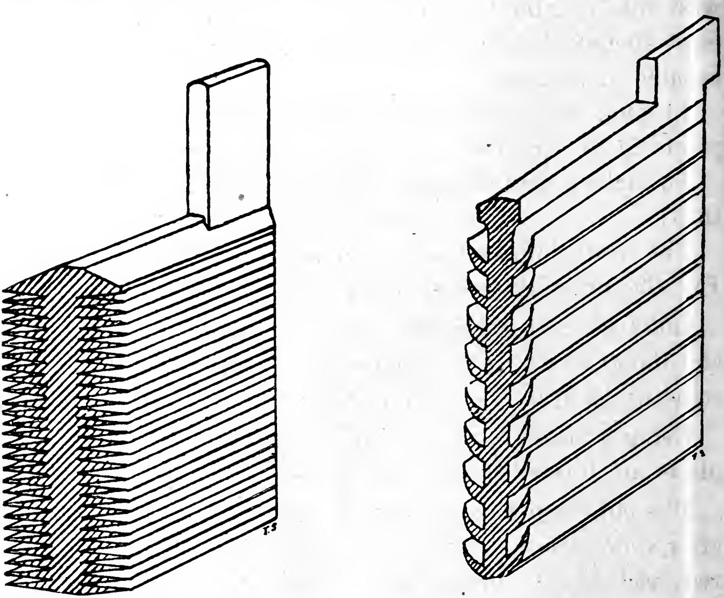


FIG. 694
GROOVED LEAD PLATES

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*Turned back to a solid.

small blocks or tablets about ¾ inch square and of the thickness of the negative plate, which according to the size of the battery varies from ¼ inch to $\frac{5}{16}$ inch. These tablets are then put in molds and held in place by pins, so that they clear each other 0.2 inch and are at the same distance from the edges of the mold. Molten lead is then forced into the mold under about seventy-five pounds pressure, completely filling the space between the tablets. The result is a solid lead grid holding small squares of active material. The lead chloride is then reduced by stacking the plates in a tank containing a dilute solution of zinc chloride, slabs of zinc being alternated with them. The assemblage of plates constitutes a short-circuited cell, the lead chloride being reduced to metallic lead. The plates are then thoroughly washed to remove all traces of zinc chloride.

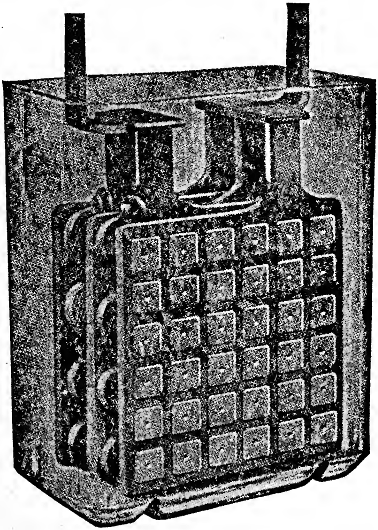

Fig. 695
CHLORIDE ACCUMULATOR

A later form of negative plate consists of a "pocketed" grid, the opening being filled with a litharge paste; this is then covered with perforated lead sheets, which are soldered to the grid. The positive plate is a firm grid, composed of lead alloyed with about 5% of antimony, about $\frac{7}{16}$ inch thick, with circular holes $\frac{25}{32}$ inch in diameter, staggered so that the nearest points are .2 inch apart. Corrugated lead ribbons $\frac{25}{32}$ inch wide are then rolled into close spirals of $\frac{25}{32}$ inch in diameter, which are forced into the circular holes of the plate. By electro-chemical action these spirals are formed into active material, the process requiring about thirty hours; at the same time the spirals expand so that they fit still more closely in the grids. This form of positive is known as the Manchester Plate.

In setting up the cells the plates are separated from each other by special cherry wood partitions, the perforations being connected by vertical grooves to facilitate the rising of the gases. Sometimes glass rods are used as separators.

There are ten sizes of cell, the smallest containing three plates 3 by 3 inches, and the largest having seventy-five plates 15½ by 30¾ inches, ranging in capacity from 5 to 12,000 ampere-hours, and in weight from 5½ to 5,800 lbs. The smaller sizes are provided with either rubber or glass jars, and the larger one with lead-lined tanks.

In the lead-lead cells the negative plates deteriorate in capacity, while the positive plates increase in capacity with continued use.

To even things up, the two end plates are made negative and they then alternate, thus giving one more negative plate per cell.

A lead-zinc cell is made by the United States Battery Co. It is shown in Fig. 696.

The positive plate is of perforated lead sheets riveted together with lead rivets, and formed by the slow process of charging and reversal as previously described. The negative element is a zinc amalgam which swells up when charged.

This amalgam lies on bottom of jar, while the lead element hangs over it.

The pressure given by these cells is a little higher than a lead-lead cell, and they weigh less for the same capacity. For signal work they are excellent, while for reserve power use, the lead-lead cell is preferred as being better under such severe conditions.

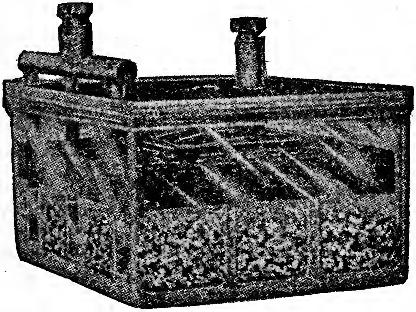

Fig. 696

LEAD-ZINC STORAGE BATTERY

The Edison Cell uses grids of nickel plated iron, the grids being filled with small nickel plated steel boxes which are perforated with very small holes.

The boxes in positive plate are filled with oxide of nickel and pulverized carbon, the negative boxes being filled with oxide of iron and pulverized carbon.

The carbon in each case is merely to render material a better conductor.

A 20% solution of caustic potash is used in a nickel plated steel vessel.

The advantage of this cell is its lightness and ability to stand the most reckless abuse. For railway work it is no better than any other cell and its price puts it out of consideration.

UNDERWRITER'S RULES

1. *Generators.*

a. Must be located in a dry place.

It is recommended that water-proof covers be provided, which may be used in case of emergency.

If generators are allowed to become wet, there is likely to be more or less charring or burning of the cotton insulation of the wires, due to the fact that shellaced cotton will conduct electricity when wet. The current leaking over this moist conducting path, the resistance of which is being constantly decreased by the formation of copper salts by electrolytic action, may eventually develop excessive heat or even fusion of some of the metallic parts.

b. Must never be placed in a room where any hazardous process is carried on, nor in places where they would be exposed to inflammable gases or flyings of combustible materials.

Any generator, if badly designed, improperly handled, poorly cared for or overloaded, is liable to produce sparks, which may be of sufficient intensity to set fire to readily inflammable gases, dust, lint, oils and the like.

c. Must, when operating at a potential in excess of 550 volts, have their base frames permanently and effectively grounded.

Must, when operating at a potential of 550 volts or less, be thoroughly insulated from the ground wherever feasible.

Wooden base frames used for this purpose, and wooden floors which are depended upon for insulation where, for any reason it is necessary to omit the base frames, must be kept filled to prevent absorption of moisture, and must be kept clean and dry.

Where frame insulation is impracticable, the Inspection Department having jurisdiction may, in writing, permit its omission in which case the frame must be permanently and effectively grounded.

A high potential machine should be surrounded by an insulated platform. This may be made of wood, mounted on insulating supports, and so arranged that a man must always stand upon it in order to touch any part of the machine.

In case of a machine having an insulated frame, if there is trouble from static electricity due to belt friction, it should be overcome by placing near the belt a metallic comb connected with the earth, or by grounding the frame through a resistance of not less than 300,000 ohms.

By "ground" is to be understood the earth, walls or floors of masonry, pipes of any kind, iron beams, and the like.

If frame insulation is not provided, a slight fault in the insulation of the magnet or armature coils is likely to ground the electric system, and a short-circuit will then occur the instant another ground occurs at any point on the system.

The reason for requiring a positive ground wherever frame insulation is impracticable, is to provide a definite path for leak currents, and thus prevent them from escaping at points where they might do harm. A good ground can be made by firmly attaching a wire to the dynamo frame and to any main water pipe that is thoroughly connected with underground pipes. The wire should not be smaller than No. 6 B. & S. gage and should be securely attached to the pipe by soldering it to a brass plug screwed into a fitting, or by binding it under a heavy split clamp, or by any other equally thorough method. With direct-connected units, the engine or water-wheel would generally furnish a sufficiently good ground.

It is best to provide a solid timber base-frame, even with a wooden floor, for it is difficult to be sure that even a dry floor will furnish perfect insulation, by reason of the many nails driven through it, the pipe hangers likely to be screwed into its under side and the many other possibilities of metallic connection to the ground. For the same reason, care should be taken that the bolts which hold the generator in place do not pass way through the base-frame, so as to come in contact with the floor.

The base-frame should raise the generator several inches above the floor level, as a raised frame is more easily kept free from metal dust, dampness, etc., which may afford an opportunity for the escape of current to the ground. A hard and durable finish for the timber can be made by several coats of linseed oil, and a finish coat of shellac or hard varnish.

When generators are direct-connected to engines or water-wheels, it is necessary to use an insulating coupling if the frames are to be insulated from the ground. The insulation of such couplings is not entirely reliable, as the vibrations, shocks and constant strain of driving, together with oil and dirt, are very liable to destroy the insulating material.

d. Constant potential generators, except alternating current machines and their exciters, must be protected from excessive current by safety fuses or equivalent devices of *approved* design.

For two-wire, direct-current generators, single pole protection will be considered as satisfying the above rule, provided the safety device is located in the lead not connected to the series winding. When supplying three-wire systems, the generators should be so arranged that these protective devices will come in the outside leads.

For three-wire, direct-current generators, a safety device must be placed in each armature, direct-current lead, or a double pole, double trip circuit breaker in each outside generator lead, and corresponding equalizer connection.

In general, generators should preferably have no exposed live parts, and the leads should be well insulated and thoroughly protected against mechanical injury. This protection of the bare live parts against accidental contact would apply also to any exposed, uninsulated conductors outside of the generator, and not on the switchboard unless their potential is practically that of the ground.

Where the needs of the service make the above requirements impracticable, the Inspection Department having jurisdiction may, in writing, modify them.

If this protection is not provided, an accidental short-circuit across the bus-bars, or the exposed metal parts of the main switch on the switchboard is liable to result in the burning out of the armature.

Owing to inherent qualities possessed by the alternating current generator it is not considered necessary to protect it, especially as the quick opening of a protective device would be liable to give rise to momentary high voltage on the system.

e. Must each be provided with a nameplate, giving the maker's name, the capacity in volts and amperes, and the normal speed in revolutions per minute.

The name-plate shows exactly what the machine was designed for. Such information is often of great convenience, and also tends to prevent overrating, either from ignorance, or from a desire to magnify the merits of a machine in order to help a sale.

f. Terminal blocks when used on generators must be made of *approved* non-combustible, non-absorptive, insulating material, such as slate, marble or porcelain.

A reliable voltmeter should be provided on the switchboard, and it is best to have it so arranged as to show the voltage not only between the wires of opposite polarity, but also between each wire and the earth, thus serving as a very sensitive ground detector.

It is also advised that a reliable ammeter be provided with every constant-potential generator, and that it be clearly marked to indicate the full load of the machine. This instrument measures the amount of current given out by the generator and shows instantly if there is any undue load, such as would be produced if too many lamps were put in circuit, or if there were serious leakage of current at any point on the system. It is always desirable to have all generator ammeters on a switchboard so graduated that a full scale deflection corresponds to the same degree of overload on each, so that when several machines of different sizes are running in parallel, each machine will be doing its share of the work when the ammeter pointers are in similar positions.

2. *Conductors.*

From generators to switchboards, rheostats or other instruments, and then to outside lines:

a. Must be in plain sight or readily accessible.

Wires from generator to switchboard may, however, be placed in a conduit in the brick or cement pier on which the generator stands, provided that proper precautions are taken to protect them against moisture and to thoroughly insulate them from the pier. If lead-covered cable is used, no further protection will be required, but it should not be allowed to rest upon sharp edges which in time might cut into the lead sheath, especially if the cables were liable to vibration. A smooth runway is desired. If iron conduit is provided, double braided rubber-covered wire will be satisfactory.

Main conductors in immediate connection with the source of power must be treated as especially dangerous, because the whole capacity of the system would be concentrated in them should an arc start, or an accidental short-circuit be made between them.

b. Must have an *approved* insulating covering as called for by rules in Class "C" for similar work, except that in central stations, on exposed circuits, the wire which is used must have a heavy braided, non-combustible outer covering.

Bus-bars may be made of bare metal.

Rubber insulations ignite easily and burn freely. Where a number of wires are brought close together, as is generally the case in dynamo rooms, especially about the switchboard, it is therefore necessary to surround this inflammable material with a tight, non-combustible outer cover. If this is not done, a fire once started at this point would spread along the wires, producing intense heat and a dense smoke. Where the wires have such a covering and are well insulated and supported, using only non-combustible materials, it is believed that no appreciable fire hazard exists, even with a large group of wires.

Flame proofing should be stripped back on all cables a sufficient amount to give the necessary insulation distances for the voltage of the circuit on which the cable is used. The stripping back of the flame proofing is necessary on account of the poor insulating qualities of the flame proofing material now available. Flame proofing may be omitted where satisfactory fire proofing is accomplished by other means, such as compartments, etc.

It is also recommended that all live parts of the switchboard, such as bus-bars and other conductors, be protected against accidental contact as far as practicable by suitable insulation, which shall be "flame proof" or "slow-burning" and designed to withstand a reasonable amount of abrasion. The chances of accidental short-circuits may thereby be greatly reduced. Insulated cable for bus-bars and connections is excellent for this purpose. However, the conductors could be wrapped or taped if this should be found more convenient, but this method should never be used unless it can be done well. Due to the possibly rather low insulating properties of most fireproofing compounds as used, special precautions would be necessary on high-voltage circuits to prevent current leakage over the outer fireproofed covering.

c. Must be kept so rigidly in place that they cannot come in contact.

It is necessary, also, to protect the wires against accidental blows from belt, or from ladders, etc., in the hands of careless workmen.

d. Must in all other respects be installed with the same precautions as required by rules in Class "C" for wires carrying a current of the same volume and potential.

e. In wiring switchboards the ground detector, voltmeter, pilot lights and potential transformers must be connected to a circuit of not less than No. 14 B. & S. gauge wire that is protected by an *approved* fuse, this circuit is not to carry over 660 watts.

For the protection of instruments and pilot lights on switchboards, *approved* N. E. Code Standard Enclosed Fuses are preferred, but *approved* enclosed fuses of other designs of *not over two* (2) *amperes capacity,* may be used.

Voltmeter switches having concealed connections must be plainly marked, showing connections made.

3. *Switchboards.*

a. Must be so placed as to reduce to a minimum the danger of communicating fire to adjacent combustible material.

It is often necessary, also, to protect the wires against accidental blows from belt, or from ladders, etc., in the hands of careless workmen. This may be done in about the same manner as is recommended for wires on side walls.

Special attention is called to the fact that switchboards should not be built down to the floor, nor up to the ceiling. A space of at least ten or twelve inches should be left between the floor and the board, except when the floor about the switchboard is of concrete or other fireproof construction, and a space of three feet, if possible, between the ceiling and the board, in order to prevent fire from communicating from the switchboard to the floor or ceiling, and also to prevent the forming of a partially concealed space very liable to be used for storage of rubbish and oily waste.

Great care in designing and locating a switchboard is necessary for several reasons; the rheostats, measuring instruments, fuses, etc., are possible sources of fire; there is a considerable number of bare live parts on the ordinary board which afford good opportunity for accidental short-circuits; and there is frequently a large amount of power available at the board to quickly follow up any trouble at this point.

b. Must be made of non-combustible material or of hardwood in skeleton form, filled to prevent absorption of moisture.

If wood is used all wires, and all current carrying parts of the apparatus on the switchboard must be separated therefrom by non-combustible, non-absorptive insulating material.

Switchboards of slate or marble are now mostly used. A slate board complete is but little more expensive than a properly wired and equipped wooden board in skeleton form. The non-combustible board is undoubtedly preferable, and is therefore strongly recommended, especially for the larger equipments.

c. Must be accessible from all sides when the connections are on the back, but may be placed against a brick or stone wall when the wiring is entirely on the face.

If the wiring is on the back, there should be a clear space of at least eighteen inches between the wall and the apparatus on the board, and even if the wiring is entirely on the face, it is much better to have the board set out from the wall. The space back of the board should not be closed in, except by grating or netting either at the sides, top or bottom, as such an enclosure is almost sure to be used as a closet for clothing or for the storage of oil cans, rubbish, etc. An open space is much more likely to be kept clean, and is more convenient for making repairs, examinations, etc.

d. Must be kept free from moisture.

Water on a switchboard is liable to produce serious trouble, as it is almost certain to start leaks over the surface of the insulating coverings on the wires and over the board itself; for water-soaked insulators, or a film of water on a non-absorptive insulator, like glass, porcelain or hard rubber, will conduct electricity to some extent. By electrolytic action this leakage current will form salts of copper over the surface of the insulating parts, and as these salts are good conductors, the leakage current will be increased, resulting in the inevitable destruction of the weakest part, be it insulation, wire or dynamo. Under such conditions there would also be great danger of the attendant receiving severe shocks.

e. On switchboards the distances between bare live parts of opposite polarity must be made as great as practicable, and must not be less than those given for tablet-boards.

4. *Resistance Boxes and Equalizers.*

a. Must be placed on switchboard, or if not thereon, at a distance of at least one foot from combustible material, or separated therefrom by non-combustible, non-absorptive insulating material such as slate or marble.

This will require the use of a slab or panel of non-combustible, non-absorptive insulating material such as slate or marble, somewhat larger than the rheostat, which shall be secured in position independently of the rheostat supports. Bolts for supporting the rheostat shall be countersunk at least 1/8 inch below the surface at the back of the slab and filled. For proper mechanical strength, slab should be of a thickness consistent with the size and weight of the rheostat, and in no case to be less than 1/2 inch.

If resistance devices are installed in rooms where dust or combustible flyings would be liable to accumulate on them, they should be equipped with a dustproof face-plate.

Resistance boxes should be considered as stoves, which under some conditions may become red hot, and from which drops of heated metal may fall, or even be thrown some distance.

Motor-starting rheostats, arc lamp compensators, electric heaters and the like would all come under this rule unless so designed as to make these precautions unnecessary for the desired safety.

b. Where protective resistances are necessary in connection with automatic rheostats, incandescent lamps may be used, provided that they do not carry or control the main current nor constitute the regulating resistance of the device.

When so used, lamps must be mounted in porcelain receptacles upon non-combustible supports, and must be so arranged that they cannot have impressed upon them a voltage greater than that for which they are rated. They must in all cases be provided with a name-plate, which shall be permanently attached beside the porcelain receptacle or receptacles, and stamped with the candle-power and voltage of the lamp or lamps to be used in each receptacle.

c. Wherever insulated wire is used for connection between resistances and the contact plate of a rheostat, the insulation must be slow burning. For large field rheostats and similar resistances, where the contact plates are not mounted upon them, the connecting wires may be run together in groups so arranged that the maximum difference of potential between any two wires in a group shall not exceed 75 volts. Each group of wires must either be mounted on non-combustible, non-absorptive insulators giving at least half-inch separation from surface wired over or, where it is necessary to protect the wires from mechanical injury or moisture, be run in approved lined conduit or equivalent.

5. *Lightning Arresters.*

a. Must be attached to each wire of every overhead circuit connected with the station.

It is recommended to all electric light and power companies that arresters be connected at intervals over systems in such numbers and so located as to prevent ordinary discharges entering (over the wires) buildings connected to the lines.

The kind and degree of protection necessary depend largely on circumstances. A short outdoor line from one mill building to another will often require nothing, while a long overhead line through an open exposed country will generally need the most careful engineering to secure reasonable freedom from lightning disturbances.

b. Must be located in readily accessible places away from combustible materials, and as near as practicable to the point where the wires enter the building.

In all cases, kinks, coils and sharp bends in the wires between the arresters and the outdoor lines must be avoided as far as possible.

The switchboard does not necessarily afford the only location meeting these requirements. In fact, if the arresters can be located in a safe and accessible place away from the board, this should be done, for, in case the arrester should fail or be seriously damaged there would then be less chance of starting arcs on the board.

The arresters should be accessibly located, so that they may be easily examined from time to time, and should always be isolated from combustible materials, as sparks are sometimes produced when lightning is discharged through them.

Kinks, coils, sharp bends, etc., may offer enormous resistance to a lightning current, possibly preventing its discharge to ground through the arrester and causing it to leave the wires at some other point, where it might do considerable damage.

c. Must be connected with a thoroughly good and permanent ground connection by metallic strips or wires having a conductivity not less than that of a No. 6 B. & S. gauge copper wire, which must be run as nearly in a straight line as possible from the arresters to the ground connection.

Ground wires for lightning arresters must not be attached to gas pipes within the buildings.

It is often desirable to introduce a choke coil in circuit between the arresters and the dynamo. In no case should the ground wires from lightning arresters be put into iron pipes, as these would tend to impede the discharge.

d. All choke coils or other attachments, inherent to the lightning protection equipment, shall have an insulation from the ground or other conductors equal at least to the insulation demanded at other points of the circuit in the station.

6. *Care and Attendance.*

a. A competent man must be kept on duty where generators are operating.

b. Oily waste must be kept in *approved* metal cans and removed daily.

Approved waste cans shall be made of metal with legs raising can three inches from the floor, and with self-closing covers.

7. *Testing of Insulation Resistance.*

a. All circuits except such as are permanently grounded must be provided with reliable ground detectors. Detectors which indicate continuously, and give an instant and permanent indication of a ground are preferable. Ground wires from detectors must not be attached to gas pipes within the building.

b. Where continuously indicating detectors are not feasible, the circuits should be tested at least once per day, and preferably oftener.

c. Data obtained from all tests must be preserved for examination by the Inspection Department having jurisdiction.

These rules on testing to be applied at such places as may be designated by the Inspection Department having jurisdiction.

8. *Motors.*

The use of motors operating at a potential in excess of 550 volts will only be approved when every practicable safeguard has been provided. Plans for such installations should be submitted to the Inspection Department having jurisdiction before any work is begun.

a. Must, when operating at a potential in excess of 550 volts, have no exposed live metal parts, and have their base frames permanently and effectively grounded.

Motors operating at a potential of 550 volts or less must be thoroughly insulated from the ground where feasible. Wooden base frames used for this purpose, and wooden floors, which are depended upon for insulation where, for any reason, it is necessary to omit the base frames, must be kept filled to prevent absorption of moisture, and must be kept clean and dry. Where frame insulation is impracticable, the Inspection Department having jurisdiction may, in writing, permit its omission, in which case the frame must be permanently and effectively grounded.

A high-potential machine should be surrounded with an insulated platform. This may be made of wood, mounted on insulating supports, and so arranged that a man must stand upon it in order to touch any part of the machine.

In case of a machine having an insulated frame, if there is trouble from static electrcity due to belt friction, it should be overcome by placing near the belt a metallic comb connected to the earth, or by grounding the frame through a resistance of not less than 300,000 ohms.

b. Motors operating at a potential of 550 volts or less must be wired with the same precautions as required for wires carrying a current of the same volume.

Motors operating at a potential between 550 and 3,500 volts must be wired with approved multiple conductor, metal sheathed cable in approved unlined metal conduit firmly secured in place. The metal sheath must be permanently and effectively grounded, and the installation of the conduit must conform to rules for interior conduits, except that at outlets approved outlet bushings shall be used.

The motor leads or branch circuits must be designed to carry a current at least 25 per cent greater than that for which the motor is rated, in order to provide for the inevitable occasional overloading of the motor and the increased current required in starting, without overfusing the wires; but where the wires under this rule would be overfused, in order to provide for the starting current, as in the case of many of the alternating current motors, the wires must be of such size as to be properly protected by these larger fuses.

The insulation of the several conductors for high potential motors, where leaving the metal sheath at outlets must be thoroughly protected from moisture and mechanical injury. This may be accomplished by means of a pot head or some equivalent method. The conduit must be substantially bonded to the metal casings of all fittings and apparatus connected to the inside high tension circuit. It would be much preferable to make the conduit system continuous throughout by connecting the conduit to fittings and motors by means of screw joints, and this construction is strongly recommended wherever practicable.

High potential motors should preferably be so located that the amount of inside wiring will be reduced to a minimum.

Inspection Departments having jurisdiction may permit the wire for high potential motors to be installed according to the general rules for high potential systems when the outside wires directly enter a motor room. Under these conditions there would generally be but a few feet of wire inside the building and none outside the motor room.

c. Each motor and resistance box must be protected by cut-out and controlled by a switch, said switch plainly indicating whether "on" or "off." With motors of one-fourth horse-power or less on circuits where the voltage does not exceed 330, single pole switches may be used. The switch and rheostat must be located within sight of the motor, except in cases where special permission to locate them elsewhere is given, in writing, by the inspection department having jurisdiction.

The use of circuit-breakers with motors is recommended, and may be required by the Inspection Department having jurisdiction.

Where the circuit-breaking device on the motor-starting rheostat disconnects all wires of the circuit, the switch called for in this section may be omitted.

Overload-release devices on motor-starting rheostats will not be considered to take the place of the cut-out required by this section if they are inoperative during the starting of the motor.

The switch is necessary for entirely disconnecting the motor when not in use, and the cut-out to protect the motor from excessive currents due to accidents or careless handling when starting. An automatic circuit-breaker disconnecting all wires of the circuit may, however, serve as both switch and cut-out.

In general, motors should preferably have no exposed live parts.

d. Rheostats must be so installed as to comply with *all* the requirements of No. 4. Auto starters must comply with requirements of No. 4*c*.

Starting rheostats and auto starters, unless equipped with tight casings enclosing all current-carrying parts, should be treated about the same as knife switches, and in all wet, dusty or linty places, should be enclosed in dust-tight, fireproof cabinets. If a special motor room is provided, the starting apparatus and safety devices should be included within it. Where there is any liability of short circuits across their exposed live parts being caused by accidental contacts, they should either be enclosed in cabinets, or else a railing should be erected around them to keep unauthorized persons away from their immediate vicinity.

e. Must not be run in series-multiple, or multiple-series, except on constant-potential systems, and then only by special permission of the Inspection Department having jurisdiction.

The objection to combinations of this character is that the cutting-out of one motor, by accident or carelessness, may subject the others to a current or voltage greater than that for which they are designed; and if this occurs, and the protecting devices fail, as sometimes happens, there is very likely to be severe arcing, or a burn-out.

f. Must be covered with a waterproof cover when not in use, and if deemed necessary by the Inspection Department having jurisdiction, must be enclosed in an *approved* case.

When it is necessary to locate a motor in the vicinity of combustibles or in wet or very dusty or dirty places, it is generally advisable to enclose it as above.

Such enclosures should be readily accessible, dust proof and sufficiently ventilated to prevent an excessive rise of temperature. The sides should preferably be made largely of glass, so that the motor may be always plainly visible. This lessens the chance of its being neglected, and allows any derangement to be at once noticed.

The use of enclosed type motor is recommended in dusty places, being preferable to wooden boxing.

From the nature of the question the decision as to details of constructon must be left to the Inspection Department having jurisdiction to determine in each instance.

If possible, the enclosure should be large enough to permit the attendant to enter it and easily get at any part of the apparatus, and this would generally mean a small room. If the motor is suspended from the ceiling, a floor could generally be constructed below it and the four sides of this elevated motor room could be built mainly of windows. Ready access to the room could be secured by means of a short flight of stairs or a ladder. This can also be done where the motor is supported on an elevated platform.

With alternating-current motors having no brushes, the enclosure would generally be unnecessary. When located on the floor, it would often be advisable to surround the machine by a substantial pipe rail to keep people from passing near it.

g. Must, when combined with ceiling fans, be hung from insulated hooks, or else there must be an insulator interposed between the motor and its support.

h. Must each be provided with a name-plate, giving maker's name, the capacity in volts and amperes, and the normal speed in revolutions per minute.

i. Terminal blocks when used on motors must be made of *approved* non-combustible, non-absorptive, insulating material such as slate, marble or porcelain.

j. Variable speed motors, unless of special and appropriate design, if controlled by means of field regulation, must be so arranged and connected that they cannot be started under weakened field.

9. *Railway Power Plants.*

a. Each feed wire before it leaves the station must be equipped with an *approved* automatic circuit-breaker or other device, which will immediately cut off the current in case of an accidental ground. This device must be mounted on a fireproof base, and in full view and reach of the attendant.

An automatic circuit-breaker is preferable to a fuse, as it acts more quickly, is more reliable, and can be more quickly and safely replaced.

10. *Storage or Primary Batteries.*

a. When the current for light and power is taken from primary or secondary batteries, the same general regulations must be observed as apply to similar apparatus fed from dynamo generators developing the same difference of potential.

Charged storage batteries have in them at all times a large amount of stored energy, and should therefore be treated as carefully as generators of similar output.

b. Storage battery rooms must be thoroughly ventilated.

The action of the current in charging the battery liberates at times large quantities of hydrogen and oxygen, and if these should accumulate in the right proportions they would form an explosive mixture which might be exploded by any accidental spark.

c. Special attention is directed to the rules for wiring in rooms where acid fumes exist.

d. All secondary batteries must be mounted on non-absorptive, non-combustible insulators, such as glass or thoroughly vitrified and glazed porcelain.

The battery needs to be insulated and nothing but glass, porcelain and similar materials will retain their insulating properties when exposed to the action of the water and acid freely used about storage batteries.

e. The use of any metal liable to corrosion must be avoided in cell connections of secondary batteries.

Reduction of the cross-section of the connections by corrosion would probably cause them to be burned out by the normal current of the battery.

11. *Transformers.*

a. In central or sub-stations, the transformers must be so placed that smoke from the burning out of the coil or the boiling over of the oil (where oil filled cases are used) could do no harm.

If the insulation in a transformer breaks down, considerable heat is likely to be developed. This would cause a dense smoke, which might be mistaken for a fire and result in water being thrown into the building, and a heavy loss thereby entailed. Moreover, with oil-cooled transformers, especially if the cases are filled too full, the oil may become ignited and boil over, producing a very stubborn fire.

b. In central or sub-stations casings of all transformers must be permanently and effectively grounded.

Transformers used exclusively to supply current to switchboard instruments need not be grounded, provided they are thoroughly insulated.

While from a fire standpoint it is not considered necessary to ground the casings of instrument transformers above mentioned, it is believed advisable to ground them in order to guard against danger from shock. It is evident that all other metal work such as switchboard frames, instrument cases, etc., which are liable to come in contact with a live circuit should also be grounded to protect against this danger.

Definitions

A

A. C.—Alternating Current.

Absorption.—The act of one form of matter sucking, or draining in some other form of matter, as in the case of a sponge taking up water.

Acceleration.—The increase of motion.

Accumulated Electricity.—Electricity confined or stored, as in a condenser.

Accumulator.—Sometimes used to designate a condenser, a Leyden jar, or a storage battery.

Active Coil.—A coil or conductor conveying a current of electricity.

Active Current.—The active constituent of an alternating current, in contradistinction from the wattless component.

Active Wire.—The section of wire on the armature of a dynamo which goes through the field of force, in contradistinction from the remaining wire, which does not pass through the flux.

Aerial Circuit.—An elevated circuit.

Air Blast.—A blast of air acting upon the surface of a commutator to prevent damaging flashes. Also used to cool transformers in some cases.

Air Gap.—Any gap or aperture in a circuit which contains air only.

Air Insulation.—Insulation produced by the action of air.

American Wire Gauge.—The name by which the Brown & Sharpe wire gauge is known, in which the diameter of the largest wire, No. 0000, is 0.46 inches, and wire No. 36, 0.005 inches, and all other diameters progress in geometrical order.

Ammeter.—An abbreviation for ampere meter. Used for measuring current rate, or volume. Any calibrated galvanometer having its scale marked to read amperes is an ammeter.

Ampere.—The unit of electric current flow. An ampere is that volume of current which would pass through a circuit that offered a resistance of one ohm under an electromotive force of one volt.

Ampere Hour.—A unit of quantity equal to the amount of electricity transmitted by one ampere flowing during one hour.

Ampere Turn.—A unit of magneto-motive force equal to the force resulting from the passing of one ampere over a single turn of wire.

Anode.—The positive pole a battery.

Arc.—A segment of a circle. A voltaic arc.

Armature Reaction.—The reactive magnetic effect resulting from the action of the current in the armature of a dynamo on the magnetic circuit of the machine.

B

B. S. G.—British standard gauge.

B. & S. W. G.—Brown & Sharpe wire gauge.

B. W. G.—Birmingham wire gauge.

Balanced Load.—A load uniformly apportioned to two or more generators.

Balanced Resistance.—A resistance arranged in a bridge, and balanced by the residuary resistance in the bridge.

Bar Windings.—Armature windings constructed of copper bars.

Bipolar.—Possessing two poles.

Birmingham Wire Gauge.—A wire gauge used in England.

Booster.—An auxiliary dynamo used to increase the voltage of a feeder, or a set of feeders beyond the voltage of the rest of the system.

Bridge, Electric.—A contrivance used to measure unknown resistances by comparison with adjustable ones.

Bunched Cable.—A cable having more than one wire, or conductor.

Bus-bars.—Bars composed of heavy conducting metal, and connected directly with the poles of generators.

C

C. G. S.—Centimetre, Gramme, second.

C. P.—Candle power.

Calibrate.—To ascertain the complete or relative values of the indications of electrical measuring instruments.

Candle.—The unit of photometric energy. Equals the light produced by a standard candle burning at the rate of two grains per minute.

Cathode.—Opposed to anode.

Condenser.—A device for augmenting the capacity of an insulated conductor by placing it in contiguity to another earth-connected conductor, but from which it is separated by an intervening body which will permit electrostatic induction to occur through it.

Constant Current.—A current, the strength of which does not vary.

Continuous Current.—A current flowing in the same direction only.

Cycle of Alternations.—Alternations of the current per second.

Coulomb.—The unit of electric quantity accepted for practice. That quantity of electricity that would pass in one second through a circuit conveying one ampere. That quantity of electricity contained in a condenser of one Farad capacity when subjected to an E. M. F. of one volt.

D.

D. C.—Direct current.

D. P. S.—Double pole switch.

Differential Winding.—Double winding of magnet coils resulting in the opposition of the two poles to each other.

Dynamic Electricity.—Current electricity as distinguished from static electricity.

Dyne.—The C. G. S. unit of force.

E

E. H. P.—Electrical horse-power.

E. M. F.—Electromotive force.

Electrolysis.—Chemical decomposition by the action of an electric current.

F

Farad.—The practical unit of electrical capacity. That capacity of a conductor that is capable of holding one coulomb at one volt potential.

Feeders.—Wires furnishing the main conductors with currents at different points, thus serving to equalize the potential under load.

Five-wire System.—A system wherein four series connected dynamos are connected to five conductors.

Flux.—Magnetic induction; the number of lines of force which pass through a magnetic circuit.

Frequency.—Number of cycles per unit of time by an alternating current.

G

Gramme.—A unit of weight equal to the weight of one cubic centimetre of pure water at its maximum density, at a temperature of 39.2° Fahr. in a vacuum. A weight equal to 15.44 grains troy.

H

H. P.—Horse-power.

Hard-drawn Copper Wire.—Copper wire hardened without annealing, by being drawn several times.

Henry.—The practical unit of electro-magnetic, or magnetic inductance.

Horse-power, Electric.—A rate of electrical work equal to 746 watts, or 746 volt-coulombs per second.

Hysteresis.—Slowness of magnetization in respect to magnetizing force.

I

Induction.—The influence exerted without contact, by a magnetic field, or a charged mass upon neighboring bodies.

Inverted Arc Lamp.—An arc lamp wherein the positive carbon is below instead of above, as in the regular arc lamp.

J

Jump Spark.—A disruptive spark excited between two conductors, in distinction from a spark excited by a rubbing contact.

K

K. W.—Kilowatt.

Kilowatt.—One thousand watts.

Kilowatt-Hour.—Work equal to the expenditure of one K. W. in one hour.

L

Lag.—Dropping behind.

Lagging of Current.—The retarding in phase of an alternating current behind the pressure which produces it.

M

Megohm.—One million ohms.

Metre.—A measure of length equal to 39.368 inches.

Micro-Fard.—The millionth of a Farad.

Mil.—One thousandth of an inch.

Multiphase.—Containing more than one phase.

Multiple Circuit.—A circuit in which the positive poles of a number of separate sources, and receptive devices are connected to a single positive lead or conductor; their negative poles being connected to a single negative lead or conductor.

Multiple Series.—Series groups connected in multiple.

O

Ohm.—The practical unit of resistance. A resistance that would confine the electric flow under an electromotive force of one volt to a current of one ampere, or one coulomb per second.

Ohm's Law.—The basic law, expressing the relation between current, E. M. F., and resistance in active circuits. Expressed algebraically $I = \frac{E}{R}$, in which I equals current intensity, E equals E. M. F., and R equals resistance. Other forms of expressing ohms law are as follows:

$$R = \frac{E}{I}. \quad E = RI.$$

Over Compounded.—Compound winding of such a character on a dynamo that its voltage at its terminals is caused to increase under a greater load.

P

Parallel Circuit.—A term signifying multiple circuit.

Parallel Series.—Signifies a multiple series connection.

Periodicity of Alternation.—The rate of succession of alternations per second, or per minute. The frequency.

Polyphase Current.—Currents that constantly differ from each other, due to their proportion of periods of alternation, and adapted to polyphase motors.

Proposed Definition for 2,000 Candle Power.—An arc whose maintenance will require 450 watts.

R

Rheostat.—Will adjust the resistance without opening the circuit.

S

Standard Ohm.—A piece of pure copper wire one circular mil in diameter, and one foot long at a certain temperature.

Static Electricity.—Electricity generated by friction.

V

Volt.—The practical unit of electromotive force. An E. M. F. that would cause a current of one ampere to flow through a resistance of one ohm.

W

Water Horse-Power.—The power developed by 15 cubic feet of water falling through a distance of one foot per second.

Watt.—The practical unit of electric activity, rate of work, or energy. A watt equals 44.25 foot pounds of work done per minute, or 0.7375 foot-pounds of work done per second.

Watt-Hour.—Unit of electric work. One watt exerted or expended for one hour.

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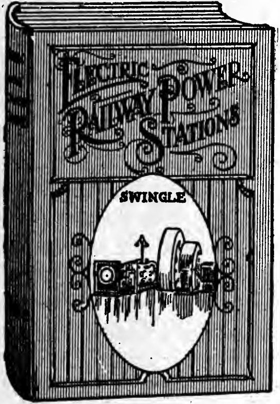
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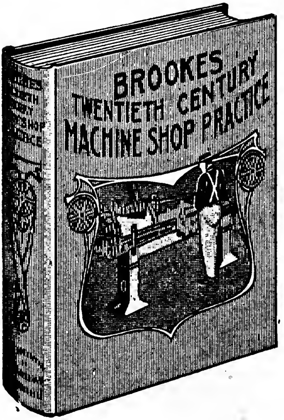
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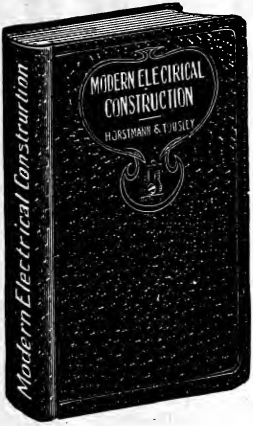

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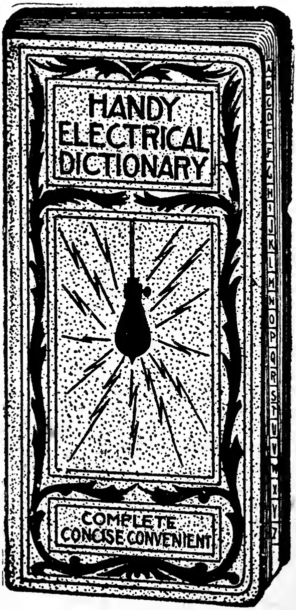
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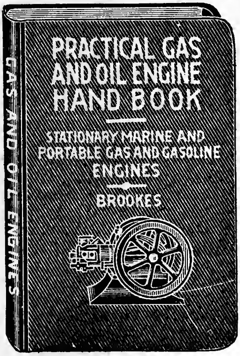

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