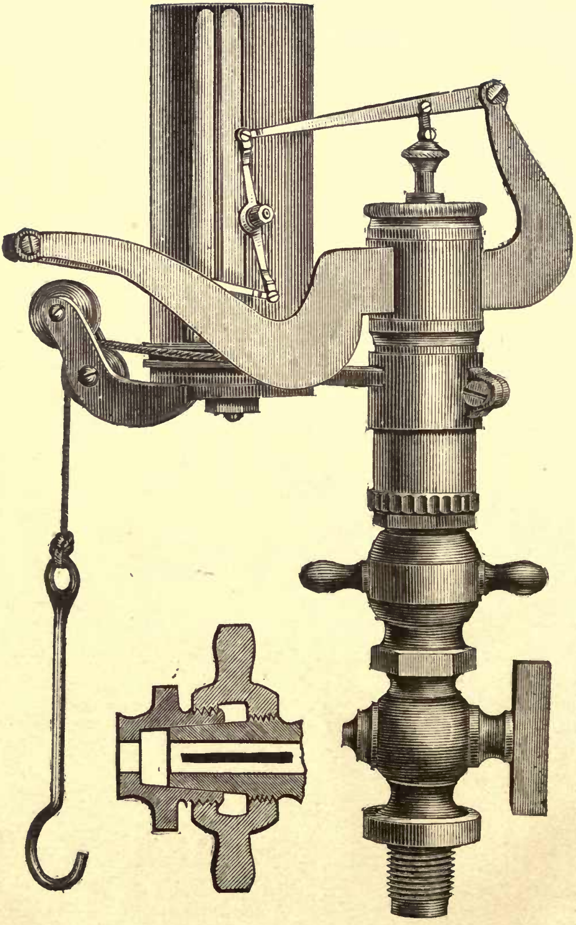
RICHARDS'
STEAM-ENGINE INDICATOR.

BACON.



A TREATISE

ON THE

RICHARDS STEAM-ENGINE INDICATOR,

WITH

DIRECTIONS FOR ITS USE.

BY CHARLES T. PORTER.

REVISED,

WITH NOTES AND LARGE ADDITIONS AS DEVELOPED BY AMERICAN PRACTICE; WITH A SUPPLEMENT, DESCRIBING THE LATEST IMPROVEMENTS IN THE INSTRUMENTS FOR TAKING, MEASURING, AND COMPUTING DIAGRAMS.

ALSO, AN APPENDIX,

CONTAINING USEFUL FORMULAS AND RULES FOR ENGINEERS.

BY F. W. BACON, M. E.,
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FOURTH EDITION.

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PREFACE.

In introducing the Richards Improved Steam-Engine Indicator, we desire to call the attention of the numerous class who, as constructors, managers or owners, are interested in the steam-engine, to the advantages which it possesses. In the following pages all necessary information is furnished concerning the instrument and its application, and such instruction is given to those who are not already skilled in the use of the Indicator, as will enable them to employ it to the best advantage.

The Indicator was invented by Watt. For some time it was kept by him a secret, but became known before his death, and to its use, now quite general, we are more indebted than to anything else, for the degree of excellence which the steam-engine has attained. The employment of more rapid velocities of piston, with higher pressures of steam, and higher grades of expansion, which has become so extensive and promises ultimately to be universal, has increased greatly the importance of the Indicator; since this is the only means as yet known, by which the engineer can render himself familiar with the action of steam under these new conditions. Unfortunately, every form of this instrument has hitherto failed in its application to engines of this class. The long and tremulous spring used in them was put in a state of violent oscillation by the momentum of the piston and attached parts, and the result was a serrated figure, from which but little information could be extracted; so that, after a time, attempts to employ the Indicator in this important and rapidly enlarging field were quite abandoned.

Under these circumstances, the appearance at the Great Exhibition of 1862 of the improved form of this instrument, invented by Mr. Charles B. Richards, an engineer of Hartford, Connecticut, U. S., may not improperly be regarded as an event of some importance. The action of this Indicator was found to be quite perfect, under the severest tests to which it could there be subjected, and recently it has been still more thoroughly tried, on an express engine on the London and South-Western Railway, and its performance has more than realized the expectations formed of it. Two instruments, among the first manufactured by us, were employed, with which nearly two hundred diagrams were taken, on a trip to Southampton and back, at pressures varying from 80 lbs. to 130 lbs., at rates of motion varying from the slowest up to 260 revolutions per minute, giving a speed of 55 miles per hour, and at all points of cut-off; and they were found uniformly to work with the same steadiness at the highest velocity as at the lowest, and at the earliest point of cut-off as at the latest. Copies of a few of the diagrams are here given.

We do not claim for these Indicators superiority on engines running at high velocities only, though certainly it is there most apparent where others will not answer at all ; but we believe also, for reasons herein explained, that they will be found in practice to be the only *correct* Indicators for engines running at any speed, even the lowest.

We have only to add, that no pains have been spared to attain, in the manufacture of these instruments, the highest degree of accuracy and excellence, and that if the directions here given are attended to, their indications may be implicitly relied on.

ELLIOTT BROTHERS.

PREFACE.

The demand for an elementary treatise on the Richards Steam-Engine Indicator, together with the solicitation of professional friends, has induced me to undertake the preparation of the work.

The original and very excellent work of Mr. Porter, now out of print, being principally an illustration of English engines and English practice, leaves room for a work combining American engines and American practice.

I have therefore used much of Mr. Porter's, and added new matter and new diagrams—the result of a large experience, extending over six years.

The new diagrams introduced were, with one or two exceptions, taken by myself.

The diagrams taken November 14th, 1867, from the locomotive No. 50, built by the "Taunton Locomotive Works," are believed to be the first ever taken in this country from a locomotive when making a regular trip with an express train.

It will be of interest to the American engineer to compare them with those from an English locomotive, as shown in the work.

In order to make the work more useful to the practical engineer, an Appendix has been added, containing various formulas, which, during an experience of more than thirty years as a practical engineer, have been collected, but never before given to the public. The new rule to measure and compute diagrams (page 42), will be found a very expeditious and correct mode. The liabilities to error being reduced as *ten* to *one*. It was brought to my notice by Mr. Chas. E. Emery, engineer, New York City. It is now for the first time published, so far as I know.

The prime object has been to give nothing that is not known by practical experience to be correct, also to give it in a way that will be understood by any one capable of filling the place of an engineer.

F. W. BACON.

BOSTON, *October, 1873.*

PREFACE TO THIRD EDITION.

A THIRD edition of this work is called for, showing that the Indicator is now being appreciated. Engineers are becoming educated in its use ; it reveals to them many things which they *thought* they knew, but find they *didn't ;* it has got the attention of engine constructors ; it has inspired the genius of the inventor and designer ; the speed of the engine is increased, the immense ponderous mass of matter formerly set in motion is largely reduced, space is economized, compounding is shown to be a success and a necessity, coal and water bills are being reduced to a minimum.

All these desirable things, it is safe to say, the teachings of the Indicator has not only rendered *possible*, but has accomplished *de facto.*

Still there is a wide margin yet to fill before its office is accomplished.

Increasing the speed of the engine rendered an improvement necessary in the Indicator, which our

Supplement shows to have been admirably accomplished by Mr. Thompson.

The measurement and computation of diagrams heretofore was a long, tedious, and unsatisfactory work; now the Planimeter has been produced, at a price that can be reached by all, it has reduced the time and labor to a few minutes, with the greatest accuracy.

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RICHARDS'

IMPROVED

STEAM-ENGINE INDICATOR.

THE NATURE AND USE OF THE INDICATOR.

THE Steam-Engine Indicator is an instrument designed to show the pressure of steam in the cylinder, at each point of the piston's stroke. It does this in the following manner: A pencil, moving up and down with the varying pressure of the steam, draws a line on paper, which has a motion backward and forward, coincident with that of the piston. The paper is placed on a drum, which, while the piston is advancing, is caused to make about three-quarters of a revolution, by means of a cord connected with a suitable part of the engine, and while the piston is receding, is brought back to its first position by the reaction of a spring. The pencil is attached to a small piston, moving without friction in a cylinder, and the motion of which is resisted by a spring of known elastic force.

The pressure of the atmosphere is always on the upper side of this piston, and when the communication with the cylinder of the engine is closed, it is on the under side also; and if then the motionless pencil be applied to the moving paper, it will draw a line which is called the atmospheric line. When the communication is opened between the under side of this piston and one end of the cylinder of the engine, the piston will be forced upward by the pressure of the steam, or downward by that of the atmosphere, as the one or the other preponderates; and if now the pencil be applied to the moving paper, it will describe, during one revolution of the engine, a figure, each point in the outline of which will show, by its distance above or below the atmospheric line, the pressure in that end of the cylinder, when the piston was at the corresponding point of its forward or return stroke. The spring which resists the motion of the Indicator piston is so proportioned in strength that a change of pressure of one pound on the square inch shall cause the pencil to move up or down a certain fractional part of an inch.

The diagram thus described shows on inspection the following particulars, viz., what proportion of the boiler-pressure is obtained in the cylinder; how early in the stroke the highest pressure is reached; how well it is maintained; at what point, and at what pressure, the steam is cut off; whether it is cut off sharply, or in what degree it is wire-drawn; at what point, and at what pressure it is released; in a non-condensing engine, whether it is freely discharged, or what proportion of it remains to exert a counter-pressure; in a condensing engine, the amount of the vacuum, and how quickly, or how gradually it is obtained; and in both classes of engines, whether, before the commencement of the stroke, there is any compression of the vapor remaining in the cylinder, and if so, at what point it commences, and to how high a pressure it rises. From the diagram, the mean pressure exerted during the stroke, to produce and to resist the motion of the piston, may be ascertained, and thus the engineer may come to know accurately the amount of power required to overcome the whole aggregate resistance on the engine, and also, by taking separate diagrams for each, the power required by each of the several resistances or classes of resistance separately.* He may en-

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* This we find of great use when called to determine (as we often are) the power used by tenants. The landlord lets power to his tenants; it is fixed at a given price per horse-power. The question arises, how much the tenant *does use.* This is accurately determined. The practice is this: We take several diagrams, one from each end of the cylinder, when the engine is doing all the work, noting the number of revolutions being made when each pair is taken. Should there

deavor also to ascertain the *causes* of the various features presented in the diagram, and thus to learn the effect produced by this or that form or arrangement of parts, and to detect any imperfection in their construction or action.

It must be borne in mind, that the Indicator shows only the pressure at each point of the stroke; to represent this faithfully is its sole office. It tells nothing about the causes which have determined the form of the figure which it describes. The engineer concludes what these are, as the result of a process of reasoning, and this is the point where errors are liable to be committed.

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be a difference of speed of the engine during the time of taking these diagrams it is noted on each pair, and arranged when worked up.

These diagrams and the result we mark "*all on;*" then we stop tenant No. 1, throw off the belt that carries his work, take say three pairs of diagrams, and work them up. Now, as much as these are less than the average of those taken with "*all on,*" so much we charge tenant No. 1. We then put his belt on and proceed with tenant No. 2, and charge him in the same manner. Thus we proceed with all. In making up our accounts for each, and adding them, we find the aggregate will fall short of the gross of "*all on.*" This is as it should be, from the well-known fact that the friction of the engine and intervening machinery decreases as the power required decreases, and *vice versa.*

This amount of decrease or increase, as the case may be, we have found to vary from 5 per cent. to 8 per cent., depending on circumstances. Whatever it may be it should be charged to the tenant.

Conclusions which seem obvious sometimes turn out to have been wrong, and the ability to form an accurate judgment, as to the causes of the peculiarities presented in a diagram, is one of the highest attainments of an engineer.

The variety of diagrams given by different engines, and by the same engine under different circumstances, is endless; and there is perhaps nothing more instructive to the student of engineering, as there is nothing more interesting to the accomplished engineer, than their careful and comprehensive study, with a knowledge of the modifying circumstances under which each one was taken. Lines at first meaningless become full of meaning; that which scarcely arrested his attention, comes to possess an absorbing interest; he becomes acquainted with the innumerable variety of vicious forms, and learns the points and degrees, as well as the causes, of their departure from the single perfect form; he becomes familiar with the effects produced by different constructions and movements of parts, and competent to judge correctly as to the performance of engines, and to advise concerning changes, by which it may be improved; he ceases to be a mere imitator of material shapes, and learns to strive after the highest excellence, and, at the same time, to comprehend its conditions. No one at the present day can claim to be a mechanical engineer who has not become familiar with the use of the Indicator, and skilful in turning to practical advantage the varied information which it furnishes.

This brief summary of the uses of the Indicator would be incomplete without calling attention to the importance of applying it to boilers, as a means of testing the accuracy of the pressure-gauges, and to pumps, for the purpose of ascertaining the causes of any inefficiency in their action, and also to the condenser and the air pump of condensing engines.

The diagram, No. 1, taken from one of the engines of a well-known steamship,* is introduced here to illustrate the action of the Indicator, as just described.

The scale of the Indicator was twelve pounds to the inch. The line A B is the atmospheric line, and C D the line of perfect vacuum. The lines forming the outline of the diagram will be designated, for convenience of description, as follows:—

The line from *a* to *b*, the admission-line.
" *b* to *c*, the steam-line.
" *c* to *d*, the line or curve of expansion.
" *d* to *e*, the exhaust-line.
" *e* to *f*, the line of counter-pressure.
" *f* to *a*, the compression-line.

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* The engines from which the diagrams here employed for illustration were taken, will not be mentioned, except in two or three exceptional cases; the object of this paper being, not to publish the comparative performance of different engines, but to give instruction to those who may require it, in the use of the Indicator.

The steam-line does not in fact end at *c*, but at some unknown point beyond *c*. The diagram is divided by lines drawn perpendicular to the atmospheric line into ten equal parts, and also by lines drawn parallel with the atmospheric line at intervals of five pounds pressure. The object of these is to enable the engineer to observe more accurately the nature of the diagram, and to ascertain the mean pressure exerted during the stroke, the mode of doing which will be explained hereafter. The line *c g* is the theoretical expansion curve drawn from the point *c*.

From an examination of this diagram, we conclude that the exhaust-port was covered at the point *f*, of the return stroke, and the vapor remaining in the cylinder was then compressed by the advance of the piston to a density, at the commencement of the forward stroke, of about five pounds above the atmosphere. The port was then opened for admission, and the pressure instantly rose to fourteen and a half pounds above the atmosphere. The port being opened wider and wider, this pressure was maintained behind the advancing piston to the point *c*, at which it began to fall, at first very slowly, from the gradual closing of the port by the cut-off valve. The point at which the port was covered cannot be identified. It was certainly, however, far beyond the point *c*, and strictly the steam-line continues to the point of cut-off, however the pressure may fall before that point is reached. At the point *d*, the pressure had fallen by expansion to two pounds above the atmosphere. Here the valve began to open communication with the condenser, and before the piston commenced its return stroke the pressure on this side of it fell to nearly ten pounds below the atmosphere, and almost immediately after a vacuum of twelve pounds was formed; and when the return stroke was two-thirds accomplished, the counter-pressure suddenly fell half a pound lower, and this vacuum was maintained until the exhaust-port was closed at the point *f*. We shall refer to this diagram again, when on the subjects of calculating the power of the engine from the diagram, and of working steam expansively.

OF TRUTH IN THE DIAGRAM.

It is, of course, of the first importance that the diagram given by the Indicator shall be true. Causes of error appear at every point, and the degree of falsity arising from them increases greatly with an increase in the rate of revolution of the engine. It is not possible to be too critical in using the Indicator, especially at high speeds; the errors we are not conscious of are the ones sure to mislead us.

The Conditions of a correct Diagram are—1st, that the movements of the paper shall coincide exactly with those of the piston; and, 2nd, that the movements of the pencil shall *simultaneously* and precisely represent the changes of pressure in that end of the cylinder to which the Indicator is attached.

1st. *Errors in the Motion of the Paper.*—The common errors in communicating motion to the paper are of two kinds—those which arise out of the movements employed, and those which, when the movements are correct, are occasioned by a high velocity of the parts; but with proper care these may all be avoided. We shall mention them in detail presently, in connection with instructions for applying the Indicator.

2d. *Errors in the Motion of the Pencil.*—These are of a more serious nature. The spring may be accurate, but its unavoidable length and weakness, and its weight, joined to that of the piston and other attached parts, and the distance through which these must move, in order that the indications may be on a scale of sufficient magnitude, render it impossible to obtain from engines which run at any considerable speed, with any form of Indicator hitherto in use, diagrams which can make any claim to accuracy.

THE RICHARDS INDICATOR

Is constructed on a plan by which it is found that these difficulties are quite avoided, and correct diagrams are obtained under all circumstances. The principal distinguishing features of this instrument are a short and strong spring, a short motion of piston and light reciprocating parts, combined with a considerable area of cylinder, and an arrangement of levers and a parallel motion, for multiplying the motion of the piston in such a manner that the diagram is described in the usual way and of the ordinary size. The proportion between the motion of the piston and that of the pencil is a matter of discretion; that which has been adopted is 1 to 4, and the steadiness with which the indication is drawn by these instruments, even at the highest speeds of piston, leaves nothing to be desired.

The diagrams numbered 2, 3, 4, 5, are fair samples of a large number taken from the locomotive "Eagle," on the London and South-Western Railway, in April, 1863. In three of them, the pencil was held to the paper during a number of revolutions; in diagram No. 5 it passed over the paper only once and a half. They are introduced here to show the correct action of the instrument; we shall have occasion to consider them also as illustrations of working steam expansively.

General Construction of the Indicator.—The parallel motion is made as compact as possible. For this purpose, a lever of the third order is employed to multiply the motion, and the extremities of the line drawn by the pencil are permitted to have a slight curvature, which considerably reduces the length of the rods, and does not affect the usefulness of the instrument, the curvature at the lower end being below any attainable vacuum, while the extremity of the scale above is very rarely employed.

The Indicators are made of a uniform size; the area of the cylinder is one-half of a square inch, its diameter being .7979 of an inch. The piston is not fitted quite steam-tight, but is permitted to leak a little; this renders its action more nearly frictionless, and does not at all affect the pressure on either side of it. The motion of the piston is $\frac{25}{32}$ of an inch, and the motion of the pencil, or extreme height of the diagram, is $3\frac{1}{8}$ inches. The paper cylinder is 2 inches in diameter, and the length of the diagram may be $5\frac{1}{4}$ inches, if this extent of motion is given to the cord. The diagram is drawn by a pointed brass wire on metallic paper. This is a great improvement over the pencil; the point lasts a long time, cannot be broken off, and is readily sharpened, and the diagram is indelible.* The steam-passage has two or three times the area usu-

* We have used the metallic pencil with the prepared metallic paper. It works well, but the difficulty of procuring it, together with its high cost, renders it objectionable. We use heavy, unsized paper with a Faber No. 4 pencil; we succeed in getting good, distinct diagrams, with lines sufficiently fine to measure correctly.

ally given to it. The stem of the Indicator is conical, and fits in a corresponding seat in the stopcock, where it is held by a peculiar coupling, shown in section in the accompanying cut of the Indicator. This arrangement permits the Indicator to be turned round, so as to stand in any desired position, when, the coupling being turned forward, the difference in the pitch of the screws draws the cone firmly into its seat; and when the coupling is turned backward, the cone is by the same means started from its seat. The leading pulleys may be turned by some pressure, to give any desired direction to the cord, and will remain where they are set. By these means the Indicator can be readily attached in almost any situation.

The Springs.—In order to adapt this Indicator for use on engines of every class, springs are made for it to 4 different scales, as follows :

No. 16,	which is	graduated	16 lbs.	to the	inch.	35 lbs.
No. 20,	"	"	20 "	"	"	56 "
No. 30,	"	"	30 "	"	"	75 "
No. 40,	"	"	40 "	"	"	105 "

All the above will also indicate 15 lbs. below the atmospheric line.

PRACTICAL DIRECTIONS FOR APPLYING AND TAKING CARE OF THE INDICATOR.

I. OF ATTACHING THE INDICATOR.

When it is practicable, diagrams should be taken from each end of the cylinder. The assumption commonly made, that if the valves are set equal, the diagram from one end will be like that from the other, will be shown by this instrument to be erroneous. This is owing to the difference in the speed of the piston at the opposite ends of the cylinder, which is, at the outer end of a direct-acting engine, from one-sixth to one-third greater than at the crank end, the difference varying according to the degree of angular vibration of the connecting rod. In side-lever, or beam-engines, these proportions are reversed, and the speed of the piston is greater at the upper end of the cylinder. Often, also, there is a difference in the lengths of the thoroughfares, and in the lead, or the amount of opening, or the point of closing; and many times the valves are supposed to be correctly set when this Indicator will show that they are not. These, and many other causes, will make a difference in the diagrams obtained from the opposite sides of the piston.

Pipes to be avoided.—The Indicator should be fixed close to the cylinder, especially on engines working at high speeds. If pipes must be used, they should not be smaller than half an inch in diameter, and five-eighths in the bends, and as short and direct as possible. Any engineer can satisfy himself with this instrument that each inch of pipe occasions a perceptible fall of pressure between the engine and the Indicator, varying according to its size and number of bends and the speed of the piston. Diagrams have been known to show, from this cause alone, forty per cent. less pressure than was actually in the cylinder.

Where to connect the Indicator.—On vertical cylinders, for the upper end, the Indicator-cock is usually screwed into the cover, where the oil-cup is set, this being removed for the purpose. For the lower end, it is necessary to drill into the side of the cylinder, at a convenient point in the space between the cylinder bottom and the piston, when on the centre, and screw in a short bent pipe, with a socket on the end to receive the Indicator-cock. The Indicator can be used in a horizontal position; but it will be found much more convenient to put in a bent pipe, and set it vertical. Sometimes it will be necessary to drill in the side of the cylinder at the upper end also, especially in double-cylinder engines having parallel motions, when the Indicator cannot generally be set on the covers. Care must be taken that the piston does not cover the hole when on the centre. No putty is necessary to make these small joints, and it should never be used, as it is liable to clog the instrument. If the screw fits loosely, a few threads of cotton wound round the stem will prevent the escape of steam. Objections are sometimes made to drilling a cylinder or its heads, for the reason that the borings as the drill passes through will be left in the cylinder and likely to scratch it; this, with a little management, can be wholly prevented, by letting a little steam on as the drill enters, which will blow it outwards.

On horizontal engines, the best place for the Indicator is on the top or upper side, at each end; if it cannot be placed there, bent pipes may be screwed into the covers or into the side of the cylinder. In other respects follow the directions given for vertical engines. The Indicator should never be set to communicate with the thoroughfares. The current of steam past the end of the pipe or the hole reduces the pressure in the instrument, and the diagram given is utterly worthless, as any engineer can readily ascertain by making the experiment. On oscillating cylinders care must be taken to set the instrument in such a position that the motion of the cylinder will not have the effect to throw the pencil to and from the paper.

The stopcock being screwed firmly to its place, screw the Indicator down to its seat, turning it to the most convenient position, and make it fast by turning the coupling; then move the guiding pulleys to their proper position to receive the cord, and the instrument is in readiness for use.

II. OF GIVING MOTION TO THE PAPER.

The Drum the best Means.—The revolution of a drum is probably the most correct as well as convenient method of giving motion to the paper. It may be supposed that a flat slide, worked by positive means, would have a perfectly accurate motion; but, in fact, at high velocities, where alone any trouble is met with, the difficulties involved in its use are more troublesome than those presented by the cylinder. In most cases the connecting-rod must necessarily be somewhat long; it must not tremble, or the line on the paper will be tremulous, and the weight required for stiffness, joined to the weight of the slide, causes a momentum, which, if the rod is worked by a vibrating arm, will give to the paper, on each centre, a motion opposite to that of the piston of the engine; and precisely at these points it is of the greatest consequence that the two motions shall coincide.

In the use of the cylinder at any speed, the question of obtaining a positive motion, if there is no elasticity in the cord or the parts to which it is connected, is simply one of proportion between the momentum of the revolving parts and the strength of the spring by which this is resisted. In this Indicator these parts are made as light as possible consistently with other requirements, and the spring is of such strength that they may be reciprocated from 250 to 300 times per minute, without any increase in the length of the diagram, and of course, therefore, without any error in the motion. There is no difference in the construction of these Indicators in this respect, it being intended that every instrument shall be applicable to any engine.

From what Points to derive the Motion.—This may be taken from any part of the engine which has a motion coincident with that of the piston. For a beam-engine a point on the beam, or beam-centre, or on the parallel-motion rods where these are employed, will give the proper motion; but care must be taken that the cord be so led off, that when the engine is on the half stroke it will be at right angles to whatever gives it motion (a requirement too often omitted); afterwards its direction of motion may be changed as required, always taking care, however, to use as few carrying pulleys as possible, and the shortest possible cord, which should be of linen, size No. 3; it should be well stretched by suspending a weight to it for several days.

In some cases it is most convenient to take the motion from a point on the end of the revolving shaft; this is frequently the case on horizontal engines, working at high speeds, because then the motion does not need to be reduced. Exact accuracy cannot be got in this way, however, without employing a moving slide, and connecting it with the pin in the end of the shaft by a rod or cord of such length that its angular vibration shall be the same as that of the connecting-rod. This will be found generally a troublesome matter; and the engineer will probably prefer in most cases to disregard the error resulting from its omission—which is, that the motion of the paper will be more nearly equal at the two ends of the stroke, being slower than that of the piston at the one end, and faster at the other. The crank or pin from which the cord receives its motion must be on its centre relatively to the direction of the cord, whatever that direction may be, precisely when the crank of the engine is on *its* centre. If this requirement is not carefully attended to, the diagram will be worthless.

Generally, on horizontal engines, the motion of the paper is taken from the cross-head. In an engine-room, a strip of board may be suspended from the ceiling, or carried off horizontally in such a manner as to permit it to swing backward and forward edgeways by the side of the guides, and motion may be given to it by a pin, secured firmly to the cross-head, and projecting through a slot in the board, in which it should fit nicely to prevent lost time on the centres. To save drilling and defacing the cross-head to insert a pin, we use a clamp made fast to the cross-head or some of its appendages by a set screw; a projecting pin plays in a slot in the board, or if preferred, a short connecting rod may be used to make the connection. The board must hang plumb when the piston is in the middle of its stroke, or if horizontal at right angles. The cord may be connected to this strip of board at a point sufficiently near to its point of suspension to give the required reduction of motion for the paper, and must be led off in a horizontal direction, and then over one or more pulleys in any required direction to the Indicator. At high speeds, however, pulleys should be avoided. On portable engines, the motion may be attained in the manner just described, the lever swinging from a pin supported in a standard about two feet in height, set on one of the guide-bars.

On locomotives having outside connections, the motion must be taken from the cross-head. It is indispensably necessary to use only a short direct cord, free from elasticity, and connected to a point the motion of which is reduced from that of the cross-head by positive means. Care must be taken also so to proportion the parts employed for this purpose, that the point at which the cord is connected shall have a positive motion without any fling, a matter not by any means free from difficulty at 250 revolutions per minute. A rock-shaft, turning in bushings, supported by two angle iron standards, precisely over the mid-position of that point of the cross-head from which the motion is derived, affords perhaps the best means of reducing the motion. A long-arm is worked by the cross-head and a short-arm gives motion to the cord. The short-arm must be keyed in such a position that when the piston is in the middle of its stroke it will stand at right angles with the direction of the cord, whatever that may be. The direction of the cord may form any necessary angle with the horizontal line, but must be at right angles with the rock-shaft.

On locomotives having inside connections, and a single pair of driving-wheels, where it is practicable, it will be found to be the better way to take the motion from a pin set in the end of the shaft, and to communicate it by a connecting-rod to a point convenient for attaching the cord. The parts should be all substantially made; the momentum of the connecting-rod will be perfectly resisted by the pin.

On oscillating engines, the motion may be taken from the brasses at the end of the piston-rod. If the stroke is long, it is sometimes difficult to reduce this motion to that required for the paper, and in such cases it is necessary to take the motion from an eccentric on the main shaft, to a point as near as possible to the trunnion, and thence to communicate it to the Indicator. In all these connections, it is of the first consequence that there be *no* lost time, which will require to be made up on every centre, and will thus cause the paper to stand still while the piston is moving.

Pulleys of different diameters on the same spindle have often been used as a means of reducing the motion from that of the cross-head, but we do not recommend them; at high speeds it is very difficult to make them answer. The experience of the careful operator will teach him to guard against the various causes of error here mentioned, and others which will arise in the great diversity of situations in which the Indicator is used, and the effects of which are the more mischievous because often the diagram itself furnishes no means of detecting them. The mathematician will perceive that *perfect* accuracy of motion is attained by only a very few of the methods here suggested. Most of them are only approximately accurate, but they are the best which can be readily employed, and the errors which they involve are too slight to be of practical moment. For the professional engineer, of course, directions are unnecessary.

III. HOW TO TAKE A DIAGRAM.

To fix the Paper.—Take the outer cylinder off from the instrument, secure the lower edge of the paper, near the corner, by one spring, then bend the paper round the cylinder, and insert the other corner between the springs. The paper should be long enough to let each end project at least half an inch between the springs. Take the two projecting ends with the thumb and finger, and draw the paper down, taking care that it lies quite smooth and tight, and that the corners come fairly together, and replace the cylinder.

To connect the Cord.—The Indicator having been attached, and the correct motion obtained for the drum, and the paper fixed, the next thing is to see that the cord is of the proper length to bring the diagram in its right place on the paper—that is, midway between the springs which hold the paper on the drum. In order to connect and disconnect readily, the short cord on the Indicator is furnished with a hook, and at the end of the cord coming from the engine, a running loop may be rove in a thin strip of metal, in the manner shown in the following cut, by which it can be readily adjusted

to the proper length, and taken up from time to time, as it may become stretched by use. On high-speed engines, it is as well, instead of using this, to adjust the cord and take up the stretching, as it takes place, by tying knots in the cord. If the cord becomes wet and shrinks, the knots may need to be untied, but this rarely happens. The length of the diagram drawn at high speeds should not exceed four and a half inches, to allow changes in the length of the cord to take place to some extent, without causing the drum to revolve to the limit of its motion in either direction. On the other hand, the diagram should never be drawn shorter than is necessary for this purpose.

To take the Diagram.—Everything being in readiness, turn the key of the stopcock to a vertical position, and let the piston of the Indicator play for a few moments, while the instrument becomes warmed. Then turn the key horizontally to the position in which the communication is opened between the under side of the piston and the atmosphere, hook on the cord and draw the atmospheric line. Then turn the key back to its vertical position, and take the diagram. When the key stands vertical, the communication with the cylinder is wide open, and care should be observed that it does stand in that position whenever a diagram is taken, so that this communication shall not be in the least obstructed.

To apply the pencil to the paper, take the end of the longer brass arm with the thumb and forefinger of the left hand, and touch the point as gently as possible, holding it during one revolution of the engine, or during several revolutions if desired. There is no spring to press the point to the paper, except for oscillating cylinders; the operator, after admitting the steam, waits as long as he pleases before taking the diagram, and touches the pencil to the paper as lightly as he chooses. Any one, by taking a little pains, will become enabled to perform this operation with much delicacy. As the hand of the operator cannot follow the motions of an oscillating cylinder, it is necessary that the point be held to the paper by a light spring, and instruments to be used on engines of this class are furnished with one accordingly.

Diagrams should not be taken from an engine until some time after starting, so that the water condensed in warming the cylinder, etc., shall have passed away. Water in the cylinder in excess always distorts the diagram, and sometimes into very singular forms. The drip-cocks should be shut when diagrams are being taken, unless the boiler is priming. If when a new instrument is first applied the line should show a little evidence of friction, let the piston continue in action for a short time, and this will disappear.*

As soon as the diagram is taken, unhook the cord; the paper cylinder should not be kept in motion unnecessarily, it only wears out the spring, especially at high velocities. Then remove the paper, and minute on the back of it at once as many of the following particulars as you have the means of ascertaining, viz :—

The date of taking the diagram, and scale of the Indicator.

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* Thus, by the motion of the pencil up and down, and the paper from right to left, and left to right, we transfer the pressure of the steam and vacuum (if there be any), and the movement of the piston to the paper, giving us a map or diagram of the action required to move the load at any and all points of the stroke, from which the power exerted may be computed and the condition of the internal action seen.

The engine from which the diagram is taken, which end, and which engine, if one of a pair.

The length of the stroke, the diameter of the cylinder, and the number of double strokes per minute.

The size of the ports, the kind of valve employed, the lap and lead of the valve, and the exhaust lead.

The amount of the waste-room, in clearance and thoroughfares, adds to the length of the cylinder.

The pressure of steam in the boiler, the diameter and length of the pipe, the size and position of the throttle (if any), and the point of cut-off.

On a locomotive, the diameter of the driving-wheels, and the size of the blast orifice, the weight of the train, and the gradient, or curve.

On a condensing-engine, the vacuum by the gauge, the kind of condenser employed, the quantity of water used for one stroke of the engine, its temperature and that of the discharge, the size of the air-pump and length of its stroke, whether single or double acting, and, if driven independently of the engine, the number of its strokes per minute, and the height of the barometer.

The description of boiler used, the temperature of the feed-water, the consumption of fuel and of water per hour, and whether the boilers, pipes, and engine are protected from loss of heat by radiation, and if so to what extent.

In addition to these, there are often special circumstances which should be noted.

IV. HOW TO KEEP THE INDICATOR IN ORDER.

Having the attachments made; before we admit steam to the instrument, we open the cocks and blow through the connections to clear them from any foreign matter, that it may not enter and injure the instruments.

The Indicator will not continue to work well, unless it is kept in good order. When used, it generally becomes filled with water, which will rust and thus weaken the spring, and the steam often contains impurities and grit, a portion of which is lodged in it. After the Indicator has been used, and before putting it up, unscrew the cover of the cylinder case, and draw off the upper ferule, with the pencil movement and the piston and spring attached, empty the water from the cylinder case, carefully clean and dry all the parts, and replace them, lubricating the cylinder with a few drops of oil which is entirely free from gum.* The cylin-

* The oil is very important; it should be of the purest kind, free from gum and all foreign matter. The porpoise oil we have found to answer all the requirements ; it has wonderful ability to resist the action of steam and water. We have found the cylinder well lubricated after having taken a hundred diagrams. It has equal merit in preventing corrosion; hence it should be used on the springs, piston-rod, and arms. It costs high, but a small bottle of it will, if properly used, last for years. It can be obtained of any first-class clock-maker or dealer in clock materials.

der is not to be removed from the case under any circumstances; the operation above directed gives complete access to it.

Sometimes the surfaces of the piston and cylinder become scratched or roughened by impurities in the steam, which will be detected at once in the diagram by the unsteadiness of the line. If this shows the existence of any obstruction to the perfectly free action of the Indicator, take the instrument apart, as for cleaning; take out the two screws at the top of the piston-rod connecting it with the pencil movement, and unscrew the spring from the piston and the cover; then replace the piston in the cylinder, after cleaning and lubricating them; screw on the cover to guide the stem, and rub the piston up and down in the cylinder, at the same time revolving the stem between the thumb and finger. The surfaces will quickly wear each other smooth; no grinding or polishing material should be used; the piston should be taken out once or twice during the operation, and the surfaces cleaned. The piston, if dry, ought to drop perfectly free from every position. Before replacing, lift the levers, and let them fall, to see if their action also is entirely free. Then replace everything, taking care to screw the heads of the spring firmly up to the piston and cover. Before putting the piston in the cylinder, revolve it between the thumb and finger, to ascertain if the pins connecting it with the pencil movement turn quite smoothly in the groove at the end of the stem. The paper cylinder requires to be lubricated occasionally with a drop or two of pure oil, applied at the end of the arbor, also the leading pulleys and the joints of the pencil movement.

V. HOW TO CHANGE THE SPRINGS.

The directions already given for taking the instrument apart, for the purpose of smoothing the surfaces of the cylinder and piston, are sufficient also for changing the spring. Merely introduce another, instead of replacing the one removed. The lengths of the springs for the different scales are so proportioned to each other, that the pencil will always come to the proper position for drawing the atmospheric line. Be careful that the heads are screwed up firmly to the piston and cover.

The spring, which gives reaction to the paper cylinder, is liable to break after considerable use, especially on engines running at high speeds; for which reason this cylinder should never be left to run unnecessarily. When this happens, a new spring can be readily inserted, as follows. Set the Indicator on the engine; if there is no other convenient means for holding it firmly, remove the cover of the spring case and the broken spring; then take out the screw, and remove the brass ring from the arbor. Screw the new spring to the brass ring, replace this on the arbor, and set the screw firmly up to the head. Then coil the spring into the case, and hook the end on the rim; see that it is coiled in the same direction with the cord. If the spring has not sufficient strength to keep the cord quite tight, another coil must be given to it, but it should not be coiled any tighter than is necessary for this purpose.

HOW TO ASCERTAIN THE POWER EXERTED BY THE ENGINE.

The custom was introduced by Watt, and has since been generally followed in England, to designate the *size* of engines in measures of "horse power." Watt ascertained by experiment that the power of London draught horses, exerted with ordinary continuance, was to lift 33,000 lbs. one foot in one minute, and this is now employed, wherever English measurements are used, as the unit of measurement of the *actual* power of steam engines.

The Indicator furnishes one of the data for ascertaining the power exerted by the steam-engine, namely, the mean or average pressure of steam during the stroke, on each square inch of the piston; or, more accurately, the excess of pressure on the acting side of the piston to produce motion, over that on the opposite side to resist it. This being multiplied into the whole number of square inches, and the product by the mean or average speed of the piston, in feet per minute, gives the total number of pounds of force acting through one foot in a minute, which are called foot pounds, and by dividing this by 33,000, which is the unit for a horse power, we obtain the gross power of the engine in actual horse powers.

In order to ascertain the *effective* power, however, there must be deducted from this the friction of the engine, or the power required to drive the engine alone at the same speed, which, except in the case of vessels with the wheels submerged, the Indicator generally enables us to ascertain; and also the increase in this friction which arises when the resistance is being overcome, which the Indicator does not show. The amount of this latter is not generally known with any accuracy; but we know that the percentage of loss from this cause diminishes as the size of the engine is enlarged, because the increase in the motion of the surfaces in contact is much slower than the increase in the area of the piston, and also that it varies according to the nature of the lubricating material employed, and the degree of completeness attained in the separation of the surfaces by means of it. Five per cent. is usually allowed for this increase of friction; but it may, in fact, be considerably more or less than this. On small engines, the friction-brake can be applied, to show the amount of effective power exerted, and a comparison of this with the gross power, and with the friction of the engine alone, as shown by the Indicator, will exhibit the increase of friction occasioned by different amounts of resistance, and show the value of different lubricants, and the utility of extended wearing surfaces.

We will now describe the mode of ascertaining from the diagram the mean pressures on the opposite sides of the piston, in condensing and in non-condensing engines. For this purpose, divide the diagram into any desired number of equal parts, by lines drawn perpendicular to the atmospheric line. Sometimes these divisions are made very numerous; but the usual practice is to make ten, which number is probably sufficient, unless great accuracy is desired, when twenty divisions may be made. A convenient instrument for facilitating this operation, saving time, and insuring accuracy, is furnished with these Indicators. It consists of a parallel ruler, of eleven bars of thin steel, and a small square. The perpendiculars are first drawn by the square at each end of the diagram, when, the outer edge of bar No. 1 being brought to the beginning, and the inner edge of bar No. 11 to the termination of the stroke, the dividing lines are drawn with a sharp-pointed pencil. If twenty divisions are desired, the intermediate lines for this purpose will also be readily drawn by means of this instrument, points being first marked in the middle of the outer divisions. It is an excellent practice to divide the diagram also by lines drawn parallel with the atmospheric line, into equal divisions, each representing a certain number of pounds pressure, generally five or ten, and numbered on the margin according to the scale of the Indicator; by which means the engineer is able to observe much more accurately the general nature of the diagram. The same instrument may be employed for this purpose.

On diagrams from condensing engines, the line of perfect vacuum should be drawn at the bottom, and the line of the boiler pressure, as shown by the gauge, at the top.* The line of perfect vacuum varies in its distance from the atmospheric line, or, more correctly, the latter varies in its distance from the former, according to the pressure of the atmosphere, as shown by the barometer, from 13.72 lbs. on the square inch when the mercury stands at 28 inches, to 15.19 lbs. when it stands at 31 inches (*vide* Table II.); and it should be drawn according to the fact, if this can be ascertained. The engineer should always have a good aneroid in his pocket. The pressure of the atmosphere is usually reckoned at 15 lbs., which, as a general rule, is too high, being correct only when the barometer stands at 30.6 inches; but the error is unimportant, and it is very convenient to avoid the use of a fraction, and to say that 30 lbs., 45 lbs., 60 lbs.,

* When accuracy is required, the steam-gauge should be tested by the Indicator, which may be done by stopping the engine on the centre, opening the steam-valve, and letting the full pressure on the instrument; when the indications of the two instruments may be compared and noted.

and so on, represent 2, 3, 4, 5, 6 atmospheres of pressure.

The principal object of knowing the exact pressure of the atmosphere is, to ascertain the duty performed by the condenser and air-pump. The temperature of the discharge being known, the pressure of vapor inseparable from that temperature is also known (*vide* Table No. III.), and this being deducted from the actual pressure of the atmosphere, the remainder is the total attainable vacuum *at that temperature.*

The areas of the diagram above and below the atmospheric line are usually calculated separately, to ascertain how effectually the resistance of the atmosphere is removed from the non-acting side of the piston, by those parts of the engine whose function this is. In case of engines working very expansively, however, the expansion curve crosses the atmospheric line, and sometimes at an early point of the stroke, as in diagram No. 10. In such cases, the whole space between the atmospheric line and the line of counter-pressure should be credited to the condenser and air-pump; not, of course, to be considered in estimating the power exerted, but for ascertaining the degree of economy in the consumption of steam, which depends greatly on the amount of vacuum maintained.

The lines having been accurately drawn as above directed, ascertain, by careful measurement with the scale, the mean pressure in each division, between the atmospheric line and the upper line of the diagram, until this crosses the former, if it does so; add these together, and point off one place of decimals, or divide their sum by the number of divisions, if there are more than 10, and the quotient will be the mean pressure above the atmosphere during the stroke. Then repeat the process for the area between the atmospheric line, or the expansion curve after it has crossed this line, and the lower outline of the diagram. Add the two mean pressures so ascertained together, then find in Table No. I. the number of square inches in the surface of the piston, if you know the diameter, and multiply the pressure on one square inch by the number of square inches, and the product by the mean velocity of the piston, in feet per minute, and divide by 33,000, and the quotient will be the gross amount of horse-power exerted; or the power represented by the two areas of the diagram, above and below the atmospheric line, may be calculated separately.

[Since the publication of the First Edition, my attention has been called to an improved method of measuring the diagram which is more expeditious and less liability to error.]

Thus, your diagram is divided into equal parts as usual—say 10. Now, we take a narrow slip of paper, or what is better, card-board that is thin and smooth; this we place across the diagram as we would the scale, letting the end of it be exactly over the base line; then with a sharp-pointed knife prick the slip exactly over the line opposite the base (steam-line), advance the slip to the next division, and carrying the point made by the knife to the base line, then remove the knife and make another prick exactly over the line opposite. Repeat the movement until you have measured each space; then make a mark with your pencil. Now, with a rule, you measure the distance from the end of the slip to your pencil mark; we will assume that it is $6\frac{1}{4}$ inches. Now, as you have measured 10 spaces, to get the average, we divide it by 10; thus, $6\frac{1}{4}$ expressed decimally is 6.25. This, divided by 10, is equal to .625.

Now the scale of the diagram we will assume to be 40 to one inch. We then multiply .625 by the scale, which we have assumed to be 40, and we get the following result as an average pressure per square inch:

$$\begin{array}{r} .625 \\ 40 \\ \hline 25.000 \end{array}$$ lbs. pressure.

Expressed in arithmetical signs, it is

$$6.25 \div 10 = .625 \times 40 = 25.000.$$

Should there be more or less than 10 divisions of the diagram, divide by the number, whatever it is. Should the scale of the instrument be other than 40, then multiply by the number, whatever it may be.

This mode is much less liable to error than the ordinary mode; in fact, it reduces the liability as ten to one. It is more expeditious, in so much as it saves the additions of a long column of figures.

The space between the steam line and the line of boiler pressure shows how much the pressure is reduced in the cylinder by throttling, or by the insufficient area of the ports, proper allowance being made for the difference of pressure necessary to give the rapid motion to the steam, and that between the line of counter-pressure and the line of perfect vacuum shows the amount of resistance to the motion of the piston.

In illustration of the foregoing directions, let it be required to find the effective power exerted by the pair of engines, from the upper end of one of which diagram No. 1 was taken, the diameter of cylinder being 95″, the stroke of the piston 10′, and the number of revolutions 15 per minute. We will assume that the other engine would have given the same diagram, which is possibly correct, and also that the lower ends of the cylinders would have given the same, which is probably quite incorrect, because in side-lever, or beam engines, the speed of the piston at the lower end is slower, and therefore probably the pressure obtained is greater, than in the upper end, the motion of the valves being the same.

The mean pressure of steam above the atmosphere was	9.82 lbs.
The average vacuum was	11.46 "
Total excess of pressure above the resistance was.	21.28 "

The better mode of calculation in all cases is, to obtain first the number of horse-powers for 1 lb. to mean pressure on the square inch, as follows :

Multiply the number of square inches in the surface of the piston 7088.2
By the speed of the piston in feet per minute. 300

33.(000)2126(460.0(64.44
198
146
132
144
132
126

Which is the number of horse-powers exerted, for each pound of pressure during the stroke on 1 square inch of the piston 64.44
To obtain the gross power we multiply this by the average pressure per square inch on the piston..... 21.28

51552
12888
6444
12888

Gross horse-powers exerted in one engine 1371.2832

To obtain the effective power we must abstract from the multiplier............. .... 21.28 lbs.
The pressure required to run the engine alone, which in so large an engine would probably not exceed .... 1.00 lb.
And the increase in this pressure required to overcome the increased friction when the resistance is being overcome, say 5 per cent.....................................=1.06 "

2.06 lbs.

Effective pressure on each square inch.... 19.22 "
Which multiplied by.................... 64.44

7688
7688
7688
11532

Gives amount of effective horse-power ... 1238.5368
Which multiplied by..................... 2

Gives........................ 2,477.0 horse-power as the effective power of the engines.

It will be observed that, by the above mode of calculation, we obtain for any engine, the speed of piston continuing the same, a constant number, which, multiplied by the mean pressure on a square inch, gives at once the amount of horse-power exerted at any time.

On diagrams from non-condensing engines, the line of boiler pressure should be drawn at the top, and it is well to draw the line of perfect vacuum also, that the engineer may be able to see at a glance the quantity of steam consumed, and to compare with it the amount of work done. It is not possible that the back pressure resisting the motion of the piston shall be less than the pressure of the atmosphere, but it may be a great deal more, and very commonly in non-condensing engines the line of resistance is as much as 2 or 3 lbs. above the atmospheric line, though it is quite possible to avoid this excess altogether, as is shown in diagrams Nos. 6 and 9.

The mean pressure is ascertained in the manner already directed for obtaining the pressure in condensing engines above the atmospheric line, and the power is calculated in the same way.

For example, let it be required to find the effective power exerted by the engine from which diagram No. 6 was taken, the diameter of the cylinder being 18'', the stroke of the piston 42'', and the number of revolutions 60 per minute—

The mean pressure of steam during the stroke, above the resistance of the atmosphere, was........................		25 lbs.
From this we must subtract the pressure required to run the engine alone, say..	1.75 lbs.	
And the increase of pressure required to overcome the increased friction when the load is on, estimated at 5 per cent..	1.25 "	
		3 lbs.
Leaving effective pressure................		22 "

The area of the piston is........... 254.5 square inches,
Which, multiplied by the velocity of the piston..................... 420 feet per minute,

50900
10180

And divided by 33.(000)106(890.0(3.24
99
78
66
129
132

Gives 3.24 horse-powers, for each pound of pressure on 1 square inch during the stroke.................... 3.24 horse-powers,
Multiplied by.......... 22 lbs. pressure,

648
648

Gives.. .... 71.28 effective horse-powers,

assuming the pressure on the opposite side of the piston to have been the same.

In the same manner, on stationary engines, the power shown by the frictional diagrams can be calculated, and by diagrams taken when the shafting only is being driven, and when greater or lesser proportions of the whole resistance are being overcome, and on vessels at different depths of immersion.

Generally, engines will give the same figures at each revolution, the pencil retracing the same line so long as the resistance continues the same; but sometimes this is not the case, as in the engine from which the diagram just calculated was taken, where are shown four distinct expansion curves. In such cases care must be taken to obtain the average diagram. Also, in comparing the pressures required to overcome different resistances, it is essential that the speed of the engine in each case be the same, a requirement often disregarded.

In all calculations of power from the diagram, it is assumed, and correctly so, that the value of each unit of motion of the piston is the same, whether measured at the extremes or in the middle of the stroke. The motion of the crank should be uniform; and if this is the case, the divisions of the time occupied in a revolution can be accurately measured on the circle which it describes. The motion of the piston, on the contrary, changes at every point of the stroke. At the instant when the crank is on the centre it is at rest; then its speed, at first infinitely slow, becomes gradually accelerated, until, at the point where the direction of motion of the piston and that of the crank-pin coincides, the velocities of the two are equal, and for some distance before reaching and after passing this point they differ but little; then its motion is gradually retarded, until on the opposite centre it is at rest again.

TO MEASURE FROM THE DIAGRAM THE AMOUNT OF STEAM CONSUMED.

For this purpose, draw the line of perfect vacuum, if not precisely known, at 14.7 lbs. below the atmospheric line. Ascertain how much the clearance and the thoroughfare add to the length of the cylinder at one end, and add a proportionate quantity to the length of the diagram by a line drawn perpendicular to the atmospheric line, at the proper distance from the admission line. Then ascertain the point in the stroke at which the steam is released, and the pressure in the cylinder at that point. Multiply this pressure, reckoned from the line of perfect vacuum (and which must be taken before the exhaust-port has been opened), by the sectional area of the cylinder in square inches, and the product by the length of the stroke in inches, up to the point at which the steam was released, and including the addition for the clearance and thoroughfare, and divide by 14.7, and the quotient will be the number of cubic inches of steam, at the pressure of the atmosphere, discharged from the cylinder at a single stroke. If the valves do not leak, and there is no water with the steam, the cubic contents of the cylinder multiplied by the pressure, at the point of cut-off, should equal the cubic contents multiplied by the pressure, at the point of release, and in a compound engine the cubic contents of each cylinder multiplied by the pressure, at the point of release, should give the same result. Multiply this by the number of strokes in an hour, and divide the product by 1728 to reduce the cubic inches to cubic feet, and the quotient again by 1700, to reduce the steam at atmospheric pressure to water, and the result will be the number of cubic feet of water used per hour; multiply this by 62.5 for pounds, and divide the product by 8.33 lbs. for wine gallons. The supply of water to the boilers will need to be greater than the quantity thus ascertained, and the excess required will measure the aggregate loss from all causes, including leakage, priming, blowing off, and radiation from the cylinder and pipes where the water of condensation does not flow back into the boiler. It is essential, of course, that the diagram measured shall represent the uniform power exerted, or the mean power, if it is subject to variations.

The detection in this manner of losses of heat, from occult causes, is one of the most remarkable and important services which have been rendered by the Indicator. It has been proved in some cases that nearly or quite twice the volume of steam must have entered the cylinder at every opening of the ports, either in the form of steam or of water already condensed, that existed in the form of steam at the point of cut-off. The field here presented is one of the most useful in which the Indicator can be employed.

OBSERVATIONS ON THE SEVERAL LINES OF THE DIAGRAM.

In order to point out clearly the principal points of excellence and defect in the action of engines, which are made known by the Indicator, it will be best to consider each line of the diagram separately, beginning at the commencement of the stroke.

I. THE ADMISSION-LINE.

At low pressures of steam this line may be very nearly vertical, especially when the opening of the ports is preceded by considerable compression of the steam in the cylinder, as in diagram No. 1. Diagram No. 13, also taken from a celebrated steamship, shows a more gradual opening, but not preceded by any compression. At high pressures it is important to avoid the shock of the full force of the steam on the centre, especially when there has been no compression. Diagrams Nos. 6 and 7, from non-condensing engines, show a moderate advance of the piston, and, the former especially, a considerable movement of the crank, while the pressure was being attained in the cylinder, the latter with and the former without precedent compression. These are all excellent admission-lines.

The direction of this line is determined by the amount of lead given to the valve, for which no general rule can be laid down. It depends upon the speed of the piston, the proportion between the area of the ports and that of the cylinder, the rapidity or slowness of the opening movement, and the density of the steam already in the cylinder at the instant of opening. The proper lead can be ascertained only by the application of the Indicator. Without its assistance the best judgement is liable to err in a case presenting novel conditions. By the best judgment is meant a judgment formed by careful comparison of the lead given with the admission-line drawn by the Indicator, in a wide diversity of cases.

II. THE STEAM-LINE.

Here we find engines divided into four classes, namely—

1. Those in which the valves have an invariable motion, without any or with only very trifling lap, causing the port to remain open, or, technically, the steam to follow the piston, quite or nearly to the end of the stroke.

2. Those in which the valves have also an invariable motion, but with more or less lap, causing the steam to be cut off at a certain fixed point of the stroke.

3. Those in which the point of cut-off may be varied by hand, either by means of the link motion or of an independent cut-off gear; and,

4. Those in which the point of cut-off is adjusted by the action of the governor, according to the changes either in the pressure of steam or the resistance to be overcome.

In the first two classes, when less than the full pressure is required in the cylinder, the governor or the engineer adjusts the pressure by changing the position of the regulating valve. In the third class the regulating valve may be employed for this purpose, but the more usual and better way is to run such engines with this valve entirely open, and to adjust the mean pressure in the cylinder by changing the point of cut-off. Engines of the fourth class have no regulating valve, but the full attainable pressure of steam is admitted to the cylinder.

The action of the regulating valve varies the position of the steam line upward or downward, to that distance from the atmospheric line which gives the mean pressure required. The action of the cut-off gear, on the contrary, varies its length for the same purpose. In engines in which the steam follows to the end, or nearly to the end, of the stroke, and indeed in all cases where the pressure is reduced between the boiler and cylinder by the action of the regulating valve, it is a matter of very little interest what the steam-line may be. Not only its distance from the atmospheric line, but also its direction, is changed by every change in the position of the regulating valve, so that it is not at all a fit subject for consideration.

In engines which have no regulating valve, or where it is not employed, as in marine engines except in rough weather, the steam-line should approach nearly to the line of boiler pressure, and should be parallel with this line up to the point of release or cut-off. Diagrams Nos. 1, 6, 8, 9, afford examples of correct steam-lines, except that in No. 1 it is not continued parallel nearly up to the point of cut-off. Diagram No. 10 shows a slight fall of the steam-line as the piston advanced, but the point of cut-off is well shown. Diagram No. 12 from a marine condensing engine, at 336 feet travel of piston per minute; and Nos. 2, 3, 4, and 5, from a locomotive, at 730, 820, and 950 feet travel of piston per minute, afford, on the contrary, examples of bad steam-lines. The boiler pressure is very nearly attained at the commencement of the stroke, in the first case, by lead given to the valve, and in others by lead superadded to excessive compression ; but as the piston advances, the pressure falls with great rapidity, and the point at which the port was closed there is no means of discovering.

In all these cases the passage of steam to the valve-chamber was entirely unimpeded. Diagrams Nos. 15 and 16 are good admission and steam lines. Locomotive diagrams Nos. 19, 20, and 21, are remarkably good steam and admission lines. In No. 22, steam-line falls off slightly. The nature of the steam-line depends principally on the proportion between the area of the ports, supposing them to be, as they ought, the smallest passages through which the steam is taken, and the cubical capacity of cylinder to be filled in a given time. A given cubical capacity may be formed in the same time by the slow advance of the piston in a larger cylinder, or by its more rapid advance in a smaller one. The sectional area of cylinder and the speed of the piston must be equally considered in determining the area of the ports, as they are equal elements in determining the capacity of cylinder to be filled.

While, therefore, very high velocity of piston does not render impossible the attaining of a correct steam-line, still the size of port required for this purpose becomes so considerable, and the amount of power absorbed in working the valves, under the pressure which is generally associated with high speed of piston, is already so serious, that with the present form of valve in use—on locomotives, for example—it is better probably to submit to the defect at high velocities, than to attempt to mend it by enlargement. Improvement in this feature can be looked for only from a radical change in the valves and movements. It should be observed, however, that the velocity of piston at which diagrams Nos. 7 and 8 were drawn was 600 feet per minute. Another cause often contributes largely to injure the steam-line, especially in condensing engines—namely, the condensation of the steam on entering the cylinder; and to this the enormous fall of pressure in diagram No. 11 must undoubtedly be in part attributed, the smallness of the ports not being sufficient to account for it.

There is obviously a point beyond which expansion can not be advantageously carried, because it is possible to cut the steam off so early that even with the highest pressure the engine will not perform any duty at all, but only run itself. Of course the power absorbed in running the engine should be only a small percentage of the gross power exerted. But there is also another limitation. The loss of heat by radiation and conduction, external and internal, is far greater than was till lately generally supposed. It is possible to protect pretty thoroughly against external radiation; but against internal radiation, which is so much greater than the other, as the capacity for heat of the exhaust steam, at the density it may have, is greater than that of the atmosphere, it is not possible to protect at all, and the earlier the steam is cut off, the greater is the proportionate time during which the exposed surfaces are being cooled, and the smaller the quantity of steam admitted from which they must be warmed again.* The phenomenon of a higher terminal pressure, in cylinders working steam expansively, than the law of the gases could account for, was generally explained, until quite recently, by supposing that the valves leaked; but when it was found to be universal, and to be most remarkable where the steam was most charged with moisture, thoughtful men were not long in detecting the true cause. The temperature of this moisture, as it enters the cylinder, is the same as that of the steam, and being in great part relieved from pressure by the expansion, it will instantly assume the gaseous form, provided the heat, which must be rendered latent on its change of state, is furnished. This is abstracted from the surfaces with which the particles of moisture come in contact, and the excess of terminal pressure above that which should exist measures the heat thus lost, and which must be regained at the commencement of the next stroke from the entering steam. If the steam enters the cylinder nearly dry, this process, when the cylinder becomes heated, soon reaches a very moderate point, as is illustrated in diagram No. 6, where the theoretical curve is closely approximated to. Diagrams No. 7 and 8, on the

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* The recent experiments of Professor Tyndall reveal the astounding fact, that the power of aqueous vapor, at the pressure of the atmosphere, to absorb heat, is 6,000 times greater than that of dry air.

contrary, being taken at the Great Exhibition of 1862, where the steam was charged with moisture in an excessive degree, show a great amount of re-evaporation to have taken place, as the pressure fell in the cylinder.

The best means at present known for diminishing the loss from this cause is, to dry the steam by moderate superheating, perhaps sufficient to affect the thermometer but very slightly, since every atom of moisture must change its state to steam before the temperature can rise above that due to the pressure. The height of the terminal pressure, as shown by the Indicator, above that which the law of Mariotte and the law of contraction of gases by cooling call for, affords some indication of the loss from this cause. If the curve drawn could agree with the requirements of these laws, there would be demonstrably no loss at all; but this is not attainable. Indeed, the higher temperature of the cylinder would probably affect sensibly the fall of pressure, even if the steam was perfectly anhydrous. It is obvious, that the percentage of loss will be diminished, other circumstances being the same, in proportion as the speed of piston is increased, the actual loss continuing the same, but the power exerted becoming greater. Whether the employment of two cylinders enables this loss to be avoided to a greater extent than it can be in a single cylinder, must at present be regarded as an open question, and is one the discussion of which is foreign to the purpose of this work.

To expand steam properly, it is essential that it be cut off instantaneously—that is, that the port shall be closed so quickly, that the pressure shall not fall in the cylinder, from the advance of the piston during the operation of closing. This Indicator enables us to pronounce unerringly upon the value of every means which is employed to effect this object.

Diagram No. 6 shows unquestionably the closest approximation to this requirement. It was taken from an engine in the city of New York, of the celebrated style known as the Corliss Engine, which is extensively used in the eastern part of the United States for stationary purposes. The speed of piston of this engine was 420 feet per minute.

Diagrams 9 and 13 show the cut-off made by the Sickels valve-gear, also in extensive use in the United States, especially on boats and vessels. No. 9 was taken from a non-condensing stationary engine, making 30 revolutions per minute, and No. 13 from the engines of a steamship at 16 revolutions per minute. It is hardly necessary to add that these were not taken with the Richards Indicator. The theoretical expansion curves cannot be drawn on either of these diagrams, because the amount of waste room, which is considerable, from the nature of the valves employed, is not known.

The speed of piston in each was about 300 feet per minute.

Diagrams Nos. 7 and 8 were taken from the Allen Engine at the Great Exhibition of 1862, at a speed of piston of 600 feet per minute. The pressure fell somewhat at this great speed, as the closing movement of the valve was being completed, giving a rounded corner. In Diagram No. 7 we find the expansion curve changed to a waving line. The pressure of steam was removed from the piston of the Indicator with such extreme suddenness that the reaction of the spring was necessarily violent; but the rounded, flowing nature of the oscillations show the action of the instrument to have been frictionless, and these gradually subside into the correct curve, which the mean of the oscillations gives throughout, as shown. Diagram No. 10, from the engines of a steamship, shows very superior action of the cut-off gear.

The vice which is the opposite of this excellence is technically termed wiredrawing, and consists in a gradual fall of pressure in the cylinder, while the port is being closed. It is illustrated in various degrees in several of these diagrams, and is a source of serious loss. The object of cutting off is, to obtain the greatest mean pressure with the lowest terminal pressure, and it is clear that the sharper the cut-off the more completely this object is attained. For example, in diagram No. 1, the steam expands to a pressure of 17 lbs. at the point of release, and a mean pressure of 21.28 lbs. is exerted during the stroke; had it been cut off sharply at the point *c*, it would have expanded to a pressure of 9 lbs. at the point of release, describing the curve *c g*, and would have exerted a mean pressure of 15.87 lbs. But 21.28 : 15.87 : : 17 : 12.67. The gain of steam from cutting off sharply would be then 12.67 - 9=3.67 lbs., or 29 per cent. But this is by no means the full amount of the gain, for so much less steam being to condense, 1 lb. better vacuum at least would have been formed, and the boilers would easily have maintained a pressure 5 lbs. higher, with much more moderated firing; so that the full mean pressure of 21.28 lbs. would have been obtained by cutting off at the point *c*, and expanding to a terminal pressure of 10.5 lbs., a gain of 6.5 lbs., or 38 per cent., and improvements equal to this have by this single means been often realized in practice. The slide-valve in its best form wiredraws the steam considerably, unless a great travel is given to it; the vicious practice of making the end V-shaped of course raises the loss from this cause to the very highest point.

Diagram No. 14 shows the action of a single slide-valve with a serrated end, expressly contrived to wiredraw the steam as much more than it can be with the ordinary slide as possible.

The mean pressure for different points of cut-off, may be found by

HYPERBOLICAL LOGARITHMS.

RULE.—Divide the length of the stroke by the length of the space into which the steam is admitted; find in Table No. IV. the logarithm of the number nearest to the quotient, to which add 1, the sum is the ratio of the gain; then find the terminal pressure, by dividing the initial pressure by the proportion of the stroke during which the steam is admitted, and multiply it by the logarithm + 1, found as above; the product will be the mean pressure through the stroke.

EXAMPLE.—Suppose the length of the stroke to be 48 inches, the initial pressure to be 40 lbs. per square inch, and the steam to be cut off at 12 inches of the stroke, what will be the mean pressure?

$48 \div 12 = 4$. Hyp. log. of $4 = 1.38629 + 1 = 2.38629$.

Then, $40 \div 4 = 10 \times 2.38629 = 23.8629$ lbs., the mean pressure required.

To find the initial pressure, add the atmospheric pressure, 15 lbs., to the pressure shown by the gauge, and from the mean pressure found as above subtract the counter-pressure, to ascertain the actual mean pressure exerted. Thus, in the above case, the gauge is supposed to show a pressure of 25 lbs. only, and if the calculation is being made for a condensing engine, the estimated loss from imperfect vacuum must be subtracted, and if for a non-condensing engine, the pressure of the atmosphere, and also any estimated counter-pressure above that, must be subtracted from 23.8629, the mean pressure found by the calculation.

The editor remarks that the above rule requires a little qualification, to be considered correct. If the diagram shows the cut-off at $\frac{1}{4}$ of the stroke, it does not follow that $\frac{3}{4}$ is the grade of expansion, because the clearance has not been taken into account.

EXAMPLE.—Suppose the length of the stroke to be 36″; initial pressure, to be 50 lbs. per square inch, and the steam to be cut off at 9″ of the stroke, what will be the average pressure?

36÷9=4. Hyp. Log. of 4=1.38629+1=2.38629. Then 50÷4=12.5×2.38=29.75, mean pressure required. This is correct without taking the clearance into account.

Now, let us see what the result is, when we add the clearance in the following examples; which is an actual case occuring in my practice during the week in which this was written.

Engine 36″ stroke×14″ diameter, cutting off at $\frac{1}{4}$ (9″); initial pressure 50 lbs. to the square inch; revolutions per minute, 80; clearance equal to $\frac{1}{22}$ of the cubical contents of the part of the cylinder occupied by the piston stroke; or what is the same thing, $\frac{1}{22}$ of the stroke, which is equal to 1.64″, added to 9″, the point of cut-off, is 10.64″; which being divided by the length of the stroke, gives us as a quotient 3.39, with a mean pressure of 32.59 lbs., as calculated by the above rule, adding the clearance.

Computing it by the same rule, without taking account of the clearance, the average pressure is 29.75 lbs. The result stands thus, computing with the clearance added................ 73.00 H. P.

Without the clearance.......... 66.64 " "

Difference..................... 6.36

In using Table No. V., the clearance must be added to get the correct mean pressure.

IV. THE EXHAUST LINE AND THE LINE OF COUNTER-PRESSURE

may properly be considered together. It is, of course, desirable that the pressure of the steam be got rid of as completely as possible before the piston commences its return stroke. This is accomplished in a non-condensing engine by having the exhaust port and passages sufficiently large, and opening the port a sufficient time before the termination of the stroke, according to the density of the steam to be released and the velocity of the piston. The passages and pipes communicating with the atmosphere should be at least 50 per cent. larger than the ports, and as free from angles as possible.

These requirements apply to condensing engines even more strongly, and in addition the condenser and air-pump must be able to maintain a proper vacuum.

Diagrams Nos. 6 and 9 show no back-pressure at all above the atmosphere; diagrams Nos. 7 and 8 show a trifling back-pressure, attributable to the number of angles in the pipe necessary for connecting with the exhaust main at the Exhibition.

Diagram No. 10 exhibits remarkable exhaust and counter-pressure lines, obtained by a surface condenser, while No. 13 shows a great loss of power from imperfect vacuum, which was very partial at the best, and that only gradually obtained.

V. THE COMPRESSION-LINE.

This line, when it exists, is formed by the closing of the exhaust port at some point before the termination of the stroke, when the advancing piston compresses the confined steam to a density proportioned to the decrease of volume. This is illustrated in various degrees in several of the diagrams here shown. This action occasions a loss of power, but not much waste of stream, because the confined steam reacts on the return stroke with a force equal to that expended to compress it. It is useful on engines running at high velocities, by taking up gradually all looseness of the joints, and preventing the entire force of the steam from striking suddenly on the piston. Indeed, so important is the compression in preventing shocks on the centres in engines of this class, that probably locomotives could not be safely run without it. At the same time, the nature of the valve and gear employed on this class of engines is such, that when cutting off very early the compression becomes excessive, involving an increase in the counter-pressure as the piston approaches the centre, which is quite unnecessary for any useful purpose, as is illustrated especially in diagram No. 4. At any ordinary number of revolutions per minute made by stationary or marine engines, the compression is not required, but in a moderate degree is never, perhaps, objectional.*

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* We do not think our author gives sufficient prominence to the advantages of compression; *all* engines *require* it, to a greater or less degree, depending, of course, on the speed and action of the valves. Our practice is, when we can control the exhaust valves, to compress from one-half to the whole initial pressure. A great point gained by compression is, to take up and store away, to assist on the return stroke the momentum of the piston and its connections with the crank; also, to fill the ports, passage-ways and clearance with exhaust steam, that we may not have to call on the boiler for it. It is certainly easier on the machine to take up slack motion of the joints thus gradually, than to take high steam on before reaching the centre. It is true, we reduce the capacity of the cylinder, but lose no steam; on the contrary, save the momentum of the reciprocating parts, by compressing a portion of the exhaust steam. When the slide-valve is used, it serves to partially balance it during the compression, thereby relieving it from friction and wear; a very important consideration, particularly on large valves. We prefer also to give very little or no steam lead; let the centre be past or nearly so, and the piston on its way back, before the steam is admitted.

Many a crank and its connections have been broken, brasses

Diagram No. 12, not taken by the Richards Indicator, shows the usual form of diagram made by the double opening slide-valves now in general use on marine engines, with an independent cut-off valve. It will be observed, that the steam line is well maintained until the cut-off valve commences to close, when the pressure falls in an increasing ratio, probably to about the pressure indicated by the dots at the exact distance of closing.

In the preparation of this paper, and in the selection of diagrams for its illustration, its object has been carefully kept in view, and while it is hoped that nothing has been omitted which is essential to guide one before unacquainted with the Indicator in learning how to employ it correctly and intelligently, care has been taken to introduce only those topics, and to consider these, only to that extent which seemed to be necessary for this purpose.

THE THEORETIC CURVE AND ITS USES.

When we wish to know the condition of the internal working of an engine from a diagram we have taken from it, we make a perfect diagram

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worn out; heating, straining, and thumping, with all their concomitant evils, are daily caused by excessive steam lead; while, by compressing, the piston meets the thin elastic vapor remaining in the cylinder without a shock. It is technically called "cushioning," a most appropriate term.

around it so we may compare the one with the other.

To do this: First, we ascertain the clearance between the piston and cover, also the areas of the ports and passage-ways clear back to the valves, both steam and exhaust, if they be separate.

This we reduce to cubic inches; we then get the cubic inches of the cylinder, or that part of it occupied by the stroke. Suppose the cylinder to be 14″ diameter, and 36″ stroke, it will contain 5541.48 cubic inches. Now, then, suppose our clearance is 206.44 cubic inches; this being divided into the contents of the stroke part of the cylinder, 5541.48, gives us 27, or is $\frac{1}{27}$ part of it. We then add to the steam end of our diagram $\frac{1}{27}$ part of its length. We then draw the line of perfect vacuum, whether it is a condensing engine or not. Then we space the whole in ten or more equal divisions, and erect lines (ordinates) on these spaces at right angles to our vacuum line, as shown in diagram No. 0.

We will suppose we have 100 lbs. from A to B, Diagram No. 0, measuring from the line A E, and we cut off at C, which is $\frac{2}{10}$ or $\frac{1}{5}$; by the law of expansion we should find (having expanded the steam $\frac{4}{5}$) the terminal pressure to be $\frac{1}{5}$ of the pressure at C, the steam having expanded, $\frac{4}{5}$ of the whole diagram. To find the point where the true curve should bisect the ordinates, we have numbered them from one to ten. We find the steam is cut off at 2, the next ordinate is 3, this being $\frac{3}{2}$ the length of 2; hence, we use 2 for the numerator and 3 for the denominator, and so on to the end, using for the numerator the number of the ordinate where the steam is cut off, and for a denominator the number of the ordinate whose length we seek.

It often happens in spacing our diagrams that we can't find a space that will come right in both divisions of the diagram. In that case we space the parts from B to C into equal spaces, say from $\frac{1}{4}''$ to $\frac{3}{8}''$ each and then space the remainder the same; if it should run over the termination of the diagram it is of no importance, as after the curve is established the measure will be taken at the terminal point. The practical application of the theoretic curve is this: If we find it below the curve given by the instrument, we seek for the cause; if the engine cuts off short, say at $\frac{1}{4}$ or less of the stroke, we may expect to find it a little, say a pound or two, above, at the last $\frac{1}{2}$ or $\frac{3}{8}$ of the stroke; this is accounted for by re-evaporation of the water condensed in the first part of the stroke. But, if it should run as it often does 10 or 15 pounds above, we conclude at once that the steam valve leaks. If we find the curve made by the instrument falling below the theoretic line, we are certain that either the piston or exhaust valve leaks, or may be both.

Diagram No. 15 was taken from an engine $24'' \times 48''$, making 50 revolutions per minute. The steam valves are of the class known as balanced poppet; the exhaust valves plain slide; point of cut-off adjusted by the action of the governor. Boiler pressure 48 lbs., steam pipe 6″ diameter by 150′ in length, the exhaust pipe 7″ diameter by 175′ long, scale of the instrument 30 lbs. to the inch; work being done, driving two trains of rolls, one of 20″, the other of 16″ diameter, with the concomitant and other machinery.

It will be observed that the pressure in the cylinder fell off some 10 lbs. from the initial in the boiler, which is easily accounted for by the great length of the steam pipe. The 2 lbs. back pressure may be accounted for by the excessive length of the exhaust pipe; these defects are no fault of the engine.

The card is a very excellent one; we rarely see its equal—no superiors, unless from an engine whose cylinder is jacketed with high steam. It will be seen that the lines given by the instrument vary but little from theoretic curve. The engine was constructed by Messrs. Woodruff & Beach, under Mr. Wm. Wright's patent.

Diagram No. 16 was taken from the top of the cylinder of the steamer Newport; it will be recognized by the engineer as very good. The steam pressure on the boiler was by the gauge 22 lbs., vacuum per gauge 26″. It will be seen that the diagram shows 20.5 lbs. The terminal point is supposed to be as should be; yet, not having the data to calculate the area of the clearance, passage-ways, etc., we cannot ascertain where the terminal point should be, exactly.

If the exhaust had opened a little earlier, it would have improved the vacuum at its commencement.

Diagram No. 17 is from an engine 24″ diameter ×48″ stroke, 60 revolutions per minute, Babcock & Wilcox patent; cylinder jacketed with steam from the boiler. The clearance is $\frac{1}{48}$ of the stroke, boiler pressure 72 lbs. to square inch, scale 40″=1″.

This engine is in the flouring mills of Messrs. Chapin, Miles & Co., Milwaukie.

The work being done when the diagrams were taken was driving 4 runs of 4′ 6″ stones, and 2 runs of 4′; 180 revolutions per minute, with all the required flouring machinery as used in such mills.

We give this data, that any one who wishes can make the theoretical curve; it will be found almost perfect.

The expansion line, it will be noticed, is somewhat waved, which is incident to the high speed, high pressure, and early opening of the valves.

The terminal point of the expansion line will be found about 3 lbs. above the true line, caused by evaporation of water that went over with the steam.

Another and unusual point is the very near approach of the pressure in the cylinder to that in the boiler, being but 2½ lbs. less. When we take into consideration the speed of the piston, 480′ per minute, the result is extraordinary and seldom attained.

Diagram No. 18; these cards were taken from a Wilcox air engine, and beautifully illustrate the delicate action of the Richards Indicator. Fig. 1 is from the working cylinder; the receiving line shows the induction valve to be slightly behind time; the pressure gradually reduces the first of the stroke, as the reservoir containing the compressed air is small, but as soon as the pump begins to deliver into the reservoir, the pressure continues uniform till the induction valve closes near the end of the stroke; the exhaust is free, and there is a slight compression at the end of the return stroke.

Fig. 2 is from the pump, which is $\frac{2}{3}$ of the capacity of the working cylinder, and shows the gradual increase of pressure as the piston descends and compresses the air; the curves or waves at the point of greater pressure show the power required to open the eduction valve; the pressure then continues uniform till the induction to the working cylinder closes, when the pressure runs up; at the commencement of the return stroke of the pump piston, the pencil mark inclines back, showing the time required for the closing of the eduction valve, and the wave below the atmospheric shows the time and power for opening the induction valve.

The working cylinder is $16'' \times 16''$ stroke, and makes 70 revolutions per minute, scale 12 lbs. to one inch.

The pump, Fig. 2, is $\frac{2}{3}$ the capacity of the working cylinder, Fig. 1; hence, we measure the average pressure of the two diagrams, each separately. Suppose the working cylinder to show an average of 10 lbs. to the square inch, and the pump diagram to show 9 lbs. to the square inch. The pump being $\frac{2}{3}$ of the capacity of the working cylinder, we divide the mean pressure, which we have assumed as 9 lbs., by 3, the quotient is 3, this added to 10 is 13; 3 subtracted from 9 leaves 6, which subtracted from 13 leaves 7 lbs. effective pressure per square inch on the piston.

Our author concludes the work with a graphic account of "A Ride on the Buffer Beam" on the Great Eastern Railway, making the trip from London to Yarmouth (England) in company with Mr. Zerah Colburn, for the purpose of taking diagrams from the engines, in which they were eminently successful; which the compiler of this, owing to the prescribed limits of this work, reluctantly feels compelled to omit, and substitute an account of a similar, though shorter, trip—from Wilmington, Del., to Philadelphia, on the Philadelphia, Wilmington and Baltimore R. R. Through the kindness of Mr. G. W. Perry, master of machinery of that road, Locomotive No. 50, a first-class express engine built by "the Taunton Locomotive Works" —cylinders 16″ diameter by 24″ stroke, four driving wheels 5′ 6″ diameter, making 305.46 revolutions to the mile—was placed at the disposal of the writer, and fitted for the occasion under his directions by Mr. S. A. Hodgman, the able and efficient master mechanic of the shops. The engine is outside connected. The diagrams were taken from the forward end of each cylinder.—Short $\frac{1}{2}''$ pipes were screwed into the top parts of the cylinder covers, with elbows $\frac{3}{4}''$ internal diameter pointing upwards, to which the Indicators were attached. An iron rail was secured to the signal flag-stands on the narrow platform in front; a packing-box some 9'' high served as a seat for each operator, with his back to the wind, and the Indicator between his knees.

The method employed for giving motion to the papers was very simple. A plank on each side of the boiler, running from the cab to the platform, about 3′ above the cross-head, and directly over it, which was used for the purpose of going forward to oil, etc., was morticed through in the proper place, and a bracket with a hole through it to secure the arm to, was bolted to the plank beside the mortice. A stud with a nut on it was fastened to the bracket, pointing outwards horizontally. A light arm swung from this stud and received a vibratory motion from another stud screwed into the side of the cross-head, working in a well-fitted slot in the lower end of the arm. A button-headed pin was inserted in this arm at about 7″ below the point of suspension, and to this was attached the cord leading directly to the Indicator, giving to the paper a motion of $4\frac{1}{4}''$. Great care was taken to set the arm, so that when the engine was on the half-stroke and the cord attached to the instrument, it might be at right angles with the arm. The cord had a hook about $2''$ long, with a bend about $1\frac{1}{4}''$ diameter, with a corresponding one on the instrument cord, which made it easy to attach under any speed. The hook on the cord was secured by two other cords to keep it in position, allowing it to move back and forth, but not to fall when disengaged, where it could not be readily seized.

It was arranged with the engineer that he should run at all times with the throttle-valve fully open, governing the speed entirely by changing the point of cut-off. Everything being ready, Mr. Hodgman, the master mechanic of the shops, and myself, prepared to mount the platform. It being the month of November, and not being very warm, an extra overcoat was put on; a pair of woollen gloves, fingers amputated at the second joint, leaving enough of the finger bare to manipulate the instruments, were found to work well.

Our first essay was with the engine and tender alone, to see that all was right. We took several diagrams, both on the forward and backward motions. We found the valves remarkably well set.

Diagram No. 19 is one of a pair that were taken when running about 20 miles per hour; working the steam full stroke, both backwards and forwards, shows how nearly the two actions correspond. Its mate from the right-hand cylinder is a perfect fac-simile of the one we engrave. In taking these cards, the throttle was quite open. Pressure of steam not noted. The scale of the instrument 40 to the inch. During these preliminary experiments, an unfortunate accident happened to one of the instruments by breaking a spring. Not having an extra 40 spring, we substituted a 30 spring in each instrument, and that we might get sufficient range, we put washers between the end of the spring and the piston, of sufficient thickness to carry the piston down to the vacuum line, thereby giving us a scope of 15 lbs. more, and sufficient to answer the requirements for 105 lbs. pressure in the cylinders. I mention this for the reason that should the young engineer meet with a similar mishap, he may be posted on the subject. The delay caused by this mishap prevented us from carrying out a programme we had made previously. At 4 P. M. the express train arrived from Baltimore, which it had been arranged for us to take to Philadelphia. We took diagrams at speeds varying from 30 to 60 or more miles per hour, with great facility, at full stroke, and cutting off at various points. In consequence of our weak springs, our experiments were limited in pressure to 105 lbs., hence we could not maintain our speed when cutting off short.

Diagram No. 20, scale 30 to the inch from the right hand cylinder, cutting off at about one fourth stroke, was taken at 60 miles per hour, piston making 1,222 feet per minute, 305.46 revolutions. Notwithstanding this extraordinary speed of piston, the lines are all well defined, showing distinctly the points of cut-off and release. A remarkable point in the diagram is, that though the pencil passed over it certainly twice or more, the lines are very near to each other, showing that even under this unprecedented speed of piston the instrument was uniform and reliable in its action. This is not a selected diagram; all others taken on the trip show the same characteristics.

Diagram No. 21, same scale, from the left-hand cylinder, cutting off one notch shorter, with a higher pressure of steam, taken next after the foregoing, exhibits the same general features, though taken under a higher speed.

Diagram No. 22, same scale, was next taken, working full stroke, with, as will be seen, throttle full open; the speed increasing to such a degree that the engineer thought it prudent to put on $\frac{1}{4}$ cut-off.

This, as do all the other diagrams taken from the engine, shows most marked points in the construction and setting of the valves; notwithstanding the great speed, the steam line is held uniform to the points of release. The exhaust line is all that can be desired. The back pressure is merely nominal, the exhaust nozzles being $4\frac{1}{4}''$ each. In getting the diagrams, the writer was ably seconded by Mr.

Hodgman, who, though it was his first attempt at taking diagrams, was remarkably efficient and correct.

We have spoken of the accuracy of the valve-setting. These valves were set wholly by marks on the wheels, slides, and valve-rods, with steam on, and of course valve-chest covered, which is the only method by which they can be correctly set, owing to the expansion of the parts by heat.

We would here refer the engineer who wishes to be well informed on the important art of valve-setting, to a very excellent work on the slide valve and link motion by Mr. W. S. Auchincloss, recently published by D. Van Nostrand, 23 Murray-street, New York, which is the result of great research and practical experience; from which we copy:

"HOW TO SET A SLIDE VALVE HAVING EQUALIZED EXHAUST.

"1. Place the crank at the 180° location, mark on the cross-head and one of its guides opposing 'centre punch' points.

"2. Bring the crank to the zero and mark a second point on the guide. The two points thus found, measure the length of the stroke. Move the eccentric until the valve has the required lead for the forward stroke.

"3. Advance the crank in the direction of the motion until the exhaust of the opposite stroke closes; scribe a line across the guide which shall pass through the point on the cross-head.

"4. Move the crank until the other exhaust closes and scribe a second line on the guide.

"5. If now the exhaust should close at equal distances from the commencement of each stroke, the motion would be in adjustment; if not, alter the length of the eccentric rod until the closure becomes equalized, then return the crank to the zero position, and alter the angular advance of the eccentric until the required lead of the forward stroke is secured.

"The position of the valve at the moment of closure may readily be fixed by means of a 'valve gauge' fitting centre punch points on the valve stem and its stuffing box.

"The above process will serve also to equalize the cut-off if the valve be proportioned for this object."

The trip was not without its discomforts, however successful it might have been, being accomplished on a November afternoon, with rather a low thermometer; with nothing at our backs to break off the wind, with low seats and otherwise constrained positions, we at the conclusion of our trip found ourselves somewhat cold and a little stiff. Had it been a summer day, this source of discomfort would not have been, and we should have enjoyed the excitement of our trip much.

So far as it is known to the writer, the above is the first successful application of the Indicator to a locomotive, when making a regular trip on the road, in this country. It is quite certain that there is no Indicator known but the Richards, that can be successfully used for the purpose. We will conclude with Mr. Porter's concluding paragraphs of his "Ride on a Buffer-Beam :"

"These diagrams are taken under fewer difficulties than would be at first imagined, if the weather is pleasant, and the proper provision is made for the comfort and security of the operators. The principal difficulty is from the wind, which, at very high speed, approaches more nearly to a hurricane than anything that one is able to experience in this latitude in any other way, and the labor of resisting it becomes quite wearisome, if the operator is not somewhat protected from its force. No unpleasant sensation whatever is produced by the rapid motion, the passing of trains is scarcely observed, and if no accident happens, there is no danger more than in the carriages. Good weather is essential to the satisfactory accomplishment of the objects of such an excursion."

TABLE No. I.—Areas of Circles, advancing by 10ths.

Diam'r.	AREAS.										Diam'r.
	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9	
0	.0	.0078	.0314	.0706	.1256	.1963	.2827	.3848	.5026	.6361	0
1	.7854	.9503	1.1309	1.3273	1.5393	1.7671	2.0106	2.2698	2.5446	2.8352	1
2	3.1416	3.4636	3.8013	4.1547	4.5239	4.9087	5.3093	5.7255	6.1575	6.6052	2
3	7.0686	7.5476	8.0424	8.5530	9.0792	9.6211	10.1787	10.7521	11.3411	11.9459	3
4	12.5664	13.2025	13.8544	14.5220	15.2053	15.9043	16.6190	17.3494	18.0956	18.8574	4
5	19.6350	20.4282	21.2372	22.0618	22.9022	23.7583	24.6301	25.5176	26.4208	27.3397	5
6	28.2744	29.2247	30.1907	31.1725	32.1699	33.1831	34.2120	35.2566	36.3168	37.3928	6
7	38.4846	39.5920	40.7151	41.8539	43.0085	44.1787	45.3647	46.5663	47.7837	49.0168	7
8	50.2656	51.5300	52.8102	54.1062	55.4178	56.7451	58.0881	59.4469	60.8213	62.2115	8
9	63.6174	65.0389	66.4762	67.9292	69.3979	70.8823	72.3824	73.8982	75.4298	76.9770	9
10	78.5400	80.1186	81.7130	83.3230	84.9488	86.5903	88.2475	89.9204	91.6090	93.3133	10
11	95.0334	96.7691	98.5205	100.287	102.070	103.869	105.683	107.513	109.359	111.220	11
12	113.097	114.990	116.898	118.823	120.763	122.718	124.690	126.677	128.679	130.698	12
13	132.732	134.782	136.848	138.929	141.026	143.139	145.267	147.411	149.571	151.747	13
14	153.938	156.145	158.368	160.606	162.860	165.130	167.415	169.717	172.034	174.366	14
15	176.715	179.079	181.458	183.854	186.265	188.692	191.134	193.593	196.067	198.556	15
16	201.062	203.583	206.120	208.672	211.241	213.825	216.424	219.040	221.671	224.318	16
17	226.980	229.658	232.352	235.062	237.787	240.528	243.285	246.057	248.846	251.650	17
18	254.469	257.304	260.155	263.022	265.905	268.803	271.716	274.646	277.591	280.552	18
19	283.529	286.521	289.529	292.553	295.593	298.648	301.719	304.805	307.908	311.026	19
20	314.160	317.309	320.474	323.655	326.852	330.064	333.292	336.536	339.795	343.070	20
	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9	

Areas of Circles, advancing by 10ths.

Diam'r.	AREAS.										Diam'r.
	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9	
21	346.361	349.667	352.990	356.328	359.681	363.051	366.436	369.837	373.253	376.685	21
22	380.133	383.597	387.076	390.571	394.082	397.608	401.150	404.708	408.282	411.871	22
23	415.476	419.097	422.733	426.385	430.053	433.737	437.436	441.151	444.881	448.628	23
24	452.390	456.168	459.961	463.770	467.595	471.436	475.292	479.164	483.052	486.955	24
25	490.875	494.809	498.760	502.726	506.708	510.706	514.719	518.748	522.793	526.854	25
26	530.930	535.022	539.129	543.253	547.392	551.547	555.717	559.903	564.105	568.323	26
27	572.556	576.805	581.070	585.350	589.646	593.958	598.286	602.629	606.988	611.363	27
28	615.753	620.159	624.581	629.019	633.472	637.941	642.425	646.926	651.442	655.973	28
29	660.521	665.084	669.663	674.258	678.868	683.494	688.136	692.793	697.466	702.155	29
30	706.860	711.580	716.316	721.067	725.835	730.618	735.417	740.231	745.061	749.907	30
31	754.769	759.646	764.539	769.448	774.372	779.313	784.268	789.240	794.227	799.230	31
32	804.249	809.284	814.334	819.399	824.481	829.578	834.691	839.820	844.964	850.124	32
33	855.300	860.492	865.699	870.922	876.160	881.415	886.685	891.970	897.272	902.589	33
34	907.922	913.270	918.635	924.011	929.410	934.822	940.249	945.692	951.150	956.625	34
35	962.115	967.620	973.142	978.679	984.231	989.800	995.384	1000.98	1006.60	1012.23	35
36	1017.87	1023.54	1029.21	1034.91	1040.62	1046.34	1052.09	1057.84	1063.62	1069.40	36
37	1075.21	1081.03	1086.86	1092.71	1098.58	1104.46	1110.36	1116.28	1122.21	1128.15	37
38	1134.11	1140.09	1146.08	1152.09	1158.11	1164.15	1170.21	1176.28	1182.37	1188.47	38
39	1194.59	1200.72	1206.87	1213.04	1219.22	1225.42	1231.63	1237.86	1244.10	1250.36	39
40	1256.64	1262.93	1269.23	1275.56	1281.89	1288.25	1294.62	1301.00	1307.40	1313.82	40
	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9	

Areas of Circles, advancing by 10ths.

Diam'r.	AREAS.										Diam'r.
	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9	
41	1320.25	1326.70	1333.16	1339.64	1346.14	1352.65	1359.18	1365.72	1372.28	1378.85	41
42	1385.44	1392.05	1398.67	1405.30	1411.96	1418.62	1425.31	1432.01	1438.72	1445.45	42
43	1452.20	1458.96	1465.74	1472.53	1479.34	1486.17	1493.01	1499.87	1506.74	1513.62	43
44	1520.53	1527.45	1534.38	1541.33	1548.30	1555.28	1562.28	1569.29	1576.32	1583.37	44
45	1590.43	1597.51	1604.60	1611.71	1618.83	1625.97	1633.12	1640.30	1647.48	1654.68	45
46	1661.90	1669.13	1676.38	1683.65	1690.93	1698.23	1705.54	1712.87	1720.21	1727.57	46
47	1734.94	1742.33	1749.74	1757.16	1764.60	1772.05	1779.52	1787.01	1794.51	1802.02	47
48	1809.56	1817.10	1824.67	1832.25	1839.84	1847.45	1855.08	1862.72	1870.38	1878.05	48
49	1885.74	1893.45	1901.17	1908.90	1916.65	1924.42	1932.20	1940.00	1947.82	1955.65	49
50	1963.50	1971.36	1979.23	1987.13	1995.04	2002.96	2010.90	2018.86	2026.83	2034.82	50
51	2042.81	2050.84	2058.87	2066.92	2074.99	2083.07	2091.17	2099.28	2107.41	2115.56	51
52	2123.72	2131.89	2140.08	2148.29	2156.51	2164.75	2173.01	2181.28	2189.56	2197.87	52
53	2206.18	2214.52	2222.87	2231.23	2239.61	2248.01	2256.42	2264.85	2273.29	2281.75	53
54	2290.22	2298.71	2307.22	2315.74	2324.28	2332.83	2341.40	2349.98	2358.58	2367.20	54
55	2375.83	2384.48	2393.14	2401.82	2410.51	2419.22	2427.95	2436.69	2445.45	2454.22	55
56	2463.01	2471.81	2480.63	2489.47	2498.32	2507.19	2516.07	2524.97	2533.88	2542.81	56
57	2551.76	2560.72	2569.70	2578.69	2587.70	2596.72	2605.76	2614.12	2623.89	2632.98	57
58	2642.08	2651.20	2660.33	2669.48	2678.65	2687.83	2697.03	2706.24	2715.47	2724.71	58
59	2733.97	2743.25	2752.54	2761.85	2771.17	2780.51	2789.86	2799.23	2808.62	2818.02	59
60	2827.44	2836.87	2846.32	2855.78	2865.26	2874.76	2884.26	2893.79	2903.34	2912.89	60
	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9	

Areas of Circles, advancing by 10ths.

Diam'r.	AREAS. .0	.1	.2	.3	.4	.5	.6	.7	.8	.9	Diam'r.
61	2922.47	2932.06	2941.66	2951.28	2960.92	2970.57	2980.24	2989.93	2999.63	3009.34	61
62	3019.07	3028.82	3038.58	3048.36	3058.15	3067.96	3077.79	3087.63	3097.49	3107.36	62
63	3117.25	3127.15	3137.07	3147.01	3156.96	3166.92	3176.91	3186.90	3196.92	3206.95	63
64	3216.99	3227.05	3237.13	3247.22	3257.33	3267.46	3277.59	3287.75	3997.92	3308.11	64
65	3318.31	3328.53	3338.76	3349.01	3359.28	3369.56	3379.85	3390.17	3400.49	3410.84	65
66	3421.20	3431.57	3441.96	3452.37	3462.79	3473.23	3483.68	3494.16	3504.64	3515.14	66
67	3525.66	3536.19	3546.74	3557.30	3567.88	3578.47	3589.08	3599.71	3610.35	3621.01	67
68	3631.68	3642.37	3653.08	3663.80	3674.54	3685.29	3696.06	3706.84	3717.64	3728.45	68
69	3739.28	3750.13	3760.99	3771.87	3782.76	3793.67	3804.60	3815.54	3826.50	3837.47	69
70	3848.46	3859.46	3870.48	3881.51	3892.56	3903.63	3914.71	3925.81	3936.92	3948.05	70
71	3959.20	3970.36	3981.53	3992.73	4003.93	4015.16	4026.40	4037.65	4048.92	4060.21	71
72	4071.51	4082.83	4094.16	4105.51	4116.87	4128.25	4139.65	4151.06	4162.49	4173.93	72
73	4185.39	4196.87	4208.36	4219.86	4231.38	4242.92	4254.48	4266.04	4277.63	4289.23	73
74	4300.85	4312.48	4324.12	4335.79	4347.47	4359.16	4370.87	4382.60	4394.34	4406.10	74
75	4417.87	4429.66	4441.46	4453.28	4465.12	4476.97	4488.84	4500.72	4512.62	4524.54	75
76	4536.47	4548.41	4560.37	4572.35	4584.35	4596.35	4608.38	4620.42	4632.47	4644.54	76
77	4656.63	4668.73	4680.85	4692.99	4705.14	4717.30	4729.49	4741.68	4753.96	4766.12	77
78	4778.37	4790.63	4802.90	4815.20	4827.50	4839.83	4852.16	4864.52	4876.89	4889.27	78
79	4901.68	4914.09	4926.53	4938.98	4951.44	4963.92	4976.42	4988.93	5001.45	5014.00	79
80	5026.56	5039.13	5051.72	5064.32	5076.95	5089.58	5102.24	5114.90	5127.59	5140.29	80
	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9	

Areas of Circles, advancing by 10ths.

Diam'r.	AREAS.										Diam'r.
	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9	
81	5153.00	5165.74	5178.48	5191.25	5204.02	5216.82	5229.63	5242.45	5255.29	5268.15	81
82	5281.02	5293.91	5306.82	5319.74	5332.67	5345.62	5358.59	5371.57	5384.57	5397.59	82
83	5410.62	5423.66	5436.72	5449.80	5462.89	5476.00	5489.12	5502.26	5515.42	5528.59	83
84	5541.78	5554.98	5568.20	5581.43	5594.68	5607.95	5621.23	5634.53	5647.84	5661.17	84
85	5674.51	5687.87	5701.25	5714.64	5728.04	5741.47	5754.90	5768.36	5781.83	5795.31	85
86	5808.81	5822.33	5835.86	5849.41	5862.97	5876.55	5890.15	5903.76	5917.39	5931 03	86
87	5944.69	5958.36	5972.05	5985.76	5999.48	6013.21	6026.97	6040.73	6054.52	6068.32	87
88	6082.13	6095.96	6109.81	6123.67	6137.55	6151.44	6165.35	6179.28	6193.22	6207.18	88
89	6221.15	6235.14	6249.14	6263.16	6277.19	6291.20	6305.31	6319.39	6333.49	6347.61	89
90	6361.74	6375.88	6390.04	6404.22	6418.41	6432.62	6446.84	6461.08	6475.34	6489.61	90
91	6503.89	6518.19	6532.51	6546.85	6561.20	6575.56	6589.94	6604.34	6618.75	6633.18	91
92	6647.62	6662.08	6676.55	6691.05	6705.55	6720.07	6734.61	6749.16	6763.73	6778.32	92
93	6792.92	6807.54	6822.17	6836.82	6851.48	6866.16	6880.85	6895.56	6910.29	6925.03	93
94	7939.79	6954.56	6969.35	6984.16	6998.98	7013.81	7028.67	7043.53	7058.42	7073.32	94
95	7088.23	7103.16	7118.11	7133.07	7148.05	7163.04	7178.05	7193.07	7208.11	7223.17	95
96	7238.24	7253.33	7268.43	7283.55	7298.69	7313.84	7329 00	7344.18	7359.38	7374.59	96
97	7389.82	7405.07	7420.33	7435.60	7450.90	7466.20	7481.53	7496.87	7512.22	7527.59	97
98	7542.98	7558.38	7573.80	7589.23	7604.68	7620.14	7635.62	7651.19	7666.63	7682.16	98
99	7697.70	7713.26	7728.83	7744.42	7760.03	7775.65	7791.29	7806.94	7822.61	7838.29	99
100	7854.00	7869.71	7885.44	7901.19	7916.95	7932.73	7948.53	7964.34	7980.16	7996.00	100
	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9	

Circumferences of Circles, advancing by 10ths.

Diameter.	CIRCUMFERENCES.									
	0	.1	.2	.3	.4	.5	6	.7	.8	.9
0	.00	.31	.62	.94	1.25	1.57	1.88	2.19	2.51	2.82
1	3.14	3.45	3.76	4.08	4.39	4.71	5.02	5.34	5.65	5.96
2	6.28	6.59	6.91	7.22	7.53	7.85	8.16	8.48	8.79	9.11
3	9.42	9.73	10.05	10.36	10.68	10.9	11.30	11.62	11.93	12.25
4	12.56	12.88	13.19	13.50	13.82	14.13	14.45	14.76	15.07	15.39
5	15.70	16.02	16.33	16.65	16.96	17.27	17.59	17.90	18.22	18.53
6	18.84	19.16	19.47	19.79	20.10	20.42	20.73	21.04	21.36	21.67
7	21.99	22.30	22.61	22.93	23.24	23.56	23.87	24.19	24.50	24.81
8	25.13	25.44	25.76	26.07	26.38	26.70	27.01	27.33	27.64	27.96
9	28.27	28.58	28.90	29.21	29.53	29.84	30.15	30.47	30.78	31.10
10	31.41	31.73	32.04	32.35	32.67	32.98	33.30	33.61	33.92	34.24
11	34.55	34.87	35.18	35.50	35.81	36.12	36.44	36.75	37.07	37.38
12	37.69	38.01	38.32	38.64	38.95	39.27	39.58	39.89	40.21	40.52
13	40.84	41.15	41.46	41.78	42.09	42.41	42.72	43.03	43.35	43.66
14	43.98	44.29	44.61	44.92	45.23	45.55	45.86	46.18	46.49	46.80
15	47.12	47.43	47.75	48.06	48.38	48.69	49.00	49.32	49.63	49.95
16	50.26	50.57	50.89	51.20	51.52	51.83	52.15	52.46	52.77	53.09
17	53.40	53.72	54.03	54.34	54.60	54.97	55.29	55.60	55.92	56.23
18	56.54	56.86	57.17	57.49	57.80	58.11	58.43	58.74	59.06	59.37
19	59.69	60.00	60.31	60.63	60.94	61.26	61.57	61.88	62.20	62.51
20	62.83	63.14	63.46	63.77	64.08	64.40	64.71	65.03	65.34	65.65
21	65.97	66.28	66.60	66.79	67.29	67.54	67.85	68.17	68.48	68.80
22	69.11	69.42	69.74	70.05	70.37	70.68	71.00	71.31	71.62	71.94
23	72.25	72.57	72.88	73.19	73.51	73.82	74.14	74.45	74.76	75.08
24	75.39	75.71	76.02	76.34	76.65	76.96	77.28	77.59	77.91	78.22
25	78.54	78.85	79.16	79.48	79.79	80.11	80.42	80.73	81.05	81.36
26	81.68	81.99	82.30	82.62	82.93	83.25	83.56	83.88	84.19	84.50
27	84.82	85.13	85.45	85.76	86.07	86.39	86.70	87.02	87.33	87.65
28	87.96	88.27	88.59	88.90	89.22	89.53	89.84	90.16	90.47	90.79
29	91.10	91.42	91.73	92.04	92.36	92.67	92.99	93.30	93.61	93.93
30	94.24	94.56	94.87	95.19	95.50	95.81	96.13	96.44	96.76	97.07
31	97.38	97.70	98.01	98.33	98.64	98.96	99.27	99.58	99.90	100.2
32	100.5	100.8	101.1	101.4	101.7	102.1	102.4	102.7	103.0	103.3
33	103.6	103.9	104.3	104.6	104.9	105.2	105.5	105.8	106.1	106.5
34	106.8	107.1	107.4	107.7	108.0	108.3	108.6	109.0	109.3	109.6
35	109.9	110.2	110.5	110.8	111.2	111.5	111.8	112.1	112.4	112.7

Circumferences of Circles, advancing by 10ths.

Diameter.	CIRCUMFERENCES.									
	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
36	113.0	113.4	113.7	114.0	114.3	114.6	114.9	115.2	115.6	115.9
37	116.2	116.5	116.8	117.1	117.4	117.8	118.1	118.4	118.7	119.0
38	119.3	119.6	120.0	120.3	120.6	120.9	121.2	121.5	121.8	122.2
39	122.5	122.8	123.1	123.4	123.7	124.0	124.4	124.7	125.0	125.3
40	125.6	125.9	126.2	126.6	126.9	127.2	127.5	127.8	128.1	128.4
41	128.8	129.1	129.4	129.7	130.0	130.3	130.6	131.0	131.3	131.6
42	131.9	132.2	132.5	132.8	133.2	133.5	133.8	134.1	134.4	134.7
43	135.0	135.4	135.7	136.0	136.3	136.6	136.9	137.2	137.6	137.9
44	138.2	138.5	138.8	139.1	139.4	139.8	140.1	140.4	140.7	141.0
45	141.3	141.6	142.0	142.3	142.6	142.9	143.2	143.5	143.8	144.1
46	144.5	144.8	145.1	145.4	145.7	146.0	146.3	146.7	147.0	147.3
47	147.6	147.9	148.2	148.5	148.9	149.2	149.5	149.8	150.1	150.4
48	150.7	151.1	151.4	151.7	152.0	152.3	152.6	152.9	153.3	153.6
49	153.9	154.2	154.5	154.8	155.1	155.5	155.8	156.1	156.4	156.7
50	157.0	157.3	157.7	158.0	158.3	158.6	158.9	159.2	159.5	159.9
51	160.2	160.5	160.8	161.1	161.4	161.7	162.1	162.4	162.7	163.0
52	163.3	163.6	163.9	164.3	164.6	164.9	165.2	165.5	165.8	166.1
53	166.5	166.8	167.1	167.4	167.7	168.0	168.3	168.7	169.0	169.3
54	169.6	169.9	170.2	170.5	170.9	171.2	171.5	171.8	172.1	172.4
55	172.7	173.1	173.4	173.7	174.0	174.3	174.6	174.9	175.3	175.6
56	175.9	176.2	176.5	176.8	177.1	177.5	177.8	178.1	178.4	178.7
57	179.0	179.3	179.6	180.0	180.3	180.6	180.9	181.2	181.5	181.8
58	182.2	182.5	182.8	183.1	183.4	183.7	184.0	184.4	184.7	185.0
59	185.3	185.6	185.9	186.2	186.6	186.9	187.2	187.5	187.8	188.1
60	188.4	188.8	189.1	189.4	189.7	190.0	190.3	190.6	191.0	191.3
61	191.6	191.9	192.2	192.5	192.8	193.2	193.5	193.8	194.1	194.4
62	194.7	195.0	195.4	195.7	196.0	196.3	196.6	196.9	197.2	197.6
63	197.9	198.2	198.5	198.8	199.1	199.4	199.8	200.1	200.4	200.7
64	201.0	201.3	201.6	202.0	202.3	202.6	202.9	203.2	203.5	203.8
65	204.2	204.5	204.8	205.1	205.4	205.7	206.0	206.4	206.7	207.0
66	207.3	207.6	207.9	208.2	208.6	208.9	209.2	209.5	209.8	210.1
67	210.4	210.8	211.1	211.4	211.7	212.0	212.3	212.6	213.0	213.3
68	213.6	213.9	214.2	214.5	214.8	215.1	215.5	215.8	216.1	216.4
69	216.7	217.0	217.3	217.7	218.0	218.3	218.6	218.9	219.2	219.5
70	219.9	220.2	220.5	220.8	221.1	221.4	221.7	222.1	222.4	222.7

Circumferences of Circles, advancing by 10ths.

Diameter.	CIRCUMFERENCES.									
	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
71	223.0	223.3	223.6	223.9	224.3	224.6	224.9	225.2	225.5	225.8
72	226.1	226.5	226.8	227.1	227.4	227.7	228.0	228.3	228.7	229.0
73	229.3	229.6	229.9	230.2	230.5	230.9	231.2	231.5	231.8	232.1
74	232.4	232.7	233.1	233.4	233.7	234.0	234.3	234.6	234.9	235.3
75	235.6	235.9	236.2	236.5	236.8	237.1	237.5	237.8	238.1	238.4
76	238.7	239.0	239.3	239.7	240.0	240.3	240.6	240.9	241.2	241.5
77	241.9	242.2	242.5	242.8	243.1	243.4	243.7	244.1	244.4	244.7
78	245.0	245.3	245.6	245.9	246.3	246.6	246.9	247.2	247.5	247.8
79	248.1	248.5	248.8	249.1	249.4	249.7	250.0	250.3	250.6	251.0
80	251.3	251.6	251.9	252.2	252.5	252.8	253.2	253.5	253.8	254.1
81	254.4	254.7	255.0	255.4	255.7	256.0	236.3	256.6	256.9	257.2
82	257.6	257.9	258.2	258.5	258.8	259.1	259.4	259.8	260.1	260.4
83	260.7	261.0	261.3	261.6	262.0	262.3	262.6	262.9	263.2	263.5
84	263.8	264.2	264.5	264.8	265.1	265.4	265.7	266.0	266.4	266.7
85	267.0	267.3	267.6	267.9	268.2	268.6	268.9	269.2	269.5	269.8
86	270.1	270.4	270.8	271.1	271.4	271.7	272.0	272.3	272.6	273.0
87	273.3	273.6	273.9	274.2	274.5	274.8	275.2	275.5	275.8	276.1
88	276.4	276.7	277.0	277.4	277.7	278.0	278.3	278.6	278.9	279.2
89	279.6	279.9	280.2	280.5	280.8	281.1	281.4	281.8	282.1	282.4
90	282.7	283.0	283.3	283.6	284.0	284.3	284.6	284.9	285.2	285.5
91	285.8	286.1	286.5	286.8	287.1	287.4	287.7	288.0	288.3	288.7
92	289.0	289.3	289.6	289.9	290.2	290.5	290.9	291.2	291.5	291.8
93	292.1	292.4	292.7	293.1	293.4	293.7	294.0	294.3	294.6	294.9
94	295.3	295.6	295.9	296.2	296.5	296.8	297.1	297.5	297.8	298.1
95	298.4	298.7	299.0	299.3	299.7	300.0	300.3	300.6	300.9	301.2
96	301.5	301.9	302.2	302.5	302.8	303.1	303.4	303.7	304.1	304.4
97	304.7	305.0	305.3	305.6	305.9	306.3	306.6	306.9	307.2	307.5
98	307.8	308.1	308.5	308.8	309.1	309.4	309.7	310.0	310.3	310.7
99	311.0	311.3	311.6	311.9	312.2	312.5	312.9	313.2	313.5	313.8
100	314.1	314.4	314.7	315.1	315.4	315.7	316.0	316.3	316.6	316.9

If the areas of larger cylinders are required, they will be found by the following Rule :—Multiply the square of the diameter by the decimal .7854, and the product will be the area in square inches ; or, multiply half the circumference by half the diameter.

TABLE No. II.

Showing the weight of the atmosphere, in lbs. avoirdupois, on 1 *square inch, corresponding with different heights of the barometer, from* 28 *inches to* 31 *inches, varying by tenths of an inch.*

Barometer in Inches.	Atmosphere in lbs.	Barometer in Inches.	Atmosphere in lbs.	Barometer in Inches.	Atmosphere in lbs.
28.0	13.72	29.1	14.26	30.1	14.75
28.1	13.77	29.2	14.31	30.2	14.80
28.2	13.82	29.3	14.36	30.3	14.85
28.3	13.87	29.4	14.41	30.4	14.90
28.4	13.92	29.5	14.46	30.5	14.95
28.5	13.97	29.6	14.51	30.6	15.00
28.6	14.02	29.7	14.56	30.7	15.05
28.7	14.07	29.8	14.61	30.8	15.10
28.8	14 12	29.0	14.66	30.9	15.15
28.9	14.17	30.0	14.70	31.0	15.19
29.0	14.21				

Elastic force in		Tempe-rature.	Volume.	Elastic force in		Tempe-rature.	Volume.
Inches of Merc'y.	Pounds per Sq. In.			Inches of Merc'y.	Pounds per Sq. in.		
193.82	95.	328.2	310	306.	150.	363.4	205
203.99	100.	332.	295	316.19	155.	366.	198
214.19	105.	335.8	282	326.39	160.	368.7	193
224.39	110.	339.2	271	336.59	165.	371.1	187
234.59	115.	342.7	259	346.79	170.	373.6	183
244.79	120.	345.8	251	357.	175.	376.	178
254.99	125.	349.1	240	367.2	180.	378.4	174
265.19	130.	352.1	233	377.1	185.	380.6	169
275.39	135.	355.	224	387.6	190.	382.9	166
285.59	140.	357.9	218	397.8	195.	384.7	161
295.79	145.	360.6	210	408.	200.	387.3	158

TABLE No. IV.

No.	Logarithm.	No.	Logarithm.	No.	Logarithm.
1.25	.22314	5.	1.60943	9.5	2.25129
1.5	.40546	5.25	1.65822	10.	2.30258
1.75	.55961	5.5	1.70474	11.	2.39789
2.	.69314	5.75	1.74919	12.	2.48490
2.25	.81093	6.	1.79175	13.	2.56494
2.5	.91629	6.25	1.83258	14.	2.63905
2.75	1.01160	6.5	1.87180	15.	2.70805
3.	1.09861	6.75	1.90954	16.	2.77258
3.25	1.17865	7.	1.94591	17.	2.83321
3.5	1.25276	7.25	1.98100	18.	2.89037
3.75	1.32175	7.5	2.01490	19.	2.94443
4.	1.38629	7.75	2.04769	20.	2.99573
4.25	1.44691	8.	2.07944	21.	3.04452
4.5	1.50507	8.5	2.14006	22.	3.09104
4.75	1.55814	9.	2.19722		

TABLE No. V.

Table of Steam used Expansively.

Initial Pressure, lbs. per square inch.	Average Pressure of steam in lbs. per. square inch for the whole stroke.					
	Portion of stroke at which steam is cut off.					
	¾	⅝	½	⅜	¼	⅛
5	4.8	4.6	4.2	3.7	2.9	1.9
10	9.6	9.1	8.4	7.4	5.9	3.8
15	14.4	13.7	12.7	11.1	8.9	5.7
20	19.2	18.3	16.9	14.8	11.9	7.6
25	24.1	22.9	21.1	18.5	14.9	9.5
30	28.9	27.5	25.4	22.2	17.9	11.5
35	33.8	32.1	29.6	25.9	20.8	13.4
40	37.5	36.7	33.8	29.6	23.8	15.4
45	43.4	41.3	38.1	33.3	26.8	17.3
50	48.2	45.9	42.3	37.0	29.8	19.2
60	57.8	55.1	50.7	44.5	35.7	23.1
70	67.4	64.3	59.2	52.4	41.7	26.9
80	77.1	73.5	67.7	59.3	47.7	30.8
90	86.7	82.6	76.1	66.7	53.6	34.6
100	96.3	91.8	84.6	74.1	59.6	38.4
110	106.0	101.0	93.1	81.5	65.6	42.5
120	115.2	110.2	101.5	89.4	71.5	46.1
130	125.4	119.1	110.0	95.3	77.5	50.0
140	134.9	128.6	118.5	103.8	83.3	53.8
150	144.7	137.8	126.4	111.2	89.4	57.7
160	153.6	147.0	135.4	118.2	95.4	61.5
180	173.5	164.6	152.3	132.9	107.3	69.2
200	192.7	183.7	169.3	148.3	119.3	76.9

We insert the Table No. V, not for general use in determining the mean pressure, as we have seen in the example on page 62, that another element, the clearance, has to be taken into account to get a correct result. Now, it is seldom we can get at the drawings or patterns to get the measurement of the clearance, hence we must seek some other mode.

We can easily find if the engine is tight or not, by taking off the cylinder cover, putting the engine on the half stroke, blocking the fly-wheel, and letting steam on the opposite side of the piston. Suppose we find it tight in valves and piston, we then replace the cover and take some diagrams, and find the mean by measurement, as directed on page 62. We then refer to the table for the mean pressure, which will be found too low when compared with the result by measurement. Then, this excess given by measurement over the table is approximately the clearance.

The editor is responsible for the above. He is aware that it is, at best, but an *approximation*, owing to the condition of the steam, whether wet or dry, influenced, also, by the point of cut-off, pressure of steam, etc. The engineer has to adopt this mode, or guess, or he may avail himself of both.

Where time and circumstances permit, the clearance may be accurately found, if the piston is tight, as follows: Put the engine on the centre, remove the cover of the valve chest, uncover the steam-port on the end where the piston is, and pour in water until it is filled level with the valve seat; wait a few minutes, and if it maintains its level we know it is tight; then draw off the water, measure or weigh it, reduce it to cubic inches, and we have it exactly. Should the piston leak, we remove it out of our way; cut a segment from soft wood of sufficient length and width to cover the port at its entrance to the cylinder, fasten it in its place, and fill with water as above. To this must be added the clearance between piston, when on the centre and cover.

Again, the clearance being known and added, we compute them by measurement. If the mean pressure falls short of that, we know that there is a leak in the exhaust valves or piston. If it overruns that, we know the cut-off valves leak. Hence the utility of the table is to make those points manifest.*

DIAGRAM No. 0.

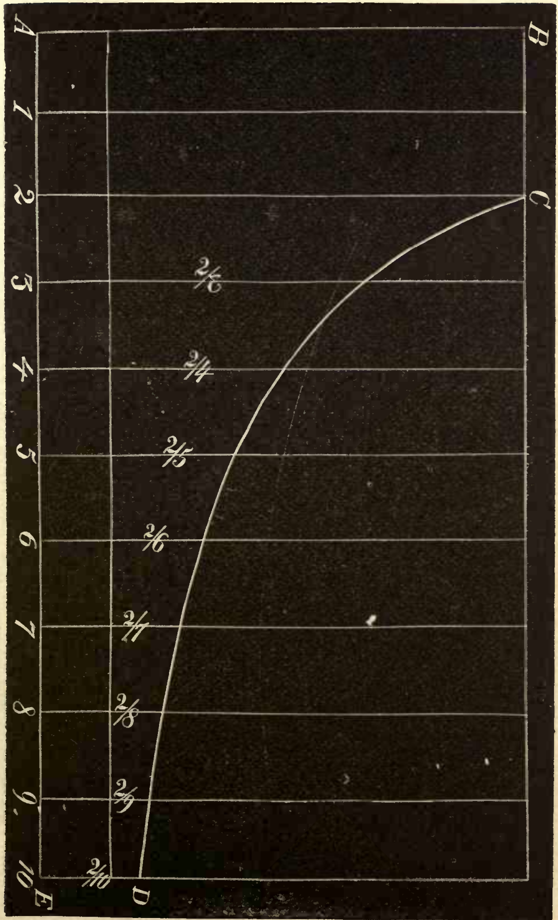
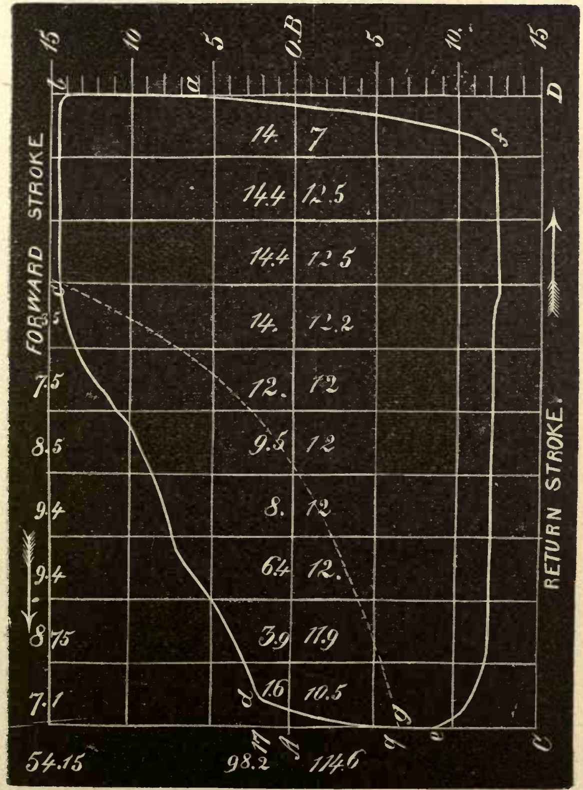
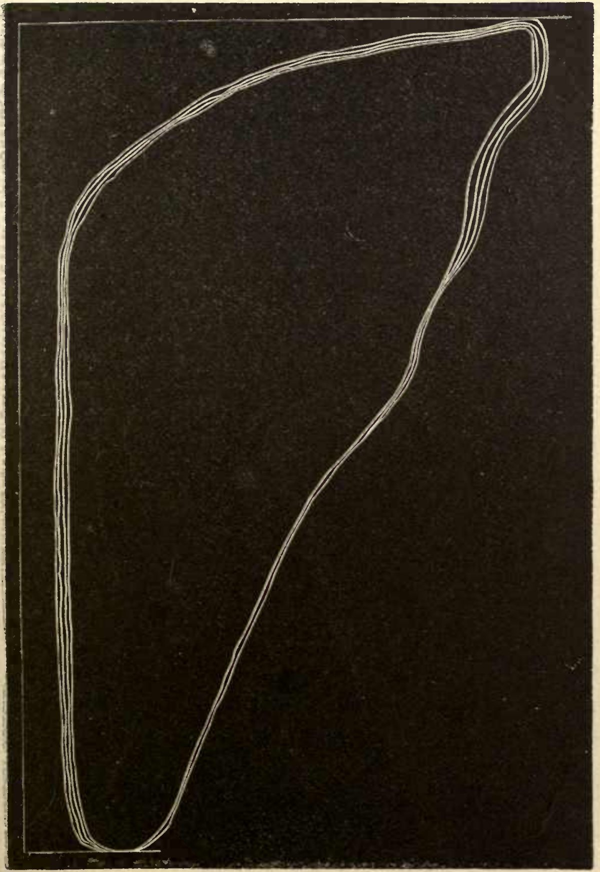


DIAGRAM No. 1.



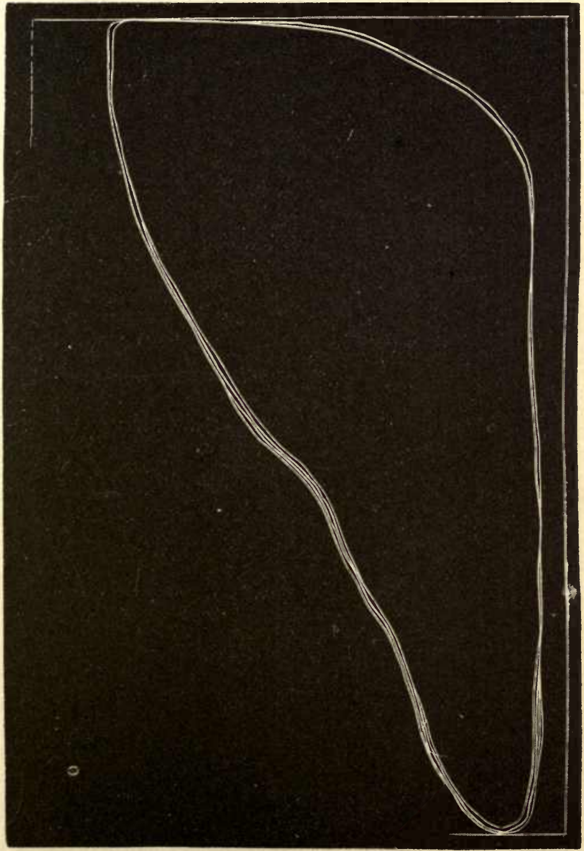
Scale, 12 lbs. to the inch.

DIAGRAM No. 2.



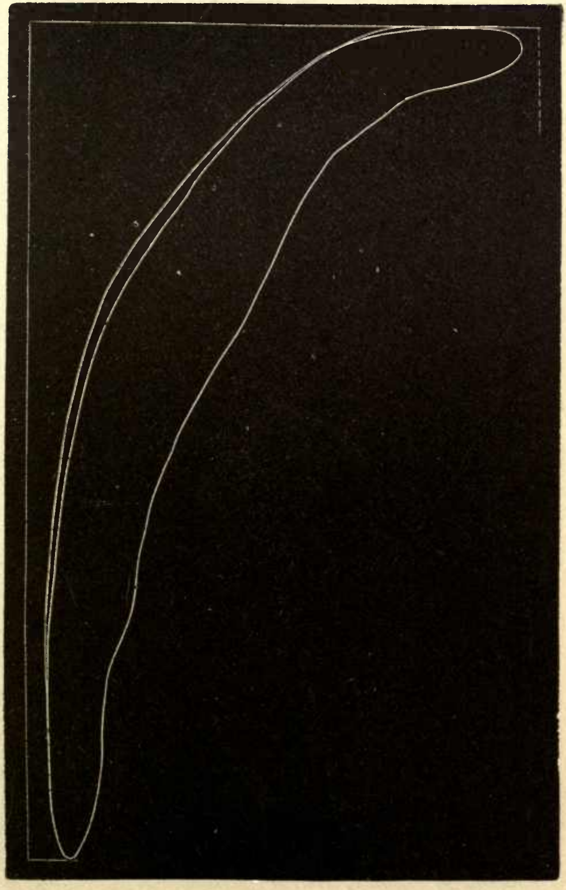
200 revolutions per minute. 132 lbs. pressure of steam cut off at second notch.

DIAGRAM No. 3.



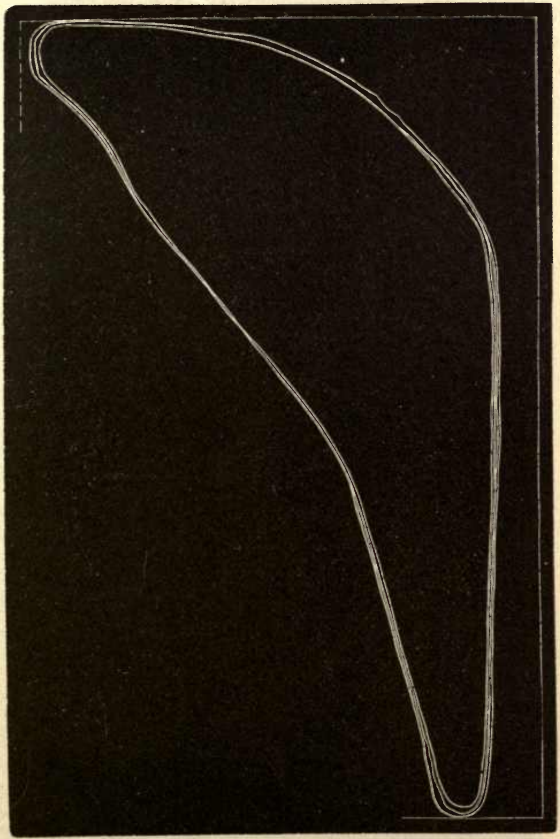
200 revolutions per minute. 109 lbs. pressure of steam cut off at second notch.

DIAGRAM No. 4.



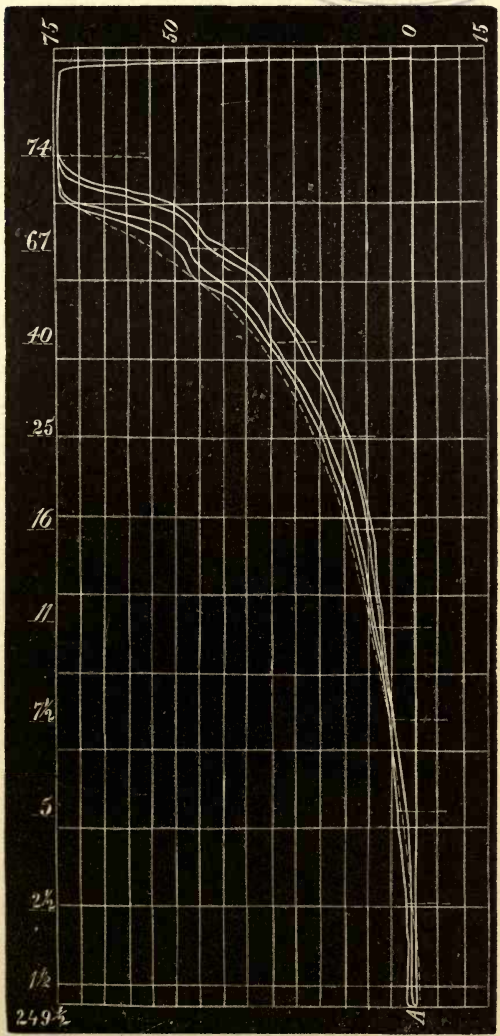
260 revolutions per minute. 105 lbs. pressure of steam cut off at first notch.

DIAGRAM No. 5.



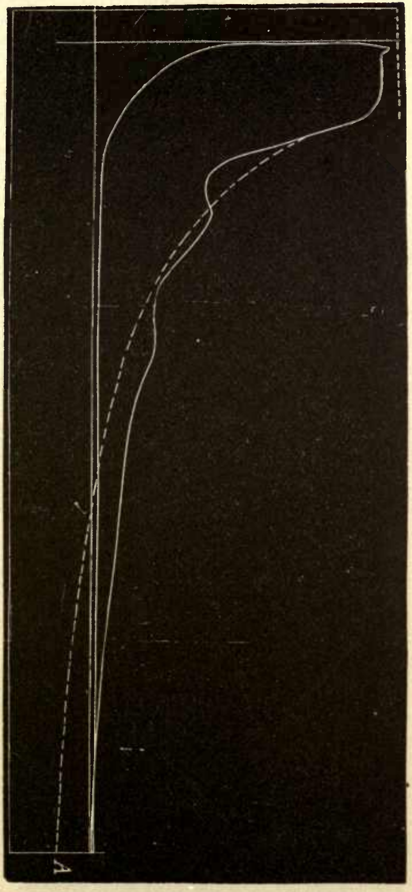
224 revolutions per minute. 107 lbs. pressure of steam cut off at first notch.

DIAGRAM No. 6.



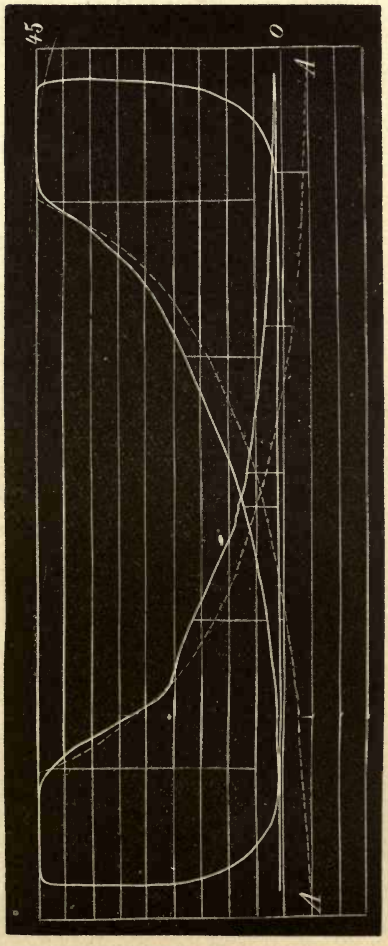
A, termination of correct expansion curve.

DIAGRAM No. 7.



A, termination of correct expansion curve.

DIAGRAM No. 8.



A, *A*, termination of correct expansion curve.

DIAGRAM No. 9.

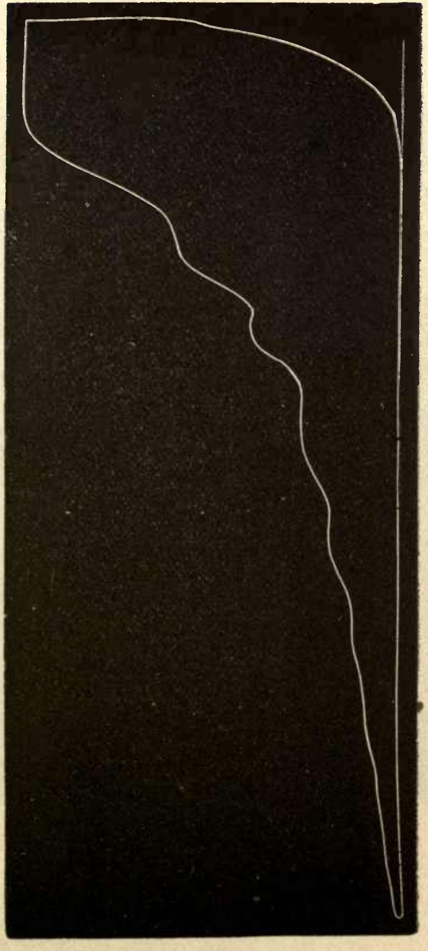


DIAGRAM No. 10.

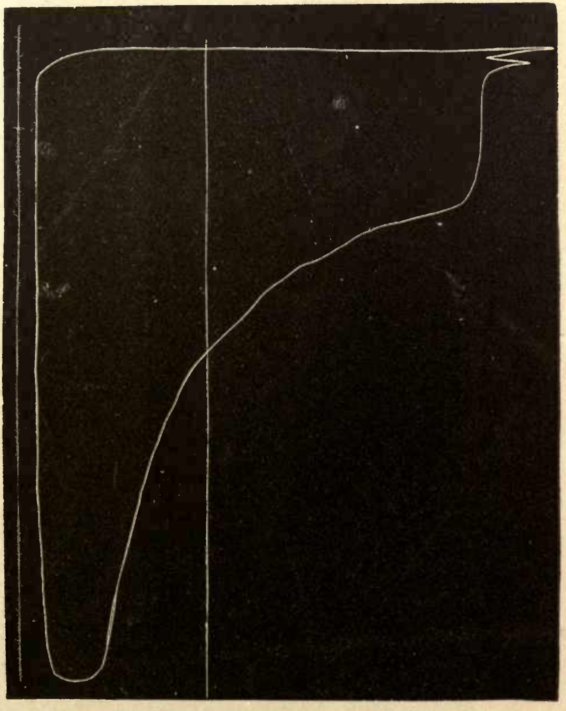


DIAGRAM No. 11.

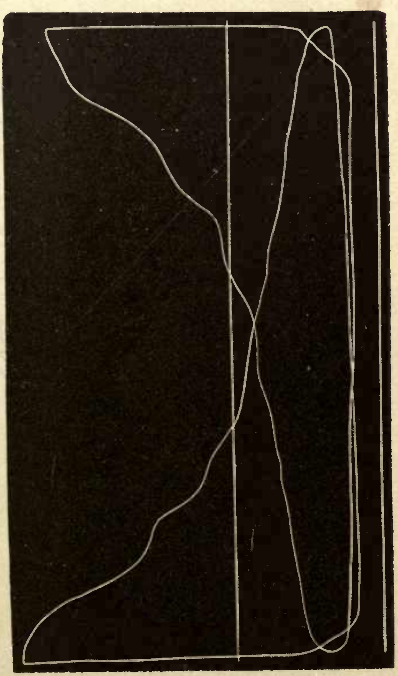


DIAGRAM No. 12.

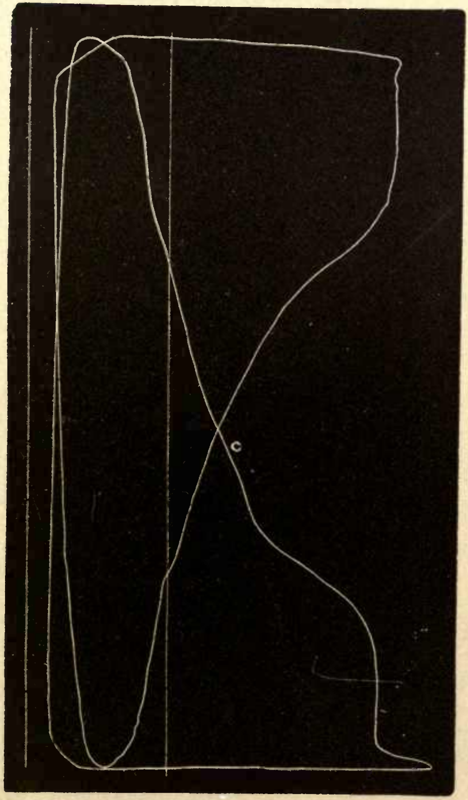


DIAGRAM No. 13.

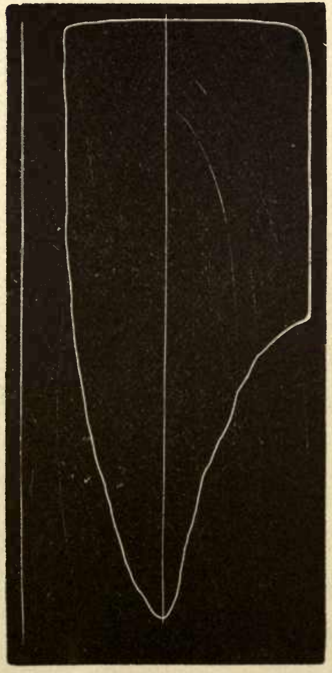


DIAGRAM No. 14.

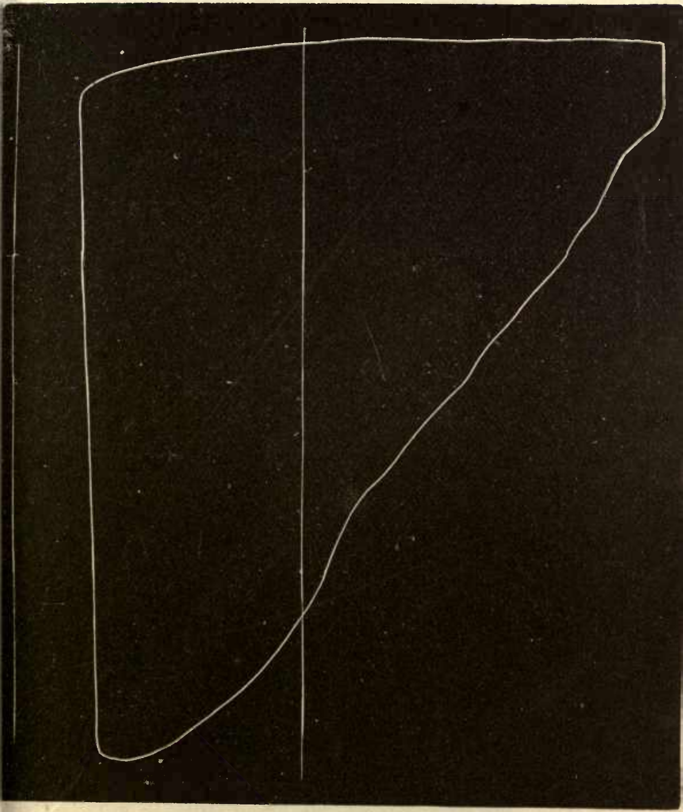


DIAGRAM No. 15.

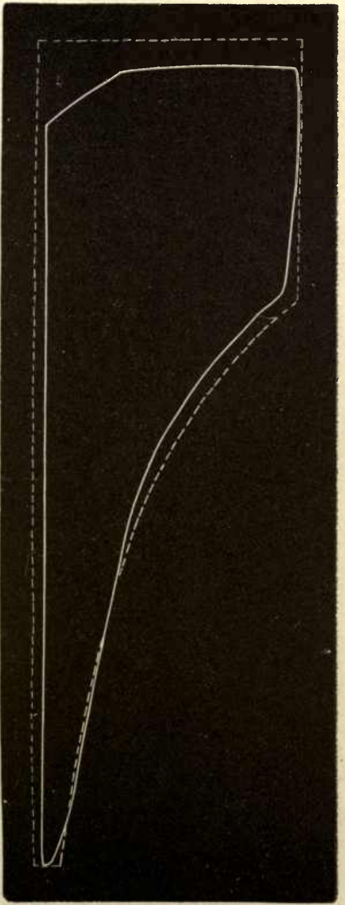


DIAGRAM No. 16.

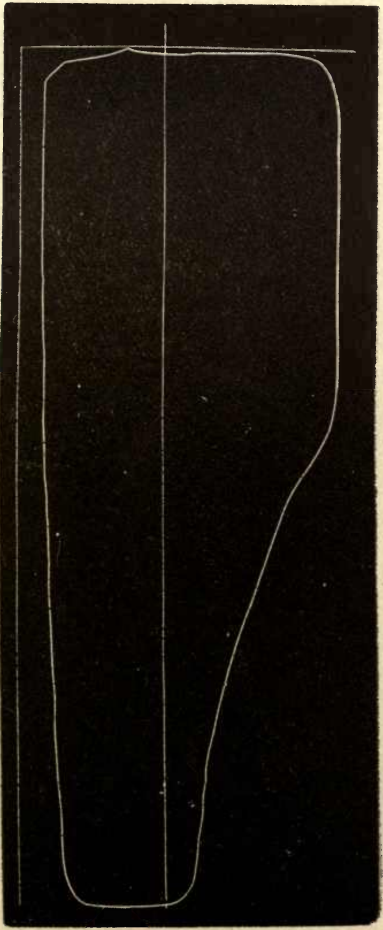


DIAGRAM No. 17.

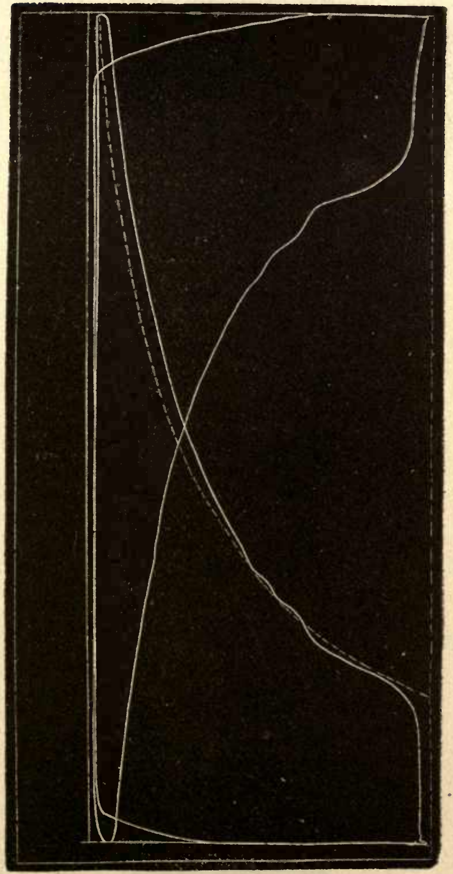


DIAGRAM No. 18.

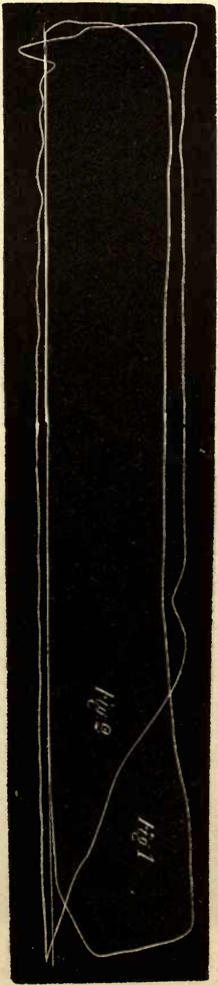
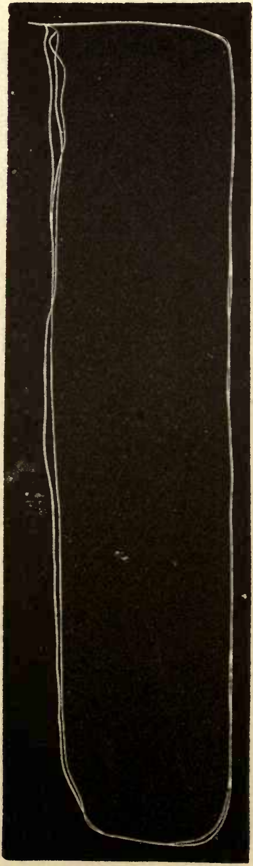


DIAGRAM No. 19.



Back and forward.

DIAGRAM No. 20.

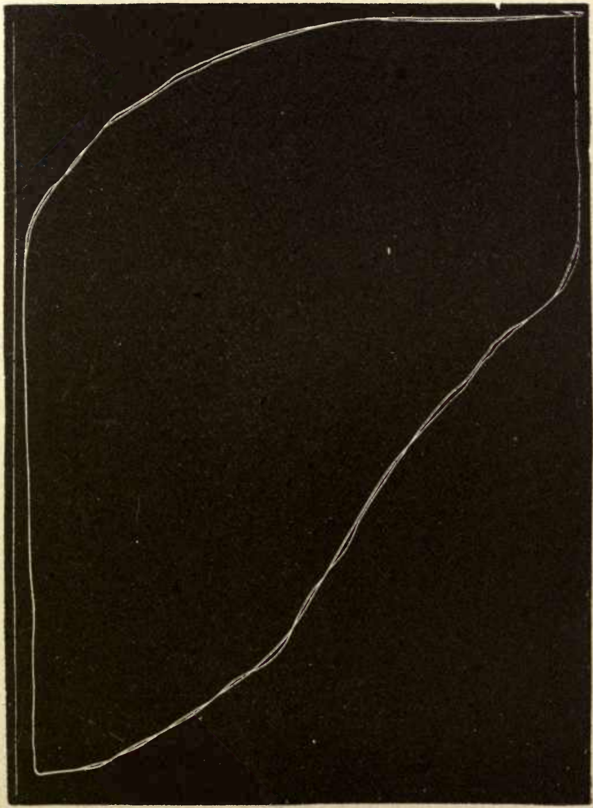


DIAGRAM No. 21.

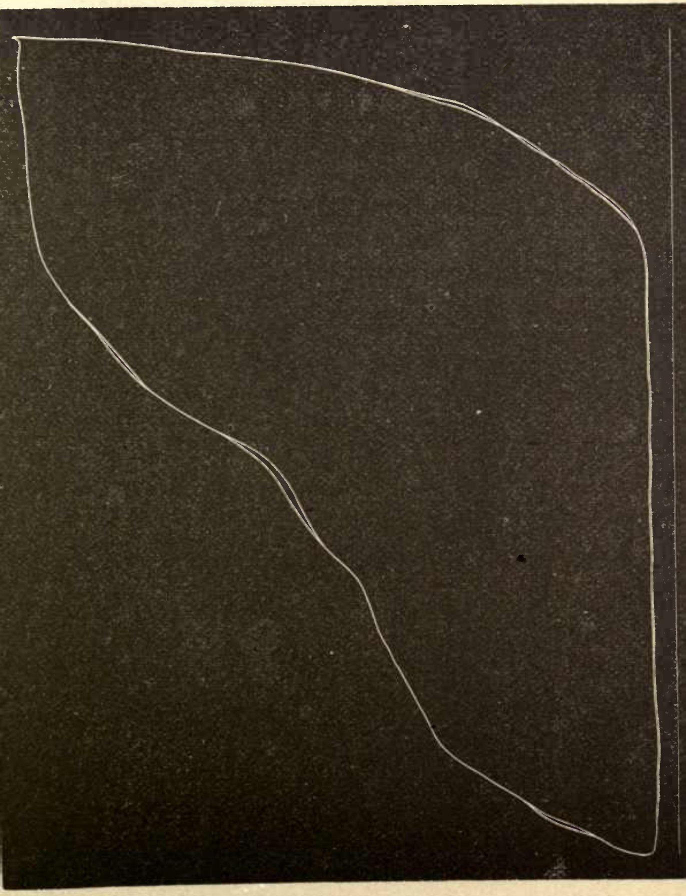


DIAGRAM No. 22.

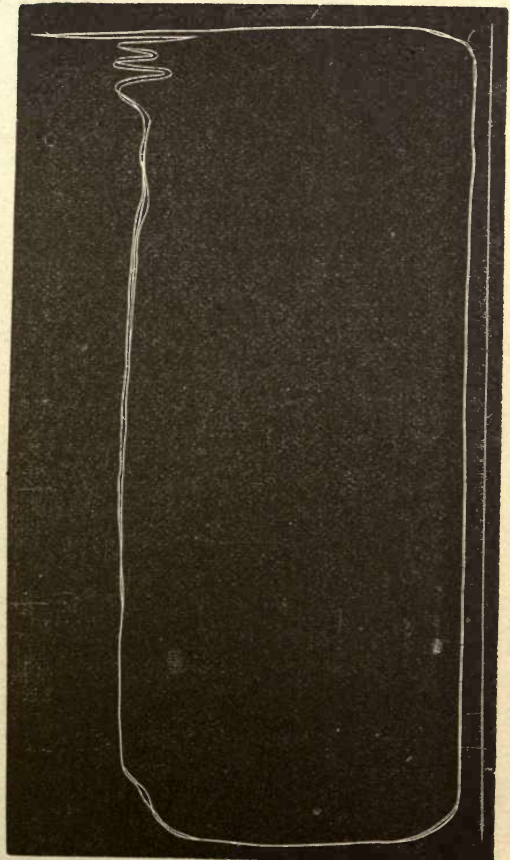
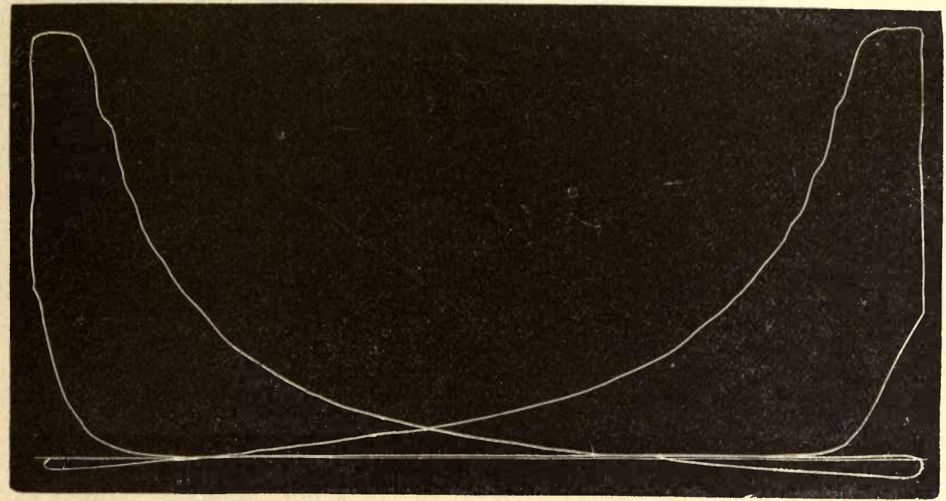


DIAGRAM No. 23.



The above diagrams from an engine 24″ × 60″. 30 revolutions per minute. Boiler pressure 66 lbs. Scale, 30 lbs. to inch. Clearance equal to 3.7″ of the stroke. Upright beam engine. Sickles' cut-off, improved by Rockwell & Burr.

APPENDIX.

USEFUL INFORMATION.

Cement for Steam Joints.

Take a quantity of pure red lead, put it in an iron mortar or on a block or thick plate of iron. Put a quantity of pure white lead ground in oil; knead them together until you make a thick putty, then pound it; the more it is pounded the softer it will become. Roll in red lead and pound again; repeat the operation, adding red lead and pounding until the mass becomes a good stiff putty. In applying it to the flange, it is well to put a thin grummet around the orifice of the pipe to prevent the cement being forced inward to the pipe when the bolts are screwed up. The more pounding the better.

Another, to be used when the flanges are not faced: Make the above mass rather soft and add cast-iron borings, pounding in thoroughly until it is sufficiently soft to spread.

Both the above are the most durable cements known to the engineer. They will resist fire and set in water.

Another (English), said to be very good: Take 10 lbs. ground litharge, 4 lbs. ground Paris white, $\frac{1}{2}$ lb. yellow ochre, $\frac{1}{2}$ oz. of hemp cut into lengths of $\frac{1}{2}''$; mix all together with boiled linseed oil to the consistence of a stiff putty. Resists fire and will set in water. [Pounding would improve it.—Ed.]

A Good Dressing for Leather Belts.

One part of beef kidney tallow and two parts of castor oil, well mixed and applied warm. It will be well to moisten the belt before applying it.

No rats or other vermin will touch a belt after one application of the oil. It makes the belt soft, and has sufficient gum in it to give a good adhesive surface to hold well without being sticky.

A belt with a given tension will drive 34 per cent. more with the grain or hair side to the pulley than the flesh or rough side.

Rules for Calculating Belting.

This is one of the most difficult problems the engineer has to solve. There are so many different conditions attending the conveying of power by belts that no *definite* rule can be given. I have found, however, that where the conditions are fair to middling, that a belt one inch wide, running 800 feet per minute, is equal to one horse power. Increased width in proportion. This will do the work under a safe and proper tension. There are conditions, however, which might require double the above width or speed.

How to make belts run on the centres of pulleys.

It often happens that a belt will persist in running on one side of the pulley.

In this case one or more things cause it. First, one or both of them may be conical, and of course the belt would run on the higher side. Second, the shafts may not be parallel; in this case the belt would incline off, on the side towards where the ends of the shaft are nearest to each other. The remedy in this case is, to make them parallel to each other by carrying the ends of the shaft towards which the belt inclines, farther apart.

In giving rules for calculating the horse-power of belts, we would not be understood as saying that a belt will not do more than the rule would give; on the contrary, we know that double and even more power may be transmitted by them by a sufficient tension, which would create a ruinous amount of friction and a speedy destruction of the belt. We would be understood to say that the rules give data for a belt that will run with a moderate and safe tension. The attempt often made to calculate the work that a belt of given width and travel in feet per minute without any known tension is doing, or *will* do, is very like comparing the size of a pebble-stone to a piece of chalk. The Indicator tests that with certainty.

The practice of putting an idler against a belt to make it drive is a most pernicious one, destructive alike to the belt and power; its only merit is to disguise bad engineering.

Measuring Steam used for heating.

The engineer is often called to determine the amount of steam that is used to heat apartments, liquids, etc. This the Indicator does not reveal directly, no farther than it shows how much steam it requires for a horse-power; varied, of course, by the point of cut-off and its efficiency.

Under these circumstances we have followed the rule of Watt, which is to allow one cubic foot of water per hour for each horse-power; hence we measure the water condensed in the heating pipes in a given time, and estimate accordingly.

If it is inconvenient to reduce the water to cubic feet, it may be weighed, allowing 62.5 lbs. to the cubic foot, or it may be measured by the gallon, or 7.48 gallons per cubic foot.

When the steam pipe enters the vessel and it discharges the steam directly into the liquid to be heated, the water then cannot be caught to be measured; in that case we measure the increment of its contents, and thereby find the quantity of steam condensed.

Condensation of pipes and coils.

Steam pipes in the ordinary circulation, such as are used to warm buildings, when one or more run around the sides of the apartment, having and maintaining a temperature of 60°, will condense .357 lbs. of water per hour for each square foot of surface of pipe.

A coil maintaining the same temperature will condense .29 lbs. per hour per square foot of surface.

The radiating surface of steam pipe required to warm buildings and apartments.

This varies in consequence of the character of the structures, the exposure, the quantity of glass, the use the space required to be heated is put to, climate, etc.

In the city of New York the data of calculation, modified by the above-mentioned circumstances, is this :

For dwellings—when the pipes in form of a coil are placed in the cellar and supplied with air from outside—one square foot of pipe surface to 50 cubic feet of apartment to be warmed.

When the coil is placed in the apartment, one square foot of surface of pipe to 65 cubic feet of space.

In stores and warehouses, one square foot of pipe surface to 175 to 200 cubic feet.

In workshops, one square foot of pipe surface to 100 cubic feet of space.

Heating with exhaust steam is of questionable economy. It is not economical, certainly, when used in small pipes, in consequence of the power required to force the steam through them. We have seen exhaust steam used economically in workshops and factories where it is permissible to use large cast-iron pipes, which present so much less friction surface in proportion to the area, that the power used to force the steam into them shows but a small back pressure on the engine—1 or $1\frac{1}{2}$ lbs. per square inch—if the pipes are of sufficient size and properly arranged. We have found the following to work well in practice :

We use for the smallest, flanged pipe, without regard to the size of the engine, 4″ diameter. If it is required to be over 75 feet in length, we use 5″ ; if over 100 feet, we use 6″.

The pipes should be $\frac{3}{8}$ thick, with flanges at least 4 inches larger than the outside diameter of the pipe.

These flanges should be faced so as to have a fair bearing over the whole surface, and when faced, not less than $\frac{5}{8}''$ thick, fastened with five bolts, $\frac{5}{8}''$ diameter. We place them, when practicable, around the walls of the room, near the floor, on the sides most exposed, giving them an inclination of not less than one inch in ten feet ; for our joints, the cement No. 1 (rubber not permissible).

The main exhaust pipe we carry out of the building, without reference to our heating pipes, except to have a nozzle to carry off steam to the highest end of the heating pipe. Should there be one or more rooms above or below, separate pipes from the main should be led off in the same way. The drain pipes should be at the lowest end of the pipe, and $\frac{1}{2}''$ to $\frac{3}{4}''$ diameter. If it is desirable to let only water escape, a siphon may be fixed to the end of the tail pipe, with legs of sufficient length to overbalance the steam pressure, yet leaving the water by its superior gravity to escape.

The supports should be firmly fixed to the wall, in perfect line with each other, that there be no bend or low place for the water to collect, which would inevitably destroy the pipe.

We have used a system of pipes arranged as above, for eight years, without the least attention to them. Not a joint has leaked.

Since the publication of the first edition, I have seen exhaust steam used in $1\frac{1}{4}''$ pipes with good result, and with but little back pressure. The arrangement was to take the steam off the main pipe into 4—$4\frac{1}{4}''$ pipe, from the right and left side, carried around on each side of the rooms. At the termination of each coil, a pipe $2''$ diameter carried off the water and uncondensed steam. The back pressure shown was less than 2 lbs.

It is not safe to allow steam pipes in contact with wood.

Value of Pea and Dust Coal, as compared with lump of good merchantable quality, with a blast induced by "Hancock's Steam Blower."

2,000 lbs. of pea and dust, the screenings from the coal-yards, have been found equal to 1,600 lbs. of lump. This is a result of several weeks' trial with the same engine and boiler doing the same work.

Gauge glasses, when required to be cleaned, should have a wooden swab-stick. A metallic one will cause the tube to fall to pieces inevitably, and sometimes immediately.

Value of Cumberland coal as compared with anthracite. Two tons (4,000 lbs.) of anthracite furnished steam for an engine seven days. The same amount of Cumberland served the same engine, everything else the same, eight days.

This experiment was continued with alternate changes for two months.

Boiler, locomotive type, with natural draft.

When there are indications of an extraordinary corrosion of the steam-boiler and its fittings, the gauge-cocks and valves leak. Acid is suspected. Test it by putting into a sample of the water a strip of litmus paper ; if acid is present, the purple paper will be changed to red.

To ascertain if iron is in solution, put into the samples a few grains of tannic acid; if iron is present, it will immediately become a dark purple or black.

The writer has found two cases where the wells that supplied steam-boilers were poisoned by the *spent pickle* finding its way into the wells, thence to the boilers, and was detected as above. The iron (sulphate) was so abundant, when a proper quantity of tannin was put in, it formed a sufficient ink so that the report of the examination was written with it. F. W. B.

Water when converted into steam can heat about 6 times its own weight of well water to 212° Fahr.
JAMES WATT.

Sir Wm. Fairbairn found, by a series of experiments, that in constructing internal flues for boilers, when the pressure was from outward to the center (centripetal), that as the *length* was increased, the thickness of plate must be increased in direct proportion. That is, if $\frac{1}{4}$-inch plate was right for a 10 ft. length, if the flue was 20 ft. in length, the plate must be $\frac{1}{2}$ inch to stand the same pressure.

Dressing for an Emery Wheel, to give a fair polish, say such as is usual on carpenter's tools.

The tool has been surfaced on a wheel covered with No. 60 emery. Take another wheel covered with same No., and rub on a composition of flour, emery and beeswax. Set the wheel running and hold on a flint; again rub on the composition and again the flint, until it gives the polish required.

To make the composition, melt the wax with a gentle heat; stir the emery in until it is thick; remove the heat, and keep up the stirring until it is so cool that the emery won't fall to the bottom.

The wheel must be kept nicely balanced, or the polish will be cloudy. F. W. B.

To Cool Off a Hot Bearing.

Take off the top box, and while the shaft is slowly turning, put on white-lead ground in oil from the keg. When the lead is seen coating the bearing as it turns slowly, it shows that the lead has interposed itself between the two surfaces and will cool down, when the ordinary lubricant may be resumed.

F. W. B.

Water, Scales the Boiler. Lime is suspected.

Test.—Into a tumbler containing the suspected water put 8 or 10 grains of oxalic acid; if lime is present, the water will become milky, and after standing quiet awhile, the lime will be precipitated (oxalate of lime).

Should the precipitate not show itself, add a little ammonia, which is a more delicate test. If no precipitate is shown, it is not lime that forms the scale.

F. W. B.

For Calculating the Horse-powers of a Given Quantity of Water in a Given Time, 7,000,000 gallons of Water passing through the Turbine in 60 hours.

RULE.—Multiply the fall in feet by .3682. The product is the horse-powers, net. This is a unit. If there is more or less water, or more or less time, the horse-power developed will be more or less in direct proportion.

From testimony of J. B. FRANCIS, C. E.

ANOTHER RULE.—8.8 cubic feet of water per second falling one foot is equal to one horse-power.

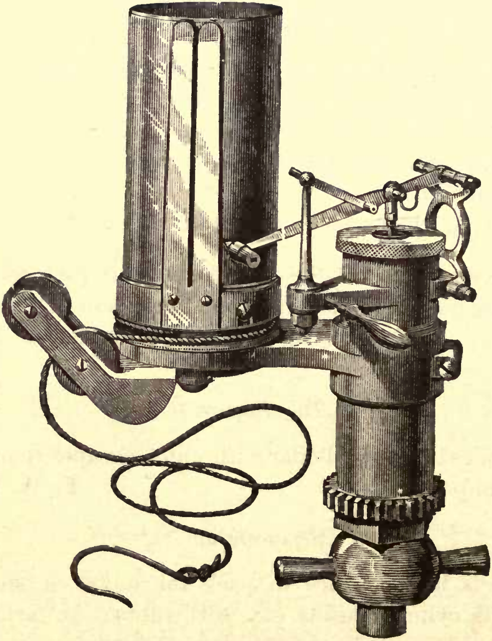
From testimony of C. HERSCHEL, C. E.

The Inspirator

supplies the steam-boiler with water cheaper than the steam-pump. F. W. B.

Memorandum.

It is bad practice to pack the joints of steam-chests, cylinder-heads, etc., with rubber; in fact, any joint that is exposed to heat, as the sulphur used in volcanizing, disintegrates the cast iron and erodes the bolts *inevitably in time.* It may be *tolerated* in the manhole of the boiler. F. W. B.



RICHARDS-THOMPSON'S STEAM-ENGINE INDICATOR.

SUPPLEMENT

TO THE

PORTER-BACON TREATISE ON THE

RICHARDS STEAM-ENGINE INDICATOR;

BEING NOTES ON THE

RICHARDS-THOMPSON INDICATOR,

THE AMSLER POLAR-PLANIMETER AND THE PANTOGRAPH,

AS USED IN CONNECTION WITH THE INDICATOR.

By F. W. BACON, M. E.,
Member of the American Society of Civil Engineers.

1879.

THE

RICHARDS-THOMPSON

STEAM-ENGINE INDICATOR.

THE constant demand for high piston speed of stationary and locomotive engines, has outrun the capacity even of the Richards instrument, and rendered it imperative, if we would have a correct result, that an instrument be produced that would meet the call. Therefore, "necessity being the mother of invention," the patentee has given us the instrument which is all that can be desired. It is believed that it will give correct results under any attainable speed of a steam-engine. It will be observed that Mr. Thompson's improvement mainly consists in reducing the weight 43.65 per cent of the parallel motion, by reducing the number of vibrating pieces, thereby reducing the tendency to make wavy lines in both steam and expansion. By the new arrangement the instrument is lighter and more compact, qualities that will be fully appreciated by the engineer.

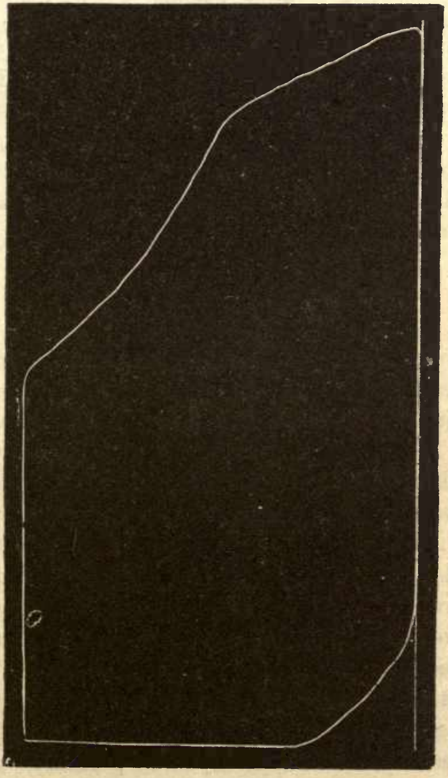
With these improvements, and the facilities provided for the attachment of the instrument, it is obvious that the engineer in charge should be educated to its use, and required to make weekly reports of power indicated and fuel expended.

The Indicator is the light to the engineer's eye: without it he gropes in the dark; he can't set his valves correctly; he has no mode of measuring the power even approximately without it; hence he can make no comparative test of fuel used and power eliminated; he may be burning 10 or 15 lbs. of coal per hour per horse-power, when he should burn but 2½ to 3 lbs. per hour per horse-power; a most scandalous and wicked waste of fuel.

The locomotive presents a great field for its application, though as yet but partially cultivated. Those master mechanics who have had the courage to apply it, and have followed its indications, have shown most curious results, which have prompted a change in valve gear, valve settings, enlargements of ports and thoroughfares, an increase in the areas of nozzles, etc.

The following diagram (No. 1), taken by J. A. Lauder, Esq., M. M., of the Northern (N. H.) Railroad, is one of the many taken from engines under his charge, which he has kindly furnished me; it is not an exceptional one. It will, however, be hard to find its superior. To attain this excellence, he followed the dictation of the Indicator. Its mate from the other end is a *fac-simile*.

DIAGRAM No. 1.



The LOCOMOTIVE, MOGUL PATTERN, of the following description:

WOOD BURNER.

Cylinders, 17×24 in.; diameter of wheel, 54 in.; admission ports, $16 \times 1\frac{1}{8}$ in.; exhaust ports, $16 \times 2\frac{3}{4}$ in.; outside lap, $\frac{7}{8}$ in.; inside lap, $\frac{1}{8}$ in.; travel of valve, 5 in.; lead full gear, $\frac{1}{10}$ in.; boiler pressure, 130 lbs.; cutting off at 12 in.; exhaust nozzles, two, 3 in. diameter; revolutions, 50 per minute; scale of instrument, 60 to one inch.

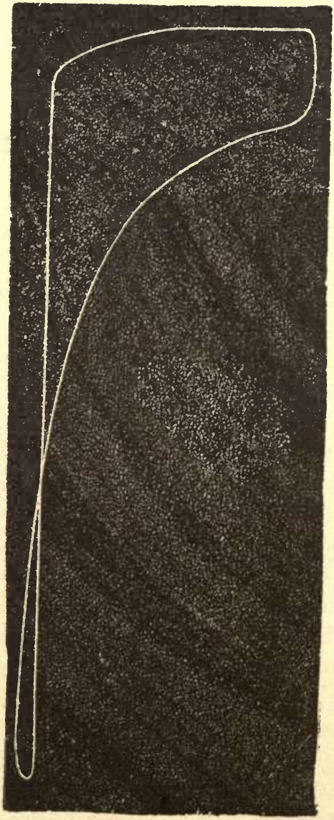
DIAGRAM NO. 2

is introduced to supply information to beginners, who will sometimes, when getting diagrams from engines without any or but little load, find the expansion curve fall below the atmospheric line, showing a partial vacuum *behind* the piston, and are often at loss how to account for, or what to do with it. The writer does not remember having seen it mentioned in any of the books, and having known of some rather ridiculous blunders made in disposing of it, ventures to take it up and explain it, though it may seem to the expert unnecessary.

This "*loop below*" is made by the advancing piston passing the point due to reducing the volume of steam by expansion to the atmospheric pressure—at that point the expansion-curve crosses the atmospheric line, and might, under certain circumstances, create nearly a perfect vacuum, were it not for the presence of water, which re-evaporates and partially fills the space.

In treating this loop, it must be measured *out*, the same as any back or negative pressure. It don't suffice *not* to measure it *in*—measure the diagram without including it, then measure *it*, and deduct it from the sum of first measurement. This "loop" incidentally serves a very important purpose, insomuch as its presence shows that there is no leak either in the valves or piston.

DIAGRAM No. 2.

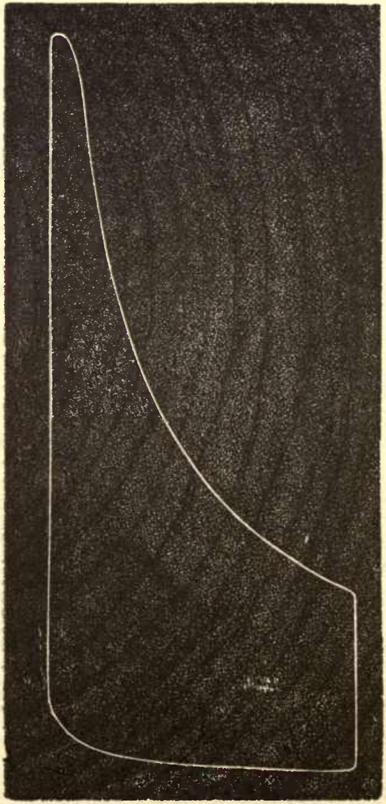


The following diagram (No. 3) is introduced as one of the most perfect that is obtained from a high-pressure, non-condensing engine. It was taken with the Thompson Indicator, actuated by the Pantograph, from "*The Brown*" engine, 16″ × 42″ × 60 revolutions, exhibited at the Fair of the Massachusetts Charitable Mechanic Association. When we consider the speed of the piston, 420 ft. per minute, the steam pressure, 67 lbs., scale 40, we think uncommonly perfect lines are shown, especially the steam line and expansion curve. It shows also a most prompt and perfect action of the admission and eduction valves; the point of cut-off is sharp, decided, and unmistakable, qualities that will be fully appreciated by the engineer.

It is one of many hundred diagrams taken by the writer from the engine during the exhibition, all with the same characteristics.

Should any one wish to make the theoretic curve around the diagram, we give in addition to the above data the clearance, 2½ per cent.

DIAGRAM No. 3.



For reducing the motion of the piston to the required length of the diagram, there are many devices. The one most in use is a strip of board suspended from the ceiling above, or carried off horizontally, as circumstances dictate, and it often requires considerable ingenuity to effect it without too much cost and delay. The pendulum should be not less than *one and one-half* the length of the piston-stroke from the point of suspension to the point of attachment to the cross-head ; if longer, say twice the length of the stroke, it is better.

To find the point of attachment of the line leading off to the indicator, the following is the

Rule.—Divide the length of piston-stroke in inches by the required length of the diagram ; divide the length of the pendulum in inches by the above quotient, and *this* quotient is the distance in inches from the point of suspension to the point of attachment of the line, approximately.

Example.—Stroke of piston, 36″. Length of required diagram, 4.5″. Length of pendulum, 54″.

Then $36'' \div 4.5 = 8. \quad 54 \div 8 = 6.75.$

Or, 4.5) 36.0 (8
36.0

8) 54 (6.75″ from point of suspension to
48 attachment of line.
60
56
40

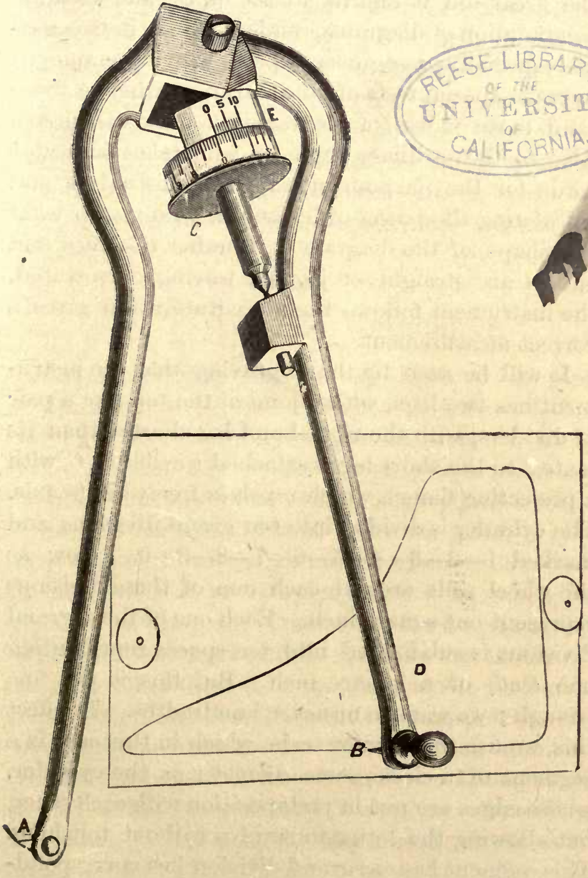
This is approximate, but not mathematically correct, owing to the arc of a circle described by both points of attachment, yet is considered sufficiently accurate for practical purposes. The *pantograph* gives us a correct result.

On page 24 of the "*Treatise*," and onward, the question of the mode of giving motion to the Indicator is discussed. Since that was published, there has been a new mode applied, which is invaluable, insomuch as it is mathematically correct, can be applied in almost any case, renders long lines and carrying pulleys unnecessary, is compact and portable, being when folded about 18″ long by 3″ × 5″. It is known as the *Indicator Pantograph.* It is furnished with or without the instrument, when required. It is an old, well-known device, applied to a new purpose.

If the Indicator is applied to the *side* of the cylinder, it enables us to use short cords, without the use of carrying pulleys to lead the cord to the Indicator. We would advise the operator to use the *braided* cord, as it is far less elastic.

A medal was awarded to the Indicator Pantograph at the late Mechanics' Fair of Massachusetts.

Since the second edition of the Treatise was published, an instrument for measuring and computing diagrams has been introduced. It can be used also to measure any other irregular or regular form within its compass. It is known as


0 5 10
E
C
D
B
A

Its use greatly diminishes liability to error; and the great aid it affords to the quick and accurate computation of diagrams, renders its use indispensable, especially to engineer experts who are employed to make special tests of long duration, where a thousand, more or less, of diagrams are to be calculated. Also to the ordinary engineer who takes indicator cards for the purpose of adjusting his valves and calculating the power of his engine; no matter what the shape of the diagram is, whether the lines and curves are straight or jagged, waving or serrated, the instrument follows them accurately and gives a correct measurement.

It will be seen by the engraving that the instrument has two legs, with a joint at the top like a pair of dividers, with the right-hand leg shorter than its mate; to the short leg is attached a cylinder *C*, with a projecting flange, which revolves freely on its axis. The cylinder is divided into ten grand divisions, and marked 1—2—3—4—5—6—7—8—9—0. Now as the wheel rolls around, each one of these divisions represent one square inch. Each one of these grand divisions is subdivided into ten spaces representing one *tenth* of a square inch. But this is not fine enough; we want to measure hundredths. To effect this, we use the Vernier scale, which in this case is a segment of a circle, same diameter as the cylinder, whose edges are put in juxtaposition with each other, but allowing the latter to revolve without touching. This segment has *one* grand division just corresponding to *nine* of the subdivisions on the cylinder. This grand division is subdivided into ten spaces, and marked 0—5—10. This segment is firmly fixed to the head of the instrument, so that the edge of it exactly corresponds with the edge of the revolving cylinder. It is called the Vernier scale. With these relative positions, the graduations come opposite each other, but as the spaces are not the same on each, it is evident that but *one* mark on each can be opposite.

HOW TO USE THE INSTRUMENT.

Fasten the diagram to your drawing-board by pins or springs; alongside of it a half-sheet of fine glazed paper for the wheel of the instrument to move on. Place the needle-point *A* at a proper point on the paper and the tracer *B* on a marked point of the outline of diagram *D*; then raise the wheel *C* and turn it until 0 on the cylinder corresponds with 0 on the vernier *E*, press lightly with a finger of the left hand on the point *A*, and with the fingers of the right hand take hold of the top of the tracer *B*, and carefully follow the line in the direction of the hands of a watch until it reaches the starting-point. We now read the instrument. We find that 0 on the cylinder has passed on from 0 on *E*, and 2 has passed it. We write 2 (2 inches). We follow it by seeing how much 2 has passed. We find it shows four marks on the cylinder and a little more. We write

4, which is $\frac{4}{10}$. We now look for a mark on the cylinder that corresponds with one on the Vernier *E*. In this case we find the second mark from Vernier 0 corresponds with a mark on the cylinder. We write 2, being $\frac{2}{100}$. The reading then is thus, 2.42 square inches, area of diagram. We now measure the length of the diagram in inches, parallel to the atmospheric line, which in this case is four inches. We now divide the area by the length; the quotient is the mean height in inches of the diagram, which is .605 inches; this we multiply by the scale of the indicator, which is thirty to the inch in this case; the product gives us 18.15 lbs. mean pressure on each square inch of the piston. The sum is thus:

$$
\begin{array}{r}
4\ )\ \underline{2.42} \\
.605 \\
\underline{30} \\
18.150
\end{array}
$$

18.150 lbs., mean pressure.

Expressed thus:

$$2.42 \div 4 = .605 \times 30 = 18.15.$$

N. B.—If the diagram should measure more or less than four inches in length, divide by what it may be; so also with the indicator scale, multiply by what it *is*.

If the figure to be measured is a plan drawn to a scale, we proceed as above to get the square inches; we find in this case the reading to be nine square inches, our scale is one inch to one foot, which is one-twelfth size ; to raise this to full size, we multiply the reading by the square of the ratio, thus: $12 \times 12 = 144 \times 9 = 1296$ square inches full size. Same in all other scales. *Square the denominator and multiply the product by the reading;* the product is full size in square inches.

In giving in the foregoing direction how to read the record of the instrument, we have supposed that the operator was not familiar with the Vernier scale, hence we advised him to put 0 and 0 to correspond ; this is *right*, though not necessary.

For Example: The instrument is in place, the reading is 1.14, the tracer is carried around the outlines as directed, and the reading is 3.56 ; now we subtract the first reading from the second, thus :

$3.56 - 1.14 = 2.42$

$$\begin{array}{r} 3.56 \\ 1.14 \\ \hline 2.42 \end{array}$$

This the learner will soon get familiar with.

THE CARE OF THE INSTRUMENT.

It is exceedingly delicate ; it will not bear *banging* like a horse-shoe, nor suffered to become foul. Care must be taken that the roller-wheel revolves *perfectly free and yet no looseness in its pivots*, the same in all the joints. Take great care that the roller-wheel and vernier-scale don't get rusty or foul with dirt. Oil the movable points with *porpoise oil and none* *other.* It can always be procured at the watch or clock maker's. This is imperative, if correct results are to be attained.

The above description is believed to be sufficient for all practical purposes. For a mathematical exposition, disclosing the scientific principles on which it acts, see Spon's Dictionary.

For convenience in using the common rule to measure the length of the diagram, we have calculated the following table, reducing the common fraction to decimals :

Com. Frac.	Decimal.	Com. Frac.	Decimal.	Com. Frac.	Decimal.	Com. Frac.	Decimal.
$\frac{1}{32}$	.0312	$\frac{9}{32}$	.2812	$\frac{17}{32}$	.5312	$\frac{25}{32}$	.7812
$\frac{1}{16}$	.0625	$\frac{5}{16}$	.3125	$\frac{9}{16}$	.5625	$\frac{13}{16}$	.8125
$\frac{3}{32}$	.0937	$\frac{11}{32}$	.3437	$\frac{19}{32}$	.5977	$\frac{27}{32}$	.8437
$\frac{1}{8}$	.1250	$\frac{3}{8}$	.3750	$\frac{5}{8}$	.6250	$\frac{7}{8}$	.8750
$\frac{5}{32}$	.1562	$\frac{13}{32}$	.4062	$\frac{21}{32}$	.6562	$\frac{29}{32}$	.9062
$\frac{3}{16}$	.1875	$\frac{7}{16}$	.4375	$\frac{11}{16}$	.6875	$\frac{15}{16}$	.9375
$\frac{7}{32}$	.2187	$\frac{15}{32}$	.4687	$\frac{23}{32}$	.7187	$\frac{31}{32}$	.9687
$\frac{1}{4}$	.2500	$\frac{1}{2}$	.5000	$\frac{3}{4}$	.7500	$\frac{32}{32}$	1.0000

From the above description and examples it will be seen that calculating the diagram is reduced to the minimum of time and maximum of accuracy. We dispense with the use of the parallel rule, with ten or more measurements, with adding up a long column of figures and the required divisions, to get a doubtful result at best, and substitute the described manipulation of the instrument; note its reading, and by the use of *fourteen figures* get a positively accurate result.

DIRECTIONS.

Before taking the diagram, shut off the supply of whatever lubricant is used in the cylinder of the engine, which is usually some gummy oil or other villainous compound, that gums the piston and cylinder of the instrument, rendering its action dull, showing curves where there should be angles, and retarding its free action generally.

Oil the piston of the instrument often when in use, and see that the cylinder is smooth and clean, for on these points depend largely the integrity of its action and correctness of the diagrams.

TO SELECT A SPRING FOR A GIVEN PRESSURE.

RULE.—Divide the boiler pressure by 2.5; the quotient is the proper number of spring.

EXAMPLE.—Boiler pressure, 75 lbs. $\div$ 2.5 $=$ 30.

It is good practice to use as low number as will do for the pressure, so as to get the diagram on a large scale.

INDEX TO SUPPLEMENT.

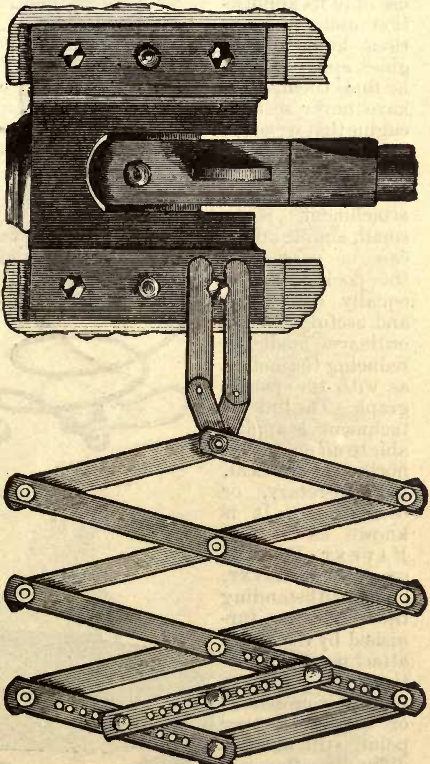
INDEX.

TABLES.

APPENDIX.

ANOTHER edition, the fourth, of this work is called for, which *indicates* that our working engineers are becoming educated in the use of the Indicator to their great advantage and the interest of their employers, who, as a rule, appreciate the great advantages made manifest and tangible by its intelligent use. Combined with the Fairbanks Scale it shows them unerringly how much power they get for a *dollar* from the various kinds of fuels in use.

In our third edition, page 168, we noted the pantograph, which is now in general use, which is shown in the engraving. It is shown to be connected with the old-style horizontal cross-head, links held fast by the lock-nut of the gib adjusting screw.



THE PANTOGRAPH.

It will be seen that the link is by its joints capable of being expanded or contracted in its opening from 0 to 3½″, so that it will embrace the largest Corliss vertical crosshead to the smallest adjusting or other screw. There are some small pieces go with it, to adjust and attach it, which the engineer will at once see the use of in its application under the various kinds of engines and positions he finds them. We have never seen an engine that we could not get an attachment with it in ten minutes. This link attachment is a small, simple affair, can be carried in the pocket, and is equally convenient and useful with the ordinary mode of reducing the motion as with the pantograph. The link attachment is applicable to *all* engines—horizontal, vertical, inclined-rotary, or oscillating. It is known as Bacon's Patent Pantograph Attachment.

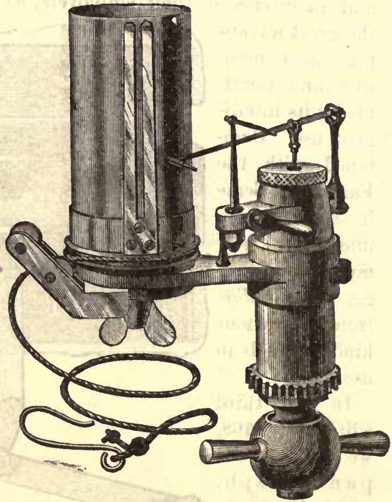
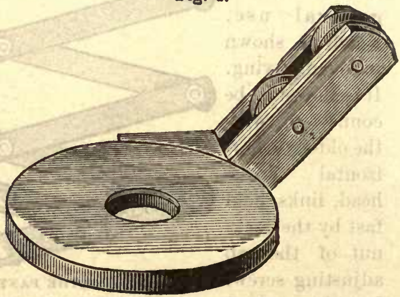


Fig. 1.



1A.

Notwithstanding the facilities furnished by the above attachment in getting the motion from the crosshead or other proper point, still another difficulty often occurs which gives us more or less trouble to manage, and that is to lead the line off in the proper direction so as to give a correct result. Steam-pipes, exhaust-pipes, and other obstructions incident to the structure of the engine, often the contracted space allotted to it, and unforeseen awkward conditions often with the old arrangement, render it impossible to get the line to run parallel with the piston-rod (a *sine qua non*) without too many carrying pulleys or chafing the lines, which must in any event be avoided if we would have correct results. Happily the patentee has helped us out of this, as the accompanying cuts will show.

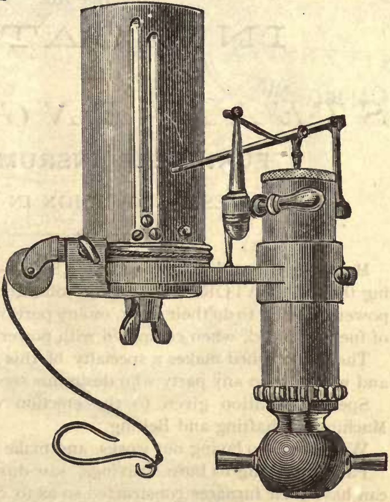
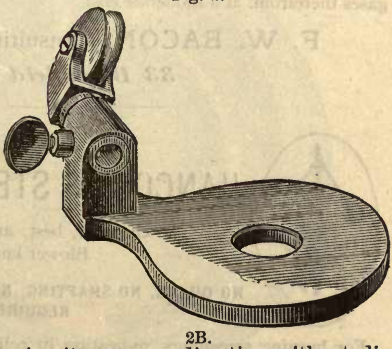


Fig. 2.

Fig. 1 shows the original Thompson instrument. 1A shows the swivel-base and carrying-pulleys. This base can swivel around to the right or left, but the pulleys remain upright, which is sometimes exceedingly inconvenient.

The improved swivel-base is shown attached in Fig 2, and detached in Fig. 2B.



2B.

It will be seen that by its construction a swivel of itself, which can be set and held by the thumb-screw at any angle to suit the line and give it a proper direction without distorting the diagram or abraiding the line.

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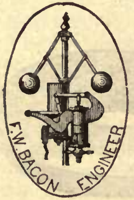

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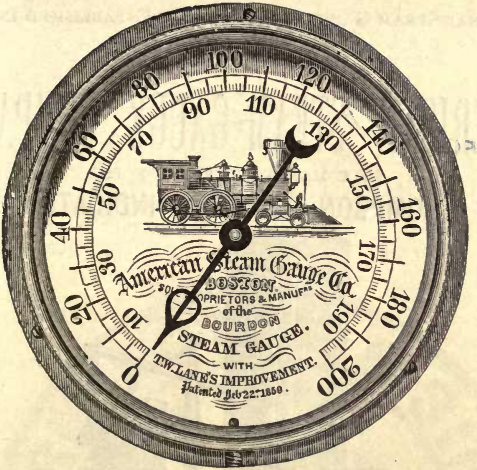
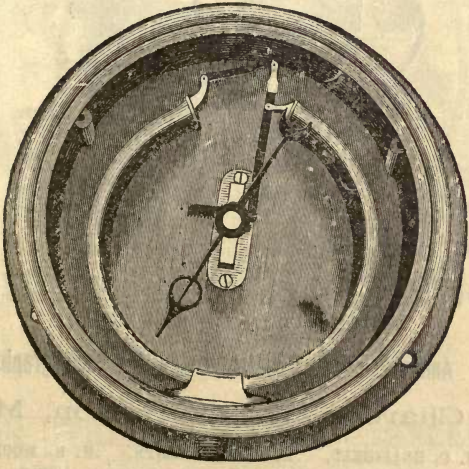
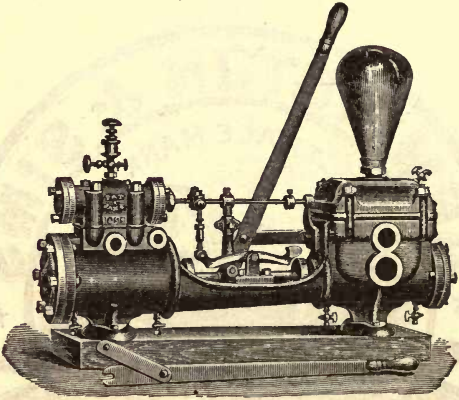




Lane's Improvement—Inside View.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