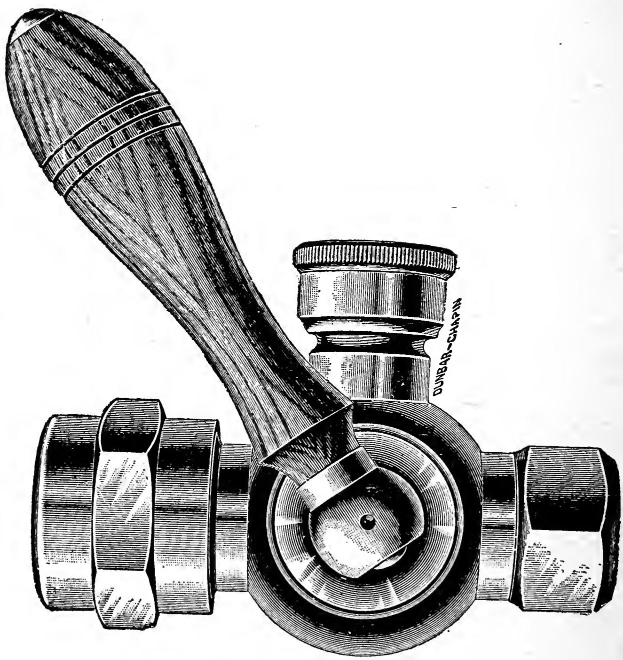
PRACTICAL TREATISE
ON THE
STEAM ENGINE INDICATOR

HAWKINS'

INDICATOR

CATECHISM.

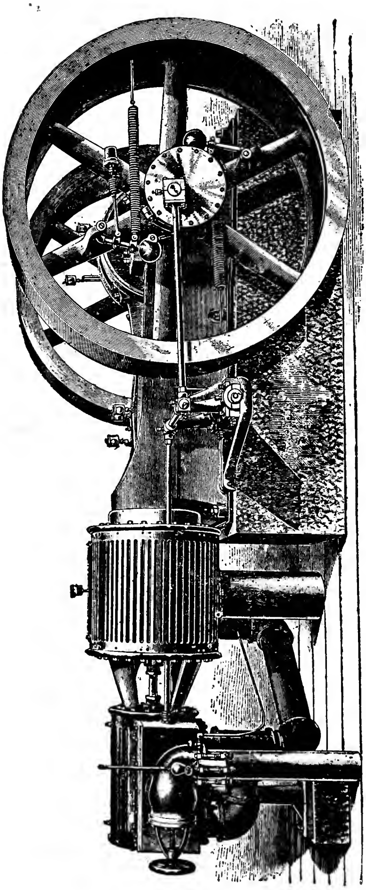


THREE WAY COCK.

THIS WORK IS DEDICATED TO

HENRY RAABE, M. E.,

AS A TOKEN OF APPRECIATION OF VALUABLE ASSISTANCE IN ITS MAKING UP, AND A REMINDER OF A LONG SUMMER SPENT AGREEABLY TOGETHER IN COMPILING AND EDITING THE AUTHOR'S NEW CATECHISM OF THE STEAM ENGINE.



HAWKINS'

INDICATOR CATECHISM.

A PRACTICAL TREATISE

FOR THE USE OF ERECTING AND OPERATING ENGINEERS,
SUPERINTENDENTS, STUDENTS OF STEAM
ENGINEERING, ETC.

RELATING TO THE DESCRIPTION OF THE INSTRUMENT AND
DIRECTIONS FOR ITS APPLICATION IN OBTAINING
THE BEST RESULTS IN THE ECONOMICAL
PRODUCTION AND USE OF STEAM.

BY

N. HAWKINS, M. E.,

AUTHOR OF "AIDS TO ENGINEERS' EXAMINATIONS," "CALCULATIONS FOR ENGINEERS," THE "NEW CATECHISM OF THE STEAM ENGINE," ETC., ETC.

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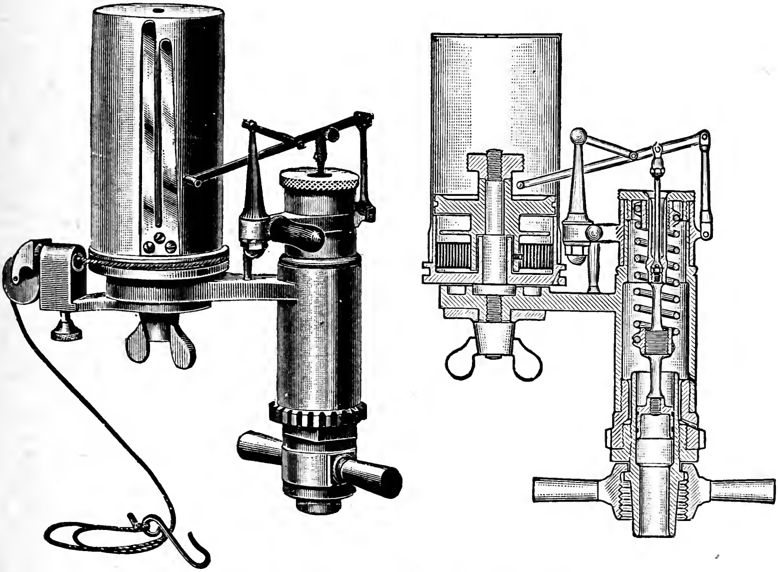
CONTENTS.

"*Much care is necessary in indicator practice, both of the instrument and its method of attachment, since so very much depends on a very small area; and the engineer who obeys this rule, and puts a little thought into his work, will find there is nothing difficult nor mysterious in the use of the Steam Engine Indicator.*"

—THOMAS HAWLEY.

THE STEAM ENGINE INDICATOR.

The measuring instrument best designed to show the power of the steam engine is that invented by Watt—the steam engine indicator.



Figs. 5 and 6. THE INDICATOR.

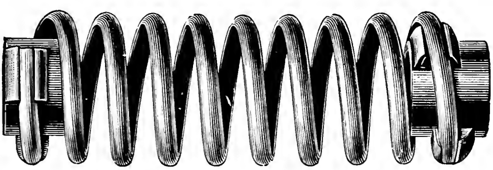


Fig. 7. THE INDICATOR SPRING.

NOTE.—The purpose of the instrument is the same as a recording steam gauge, with this difference, that it records the pressure at each instant of the engine stroke, and this pressure is usually a variable one in different parts of the stroke. This is its object, simply to put upon paper the steam pressure pushing the piston at each point in the stroke, and at the same time to put on paper what pressure is opposing the piston at each portion of the piston stroke. That is all it does. The instrument may be considered as a steam gauge with a spiral spring to measure the pressure, and a pencil to record it.

INTRODUCTION.

The indicator is a miniature of the larger cylinder whose performance it is designed to reveal. The object of the instrument is simply to record the pressures that are in the cylinder of the engine at certain points of the stroke, and from this can be told, first, the action of the valve gear, and second, the distribution of pressure. This is all that the indicator shows; it indicates how much pressure is in the cylinder, and the exact location of the piston when that pressure existed in the cylinder.

Figs. 5 and 6 show an exterior and interior view of the American Thompson Indicator and Fig. 7 exhibits the spring which is the real measuring factor of the indicator; this spring is enclosed in a cylinder which is constructed so that its area is generally one-half of a square inch.

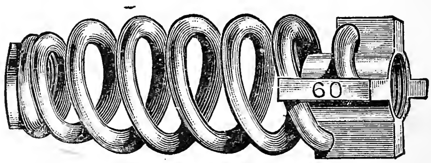


Fig. 8. INDICATOR SPRING.

Fig. 9.

Fig. 319 is the piston rod of the Robertson-Thompson Indicator, shown in Figs. 10 and 11.

These two instruments are shown out of a variety of excellent and reliable devices on the market, to which the following general description will apply.

The indicator consists of a cylinder of ½ a square inch area and about two inches long to the upper end of which is attached an arm or bracket which carries a drum around which the indicator "card" is wound; this drum has a diameter of about two inches and is capable of a semi-rotary motion which is given to it by a cord operated from the engine crosshead.

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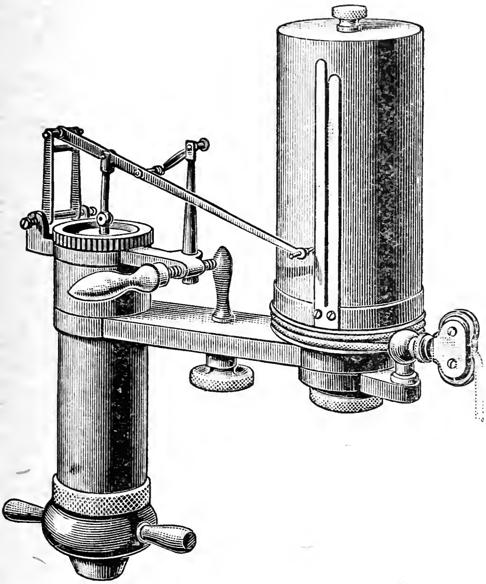

Fig. 10. INDICATOR.

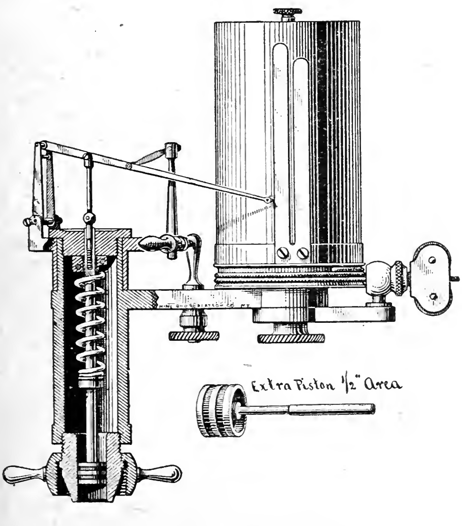

Fig. 11. INDICATOR.

The "diagram" is marked upon the card by a pencil which is on the end of a lever and which is attached by means of links to the piston rod of the indicator. Upon the piston is mounted a spring which counteracts the steam pressure; these springs are of different tensions, or strength, to be used according to the steam pressure.

To impart a straight vertical motion upon the paper card wound around the drum, a parallel motion device, Fig. 12, is attached to the lever which carries the pencil. The one shown in the illustration is the "Thompson parallel motion" and is that most frequently in use.

This brief description of this important instrument will be readily understood by study of the several illustrations.

INTRODUCTION.

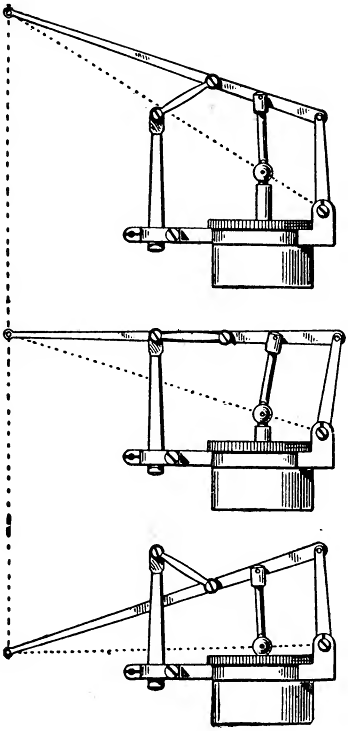

Fig. 12. THOMPSON PARALLEL MOTION.

The operation of the indicator is as follows: steam enters the cylinder of the instrument forcing the piston upwards against the pressure of the spring, this gives a vertical motion to the pencil on the paper mounted upon the drum. The drum receives its revolving motion by a cord which is wound around the lower part of the drum, its other end being connected by means of a reducing motion to the cross-head of the engine, which upon commencing its stroke exerts a pull upon the cord, thus giving the drum a revolving motion. This causes the pencil to make a horizontal line upon the paper.

Upon the return of the engine cross-head the drum is revolved by a spring which is constantly held under tension. A section of the paper drum of the Robertson-Thompson Indicator is shown in Fig. 13.

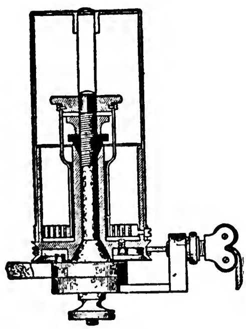

Fig. 13. PAPER DRUM.

In preparing to indicate an engine, then, we have two problems to consider only; one is to place the indicator in perfect communication with the cylinder at each end, and the other is to rig a reducing motion that will give to the indicator in its reduced scale an exact reproduction of the movement of the piston. Usually the indicator holes may be found plugged on removing the laggings. Most engine builders provide their engines for indication.

In a perfect indicator the pencil should, by its vertical position upon the diagram, represent exactly the pressure beneath the indicator piston at any instant; and by its horizontal position, the point which the piston has reached in its stroke at the same instant. This is accomplished by the spring upon whose accuracy depends the correctness of its conclusions or records. To secure this accuracy, it is well to have the springs tested. All of the manufacturers will make such tests of springs for purchasers, and the diagrams of the test may be kept as a record of the degree of accuracy of the instrument at that time. It is well also to have such tests made occasionally after the instrument has been in use, and especially just before and after applying it to work of particular importance. The test consists of applying steam to the indicator piston at pressures increasing by equal amounts, say, for ordinary springs, five pounds. As each five pounds is reached a line is drawn upon the card, a standard gauge or, better, a mercury column being used to indicate the pressures.

The movement of the pencil should be exactly proportional to that of the piston—a principal of operation that is closely followed by all makers of the instruments.

Another quality of importance is the freedom from friction that an indicator should possess in the greatest possible degree. To make a test detach the piston and see that the pencil levers will drop freely and without any suspicion of a catch from any position within the working range of the instrument. With the piston attached, but without any spring, raise the piston by taking lightly hold of the pencil, and work the pencil lever up and down through the full limit of its motion, feeling carefully for any interruption to its movement. Then raising the pencil nearly to the top of the paper-drum, cover the hole through which steam is admitted to the indicator with the thumb;

NOTE.—This test must be made with a dry instrument—hence, before beginning, wipe carefully.

INTRODUCTION.

when the pencil should sink slowly down through the whole range of its motion, but should drop instantly from any point upon the removal of the thumb.

Do not get the piston too tight, through fear of its leaking. It has a whole boiler full of steam behind it part of the time, and a large volume always, and no noticeable difference in pressure will result from any leakage which can take place unless the leakage is so excessive as to increase the pressure on top of the piston.

On condensing engines the vacuum, as indicated by the indicator, may be materially reduced if the piston is too loose, and it is unpleasant and uncleanly to have too much steam and water leaking and spattering about the instrument. The piston which will sustain the test just described will be found tight enough without excessive friction.

The line in which the point of the pencil moves should be exactly parallel with the axis of the paper drum, in order both that the pencil may bear upon the paper equally in all portions of its stroke, and that its vertical movement may be at right angles with the horizontal movement of the paper.

If the line does not comply with these conditions, the natural inference will be that the pencil movement is incorrect, although the horizontal line may be thrown out by any vertical movement of the cylinder upon its spindle.

Lost motion is usually a matter more of adjustment than of manufacture. Put a stiff spring into the indicator, and carefully feel at the end of the pencil lever for any unrestrained movement. Should such be found, its cause should be searched for in the connection of the piston rod to the piston and pencil motion, through all the joints of

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NOTE.—An elaborate apparatus for drawing these lines automatically as the mercury rises in the column is maintained by the United States Government at the New York Navy Yard, for testing and standardizing the indicators used by the navy.

INTRODUCTION.

the parallel motion, in the fit of the collar which carries the mechanism, and if it cannot be corrected by adjustment without making the instrument too stiff to comply with the friction test above described, the instrument should be rejected.

The above qualities are necessary to an indicator for accuracy. Other points, more in the nature of conveniences than essentials, but which may be well considered in selecting an instrument, are the comparative simplicity of changing springs, adjustment for height of atmospheric line, changing from right to left hand and *vice versa*, adjusting the drum-spring and leading pulley, attaching the indicator to the cock, etc. For holding the lead, the end of the pencil lever in some indicators is formed into a light steel quill of a size that will hold the lead firmly when forced through it. In other makes the end of the pencil lever is reinforced and threaded internally, the lead being screwed through it.

HAWKINS'

INDICATOR CATECHISM.

QUESTIONS AND ANSWERS.

QUES. What is the first thing important to be known relating to the Steam Engine Indicator?

ANS. The name of its essential parts.

QUES. What next is of importance?

ANS. To know the special terms, definition and "shop names" in ordinary use.

QUES. Cannot the instrument be used without this knowledge?

ANS. Yes; it can be done, but it is next to impossible.

NOTE.—It is an unwritten law that each art, science, and mechanical contrivance has related to it certain words, phrases and definitions, which are known mainly and almost exclusively to those who practice the arts or use the tools. In order to gain the necessary instruction in the shortest time and in the most thorough manner it is well for the learner to have already memorized and at his tongue's end those elementary shop names and definitions.

QUESTIONS AND ANSWERS.

QUES. Is the indicator more properly a machine or an instrument?

ANS. It is an instrument because it is a device by which work is performed or anything is effected; a machine or engine implies a much larger piece of mechanism.

QUES. What are the special important uses of the indicator?

ANS. It is used primarily to measure the power of the steam engine; second, to show the quantity of steam used per horse power for a given time; also, to indicate how to adjust the valve gear of the engine.

QUES. What other uses can be named for which the instrument is serviceable?

ANS. It shows the vacuum obtained by the use of the condenser and the relative pressure existing between the steam in the boiler and the pressure of the steam in the cylinder.

QUES. What are the principal (four) parts of the indicator?

ANS. The cylinder, the spring, the piston with its connections, and the drum.

QUES. Does the steam required to operate the indicator go to waste?

ANS. Yes; in effect it is so much added to the percentage of clearance of the cylinder.

NOTE.—The indicator does no work, any more than a guide post; it simply records on the diagram the work being performed by the engine.

QUESTIONS AND ANSWERS.

QUES. What parts of the instrument will have to be closely observed when diagrams are being taken?

ANS. 1, The pencil levers, that they do not get bent; 2, the lead, which must not be too large, and always should have a fine round point; 3, the drum spring, which must not be too slack nor too tight; 4, the piston rod, which must not be too short nor too long, otherwise the pencil will travel either too high or too low on the card.

QUES. What other parts should be looked after while indicating or preparing for indicating?

ANS. Care should be taken that no lost motion is in the reducing mechanism and its connections, for this would produce serious error on the diagram. In adjusting the cord, it should not be made too long or too short, and, when putting the paper upon the drum, it should be placed smooth, so it will not offer any obstructions to the pencil.

QUES. When piping up the indicator, what is there important to be guarded against?

ANS. No pipe chips, red lead or other foreign matter must be allowed to remain in the pipes, and when tapping apertures into the cylinder for indicator connections they must be so located that the piston will not obstruct the holes.

QUES. How should the instrument be treated after use?

NOTE.—Also, care should be taken not to allow the pencil to press too tightly upon the paper, which may produce unnecessary friction, and produce error in the final results.

QUESTIONS AND ANSWERS.

ANS. It should be cleaned, wiped dry, and oiled, so as to be ready for the next test.

QUES. What about the springs?

ANS. The springs are the most vital part of the instrument, and need particular attention. They must not be allowed to get rusty, otherwise they will be useless for accurate work.

QUES. Is there any other simple way of causing serious error in applying the indicator?

ANS. Error is often produced by not shutting the indicator cock properly. It is not supposed to be pressed tightly into its seat, as this would soon cut both plug and seat, and cause the cock to leak. Besides the steam passage through the plug of the indicator cock, there is a small hole drilled at right angles to the steam passage, which communicates with a similar hole in the body of the cock; now, when shutting the cock, the plug should be turned so that this hole will point toward the indicator cylinder, and thus open communication between the atmosphere and the cylinder of the instrument, and thus allow the atmospheric line to be drawn in its proper place.

When opening the cock, this hole should be turned so that the steam will not escape through it.

QUES. In indicator practice, what is meant by absolute pressure?

ANS. Absolute pressure is the pressure of the steam above a perfect vacuum.

QUES. What is gauge pressure?

QUESTIONS AND ANSWERS.

ANS. Gauge pressure, or pressure by gauge, is the boiler pressure, as indicated by the steam gauge, or the pressure per square inch of boiler surface above the atmospheric pressure.

QUES. What is initial pressure?

ANS. Initial pressure is the pressure in the engine cylinder as shown by the indicator, at the beginning of the stroke. The initial pressure is ordinarily below the gauge pressure, on account of the wire drawing in the connection between the cylinder and boiler.

QUES. What is wire drawing?

ANS. Wire drawing is a term used in describing the reduction of pressure caused by passing the steam air or gas through a narrow opening.

QUES. What is the definition of mean effective pressure?

ANS. Mean effective pressure is the average of the pressures recorded by the indicator at different points of the stroke above the exhaust pressure. It is the pressure which would have to act upon the piston throughout the entire stroke to cause the engine to develope the same power as under the indicated conditions.

QUES. What is terminal pressure?

ANS. Terminal pressure would be the pressure at the end of the stroke, if the exhaust valve did not open before the piston comes a dead standstill.

NOTE.—As in all engines the exhaust valve opens before the end of the stroke, the terminal pressure is never reached.

QUESTIONS AND ANSWERS.

QUES. What is back pressure?

ANS. Back pressure, or counter pressure, is the amount of pressure above the atmosphere during the exhaust stroke. The back pressure counteracts the forward movement of the piston, and therefore should be avoided. On an indicator diagram it is found by allowing the instrument to trace the atmospheric line after taking the diagram.

QUES. What is meant by "ratio of expansion"?

ANS. Ratio of expansion is the entire cylinder volume, divided by the volume before cut-off.

QUES. What does clearance mean?

ANS. Clearance is the space included between the piston at the end of the stroke and the cylinder head; to this is added the volume of the steam ports. The clearance is generally expressed in percentage of the cylinder volume.

QUES. What is saturated steam?

ANS. Saturated or dry steam is steam in a perfect gaseous state. Any loss of heat will change its condition by partial condensation.

QUES. What is superheated steam?

ANS. Superheated steam is such as is heated above the temperature of saturation.

QUES. What is the difference between an indicator diagram and an indicator card?

ANS. The diagram is the outline traced by the pencil upon a card or paper, and a piece of paper becomes an "indicator card" when it is used to record one or more diagrams. A card often contains a diagram from both the head and crank ends of the steam cylinder.

AN INDICATOR OUTFIT.

An indicator outfit consists of the following articles:

The indicator, or if a very accurate test is required, both ends of the cylinder have to be indicated simultaneously, and thus two instruments are needed.

A good reducing motion, as preferably a pantograph or reducing wheel.

The cord for connecting reducing motion to indicator.

The indicator cards.

Pencils.

One three-way cock, or two straight-way cocks.

Three or more springs, of different tensions.

The corresponding scales for the springs.

A bottle of pure machinery oil.

The necessary wrenches, spanners, screw-drivers, etc., belonging to the indicator.

Planimeter.

NOTE.—The original indicator, as first invented by Watt, consisted simply of a piston working in a cylinder against the resistance of a spring. The movement of the spring, due to the pressure of the steam on the piston, was shown by a pointer attached to the piston rod of the instrument, and pointing to a scale. Later, Watt added a board, on which was attached a piece of paper moving simultaneously with the piston of the engine; a pencil was substituted for the pointer, and a card traced on the paper on the board. Watt did not use the paper drum, which was added by a contemporary and generally adopted, and substantially in this form the instrument remained until the introduction of the Richardson Indicator. Richards added to the indicator Watt's parallel engine motion, and by multiplying the movement of the spring by using a lever, allowed a stiffer spring to be used.

PREPARING THE INDICATOR FOR USE.

In selecting a spring, aim to get as large a card as possible without undue distortion. If a card be taken with a 20 spring, an error of measurement of $\frac{1}{100}$ of an inch would influence the results only one-fifth of a pound. With a 50, spring the same error in measurement would represent a departure of one-half a pound.

It is, therefore, advisable to have the area as large as possible.

On the other hand, the allowable movement of both the pencil and the drum is limited by the effects of momentum At high speeds a light spring and long movement of the drum would result in a diagram so distorted by the effects of momentum and inertia as to introduce errors much more serious than those that are likely to occur from inaccurate measurement of a smaller and more perfect diagram. The speed as well as the pressure will therefore have a bearing on the spring selected, and will also influence the selection as between the standard size of paper drum which is used for moderate speeds, and the smaller drums which some of the makers supply for high-speed work. Some manufacturers furnish two sizes of drums, which may be used interchangeably upon the same instrument, adapting it to the highest and slowest speeds.

In changing the spring, unscrew the head of the indicator, hold the carrying ring as shown in Fig. 14, and the piston and spring may easily be disconnected from the moving parts and head.

PREPARING THE INDICATOR FOR USE.

In some instruments the position of the atmospheric line is fixed; in others it is adjustable, so that in indicating a non-condensing engine the base-line may be lowered, and the whole of the allowable movement of the pencil utilized for the height of the diagram.

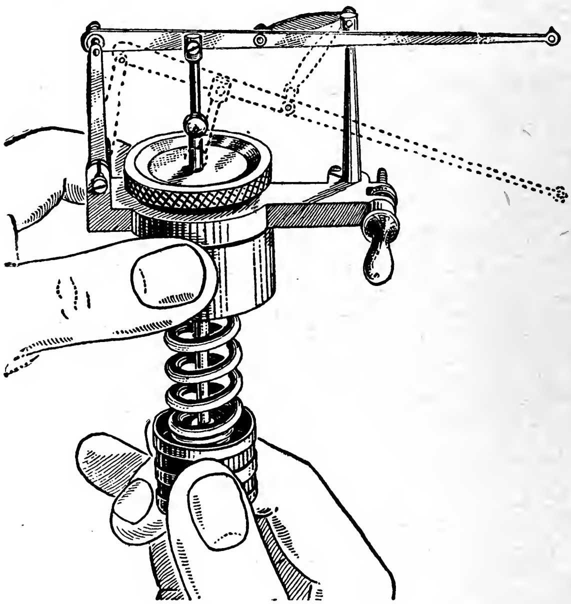

Fig. 14.

The adjustment for height is effected by lengthening or shortening the distance between pencil lever and piston.

It is frequently desirable, in condensing engines, to obtain the lower or condensing portion of the diagram on a larger scale than that of the spring available with the initial pressures used. With an initial pressure that demands a 60 spring, a realized vacuum of twelve pounds would be represented by a line only one-fifth of an inch below the atmospheric line, Fig. 15, giving a very small area to the condenser portion of the card. In order to obtain this area

PREPARING THE INDICATOR FOR USE.

upon a larger scale, giving increased accuracy of measurement, showing more clearly the points of release and compression, etc., springs of low tension are sometimes fitted with bosses or studs, which prevent their closing beyond a certain point, while they are free to extend to any amount.

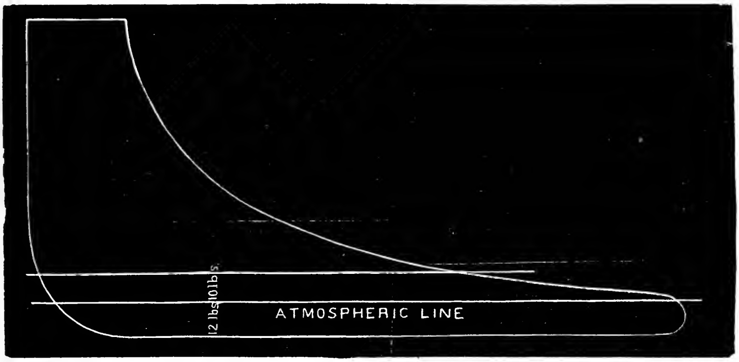

Fig. 15.

In Figs. 15 and 16 are shown two diagrams, the first drawn to a 60 scale; and beneath it the shaded portion of the diagram is shown expanded to a 10 scale. Notice how much more prominently the points of release and compression are shown, on account of the more rapid vertical movement with the same horizontal movement; and how much less an error of a few hundredths of a square inch in measuring the area of the condensing portion of the card would affect the result.

Select a hard lead of good smooth quality and of small diameter, and use only a small piece at a time. At the end of the pencil lever, where the motion is greatest, the weight should be reduced to the smallest possible value. If pointed with a fine file and rubbed down with an emery

PREPARING THE INDICATOR FOR USE.

stick, such as is used for sharpening draftsmen's pencils, or a fine stone, it will wear longer and be smoother and more satisfactory than if whittled into shape.

For lubricating the bearings of the instrument a light machinery oil should be used—one that will not gum or corrode. A small vial of such oil usually accompanies the

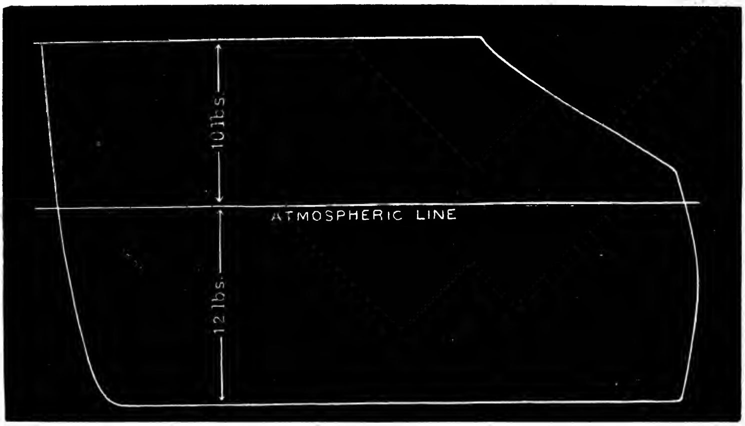

Fig. 16.

instrument, some makers furnishing porpoise oil, such as is used for clocks and watches. The piston, however, is better lubricated with cylinder oil, which must be absolutely free of grit.

Filter the oil carefully and make sure that the can is perfectly clean; a small particle of grit upon the piston of an indicator will not only throw the diagram into misleading forms, but may scratch and injure both cylinder and piston to a serious degree.

Use hard, tough smoothly calendered paper of a width sufficient to include the highest allowable pencil travel, and about an inch longer than the circumference of the barrel.

REDUCING MOTIONS.

In order to use the indicator, a means must be provided for moving the paper drum exactly in time with the engine piston. This movement is usually derived from the cross-head, and the appliance used to reduce the movement to that adapted to the paper barrel is spoken of as the "reducing motion."

The most simple expedient for this purpose is a lever suspended from the ceiling or other suitable support, and connected at its lower end with the cross-head in such a way that it will be swung back and forth as the engine makes its revolutions. The motion of the lever increases from nothing at the point of suspension to approximately the full stroke of the engine at the cross-head end, the amount of motion being directly proportional to the distance from the point of suspension. A point midway of the lever would have a motion equal to one-half the stroke; one-quarter of the way from the point of suspension, one-quarter stroke, etc.

In order to find the distance of cord-pin from the fulcrum of the lever, multiply the total length of the lever by the desired length of diagram, and divide by the stroke of the engine, all in inches.

The total length of the lever is measured from the point of suspension to the point of attachment to the cross-head, and is variable in some of the arrangements to be shown. As the variation bears a small proportion to the total length, and the length of card is usually figured only to keep within the limits of the paper drum, especial refinement in this particular is unnecessary.

REDUCING MOTIONS.

In order to get the full motion of the cord-pin, the cord must be led off in the direction of the pin's greatest movement, *i. e.*, at right angles to the lever when the lever is itself at right angles to the guides. It will be readily seen that if the cord were led off parallel to the lever, it would receive very little motion. It is desirable to avoid the use of leading pulleys, and Figs. 17 and 18 show two methods of accomplishing this; the first by putting on a segment of a circle, called a brumbo pulley, having a radius equal to

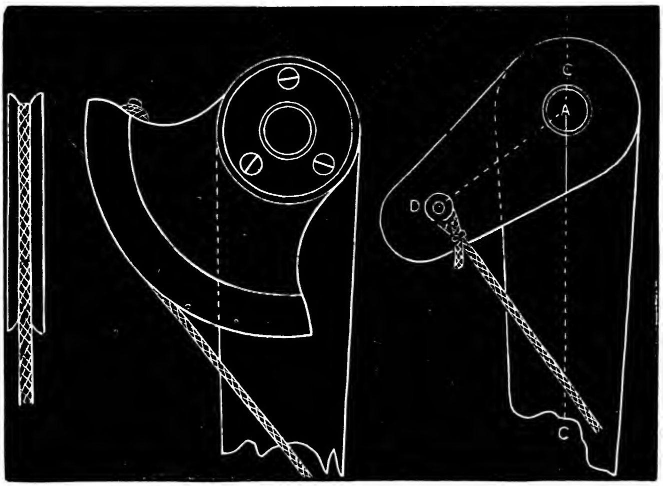

Fig. 17. Fig. 18.

the distance from the fulcrum to the attachment of the cord, and so placed that the cord may be led straight to the indicator without running on to the corners of the segment at the extremes of the stroke.

In Fig. 18 a supplementary lever is added in such a position that when the main lever *CC* is at right angles to the guides the line *AD* will be at right angles to the cord when the latter is led in the desired direction.

REDUCING MOTIONS.

If a lever reducing motion is employed, the lever should not be less than twice the length of the stroke.

The point of suspension of the lever should be directly over its point of attachment to the cross-head when the latter is in the center of its stroke.

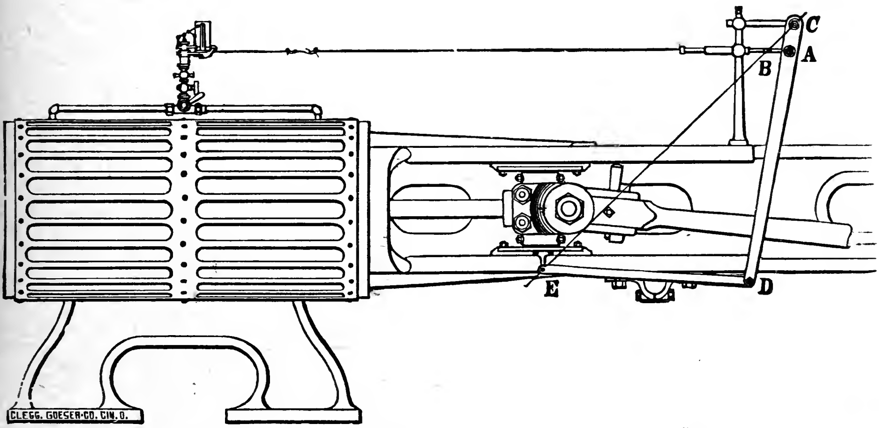

Fig. 19.

In Figs. 19 and 20 are shown two devices for reducing the motion of the cross-head. Fig. 19 represents the reducing motion manufactured by the Buckeye Engine Company, while the simple device in Fig. 20 can easily be made by any mechanic.

A far better method of reducing the motion of the cross-head is the pantograph, two kinds of which are shown in Figs. 21 and 22, and their application can be seen in Figs. 23 and 24.

There is no patent upon the pantograph in either of these forms, and anybody who has tools and knows how

NOTE.—In all motions of this kind there is a radical defect due to the fact, that while the cross-head moves in a straight line, any point on the lever swings through the arc of a circle.

REDUCING MOTIONS.

to use them can make one for himself. The members are usually made of strips of hard wood, one and one-eighth by five-sixteenths of an inch, and sixteen inches between the pivoted points.

Besides these devices there are a number of reducing

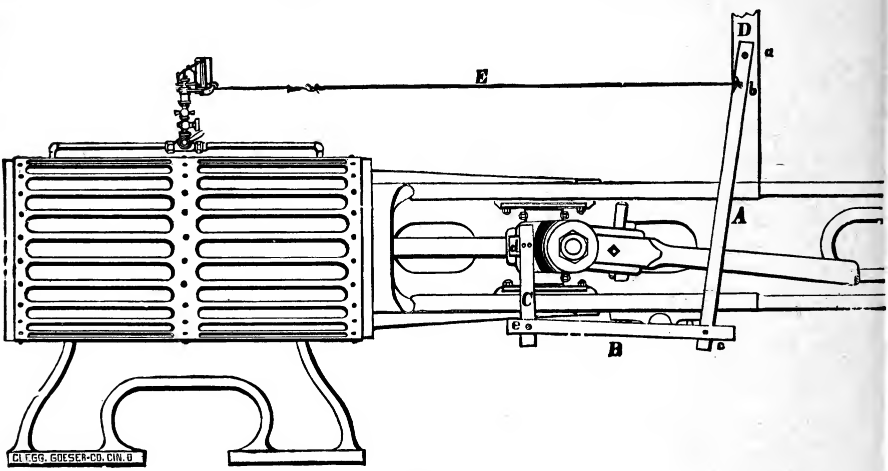

Fig. 20.

wheels on the market, one of which, called the "Victor" reducing wheel, is shown in Fig. 25. The cord that is wound upon the large wheel is attached to the engine cross-head, while the drum cord is wound upon a small pulley, which is in communication with the large one in the manner shown in Fig. 25.

In Fig. 26 is shown the "Ideal" reducing wheel attached to the American Thompson indicator.

Fig. 27 shows the attachment of the Ideal reducing wheel to a Bachelder indicator, and their application to the cylinder and cross-head of a Corliss engine.

In Fig. 28 is shown the Houghtaling reducing motion, in connection with the Tabor indicator.

REDUCING MOTIONS.

This reducing motion is composed of a supporting base-piece *K*, provided with short standards that form bearings for the worm-shaft *R*, on which the flanged pulley *O* is rotated, the outer bearing being a pivot *p*, which receives the entire thrust of the shaft *R*, thus reducing the friction to a minimum. It is connected direct to the indicator

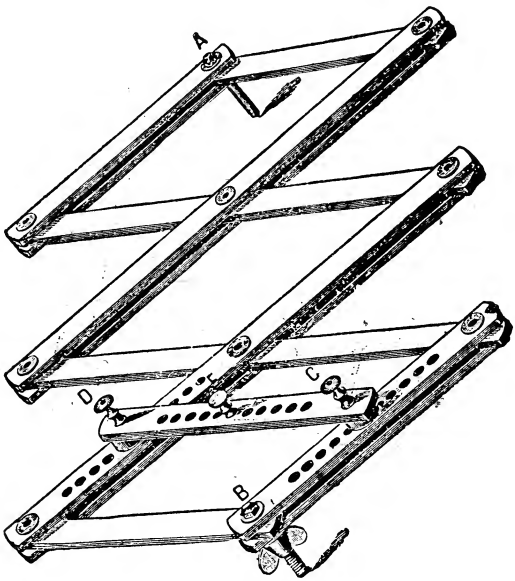

Fig. 21. PANTOGRAPH.

upon the projecting arm that supports the paper drum *B*, and the teeth of the worm-shaft *R*, mesh directly with the teeth on the spool *g*. Connected with the base-piece *K* is a spring case *d*, and on the extreme end of the worm-shaft *R* is a thumb-piece *u*. There is also secured upon this worm-shaft *R*, a collar, not shown in the illustration, through which a clutch-pin secured directly to the thumb-piece *u* slides.

The flanged pulley *O* runs freely and independently on

REDUCING MOTIONS.

worm-shaft *R*, and has on its outside a clutch-shaped hub. To this pulley *O* is connected the actuating cord, which should encircle it a sufficient number of times to have its length when unwound a little more than equal the length of the stroke of the engine. The other end of the cord is secured either to the cross-head of the engine, to a standard

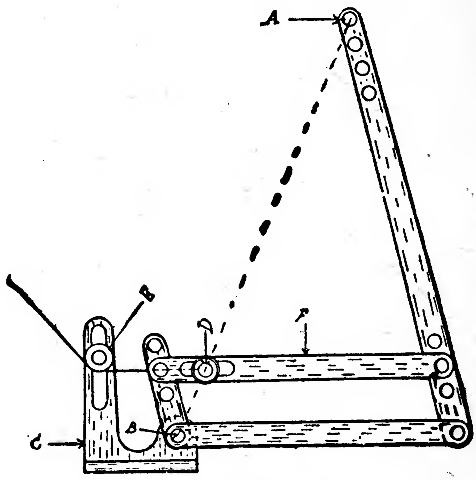

Fig. 22. Pantograph.

bolted to the same, or to any moving part that has an exactly similar motion, and must be connected in line from the pulley *O*.

Inclosed in the spring case *d* is a small, plain spiral steel spring which operates to return the pulley *O* back to its starting point, after it has been revolved in one direction by the forward movement of the engine cross-head. As this pulley *O* has an independent, rotating back and forth motion on the worm-shaft *R*, the necessity of unhooking the cord when the indicator is not being operated is entirely overcome. The paper drum *B* is rotated forward by the

REDUCING MOTIONS.

pulley *O* through its worm-shaft *R*, engaging with the worm-gear *g*, and in the opposite direction by the action of its own retracting spring.

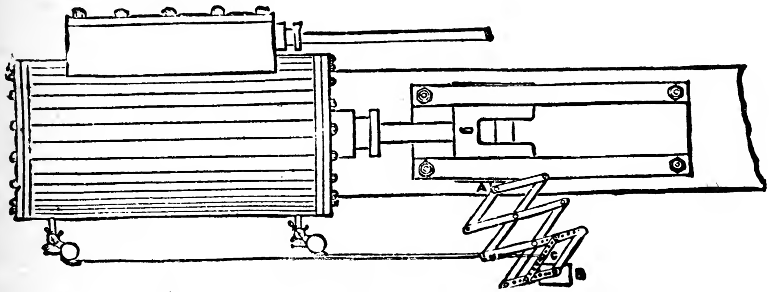

Fig. 23. APPLICATION OF PANTOGRAPH.

To operate this device, first select a pulley whose circumference is from one-quarter to one-fifth the length of the engine stroke.

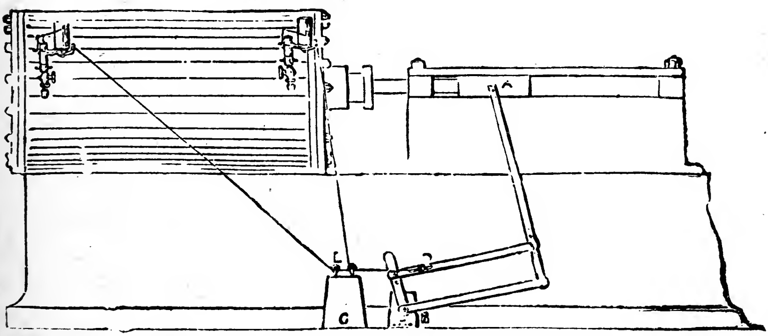

Fig. 24. APPLICATION OF PANTOGRAPH.

In placing this pulley on the worm-shaft *R*, after removing the clutch and its collar, care should be taken to have it set on the small projecting pin on the cover of the spring case *d*; then replace the clutch collar and clutch, pushing the collar on to the shaft as far as it will go and holding it in place by the set screw.

REDUCING MOTIONS.

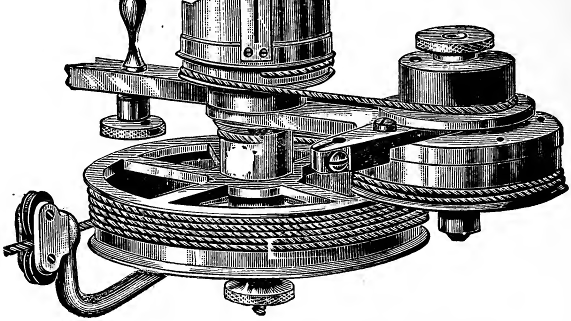

Fig. 25. VICTOR REDUCING WHEEL.

Next, place the indicator in position and run out the loose end of the cord in a direct line with the pulley *O*, to the point on the engine to which it is to be connected;

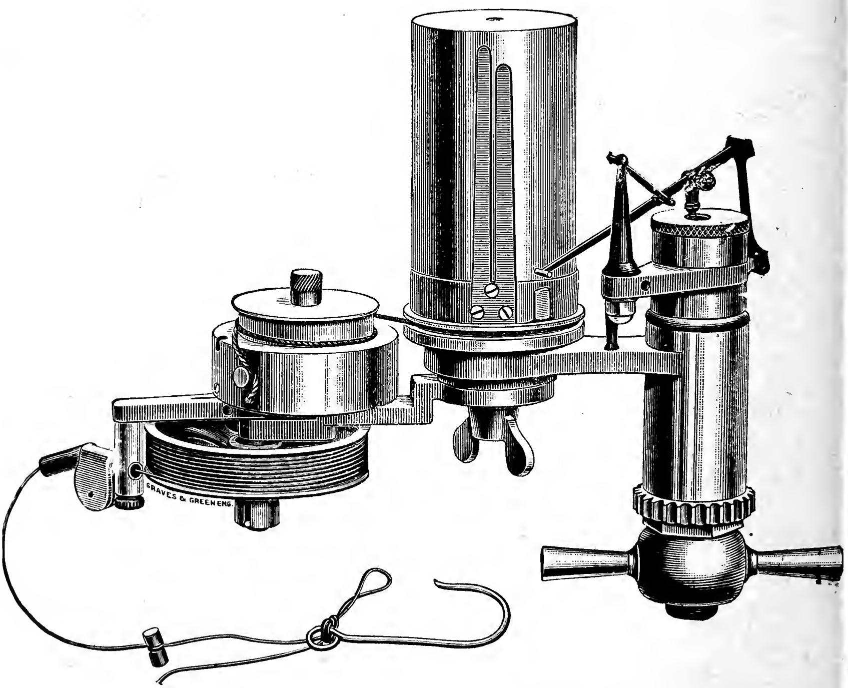

Fig. 26. IDEAL REDUCING WHEEL.

REDUCING MOTIONS.

then bring the cross-head of the engine to the extreme limit of the forward travel, and with one or two turns of the cord left unwound on the pulley.

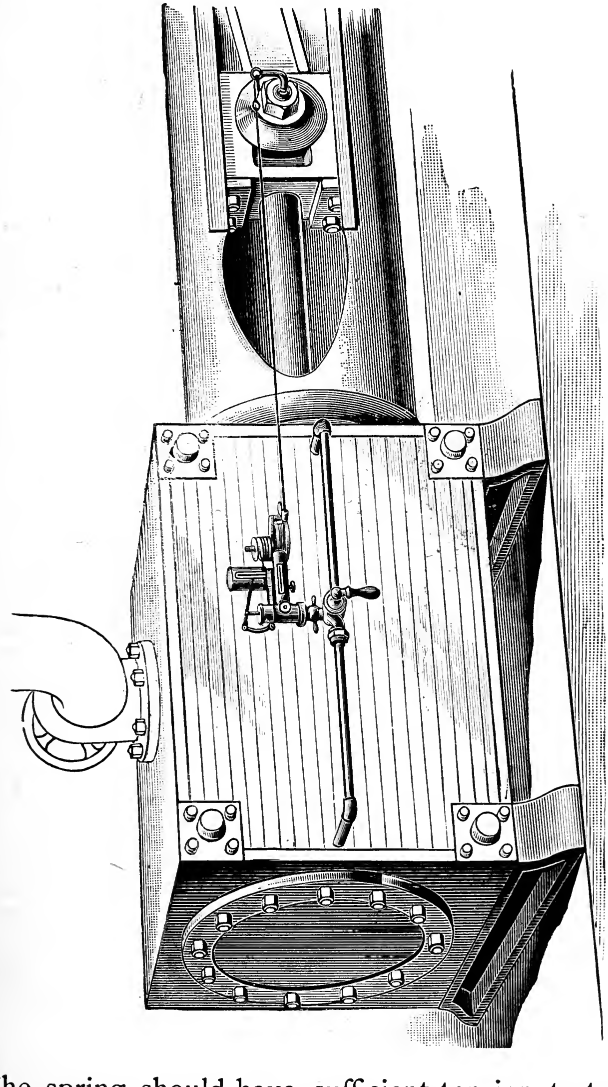

Fig. 27. The Bachelder Indicator and Ideal Reducing Wheel.

The spring should have sufficient tension to take in all the slack of the cord when on the return stroke.

REDUCING MOTIONS.

When pulley *O* is running, motion to the paper drum *B* is obtained by pushing in the thumb-piece *u*, to which the clutch-pin is secured. When ready to take diagrams, after placing the paper on the drum *B*, it is first necessary to advance the drum away from its stop fully one-quarter

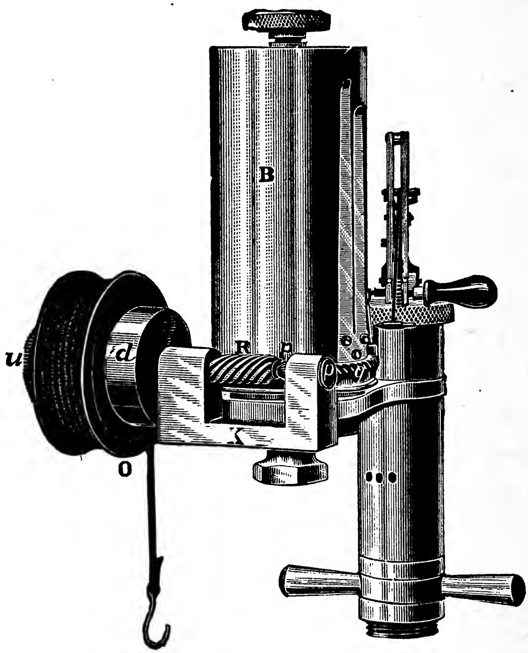

Fig. 28. HOUGHTALING REDUCING MOTION.

inch, which can be done by turning with one hand the nerled top-piece. While holding the drum in this position, with the other hand push in gently the thumb-piece *u*, to start the paper drum in motion.

The motion of the paper drum can at any time be instantly stopped for removing the diagrams, by withdrawing the clutch thumb-piece *u*, or by turning the top thumb-piece; the latter method is the best.

PIPING UP THE INDICATOR.

The connection between the indicator and the steam cylinder of the engine must be as direct as possible, so that the same pressure that is acting upon the piston in the engine may at the same instant act upon the piston in the indicator. The steam is acting in the indicator exactly as it does in the cylinder, but its load is a spring, and the tension of a spring is known; so, if it is known how much the spring has been compressed, it will also be known what pressure the steam must have exerted upon it.

All modern engines are tapped for the indicator; but if there should be no provisions made, the holes should be drilled into the counterbore of the cylinder, and tapped for a half-inch pipe thread.

Care should be taken that none of the drill-chips drop into the engine cylinder, and that the holes thus drilled are not obstructed by the piston.

If a single indicator is employed, the connection is usually made in the manner shown in Fig. 29.

When this connection is used, the bends should be as easy as possible. The ordinary elbows are not the proper thing to be used; but in Fig. 32 is shown a large turn angle valve, which gives a very easy course for the steam,

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NOTE.—Be very sure that the passage to the cylinder is free, and that the piston does not even partially obstruct it at the end of the stroke. The beginning of the stroke is when the indicator makes its quickest movement, and a choking of the passage will produce apparently unaccountable results. By throwing a ray of light into the hole tapped for the indicator, the directness of the passage can be ascertained.

PIPING UP THE INDICATOR.

and possesses the advantage of allowing the piping to be cut off from the cylinder, when the indicator is not in use, thus reducing the clearance.

A three-way cock should also be used, an example of which is shown in Fig. 33; this allows the indicator to be connected to either end of the cylinder, by a quarter turn of the handle.

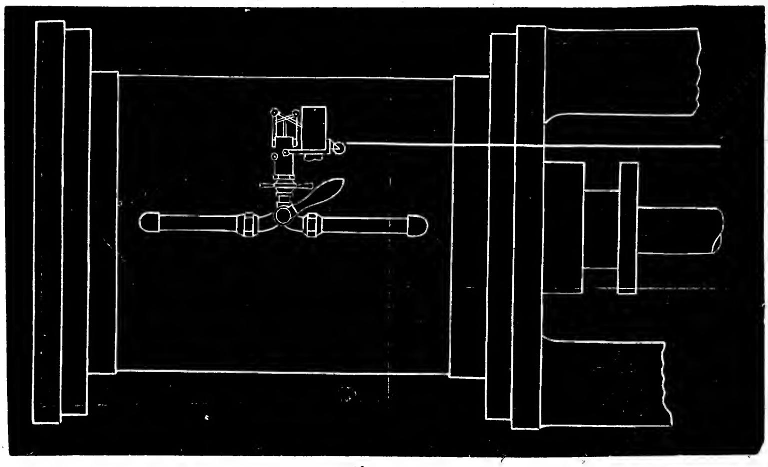


Fig. 29.

In Figs. 30 and 31 are shown other ways of connecting the instrument, of which Fig. 30 is the better way, as it dispenses with the elbow, and should always be used if two instruments are employed.

In putting up piping or connections for use with the indicator, no red lead or other mixture should be used, as it will be carried by the steam to the indicator cylinder and produce trouble. A few drops of oil on the thread is usually all that is required.

Particular pains should be taken to remove from all pipes

PIPING UP THE INDICATOR.

and fittings all dirt, scale and burr that can become detached and work into the cylinder.

When the connections are all up, allow the steam to blow through them freely some time before attaching the instrument, to remove any scale or dirt that is liable to become detached.

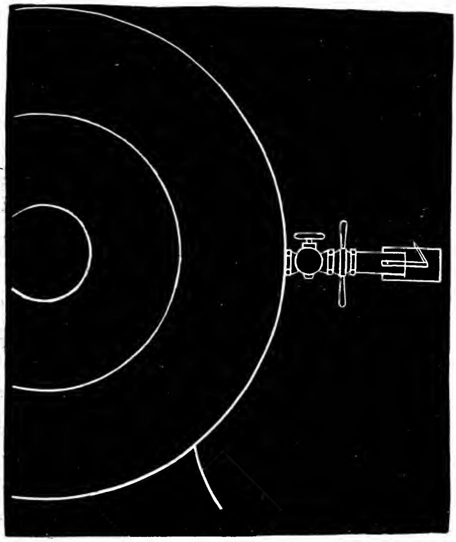


Fig. 30.

In connecting the paper drum to the reducing motion, a fine, flexible, braided cord should be used, and here a good deal of attention has to be paid not to have the cord either too long or too short.

With the indicator in position and the engine in motion, loop the cord between the fingers and put it over the pin or hook, drawing it up enough to set the paper barrel in motion and clear the stop. Now draw the cord carefully up until the barrel touches the stop on the outward stroke, then let it slip back until it touches very lightly on the

PIPING UP THE INDICATOR.

backward stroke. Midway between these two positions is where the point of the loop ought to be. Take back nearly half as much cord as has been allowed to slip past, tie the loop, and the length should be pretty nearly right. Do not throw the tied loop over the pin, however, nor hook it on, until it has been first held against the pin or hook and tried for proper length with the engine in motion.

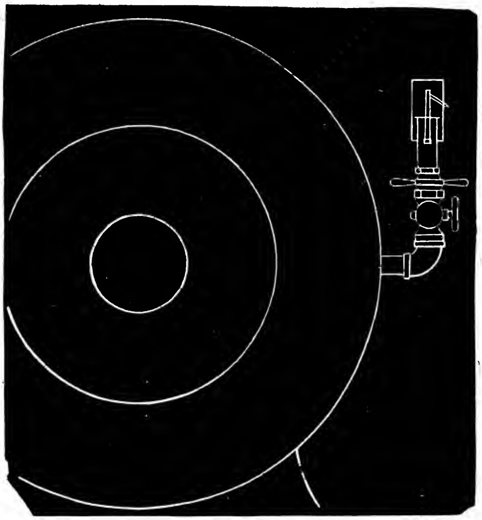


Fig. 31.

The tension of the drum or barrel spring should now be seen to. When the engine is making its outward stroke this drum is put in motion, and, having mass, acquires a certain amount of momentum, so that when the piston arrives at the end of its stroke and the string stops pulling, the drum continues to move by reason of its momentum until its stored energy is absorbed by the spring. If a high-speed engine be run at a very moderate speed and an atmospheric line be drawn, then with the engine running at

PIPING UP THE INDICATOR.

governor speed if another line be drawn just above it, there will be found to be a difference in the length of the lines. This produces, of course, a distortion in the card, and can be reduced by tightening up the barrel spring. For high-

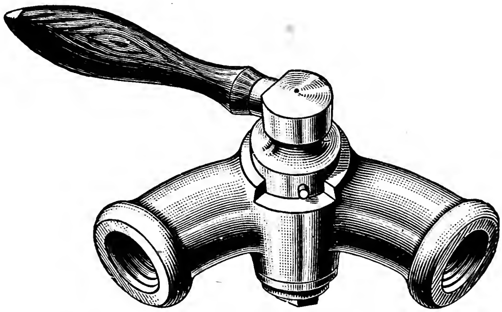


Fig. 32. LONG-TURN ANGLE COCK.

speed engines this spring will have to be kept under considerable tension, but on slower-moving machines it may be let down, and should in all cases be run only tight enough to keep the barrel well under the control of the cord.

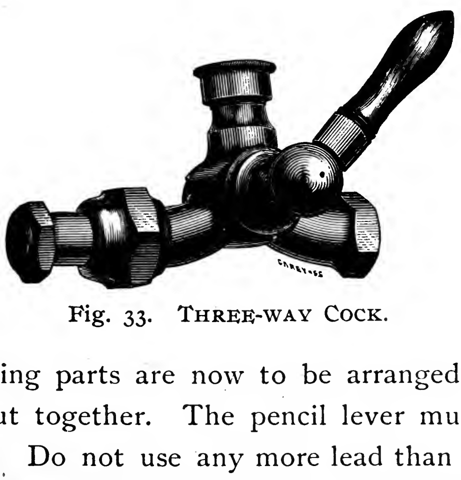


Fig. 33. THREE-WAY COCK.

The working parts are now to be arranged and the instrument put together. The pencil lever must be fitted with a lead. Do not use any more lead than is necessary to hold firmly in the quill or stub. Any extra weight is

PIPING UP THE INDICATOR.

especially to be avoided at this point, where it has so much motion, and if allowed to stick out on the barrel side of the arm it furnishes a lever to work itself loose in the holder or to twist the pencil arm sideways in its bearings. Bring the lead to a fine round point, not sharp enough to catch in and scratch the paper. This is best done by finishing with a very fine file. Then let it stick through as little as possible, leaving a little stock for filing the point as it wears on the side toward the paper, and break it off short at the other side.

In selecting a spring, be sure to get one stiff enough. Attach the spring selected in its position, being careful to screw everything up to its place, put a few drops of cylinder oil on the piston, open the cock on the indicator and let the steam blow once or twice through the cylinder ; then put in the piston, and screw the instrument together. If it is a condensing engine, do not open the cock when that end is exhausting, or it will make more work for the air-pump than it can conveniently handle.

TAKING INDICATOR CARDS.

When the instrument has been put together properly, open the cock and let steam into it, setting the piston and levers in motion, and press one finger lightly on the top of the piston-rod, to see if everything is working smoothly.

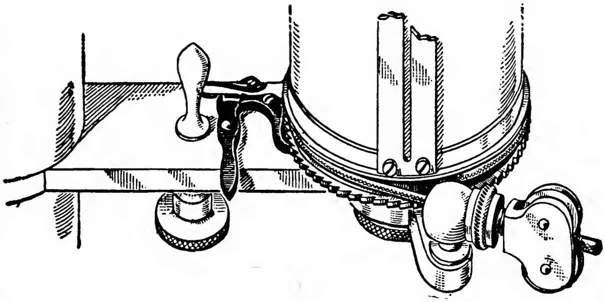


Fig. 34. DRUM-STOP DEVICE.

If the least indication of gritty, scratchy action is felt, shut off the steam at once, take the instrument apart, and find the cause.

The paper is put upon the barrel by wrapping it snugly around the drum at the top, bending it around and allowing the ends to project between the clips at the top; then by taking the lower corners as they protrude between the clips between the thumb and forefinger, as shown in Fig. 42, the paper may be drawn down over the barrel as smoothly as a glove. An additional pinch near the top, and a squaring of the corners if they need it, will render the operation complete.

Now turn on the steam and warm up the instrument. On non-condensing engines it is well to turn the cock so that the steam will blow out into the atmosphere until it shows blue and dry. When the water has disappeared and the pencil is vibrating smoothly, the paper drum being in motion, hold the pencil lightly against the paper and allow it to trace the diagram. For ordinary purposes of exhibition, showing the valve action, distribution, etc., one revolution is sufficient to hold the pencil on. To show the governor action, variation of load, etc., the pencil will have to be held on for a number of revolutions; and when measuring power, the pencil should be allowed to pass from ten to twenty times over, and the average diagram measured.

Turn the cock off and bring the pencil again to the paper, tracing the atmospheric line. It is not good practice to trace the atmospheric line first, as the indicator and spring are not then heated, and under the same conditions as when the diagram is taken.

If there are more than one card to be taken, it is necessary to stop the drum while removing the card from the clips; this is done in some cases by making the cord in two lengths, and unhooking, whenever the drum is to be stopped.

In Fig. 34 is shown a device, attached, if desired, to the Robertson-Thompson indicator, which enables the drum to be held with the spring under tension, while the paper is being removed. The slack of the cord is meanwhile taken up by a fine rubber band attached to the cord.

In Fig. 35 is shown another attachment for this purpose, manufactured by the Ashcroft Mfg. Company, for stopping the drum without unhooking the cord.

It consists of an arm attached to a part of the indicator by the screw. A slide is adjustable on the arm, and upon

TAKING INDICATOR CARDS.

it there is mounted a cord pulley for directing the actuating cord around the paper drum of the indicator. This slide can be instantly secured in any desired position on the arm by the thumb nut and washer.

The manner of connecting and operating the attachment is as follows: the actuating cord from any ordinary form of

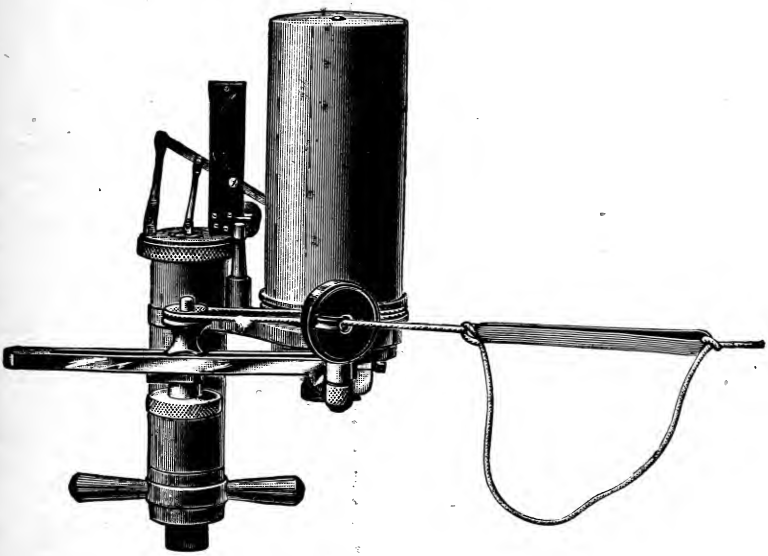


Fig. 35. DRUM-STOP DEVICE.

reducing motion connected with the engine is passed around the cord pulley, thence on the paper drum of the indicator.

When the slide is at its inner position no motion will be transmitted to the paper drum; but by taking hold of the thumb-nut and moving the slide outward on the arm, it will cause the paper drum to rotate back and forth in the usual way while taking a card.

At any convenient position on the actuating cord there is superposed a rubber band for the purpose of taking care

TAKING INDICATOR CARDS.

of any slack in the cord when the slide is at its extreme inner position and paper drum at rest, thus avoiding any unhooking of the actuating cord during the time of operating the indicator in making tests.

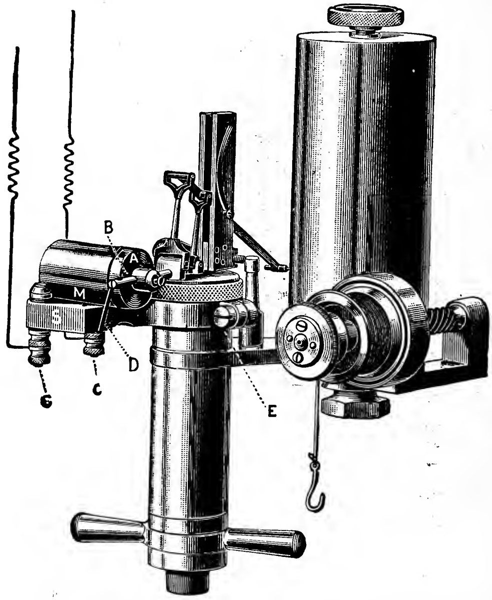


Fig. 36. Electrical Indicator Attachment.

If two or more indicators are used at once, it is desirable to set the pencils on the drums at practically the same moment. To do this there are several devices on the market, some of which are operated by an electromagnet. When the operator desires to allow the pencils to touch the cards, he presses a button, which causes the magnetized poles of the magnet to attract an armature attached to the carrying ring of the indicator.

Fig. 36 illustrates this electrical attachment as applied to the Tabor indicator.

TAKING INDICATOR CARDS.

The attachment consists of a magnet support *S*, which is clamped to the body of the indicator and held in place by the set screw *E*.

A magnet *M* is secured to the support, also binding screws *C* and spring *D*.

An armature *A* is mounted on the rod *B*, and adjusted to coincide with the magnet *M*, and then secured to the

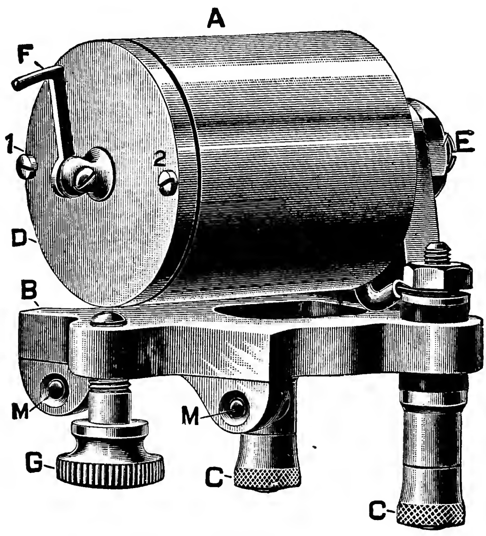


Fig. 37.

rod *B* by the small set screw in the armature for that purpose. The rod *B* is screwed into the upright on the swivel plate of the indicator, and any movement of the armature *A* produces a similar movement of the pencil toward or from the paper drum.

The spring *D* is for the purpose of holding the armature within the field of the magnet before the current is established, and also to quickly release it when the current from the battery is broken.

TAKING INDICATOR CARDS.

Fig. 37 represents Sargent's Electrical Attachment, and consists of an electromagnet, *A*, which is supported by a bracket, *B*, which also secures it to the indicator plate. Binding posts, *C C*, are attached to the same bracket. The armature, *D*, is opposed to the magnet by a spiral spring in the centre of the coil, the tension of which is adjustable by means of a screw, *E*, at the back of the magnet. The movement of the armature outwardly is limited by two

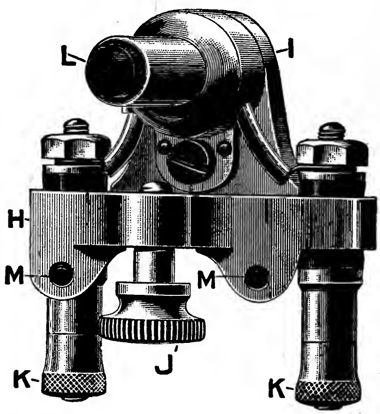


Fig. 38.

screws, a and 2. To the armature is secured a small latch or hook, *F*, which is free to work vertically and engage with a screw-eye inserted in the arm *A*. The thumb-screw *G*, is for fastening the attachment to the plate of an indicator through a hole therein.

Fig. 38 represents the Circuit Closer, and is designed to operate the electrically connected indicators, by closing the circuit through them, when the stylue or marking point is put against the paper on the drum of the indicator, to which it is attached. This enables the engineer making

TAKING INDICATOR CARDS.

the test to control one of the indicators directly by hand, and by its use one Sargent attachment is dispensed with.

It consists of a bracket, *H*, with a tubular projection, *I*, fastened to it, which contains the circuit closing mechanism. It is attached to the indicator plate by the thumb-

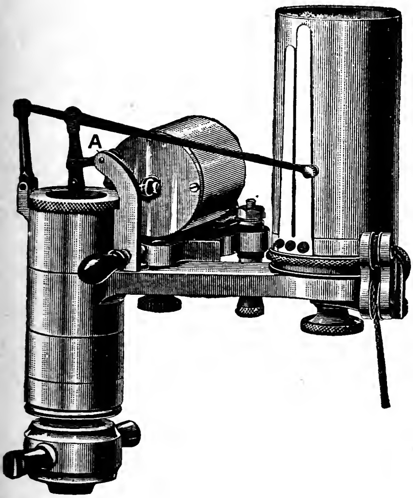


Fig. 39.

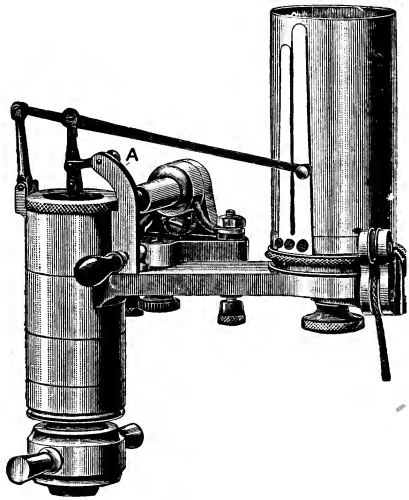


Fig. 40.

screw, *J*, in precisely the same way that the magnets are to the other indicators, and is electrically connected in the same manner through the binding posts, *K K*.

Fig. 39 shows a Crosby indicator fitted with a Sargent Electrical Attachment.

Fig. 40 shows a Crosby indicator fitted with a Circuit Closer.

In Fig. 41 is shown a pneumatic device, manufactured by Robertson & Sons, the operation of which can be clearly seen in the illustration. By squeezing the ball the pencil is caused to touch the drum.

TAKING INDICATOR CARDS.

When finished indicating, remove the spring, piston, etc., from the indicator, and allow the steam to blow through the cylinder once or twice. Unscrew the spring from the piston and cap, dry it thoroughly, and wipe it clean. The springs are the vital part of the instrument. Upon their accuracy the value of all the work depends. Too much pains cannot be taken to have them perfectly accurate when bought, to keep them from deteriorating by rust or otherwise, and to ascertain their condition from time to time.

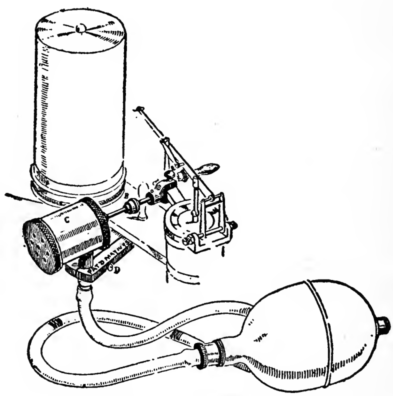


Fig. 41. PNEUMATIC INDICATOR ATTACHMENT.

Wipe up and clean the levers, oiling the joints, and you will find the instrument all ready for application next time. When the lighter parts have been attended to, the main body of the indicator will be found to be quite dry, from having the steam blown through it, and may be cleaned like the rest and put together.

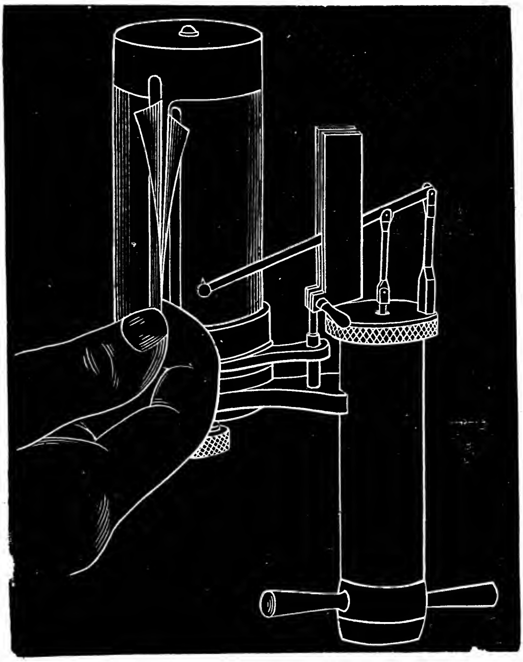


Fig. 42.

THE INDICATOR DIAGRAM.

In Fig. 43 is shown a theoretical diagram, which would be traced by the indicator pencil, if the action of all the different operations should be perfect.

This, however, does not occur in practice, as it takes time for the valve to open, and to cut off the steam: thus the corners of the diagram cannot be as sharp as in Fig. 43, also the expansion line can never be as perfect, on account of the cylinder condensation and re-evaporation.

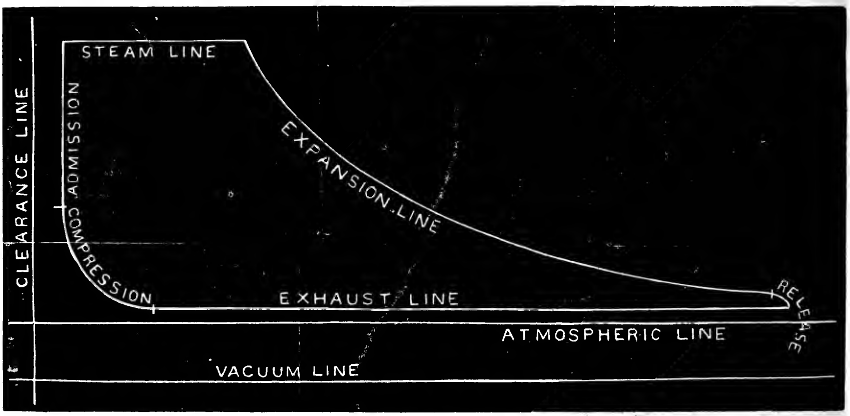


Fig. 43. IDEAL DIAGRAM.

The outlines of an indicator diagram represent six different operations, which are indicated by different lines made by the pencil, and are partly due to the steam pressure acting upon the indicator piston, and partly due to the motion of the cross-head and the corresponding revolving of the drum.

THE INDICATOR DIAGRAM.

These lines are named as follows: 1, admission line; 2, steam line; 3, expansion line; 4, release line; 5, exhaust line; and 6, compression line.

To these may be added the atmospheric line.

The tracing of an indicator card is effected in the following manner:

Steam enters the indicator cylinder, and, forcing the pencil upward on the drum, causes it to make the admission line. This happens at the beginning of the stroke.

The cross-head now begins to move outward, revolving the drum, while the pencil is held up by the steam pressure; the steam line is thus drawn until the point of cut-off is reached, when the valve cuts off the steam supply. As the cross-head still continues to move, the steam beyond the piston is expanded and its pressure reduced, which allows the indicator spring, previously held under tension, to force the pencil downward; but as, on account of the motion of the drum, it cannot descend in a straight line, it traces a curve, which records the steam pressure at all different points of the stroke after cut-off. This curve is termed the expansion line.

When the cross-head nearly reaches the end of the stroke, the exhaust valve opens, causing the steam to rush out of the cylinder and the indicator pencil to drop, making the release line.

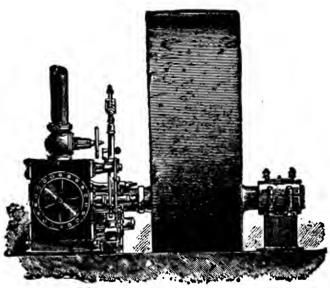
The cross-head now begins on its return stroke, and the drum spring revolves the drum in the opposite direction.

The pencil, being at a height corresponding with the exhaust pressure, now marks the exhaust line, which may be

NOTE.—If there should be no back pressure, or vacuum, the exhaust line would be at equal height with the atmospheric line.

either above or below the atmospheric line, according to whether the engine is running with back pressure or condensing.

At a point near the end of the exhaust stroke the exhaust valve closes; and the remaining steam in the cylinder, having no passage to escape, is compressed by the advancing piston, thus raising the pressure, and also the indicator pencil, which now draws the compression line.



THE ADMISSION LINE.

The admission line shows the manner in which steam is admitted to the cylinder. Under normal conditions, admission takes place suddenly while the piston is practically standing still at the end of the stroke, resulting in a straight line perpendicular to the atmospheric line, into which the compression line merges, as shown at *A*, Fig. 44.

In order that the admission line may be thus erect, it is necessary that the steam valve shall be open so as to admit the full pressure before the piston begins to move away; and this involves the question of lead, or the amount of opening which the valve has when the engine is on the center, and which, for many reasons, it is desirable to keep as small as possible, and yet allow the admission line to be perpendicular. As the steam valve is allowed to become late in opening, and the piston gets into motion before the steam is admitted, the admission line begins to curve inward, as at *B* and *C*, the leaning tendency increasing as the line progresses and the motion of the piston becomes faster. At *D* is shown a peculiar admission line on a diagram of a slide-valve engine, the eccentric of which had slipped so as to make the whole valve motion late. The exhaust closure being late as well as the steam opening, the compression was entirely cut out, and the back pressure line *b* continued straight up to the end of the stroke. When the piston commenced its return stroke the steam valve had not opened. The exhaust valve had by that time closed, the space between the cylinder head and the retreating piston was entirely shut in, and as the piston

THE ADMISSION LINE.

moved away a vacuum was created, running the pressure down toward *a*, as is shown by the arrow. At *a* the steam was admitted suddenly and the admission line ran up, leaving the loop on the heel of the diagram as shown.

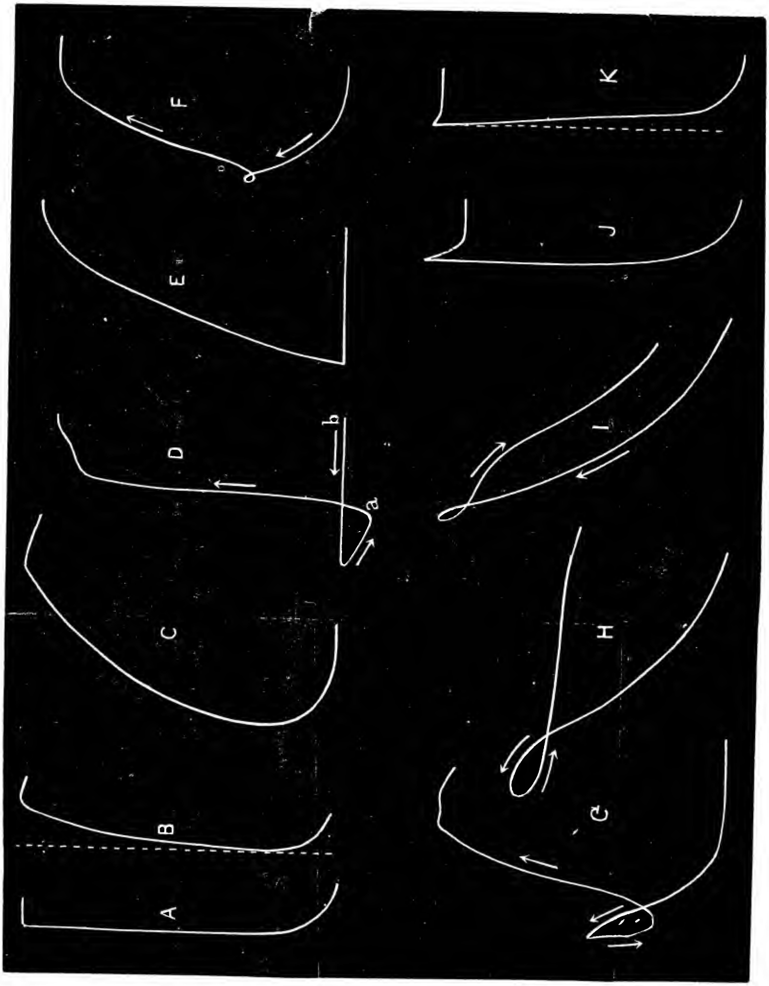


Fig. 44. EXAMPLES OF ADMISSION LINES.

The admission line may lean in, however, from another cause than that of the steam valves being late, as at *E*. The natural inference from the appearance of the diagram

THE ADMISSION LINE.

would be that the engine was late all around; but the fact is that the steam valve has plenty of lead, and opens before the return stroke is completed. The exhaust valve is so late that it not only does not close for compression, but does not close until the piston has got well started on the forward stroke, so that the steam is blowing right through into the exhaust and cannot keep the pressure up. As the exhaust closes, however, the pressure is increased, but the piston is moving away so rapidly that the line never becomes erect.

The amount of compression has a great deal to do with the appearance of the admission line. The effect shown at *F* is a very common one, produced by the pressure running up by compression to the point and falling away as the piston starts back before the steam valve opens, forming the loop. A more aggravated case of the same action is shown at *G*. This loop assumes all sorts of forms, according to the relations of the compression and admission, and the proportions of the openings and the piston speed; and it may even form when the steam valve opens promptly, by excessive compression, as is frequently seen on diagrams from the ordinary type of single valve, high-speed engines with shaft governors, where the compression is increased as the load diminishes, resulting in admission lines like those shown at *H* and *I*. In the first of these the pressure is so low that the compression line extends above it, and when the steam valve opens, there is an escape of steam from the cylinder and the pressure is lowered to that at which the steam will flow from the chest. The appearance at *I* is produced when the engine is lightly loaded, so that the compression is very considerable.

THE ADMISSION LINE.

Just as a tardy action of the steam valve results in producing an inward leaning of the admission line, so a too early opening of that valve will result in the production of a line which leans outward, as shown at *K*.

Any engine that is in line and properly adjusted in the connections, should run at the speed for which it is designed better with enough lead to bring the admission line upright than it does with more.

NOTE.—A sharp point at the top of the admission line is usually an indication of too much lead, and it will be found to result in smoother running if the corner is just given an indication of rounding, as at *A*. The projection is due to the fling of the moving parts carrying the pencil above the point due to the pressure.

THE STEAM LINE.

The steam line of the indicator diagram indicates what percentage of the boiler pressure is realized in the cylinder, and how well this pressure is maintained up to the point of cut-off

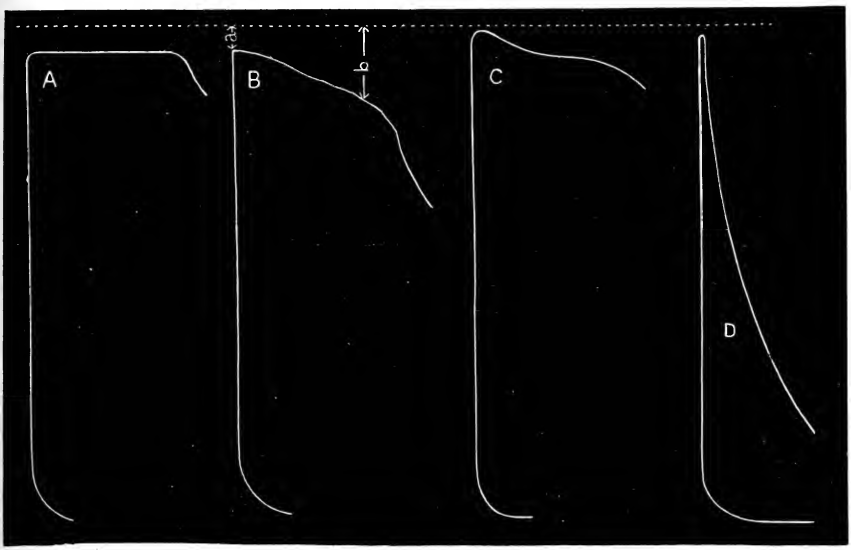


Fig. 45. Examples of Steam Lines.

In a really good diagram the steam line will appear about as at *A*, Fig. 45—approaching, in its height above the atmospheric line, the distance indicated by the boiler pressure laid off to the same scale as that of the spring with which the diagram is taken, as shown by the dotted line, and remaining horizontal, or very nearly so, up to the point

Note.—It is absolutely impossible to maintain in the cylinder the same pressure that is carried in the boiler, although with short connections, ample passages, and low-piston speeds a very large percentage can be realized.

THE STEAM LINE.

of cut-off. When the connecting pipe and passages are small for the piston speed and diameter, the steam line falls away as at *B*, the difference between the beginning of the stroke, and a point near cut-off being shown by *a* and *b*.

The steam line shown at *C* is often met with on engines having a large steam chest and small steam pipe—the steam chest in this case acting as a reservoir, and allowing the steam in the cylinder to almost equal boiler pressure at the commencement of the stroke; but if the steam pipe be small, this pressure cannot be kept up when the piston is advancing.

Diagrams are sometimes met with which have no steam line, the load being so light that the expansion of the steam in the clearance is sufficient to keep the engine in motion. In this case the expansion line meets the admission line at a point, as at *D*, Fig. 45.

The shape of the steam line is often modified by the admission, and it will be readily understood that it is difficult to say when the one leaves off and the other begins, under frequently occurring conditions.

THE EXPANSION LINE.

In all engines in which any pretension is made to economy, steam is used expansively, the supply being cut off at some point in the stroke, determined either automatically by the governor or positively by the valve. By this means the piston is urged not only while there is a direct draught of steam from the boiler, but by the expansive force of the steam in the cylinder after this draught has ceased.

The expansion curve is often found to be wavy—a fact generally due to the indicator piston fitting too tight, which will allow it to bind, thus working in jerks instead of steadily.

A gas in expanding varies in pressure inversely as its volume; and steam follows this law with sufficient accuracy to make its application to the indicator diagram and to engine practice of value.

Thus if steam should be cut off at ¼ of the stroke, the pressure in the cylinder would be reduced to ½ when the piston reaches ½ stroke, ⅓ when the piston reaches ¾ stroke, etc.

If the steam should be a gas, whose volume is not affected by the temperature of its surroundings, this law would hold true; but as the steam upon entering the cylinder will condense, its pressure falls more rapidly than due to expansion, until a point is reached where the temperature of the steam equals the temperature of the cylinder walls, and from thence the condensed steam will be re-evaporated, because the metal of the cylinder is hotter than the steam. Thus it will be understood, that the true expansion curve never equals the theoretical curve.

It falls below the theoretical curve at the first stages of expansion, and above it, crossing it at some point in the stroke, at a later stage.

Also, that the steam in the clearance space will affect the expansion, as it is filled with steam during admission, and all this steam expands with the steam that filled the cylinder volume before cut off, without the clearance volume being changed during expansion.

THE RELEASE LINE.

The proper appearance of the release line would be as at *A*, Fig. 46, the release occurring early enough to allow the pressure to fall nearly or quite to the line of counter-pressure by the time the end of the stroke is reached. If the release is delayed until the end of the stroke the appearance will be more like that indicated at *B*. If the pressure could be carried to the end of the stroke and immediately reduced to the line of counter-pressure, as indicated by the outline of the shaded space, it would be advisable to retain the full area; but since some area must be lost here in expelling the exhaust, it is better that it should be above the diagram at *A* than below as at *B*. When the piston is approaching the end of its stroke, it has come to be a question of stopping it and sending it in the other direction. To do this smoothly, compression is applied on the other side of the piston, and obviously there is no object in keeping up the forward pressure, as at *B*.

It is therefore better to let the pressure fall off, as at *A*, assisting instead of opposing the compression in bringing the moving parts quietly to rest, and by this early release removing the back pressure represented by the shaded portion at *B*, so that the piston encounters less resistance in starting upon its backward stroke when it is an object to get it in motion.

The difficulty of attaining this result on most engines is that where the lap is removed from a valve to cause it to open early and give an early release, this very lack of lap retards the closure and does not give sufficient compres-

THE RELEASE LINE.

sion. On the Corliss valve this may be corrected by setting the eccentric ahead, making both release and compression earlier; but disadvantages attend upon too great an angular advance of the eccentric, in the way of shortening the range of cut-off, and the advantages of the valve motion in quick movement at admission, so that it is often necessary

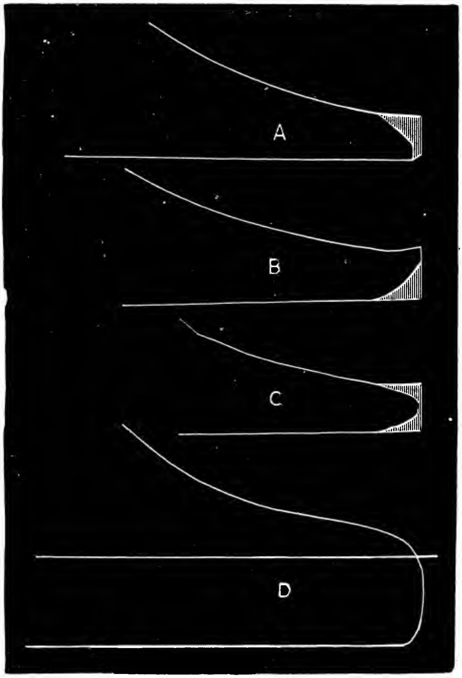


Fig. 46. EXAMPLES OF RELEASE LINES.

to divide the difference and compromise upon a point like that shown at *C*. The benefit of an early release is very apparent when a condenser is used; for, with an early release and a prompt realization of the vacuum, as at *D*, the largest possible percentage of the load is thrown upon the condenser, while a tardy release and a dragging action of the steam in leaving the cylinder results in the loss of a

THE RELEASE LINE.

large area in the vacuum portion of the diagram, as shown by the shaded portion of *E*, Fig, 47, calling for a later cut-off and more steam.

When the cut-off is late, more steam is admitted and has to be expelled; the appearance will then be more like *G*, Fig. 47. Between this and the point shown at *F*, Fig. 48, there may be any variety of shapes, according to the

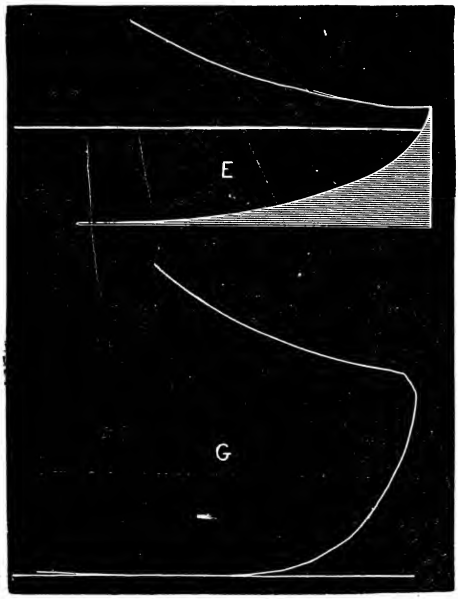


Fig. 47. EXAMPLES OF RELEASE LINES.

terminal pressure and setting of the valves. When the steam is cut off so early that the expansion extends below atmospheric pressure, or the pressure against which the engine is exhausting, the release line will be like that shown at *H*, Fig. 49.

Here at the moment of release the pressure in the exhaust pipe is greater than that in the cylinder, and when the valve is opened at *a*, Fig. 49, there is an inrush of the

THE RELEASE LINE.

previously exhausted steam, raising the pressure to the counter-pressure line. This condition is apt to cause a disagreeable slamming of the exhaust valve, which is lifted from its seat when the pressure in the cylinder becomes less than that beneath the valve, and is slammed closed again when steam is admitted. It may be stopped by throttling the initial pressure so that the lessened expansion does not cause a loop.

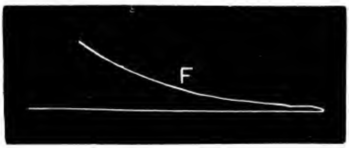


Fig. 48.

During the formation of this loop the pressure urging the piston forward has been less than that against which the piston moves, the forward motion continuing only by reason of the momentum of the fly-wheel and moving parts, so that the area of the loop represents just so much work exerted against the piston, and must be subtracted from the other area of the diagram to get at the effective work.

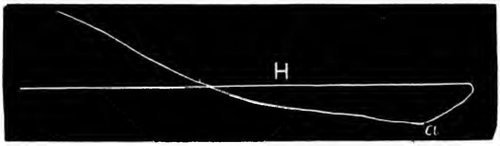


Fig. 49.

THE EXHAUST LINE.

The pressure upon the piston during the forward stroke is represented by the steam and expansion lines; the pressure in the same end of the cylinder during the backward stroke is represented by the exhaust, counter-pressure, or back-pressure line, as it is variously called. Obviously an engine will be doing the greatest amount of work when the pressure urging the piston forward is greatest and the retarding effect of the back pressure is least.

If at the end of the stroke the steam has been expanded to atmospheric pressure in a non-condensing engine, there will be no immediate outrush of steam from the cylinder, because there is no greater pressure in the cylinder than that of the atmosphere into which the steam must flow. The steam must therefore be pushed out by the piston, and the resistance to its movement will depend upon the length and directness of the exhaust pipe, as well as its size.

The compression of the steam by the piston pushing it out of the cylinder against the resistance to flow through the pipes and passages, will show on the indicator diagram in raising the line of counter-pressure above the atmospheric line.

NOTE.—The actual tendency of a piston to move depends on the difference in pressure upon its two sides. If there were 30 pounds pressure in both ends of the cylinder at once, the piston would not move any more than though there were no pressure at all. If there were 30 pounds pressure on one side and 15 pounds on the other, the force with which the piston would tend to move would be the same as though there were 15 pounds on one side and nothing on the other. In other words, the effective pressure is the unbalanced pressure, or the difference in pressure between the two sides.

THE EXHAUST LINE.

In a well-proportioned engine at moderate piston speeds, and exhausting through a short and ample exhaust pipe, this moving pressure will not be noticeable with an ordinary spring, and the line of counter-pressure will merge into the atmospheric line. In less advantageous circumstances, however, the back-pressure line will be elevated above the atmospheric line.

Sometimes a card is found where the back-pressure line starts in well enough, but makes a gradual rise toward the center of the diagram, falling again as the stroke is com-

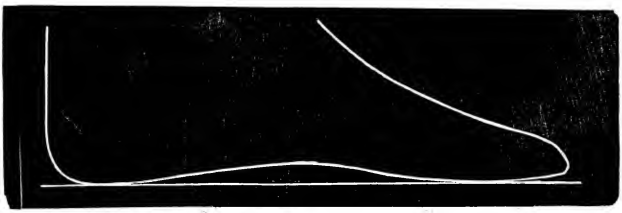


Fig. 50.

pleted, as in Fig. 50. This is caused by too much inside lap on a slide valve narrowing up the exhaust passage as the center of the stroke is reached, where the piston, and consequently the steam, has the greatest velocity. The same effect may be produced upon a Corliss engine. It is also found where a pair of cylinders working on cranks set at 90° exhaust into the same pipe, the release of one cylinder occurring practically in the middle of the stroke of the other and the efflux of steam into the pipe causing a rise of pressure.

THE COMPRESSION LINE.

The object of compression is initially to furnish a cushion or gradually increasing resistance, in order to bring the moving parts to rest and change the direction of the push upon them without the shock which would follow upon the sudden opening of the valve.

Compression is the inverse or opposite of expansion. In making the expansion line the volume of steam admitted up to the point of cut-off is increased in volume, the pressure falling in an inverse ratio.

In compression the volume of steam inclosed when the exhaust valve closes is diminished in volume with a consequent increase in pressure; and in this case, too, the product of the volume and pressure is constant.

If there is any lost motion in the bearings, and the moving parts have not been cushioned, there will be a heavy thump when the steam valve opens.

In condensing engines, where the exhaust pressure has been reduced to nearly a perfect vacuum, the exhaust valve must close much earlier than in a non-condensing engine, in order to obtain enough compression.

If a perfect vacuum could be obtained, so there would be no steam left in the cylinder, compression would not be possible.

A perfect vacuum, however, cannot be obtained in practice with a condenser.

Aside from its cushioning effect there is another advantage to compression in reducing the loss from clearance, as the clearance space is filled with steam that otherwise would be wasted.

THE COMPRESSION LINE.

Where there is no expansion the steam required to fill the clearance space is a dead waste. With a cut-off engine it gets a chance to expand with the other steam, and does some good; but still there is a saving by compression, and theoretically by compression up to the initial pressure.

When the engine is of a type in which the compression is constant, as in four-valve engines, the best results will be attained under normal loads by having the compression

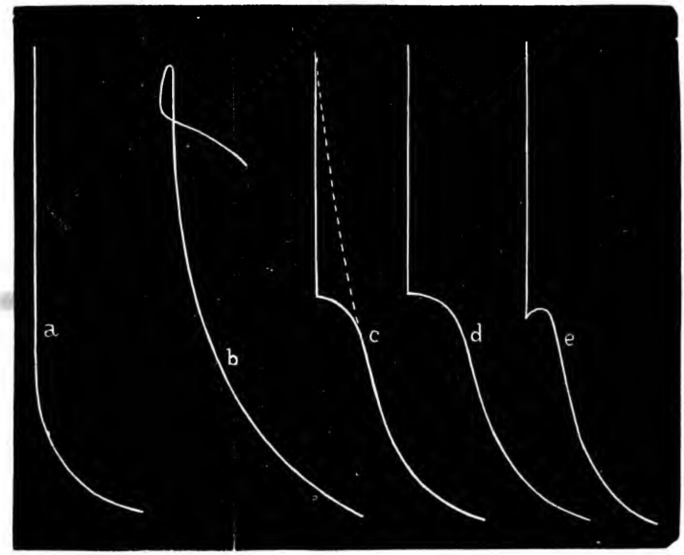


Fig. 51.

round up nicely into the admission line, as at *a*, Fig. 51, meeting the perpendicular line at about one-third of its height. This will require a different setting of the exhaust valve for different heights of the counter-pressure line.

At *b* is shown excessive compression, the pressure running up above that in the steam chest, so that when the valve opens for admission, steam flows from the cylinder to the chest and the pressure falls. A form of compression

THE COMPRESSION LINE.

line often met with is shown at *c*, where the pressure, instead of continuing upward along the dotted curve, falls away as shown. When this occurs you must look for some cause for the reduction of pressure, and you will generally find it in a leak. As the piston approaches the end of its stroke its movement becomes very slow. The volume of steam involved is small and growing smaller, and if there is even a slight leak in the exhaust valve, drip valve, or piston there will come a time when the volume of steam discharged through the leak will equal the volume generated by the movement of the piston in the same time.

If the pressure of the outrushing steam is kept constant by the advancing piston. The line will have the appearance as shown at *d*.

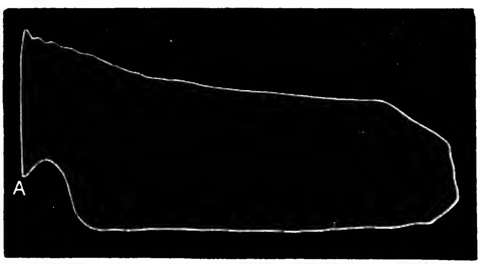


Fig. 52.

If the leak should be so excessive that the advancement of the piston is not able to compress the steam fast enough to keep up the pressure, the compression line will fall away as at *e*. A diagram, where this occurred, is shown in Fig. 52, where the compression line dropped down to *A* when steam was admitted.

In this case the leakage was in the piston; and as the pressure on the other side of the piston decreased, the leakage increased, on account of the greater difference in pressure on both sides of the piston.

THE ATMOSPHERIC LINE.

The atmospheric line is drawn after the diagram is completed, and the steam connection between the indicator and steam cylinder cut off. The atmospheric pressure is acting on both sides of the indicator piston, allowing the spring to expand into its original shape, thus indicating atmospheric pressure.

In closing the indicator cock, care should be taken to close it so that the small drip-hole, drilled into the plug at right angles with the steam passage, opens communication between the atmosphere and the indicator; otherwise an error may occur.

THE LINE OF PERFECT VACUUM.

The line of perfect vacuum would be the line which is drawn below the atmospheric line, 14.7 of a pound, measured with the scale, which corresponds with the spring used in taking the diagram.

THE CLEARANCE LINE.

The percentage of clearance of an engine can be found by setting the engine on the center, and filling the clearance space with water, which must be carefully measured.

The position of the cross-head must now be marked on the guide, and the engine moved off the center.

Next pour an equal amount of water into the cylinder, on the same end as it took to fill the clearance space, and move the engine toward the same center as before, until the water is just beginning to run over, wherever it has been poured in.

Now mark the position of the cross-head again, and measure the distance between the marks.

The ratio of this distance to the whole stroke is the ratio of the clearance volume to the whole cylinder volume. Thus the percentage can be found by multiplying the length of the stroke in inches by 100, and dividing by the distance between the marks on the guide, also in inches.

If it is desired to mark a clearance line on an indicator diagram, erect a line perpendicular with the line of perfect vacuum, at such a distance from the extreme point of the diagram on the admission side that this distance is the same fraction of the length of the diagram, as the distance between the marks on the guide is of the whole stroke. This is shown in Fig. 43.

FIGURING STEAM CONSUMPTION BY THE DIAGRAM.

Besides recording the condition and internal adjustment of the engine, the diagram as well as the horse power is used in figuring the steam consumption of the engine.

In figuring the steam consumption, the cylinder volume, as well as the clearance volume, has to be known. The clearance volume can be found by filling it with water that has been previously measured; this will enable the operator to find the number of cubic inches contained in the clearance space.

The cylinder volume is found by the following rule:

Square the piston diameter and multiply by .7854.

Multiply the result by the stroke in inches and divide by 1728. The result will be the cylinder volume in cubic feet.

The steam consumption of an engine generally is expressed in pounds per hour, and is computed in the following manner:

1. Measure the pressure indicated by the expansion line at a point near the point of release, above the line of absolute vacuum. (Measure with the scale, which corresponds with the spring used in taking the diagram.) Find the weight of a cubic foot of steam at that pressure, in the accompanying table, and multiply this by the cubic capacity of the cylinder, plus the clearance volume, all expressed in cubic feet.

FIGURING STEAM CONSUMPTION BY DIAGRAM.

Instead of using the full length of the stroke in figuring the capacity of the cylinder, the piston area should be multiplied by a portion of the stroke, up to the point where the steam pressure has been measured.

The result is the number of pounds of steam (by weight) it takes to fill the cylinder for each stroke. I.

This would be correct if there should be no compression; for as the compression is accomplished with the steam remaining in the cylinder from the exhaust stroke, it has to be deducted from the result obtained.

Measure, with the same scale, the pressure above a perfect vacuum at the point of highest compression, find the weight of the steam at this pressure in the accompanying table, and multiply this by the clearance volume. The result is the weight of steam remaining in the cylinder from the previous stroke. II.

Subtract product II from product I, and multiply by twice the number of revolutions, and by 60.

The result is the weight of steam, in pounds, that the engine consumes per hour; and by dividing this by the horse power, the steam consumption per hourly horse power is readily found. But this holds true only where there is no leakage, or outward radiation.

NOTE.—The tables giving the weight of a cubic foot of steam at various pressures are to be found on pages 146–149, 5th column of tables.

Example: Steam at 100 lbs. (absolute pressure) weighs .2307 lbs. per cubic foot (i. e., nearly ¼ lb.), while at 140 lbs. it weighs .3162 lbs. (i. e., nearly ⅓ of a lb.)

REVOLUTION COUNTERS.

In high-speed engines it is difficult to count the number of revolutions; hence a revolution counter, as in Figs. 53 and 54, is employed.

These possess the advantage of recording the revolutions made for any length of time, and during indicator tests of importance and of long duration, they are almost indispensable.

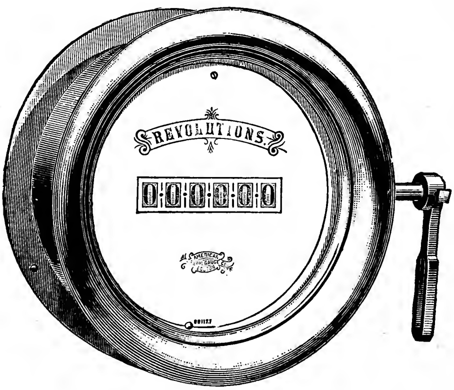


Fig. 53. REVOLUTION COUNTER.

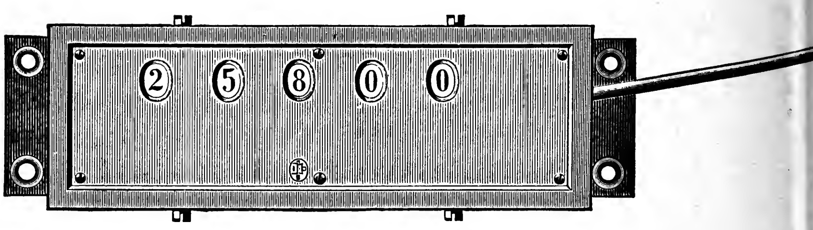


Fig. 54. REVOLUTION COUNTER.

NOTE.—The revolution counters shown are manufactured by the American Steam Gauge Company, of Boston, Mass.

REVOLUTION COUNTERS.

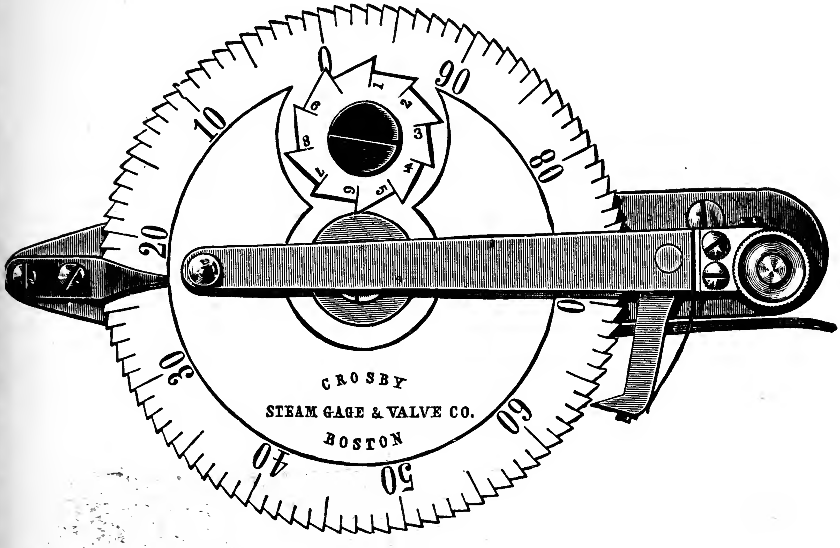


Fig. 55.

The above cut, Fig. 55, illustrates the Crosby locomotive counter—a counter designed particularly for use on locomotive and high-speed engines. The arm which moves the ratchet is connected by a cord with some reciprocating part of the engine, or with the drum motion, so as to give it about 1½ inches swing back and forth during each revolution of the shaft. The counter is provided with a convenient starting and stopping device, so that it can be made to begin or stop counting at any instant.

EXAMPLES OF DIAGRAMS.

If an engine is in good condition, so that there is no leakage in the valves or piston, and everything well adjusted, it should give a good card, without regard to its age.

The diagram Fig. 56 has been obtained from a George H. Corliss and Nightingale engine, designed and patented in 1851. It is a walking beam engine 23 in. x 60 in. 44 revolutions, and was erected in 1852—making it now 45 years old, since which time it has been in constant use.

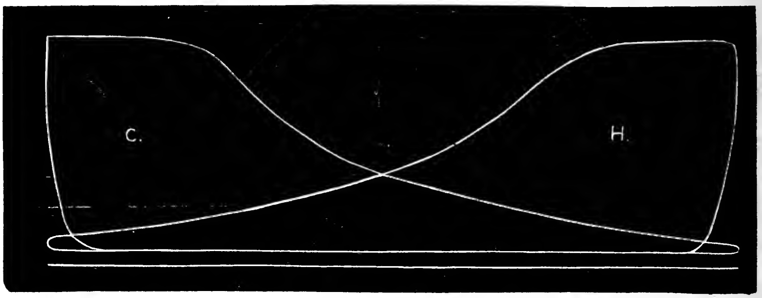


Fig. 56.

There has been one new cylinder, and the one now in use has been rebored three times. The engine is running to-day in Providence, R. I., and is quite a curiosity to professional men.

The diagram Fig. 57 was taken from a Buckeye engine, and is shown as a sample diagram. As will be seen, the compression line runs into the admission line, without any mark, almost forming one line with it. The point of admission is at *A*, at *B* the piston commences on its outward stroke, at *C* steam is cut off, at *D* is the point of release, and at *F* the point of compression. The line *G, G* is the

EXAMPLES OF DIAGRAMS.

atmospheric line, *H*, *H* the line of a perfect vacuum, and *I*, *I* the clearance line. If the load varies while taking a card, the expansion and release lines will vary for different

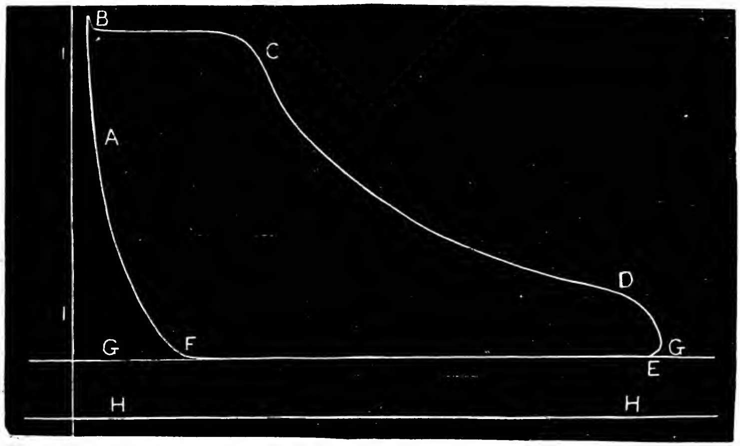


Fig. 57.

revolutions, as is shown in Fig. 58, which is taken from a Buckeye engine, while the load changes from overload to a very light load, ranging the cut-off from ½ stroke to ⅕ stroke.

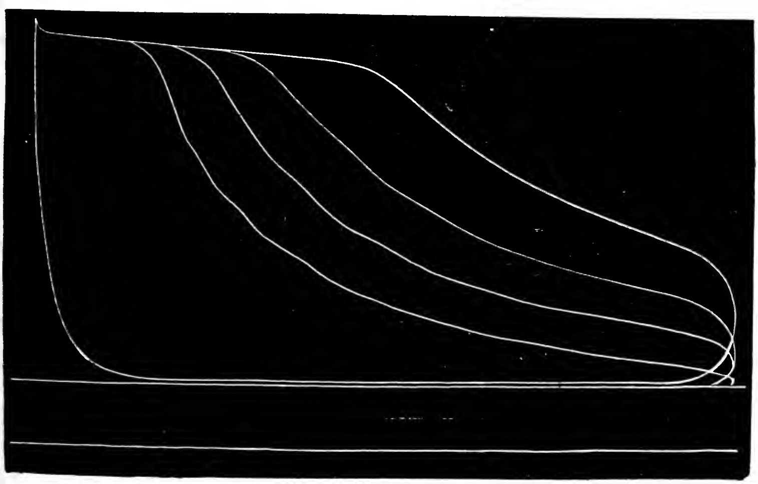


Fig. 58.

EXAMPLES OF DIAGRAMS.

As an example of a very bad card, Fig. 59 is given. In it the admission is late, the steam line wire drawn, the cut-off slow at about ⅓ stroke; the piston is leaking very badly, as is indicated by the sudden dropping of the expansion line; the release is late beyond the center, causing a loop, which is due to the compression of the steam in the cylinder, until the exhaust valve opens; and there is some back pressure, no compression.

On single valve automatic engines the compression varies with the load, as well as the cut-off; and, if the engine is lightly loaded, there is often a loop formed by excessive compression, as explained in Fig. 51 at *b*.

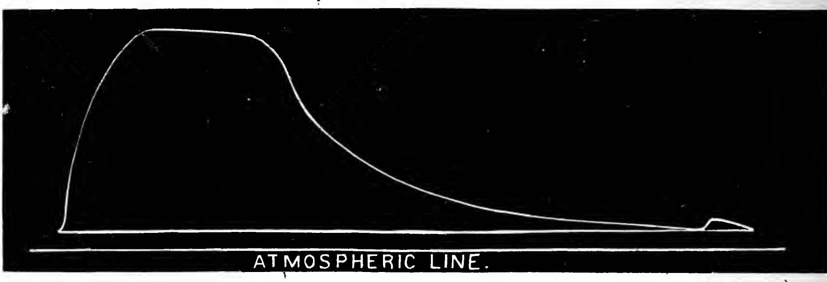


Fig. 59.

The card of a locomotive, when starting its load, is almost rectangular, as steam is admitted almost full stroke; but after the train is up to speed, the engineer begins to "link up," cutting off earlier.

But the compression is also then greater, and the admission earlier, and the card has the appearance shown in Fig. 60.

The card shown in Fig. 61 was taken off a Hewes & Phillips Corliss engine, running non-condensing and without any back pressure, with cylinder diameter 16 inches,

EXAMPLES OF DIAGRAMS.

stroke 38 inches, number of revolutions 75 per minute; the boiler pressure, at the time the card was taken, was 56 pounds by gauge.

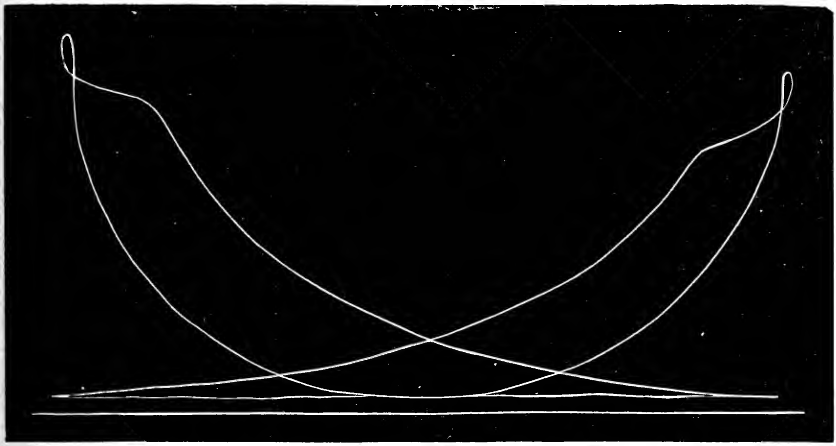


Fig. 60.

Attention is called to the straight steam line, carried out to the point of cut-off; the sharp cut-off, as well as the perfectly shaped compression line, running smoothly into the admission line.

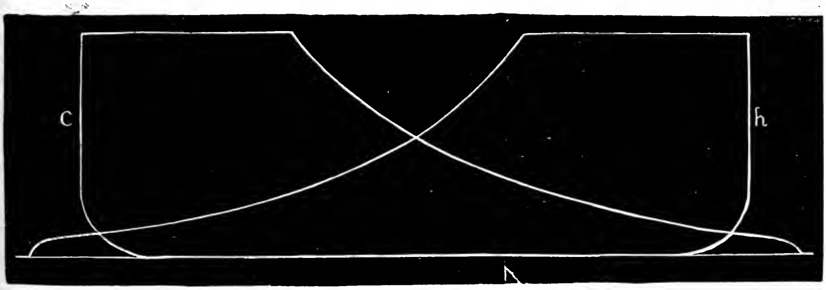


Fig. 61.

An engine which produces a card like Fig. 61 may be considered perfect both in adjustment and in design,

EXAMPLES OF DIAGRAMS.

The cards shown in Figs. 62 and 63 were taken off a Watts-Campbell tandem compound Corliss engine; Fig. 62 being taken from the high pressure cylinder, while Fig. 63 is the low pressure card.

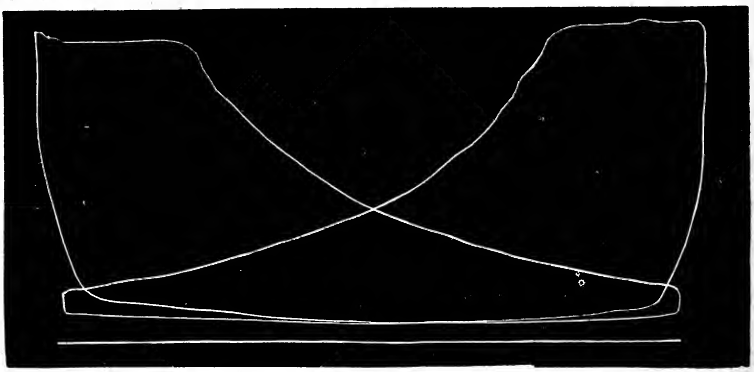


Fig. 62.

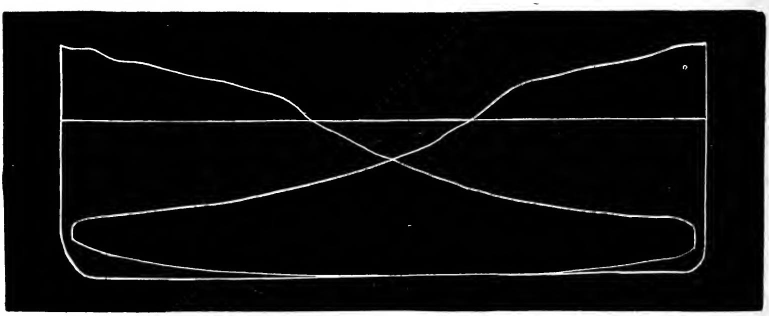


Fig. 63.

These cards show not only a very economical expansion, but also a very accurate action of both high pressure and low pressure valve gear. There is no drop in the steam lines of the high pressure cards—a fact which shows that there is ample port opening.

The low-pressure steam lines will always drop, as the receiver pressure is reduced, as soon as the low-pressure

EXAMPLES OF DIAGRAMS.

piston advances. The low-pressure card is taken with a spring of lower tension than the high pressure; the card being thus larger, and consequently giving a better idea of the valve action.

In Fig. 64 is shown a card taken of a Porter Allen engine, at very light load, as will be seen by the short cut-off. The boiler pressure was 74 pounds and the number of revolutions 286. There is considerable compression, but this is necessary at such a rate of speed.

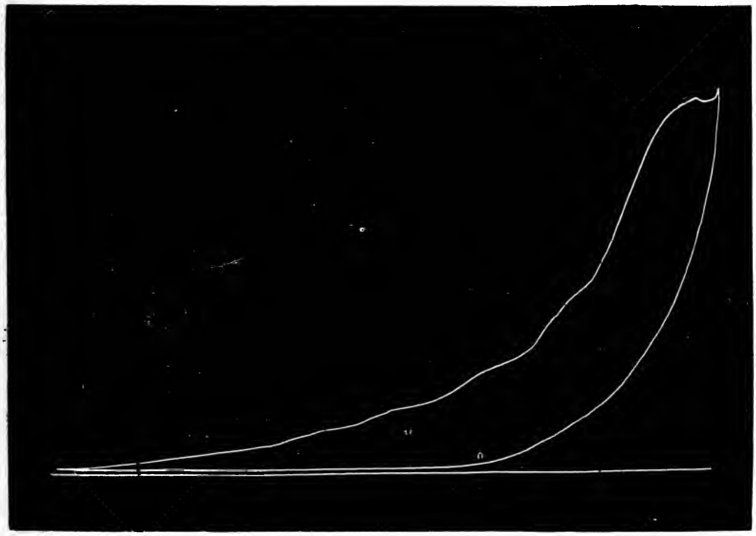


Fig. 64.

The back pressure is only very slight, and the card may be looked upon as a fair specimen, and would undoubtedly have been very good if there had been more load upon the engine.

Fig. 65 is a card of a 10 x 9 "Junior" Westinghouse engine at 350 revolutions per minute, and 80 pounds boiler pressure.

EXAMPLES OF DIAGRAMS.

The steam in this case is cut off beyond ⅓ stroke, causing an insufficient expansion; and besides, the maximum economy is not obtained; otherwise, this card shows good valve adjustment.

In indicating railroad locomotives, a great deal of attention should be paid to the reducing motion, as the jarring of the engine would greatly interfere with the correctness of the diagram.

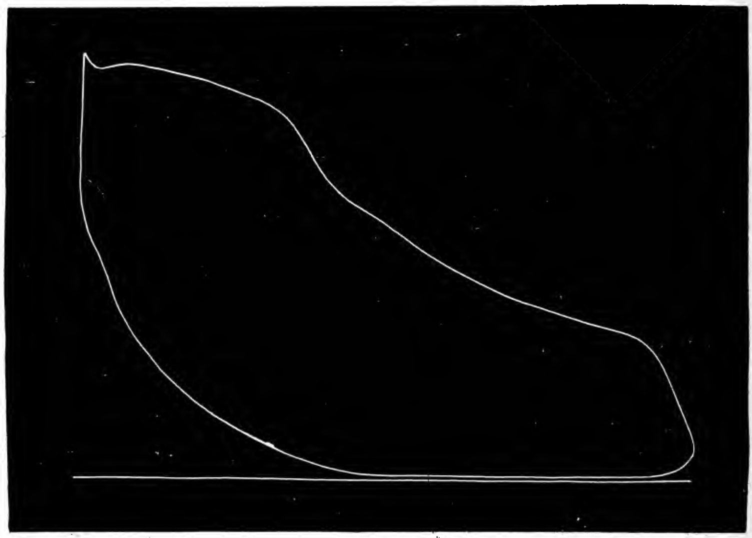


Fig. 65.

The reducing motion generally employed is a lever, which is made very solid, and well secured to the crosshead, and at its stationary point.

The indicator likewise has to be fastened more than is practiced on stationary engines, as the fastening it receives by its cylinder coupling would not be sufficient, and it would be almost impossible to keep the pencil upon the paper.

EXAMPLES OF DIAGRAMS.

The operator is protected from the wind and possible missiles by a sheet-iron box, surrounding the front of the boiler and both cylinders.

The advantage of indicating railroad locomotives is illustrated in cards Figs. 66, 67, 68 and 69. Fig. 66 was taken

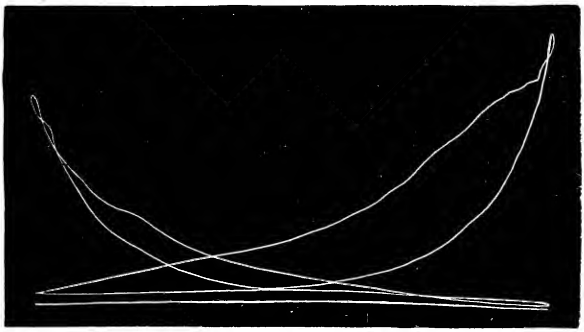


Fig. 66.

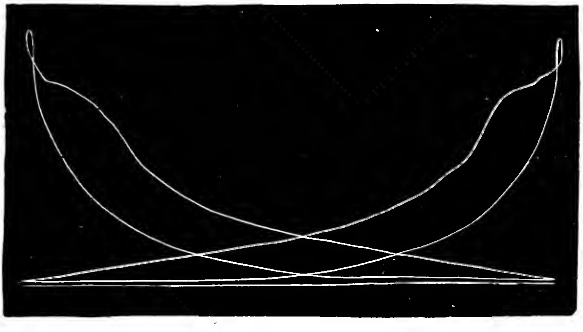


Fig. 67.

of a locomotive after the valves were set by the engineer, judging by the sound of the exhaust.

The speed at which the engine was running when the card was taken was 208 revolutions per minute, with the lever at first notch.

EXAMPLES OF DIAGRAMS.

Fig. 67 is the improvement on this card, after the valves were adjusted by the indicator.

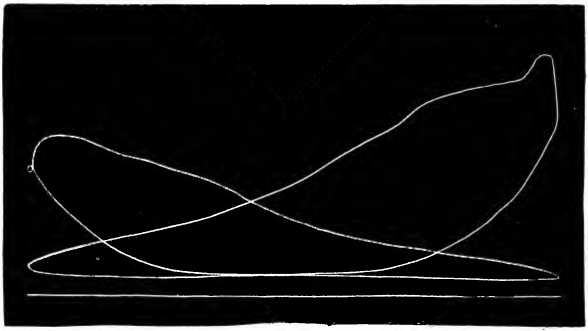


Fig. 68.

Card Figs. 68 and 69 were also taken respectively before and after adjustment by the indicator, with the lever at third notch, at a speed of 210 revolutions per minute.

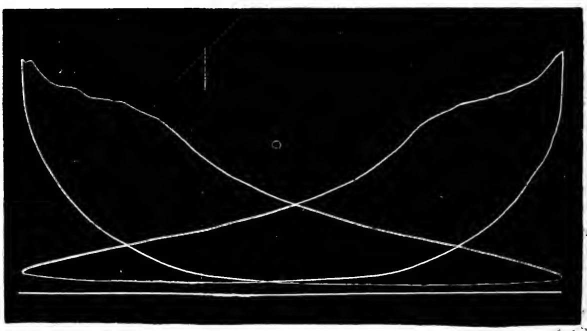


Fig. 69.

INDICATING AIR COMPRESSORS.

The use of the indicator is not entirely confined to the steam engine, although it was invented for this purpose by Watt.

It may be used on compressed air engines, with the same result as on a steam engine, just as any steam engine could be operated by compressed air.

The diagram would, in this case, have the same appearance as a steam engine diagram, and would record any defects in the valve adjustment in the same manner.

The mean effective pressure can be found in the same way as explained for steam engine diagrams, and the horse power figured from the obtained results.

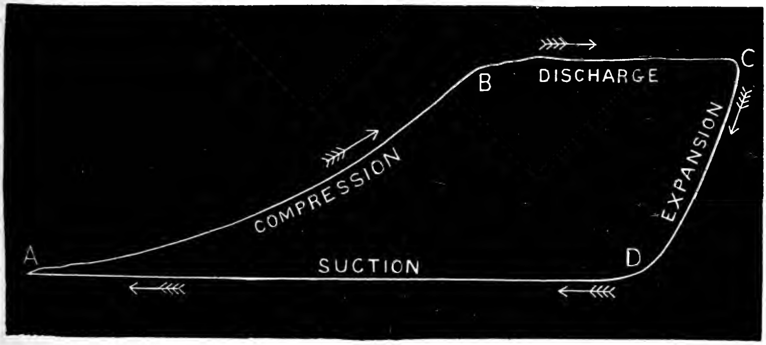


Fig. 70.

As compressed air engines are generally operated by much higher pressure than steam engines, the ordinary indicator springs will not answer for this purpose, and special springs have to be used. The indicator can also be used on the compressing cylinders of air and ammonia compressors.

INDICATING AIR COMPRESSORS.

The diagram obtained will differ from a steam engine diagram by being traced in the opposite direction, as shown in Fig. 70.

The process of the operation is as follows: At *A* the suction valve closes, and the compression piston starts on its working stroke, and the air or ammonia vapor contained in the cylinder is compressed during this stroke, this may be called the compression line.

At *B* the discharge valve opens, and the air escapes into the reservoir as fast as it is compressed by the piston; thus the pressure is uniform, providing the pressure does not rise in the reservoir.

At *C*, which is the end of the working stroke, the discharge valve closes, and the piston starts on its return stroke.

The air remaining in the clearance space of the cylinder now expands, and the pencil drops, marking the expansion line until the pressure is equal to the atmospheric pressure, or properly a little below it, and the admission valve opens at *D*, and remains open during suction.

In practice, however, the diagrams vary considerably from the one given as an example, as the operation of the valves will influence the lines to a considerable extent.

The indicating of air or ammonia compressors in everyday practice is of no commercial value, and is only practiced in experimental and erecting shops of the manufacturer.

The leakage of valves on an air or ammonia compressor is more readily ascertained by trial than by an indicator test.

THE TABOR INDICATOR.

The special peculiarity of the Tabor Indicator lies in the means employed to communicate a straight-line movement to the pencil, as shown in the appended cuts.

A stationary plate containing a curved slot is firmly secured in an upright position to the cover of the steam

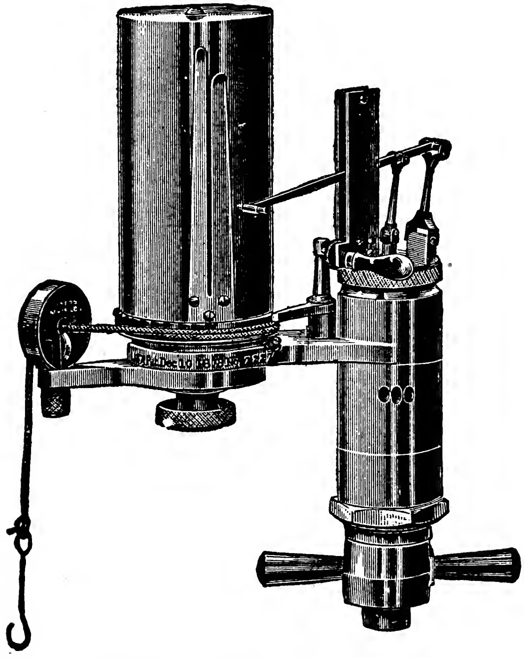


Fig. 71. Tabor Indicator.

cylinder. This slot serves as a guide and controls the motion of the pencil bar. The side of the pencil bar carries a roller which turns on a pin, and this is fitted so as to roll freely from end to end of the slot with little lost motion. The curve of the slot is so adjusted, and the pin attached to such a point, that the end of the pencil bar which carries the pencil moves up and down in a straight line, when the roller is moved from one end of the slot to the other. The curve of the slot just compensates the tendency of the pencil point to move in a circular arc, and a straight-line motion results. The outside of the curve is nearly a true circle, with a radius of one inch.

The steam cylinder and the base of the paper drum are made in one casting. Inside the steam cylinder is a movable lining cylinder, within which the piston of the indicator works. This cylinder is attached by means of a screw thread at the bottom, and openings on opposite sides at the top are provided for the introduction of a tool for screwing it in or out. Openings through the sides of the outer cylinder are provided to allow the steam which leaks by the piston to escape.

The pencil mechanism is carried by the cover of the outside cylinder. The cover proper is stationary; but a nicely fitted swivel plate, which extends over nearly the whole of the cover, is provided, and to this plate the direct attachment of the pencil mechanism is made. By means of the swivel plate, the pencil mechanism may be turned so as to bring the pencil into contact with the paper drum, as is done in the act of taking a diagram.

The pencil mechanism is attached to the swivel by means of the vertical plate containing the slot, which has been referred to, and a small standard placed on the opposite side of the swivel for connecting the back link. The slotted plate is backed by another plate of similar size, which serves to receive the pressure brought to bear on the pencil bar when taking diagrams, and also to keep it in place.

THE TABOR INDICATOR.

The connection between the piston and the pencil mechanism is made by means of a steel pitman. At the upper end, where it passes through the cover, it is hollow, and has an outside diameter measuring $\frac{3}{16}$ of an inch. At the lower end it is solid and its diameter is reduced. It connects with the piston through a ball and socket joint. The socket forms an independent piece, which fits into a square hole in the center of the piston, and is fastened by means of a central stem provided with a screw, which passes through the hole and receives a nut applied from the under side. This nut has a flat-sided head, so as to be readily operated with the fingers. A number of shallow grooves are cut upon the outside of the piston, which serve as a water packing.

The springs used in the Tabor Indicator are of the duplex type, being made of two spiral coils of wire with fittings. These springs are so mounted that the points of connection of the two coils lie on opposite sides of the fitting. The drum spring, by which the backward movement of the drum is accomplished, consists of a flat spiral spring of the watch-spring type, placed in a cavity under the drum carriage encircling the bearing. It is attached at one end to the frame below, and at the other end to the drum carriage. In its normal position the drum carriage is kept against a stop by means of the pull of the spring. By loosening a thumb-screw which encircles the shaft and holds the drum carriage down to place, the carriage may be lifted so as to clear the stop, and the tension on the spring may then be adjusted. This is done by simply winding or unwinding, as desired.

THE TABOR INDICATOR.

A simple form of carrier pulley serves to operate the driving cord from any direction. A single pulley is mounted within a circular perpendicular plate, the center of which coincides with the center of the driving cord. This center also coincides with the circumference of the pulley. The plate can be turned about its center so as to swing the pulley into any desired angular position, and thereby lead the cord off in any desired direction. The plate is held by a circular frame, which serves also as a clamp, and the pulley is fixed in position by the use of the same nut that secures the frame to the pulley arm.

THE BACHELDER ADJUSTABLE SPRING INDICATOR.

The Bachelder adjustable spring indicator is shown in Figs. 72 and 73—Fig. 73 being a longitudinal section through the instrument.

In Fig. 72 a nerled cap is removed on the side of the instrument, through which the interior of the cylinder can be seen, also the connection of the spring and piston rod.

The special features of this instrument consist in the T-shaped hollow case, adjustable flat spring, and positive parallel motion. The cylinder, being separate from the case proper, is screwed to the lower end, where it is held by a small set-screw. By turning this screw one-half of a turn the cylinder can be unscrewed; then, to remove the piston, take out the screw at the end of the spring, and at the connection with pencil lever. These are the only parts necessary to remove for cleaning. The flat steel spring works in the horizontal body of the case, one end being rigidly secured by means of a taper steel screw, and the other attached to the connecting rod between the piston and pencil lever. The change of spring is made by removing the screw that connects it to the piston rod, and the one that holds it in the case. The range of the high-pressure spring is so great that a change is only necessary when using on a compound or triple expansion engine. Connection is made to the piston with a ball and socket joint. Access can be had to the piston for oiling or removing, by unscrewing nerled cap on face of instrument.

THE BACHELDER ADJUSTABLE SPRING INDICATOR.

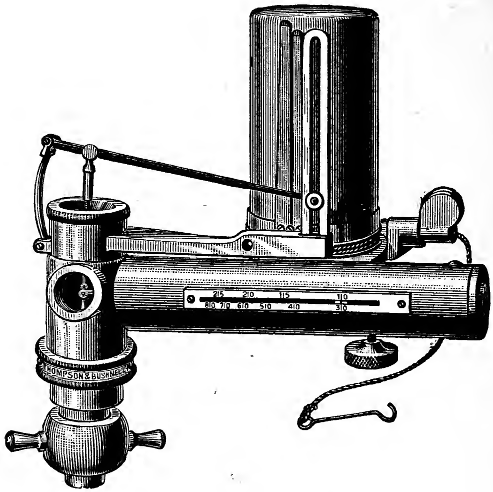


Fig. 72. BACHELDER INDICATOR.

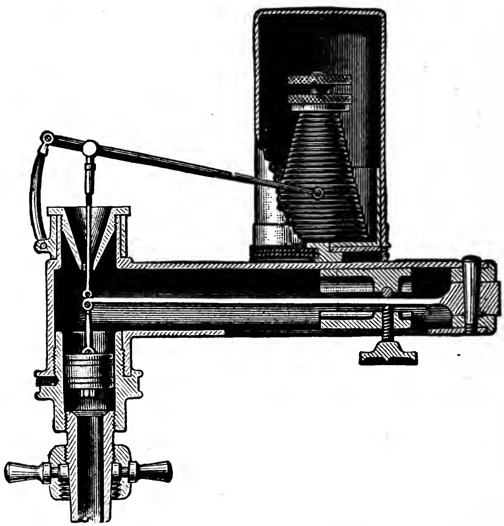


Fig. 73. LONGITUDINAL SECTION THROUGH BACHELDER INDICATOR.

THE BACHELDER ADJUSTABLE SPRING INDICATOR.

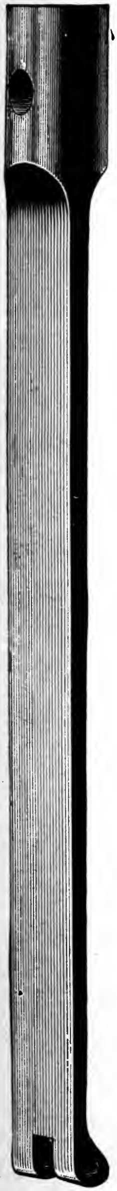


Fig. 74.

A split bushing in the case is provided with a longitudinal recess for the reception of the spring. In the upper side of the bushing a hardened steel pin is inserted. The lower side of the case has a longitudinal slot, through which a set screw passes, and through the lower side of the bushing, directly opposite the steel pin, so that when the screw is tightened, the spring is held rigidly between it and the steel pin. To change from one scale to another, loosen the set screw and slide the bushing along until the mark on projecting block is opposite the scale required; then tighten the screw. The scales are marked on the face of the case, the upper one being for high pressure, and the other for low pressure. The parallel motion is secured by confining the end of the pencil lever in a small roller which runs in the vertical slot. The height of atmospheric line is adjustable by means of a swivel in connecting rod near the pencil lever.

The flat spring used in this instrument is shown in full size in Fig. 74.

THE IMPROVED THOMPSON INDICATOR.

Figs. 75 and 76 represent the Improved Thompson Indicator, manufactured by Schaeffer & Budenberg, New York and Chicago.

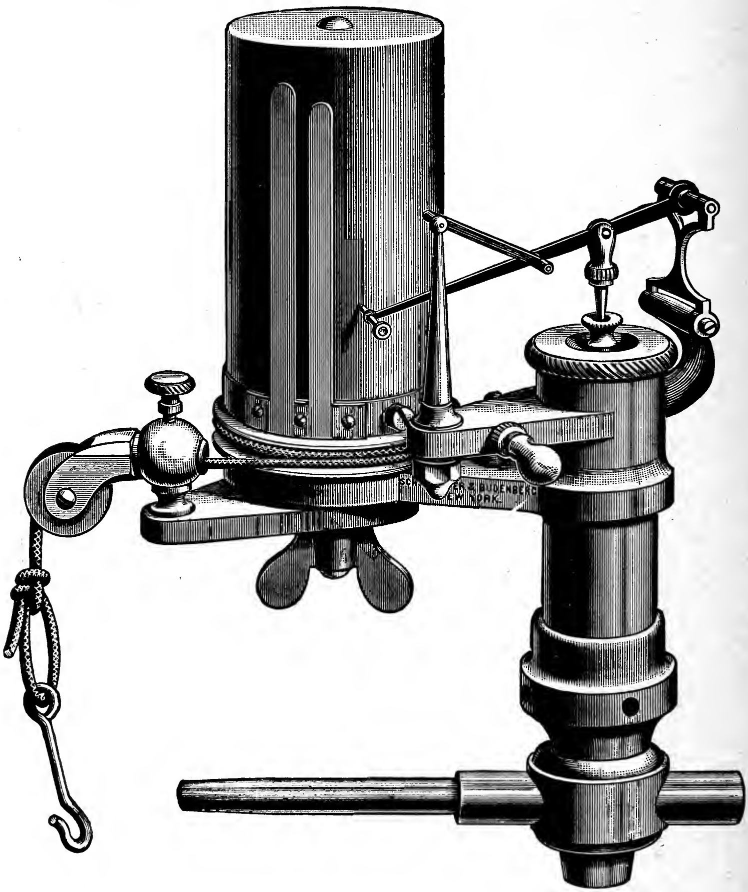


Fig. 75. IMPROVED THOMPSON INDICATOR.

Fig. 76 shows a sectional view of this instrument in its present improved form, the following being a description of the cut.

THE IMPROVED THOMPSON INDICATOR.

The swivel bar *B* is connected to the piston rod by a short pitman *P* with a ball joint *R* at its lower end.

The diameter of piston of the standard size instrument is 0.798 inch = ½ inch area.

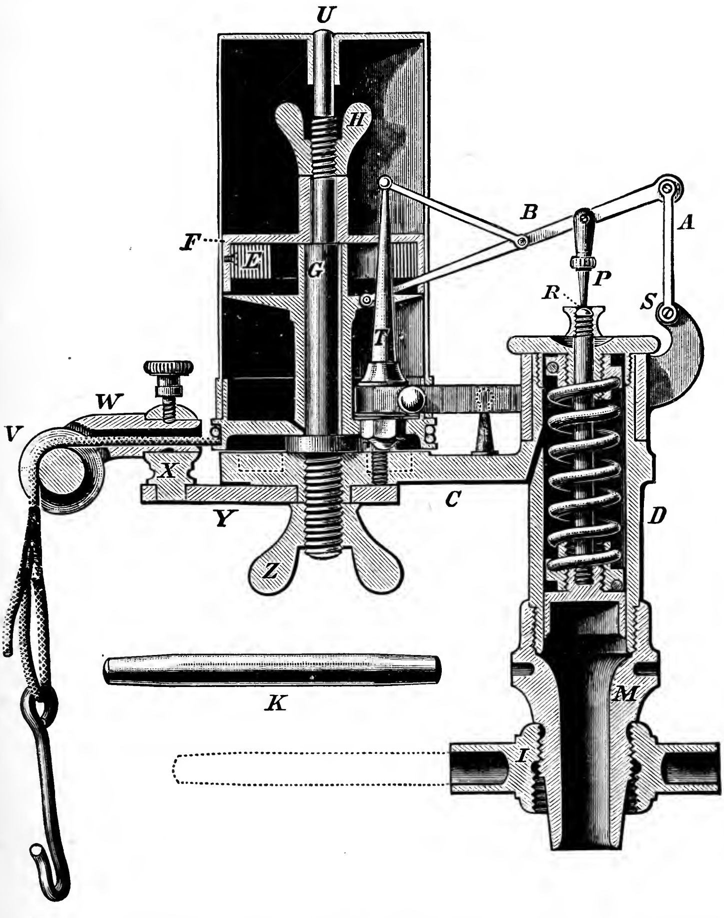


Fig. 76. IMPROVED THOMPSON INDICATOR. (Sectional View.)

The lead pulley *V* is carried by the swivel *W*, and can be locked in any position by the small set screw. The swivel plate *Y* can be swung in any direction in its plane and held

THE IMPROVED THOMPSON INDICATOR.

firmly by the thumb-screw *Z*. Thus with this combination, the cord can be run in any desired direction, and cannot ride over, being led to the drum through the small passage in *W*.

The link *A*, having long bearings, as can be seen in Fig. 75, gives a very good support to the lever *B*. The base *C*, supporting the paper drum, and the main body *D*, are cast in one piece.

The paper drum is made with a closed top to preserve its accurate cylindrical form, and the top having a journal bearing at *U* in the center, compels a true movement to its surface.

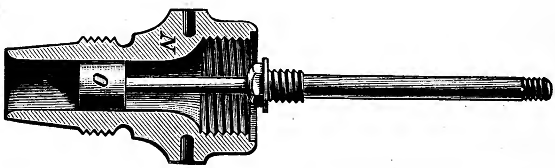


Fig. 77.

The spring *E* and the spring case *F* are secured to the rod *G* by screwing the case *F* to a shoulder on *G*, by means of a thumb-screw *H*.

To adjust the tension of the drum spring, the drum can be easily removed, and by holding on to the spring case *E* and loosening screw *H* the tension can readily be varied and adapted to any speed, to follow precisely the motion of the engine piston.

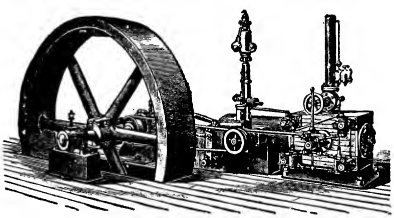
The bars of the nut *I* are made hollow, so as to insert a small short rod *K*, which is a great convenience in unscrewing the indicator when hot.

The indicator is so constructed that it can be readily changed and adapted to high-pressure work. This is done

THE IMPROVED THOMPSON INDICATOR.

by simply removing the cone *M* (see Fig. 76) and substituting the cone *N* (Fig. 77), with ¼ square inch piston and its rod.

Taking the 100-pound spring with the ½ square inch area piston, a pressure of 250 pounds can be correctly indicated. When pressures beyond this are required to be indicated, the ¼ square inch piston is used, and with the 100-pound spring, 500 pounds can be indicated.



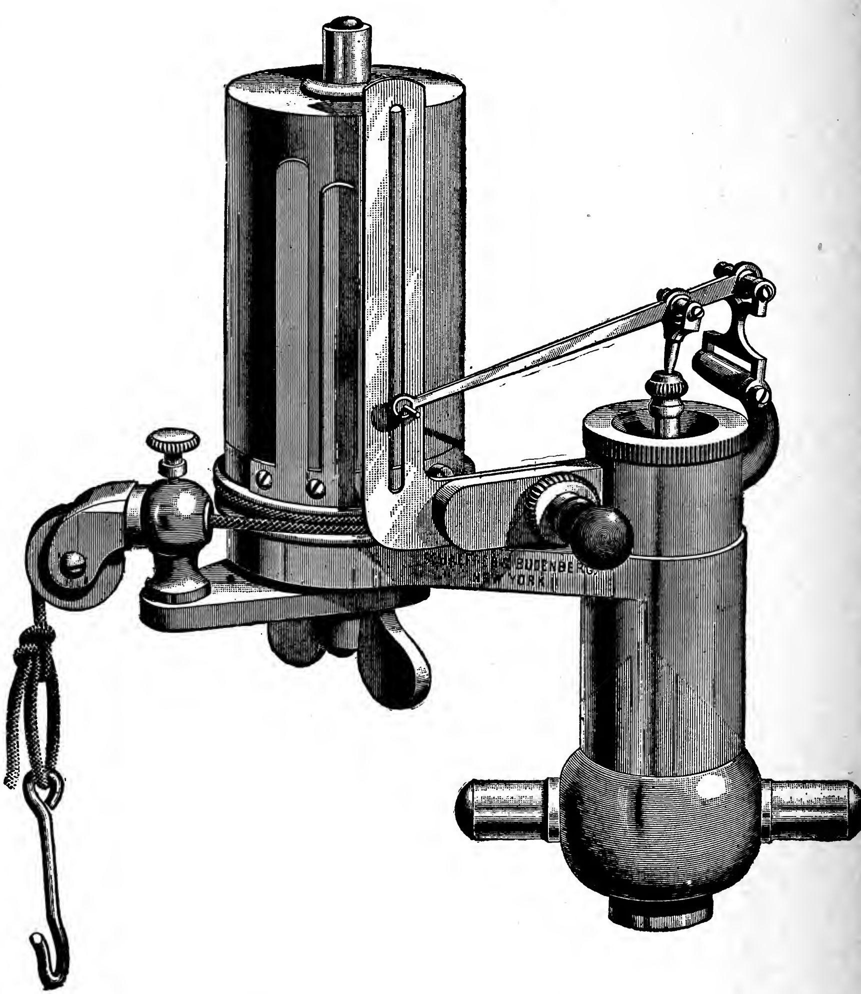


Fig. 78. The Lyne Indicator.

THE LYNE INDICATOR.

In Fig. 78 is shown another form of indicator, manufactured by Schaeffer & Budenberg.

It differs from that previously described by the parallel motion, as will be seen in the cut.

The interior construction of the paper drum is similar to the one attached to the Improved Thompson Indicator. It is also provided with the combination swivel for the guide pulley.

THE BUFFALO INDICATOR.

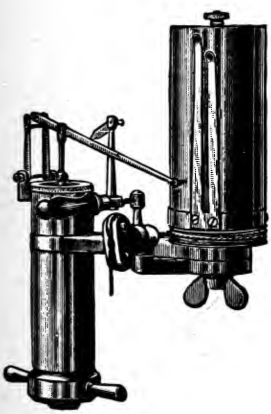


Fig. 79.

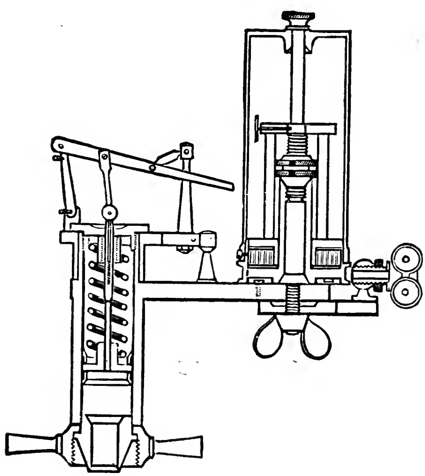


Fig. 80.

This instrument is shown in Fig. 79, and in Fig. 80 in section, exposing the interior parts.

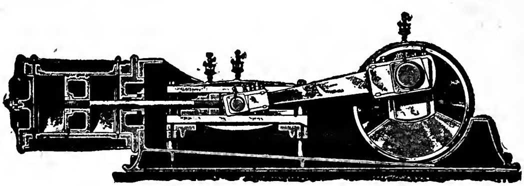
THE BUFFALO INDICATOR.

The piston is one-half inch area, provided with water-grooves. The piston rod is made of $\frac{3}{16}$ inch steel, hollow at the upper end, threaded to receive a swivel head (which permits of the adjustment of the pencil to suit weak or strong vacuum springs) and turned smaller at the lower to reduce its weight.

The parallel motion is secured by a link attached to and governing the pencil lever direct. The screws of this link are made free from any appreciable loss motion, and will remain so indefinitely. It is made of tool steel, and will trace a correct vertical line within its limit of 3 inches. The arm, link and uprights are made of $\frac{3}{16}$ x $\frac{1}{32}$ inch steel, the uprights being held together by small bars $\frac{2}{32}$ inch diameter, $\frac{1}{2}$ inch long, the ends of which are turned smaller and threaded to receive the $\frac{1}{8}$ inch hex nuts, which fasten the uprights against the shoulder.

The drum spring is a flat coil of the clock pattern, and can be adjusted for any speed by unscrewing the thumb-screw.

The indicator spring is of the double-coil pattern.



THE CROSBY INDICATOR.

The Crosby indicator is shown in Fig. 81, which is an outside view, and also in Fig. 82, which shows a sectional view.

These illustrations show the design and arrangements of the parts of the Crosby steam engine indicator.

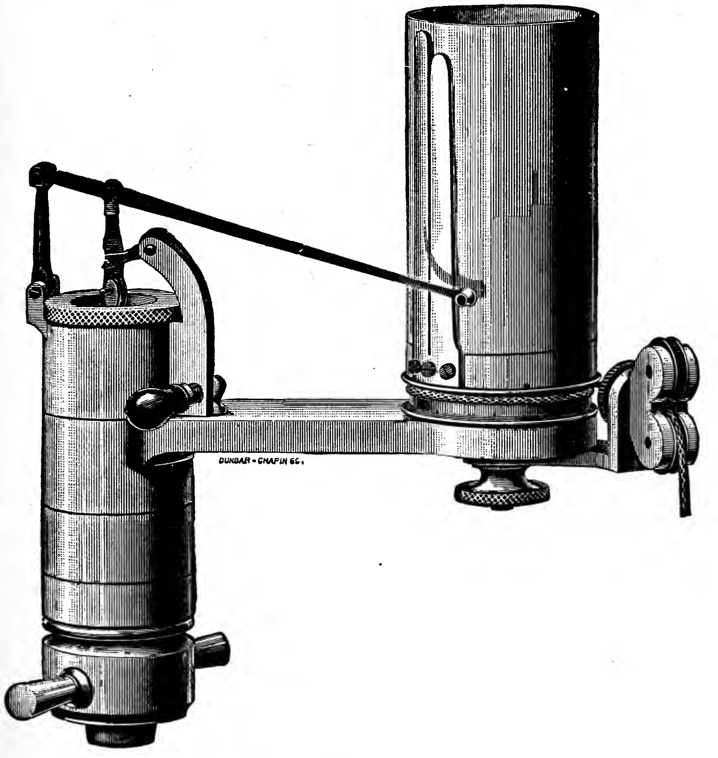


Fig. 81. Crosby Indicator.

Part 4 is the cylinder, in which the piston moves. Between 4 and 5 is an annular chamber, which serves as a steam jacket, and it is always filled with steam of nearly the same temperature as that in the cylinder.

THE CROSBY INDICATOR.

The piston, 8, is formed of tool steel. Its shell is made as thin as possible consistent with proper strength. Hollow channels in its outer surface provide a steam packing, and the moisture and oil which they retain act as lubricants.

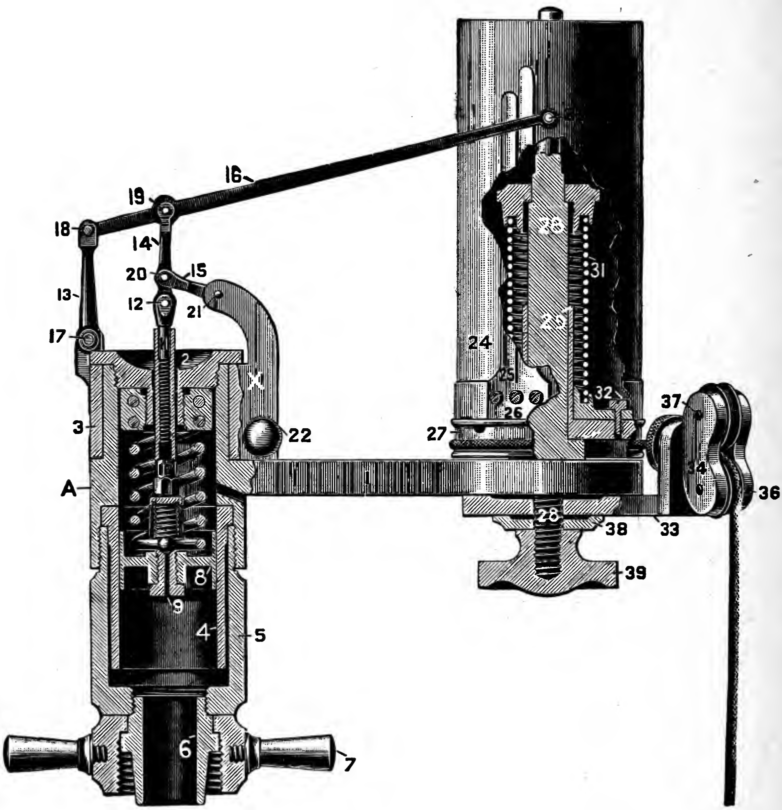


Fig. 82. Crosby Indicator (Sectional View).

The transverse web near its center supports a central socket, which projects both upward and downward; the upper port is threaded inside to receive the lower end of the piston rod.

The upper edge of this socket is formed to fit into a circular channel in the under side of the shoulder of the piston rod, when it is properly connected. It has a longitudinal slot, which permits the ball bearing on the end of the spring to drop to a concave bearing in the upper end of the piston screw 9, which is closely threaded into the lower part of the socket.

The piston rod, 10, is of tool steel, and made hollow for lightness.

When connecting the piston rod to the piston it should be screwed into the socket as far as it will go; that is, until the upper edge of the socket is brought firmly against the bottom of the channel in the piston rod.

The swivel head, 11, is threaded on its lower half to screw into the piston rod, more or less, according to the required height of the atmospheric line on the diagram.

The cap, 2, screws into the top of the cylinder, and holds the sleeve and all connected parts in place.

Its central hole is furnished with a hardened steel bushing, which forms a guide for the piston rod.

The sleeve, 3, surrounds the upper part of the cylinder, and supports the pencil mechanism.

The plate, 1, supports the paper drum, 24.

The drum spring, 31, is a short spiral spring.

MEASURING THE DIAGRAM BY ORDINATES.

In order to figure the horse power of an engine, it is necessary to know the exact pressure upon the piston.

This pressure can never be equal to the full boiler pressure, as even those engines known as full-stroke engines cut the steam supply off before the end of the stroke, and thus the same pressure does not follow the piston throughout the entire stroke. The pressure varies through the

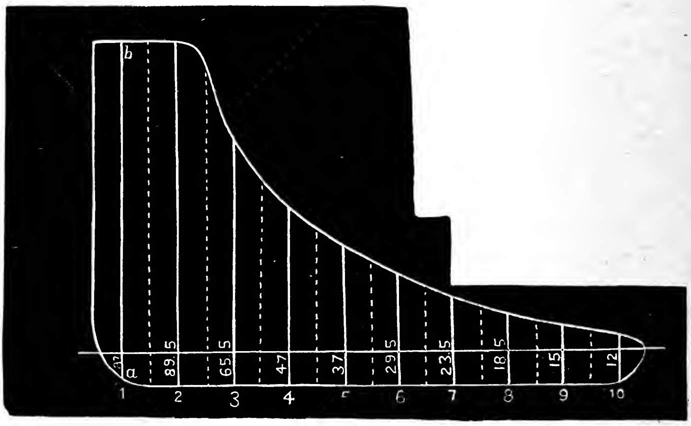


Fig. 83.

stroke, and is opposed by a varying amount of back pressure, so that the average unbalanced, or, as it is commonly called, the "mean effective pressure," must be determined. There is also some pressure lost between the cylinder and boiler by wire drawing.

The indicator diagram records the pressure at all points of the stroke, and thus allows, by a simple calculation, the finding of the mean effective pressure.

MEASURING THE DIAGRAM BY ORDINATES.

The mean effective pressure is the pressure which, if allowed to act upon the piston throughout the entire stroke, would do the same amount of work as the steam pressure, cut off and expanded down, as indicated by the diagram.

It is the average pressure, arrived at by measuring the pressure in the cylinder at different points of the stroke next adding all these together, and then dividing by the number of points measured.

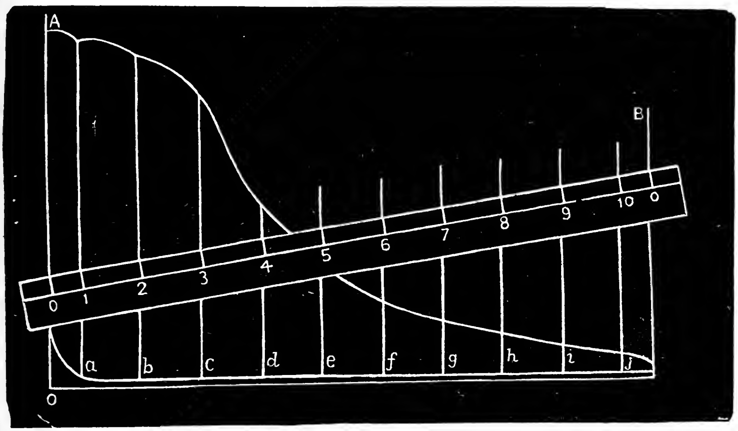


Fig. 84

In an indicator diagram, the height is proportional to the pressure, and to find the average pressure we must find the average height.

The most elementary way of doing this is by measuring the pressure upon the diagram at a number of equidistant points and taking the average. To do this, divide the diagram into a number of equal parts lengthwise, ten for ordinary work, as shown by the dotted lines in Fig. 83. Now with a scale corresponding to the spring with which the diagram was taken, measure the pressure in the center of

MEASURING THE DIAGRAM BY ORDINATES.

each of these divisions; that is, upon the full lines, or ordinates. Notice that this pressure must be measured between the steam, expansion and exhaust lines of the diagram, whether the engine is condensing or non-condensing, and not from the atmospheric or any other line.

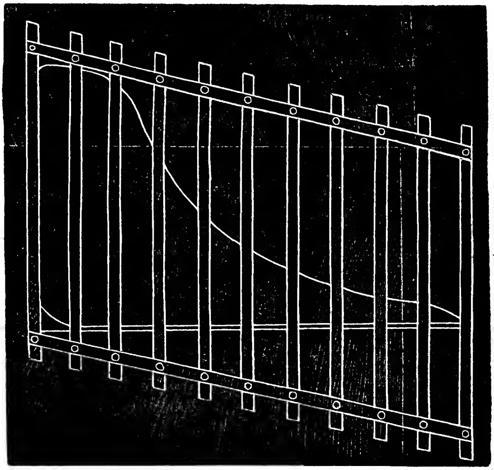


Fig. 85.

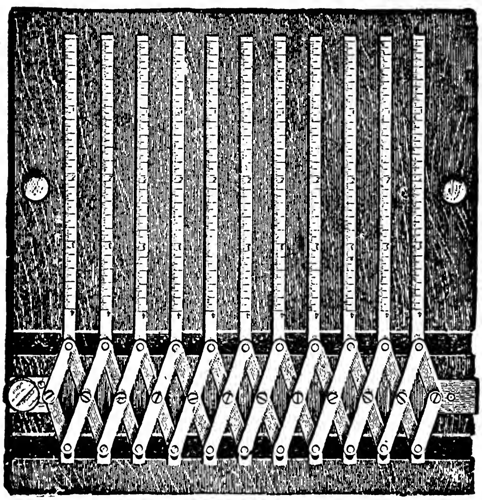


Fig. 86.

MEASURING THE DIAGRAM BY ORDINATES.

Several expedients may be resorted to for shortening the labor of dividing the diagram and locating the ordinates. The simplest of these is to have a rule, a little longer than the ordinary length of diagrams, divided as shown in Fig. 84, just as the diagram is to be divided, with nine spaces of equal length in the middle; the two end spaces, 0 to 1 and 10 to 0, being one-half the width of the others. Four inches between the zero marks of the rule is a good length for diagrams from 3½ to 4 inches in length.

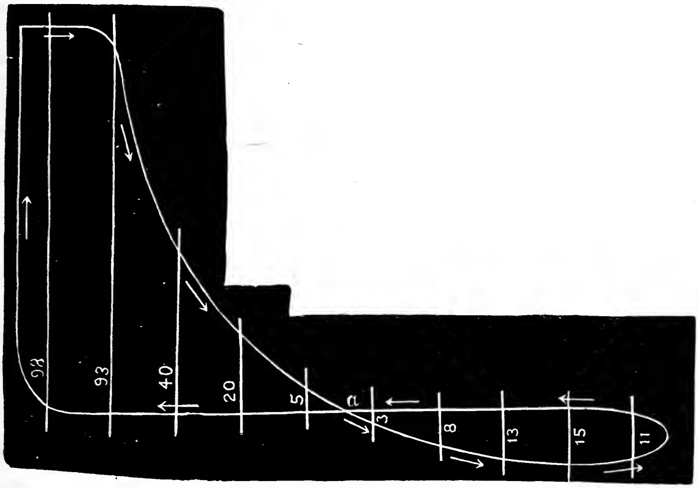


Fig. 87.

Draw the lines *O A* and *X B* at the extreme ends of the diagram and perpendicular to the atmospheric line. Place the rule between them, as shown in Fig. 84, at such an inclination that both zeros come upon the perpendiculars. Then with a needle-point prick the card opposite each division of the rule, and draw the ordinates perpendicular to the atmospheric line and through these points. Of course any other number of ordinates than 10 or 20 may be used.

MEASURING THE DIAGRAM BY ORDINATES.

There are devices on the market for simplifying this operation, and for doing it with more exactness. Two of these are shown in Figs. 85 and 86.

The method of using them will be plainly understood from the cuts.

Instead of measuring each ordinate with the scale corresponding to the spring with which the diagram was taken, some engineers prefer to lay off the lengths of the ordinates continuously on the edge of a strip of paper, then to measure the whole length with a scale of common inches, and multiply the length by the scale of the spring.

The result will be the height of a rectangle, whose base is equal to the length of the diagram, and whose area equals the area of the diagram.

If there is a negative loop in the diagram, as in Fig. 87, the cause of which has been explained, the average pressure of the loop portion of the diagram must be subtracted from that of the other portion. For the piston is actually hanging back upon the engine, and the loop not only represents no addition to the useful mean effective pressure, but a force acting against the motion of the engine equivalent to so much back pressure. For example, erecting the ordinates as before directed, and measuring with a scale, in this case 40, we have $98+93+40+20+5 = 256$ as the sum of the measurements in the main portion of the diagram, and $3+8+13+15+11 = 50$ as the sum of the measurements in the loop. Taking the difference and dividing by 10 to get the average, we have

$$\frac{256-50}{10} = 20.6 \text{ lbs. M. E. P.}$$

EXAMPLES.

In the following illustrations are given examples explaining, at some length, how to measure diagrams by ordinates.

Fig. 88 shows an ideal diagram, in which the pressure is indicated at different points of the stroke, and also showing the mean effective pressure.

Figs. 89 and 90 are diagrams of a tandem compound Watts-Campbell Corliss engine, in which the method for finding the mean effective pressure of a double diagram is given.

The diagrams in Figs. 91, 92, 93 and 94 are of a cross compound Buckeye engine, taken at the same instant, with four indicators; thus the cards are all separate, but the M. E. P. of both strokes can be found by proceeding as in Figs. 89 and 90.

The following diagrams were taken of the engines named above, and are used to more fully explain to the student the working out of an indicator diagram by ordinates.

By repeating this operation several times, the student will get so accustomed to it that he can almost tell the mean effective pressure by looking at the diagram and knowing the boiler pressure.

If the foregoing explanations and rules are well observed, the art of figuring diagrams will be found to be quite easy.

NOTE.—In the following diagrams H. P. stands for High Pressure; I. P. for Intermediate Pressure; and L. P. for Low Pressure. Letters C and H represent Crank End and Head End, as heretofore explained, M. E. P. is an abreviation for Mean Effective Pressure.

EXAMPLES.

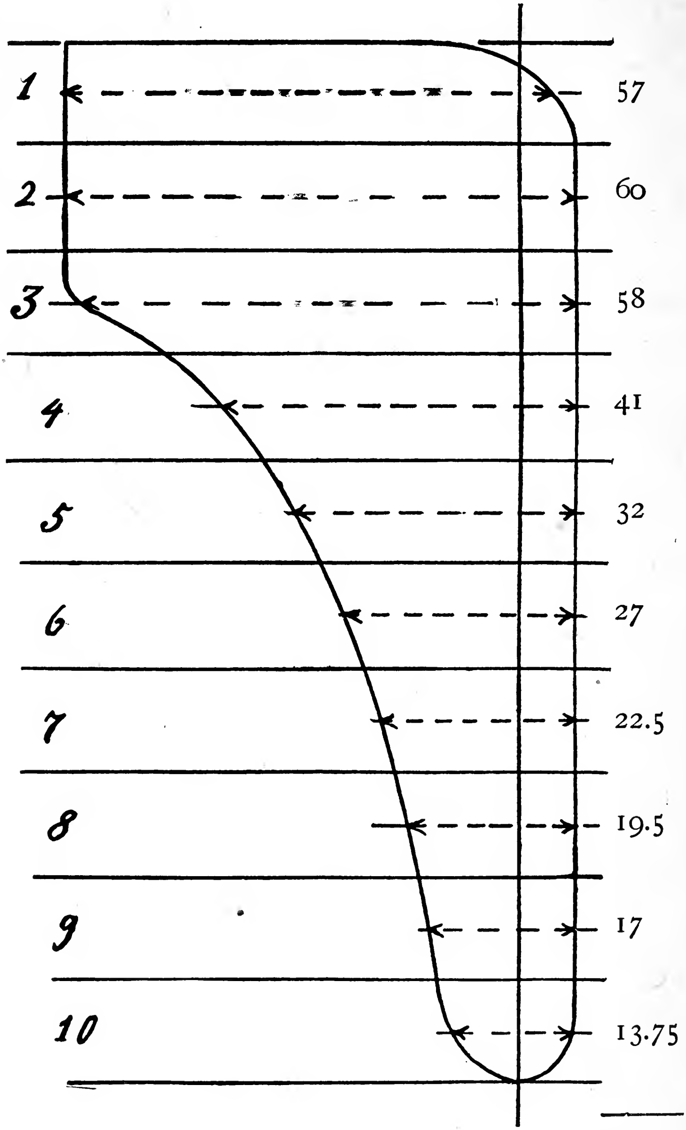
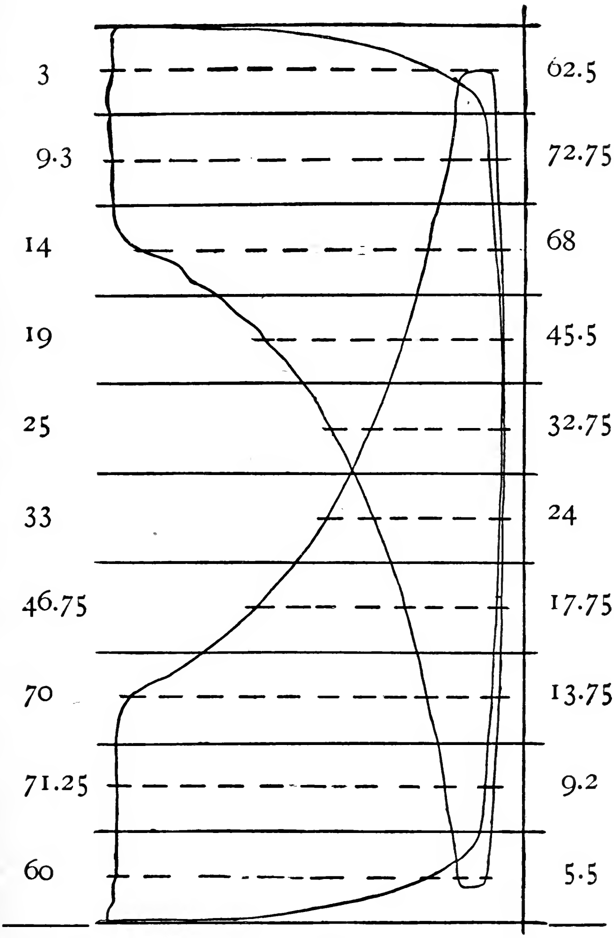


Fig. 88.

10)347.75 = 34.775 = M. E. P.

EXAMPLES.



10)351.30=35.13= M. E. P.

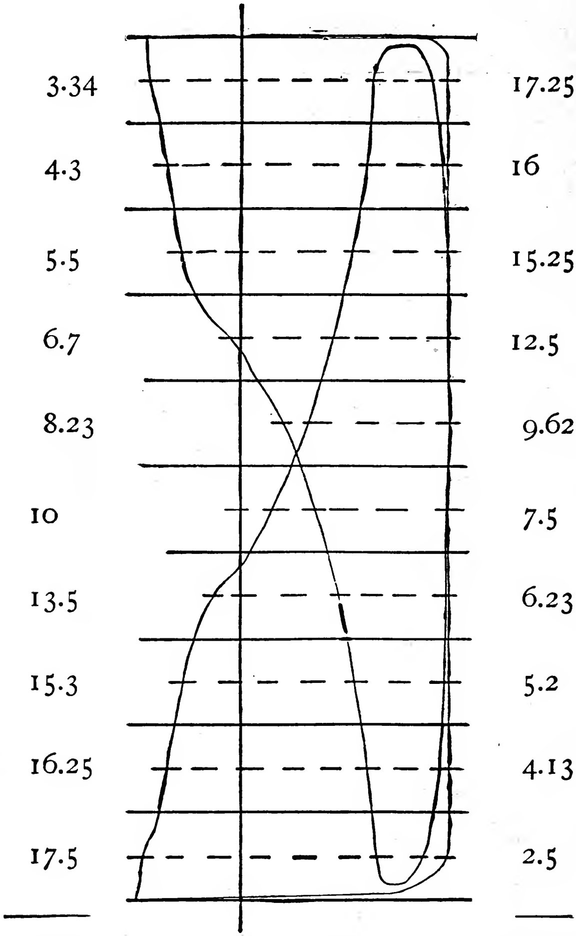
Fig. 89.

10)351.70=35.17= M. E. P.

M. E. P. of both strokes = 35.17
35.13

2)70.30 = 35.15.

EXAMPLES.



10)100.62 = 10.062 = M. E. P.

Fig. 90.

10)96.18 = 9.618 = M. E. P.

M. E. P. of both strokes = 10.062
9.618

2)19.680 = 9.84

EXAMPLES.

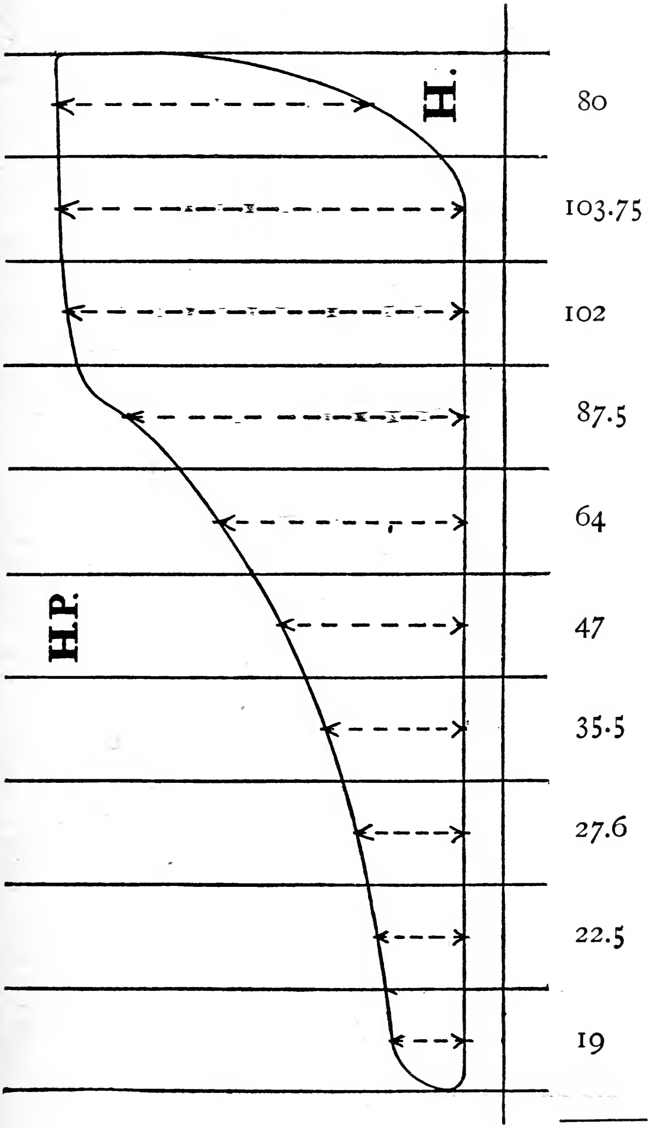


Fig. 91.

10)588.85 = 58.885 = M. E. P.

EXAMPLES.

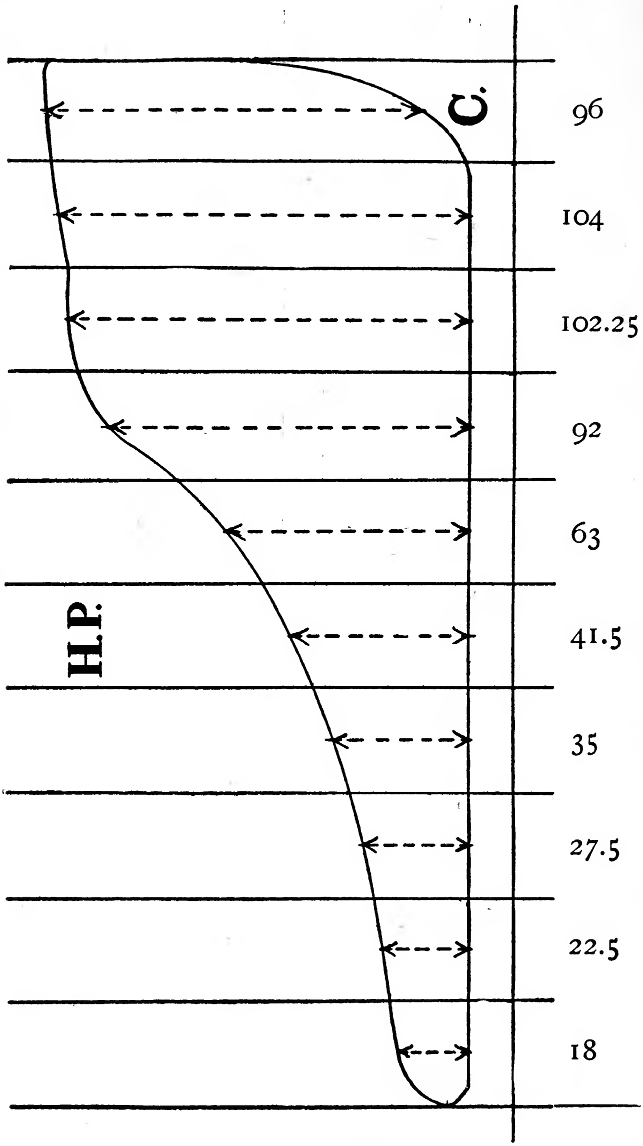
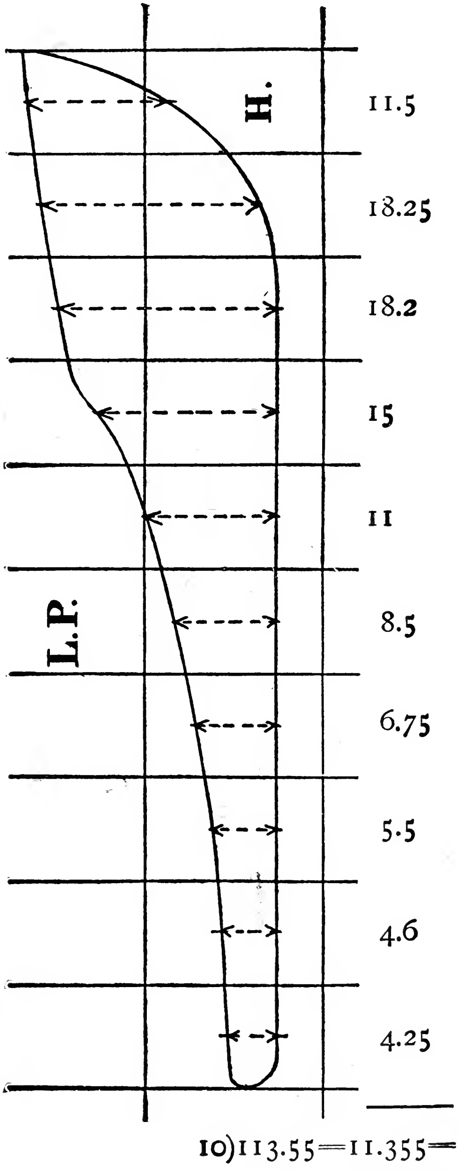


Fig. 92.

10)601.75=60.175=
M. E. P.

EXAMPLES.



10)113.55=11.355=
M. E. P.

Fig. 93.

EXAMPLES.

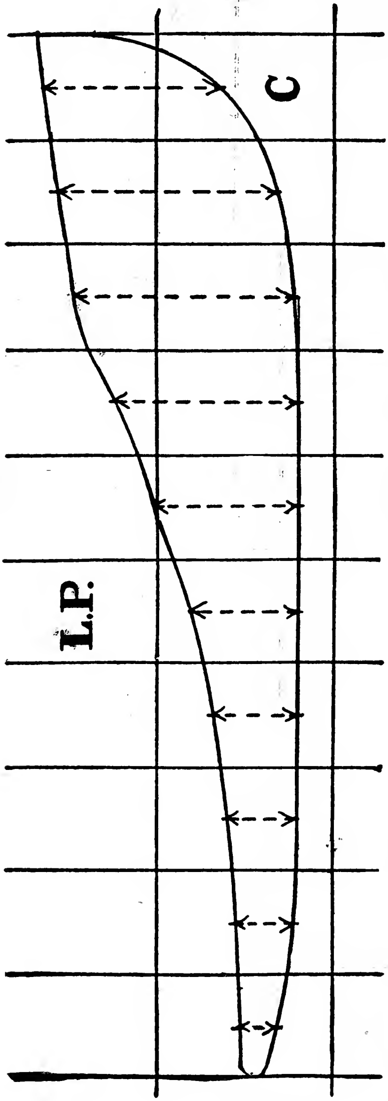
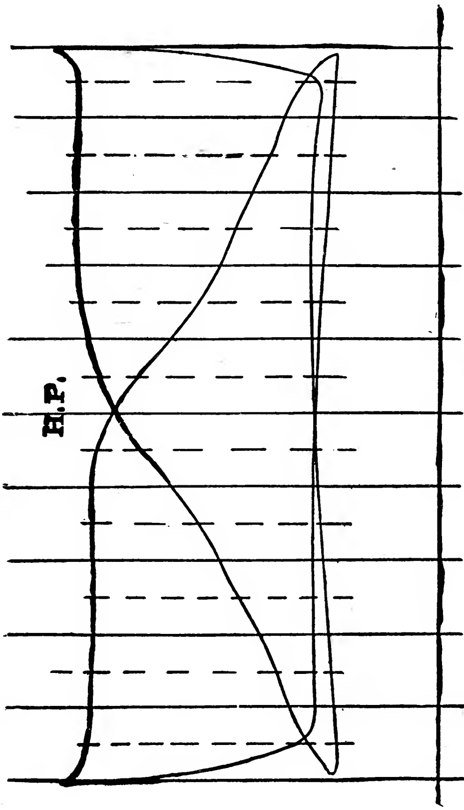


Fig. 94.

10)107.24=10.724

EXAMPLES.

Instead of finding the mean effective pressure for each end of the cylinder, and then taking the average, the sums of each end may be added together, and the result divided by 20, as in Figs. 95, 96 and 97, which are cards from a triple expansion Buckeye engine.



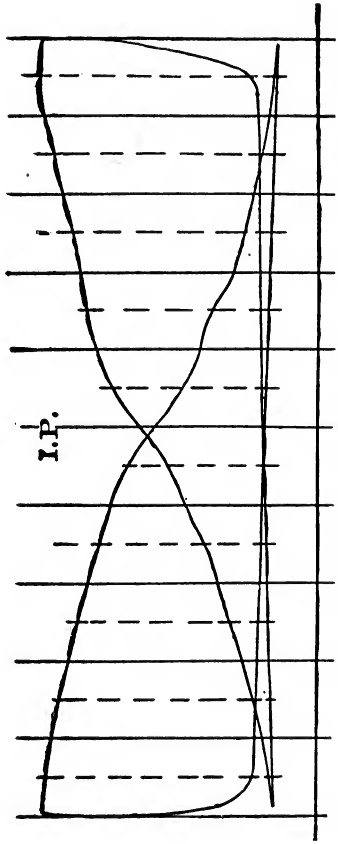
9	69.5
17	68
27	68
35.25	67
52	61.25
62	50
63.25	32
63.25	25.5
64	16
61.5	8
454.25	465.25

Fig. 95.

465.25
454.26

20)919.50=45.975=M. E. P.

EXAMPLES.



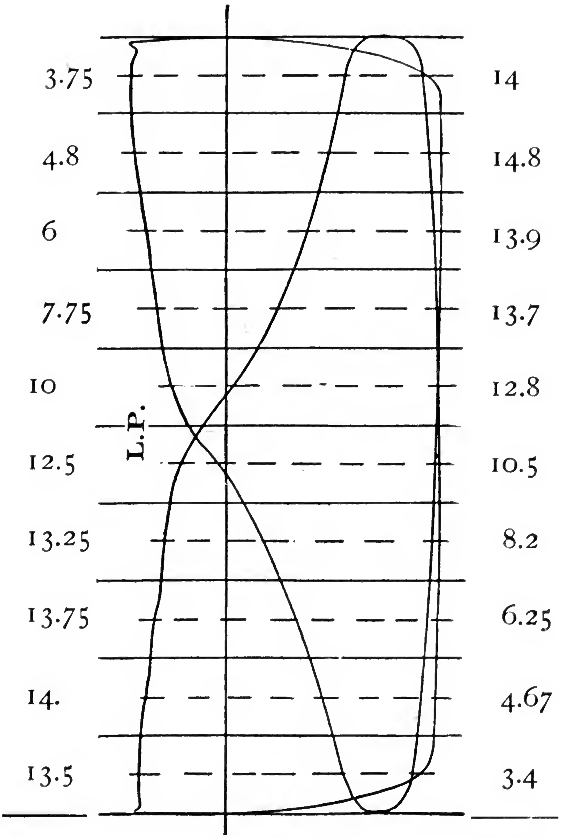
0.3	30
1.5	29.5
3.25	27
8	24.5
12	21
18.75	14
23	8.75
26.5	4.75
28.5	2
29.9	0.5
151.70	162.00

Fig. 96.

$$\begin{array}{r} 162.00 \\ 151.70 \\ \hline \end{array}$$

20)313.70=15.685=M. E. P.

EXAMPLES.



99.30 Fig. 97. 102.22

102.22
99.30

20)201.52 = 10.076 = M. E. P.

PLANIMETER.

The foregoing method of figuring the mean effective pressure is sufficiently accurate for ordinary purposes; but, if very exact results are required, an instrument is used which enables the operator to find the mean effective pressure with still greater accuracy. This instrument is called the Planimeter.

By its use the area of the diagram is measured, and by simply dividing this area by the length of the diagram, the average height is found. If the area of a rectangle and its length are given, the height can easily be found by dividing the area by the given length.

Now, if the area of an indicator diagram is given, and divided by its length, the result will be the height of a rectangle, of equal area and length with the diagram.

This would be the kind of figure marked upon the paper by the indicator pencil, if a pressure equal to the mean average should act upon the piston throughout the entire stroke.

The planimeter is made in a variety of forms. The Amsler was the first to be introduced, a typical example of which is shown in Fig. 98. It consists of two arms pivoted together at the top, upon one of which is carried a roller free to revolve upon an axis parallel to the arm itself. The roller is divided circumferentially into ten equal parts, each of which represents a square inch of area, and each of these parts is further divided into equal parts representing each one-tenth of a square inch, as shown in Fig. 99. Close to the edge of the roller is a stationary plate having

THE PLANIMETER.

the same curvature and containing a vernier made by dividing a space nine-tenths as long as one of the large divisions of the roller into ten equal parts. In Fig. 100 let the space between *A* and *B* represent one of the larger divisions of the wheel, and the space between *C* and *D* the vernier.

In reading the instrument take the number on the wheel that has passed the zero mark of the vernier when the wheel is turning to the left as indicated by the arrow,

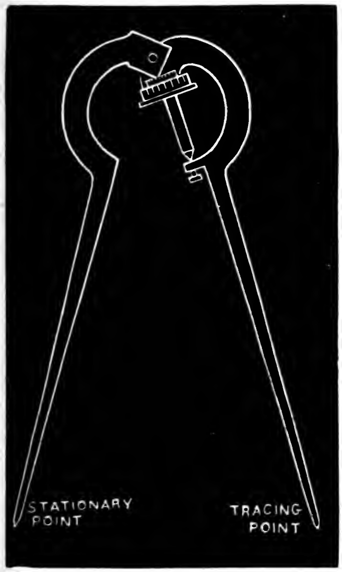


Fig. 98.

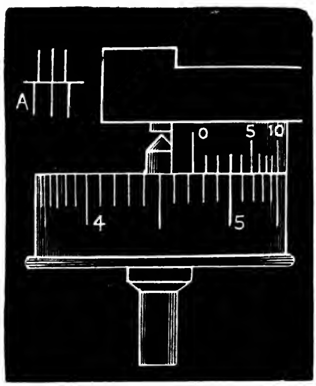


Fig. 99.

as the number of whole square inches, in this case 6. The tenths of a square inch are indicated by the number of spaces, such as *a*, which have passed the zero mark, in this case 1; so that the reading of the scale as laid down in Fig. 100 is 6.1 square inches. Now notice that the space between the line *b* and the line 1 on the vernier is just one-tenth of one of the spaces such as *a* upon the roller, the

THE PLANIMETER.

space between the lines 2 and *c* is just two-tenths, between 3 and *d* three-tenths, etc. If, then, the wheel rolls in the direction of the arrow one-tenth of one of the spaces *a*, corresponding to an area of one one-hundredth of a square inch, the lines 1 and *b* will coincide, for two one-hundredths 2 and *c* would coincide, so that we get the hundredths of a square inch by writing that number on the vernier which is opposite any line on the wheel. For instance, in reading the instrument as it stands in Fig. 99, write first the num-

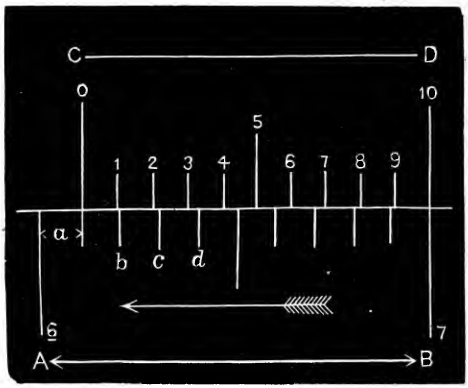


Fig. 100.

ber on the wheel to the left of the zero mark, in this case 4; then the number of whole spaces between that number and the zero mark, in this case 7; and last the number on the vernier which is in line with a mark on the wheel, in this case 3. The whole reading therefore is 4.73 square inches, the decimal point being placed after the 4, the 7 and 3 being tenths and hundredths as before explained. It will be noticed that only the zero, 5, and 10, are numbered on the vernier in Fig. 99, and this is the case in the actual instrument, the intermediate marks being easily known by their position. The eye soon becomes accus-

THE PLANIMETER.

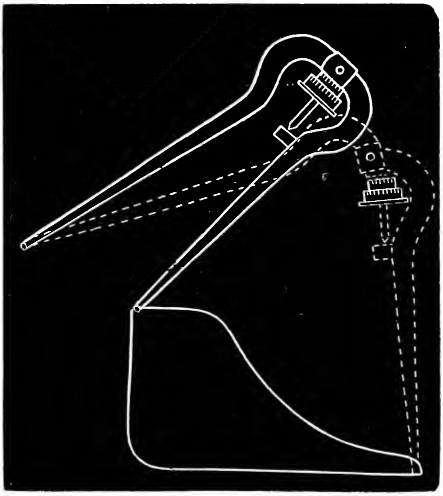


Fig. 101.

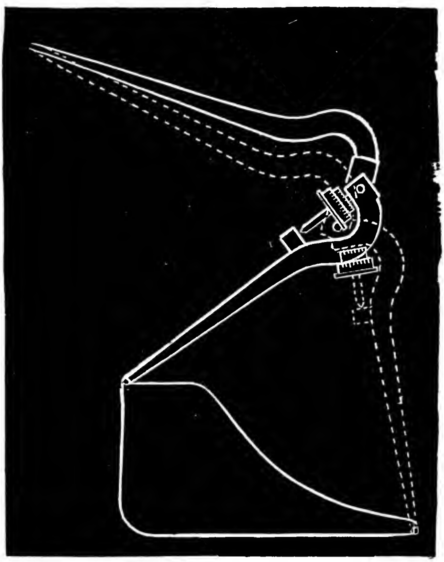


Fig. 102.

THE PLANIMETER.

tomed to quickly determining the mark upon the vernier which coincides with one upon the wheel, the marks at either side of it being just within the marks upon the wheel, giving the arrangement shown at *A* in Fig. 99.

The planimeter should be used upon a smooth but not slippery surface, such as that of heavy drawing-paper or Bristol board. Place a sheet of this large enough to include the planimeter and the diagram upon the drawing-

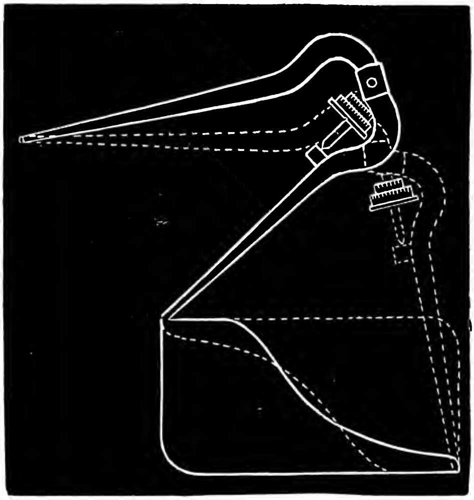


Fig. 103.

board, which is furnished with many planimeters made of hard wood polished and fasten it with thumb-tacks or paper-clips, which resemble those on the paper drum of an indicator, and are fastened to the board furnished with the planimeter. Set the stationary point of the planimeter into the paper in such a position that the tracing-point can be carried around the outline of the diagram without bringing the wheel in contact with the card. The instrument can be worked to the best advantage when it is neither

THE PLANIMETER.

allowed to close up too closely, as in Fig. 101, nor to extend too widely, as in Fig. 102. A better position for the stationary point than either of these is shown in Fig. 103, the motion of the roller being easiest when the arms are near a rectangular position. Where the areas to be measured are large, or where there is considerable space between the top of the diagram and the top edge of the card, contact of the roller with the edge of the card may be avoided by inverting the diagram, as indicated by the dotted diagram

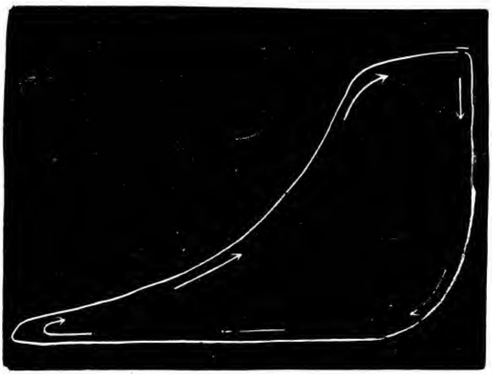


Fig. 104.

in Fig. 103, using the planimeter always in the same direction—that in which the hands of a watch run; for obviously the area of the diagram remains the same in whatever position the card is placed.

Place the tracing-point on any convenient point in the line of the diagram, and by pressing upon it get a slight indentation to mark the point of starting. Take the reading of the instrument as it stands; then with the tracing-point follow the line of the diagram in the direction in which the hands of a watch move, as indicated by the arrows in Figs. 104 and 87. Follow the line as made by the pencil; not

THE PLANIMETER.

necessarily in direction, but rather in course—as, on a right handed diagram, such as Fig. 104, it will have to be traced in the opposite direction from that of the pencil which made it, in order to carry the tracing-point in the direction of the hands of a watch.

For instance, in Fig. 105, do not leave the admission line at *a* and run out on the back pressure line, but follow the diagram naturally all the way around, as the arrows indicate, and as it was drawn by the pencil.

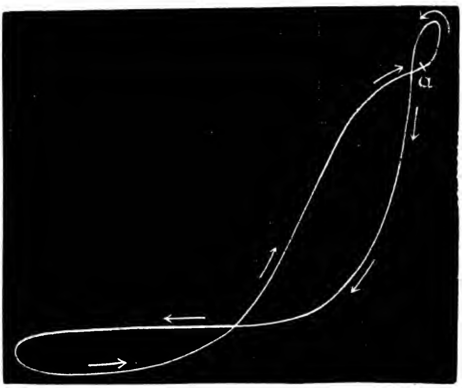


Fig. 105.

If the pointer traces in the opposite direction to the hands of a watch, the wheel will take out the area instead of adding it. In Fig. 87 it was shown that the area of the loop was negative, and that it needed to be subtracted from the other portion of the diagram to get the mean effective pressure. It will be seen that, by following the lines of the diagram as directed, the point will pass around the negative portions of the diagram in a direction contrary to that of the hands of a watch, and that these areas will be automatically subtracted. In this connection, be careful in

THE PLANIMETER.

starting to trace a diagram with loops, to move the tracing-point in the direction that will carry it with the hands of a watch over the main portion of the diagram. If Fig. 105, for instance, were started at the point *a*, or anywhere within one of the loops, the first movement of the tracer would have to be in the opposite direction from that of the watch.

FINDING THE MEAN EFFECTIVE PRESSURE BY THE PLANIMETER.

Having traced around the diagram and brought the pointer around and into the hole from which it started, take the reading in the new position, subtract from it the previous reading, and the difference will be the area of the figure traced. If the roller is placed at zero to start with, the reading would give the area at once; but it is easier to take the instrument as it stands and subtract the initial reading. Suppose the operation is started with the wheel at 1.42, and after tracing the diagram the reading is found to be 4.69, then the area will be $4.69 - 1.42 = 3.27$ square inches.

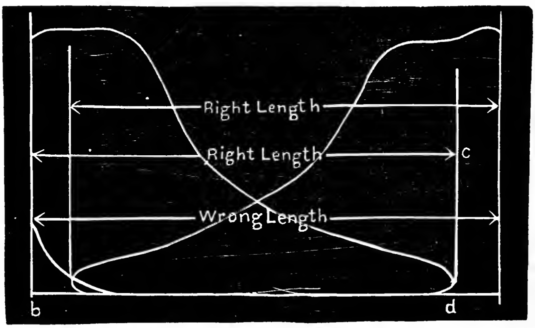


Fig. 106.

By dividing this area by the extreme length the average height is found.

The length of the diagram has to be measured between its extremes—*i. e.*, between *b* and *d*, Fig. 106.

If both diagrams are taken on one card, do not measure between the extremes of both diagrams at once, as indicated in Fig. 106, but measure each diagram by itself, as marked right length, Fig. 106.

THE LIPPINCOTT PLANIMETER.

In Figs. 107 and 109 are shown two other types of planimeters; the standard averaging planimeter, Fig. 109, is of the "Amsler" type, which has been described in the preceding pages. This can be used to measure the mean effective pressure directly, or to find the area of the diagram as previously stated.

Fig. 107 represents the Lippincott planimeter, which entirely does away with calculations. Its principal parts are a polar arm of constant length, *R C*, a tracing arm of variable length, *C T*, and a registering arm which carries a wheel. This arm is of glass in the form of a tube which is exhausted for partial vacuum, and in its interior is a paper scale which is thereby protected from discoloration and shrinkage from varying atmospheric conditions. The wheel has a sharp knife edge, and therefore does not skid laterally, as do the wheels of all other planimeters or integrators, all lateral motion being performed by the sliding of the wheel upon the tube. Thus it will be seen that a finished surface is not necessary with this instrument; it will be further noted that simple rotation of the wheel upon its axis does not register on the scale arm, therefore the diameter of the wheel is immaterial.

The wheel and tube are shown in Fig. 108.

At *C* it will be noted that there is a little button which may be depressed and push a sharp point through the exact center of the pivot of the tracing and polar-arm and thereby exactly locate it. Thus the tracing-arm can be adjusted to any length with accuracy. One or more tubes

PLANIMETERS.

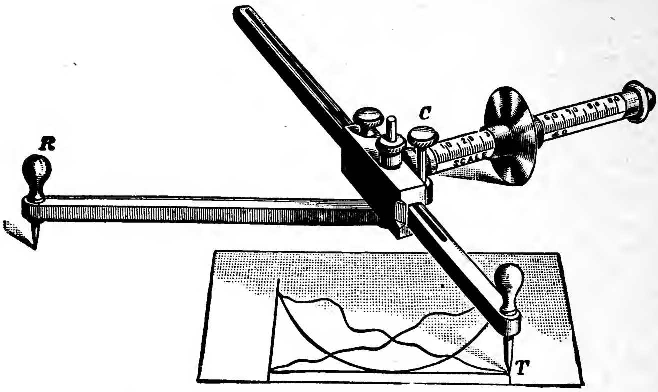


Fig. 107. THE LIPPINCOTT PLANIMETER.

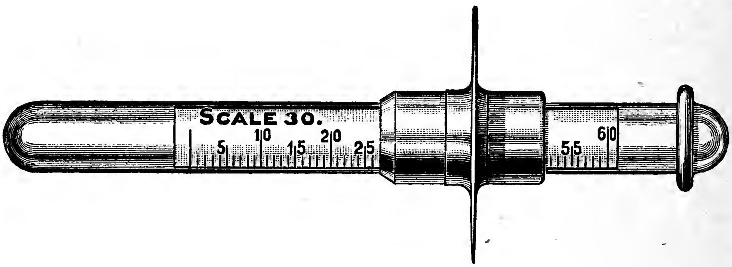


Fig. 108. SCALE AND WHEEL.

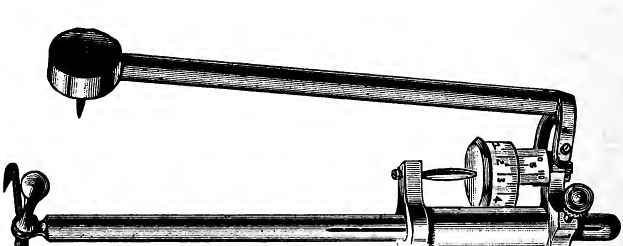


Fig. 109. THE ROBERTSON-AMSLER PLANIMETER.

NOTE.—Both these instruments are manufactured by J. L. Robertson & Sons, 204 Fulton Street, N. Y.

PLANIMETER ATTACHMENT.

are supplied with a planimeter, each corresponding with two scales of indicator spring. By adjusting the tracing-arm to the exact length of the card, clamping it in this position and selecting a tube of the proper scale, the indication thereon when the card is traced will be not the area, but the mean effective pressure.

If it be desired to find the area of the diagram, all that is necessary to do is to set the tracing-arm four inches, and select a tube with a 40 scale. The results will then be areas instead of mean effective pressures, and it will be seen that the length of the card and the scale of the spring cancel each other.

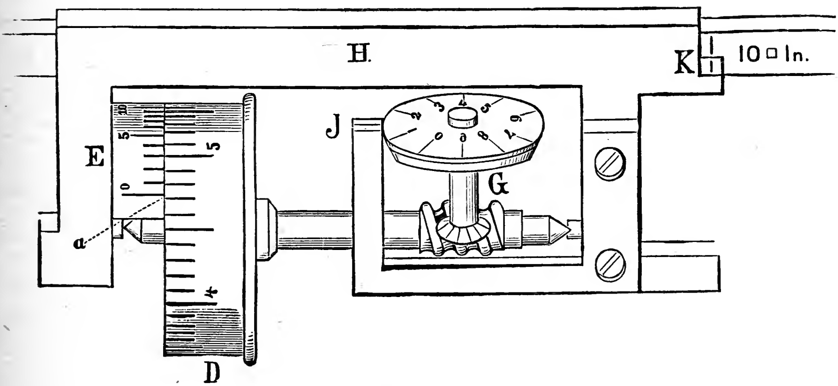


Fig. 110.

In Fig. 110 is shown in detail the recording mechanism attached to the Amsler planimeter by the Crosby Steam Gauge and Valve Company.

The drum of the roller-wheel *D* is divided into ten numbered parts, and each number represents one square inch; the spaces between the numbers are divided into ten graduations, each one of which represents one-tenth of a square inch. The vertical *E* has ten graduations, one-tenth less

PLANIMETER ATTACHMENT.

than those of the roller-wheel, and if one of them exactly coincides with a graduation on the roller-wheel, it represents—counted from zero—so many hundredths of a square inch.

The counting-disc *G* is geared to the wheel in such a manner as to rotate once for 10 rotations of the roller-wheel; it is divided into 10 numbered spaces, each one of which represents 10 square inches; its office is to count the revolutions of the roller-wheel.

Referring now to Fig. 110, and supposing that a certain area has been measured, from zero, the result is read as follows: Suppose the figure on the counting-disc which has passed the line on the post *J* is found to be 1, representing tens, and the figure on the roller-wheel which has passed zero on the vernier to be 4, representing units; and the number of intermediate graduations on the roller-wheel that have also passed zero on the vernier to be 7 (shown by the dotted line *a*), representing tenths; and the graduation on the vernier, which exactly coincides with a graduation on the roller-wheel to be the third from zero, which for instance call 3 and represents hundredths; then 14.73 square inches is the area of the figure measured.

If the movement of the roller-wheel had been three one-hundredths less, its seventh graduation would have coincided with zero of the vernier and there would have been no hundredths to read. The reading would then have been 14.7 instead of 14.73.

THE WILLIS PLANIMETER.

The Willis planimeter, which is shown in Fig. 111, reads the horse power direct from the indicator card.

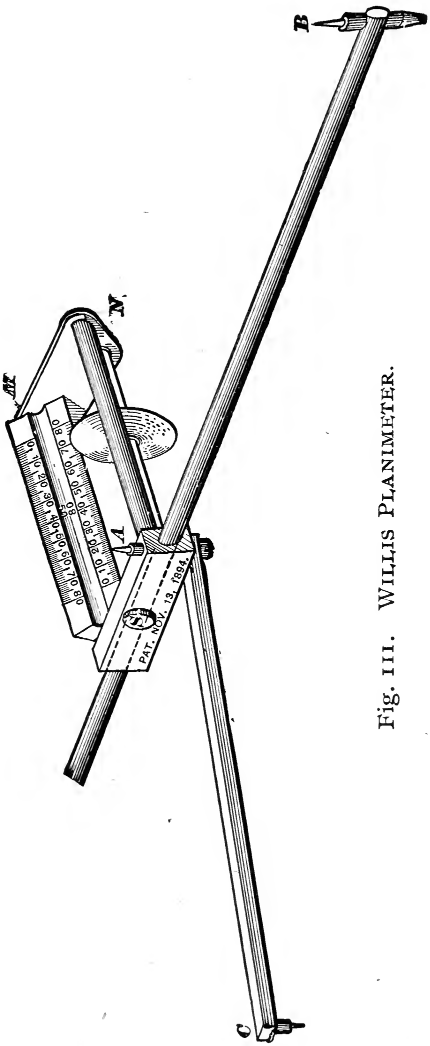


Fig. 111. WILLIS PLANIMETER.

THE WILLIS PLANIMETER.

Its wheel both rolls and slides on its axis, which is perpendicular to the tracer bar *A B*. It rolls for all movements paralled to the tracer bar, and slides on its axis for all movements perpendicular to it. After tracing a figure, the result of such perpendicular movement is read from the scale next the wheel, Fig. 111. This scale is triangular, and any one of its six graduated edges can be brought next the wheel. Thus the wheel movement can be read in the unit best suited to the work, and all factors or corrections are avoided.

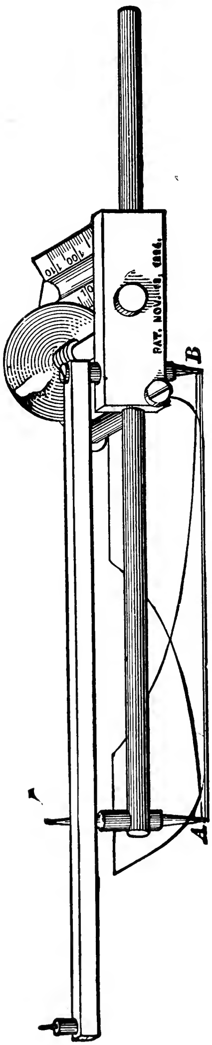


Fig. 112.

To read square inches, set the points *A* and *B* to the distance apart corresponding to the scale that is next the wheel. Thus, if the 40 scale were next the wheel, set *A* and *B* 4 inches apart. The instrument would then read square inches and tenths of a square inch; for the reading, after tracing a figure whose area was one square inch would be $4.0 \times \frac{1}{4} = 1.0$.

If the figure is large and the convenience of a longer tracer arm is desirable, turn next to the wheel the 100 scale, and set *A* and *B* 10 inches apart, and still read the same unit.

To read the mean effective pressure of an indicator card, turn next to the wheel the scale that corresponds to the

THE WILLIS PLANIMETER.

spring with which the card is taken, and set points *A* and *B* to card length, Fig. 112. On tracing-card the reading

$$\frac{\text{card area}}{\text{card length}} \times \text{spring} = \text{M. E. P.}$$

The horse-power attachment, Fig. 113, is a double-hinged scale, with a sliding pointer on each arm. Supplied with

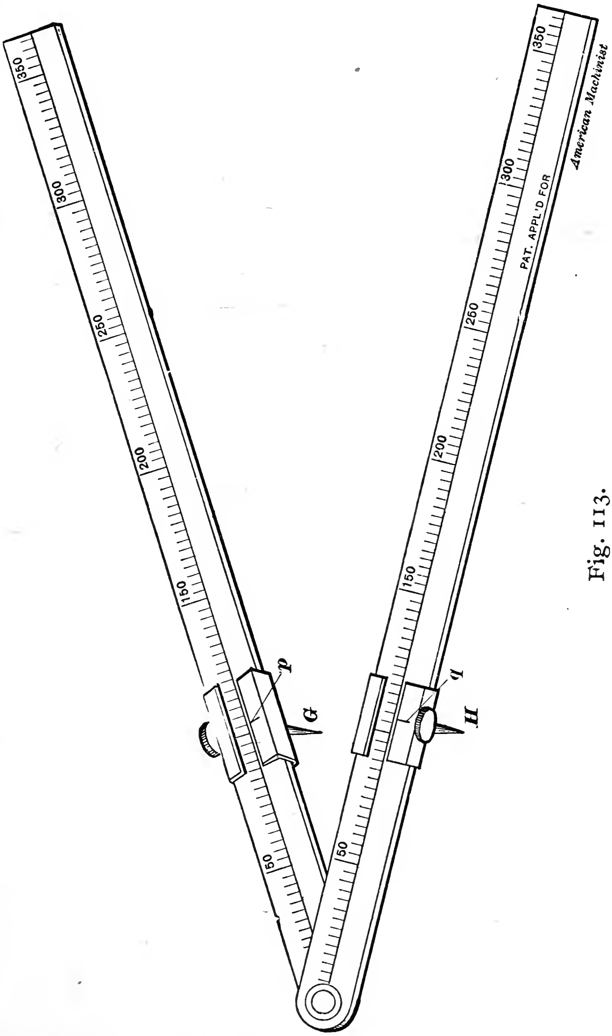


Fig. 113.

THE WILLIS PLANIMETER.

the instrument is a book of tables which give the value of $\frac{33,000}{\text{piston area} \times \text{stroke}}$ for engines from 8″x8″ to 110″x72″.

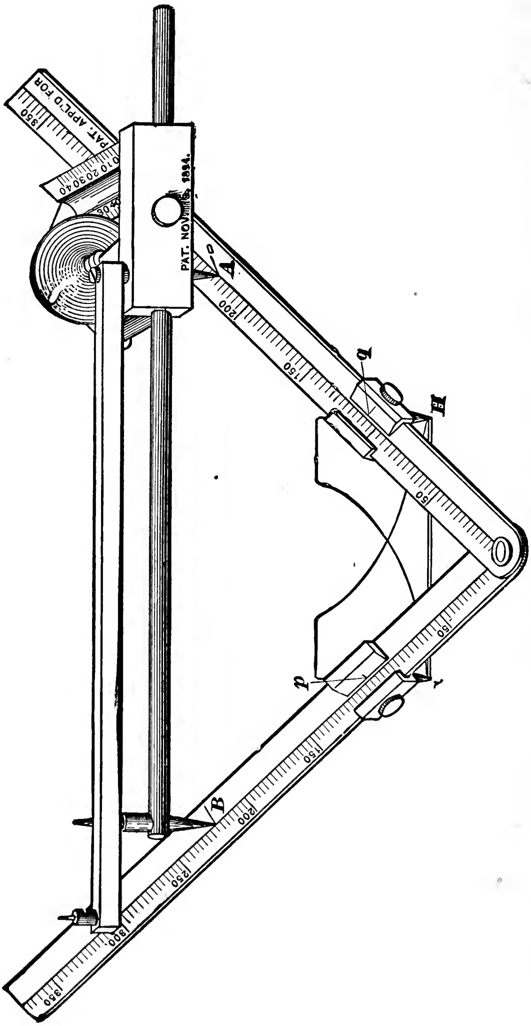


Fig. 114.

As these tables run by half-inch differences in diameters, and inch differences in strokes, they may be said to give

THE WILLIS PLANIMETER.

this value for any engine. To read horse power, the lines p and q, Fig. 113, are set to the division corresponding to the revolutions per minute of the engine, and the points G and H are set to card length, Fig. 114. The scale that corresponds to the spring with which the card is taken is turned next to the wheel, and points A and B are set to the division corresponding to the value $\frac{33{,}000}{\text{piston area} \times \text{stroke}}$ as given by the tables. The attachment is removed, and the card traced. The reading will be horse power.

If both diagrams are taken upon the same card, start the tracer point at the intersection of the two expansion curves, and tracing first one and then the other read the total horse power direct from the scale. Thus the instrument performs automatically all the operations called for by the usual formula for horse power, and does it without sacrificing accuracy, simplicity or portability.

The wheel is mounted upon a glass rod, and needs no lubrication. The scale is of box wood, finely graduated, and the rest of the instrument is of brass (nickle plated) and steel. It is supplied by its inventor, E. J. Willis, M. E., 211 East Franklin Street, Richmond, Va.

THE COFFIN AVERAGING PLANIMETER.

The Coffin Averaging Planimeter is illustrated in Fig. 115. The construction of it is plainly shown.

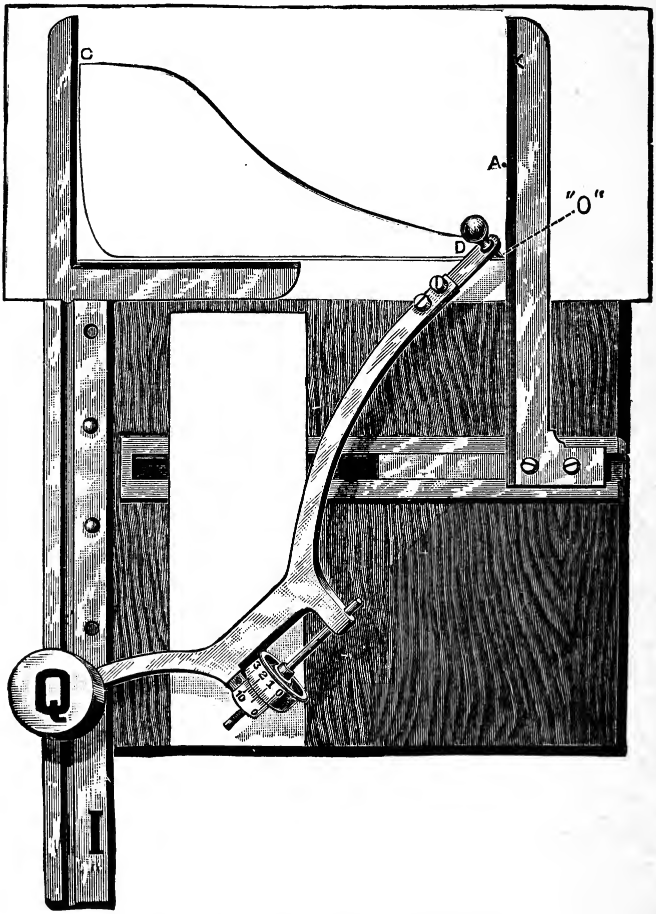


Fig. 115. COFFIN PLANIMETER

In using the Coffin averager, the grooved metal plate *I* is first connected to the board upon which the apparatus is mounted, in the position shown in the cut, being held in

THE COFFIN AVERAGING PLANIMETER.

place by a thumbscrew applied from the back side. The indicator card is then placed under the clamps *C* and *K*, which may be sprung away from the board a sufficient amount to allow the card to be introduced, and the card is moved toward the left into such a position that the atmospheric line is near to and parallel with the lower edge of the stationary clamp *C*, while the extreme left-hand end of the diagram is even with the perpendicular edge of the clamp. The movable clamp *K*, which is fastened at the bottom to a sliding plate, is then moved toward the left, till the vertical beveled edge just touches the extreme right-hand end of the diagram. The diagram shown in the cut represents the proper location which should exist when these preliminary adjustments have been completed. The slide at the bottom of clamp *K* fits closely, so that the application of a slight pressure with the thumb or finger is required to displace it.

The beam of the instrument is next placed on the board, with the pin at the lower end resting in the groove *I*, and the weight *Q* applied to the top of the pin so as to keep it securely in place. The tracer *O* is moved to the right-hand end of the diagram and set at the point *D*, on the line of the diagram, where the clamp *K* and the diagram touch each other. Here a slight indentation is made in the paper by pressing the finger on the top of the tracer, and this serves as a starting point. The graduated wheel is next turned so as to bring its zero mark to the zero mark on the vernier. The instrument is now ready for operation. The tracer *O* is carefully moved over the line of the diagram, in the direction of motion of the hands of a watch, and continued till a complete circuit is made and the tracer finally reaches the starting point *D*. Keeping the eye on the wheel, the tracer is now moved upward by sliding it along the edge of the clamp *K*, until the reading on the wheel returns to zero. Another light indentation is made in the paper to mark the new position which the tracer occupies. This point is represented at *A* in the cut. The instrument is now moved away, the clamp pushed back, and the distance between the two points, *D* and *A*, is measured by employing a scale corresponding to the number of the spring used in the indicator. The distance thus found is the mean effective pressure, expressed in pounds per square inch of piston.

The Coffin planimeter determines the desired result without computation, but it may be used also for determining the area enclosed by the diagram. This area is given by the reading on the graduated wheel, when the circuit of the diagram has been made and the tracer reaches the starting point *D*. The wheel has fifteen main divisions, each of which represents one square inch of area. Each division has five subdivisions, each subdivision representing one-fifth, or two-tenths, of a square inch of area. The vernier scale enables the subdivisions to be read to fiftieths, each of these fiftieths, therefore, representing two one-hundredths of a square inch. Having obtained the area in this manner, the mean effective pressure may be computed by dividing the number of the spring representing the pressure per inch in height by the length of the diagram (inches) and multiplying the quotient by the area (square inches). In first placing the indicator card under the clamps, care must be observed that the ends of the diagram set a little away from the edge of the clamp, so as to allow for one-half the diameter of the tracer, and to bring the centre of the tracer over the centre of the line of the diagram.

EXPLANATION OF TABLES.

Table I, in the respective columns, gives: 1, the temperature; 2, heat units; 3, latent heat; and 4, density of the steam, at certain pressures.

To use the table, find the given pressure in the first column, under " Absolute pressure per square inch, and read the corresponding property under the head needed.

For example: if the weight of a cubic foot of steam at 90 pounds pressure is to be found, find 90 in the first column, and follow the horizontal line, at the same height as 90, to the last column. The figure found here, .2098, is the weight of one cubic foot of steam at 90 pounds pressure, expressed in pounds.

Table II shows at a glance the mean effective pressure, if the point of cut-off and the absolute pressure is known.

In this table no account is taken of clearance and compression, but for ordinary figuring the results are sufficiently accurate.

The absolute pressures are shown in the first column, and the corresponding mean effective pressures at different points of cut-off are given in the other columns.

If, for instance, the mean effective pressure at an absolute pressure of 115 pounds (100 pounds gauge pressure) and $\frac{1}{5}$ stroke cut-off is to be found, proceed as follows:

Under the head, "Absolute pressure cut-off", find 115, and follow horizontally to the column under the head 5. These heads indicate the number of times the steam is

EXPLANATION OF TABLES.

expanded, at corresponding cut-off, i. e., the ratio of expansion.

At an absolute pressure of 115 pounds the M. E. P. will be found to be 60.03 pounds, if the engine cuts off at $\frac{1}{5}$ stroke.

From this result has to be subtracted the exhaust pressure, above an absolute vacuum.

Table III is used for the same purpose as Table II; the difference being that it gives "the constant", to be multiplied by the total steam pressure in the cylinder at the point of cut-off, to obtain the total mean pressure.

In Table II the total pressures from 50 to 195, at intervals of 5 pounds, are given, but Table III can be used to find the mean effective pressures at less than 50 pounds, or more than 195 pounds initial pressure, also at all other pressures.

Table IV. In this table the number of pounds of water the engine uses per horse power per hour is found, if the terminal and the mean effective pressure is known.

To use the table, locate the terminal pressure above absolute vacuum, as indicated by the diagram in the first column, and follow at the same height horizontally, to the column under the given mean effective pressure.

Example: Terminal pressure = 16 pounds absolute; M. E. P. = 35; the water consumption per I. H. P. will be 16.14 pounds per hour.

Table V gives the horse power at 100 ft. piston speed, and with one pound of mean effective pressure.

EXPLANATION OF TABLES.

To obtain the horse power: Multiply the constants opposite diameter of cylinder by the piston speed, and by the mean effective pressure, and divide by 100.

The result is the horse power.

Example: Diameter of cylinder = 52″. Piston speed = 650 ft. per minute. M. E. P. = 35 pounds. Constant of 52 = 6.43.

$$\frac{6.43 \times 650 \times 35}{100} = 1463 \text{ H. P.}$$

USEFUL DEFINITIONS.

A "Constant" may be defined as a "constant multiplyer," which is obtained by careful calculations and assumed to be surely correct.

A Heat Unit is that which is required to raise 1 lb. of water (at 39° Fahr.) 1 degree.

Mean Effective Pressure (M. E. P.) is the average force of the steam in the cylinder.

A Pound of Steam is the same as a pound of water and steam weighs according to the pressure at which it is held.

Absolute Pressure of Steam is the same as "total pressure above vacuum" to obtain "gauge pressure" 15 pounds per square inch must be subtracted, that being the weight of air at the sea level.

'ROPERTIES OF SATURATED STEAM.

TABLE I.

Absolute pressure per sq. in.	Temperat're in degrees.	Heat units, from zero, per lb.	Latent heat in degrees.	Density or weight of one cubic ft.
Lbs.	Fahr.	....	Fahr.	Lbs.
1	102.1	1145	1042.9	.0030
2	126.3	1152.5	1025.8	.0058
3	141.6	1157.1	1015	.0085
4	153.1	1160.6	1006.8	.0112
5	162.3	1163.4	1000.3	.0138
6	170.2	1165.8	994.7	.0163
7	176.9	1167.9	990	.0189
8	182.9	1169.7	985.7	.0214
9	188.3	1171.4	981.9	.0239
10	193.3	1172.9	978.4	.0264
11	197.8	1174.2	975.2	.0289
12	202	1175.5	972.2	.0314
13	205.9	1176.7	969.4	.0338
14	209.6	1177.9	966.8	.0362
14.7	212	1178.6	965.2	.0380
15	213.1	1178.9	964.3	.0387
16	216.3	1179.9	962.1	.0411
17	219.6	1180.9	959.8	.0435
18	222.4	1181.8	957.7	.0459
19	225.3	1182.6	955.7	.0483
20	228	1183.5	952.8	.0507
21	230.6	1184.2	951.3	.0531
22	233.1	1185	949.9	.0555
23	235.5	1185.7	948.5	.0580
24	237.8	1186.5	946.9	.0601
25	240.1	1187.1	945.3	.0625
26	242.3	1187.8	943.7	.0650
27	244.4	1188.5	942.2	.0673
28	246.4	1189	940.8	.0696
29	248.4	1189.7	939.4	.0719
30	250.4	1190.3	937.9	.0743
31	252.2	1190.8	936.7	.0766
32	254.1	1191.4	935.3	.0789
33	255.9	1191.9	934	.0812
34	257.6	1192.5	932.8	.0835
35	259.3	1193	931.6	.0858
36	260.9	1193.5	930.5	.0881
37	262.6	1194	929.3	.0905
38	264.2	1194.5	928.2	.0929
39	265.8	1195	927.1	.0952
40	267.3	1195.4	926	.0974
41	268.7	1195.9	924.9	.0996
42	270.2	1196.3	923.9	.1020
43	271.6	1196.7	922.9	.1042
44	273	1197.2	921.9	.1065
45	274.4	1197.6	920.9	.1089
46	275.8	1198	919.9	.1111

PROPERTIES OF SATURATED STEAM.

TABLE I.—Continued.

Absolute pressure per sq. in.	Temperat're in degrees.	Heat units from zero, per lb.	Latent heat. in degrees.	Density or weight of one cubic ft.
Lbs.	Fahr.	....	Fahr.	Lbs.
47	277.1	1198.4	919	.1133
48	278.4	1198.8	918.1	.1156
49	279.7	1199.2	917.2	.1179
50	281	1199.6	916.3	.1202
51	282.3	1200	915.4	.1224
52	283.5	1200.4	914.5	.1246
53	284.7	1200.7	913.6	.1269
54	285.9	1201.1	912.8	.1291
55	287.1	1201.4	912	.1314
56	288.2	1201.8	911.2	.1336
57	289.3	1202.1	910.4	.1364
58	290.4	1202.5	909.6	.1380
59	291.6	1202.8	908.8	.1403
60	292.7	1203.2	908	.1425
61	293.8	1203.5	907.2	.1447
62	294.8	1203.8	906.4	.1469
63	295.9	1204.1	905.6	.1493
64	296.9	1204.5	904.9	.1516
65	298	1204.8	904.2	.1538
66	299	1205.1	903.5	.1560
67	300	1205.4	902.8	.1583
68	300.9	1205.7	902.1	.1605
69	301.9	1206	901.4	.1627
70	302.9	1206.3	900.8	.1648
71	303.9	1206.6	900.3	.1670
72	304.8	1206.9	899.6	.1692
73	305.7	1207.1	898.9	.1714
74	306.6	1207.4	898.2	.1736
75	307.5	1207.7	897.5	.1759
76	308.4	1208	896.8	.1782
77	309.3	1208.2	896.1	.1804
78	310.2	1208.5	895.5	.1826
79	311.1	1208.8	894.9	.1848
80	312	1209	894.3	.1869
81	312.8	1209 3	893.7	.1891
82	313.6	1209.6	893.1	.1913
83	314.5	1209.8	892.5	.1935
84	315.3	1210	892	.1957
85	316.1	1210.3	891.4	.1980
86	316.9	1210.6	890.8	.2002
87	317.8	1210.8	890.2	.2024
88	318.6	1211	889.6	.2044
89	319.4	1211.3	889	.2067
90	320.2	1211.6	888.5	.2089
91	321	1211.8	887.9	.2111
92	321.7	1212	887.3	.2133
93	322.5	1212.3	886.8	.2155

PROPERTIES OF SATURATED STEAM.

TABLE I.—Continued.

Absolute pressure per sq. in.	Temperat're in degrees.	Heat units, from zero, per lb.	Latent heat in degrees.	Density or weight of one cubic ft.
Lbs.	Fahr.	....	Fahr.	Lbs.
94	323.3	1212.5	886.3	.2176
95	324.1	1212.7	885.8	.2198
96	324.8	1213	885.2	.2219
97	325.6	1213.2	884.6	.2241
98	326.3	1213.4	884.1	.2263
99	327.1	1213.6	883.6	.2285
100	327.9	1213.8	883.1	.2307
101	328.5	1214	882.6	.2329
102	329.1	1214.3	882.1	.2351
103	329.9	1214.5	881.6	.2373
104	330.6	1214.7	881.1	.2393
105	331.3	1214.9	880.7	.2414
106	331.9	1215.1	880.2	.2435
107	332.6	1215.3	879.7	.2456
108	333.3	1215.6	879.2	.2477
109	334	1215.8	878.7	.2499
110	334.6	1216	878.3	.2521
111	335.3	1216.2	877.8	.2543
112	336	1216.4	877.3	.2564
113	336.7	1216.6	876.8	.2586
114	337.4	1216.8	876.3	.2607
115	338	1217	875.9	.2628
116	338.6	1217.2	875.5	.2649
117	339.3	1217.4	875	.2652
118	339.9	1217.6	874.5	.2674
119	340.5	1217.8	874.1	.2696
120	341.1	1217.9	873.7	.2738
121	341.8	1218.1	873.2	.2759
122	342.4	1218.3	872.8	.2780
123	343	1218.5	872.3	.2801
124	343.6	1218.7	871.9	.2822
125	344.2	1218.9	871.5	.2845
126	344.8	1219.1	871.1	.2867
127	345.4	1219.3	870.7	.2889
128	346	1219.4	870.2	.2911
129	346.6	1219.6	869.8	.2933
130	347.2	1219.8	869.4	.2955
131	347.8	1220	869	.2977
132	348.3	1220.2	868.6	.2999
133	348.9	1220.4	868.2	.3020
134	349.5	1220.5	867.8	.3040
135	350.1	1220.7	867.4	.3060
136	350.6	1220.9	867	.3080
137	351.2	1221	866.6	.3101
138	351.8	1221.2	866.2	.3121
139	352.4	1221.4	865.8	.3142
140	352.9	1221.5	865.4	.3162

PROPERTIES OF SATURATED STEAM.

TABLE I.—Continued.

Absolute pressure per sq. in.	Temperat're in degrees.	Heat units from zero, per lb.	Latent heat. in degrees:	Density or weight of one cubic ft.
Lbs.	Fahr.	....	Fahr.	Lbs.
141	353.5	1221.7	865	.3184
142	354	1221.9	864.6	.3206
143	354.5	1222	864.2	.3228
144	355	1222.2	863.9	.3250
145	355.6	1222.4	863.5	.3273
146	356.1	1222.5	863.1	.3294
147	356.7	1222.7	862.7	.3315
148	357.2	1222.9	862.3	.3336
149	357.8	1223	861.9	.3357
150	358.3	1223.2	861.5	.3377
155	361	1224	859.7	.3484
160	363.4	1224.8	857.9	.3590
165	366	1225.5	856.2	.3695
170	368.2	1226.2	854.5	.3798
175	370.8	1226.9	852.9	.3809
180	372.9	1227.7	851.3	.4009
185	375.3	1228.3	849.6	.4117
190	377.5	1229	848	.4222
195	379.7	1229.7	846.5	.4327
200	381.1	1230.3	845	.4431

TABLE II.

Absolute Pressure at Cut-off.	NUMBER OF TIMES THE STEAM IS EXPANDED.																	
	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
50	29.85	26.10	23.20	21.00	19.20	17.75	16.50	15.40	14.50	13.70	12.95	12.35	11.75	11.10	10.80	10.35	10.00	9.650
55	32.83	28.71	25.52	23.10	21.12	19.52	18.15	16.94	15.95	15.07	14.24	13.58	12.92	12.21	11.88	11.38	11.00	10.61
60	35.82	31.32	27.84	25.20	23.04	21.30	19.80	18.48	17.40	16.44	15.54	14.82	14.10	13.32	12.96	12.42	12.00	11.58
65	38.80	33.93	30.16	27.30	24.96	23.07	21.45	20.02	18.85	17.81	16.83	16.05	15.27	14.43	14.04	13.45	13.00	12.54
70	41.79	36.54	32.48	29.40	26.88	24.84	23.10	21.56	20.30	19.18	18.13	17.29	16.45	15.54	15.12	14.49	14.00	13.51
75	44.27	39.15	34.80	31.90	28.80	26.62	24.75	23.10	21.75	20.55	19.42	18.52	17.62	16.65	16.20	15.52	15.00	14.47
80	47.76	41.76	37.12	32.60	30.72	28.40	26.70	24.64	23.20	21.92	20.72	19.76	18.80	17.76	17.28	16.56	16.00	15.44
85	50.74	44.37	39.44	35.70	32.64	30.17	28.05	26.18	24.65	23.29	22.01	20.89	19.97	18.87	18.36	17.59	17.00	16.40
90	53.73	46.86	41.76	37.80	34.56	31.95	29.70	27.72	26.10	24.66	23.31	22.23	21.15	19.98	19.44	18.63	18.00	17.37
95	56.71	49.59	44.08	39.90	36.48	33.72	31.35	29.26	27.55	26.03	24.60	23.46	22.32	21.09	20.52	19.66	19.00	18.33
100	59.70	52.26	46.40	42.00	38.40	35.50	33.01	30.80	29.00	27.40	25.90	24.70	23.50	22.20	21.60	20.70	20.00	19.30
105	62.68	54.81	48.72	44.10	40.32	37.27	34.65	32.34	30.45	28.77	27.19	25.93	24 67	23.31	22.68	21.73	21.00	20.26
110	65.67	57.42	51.04	46.20	42.24	39.05	36.30	33.88	31.90	30.14	28.49	27.17	25.85	24.42	23.76	22.77	22.00	21.23
115	68.65	60.03	53.36	48.30	44.16	40.82	37.95	35.42	33.35	31.51	29.78	28.40	27.02	25.53	24.84	23.80	23.00	22.19
120	71.64	62.64	55.68	50.40	46.08	42.60	39.60	36.96	34.80	32.88	31.08	29.64	28.20	26.64	25.92	24.84	24.00	23.16
125	74.62	65.25	58.09	52.50	48.00	44.37	41.25	38.50	36.25	34.25	32.37	30.87	29.37	27.75	27.00	25.87	25.00	24.12
130	77.61	67.86	60.32	54.60	49.92	46.15	42.90	40.04	37.70	35 62	33.67	32.11	30.55	28.86	28.08	26.91	26.00	25.09
135	80.59	71.47	62.64	56.70	51.84	47.92	44.55	41.58	39.15	36.99	34.96	33.34	31.72	29.97	29.16	27.94	27.00	26.05
140	83.58	73.08	64.96	58.80	53.76	49.70	46.20	43.12	40.60	38.36	36.26	34.58	32.90	31.08	30.24	28.98	28.00	27.02
145	86.56	75.69	67.28	60.90	55.68	51.47	47.85	44.66	42.05	39.73	37.55	35.81	34.07	32.19	31.32	30.01	29.00	27.98
150	89.55	78.30	69.60	63.00	57.60	53.25	49.50	46.20	43.50	41.10	38.85	37.05	35.25	33.30	32.40	31.05	30.00	28.95
155	92.52	80.91	71.92	65.10	59.52	55.02	51.15	47.74	44.95	42.47	40.14	38.28	36.42	34.41	33.48	32.08	31.00	29.91
160	95.52	83.52	74.24	67.20	61.44	56.80	52.80	49.28	46.40	43.84	41.44	39.52	37.60	35.52	34.56	33.12	32.00	30.88
165	98.50	86.13	76.56	69.30	63.36	58.57	54.45	50.82	47.85	45.21	42.73	40.75	38.77	36.63	35.64	34.15	33.00	31.84
170	101.5	88.74	78.88	71.40	65.28	60.35	56.10	52.36	49.30	46.58	44.03	41.99	39.95	37.74	36.72	35.19	34.00	32.81
175	104.5	91.35	81.20	73.50	67.20	62.12	57.75	53.90	50.57	47.95	45.32	43.22	41.12	38.85	37.80	36.22	35.00	33.77
180	107.5	93.96	83.52	75.60	69.12	63.90	59.40	55.44	52.20	49.36	46.62	44.46	42.30	39.94	38.88	37.26	36.00	34.74
185	110.4	96.57	85.84	77.70	71.04	65.67	61.05	56.98	53.65	50.69	47.91	45.69	43.47	41.07	39.96	38.29	37.00	35.70
190	113.4	99.18	88.16	79.80	72.96	67.45	62.70	58.52	55.10	52.06	49.21	46.93	44.65	42.18	41.04	39.33	38.00	36.67
195	116.4	101.79	90.48	79.90	74.88	69.22	64.35	60.06	56.55	53.43	50.50	48.16	45.82	43.29	42.12	40.36	39.00	37.63

TABLE III.

Portion of the stroke during which steam is admitted.	Number of times the steam s expanded, assuming there to be no clearance.	Mean pressures in terms of initial absolute
$\frac{7}{8}$	$1\frac{1}{7}$	992
$\frac{3}{4}$	$1\frac{1}{3}$	966
$\frac{2}{3}$	$1\frac{1}{2}$	.937
$\frac{5}{8}$	$1\frac{3}{5}$	.919
$\frac{1}{2}$	2	.846
$\frac{3}{8}$	$2\frac{2}{3}$	.743
$\frac{1}{3}$	3	.670
$\frac{1}{4}$	4	.597
$\frac{1}{5}$	5	.522
$\frac{1}{6}$	6	464
$\frac{1}{7}$	7	.420
$\frac{1}{8}$	8	.384
$\frac{1}{9}$	9	.355
$\frac{1}{10}$	10	.330
$\frac{1}{11}$	11	.308
$\frac{1}{12}$	12	.290
$\frac{1}{13}$	13	.274
$\frac{1}{14}$	14	.259
$\frac{1}{15}$	15	.247
$\frac{1}{16}$	16	.235
$\frac{1}{17}$	17	.222
$\frac{1}{18}$	18	.216
$\frac{1}{19}$	19	.207
$\frac{1}{20}$	20	.1998
$\frac{1}{21}$	21	.193
$\frac{1}{22}$	22	.186
$\frac{1}{23}$	23	.180
$\frac{1}{24}$	24	.174
$\frac{1}{25}$	25	.169
$\frac{1}{26}$	26	.164
$\frac{1}{27}$	27	.159
$\frac{1}{28}$	28	155
$\frac{1}{29}$	29	.151
$\frac{1}{30}$	30	.147

TABLE IV.

Terminal Pressures Absolute.	MEAN EFFECTIVE PRESSURES.																			
	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	8.25	6.87	5.894	5.158	4.584	4.12	3.745	3.435	3.173	2.947	2.750	2.516	2.427	2.292	2.168					
2	15.97	13.32	11.41	9.99	8.88	7.98	7.254	6.66	6.138	5.705	5.320	4.99	4.690	4.440	4.200	3.99				
3	23.36	19.46	16.69	14.60	12.97	11.68	10.61	9.73	8.984	8.345	7.786	7.30	6.870	6.485	6.147	5.84	5.562			
4	30.80	25.66	22.00	19.25	17.11	15.40	14.00	12.83	11.70	11.00	10.26	9.62	9.058	8.555	8.105	7.70	7.333	7.000	6.700	
5	37.90	31.61	27.10	23.62	21.07	18.97	17.24	15.80	14.60	13.60	12.64	11.81	11.16	10.53	9.984	9.48	9.033	8.620	8.240	7.900
6	44.82	37.35	32.01	28.00	24.90	22.41	20.37	18.67	17.23	16.00	14.94	14.00	13.18	12.45	11.80	11.20	10.67	10.18	9.743	9.330
7	51.98	43.30	37.11	32.47	28.86	25.98	23.61	21.65	18.98	18.55	17.32	16.23	15.28	14.40	13.67	12.99	12.37	11.80	11.29	10.82
8	58.80	49.03	42.03	36.77	32.68	29.42	26.74	24.52	22.62	21.01	19.61	18.37	17.30	16.34	15.48	14.71	14.00	13.37	12.79	12.25
9	..	54.76	46.94	41.07	36.51	32.86	29.87	27.38	25.27	23.47	21.90	20.53	19.33	18.25	17.30	16.43	15.65	14.93	14.28	13.65
10	..	..	51.86	45.37	40.33	36.30	33.00	30.25	27.92	25.93	24.20	22.68	21.35	20.16	19.10	18.15	17.28	16.50	15.78	15.12
11	..	..	56.75	49.66	44.14	39.73	36.11	33.10	30.56	28.37	26.48	24.81	23.37	22.05	20.91	19.86	18.90	18.04	17.27	16.54
12	..	..	..	53.95	47.90	43.16	39.23	35.91	33.20	30.82	28.77	26.97	25 38	23.95	22.71	21.58	20.55	19 61	18.76	18.00
13	..	..	..	..	51.55	46.48	42.25	38.30	35.70	33.10	30.98	29.05	27.34	25.77	24.42	23.24	22.13	21.12	20.21	19.15
14	..	..	..	..	55.06	49.57	45.03	41.30	38.13	35.40	33.04	30.98	29.16	27.53	26.09	24.78	23.60	22.51	21.55	20.65
15	..	..	..	..	..	53.21	47.46	44.34	40.92	38.00	35.47	33.25	31.30	29.50	28.00	26.60	25.34	23.73	23.14	22.17
16	..	..	..	..	..	56.51	51.34	47.09	43.47	40.35	37.67	35.31	33.24	31.40	29.73	28.25	26.91	25.67	24.56	23.54
17	..	..	..	..	..	..	54.33	49.84	46.00	42.72	39.87	36.63	35.18	33.22	31.47	29.90	28.48	27.16	26.00	24.92
18	..	..	..	..	..	..	..	52.60	48.54	45.00	42.07	39.47	37.12	35.06	33.21	81.55	30.05	28.68	27.44	26.30
19	..	..	..	..	..	..	..	55.34	51.08	47.43	44.27	41.50	39.06	36.89	34.98	33.20	31.62	30.18	28.87	27.66
20	..	..	..	..	..	..	..	..	53.51	49.69	46.38	43.48	40.90	38.65	36.60	34.78	33.13	31.62	30.24	28.95
21	..	..	..	..	..	..	..	..	..	52.18	48.68	45.60	43.00	40.56	38.43	36.51	34.77	33.19	31.75	30.42
22	..	..	..	..	..	..	..	..	..	54.50	50.87	47.68	44.89	42.38	40.16	38.15	36.33	34.68	33.18	31.80
23	..	..	..	..	..	..	..	..	..	..	53.16	49.81	46.91	44.30	41.97	39.87	37.98	36.25	34.67	33.23
24	..	..	..	..	..	..	..	..	..	..	..	51.63	48.60	45.98	43.50	41.31	38.87	37.55	35.93	34.43
25	..	..	..	..	..	..	..	..	..	..	..	53.70	50.54	47.73	45.22	42.96	40.92	39.06	37.10	35.80
26	..	..	..	..	..	..	..	..	..	..	..	..	52.57	49.65	47.03	44.67	42.55	40.62	38.85	37.23
27	..	..	..	..	..	..	..	..	..	..	..	..	..	51.40	48.70	46.26	44.06	42.06	40.22	38.55
28	..	..	..	..	..	..	..	..	..	..	..	..	..	53.16	50.36	48.85	45.57	43.50	41.61	39.87
29	..	..	..	..	..	..	..	..	..	..	..	..	..	..	51.95	49.85	47.01	45.32	42.92	41.13
30	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	51.05	48.62	46.41	44.40	42.50

TABLE IV.—Continued.

Terminal Pressures Absolute.	MEAN EFFECTIVE PRESSURES.																			
	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44
5	7.588																			
6	8.964	8.561	8.300	8.000																
7	10.39	9.990	9.622	9.270	8.788	8.660	8.380													
8	11.76	11.31	10.89	10.50	10.14	9.800	9.490	9.185	8.915	8.643										
9	13.14	12.63	12.17	11.73	11.33	10.98	10.60	10.26	9.958	9.665	9.388	9.120	8.881							
10	14.52	13.96	13.44	12.96	12.51	12.10	11.67	11.34	11.00	10.82	10.33	10.08	9.78	9.550	9.128	9.070				
11	15.89	15.28	14.71	14.17	13.70	13.24	12.81	12.40	12.04	11.67	11.28	11.02	10.69	10.45	10.19	9.930	9.691	9.450	9.025	
12	17.26	16.60	15.98	15.41	14.88	14.38	13.92	13.48	13.06	12.69	12.23	11.97	11.60	11.35	11.04	10.74	10.55	10.27	9.920	9.580
13	18.59	17.70	17.21	16.55	16.00	15.49	14.99	14.52	14.09	13.67	13.18	12.88	12.51	12.21	11.87	11.62	11.34	11.06	10.81	10.56
14	19.82	14.06	18.35	17.70	17.06	16.52	16.00	15.55	15.18	14.58	14.13	13.76	13.42	13.04	12.71	12.39	12.09	11.80	11.53	11.26
15	21.28	20.46	19.70	19.00	18.35	17.73	17.16	16.62	16.28	15.60	15.08	14.75	14.31	14.00	13.64	13.30	12.98	12.67	12.27	11.88
16	22.60	21.73	20.92	20.17	19.48	18.83	18.23	17.65	17.12	16.62	16.14	15.70	15.22	14.86	14.49	14.12	13.78	13.45	13.16	12.88
17	23.92	23.00	22.15	21.36	20.62	19.93	19.30	18.68	18.14	17.59	16.98	16.61	16.13	15.73	15.84	14.95	14.58	14.24	13.91	13.58
18	25.24	24.27	23.37	22.50	21.76	21.03	20.36	19.73	19.13	18.56	17.93	17.53	17.04	16.60	16.18	15.77	15.39	15.02	14.68	14.34
19	26.56	25.54	24.60	23.71	22.90	22.14	21.42	20.75	20.12	19.53	18.88	18.45	17.92	17.49	17.14	16.60	16.23	15.86	15.47	15.09
20	27.82	26.75	25.76	24.84	23.98	23.19	22.44	21.76	21.10	20.45	19.87	19.32	18.80	18.30	17.84	17.39	17.47	16.56	16.18	15.81
21	29.20	28.07	27.04	26.09	25.17	24.34	23.55	22.80	22.08	21.50	20.81	20.28	19.65	19.21	18.73	18.25	17.81	17.38	16.98	16.59
22	..	29.36	28.26	27.25	26.31	25.43	24.61	23.84	23.07	22.44	21.75	21.19	20.53	20.08	19.57	19.07	18.61	18.16	17.75	17.34
23	..	..	29.43	28.46	27.50	26.58	25.72	24.85	24.06	23.45	22.69	22.15	21.40	20.98	20.45	19.93	19.46	18.99	18.55	18.12
24	..	..	..	29.50	28.48	27.53	26.66	25.85	25.04	24.30	23.63	22.99	22.28	21.75	21.15	20.65	20.04	19.43	19.10	18.77
25	..	..	..	..	29.62	28.64	27.72	26.85	26.03	25.26	24.57	23.86	23.14	22.61	22.02	21.43	20.94	20.46	19.99	19.53
26	..	..	..	..	..	29.78	28.80	27.90	27.02	26.27	25.51	24.82	24.00	23.51	22.94	22.38	21.82	21.27	20.79	20.31
27	..	..	..	..	..	..	29.84	28.90	28.01	27.21	26.45	25.70	24.86	24.35	23.74	23.13	22.58	22.03	21.58	21.03
28	..	..	..	..	..	..	..	29.90	29.00	28.03	27.39	26.53	25.79	25.18	24.80	24.42	23.60	22.78	22.24	21.70
29	..	..	..	..	..	..	..	..	29.95	29.00	28.30	27.42	26.67	25.97	25.49	24.97	24.23	23.50	23.08	22.66
30	..	..	..	..	..	..	..	..	..	30.00	29.20	28.37	27.55	26.90	26.21	25.52	24.91	24.31	23.75	23.20
31	..	..	..	..	..	..	..	..	..	..	30.07	29.25	28.42	27.73	27.01	26.30	25.63	25.07	24.50	23.93
32	..	..	..	..	..	..	..	..	..	..	..	30.13	29.32	28.55	27.83	27.12	26.46	25.81	25.23	24.65
33	..	..	..	..	..	..	..	..	..	..	..	..	30.20	29.38	28.64	27.91	27.12	26.33	25.84	25.36
34	..	..	..	..	..	..	..	..	..	..	..	..	..	30.27	29.42	28.73	28.04	27.35	26.84	26.33

Engine Constants at 100 feet Piston Speed, and One Pound Mean Effective Pressure.

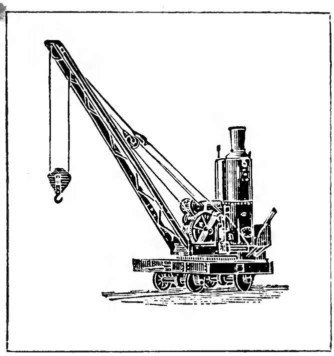
TABLE V.

Diameter of Cylinder.	Constant.	Diameter of Cylinder.	Constant.
4	.03787	26½	1.669
4½	.04818	27	1.734
5	.0594	27½	1.795
5½	.0718	28	1.865
6	.0856	28½	1.933
6½	.1004	29	2.002
7	.1166	29½	2.070
7½	.1338	30	2.141
8	.1523	30½	2.214
8½	.1718	31	2.287
9	.1927	31½	2.330
9½	.2148	32	2.437
10	.2380	32½	2.513
10½	.2623	33	2.592
11	.2878	33½	2.670
11½	.3145	34	2.751
12	.3421	34½	2.832
12½	.3718	35	2.915
13	.402	35½	2.999
13½	.433	36	3.084
14	.466	36½	3.170
14½	.500	37	3.258
15	.535	37½	3.346
15½	.571	38	3.433
16	.609	38½	3.527
16½	.648	39	3.619
17	.687	39½	3.713
17½	.728	40	3.807
18	.770	41	4.000
18½	.814	42	4.197
19	.859	43	4.400
19½	.905	44	4.606
20	.951	45	4.818
20½	1.001	46	5.033
21	1.049	47	5.254
21½	1.100	48	5.481
22	1.151	49	5.714
22½	1.204	50	5.950
23	1.258	51	6.190
23½	1.314	52	6.435
24	1.372	53	6.687
24½	1.424	54	6.938
25	1.487	55	7.199
25½	1.547	56	7.433
26	1.608	57	7.730

Engine Constants at 100 feet Piston Speed, and One Pound of Mean Effective Pressure.

TABLE V.—Continued.

Diameter of Cylinder	Constant.	Diameter of Cylinder.	Constant.
58	8.006	103	25.249
59	8.284	104	25.751
60	8.567	105	26.239
61	8.855	106	26.748
62	9 148	107	27.248
63	9.446	108	27.757
64	9.748	109	28.276
65	10.055	110	28.798
66	10.367	111	29.323
67	10.683	112	29.854
68	11.005	113	30.390
69	11.330	114	30.930
70	11.661	115	31.475
71	11.997	116	32.024
72	12.368	117	32.579
73	12 683	118	33 139
74	13.032	119	33 703
75	13.387	120	34 272
76	13 746	121	34.542
77	14.110	122	35.423
78	14.479	123	36.007
79	14.848	124	36.595
80	15.232	125	37.182
81	15.606	126	37.784
82	16.003	127	38.387
83	16.396	128	38 993
84	16.793	129	39.605
85	17.195	130	40.222
86	17.602	131	40.825
87	18.014	132	41.469
88	18.430	133	42 098
89	18.851	134	42.735
90	19.278	135	43.678
91	19.708	136	44 023
92	20.141	137	44.669
93	20.584	138	45.324
94	21.029	139	45.984
95	21.479	140	46.678
96	21.933	141	47.317
97	22.393	142	47.990
98	22.857	143	48.666
99	23.326	144	49.353
100	23.800	145	50.003
101	24.278	146	50.701
102	24.761	147	51.429



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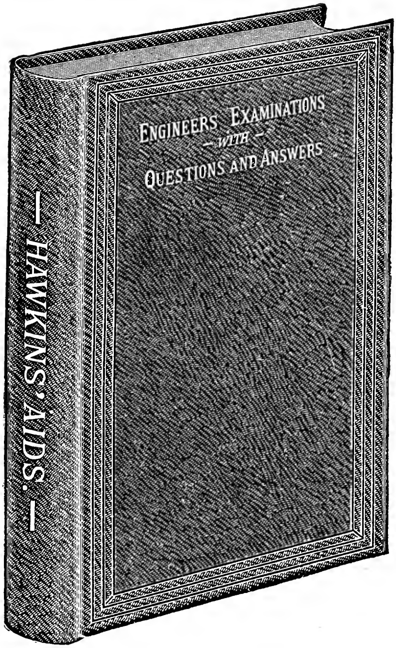

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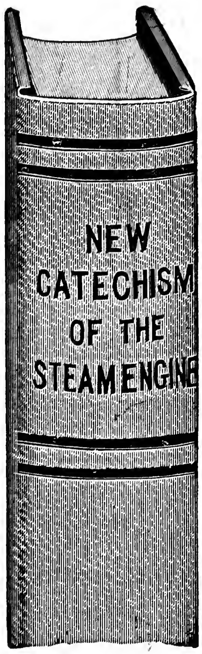

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