THE STAR IMPROVED

Steam Engine Indicator

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PREFACE.

THIS treatise was prepared for the Star Brass Manufacturing Co., who are the sole manufacturers of the Star Improved Indicator. Although in a sense an advertisement of the new indicator, it is intended to be an unbiased statement of all the facts needed by a purchaser of this indicator, whether unfamiliar with the particular form of instrument described, or with the general subject. It is intended also as a useful book of reference and instruction in the practical work of indicating.

Most of the diagrams here reproduced were taken for the purpose of this treatise, using one of the new type of instruments, and nearly all were taken by the author.

GEO. H. BARRUS.

12 PEMBERTON SQUARE, BOSTON.
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THE STAR IMPROVED INDICATOR.

CHAPTER I.

INTRODUCTION.

UNDER the modern conditions of steam-engine practice, the equipment of an engine-room is seldom regarded as complete unless it includes a steam-engine indicator, or pair of indicators; and no engineer is regarded as doing his full duty in the interests of the steam plant of which he has charge unless he makes frequent or regular use of these instruments, and thereby obtains, and constantly maintains, the fullest knowledge which such instruments give of the condition of the plant. As a result, in the great majority of first-class engine-rooms of the present day indicators are provided; and in cases where they are not provided, the engineer, as a rule, would be glad to have them as part of his equipment.

As a matter of history, it should be stated that within the last few years the indicator business has been growing rapidly, and the manufacturers of this indicator have frequently been called upon to furnish instruments of other makes in connection with the steam specialities which they have heretofore manufactured. A year or more ago they decided, in view of the increasing calls upon them for indicators, to enter this field of manufacturing; and consequently they brought out an instrument, which has been christened the "Star Improved Indicator," to supply the wants of their customers. They did not intend the instrument to be a radical departure from existing indicators, but one that should be designed and constructed on lines that had been so well proved by long experience as to meet the requirements of those desiring a high degree of efficiency and reliability in their indicator work. Profiting by the experience gained from the well known Richards, Thompson, Tabor, Crosby, and other indicators of familiar form which have preceded it, the manufacturers have sought to outrank if possible, at least in some of the details, any instrument which has heretofore been placed on the market. The instrument has now been before the public a sufficient length of time to fully test its merits, and the reception which has been accorded to it fully justifies the aims of the makers.

The steam-engine indicator is an instrument which makes a graphical representation of all the movements of the steam in the cylinder of the engine, the result being what is termed the "indicator diagram." The diagram registers the pressure at every point throughout the whole range of the stroke of the piston from beginning to end. It shows, also, the exact point in the stroke where the steam begins to be admitted to the cylinder, where the admission of steam is cut off, where the steam begins to be exhausted, and where the exhausting of the steam is completed. The record is made by a pencil, which is moved up and down by the force of the steam in the cylinder. The pencil traces a line on a sheet of paper, which is moved forward and backward during one complete revolution of the engine coincident with the travel of the piston. The diagram is the result of a combination of two motions: one, the vertical motion of the pencil representing the pressure of the steam; and the other, the horizontal motion of the paper representing the stroke of the engine. The great variation, both in the same engine and in different engines, as regards the pressure of the steam, the exact amount of pressure admitted into the cylinder, and the greatly varying points of the stroke where the operations of admission, cut-off, and exhaust take place, produce all sorts of combinations of the two motions, and the resulting diagrams have all sorts of forms depending on these conditions. The very fact that diagrams from different engines, and from the same engine under different conditions, possess such a great variety of form, shows the utility of the instrument; for one of the leading objects sought in applying the indicator is to ascertain how and when these actions take place, and by that means to be enabled to judge of the degree of excellence obtained in the operation of the engine.

CHAPTER II.

DESCRIPTION OF THE STAR IMPROVED INDICATOR.

PRINCIPAL FEATURES OF DESIGN.

THE leading features of this instrument will be seen at a glance by examination of the appended cut.

The Star Improved Indicator, like all the prominent instruments of this type which are its predecessors, consists of two main parts, — the *steam cylinder* and the *paper drum.* The steam cylinder being connected to one end of the engine cylinder, and the two being put in communication with each other, the indicator receives steam whenever the engine receives it; and it is consequently subjected at all times to the same steam pressure as that within the engine cylinder. The indicator cylinder contains a piston, against which the force of the steam is expended; and this force is resisted by the tension of a spiral spring placed above the piston. The upward and downward movement of the piston, as the steam enters and leaves the instrument, is transmitted through a piston-rod and a system of delicate multiplying levers to a pencil. By means of the pencil the indications of the instrument are registered. The paper drum carries a sheet of paper wrapped around the outside, and this is given a reciprocating motion derived from the crosshead of the engine. As the drum is moved back and forth, the pencil is brought to bear upon the paper, and the indicator diagram is traced upon it.

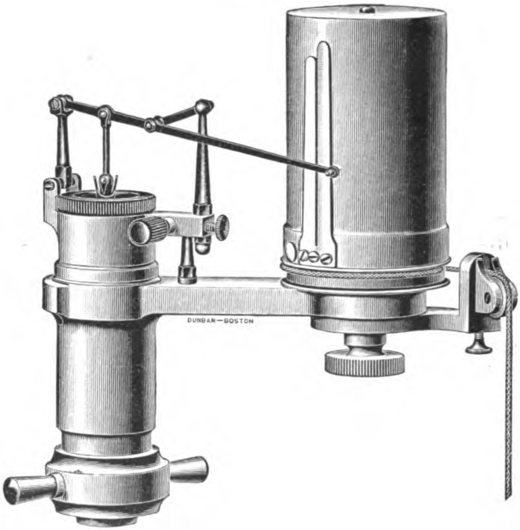
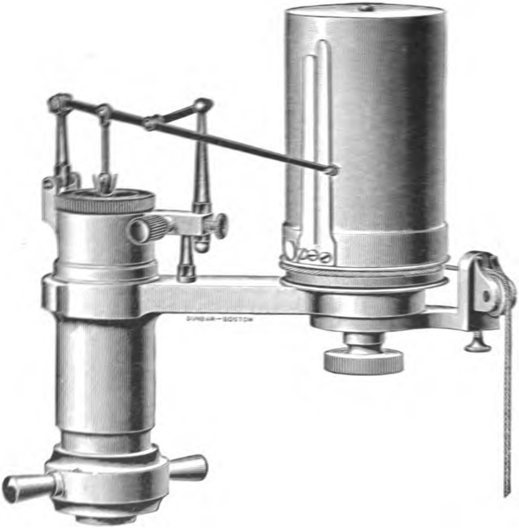


Fig. 1. Exterior View of Star Improved Indicator.

In the Star Improved Indicator, the mechanism by means of which the above-mentioned operations are carried on, has been designed with special reference to securing the lightest and most accurate reciprocating parts consistent with excellent work, and the lightest and most accurate drum mechanism ; to the end that the resulting combination may be as nearly perfect for its purpose as can be devised.

To obtain the highest efficiency in indicator work, it is most important that the piston should contain no unnecessary weight of metal, and that the mode of attaching the piston to the lower end of the spring should be such as to reduce the total weight of metal at this point to the lowest possible amount. An instrument that secures the least weight in the reciprocating parts, is the one that possesses in this feature the highest superiority. It is also important that the connection between the piston and the spring should be one that, so far as possible, prevents binding or cramping of the piston in the cylinder and throwing it out of alignment. Moreover, the connection should not be rigid, but should be free to move in a direction at right angles to the axis of the cylinder, although having no movement in the direction in which the motion of the piston is transmitted. It is believed that, in these matters, the design and construction adopted in the Star Improved Indicator represent the advanced practice of the day. Another important matter upon which the high efficiency of an indicator depends, is the use of such a form of multiplication for the pencil mechanism, that not only does the movement of the pencil within its prescribed limits take place in an exact straight line, but the design should be such that it will be maintained in this rectilinear condition even after of the instrument are registered. The paper drum carries a sheet of paper wrapped around the outside, and this is given a reciprocating motion derived from the crosshead of the engine. As the drum is moved back and forth, the pencil is brought to bear upon the paper, and the indicator diagram is traced upon it.



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the instrument has been subjected to considerable wear. It is best that the pencil mechanism should be self-contained, so to speak; in other words, that when it is disconnected from the piston-rod, the path through which the pencil moves, when worked up and down by hand, is still a straight line by virtue of its own mechanism, irrespective of its attachment to the piston-rod. The Star Improved Indicator possesses these desirable features. It is not only as efficient as such an instrument can be made when new, but it is of a character to maintain its high efficiency without undue deterioriation from age.

The excellence of an indicator depends also, in a large degree, upon the design and construction of the drum mechanism, especially when used on high-speed engines. The drum must be extremely light and well mounted, and the drum spring must be of a form which freely responds with a uniform tension whenever it is called upon to operate. The arrangement adopted in the Star Improved Indicator has been proved to be one of the best designs for securing an accurate reproduction of the stroke of the piston of the engine.

In the leading features referred to, the most efficient and best proved designs have been adopted in the Star Improved Indicator. In all the many details of construction this course has also been followed; and in those minor parts relating to convenience of manipulation, special care has been bestowed. Whether examined superficially, therefore, or made the subject of critical study, it has been planned to meet every test.

Entering now into full particulars regarding the instrument, the various parts are described as follows: —

THE CYLINDER AND ITS INTERNAL PARTS.

CYLINDER. — The parts which go to make up the cylinder, together with piston, spring, and mechanism inside, are fully shown in the sectional cut on the following page.

The cylinder consists of an outer shell, which forms a part of the main body of the indicator, and an inner shell, in which the piston operates. The inner shell is removable; and it can readily be replaced when it becomes worn by long use, without throwing away the whole instrument. The inner shell extends in one continuous piece of metal to the cap, and the alignment for the movement of the piston is thereby perfectly maintained. This is one of the improved features of the indicator not found in some of its predecessors. The inside bore of the cylinder is carefully reamed to such size as to give an area of exactly one-half of one square inch, the exact diameter being .7979 inches. The interior cylinder at the lower end is comparatively thin, and it is surrounded by an annular space extending between it and the outside case. This enables the working part of the cylinder to be free from any distortions that may result from difference of expansion in the outer shell, or from undue strain which may be brought to bear upon the body of the indi-

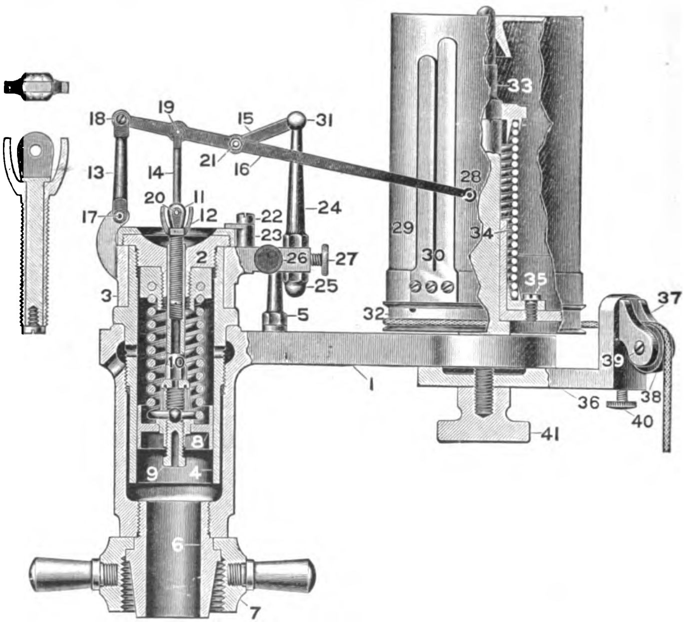


Fig. 2. Sectional View of Star Improved Indicator.

cator, insuring always a perfectly cylindrical form. The lower end of the outer shell is provided with a coupling by which the instrument is attached to the top of the indicator-cock. This coupling has a tapering end forming a ground joint, which the nut draws down into the socket of the indicator-cock, making the connection perfectly tight. The nut has a right-hand thread, and it is provided with two projecting handles, by which it is turned. The nut is held in place by a shoulder on the coupling, so that it always preserves its position attached to the lower end of the instrument, no matter which way or how far it is revolved.

The upper part of the interior cylinder is surrounded by a channel completely encircling the inner shell and communicating with it by means of a number of holes drilled through the metal. From this channel, openings through the body of the outer cylinder carry away the steam and vapor which, in the process of operation, blows by the piston. The outer openings are led to a vent tube; and the steam blowing from the tube can be turned in any direction desired away from the hand of the person who is using the indicator, thus overcoming the annoyance usually caused by the escaping steam and water where this feature is absent. This tube is not shown.

THE PISTON.

The piston consists of a thin cylindrical shell, open at the top and bottom, with a transverse web across the center. It is made of tool steel, hardened, ground, and lapped. At the center of the web is an opening which receives the hub of the piston. The hub is made of soft steel, and it is fastened securely to the web by a staking-tool. The hub has a threaded central opening running from end to end. To the top the piston-rod is screwed, and to the bottom, an adjusting-screw. The upper part of the hub is slotted so as to provide an opening for the introduction of the lower end of the spring. The slot is of slightly greater width than the diameter of the wire, so as to leave a certain amount of freedom of motion in a lateral direction. As the two parts into which the slot divides the hub have no connection at the top, they would be easily spread apart by the thread of the piston-rod and thereby become insecure, were it not for the arrangement of the upper end, whereby a collar which forms a part of the piston-rod slips over the upper end when the rod is screwed into place, and holds the two parts in a secure position. The lower end of the piston-rod and the upper end of the adjusting-screw are made concave so as to form a cavity to receive the ball on the lower end of the spring, and thereby secure a ball-and-socket joint between the piston and the spring. The piston-rod being screwed down so that the collar bears solidly upon the top of the piston hub, and the adjusting-screw below being set so as to lightly touch the ball, as is done when the parts are properly connected together, the piston and rod are free to rotate a slight amount on the axis, and still have no sensible lost motion in a direction parallel to the axis. This feature provides a flexible connection between the piston and the spring which prevents binding produced by the strains in the spring itself that might otherwise occur; and at the same time it is sufficiently rigid in the direction of the motion of the piston to transmit the movements desired.

THE PISTON-ROD.

The piston-rod carries the movement of the piston through the cap to the pencil mechanism above. It is made of tool steel, ground and lapped; and this process is carried on at the same time that the piston to which it is attached is finished. As stated in the preceding section, the lower end of the rod, which is threaded, screws into a slotted socket in the top of the piston-hub; and it is made concave at the lower end, where it bears against the ball on the spring. At the top of the threaded portion the rod is provided with a collar, which encircles the two parts of the socket and holds them in place. At the same time the collar forms a shoulder which brings up solidly on the hub. A hexagonal nut is also provided just above the collar, and a long socket wrench, slipping over the rod from the top, is used to screw the rod into place.

The upper end of the rod is hollow and threaded to receive the *swivel-head*, through which motion is communicated to the pencil mechanism. The swivel-head is a new feature in this instrument, and by its use any desired vertical adjustment of the position of the pencil can be secured without removing the cap from the cylinder. It consists simply of a delicate thumb-screw, drilled from end to end, and mounted on a light shaft to which it is nicely fitted. The screw swivels upon the shaft, being held in position by the shoulder of a small stud, which is screwed into the lower end of the shaft. The bearing-surface of the screw is of considerable length, so as to prevent appreciable wear. Users of the indicator will find this a desirable innovation, for all that is needed to adjust the height of the diagram above the lower edge of the card is to turn the swivel with the thumb and forefinger the amount desired. The arrangement is clearly shown in the sectional cut.

THE SPRING.

One of the most important parts of the whole instrument is the spring; for upon its correct action in resisting the motion of the piston, and the consequent movement of the pencil, the accuracy and reliability of the indicator depend. The spring adopted in the Star Improved Indicator is believed to satisfy the requirements of a perfect instrument better than any other design, and it has proved its superiority during a long period of practical use. An enlarged view of the spring, separated from the remaining mechanism, is shown in the following cut.

The spring consists essentially of only two parts, — one being the head, upon which the spring is mounted, and the other, the coiled wire which forms the spring itself. There is no metal at the lower end save a small sphere or ball through which the wire passes and to which it is attached. The ball forms the point of attachment for the piston, and furnishes the ball-and-socket joint between the spring and piston elsewhere referred to. This design provides the lightest construction of spring that can well be devised. When it is considered that the momentum of the mass of metal in the spring has a considerable effect upon the form of the diagram which the instrument produces, the importance of reducing the weight, especially at the piston end which moves over the longest path, is clearly realized.

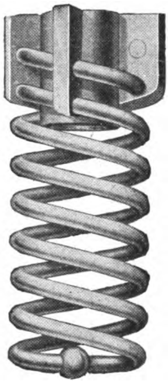


Fig. 3.

The wire of which the spring is made is continuous in one piece. Starting with the center, which forms the lower end, it is wound in a double coil to the top, the two free ends being attached to the head. The head has a central hole which is threaded, and four wings extending radially from the center. These wings are drilled with holes at the proper points and in the proper helical direction to receive the coils, and when once adjusted, they are soldered into place. In the process of constructing and adjusting the spring to the proper scale, the wire coil is revolved around the axis of the head, in or out of the wings, until the desired scale is secured. The head of the spring has a broad shoulder, and this is brought into solid contact with the bottom of the cap when screwed into place. The threaded portion screws upon the outside of the central piece projecting from the bottom of the cap.

THE CAP.

The cap, as its name signifies, is attached to the top of the cylinder, being screwed into the interior shell. The shoulder on the cap brings up solidly against the end of the cylinder, thereby fastening it securely in place. The shoulder serves also to hold in position the sleeve which carries the pencil mechanism, enabling it to be revolved freely around the outside of the cylinder. The outer rim of the cap extends slightly beyond the circle of the outside of the sleeve, and its surface at this point is milled so that it may be grasped between the thumb and forefinger, and readily unscrewed when it is desired to remove the cap from its place, as is done when the piston is oiled or the spring changed. This outside rim possesses a new feature in indicator practice, being made of a non-conducting material for the protection of the fingers from being burned by the hot metal. Without this provision, the removal of the piston from the hot cylinder, as everyone familiar with indicator work knows, is attended with considerable discomfort. A central hole is drilled in the cap to serve as a guide for the piston-rod which passes through it. No hardened bushing for preventing wear is required, nor any specially nice fit, for the design of the pencil mechanism makes these unnecessary. A strong interior hub projects from the bottom of the cap, which is threaded outside; and to this the spring is attached, the upper end of the head being screwed solidly against the body of the cap. The top of the cap has a concave recess, which serves to receive oil and thereby keeps the piston-rod lubricated.

THE SLEEVE OF THE PENCIL MECHANISM.

The pencil mechanism is mounted upon a sleeve, which encircles the top of the interior cylinder, and is held in place by the cap. The sleeve is so fitted that it can freely revolve, as requires to be done in the act of taking diagrams, without perceptible lost motion in any direction. There are two projections extending radially from the top of the sleeve, and these form supports for the attachment of the pencil mechanism. On one of these projections an adjusting-screw is attached, having a wooden handle and check-nut. This screw serves as a stop to prevent the mechanism from being brought to bear with too much force upon the paper drum, the end of the screw striking against a post which stands in a suitable place on the frame of the indicator. By means of a set-screw with milled head the screw can be set firmly, so as to maintain any desired pressure between the pencil and the drum without the annoyance of readjusting every time a diagram is taken.

THE PENCIL MOVEMENT.

The pencil movement, by means of which the reciprocating motion of the piston is transmitted in a straight line to the pencil, and there multiplied, consists essentially of three parts, — the pencil-arm, the back link, and the front link. These three parts are so proportioned, and the pins on which they are mounted so placed, that the pencil moves in its rectilinear path irrespective of any connecting link between the piston-rod and the pencil movement. This is one form of pantograph motion which has been proved by long service to be most efficient and reliable. The degree of perfection with which the rectilinear motion is obtained in this arrangement is dependent solely upon the accuracy with which delicately turned pins can be fitted to reamed holes, and it goes without saying that such construction can be made well-nigh perfect. The pins and all other parts of the pencil movement are made of hardened steel, and their weight is reduced to the smallest amount consistent with proper durability and operation. A fourth link, or connecting-rod, serves to transmit the motion of the upper end of the piston-rod to the pencil-arm. The lower end of this rod is attached by a pin to the top of the swivel-head, which forms the upper end of the piston-rod.

The pencil mechanism is so proportioned that the movement of the piston is multiplied at the pencil end of the lever six times.

The standard pencil employed is a metallic marking-point made of composition metal. It is provided with a shoulder and introduced backwards into the end of the pencil-arm, the pressure on the drum tending to push it securely into place. An alternative arrangement consists of a threaded marking-point, having a milled head by which it is readily screwed into place, the inside of the cylindrical end of the pencil-arm being tapped to receive it. Another alternative arrangement provides for the use of a pencil-lead in place of the metallic point. The end of the pencil-arm is made in the form of a small light cylinder, the axis of which is perpendicular to the drum. Where the marking-point is used, the metal at the marking-end is reduced in diameter so as to secure a suitably fine point without too frequent sharpening.

The design of this pencil movement is such that the pencil does not deviate from a straight line in any sensible degree, unless the extreme movement extends more than $1\frac{1}{4}$ inches each way from the central position.

THE PAPER DRUM.

The paper drum is carried by a stationary vertical shaft secured to the projecting body of the indicator. The drum proper consists of a very light hollow cylinder, closed at the top and provided with a central bearing. It is supported by the drum base, to which it is attached by a sliding-fit; and the base revolves about the lower end of the shaft. The drum thus has a bearing at both the top and bottom, and is always kept thereby in a line parallel with the indicator cylinder. The base projects below the end of the drum, and the periphery is grooved for the reception of the driving-cord. The cord is attached to the base by carrying it through a hole in the metal and tying a knot on the inside.

The drum-spring is of spiral form, like the thread of a screw; and it encircles the vertical shaft within the drum. The lower end is mounted on a plate, which is securely fastened by screws to the drum base, and therefore revolves whenever the drum revolves. The upper end of the spring terminates in a head-piece, at the center of which there is a square hole, forming a socket which slips over a square section of the shaft, and thereby makes the upper end stationary. Above the square the shaft is of reduced cross-section. By lifting the head-piece a short distance, and clearing it from the square, it can be revolved, and by so doing either increase or decrease the tension of the spring, as may be needed to insure the proper operation of the drum. The spring is prevented from unwinding by means of a stop, against which the base of the drum rests when there is no strain on the driving-cord. When the driving-cord is pulled with sufficient force to cause the drum to revolve, it leaves the stop; and when the strain on the cord is removed, the tension of the drum-spring carries it back again to the stop.

The outside of the drum is provided with two parallel spring clips, tightly fastened at the lower ends, and free at the upper ends, arranged so as to lie close to the cylindrical surface. By the use of these clips, the paper which surrounds the drum is held securely in place. The clips are made of different lengths for facility in handling.

The driving-cord, which is attached at one end to the drum base, passes over the carrier pulley, which is mounted on an arm projecting from the body of the indicator. This arm is central with the axis of the drum; and it can be adjusted to any angular position with reference to it, being secured in the desired position by the milled check-nut below. By this means the driving-cord can be led off in any direction perpendicular to the axis of the drum. To provide also for leading the cord in any other direction the carrier pulley is arranged to swivel around the line of the driving-cord, the circumference of the carrier pulley itself being tangential to the cord. By a combination of these two motions, the cord can be led off from the indicator in any direction whatever. When once adjusted to the right position, the carrier pulley is held by means of a set screw with milled head.

The diameter of the drum in the standard Star Improved Indicator is two inches, and the height in the clear for the reception of the indicator card is 2 $\frac{11}{16}$ inches.

The cord used in the indicator is a braided linen cord with a straight core, being strong and durable and at the same time free from undue tendency to stretch.

DETENT MOTION.

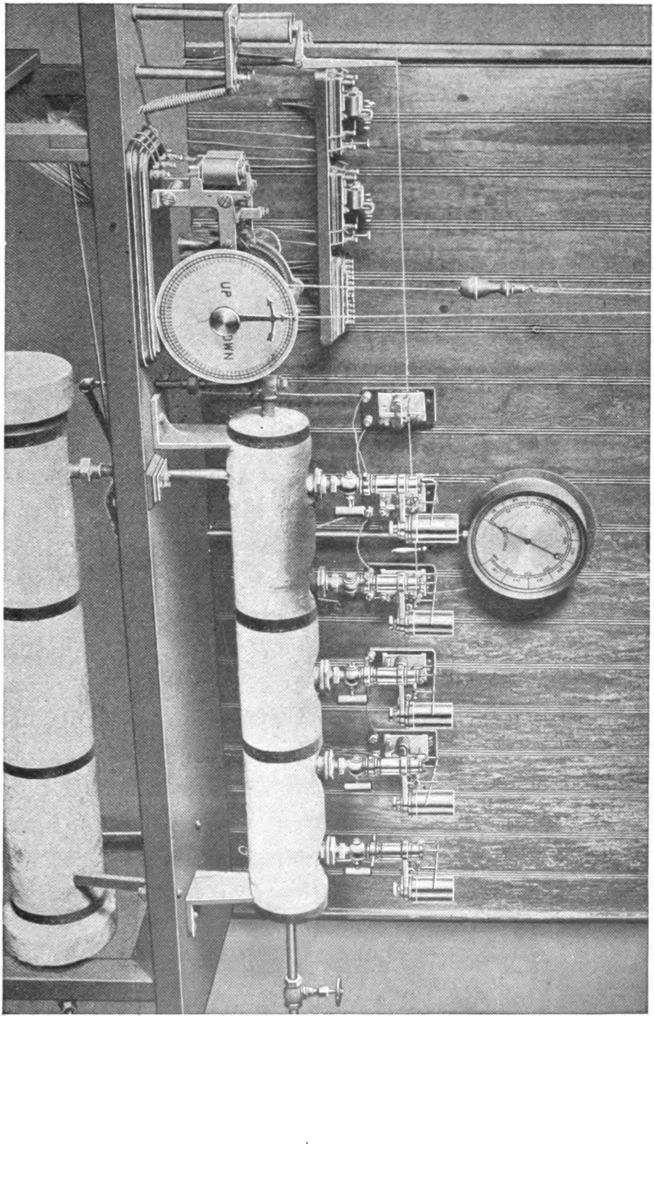
The detent motion used on the Star Improved Indicator is a novel and useful departure from the designs heretofore in common use. It is in the nature of a friction clutch or minute brake. The drum-base extends below the groove which carries the driving-cord, and a loose ball is brought to bear upon the periphery of this extension in the manner of a wedge. By turning a thumb-screw in one direction the ball is brought into contact with the base, and the motion of the drum is arrested, while a turn of the screw in the opposite direction releases the ball, and the drum is again set to work. The wedging action takes place only on the backward movement of the drum; and consequently the motion is arrested near the extreme end of the stroke, the cord becoming slack during the remainder of the stroke. The ball is placed in a suitable cavity made in the edge of a plate fastened on the body of the indicator, which also carries the releasing-screw. The edge of the base against which the ball acts has a shallow groove which the ball fits.

CHAPTER III.

TESTING SPRINGS.

THE apparatus used in testing the springs of the Star Improved Indicator, has been constructed especially for this work. The springs are tested under steam pressure, and the recording mechanism is operated electrically. The instruments are attached to a horizontal steam-drum which is provided with five indicator-cocks standing vertically. Each instrument is connected to electrical operating devices, of which there are two. One device actuates the pencil movement, and brings the pencil into contact with the paper drum. The other device operates the drum motion, and revolves the drum a short distance forward and backward. These are both under the simultaneous control of an electric circuit made by a mercurial pressure gauge or mercury column connected to the steam-drum; and whenever the circuit is completed a record is made automatically on the card, consisting of a line about one-eighth of an inch long, drawn parallel to the drum base. The general features of the steam-drum and electrical apparatus are shown in the accompanying cut.

The circuit is made and broken whenever the



Spring Testing Apparatus.

meniscus at the top of the mercury column passes certain contact points; and these points are determined by setting a circuit controller, which is wired to all the points, at certain corresponding marks. This is done automatically for each pound pressure between 0 and 10, for each five pounds pressure between 10 and 100, and for each ten pounds pressure between 100 and 300; and either of these may be omitted by setting the controller either ahead or behind, as may be desired.

The instruments being properly connected, and all parts heated and ready for operation, steam is admitted to the drum, and the pressure is allowed to rise at a slow rate. The rest of the operation is carried on automatically, unless otherwise desired, as noted; and the instruments record the various pressures on the blank cards, through the whole range from zero to the extreme pressure desired. The entering supply of steam is then choked off, and the pressure allowed slowly to fall. Records are again made the same as before, excepting on a falling, instead of a rising, pressure; and the whole range covered down to zero. There are thus obtained two records consisting of two rows of short parallel lines corresponding to the various pressures. If the two records are not coincident, the mean is taken for the true scale to be determined.

For pressures below the atmosphere, the testing-drum is connected to a vacuum-pump.

Arrangements are being made to introduce in this connection a new feature which is an advance upon anything in this line yet inaugurated. It brings into use a method of test advocated by the Engine Test Committee of the American Society of Mechanical Engineers in the "Code of 1902." Instead of keeping a continuous pressure on the indicators during the progress of the work, the apparatus will be arranged so as to momentarily close and open the indicator-cock, and thus subject the instrument to alternations of pressure and exhaust much the same as in the practical operation of the indicator attached to an engine.

CHAPTER IV.

CARE OF THE STAR IMPROVED INDICATOR.

THE same care, in general, should be exercised in handling the Star Improved Indicator as that observed with any instrument of this kind. Unless all the parts are in proper adjustment and free to move in their required manner, the indications are liable to be distorted and the efficiency of the instrument reduced. All the bearing surfaces should be well lubricated, and there should be no grit or foreign substances present to interfere with the free operation of the parts. It is specially important that the cylinder should be clean and well lubricated, for there is more or less foreign matter carried into it with the steam received from the engine and the pipes leading to it. In using the instrument it is desirable to frequently remove the piston from the cylinder and make an examination of the parts within, if for no other purpose than to be assured of the clean condition of the interior of the cylinder and the outside of the piston. When this is done, it is well to introduce one of the fingers into the cylinder, and determine by the sense of touch whether there is grit on the inside, and also ascertain by touch whether the outside of the piston is clean. Opportunity is afforded at the same time for oiling the piston. The best kind of lubricant for this purpose is a good grade of cylinder oil. When these examinations of the piston are made, it is well to revolve the piston back and forth between the thumb and forefinger, holding the cap firmly in the other hand, so as to see whether the piston is free with reference to the spring, and that there is no unnecessary lost motion between the piston and the spring in the direction of the piston-rod.

It is almost needless to say that the various pins and bearings about the pencil mechanism, drum, and carrier-pulley, should be frequently oiled and kept in good running condition, the same as in any delicate machine. For this purpose, either the porpoise oil furnished with the instrument, or some fine grade of machine oil, should be used. When the indicator is not in use for any length of time, it is well to remove the spring, carefully wipe it dry to prevent its rusting, and lay it away in its place in the indicator box, at the same time wiping the piston and cylinder dry.

It is desirable to frequently work the drum mechanism by hand, by pulling the cord back and forth, to see that it runs smoothly. Any want of uniformity in the movement will reveal itself to the touch, if one is a careful observer of such matters. It is important to examine the pencil mechanism and piston from time to time, to see that these parts are in proper working condition. For this purpose the spring should be removed from the cylinder, the piston replaced, and then the pencil-arm lifted with the finger to the end of its motion and allowed to drop back by its own weight. If all parts are free, and in proper condition, the mechanism falls back immediately and with no appearance of any resistance. The same tests should be made after disconnecting the piston-rod and then trying the pencil mechanism alone. This should likewise fall with perfect freedom simply by its own weight.

As an example of the effect produced by derangement of the parts, presence of dirt, or absence of proper lubrication, the following diagram, Fig. 4, is given. The serrated form of the expansion and compression lines and the sharp corner of the cut-off are sure indications of disorder.

TO CONNECT THE SPRING.

The piston-rod is disconnected at both ends, and placed in an inverted position within the hollow socket wrench. The spring being also inverted is slipped over the rod, and the ball placed in position on the concave end. Holding the wrench in the right hand, and thus supporting the piston-rod and spring, the piston is now taken in the fingers of the left hand and brought to its place; the socket wrench is turned and the piston-rod finally screwed into its working position. The rod should be screwed up

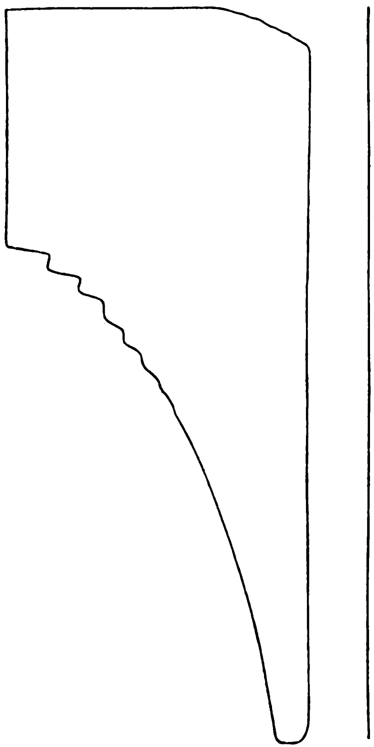


Fig. 4. Diagram Showing Disordered Indicator.

solidly against the piston-center, so that the collar at the lower end of the rod may encircle its two halves and hold them securely. The adjusting-screw, which should be loosened while this is being done, is now carefully turned until it brings up against the spring. While setting the adjusting-screw, it is well to hold the spring in one hand and the piston between the thumb and forefinger of the other hand, then turn the piston back and forth through the short range of its motion, at the same time carefully working the piston up and down in the direction of the axis. By continuing the adjustment until there is practically no lost motion between the screw and the end of the piston-rod, without impairing the freedom of rotative movement, a satisfactory result will be secured.

TO ADJUST THE POSITION OF THE ATMOSPHERIC LINE.

Without removing any of the mechanism from its place in the indicator, the position of the atmospheric line — that is, the normal level of the pencil — can be adjusted by simply turning the swivel-head at the top of the piston-rod either to the left or to the right, as the case may be. This movement lengthens or shortens the piston-rod, and has the effect of carrying the whole pencil mechanism either up or down, as may be desired to bring the pencil into its proper place. This is a new and valuable feature in the Star Improved Indicator, and it will be appreciated by parties familiar with indicator work.

TO CHANGE TENSION OF DRUM–SPRING.

It is a simple operation to change the tension of the drum-spring. First remove the drum by lifting it from the base on which it rests. Then raise the milled head of the drum-spring a short distance so as to clear the square on the shaft, and turn it between the thumb and forefinger in the proper direction to increase or decrease the tension, as the case may be, moving it first one-sixth of a turn, or one square, and then allowing the head to slip back into position. If a movement of one square is not sufficient, repeat the operation one square at a time until the desired tension is secured.

CHAPTER V.

DIAGRAMS FROM STAR IMPROVED INDICATOR.

THE efficiency attained in the operation of an indicator is shown by the character of the diagrams which it produces. The general form of a diagram is dependent upon the engine and the conditions under which the steam is distributed in the cylinder; but the delicacy and smoothness with which the line of a diagram is traced and the various changes are indicated, depends upon the efficiency with which the mechanism of the indicator operates. To judge of the action of an instrument, it is better to see the original diagram just as it is traced by the indicator, rather than examine a printed reproduction; but for the purposes of this treatise the latter course is the only one available. That a fair idea may be gained as to the character of its work a number of diagrams have been obtained with the instrument, some of which were taken for the special use of this book, and they are presented in the following pages. In the process of reproduction all the delicate changes of form of the original diagram have been followed, and as nearly a perfect reproduction as possible in such work has been obtained.

The diagrams were taken from a number of engines working under varying conditions, thereby representing a wide range of application. A careful examination of these illustrations shows that in all the points which reveal the efficiency of indicator action there is a marked degree of excellence.

The names and sizes of engines from which the diagrams were taken, and their localities, are summarized in the following list:

No. 1. 16″ and 40″ × 48″ Horizontal Cross Compound Corliss Engine, at the Atlantic Mills, Providence, R.I., built by the C. & G. Cooper Company, Mt. Vernon, Ohio.

No. 2. 18″ × 48″ Corliss Engine (H. P. Cylinder), at the Ipswich Mills, Ipswich, Mass., built by the Corliss Steam Engine Company, Providence, R.I.

Nos. 3 & 4. $22\frac{1}{2}$″ × 18″ Ball & Wood Engine at the W. Duke, Sons & Company Branch, American Tobacco Co., Durham, N.C.

No. 5. 46″ and 80″ × 60″ Vertical Corliss Compound Engine, at the 96th Street Power Station of the Metropolitan Railway Company, New York, built by the E. P. Allis Company, Milwaukee, Wis.

No. 6. 26″ × 48″ (H. P. Cylinder) Corliss Engine, at Charlestown Power Station, Boston Elevated Railway Company, built by the E. P. Allis Company, Milwaukee, Wis.

No. 7. 28″ and 50″ × 48″ Vertical Compound Engine, at the South Boston Power Station, Boston

Electric Light Company, built by McIntosh, Seymour & Co., Auburn, N.Y.

Nos. 8 & 9. 13 $\frac{1}{2}''\times 12''$ Westinghouse Standard Engine, at Boston Post Office.

No. 10. $16''\times 15''$ Steam Cylinder of an Air Com pressor, at the works of C. Brigham Company, Cambridge, Mass., built by the York Manufacturing Co.

No. 11. 12″ & $20''\times 14''$ Compound Tandem Engine (L. P. Cylinder), at Jordan, Marsh & Co., Boston, built by Ames Iron Works, Oswego, N.Y.

No. 12. $10\frac{1}{2}''$ by 12″ Duplex Compound Engine (H. P. Cylinder), at works of Warren Foundry & Machine Company, Phillipsburg, N.J., built by the American Engine Company, Bound Brook, N.J.

No. 13. 22″ and $40''\times 60''$ Cross Compound Corliss Engine, at works of Great Falls Mfg. Co., Somersworth, N.H., built by the Corliss Steam Engine Co., Providence, R.I.

No. 14. 44″ and $87''\times 60''$ Vertical Corliss Compound Engine, at the Lincoln Power Station, Boston Elevated Railway Company, built by Westinghouse Machine Co., Pittsburg, Pa.

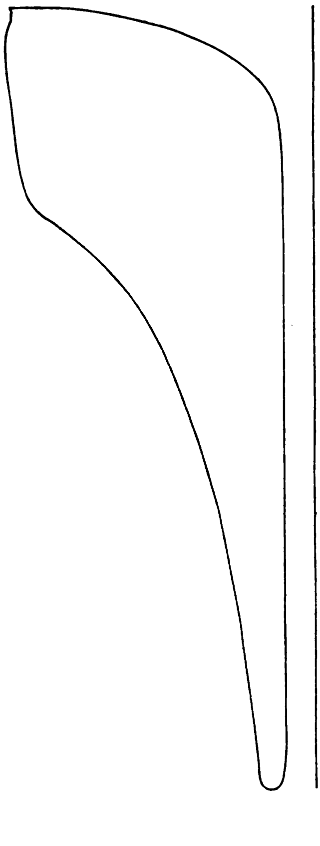


Diagram 1. H.P. Cyl.

STAR IMPROVED INDICATOR.

Corliss Compound Engine 16″ & 40″ × 48″.

Steam Pressure 167 lbs., Receiver Pressure 10 lbs., Vacuum 28 in.

Rev. per. min. 80.

Scale 100.

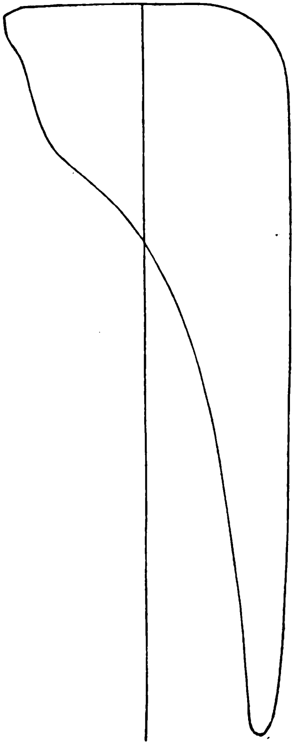


Diagram 1. L.P. Cyl.

STAR IMPROVED INDICATOR.

Corliss Compound Engine 16″ & 40″ × 48″.

Steam Pressure 167 lbs., Receiver Pressure 10 lbs., Vacuum 28 in.

Rev. per min. 80.

Scale 16.

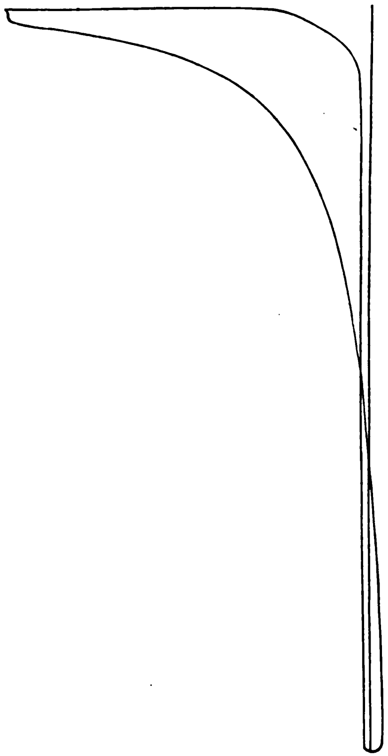


Diagram 2.

STAR IMPROVED INDICATOR.

Corliss Engine, 18″ × 48″.

Steam Pressure 120.

Rev. per min. 68.

Scale 61.

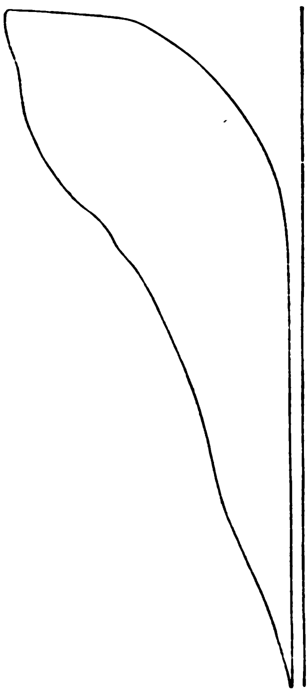


Diagram 3.

STAR IMPROVED INDICATOR.

Bull and Wood Engine 22½″ × 18″.

Steam Pressure 95 lbs.

Rev. pr min. 104.

Scale 60.

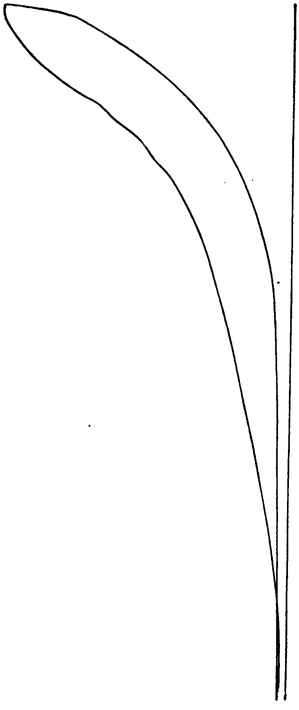


Diagram 4.

STAR IMPROVED INDICATOR.

Ball and Wood Engine 22½″ × 18″.

Steam Pressure 95 lbs.

Rev. per min. 164.

Scale 60.

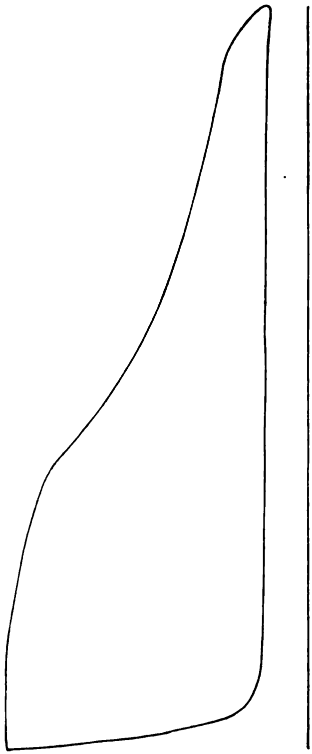


Diagram 5. H.P. Cyl.

STAR IMPROVED INDICATOR.

Corliss Vertical Compound Engine 46″ & 80″ × 60″.
Steam Pressure 148 lbs., Receiver Pressure 14 lbs., Vacuum 25 in.
Rev. per min. 75.
Scale 80.

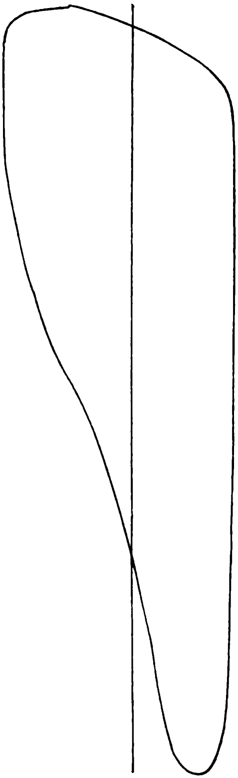


Diagram 5. L.P. Cyl.

STAR IMPROVED INDICATOR.

Corliss Vertical Compound Engine 46″ & 80″ × 60″.

Steam Pressure 148 lbs., Receiver Pressure 14 lbs., Vacuum 25 in.

Rev. per min. 75.

Scale 24.

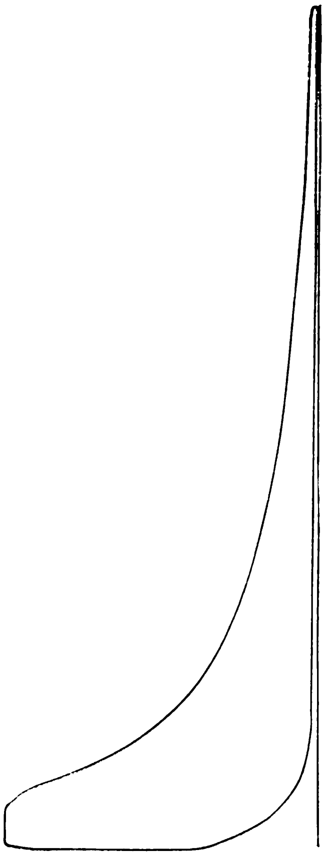


Diagram 6.

STAR IMPROVED INDICATOR.

Corliss Engine 26″ × 48″.

Steam Pressure 149 lbs.

Rev. per min. 90.

Scale 80.

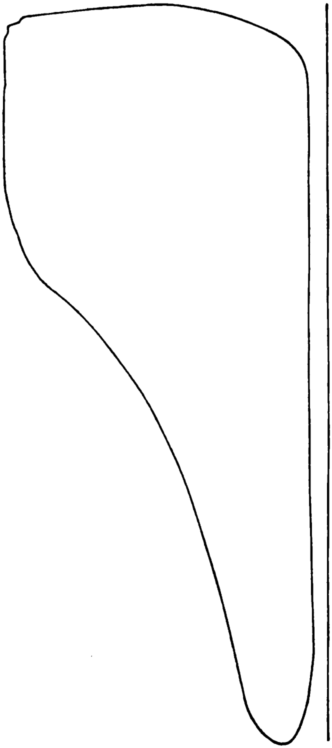


Diagram 7. H P. Cyl.

STAR IMPROVED INDICATOR.

McIntosh & Seymour Vertical Compound Engine 28″ & 50″ × 48″.
Steam Pressure 124 lbs., Receiver Pressure 8 lbs., Vacuum 26 in.
Rev. per min. 116.
Scale 60.

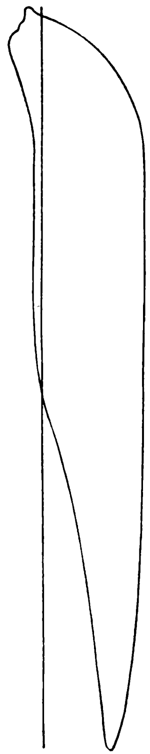


Diagram 7. L.P. Cyl.

STAR IMPROVED INDICATOR.

McIntosh & Seymour Vertical Compound Engine 28″ & 50″ × 48″.
Steam Pressure 124 lbs., Receiver Pressure 8 lbs., Vacuum 26 in.
Rev. per min. 116.
Scale 20.

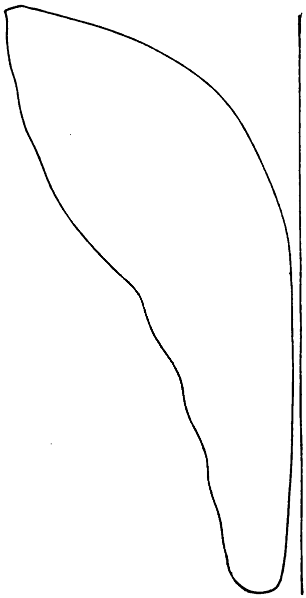


Diagram 8.

STAR IMPROVED INDICATOR.

Westinghouse Standard Engine $13\frac{1}{2}'' \times 12''$.

Steam Pressure 86 lbs.

Rev. per min. 305.

Scale 50.

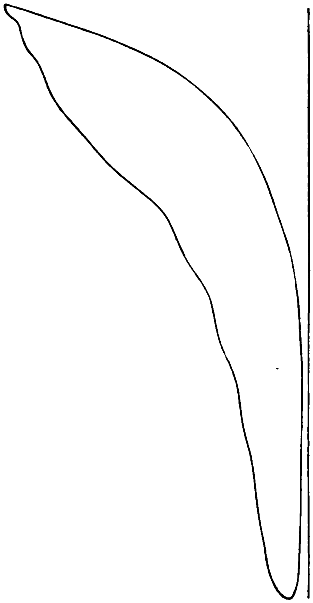


Diagram 9.

STAR IMPROVED INDICATOR.

Westinghouse Standard Engine 13½″ × 12″.

Steam Pressure 86 lbs.

Rev. per min. 305.

Scale 50.

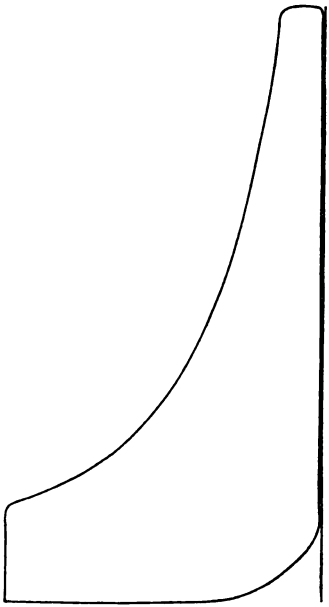


Diagram 10.

STAR IMPROVED INDICATOR.

Air Compressor Engine 16″ × 15″.

Steam Pressure 92 lbs.

Rev. per min. 57.

Scale 50.

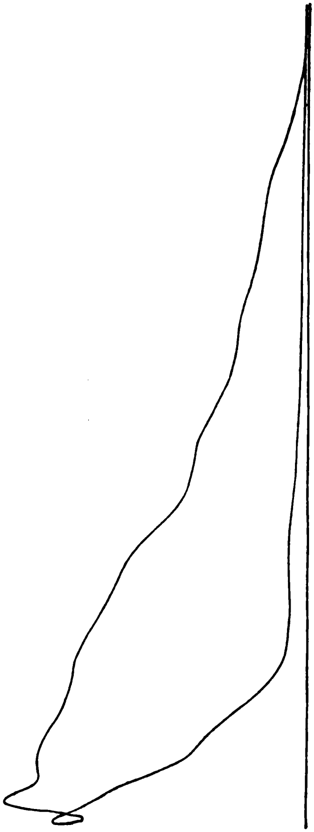


Diagram 11.

STAR IMPROVED INDICATOR.

Ames Compound Engine L. P. Cyl. 20″ × 14″.

Rev. per min. 260.

Scale 33.

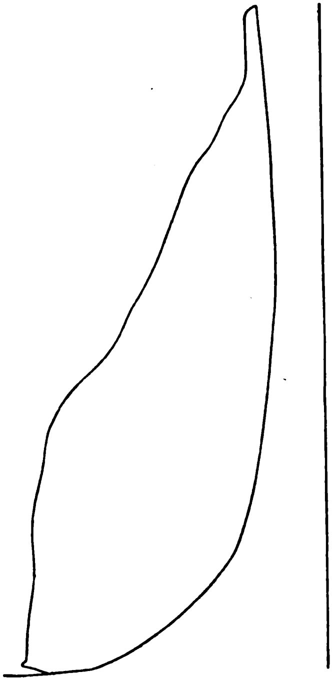


Diagram 12.

STAR IMPROVED INDICATOR.

Ball Duplex Compound Engine H.P. Cyl. 10½″ × 12″.
Steam Pressure 104 lbs. Vacuum 24.4 in.
Rev. per min. 282.
Scale 60.

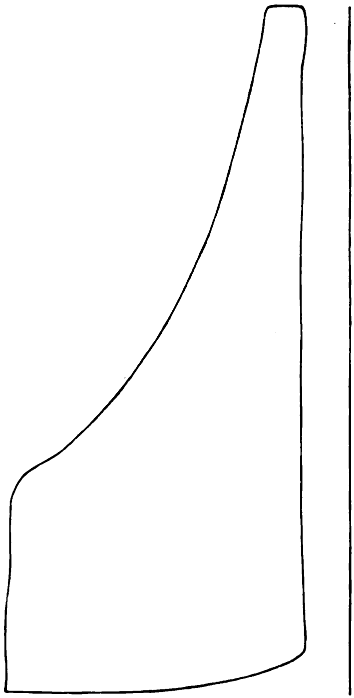


Diagram 13. H.P. Cyl.

STAR IMPROVED INDICATOR.

Corliss Compound Engine 22″ & 40″ × 60″.

Steam Pressure 115 lbs., Receiver Pressure 12 lbs., Vacuum 26.4 in.

Rev. per min. 64.

Scale 60.

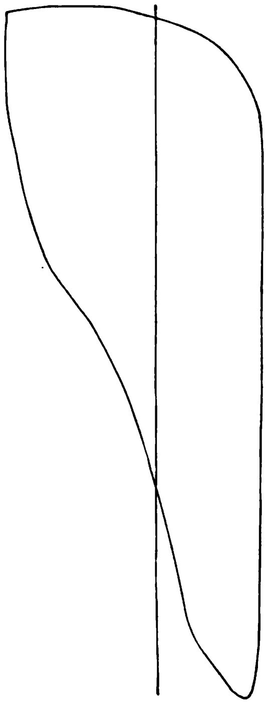


Diagram 13. L.P. Cyl.

STAR IMPROVED INDICATOR.

Corliss Compound Engine 22″ & 40″ × 60″.

Steam Pressure 115 lbs., Receiver Pressure 12 lbs., Vacuum 26.4 in.

Rev. per min. 64.

Scale 24.

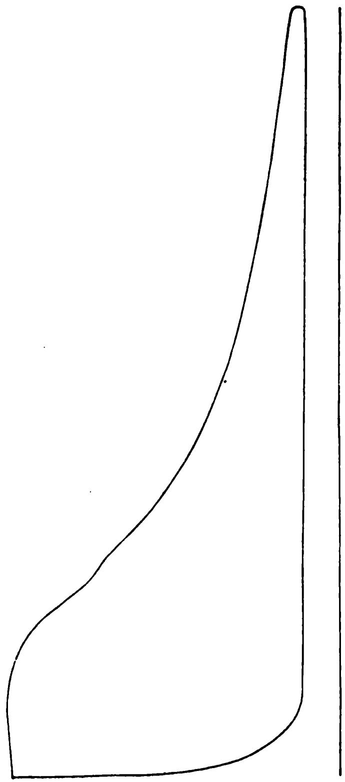


Diagram 14. H.P. Cyl.

STAR IMPROVED INDICATOR.

Corliss Vertical Compound Engine 44″ & 87″ × 60″.

Steam Pressure 170 lbs., Receiver Pressure 13 lbs., Vacuum 24.8 in.

Rev. per min. 74.

Scale 80.

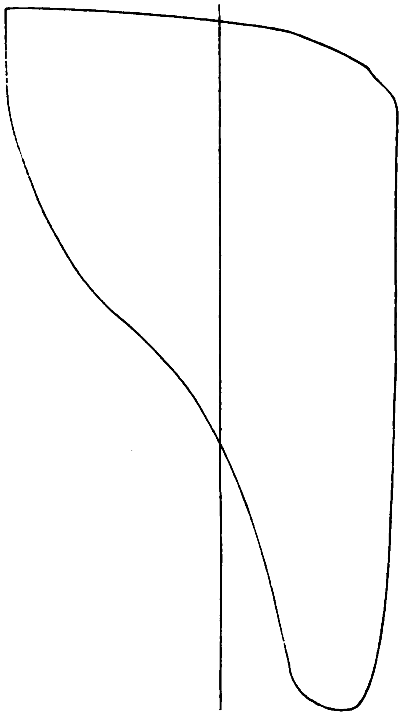


Diagram 14. L.P. Cyl.

STAR IMPROVED INDICATOR.

Corliss Compound Engine 44″ & 87″ × 60″.

Steam Pressure 170 lbs., Receiver Pressure 13 lbs., Vacuum 24.8 in.

Rev. per min. 74.

Scale 12.

CHAPTER VI.

HOW TO INDICATE AN ENGINE.

ATTACHING THE INDICATOR.

To a person who is familiar with the use of an indicator, whether it be of one make or another, it is needless to give instructions as to how an engine should be indicated; but for a beginner certain directions are required, and it is for the instruction of persons unfamiliar with the precise steps to be followed that the subject is taken up in some detail.

The first thing to be considered is the place and method of attaching the indicator to the cylinder. It has come to be a practice in engine-building to provide tapped holes at each end of the cylinder for the attachment of an indicator, before the engine is shipped from the manufactory; and in most cases therefore, especially on new work, there is no occasion for selecting a place for drilling the indicator holes, for these have already been provided, and generally provided in a proper location. It may as well be said, however, that in an engine which is not drilled for this purpose, the indicator holes should be located at a point which, if possible, is beyond the stroke of the piston; so that when the piston reaches the end of the stroke, it will not project beyond the hole, and prevent a free access of steam to the indicator-pipe at the very beginning of the stroke. Generally speaking, if the hole is located so that its center lies in the plane of the free clearance space between the cylinder-head and the face of the piston at the end of the stroke, it will secure the desired results. This presupposes that the location is on the side or barrel of the cylinder, and not on the cylinder-head. In some classes of engines, it is convenient to locate the hole by drilling through the cylinder-head. If this is done, it matters little what part of the cylinder-head is selected, and the best place is the one which will secure the most convenient attachment of the driving-gear. In some engines it requires the exercise of good judgment to locate the indicator; but as a rule the principle to be followed is to place it where it will be in free communication with the working steam in the cylinder at every point of the stroke.

The most approved method of connecting the indicator to the tapped hole in the cylinder, is to use a straight pipe having just sufficient length to pass through the lagging surrounding the cylinder, and provide the outer end with a straight coupling for the reception of the indicator-cock. If this connection is on the side, it places the indicator in a horizontal position, which is rather less handy for manipulation than the vertical position; but it provides a perfectly straight connection with the steam in the interior, which is of considerable advantage. Some prefer, however, even in this location, to use one right-angle elbow for the reception of the indicator-cock, so that the indicator can stand in a vertical position, as in this position it can be the most readily manipulated. On the whole, there is no special objection to the latter arrangement, for the influence of one elbow attached to a short pipe is hardly noticeable. In any case, it is highly important, if accurate results are to be obtained, to place the indicator close to the end of the cylinder, using an independent instrument for each end. The use of a single indicator on a three-way cock attached to the center of a pipe connecting the two ends together, produces errors in the form of the diagram; and this should not be employed for accurate work, unless the effect of these errors is determined and correction made for them. If only one indicator is available for use on the cylinder, and accuracy is desired, it is best to take the diagrams alternately from the two ends, transferring the instrument from one end to the other.

Whenever the indicator-pipes are first attached, or whenever they have remained unused for any length of time, they should be blown out thoroughly by opening the indicator-cock, this being done before attaching the instrument, so as to remove grit or foreign material that may be present. If this precaution is overlooked, the indicator cylinder is sure to become foul.

THE DRIVING-RIG, OR REDUCING MOTION.

Having attached the indicator to the cylinder, the next thing is to provide means for driving the paper drum; that is, for obtaining the reduced motion which represents the stroke of the piston. Many engines are provided with indicator driving mechanism when first built in the shop; such apparatus being intended for permanent use. Where it is already provided, nothing more is required than to connect the indicator driving-cord with the cord which leads from the permanent motion, and the process of indicating becomes a simple matter. A word of caution should be offered here, however, in regard to permanent driving-rigs which have become worn or otherwise unfit for use. Before taking diagrams, therefore, a careful examination should be made of the driving-rig, to determine whether it is in proper condition for accurately reproducing the piston's motion. If there is lost motion due to wear, or if the mechanism does not run freely and smoothly, giving evidence of being in improper adjustment, the defects should be ascertained and remedied before dependence is placed upon the diagrams. Too much care cannot be exercised in this preliminary examination of the driving-rig, for upon the accuracy of the reducing motion, next to the accuracy of the indicator itself, the reliability of the entire work depends.

In the absence of a driving-rig which forms a permanent attachment to the engine, there are a variety of ways in which the reduced motion of the paper drum can be obtained. The best plan will readily suggest itself if the principles to be followed are understood. The leading principle involved, is to so reduce the reciprocating motion of the cross-head to the limits of the motion of the paper drum, that a correct reproduction shall be obtained on the reduced scale.

One method which can be easily arranged for a temporary apparatus, consists of a reducing lever made of wood, and mounted at one end so as to oscillate back and forth like a pendulum, and connected at the other end to the cross-head. Any desired reduction in motion can be obtained by attaching the driving-cord at a greater or less distance from the point of support, the cord being carried over a pulley to obtain the desired direction of motion. To make the apparatus correct, the supporting end should be provided with a sector having the desired radius, and the driving-cord led off from the periphery of the sector in a plane parallel with the plane of motion of the lever. The cord can in many cases be led directly from the sector to the indicator without an intervening pulley. The opposite end of the lever should be attached to the cross-head by a short connecting-rod. The lever itself should be short, say twice the length of the stroke, so as to avoid the use of long stretches of cord. It is important that the point of support for the lever should be absolutely rigid, and that the screw or bolt on which the lever is mounted should be well fitted so as to prevent all lost motion. The appended cut, Fig. 5, shows how such a temporary rig can be constructed.

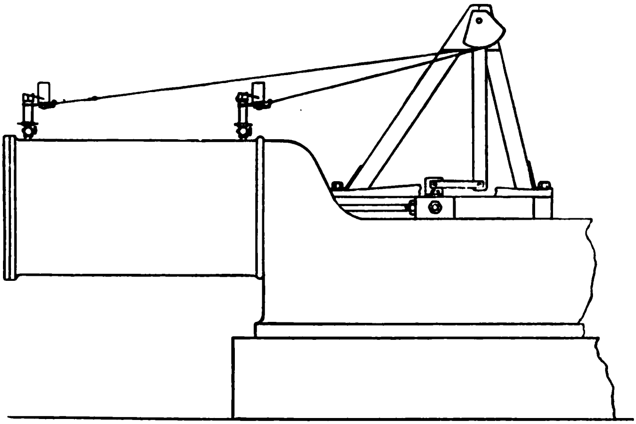


Fig. 5. Reducing Motion for Horizontal Engine.

The principle embodied in this arrangement is frequently made use of for a permanent driving mechanism on horizontal high-speed engines. The support for the vibrating lever consists of a short horizontal shaft mounted at the top of a vertical iron standard which is attached to the frame of the engine. The lever is fastened to one end of the shaft and the sector to the other end, the bearing lying between them.

PANTOGRAPH, OR LAZY TONGS.

The most satisfactory reducing motion for temporary use on many engines, especially those of the Corliss horizontal type, is the pantograph, or "Lazy

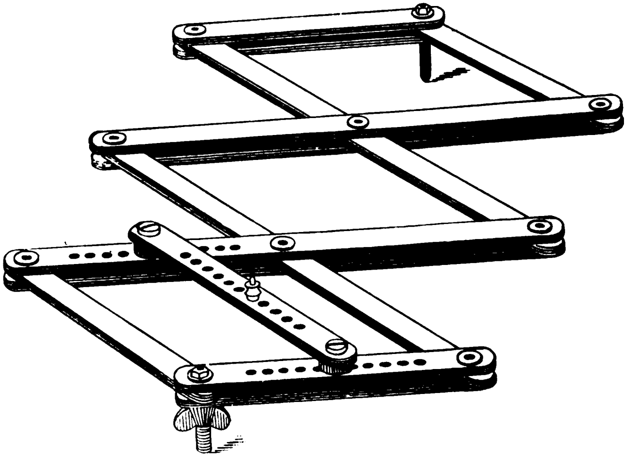


Fig. 6. Pantograph, or Lazy Tongs.

Tongs," so-called, a cut of which is shown in Fig. 6. It derives the name of "pantograph" from the drawing-instrument of that name which produces a mathematically exact reproduction of the motion of the working end. The apparatus is made of strips of wood, fastened at the ends and centers with hollow brass pins having riveted heads. One end is stationary; and at this end there is an iron stud, or pivot, upon which the apparatus turns. The other end is attached by another iron stud to the cross-head of the engine, and moves back and forth with it. A wooden cross-bar, which can be adjusted to any desired position, carries the pin which is the focus of the reduced motion; and to this is attached the driving-cord which works the indicator. The cord-pin is always located in a straight line between the two studs at the ends of the pantograph. The range of adjustment of the cross-bar is such, that when placed in the first hole the movement of the cord-pin is $\frac{1}{16}$ of the stroke of the engine; when placed in the second hole, $\frac{1}{12}$; in the third, about $\frac{1}{10}$; and in the fourth, $\frac{1}{8}$. The joints are made hollow, so that when they become loose they can be tightened by driving in a tapering mandrel and expanding them.

The manner in which the pantograph may be attached to a horizontal engine for temporary use is shown in plan in Fig. 7.

Here the pantograph works in a horizontal plane, and the stationary end is attached to an angle-iron screwed to the side of a post which is placed in front of the cross-head. This post is mounted on a base-board which is fastened to the floor, and is held securely in place by two braces. A second post mounted on the same base, and secured by a third brace, furnishes the support for a swivel pulley over

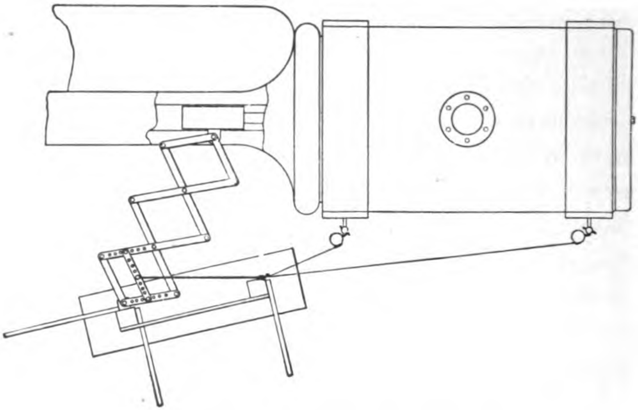


Fig. 7. Pantograph attached to Horizontal Engine.

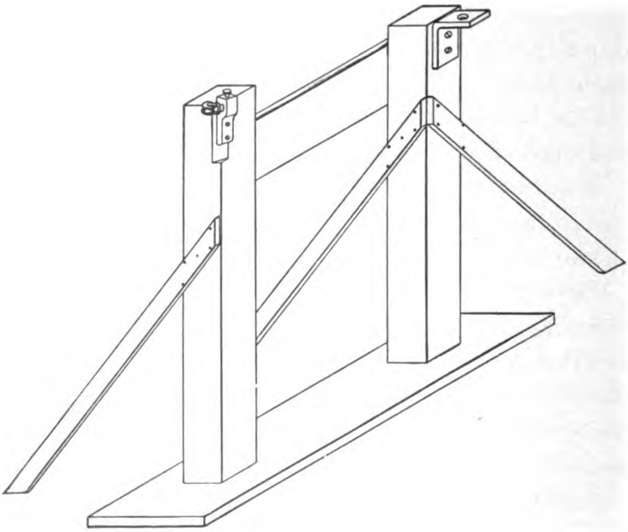


Fig. 8. Stand for Pantograph.

which the cord can be led in whatever direction the position of the indicator requires. This last, however, can be omitted if, as sometimes happens, the pantograph can be so adjusted as to height and horizontal position that the cord can pass directly to the indicators in a line parallel with the motion of the piston. A front view of the double-post wooden stand referred to is shown in Fig. 8.

The pantograph can also be used in a vertical position, where convenience of location may make this position more satisfactory.

REDUCING-WHEEL.

A popular form of reducing motion which has come into quite extensive use, is the reducing-wheel. Sometimes this apparatus is made a part of the indicator mechanism, being attached to the body of the indicator; and sometimes it is separate, and attached to the frame of the engine.

An iron arm is attached to the cross-head extending far enough forward to be in line with the wheel, and this is permanently connected. Whenever a diagram is to be taken, the driving-cord of the reducing-wheel is thrown over the end of the arm without stopping or slowing the speed of the engine, and the wheel is thus set to work. The indicators are then handled the same as with any reducing motion. When the diagrams have been obtained, the cord is unhooked from the cross-head arm, to prevent undue wear.

DRIVING-CORD.

The best kind of cord in the market for indicator work, consists of a braided linen surface surrounding a straight linen core, the outside diameter of the whole being about $\frac{1}{10}$ inch. Any cord which is free from liability to stretch is suitable for this purpose. In any case, however, it is desirable to confine the use of all such material to short distances, and so far ~~as possible,~~ to employ a fine annealed wire. Brass wire having a diameter of $\frac{1}{50}$ of an inch is an excellent material.

To avoid the annoyance arising from tangling of the cords, when these are being hooked and unhooked, it is well to keep the cord taut by hooking the end to a spiral spring when it is unhooked from the indicator, the spring being attached to the lagging of the cylinder at some point where it may be conveniently reached for the purpose. Or the cord may be continued beyond the loop by which it is attached to the indicator, and fastened permanently at some point, leaving sufficient slack line so as not to interfere with the manipulations when the cord is hooked on and the diagrams are being taken.

CHAPTER VII.

HOW TO TAKE A DIAGRAM.

A BLANK card is carefully attached to the paper drum, first slipping one corner under the spring clip which is the higher of the two, and then catching the opposite corner under the shorter clip. By pulling downwards with the thumb and forefinger of one hand, and keeping the card pressed up against the surface of the drum with the fingers and palm of the other hand, the whole card is carefully drawn into its place at the bottom of the clips. The paper is smoothed with the hand around the drum, and at the same time the ends which lie under the clips are pulled taut so as to make the card lie snugly against the cylindrical surface at every point. By tightly gripping the two ends which project beyond the clips, and giving them a suitable pull, the desired result can readily be obtained. The driving-cord is then adjusted so as to give the drum a motion which is central with reference to its complete throw. The diagram will then occupy a central position between the two ends of the card. The indicator-cock is now opened for the purpose of warming the parts preparatory to the later operations. This ought to be done immediately before taking the diagram, even if to the sense of touch the indicator appears to be already well heated, because considerable steam will condense every time the indicator is brought into use. Half a dozen revolutions of the engine are generally sufficient to thoroughly heat the instrument. It is well not to operate it any longer than necessary, so as to save undue wear. Having been heated, the steam is shut off, and the pencil or marking-point is brought into contact with the drum by pressing against the handle of the adjusting-screw. By this operation the atmospheric line is traced. If the screw has not already been adjusted so as to produce a satisfactorily clear line, it is turned one way or the other as the case may be, until the line is sufficiently distinct. It is assumed that the marking-point has previously been sharpened, so that the mark is clearly defined. The atmospheric line being traced, the cock is again opened and allowed to admit steam for two or three revolutions. Then the pencil is swung into position by again pressing the finger on the stop-screw, and there held until the diagram is taken. The cock is then closed. As a check upon the correct position of the atmospheric line, the pencil should again be applied to the drum and another line traced, which should be superposed upon the original line. The card is then removed from the drum by pulling upward on the projecting edges.

For the purpose of ordinary indicator work the pencil should be applied to the paper a sufficient time to cover half a dozen revolutions of the engine. Most governors are more or less fluctuating in their action, and in many cases the load is far from being uniform; so that it becomes necessary to record more than one revolution in order to be sure of obtaining an average indication of the operations going on in the engine cylinder. If the object of taking the diagram is simply to ascertain how the valves are set, the record of one revolution is sufficient.

Immediately after taking the diagram, the steam and vacuum gauges at the engine should be observed, the number of revolutions per minute counted, and a record of these observations noted on the face of the card. For purposes of reference a record should also be made of the date and hour when the diagram is taken, the end of the cylinder, the number of the spring, and any other memoranda which bear upon the objects for which the engine is indicated. The records on each card should be carefully made before another diagram is taken, for this is the only means of identifying the diagram when reference is subsequently made to it.

CHAPTER IX.

THE USE OF THE INDICATOR FOR SETTING VALVES.

THE diagram given as an illustration in Fig. 9 exhibits the result produced where the valves of the engine perform their functions in what may be termed a perfect manner. There are all sorts of malformations of the diagram due alone to derangement of valve-setting, and one of the most useful and widely recognized applications of the indicator is the determination of the condition of the engine with respect to this important matter. When this condition has been learned, the indicator diagram serves as a guide in correcting improper adjustments. By carefully changing the position of eccentrics and length of valve-rods, and making other adjustments depending on the design and arrangement of the valve mechanism, almost any desired form of diagram can be secured.

In making adjustments of valve-setting on an engine which has been long in service, care should be observed that the alterations are not injurious rather than beneficial. For example, the diagram may show too little "lead" of the steam-valves; that is, instead

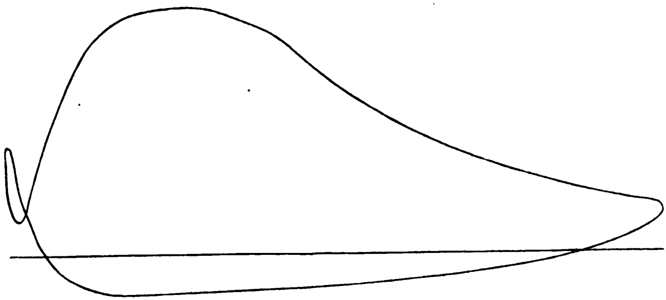


Fig. 11. Diagram Taken before Adjusting Valves.

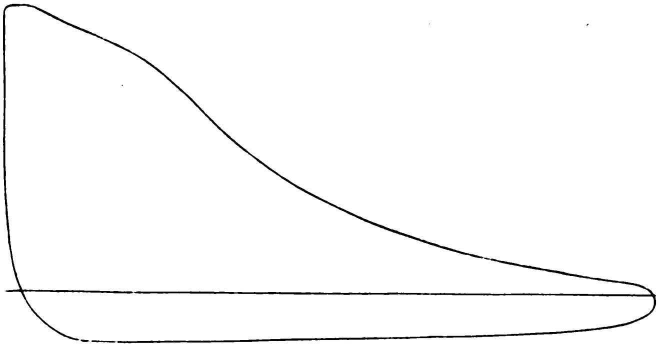


Fig. 12. Diagram Taken after Adjusting Valves.

of being perpendicular to the atmospheric line the admission line leans away from it, and at the upper end it merges into the steam line by a curve. When this is corrected by making earlier admission, the piston receives the force of the steam with greater rapidity, and if the main connections are run loose there is some likelihood of there being a knock as the engine passes the dead center. If the knock cannot be prevented by compression or by properly keying up the connections, it is best to revert to the former conditions of late lead. Again, it is unwise to reset a valve which has run a long time without refitting, if the change involves an increase or decrease of "lap." After long wear the valve is likely to have worn into the seat, leaving a shoulder or ridge at the end of its throw. If the valve, in its new position, rides over this point, leakage will result which might offset all the advantage sought.

The utility of the indicator for setting valves may be clearly illustrated by examples taken from practice. Fig. 11 shows a diagram from a single cylinder non-condensing engine of the four-valve type in which the valves were badly out of adjustment, and Fig. 12, one from the same engine after the valves had been reset. The derangement of the valve-setting in the first was so great that the only resemblance between the two diagrams lies in the form of the expansion line. All the other lines are distorted almost beyond recognition. The changes in

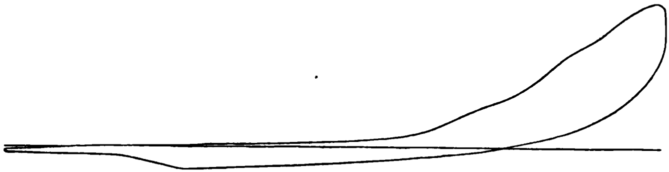
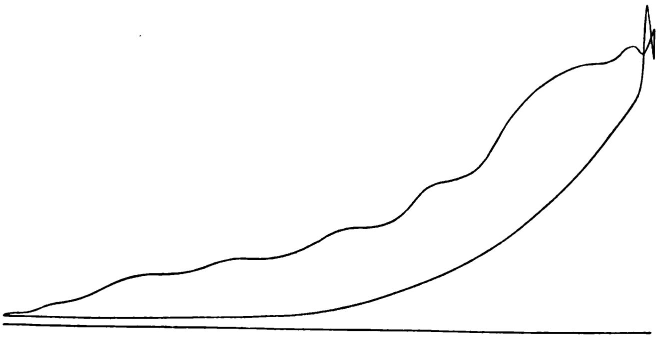


Fig. 13: Diagrams Taken before Adjusting Valve.
Scale 40. Head End.



Crank End.

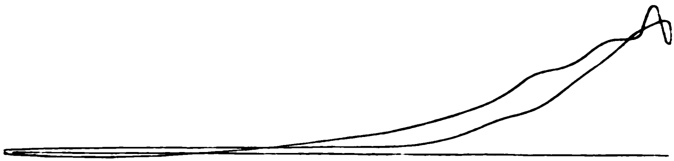
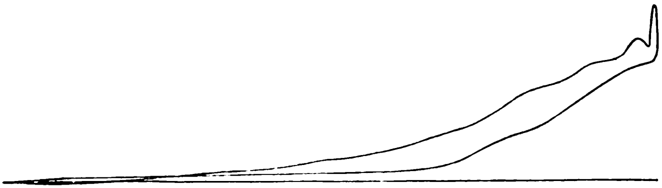


Fig. 14. Diagrams Taken after Adjusting Valve.
Scale 40. Head End.



Crank End.

the setting of the valves, by which the improvements were effected, consisted in moving the eccentric which drives the steam-valve so as to cause a considerably quicker opening of the valve, also moving the eccentric which operates the exhaust-valves so as to secure earlier release, and changing the exhaust-valve rod so as to obtain still earlier release, and at the same time, later compression.

Another illustration of valve-setting is given in Figs. 13 and 14, which show diagrams taken from the two ends of a high-speed single-valve engine cylinder, the first set being taken before, and the second after, adjustment. In the first set, Fig. 13, the valve was lapped so far over the head-end port that this end received no live steam whatever; and the diagram has a negative area, the upper line being the exhaust and compression line, and the lower line the expansion line.

For the second set, Fig. 14, the lap of the valve on the two ends was equalized, no other change being made; and the diagrams at the two ends become nearly alike, and their form and area are greatly changed.

CHAPTER X.

WORKING UP DIAGRAMS.

ONE of the principal objects of "working up" a diagram is to determine the mean pressure on the piston of the engine for use in computing the horse-power. The pressure obtained is what is called the "*mean effective pressure*"; that is, the difference between the average pressure of the forward stroke and that of the return stroke. This is most conveniently found by using an instrument called a "planimeter." By means of the planimeter the area inclosed within the line of the diagram is the first thing obtained, this being registered on the graduated scale of the instrument in terms of square inches. The mean effective pressure is then found by calculation; the method being to divide the area by the length of the diagram, and multiply the quotient by the scale of the indicator-spring which was used when the diagram was taken. Suppose, for example, that the area of the diagram is 5 sq. in., the length 4 in., and the scale of the spring 40 lbs. per inch. The mean effective pressure is found by dividing the area, 5, by the length, 4, and multiplying the quotient, 1.25, by 40, which gives 50 lbs. per square inch. The manner of using the planimeter is described in the next section.

If it is desired to ascertain the mean effective pressure without the use of the planimeter, it can be done by marking off on the diagram a number of parallel lines perpendicular to the atmospheric line, and ascertaining the average height of the diagram by measuring each of these lines and taking their average. The use of the planimeter, however, has become so common that it seems hardly necessary to give any careful directions for making the determination in this way.

HOW TO USE THE PLANIMETER.

The appended cut (Fig. 15) represents the Amsler Polar Planimeter when placed in a position to determine the area of a diagram.

It consists of the two arms "A B" and "B C" pivoted at "B," the arm "B C" being provided with a measuring-wheel "D" and a vernier "E." When in place, the instrument rests on the two points "A" and "C" and on the edge of the wheel "D." The point "A" is a needle-point; and it is pressed into a board or table on which the apparatus rests, the whole instrument turning around this point. Attached to the end "C" is a tracer or pointer, the wire of which is drawn down to a small diameter. The extreme end, although sharpened, is sufficiently smooth to slide freely over the paper

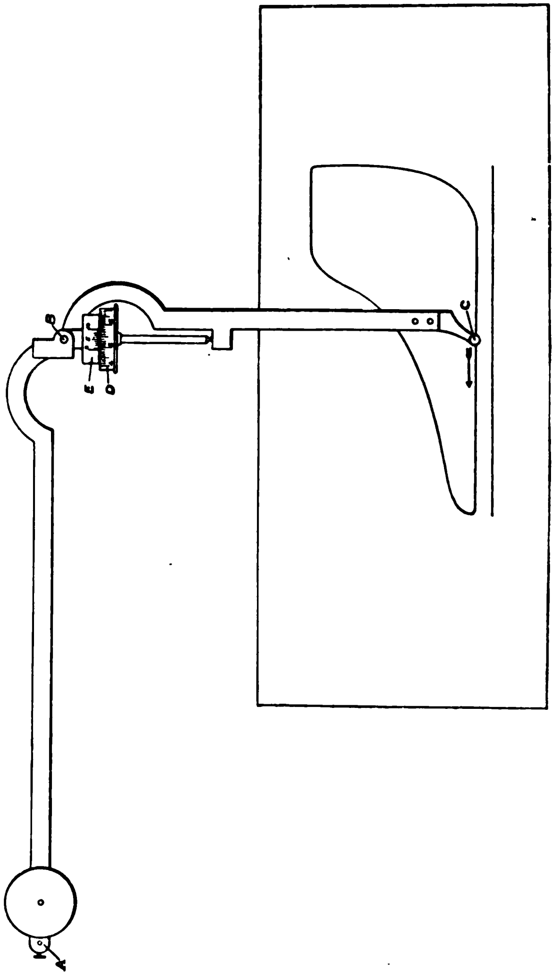


Fig. 15. Amsler Polar Planimeter.

beneath it. The whole apparatus rests on a piece of smooth paper fastened to the table; and the card, the area of which is to be determined, is placed beneath it in the position shown, and either held to the board by thumb-tacks or by the pressure of the fingers. At the start the two arms are set at an angle of about 90°, with the diagram extending equal distances on either side, so that as the tracing-point is moved over the diagram, it may cover the whole range without making the angle at "B" too sharp at one end or too great at the other. In using the instrument, the tracer is pressed into the card so as to make a slight indentation at the point where the start is made. This being done, the wheel is carefully turned by the finger until the zero point of the wheel stands opposite the zero point on the vernier. In turning the wheel for this purpose, the weight of the instrument should be overcome by lifting slightly with the forefinger, and turning the wheel with the thumb. The tracing-point is then carefully moved over the line of the diagram, the direction always being that of the hands of a watch, as shown by the arrow in the cut. If, through the unsteadiness of the hand, the tracer moves to one side of the line of the diagram, it is well to allow it to move about the same amount to the other side, in order that the area traced shall be the same as though it had remained exactly on the line throughout the whole operation. When the diagram has been completely covered, the tracer is brought back to the starting-point and dropped into the indentation in the paper made at the start. The area of the diagram is then found by reading the marks on the wheel and vernier.

Whole numbers of square inches are indicated by the numbers on the wheel, and the divisions between the whole numbers represent 10ths of a square inch. To find the 100ths of a square inch, an approximate indication can be obtained by dividing with the eye the distance between two consecutive 10th marks. To do it accurately, the reading of 100ths should be taken from the vernier. It is found by running the eye along the vernier scale to a division which is in direct line with the division on the wheel. The number of 100ths is the number representing this division on the vernier. Referring to Fig. 16, which

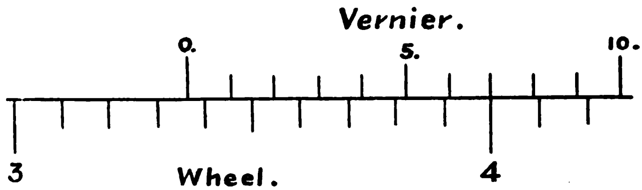


Fig. 16. Enlarged View of Vernier.

is an exact reproduction of the scales enlarged, the whole number is 3, the 10ths 3, and the number of the mark in the upper division reckoned from zero on the vernier, which is in line with a division on the wheel, is 7, which gives the 100ths. Consequently, the area shown is 3.37 sq. in.

Having determined in this way the area of the diagram, and recorded it on the card, it is well to go over the diagram a second time in the same manner as before, but without moving the wheel back to zero, and thus ascertain whether the first operation is correct. When the second complete circuit has been made and the tracer returned to the starting-point, the reading on the wheel should be just twice the area found by the first operation. In other words, in the example referred to, the first indication being 3.47, the second should be 6.94. If the two do not check each other with either exact or substantial accuracy, the operation should be repeated from the beginning, and continued until two consecutive circuits result in substantially the same determination.

The instrument described is the simplest form of Amsler planimeter built, and answers all the requirements of ordinary indicator work. More complicated instruments are made, in which the mean effective pressure can be read directly from the measuring-wheel, provided the scale of the spring is some fixed number; but it is needless to describe them here.

CHAPTER XI.

COMPUTATION OF HORSE-POWER.

THE indicator diagram furnishes the means for determining what is called the "Indicated Horse-Power" of an engine; that is, the power generated by the force of the steam within the cylinder. The diagram reveals the pressure of the steam at every point of the stroke; and the work done by that pressure in a given time, measured in foot-pounds, is the product of the pressure or force in pounds multiplied by the distance in feet through which it moves in that time. If the time is one minute, then the horse-power developed is the number of foot-pounds of work done divided by 33,000. Using the "mean effective pressure" for the force expended, the result expresses the average horse-power exerted by the working of the steam in the cylinder.

A formula for computing the indicated horse-power which can be easily remembered, is one which embodies the use of the letters in the word "Plan" as numerator, and the figure 33,000 for the denominator; that is,

$$\text{Indicated Horse-power} = \frac{PLAN}{33,000}.$$

In this formula, "P" is the mean effective pressure obtained from the indicator diagram; "L" is the length of the stroke of the engine in feet; "A" is the area of the cylinder in square inches; and "N" is the number of strokes made by the piston per minute, which is twice the number of revolutions of the shaft per minute. The numerator, PLAN, formed by the product of the various quantities referred to, represents the number of foot-pounds of work done by the steam per minute. The denominator, 33,000, is the number of foot-pounds of work per minute representing one horse-power.

For example, if the pressure determined from the diagram is 50 lbs. per square inch, the net area of the cylinder, 400 sq. in., the length of the stroke, 5 ft., and the number of revolutions per minute, 75, we have,

$$\frac{50 \times 5 \times 400 \times 2 \times 75}{33,000} = 454.54 \text{ horse-power.}$$

The area "A" is the net area obtained by subtracting the area of the piston-rod from the area of the cylinder-bore. For accurate work, the computation should be made independently for each end of the cylinder, and the mean of the two results taken for the average power. No material error, however, is ordinarily produced by taking the mean area of the two ends, and the mean pressure exerted at the two ends, and making one computation. In this case the mean net area to be used in a cylinder having no tail-rod is the area left after deducting one-half of the area of the rod from the area of the cylinder bore.

If the engine has more than one cylinder, the power is to be computed for each cylinder, and the individual results added together, to determine the power developed by the whole engine.

HORSE-POWER CONSTANTS.

In working out the horse-power in the manner just explained, it is to be noted that the quantities represented by the symbols "L" and "A" remain the same in any given engine, whatever changes may occur in the mean effective pressure and number of revolutions per minute. Consequently, the part of the formlua $\frac{LA}{33,000}$ is a constant quantity, and, when once determined, the horse-power may be found by multiplying this quantity by the mean effective pressure and by the speed. This constant quantity is termed the "horse-power constant." It may be defined as the horse-power developed by the engine when the piston-speed is one foot per minute and the mean effective pressure one pound per square inch.

Various horse-power constants corresponding to different sizes of cylinders will be found in Table

No. 2. In this table the constant is given for a piston-speed of one foot per minute and not for any definite number of revolutions per minute. To determine the constant for any desired number of revolutions, the quantities are multiplied by the number of feet per minute which the piston actually travels, determined by multiplying twice the length of the stroke in feet by the number of revolutions per minute. For example, suppose the diameter of the cylinder is 30 inches, the horse-power constant in the table is .02121. If the length of the stroke is 5 ft., and the number of revolutions per minute 65, the piston-speed is $5 \times 2 \times 65 = 650$ feet per minute, and the horse-power constant for that speed is .02121 multiplied by $650 = 13.786$.

In this connection, for convenience of reference, Table No. 3 is presented, giving the horse-power developed by different sized cylinders under different conditions of piston-speed and mean effective pressure. The speeds selected are 400, 500, 600, and 700 ft. per minute and the pressures 1 lb., 10 lbs., and 50 lbs. If it is desired to find the horse-power developed in any of these cases, for other mean effective pressures, it is simply necessary to take the figure given for the cylinder in question at 1 lb. m. e. p., and multiply it by the number of pounds m. e. p., required. For example, the H. P. constant for a 30-inch cylinder with a speed of 600 feet per minute, and 1 lb. m. e. p., is 12.726. At 40 lbs. m. e. p., the result is obtained by multiplying 12.726 × 40, which gives 509.04.

To facilitate the computation of horse-power constants, Table No. 1 is appended, giving the areas of circles of various diameters.

CHAPTER XII.

STEAM ACCOUNTED FOR BY INDICATOR DIAGRAM.

IF the indicator diagram is studied with a view to learning all that it shows with reference to the economy with which the steam is used, it is desirable to ascertain from the diagram what is termed the "steam accounted for by the indicator;" that is, the number of pounds of steam that would be used by the engine, providing that all the steam that passed through the cylinder was revealed by the diagram, and that there was no loss by condensation in the cylinder or by leakage of the valves and pistons. One method of computing this quantity is to calculate the weight of the steam present in the cylinder at the point desired, by first ascertaining the volume of the cylinder at that point, expressed in cubic feet, multiplying that volume by the weight of one cubic foot of steam having the pressure shown by the indicator at that point, subtracting from this product the weight of the steam retained in the cylinder at the closing of the exhaust-valve, determined in a similar way, multiplying the difference by the number of strokes made by the engine per hour, and dividing the product by the indicated horse-power. Although this determines the quantity desired, it is a somewhat elaborate calculation, and a somewhat round-about method of arriving at the object. The calculation can be simplified as follows: The weight of steam found by the above calculation is equal to $V \times N \times 60 \times$ steam accounted for by indicator per unit of volume, in which formula "V" is the volume of the cylinder in cubic feet (not including clearance) and "N" is the number of strokes per minute. The horse-power developed, as pointed out in Chapter XI., is P L A N divided by 33,000; consequently, the steam accounted for by the indicator per I. H. P. per hour is expressed by the formula:

$$\frac{33{,}000 \times V \times N \times 60}{P\,L\,A\,N} = \text{Steam accounted for by indicator per unit of volume.}$$

The volume of the cylinder equals the product of the area by the length of the stroke, that is,

$$V = \frac{L\,A}{144}.$$

Substituting this value of "V" the fraction becomes $\frac{33{,}000 \times L\,A\,N \times 60}{144. \times P\,L\,A\,N}$, and by cancellation, $\frac{13750}{\text{m.e.p.}}$. As thus simplified, the steam accounted for by the indicator can be readily computed from the diagram without reference to the size of the cylinder. The computation is made by the use of the formula

$$\frac{13750}{\text{m.e.p.}}[(C+E) \times Wc-(H+E) \times Wh]$$

and the quantity found is the weight of steam per I. H. P. per hour.

In this formula, the symbol "m. e. p." is the mean effective pressure, determined as pointed out in a previous chapter. If the engine is a compound, triple-expansion, or other multiple-expansion engine, the quantity to be used for the m. e. p. is the total or combined m. e. p. of the whole engine, referred to the cylinder for which the calculation is being made, whichever this may be. For example, if the mean effective pressure in the H. P. cylinder of a compound engine is 40 lbs., that in the L. P. cylinder 10 lbs., and the ratio of volumes of the two cylinders 3.75 to 1, the quantity to be used in working out the steam accounted for in the H. P. cylinder is $40 + (10 \times 3.75) = 77.5$. The quantity to use in the case of the L. P. cylinder is $10 + \frac{40}{3.75} = 20.67$. The symbol "C" refers to the proportion of the stroke completed at the point on the expansion line of the diagram where the computation is made (generally the points of cut-off and release shown in Fig. 9). The symbol "H" refers to the proportion of the return stroke completed at the compression point, shown in Fig. 9; and the symbol "E" refers to the proportion that the clearance space bears to the piston displacement. The proportions C and H are found from the diagram in question. The symbol "Wc" refers to the weight of one cubic foot of steam, having the pressure shown at the point where the computation is made, whether it be the cut-off or the release; and the symbol "Wh" refers to the weight of one cubic foot of steam having the pressure found at the compression point. The weights of steam are taken from Regnault's Steam Table, which are given in Table No. 5.

The pressures measured from the diagram should be those referred to zero, which is 14.7 lbs. below the atmosphere when the barometric pressure is 29.92 inches. If the pressure of the atmosphere varies from this point, the number of pounds to be added to the pressure above the atmosphere, measured from the diagram, may be obtained by multiplying the barometric pressure in inches by .491.

As an example, showing the method of computing the steam accounted for, take the case of a simple condensing engine in which the various measurements are as follows: —

Clearance, 2%, or	.02	
Cut-off pressure above zero	75.6	lbs.
Release pressure above zero	15.5	lbs.
Compression pressure above zero	3.	lbs.
Mean effective pressure	37.17	lbs.
Proportion of direct stroke completed at cut-off	.172	
Proportion of direct stroke completed at release	.903	
Proportion of return stroke uncompleted at compression	.048	

Referring to Table No. 5 the weight of one cubic foot of steam at the cut-off pressure is .1773 lbs.; at the release pressure, .0399 lbs.; and at the compression pressure, .0085 pounds.

Substituting these various quantities in the formula, we have the following: —

Steam accounted for at cut-off $= \frac{13,750}{37.17}[(.172 + .02) \times .1773 - (.048 + .02) \times .0085] = 369.9 \times (.03404 - .00056) = 369.9 \times .03348 = 12.39$ lbs.

Steam accounted for at release $= \frac{13,750}{37.17}[(.903 + .02) \times .0399 - (.048 + .02) \times .0085] = 369.9\ (.03682 - .00056) = 369.9 \times .03626 = 13.41$ lbs.

To enable this formula to be more conveniently used, Table No. 4 is appended, giving the quantity $\frac{13,750}{\text{m.e.p.}}$ for various mean effective pressures running from 10 lbs. per square inch up to 200 lbs. per square inch.

CHAPTER XIII.

CYLINDER CONDENSATION AND LEAKAGE.

IF it were not for cylinder condensation and leakage, the steam accounted for by the indicator (see previous chapter) would represent the actual amount of steam consumed by an engine. Whatever the class of engine, or the condition of pressure, speed, or cut-off, under which it works, there is always a considerable difference between the actual consumption and that represented by the steam accounted for, excepting in engines using steam which is superheated to such a degree as to suppress it. In tight engines of the single-cylinder class running under ordinary conditions, the percentage of difference varies from 15% to 50% according as the cut-off is long or short, and the difference is due mainly to cylinder condensation. The appended chart, Fig. 17, which is taken from the writer's book of "Engine Tests," shows the variation in the percentage of steam not accounted for (i. e., condensation and leakage) in tight or nearly tight engines, as based on actual results.

This chart is useful as a means of determining from the indicator-diagram what the actual steam-

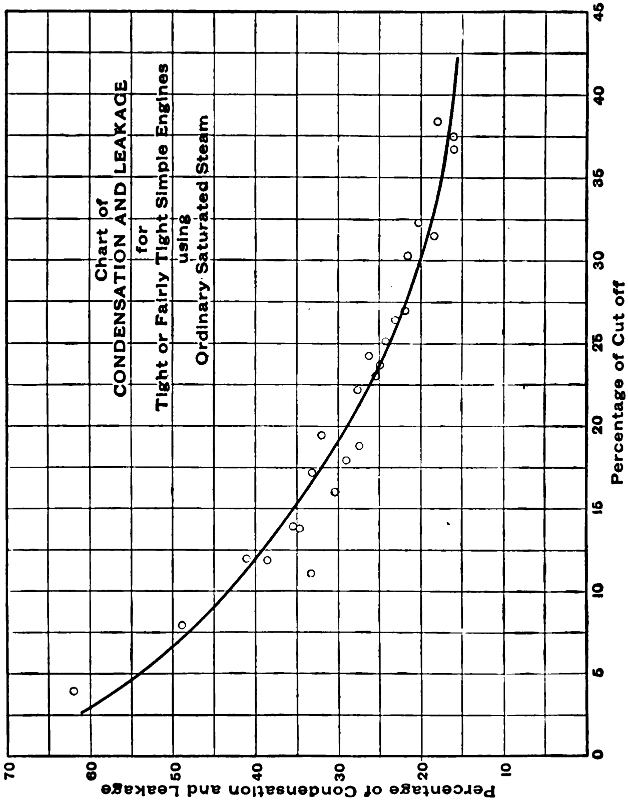


Fig. 17. Chart of Cylinder Condensation and Leakage.

consumption of a given engine per I. H. P. per hour should be if the valves and piston are practically tight, and the steam supplied is ordinary saturated steam. To use it for this purpose, divide the number representing the steam accounted for by the indicator at cut-off, determined, as pointed out in the previous chapter, by a decimal fraction representing the difference between 100% and the percentage measured from the chart at the proper point of cut-off, and the quotient is the actual consumption sought. For example, if the steam accounted for by the indicator is 20 lbs. per I. H. P. per hour, and the cut-off is 15%, the corresponding percentage of condensation and leakage measured on a vertical line to the curve is about 35%. The difference between 100% and 35% is 65%, which, expressed as a decimal fraction, is 0.65. Dividing 20 by .65 we have 30.8 lbs., as the probable consumption of steam in such an engine with tight valves and piston.

CHAPTER XIV.

COMBINING DIAGRAMS.

In compound, triple, and other multiple-expansion engines, much information can be obtained regarding the manner in which the expansive force of the steam is utilized in its passage through the various cylinders, by converting the actual diagrams taken with the indicator into what is called a "combined" diagram. The object of combining diagrams is to show graphically, on the same scale of volume, the actions going on in all the cylinders. The combined diagram shows, so far as such a thing is possible, the effect that would be produced if all the operations were carried on in the low-pressure cylinder. In constructing the diagram, the principle to be borne in mind is to produce a combination such that the volume and pressure of the steam at any point of the stroke in either cylinder can be measured or observed at a glance without mentally, or otherwise, taking into account the difference in volume of the cylinders from which the diagrams are taken. The most important information which the combined diagram reveals, is the loss of area due to imperfect expansion, to wire-drawing, to friction of ports and passages, and to clearance. If the engine were perfect, the expansion lines of the individual diagrams would, in their new positions, form an almost continuous expansion line; and there would be no gap, or uncovered area, between the contiguous parts of the various diagrams; so that, as a whole, the diagrams would form a continuous inclosed area. In so far as the area is not continuous, and departs from the theoretical expansion line, the steam and

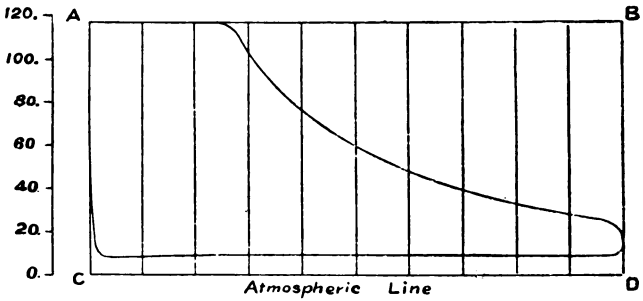


Fig. 18. (H. P. Cyl.)

zero lines of pressure, and the line of no clearance, the various operations of admission, expansion, etc., are imperfectly carried out.

The simplest process of combining diagrams, is that applying to the receiver-type of compound, or other multiple expansion engine, in which each cylinder is provided with a complete set of valves acting independently, there being an intermediate receiver into which the steam exhausts from the first cylinder before passing on to the next. The method of laying out a combined diagram in such a case is shown in Figs. 18 to 20.

The process of combining the diagrams is as follows: Inclose the high-pressure diagram in the rectangle "ABDC," and divide it by vertical lines into ten equal parts; likewise inclose the low-pressure diagram in the rectangle "EFHG," the line "GH" being the zero line parallel to the atmospheric line "UV;" that is, it is placed at a distance

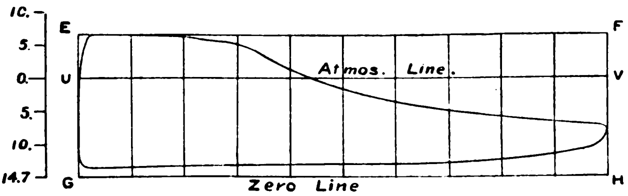


Fig. 19. (L. P. Cyl.)

from "UV" representing 14.7 lbs. vacuum when the barometer is 29.92 inches. If the barometer indicates any other atmospheric pressure, the quantity to be used in place of 14.7 is the reading of the barometer in inches multiplied by .491. Divide, also, the rectangle inclosing the low-pressure diagram, into ten equal parts. At the points where the various lines of division cross the diagram, make a sharp-pointed dot with a pencil, so as to clearly locate the intersection.

Lay off the zero line of the combined diagram

"OT" and the atmospheric line "RQ," and draw the perpendicular line of no volume "TS." It is suggested that a scale of 20 lbs. per inch is an appropriate one for ordinary pressures, although any other scale may be taken. Select any desired length for the low-pressure diagram. A length of 4 to 6 inches is convenient in most cases. Determine, also, the percentage of clearance of each cylinder, either from the builders of the engine, or from the working drawings of the cylinders and valves, or by actual measurement obtained by filling up the clearance spaces with water, and determining the

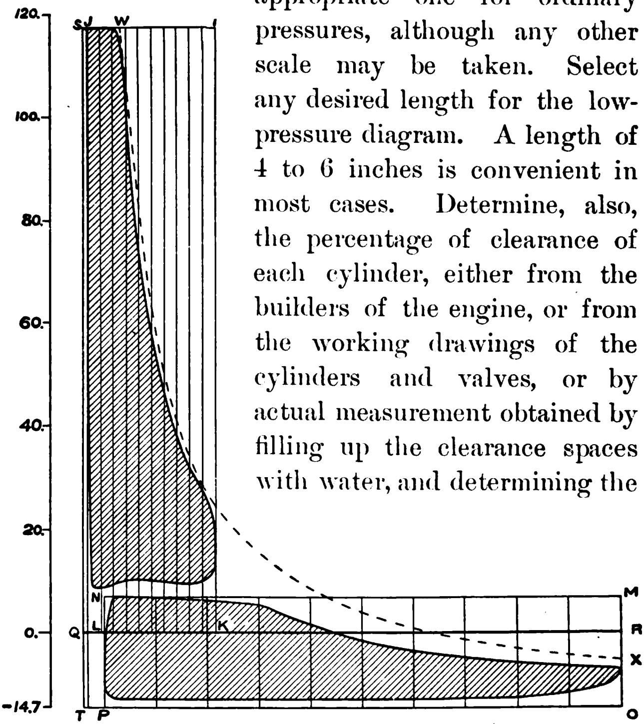


Fig. 20. Combined Diagram.

amount of water required. Having determined the length of the low-pressure diagram, locate the point "P" at such a distance from "T" that the distance

"PT," divided by "OP," the length of the diagram, is the same proportion as the percentage of clearance. Then draw the rectangle "OMNP," the line "MN" being placed at a sufficient height to inclose the new diagram, the same as in Fig. 18. Next divide the distance "OP" by the ratio of volumes of the two cylinders. This ratio is found in cases where the stroke of the two cylinders is the same, by dividing the net area of the L. P. piston by the net area of the H. P. piston. The quotient obtained by dividing "OP" by the ratio mentioned is the length "KL" of the high-pressure part of the combined diagram. Having found this length, it is then multiplied by the percentage of clearance of the H. P. cylinder, and the product is the distance "LQ." Lay off from point "Q" the distance thus determined, and then draw the rectangle "JIKL" inclosing the desired high-pressure part of the combined diagram. To make this process perfectly clear, suppose, for example, that the ratio of volumes of the two cylinders is 4 to 1; assume the length of the low-pressure diagram "OP" to be 5 inches; and the percentage of clearance of the two cylinders to be 2% and 3% respectively. Then we have the distance "PT" for the low-pressure diagram 3% of 5 inches or .15 inch, and the distance "KL" for the high-pressure diagram 5 inches divided by 4, or 1.25 inches; also, the distance "LQ," 2% of 1.25 inches, or .025 inch.

Now divide each of these inclosing rectangles into ten equal parts, by drawing vertical lines the same as on the two original diagrams. Measure the pressures on the high-pressure diagram, Fig. 18, at the two points of intersection on the first line of division. Mark these points on the first line of division of the combined diagram, using the scale of the spring selected. Likewise, measure the pressures at the two intersecting points on the H. P. diagram on the second line of division, and mark these points on the second line of division of the combined diagram, using the scale selected. Do the same, also, for the third line of division, and so on, until all the various points have been transferred from the original diagrams to the combined diagram. Do the same on the low-pressure diagram; and when all the points have been located, draw a curve through them, connecting them in the same manner as they are in the original diagrams, and the resulting figures are the desired combined diagram. Next, draw the theoretical curve " WX " through the point of cut-off " H. P. Cyl., this usually being a hyperbola. Assuming, now, that the theoretical expansion occurs in accordance with the curve just drawn, then the relation which the collective area of the combined diagram, which is shaded, bears to the entire area included between the curve " WX," the zero line " OT," and the line of no clearance " TS," shows the diagram-efficiency with which the steam is worked referred to theoretically perfect conditions; and the difference between the shaded area of the combined diagram and the area inclosed in the figure "WXOTS" represents the diagram-losses due to the departure from theoretically perfect conditions.

The method of laying out the combined diagram for a compound engine of the Wolff type is somewhat different from that employed in the case of a receiver engine. In the Wolff engine there is no receiver and no independent steam-valve for the low-pressure cylinder. The low-pressure cylinder begins to take steam when the high-pressure cylinder begins to exhaust, and steam is admitted to the low-pressure cylinder during the whole or a part of the time that the high-pressure cylinder is exhausting. For this reason, the expanding steam occupies a volume made up of two parts,—that of the steam in the low-pressure cylinder with its clearance space, and that of the steam in communication with it which still remains in the H. P. cylinder and in the clearance space of that cylinder. In laying out such diagrams the principle before stated should be kept in mind; that is, the combined diagram should, so far as possible, show the volume of the steam at any point of the stroke in either cylinder.

NOTE. — The hyperbola is a curve in which the pressure at any point, measured from the zero line, is inversely proportional to the volume measured from the clearance line. For example: If the pressure at the cut-off is 100 lbs. and the cut-off point is at 25 per cent of the stroke, including clearance, the pressure at the end of the stroke on the hyperbolic curve is 25 per cent of 100, or 25 lbs.

CHAPTER XV.

STEAM-PIPE DIAGRAMS.

A USEFUL application of the indicator lies in taking steam-pipe diagrams, and thereby determining the action of the steam in the supply pipe of the engine, and whether the pipe is of sufficient capacity. An indicator-cock is attached to the pipe at some point where the instrument may be conveniently operated by the same reducing motion as that used on the cylinders, and the diagrams are taken in the same manner as the ordinary indicator diagrams. It is well to take the pipe diagram on the same blank card as the cylinder diagram, transferring the instrument from one point to the other without removing the paper from the drum. The relation of one to the other can then be seen at a glance, and the losses of pressure between the two can be readily measured. To make the comparison to the best advantage the driving-cords should be adjusted so that the two diagrams are located one directly above the other, the ends being in the same perpendicular line. Diagrams from the steam-chest of the engine furnish similar information regarding loss of pressure in the valve-ports and steam-chest passages, and these

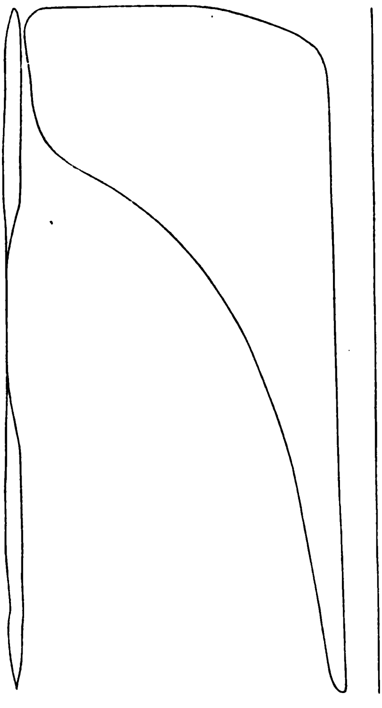


Fig. 21. Steam-Pipe Diagram.
30″ x 60″ Bass Corliss Engine (H.P. Cyl.).

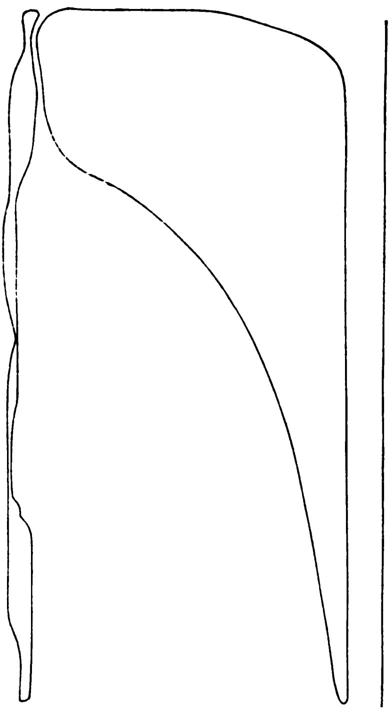


Fig. 22. Steam-Chest Diagrams.
(Same Engine as Fig. 21.)

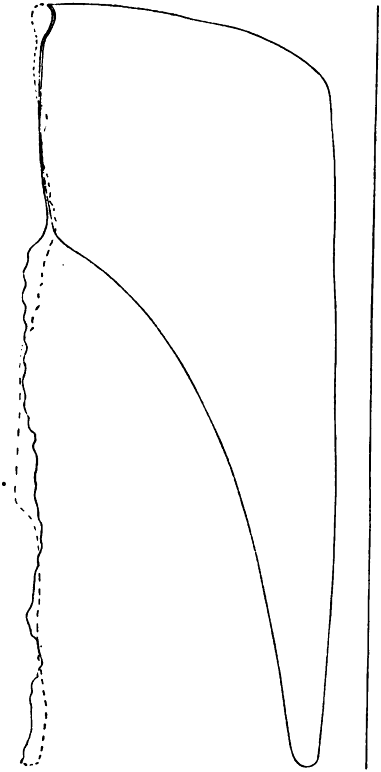


Fig. 23. Steam-Chest Diagram.
18″ x 48″ Hewes and Phillips Corliss Engine (H.P. Cyl.).

should be taken in addition to the steam-pipe diagram.

Samples of diagrams taken from the steam-pipe and steam-chest of the same engine are shown in Figs. 21 and 22. Another taken from a steam-chest is shown in Fig. 23. In both of the diagrams from the steam-chest it will be observed that the same changes of pressure occurred in the steam-chest as in the cylinder during admission, the one being at all points coincident with the other. The reason for the admission line in these cases showing a marked departure from the horizontal line of a perfect diagram is thus proved to be some cause acting between the steam-port and the boiler, and not a restricted area of opening through the port itself.

CHAPTER XVI.

LEAKAGE-TESTS OF VALVES AND PISTONS.

THE indicator finds an incidental use in connection with engine-testing for leakage examinations of valves and pistons when these are undertaken by what is termed the "time method." When steam is admitted to a tight cylinder for a sufficient time to thoroughly heat the metal, and the supply is then shut off, the pressure gradually falls as the cylinder cools and the steam condenses, eventually coming down to zero. In an engine with tight valves and piston, and steam admitted in this manner, starting with a pressure of 100 lbs., the rate at which the pressure falls is so slow that from ten to fifteen minutes time elapses before the steam wholly disappears and comes down to the pressure of the atmosphere. When, on the contrary, the valves and piston leak, the length of time which the pressure is maintained is reduced; and, if the leakage is serious, it is measured by seconds rather than by minutes. Not infrequently in a leaking engine, the pressure will entirely disappear in fifteen seconds after closing the supply-valve. To use the indicator in connection with leakage tests, it is applied to the indicator-cock on the cylinder, the same as in taking diagrams. The engine being at rest, with the piston near the dead center, or at any other point if the fly-wheel is blocked, and the valves being in such position as to admit steam to the cylinder at whichever end it is desired to make the test, the throttle-valve is opened, and the full pressure admitted until the cylinder is thoroughly heated. The atmospheric line having previously been drawn, the indicator-cock is opened and a pressure line is taken; this being done by pulling the drum by hand the same as in testing springs. The throttle is then closed, and the time noted when it reaches its seat. Thereafter, at regular intervals of say fifteen or thirty seconds, the cock is again opened, and pressure lines again drawn, one after another, as long as any pressure remains. A record of the pressure as it becomes less and less is thus obtained, and the rate of its decrease can be measured from these lines when the card is removed. By comparing this rate in any case with that obtained in some similar engine which may be taken as representative of tight conditions, the observer can judge of the relative extent of the leakage.

Figs. 24 and 25 show the records obtained on two time-tests of this kind, the former being taken from an unusually tight engine, and the latter from one in which there was excessive leakage, this being located in the exhaust-valves. In the first, the pressure fell from 81 lbs. to 11 lbs. in 14 minutes, whereas in the second the pressure dropped a like amount in about ten seconds.

Fig. 24.

Time Test – Tight Engine.

ELAPSED TIME.		TIGHT ENGINE.
Start		81. lbs.
½ min.		61. "
2 "		49. "
4 "		38. "
6 "		31. "
8 "		25. "
10 "		20. "
12 "		15. "
14 "		11. "
		Atmos. Line.

Fig. 25.

Time Test - Leaking Engine.

Elapsed Time.		Pressure.
Start	— — ——	90 lbs.
5 sec.	— — —	33 "
10 "	—— ——	16 "
	————	Atmos. Line.

TABLE No. 1.

AREAS OF CIRCLES HAVING DIAMETERS VARYING FROM 1 INCH TO 120 INCHES.

DIAM. IN INCHES.	AREA IN SQUARE INCHES.	DIAM. IN INCHES.	AREA IN SQUARE INCHES.	DIAM. IN. INCHES.	AREA IN SQUARE INCHES.
1	0.7854	$3\frac{5}{16}$	8.6180	$6\frac{1}{4}$	30.679
$1\frac{1}{16}$	0.8866	$3\frac{3}{8}$	8.9462	$6\frac{3}{8}$	31.919
$1\frac{1}{8}$	0.9940	$3\frac{7}{16}$	9.2807	$6\frac{1}{2}$	33.183
$1\frac{3}{16}$	1.1075	$3\frac{1}{2}$	9.6211	$6\frac{5}{8}$	34.471
$1\frac{1}{4}$	1.2271	$3\frac{9}{16}$	9.9680	$6\frac{3}{4}$	35.784
$1\frac{5}{16}$	1.3530	$3\frac{5}{8}$	10.320	$6\frac{7}{8}$	37.122
$1\frac{3}{8}$	1.4848	$3\frac{11}{16}$	10.679	7	38.484
$1\frac{7}{16}$	1.6229	$3\frac{3}{4}$	11.044	$7\frac{1}{8}$	39.871
$1\frac{1}{2}$	1.7671	$3\frac{13}{16}$	11.416	$7\frac{1}{4}$	41.282
$1\frac{9}{16}$	1.9175	$3\frac{7}{8}$	11.793	$7\frac{3}{8}$	42.718
$1\frac{5}{8}$	2.0739	$3\frac{15}{16}$	12.177	$7\frac{1}{2}$	44.178
$1\frac{11}{16}$	2.2365	4	12.566	$7\frac{5}{8}$	45.663
$1\frac{3}{4}$	2.4052	$4\frac{1}{16}$	12.962	$7\frac{3}{4}$	47.173
$1\frac{13}{16}$	2.5800	$4\frac{1}{8}$	13.364	$7\frac{7}{8}$	48.707
$1\frac{7}{8}$	2.7611	$4\frac{3}{16}$	13.772	8	50.265
$1\frac{15}{16}$	2.9483	$4\frac{1}{4}$	14.186	$8\frac{1}{8}$	51.848
2	3.1416	$4\frac{5}{16}$	14.606	$8\frac{1}{4}$	53.456
$2\frac{1}{16}$	3.3380	$4\frac{3}{8}$	15.033	$8\frac{3}{8}$	55.088
$2\frac{1}{8}$	3.5465	$4\frac{7}{16}$	15.465	$8\frac{1}{2}$	56.745
$2\frac{3}{16}$	3.7584	$4\frac{1}{2}$	15.904	$8\frac{5}{8}$	58.426
$2\frac{1}{4}$	3.9760	$4\frac{9}{16}$	16.349	$8\frac{3}{4}$	60.132
$2\frac{5}{16}$	4.2000	$4\frac{5}{8}$	16.800	$8\frac{7}{8}$	61.862
$2\frac{3}{8}$	4.4302	$4\frac{11}{16}$	17.257	9	63.617
$2\frac{7}{16}$	4.6664	$4\frac{3}{4}$	17.720	$9\frac{1}{8}$	65.396
$2\frac{1}{2}$	4.9087	$4\frac{13}{16}$	18.190	$9\frac{1}{4}$	67.200
$2\frac{9}{16}$	5.1573	$4\frac{7}{8}$	18.665	$9\frac{3}{8}$	69.029
$2\frac{5}{8}$	5.4119	$4\frac{15}{16}$	19.147	$9\frac{1}{2}$	70.882
$2\frac{11}{16}$	5.6723	5	19.635	$9\frac{5}{8}$	72.759
$2\frac{3}{4}$	5.9395	$5\frac{1}{8}$	20.629	$9\frac{3}{4}$	74.662
$2\frac{13}{16}$	6.2126	$5\frac{1}{4}$	21.647	$9\frac{7}{8}$	76.588
$2\frac{7}{8}$	6.4918	$5\frac{3}{8}$	22.690	10	78.540
$2\frac{15}{16}$	6.7772	$5\frac{1}{2}$	23.758	$10\frac{1}{8}$	80.515
3	7.0686	$5\frac{5}{8}$	24.850	$10\frac{1}{4}$	82.516
$3\frac{1}{16}$	7.3662	$5\frac{3}{4}$	25.967	$10\frac{3}{8}$	84.540
$3\frac{1}{8}$	7.6699	$5\frac{7}{8}$	27.108	$10\frac{1}{2}$	86.590
$3\frac{3}{16}$	7.9798	6	28.274	$10\frac{5}{8}$	88.664
$3\frac{1}{4}$	8.2957	$6\frac{1}{8}$	29.464	$10\frac{3}{4}$	90.762

TABLE No. 1. — (*Continued.*)

Diam. in Inches.	Area in Square Inches.	Diam. in Inches.	Area in Square Inches.	Diam. in Inches.	Area in Square Inches.
10⅞	92.885	15⅞	197.933	20⅞	342.250
11	95.033	16	201.062	21	346.361
11⅛	97.205	16⅛	204.216	21⅛	350.497
11¼	99.402	16¼	207.394	21¼	354.657
11⅜	101.623	16⅜	210.597	21⅜	358.841
11½	103.869	16½	213 825	21½	363.051
11⅝	106.139	16⅝	217.077	21⅝	367.284
11¾	108.434	16¾	220.353	21¾	371.543
11⅞	110.753	16⅞	223.654	21⅞	375.826
12	113.097	17	226.980	22	380.133
12⅛	115.466	17⅛	230.330	22⅛	384 465
12¼	117.859	17¼	233.705	22¼	388.822
12⅜	120.276	17⅜	237.104	22⅜	393.203
12½	122.718	17½	240.528	22½	397.608
12⅝	125.184	17⅝	243.977	22⅝	402.038
12¾	127.676	17¾	247.450	22¾	406.493
12⅞	130.192	17⅞	250.947	22⅞	410.972
13	132.732	18	254.469	23	415.476
13⅛	135.297	18⅛	258.016	23⅛	420.004
13¼	137.886	18¼	261.587	23¼	424.557
13⅜	140.500	18⅜	265.182	23⅜	429.135
13½	143.139	18½	268.803	23½	433.731
13⅝	145.802	18⅝	272.447	23⅝	438.363
13¾	148.489	18¾	276 117	23¾	443.014
13⅞	151.201	18⅞	279.811	23⅞	447.699
14	153.938	19	283.529	24	452.390
14⅛	156.699	19⅛	287.272	24⅛	457.115
14¼	159.485	19¼	291.039	24¼	461.864
14⅜	162.295	19⅜	294.831	24⅜	466.638
14½	165.130	19½	298 648	24½	471.436
14⅝	167.989	19⅝	302.489	24⅝	476 259
14¾	170.873	19¾	306.355	24¾	481.106
14⅞	173.782	19⅞	310.245	24⅞	485.978
15	176.715	20	314.160	25	490.875
15⅛	179.672	20⅛	318.099	25⅛	495.796
15¼	182.654	20¼	322.063	25¼	500.741
15⅜	185.661	20⅜	326.051	25⅜	505.711
15½	188.692	20½	330.064	25½	510.706
15⅝	191.748	20⅝	334.101	25⅝	515.725
15¾	194 828	20¾	338.163	25¾	520.769

TABLE No. 1.—(*Continued.*)

Diam in Inches.	Area in Square Inches.	Diam. in Inches.	Area in Square Inches.	Diam. in Inches.	Area in Square Inches.
25⅞	525.837	31¾	791.732	41¾	1,369.00
26	530.930	32	804.249	42	1,385.44
26⅛	536.047	32¼	816.865	42¼	1,401.98
26¼	541.189	32½	829.578	42½	1,418.62
26⅜	546.356	32¾	842.390	42¾	1,435.56
26½	551.547	33	855.30	43	1,452.20
26⅝	556.762	33¼	868.30	43¼	1,469.13
26¾	562.002	32½	881.41	43½	1,486.17
26⅞	567.267	33¾	894.61	43¾	1,503.30
27	572.556	34	907.92	44	1,520.53
27⅛	577.870	34¼	921.32	44¼	1,537.86
27¼	583.208	34½	934.82	44½	1,555.28
27⅜	588 571	34¾	948.41	44¾	1,572.81
27½	593.958	35	962.11	45	1,590.43
27⅝	599.370	35¼	975.90	45¼	1.608.15
27¾	604.807	35½	989.80	45½	1,625.97
27⅞	610.268	35¾	1,003.78	45¾	1.643.89
28	615.753	36	1,017.87	46	1,661.90
28⅛	621.263	36¼	1,032.06	46¼	1,680.01
28¼	626.798	36½	1,046.35	46½	1,698.23
28⅜	632.357	36¾	1,060.73	46¾	1,716.54
28½	637.941	37	1,075 21	47	1,734.94
28⅝	643.594	37¼	1,089.79	47¼	1,753.45
28¾	649.182	37½	1,104.46	47½	1,772.05
28⅞	654.839	37¾	1,119.24	47¾	1,790.76
29	660.521	38	1,134.11	48	1,809.56
29⅛	666.227	38¼	1,149.08	48¼	1.828.46
29¼	671.958	38½	1,164.15	48½	1,847.45
29⅜	677.714	38¾	1,179.32	48¾	1,866.55
29½	683.494	39	1,194.50	49	1,885.74
29⅝	689.298	39¼	1,209.95	49¼	1,905.03
29¾	695.128	39½	1,225.42	49½	1,924.42
29⅞	700.981	39¾	1,240.08	49¾	1,943.91
30	706.860	40	1,256.60	50	1.963.50
30¼	718.690	40¼	1.272.39	50½	2,002.96
30½	730.618	40½	1.288.25	51	2,042.82
30¾	742.644	40¾	1,304.20	51½	2,083.07
31	754.769	41	1,320.25	52	2,123 72
31¼	766.992	41¼	1,336.40	52½	2,164.75
31½	779.313	41½	1,352.65	53	2,206.18

TABLE No. 1.—(*Continued.*)

Diam. in Inches.	Area in Square Inches.	Diam. in Inches.	Area in Square Inches.	Diam. in Inches.	Area in Square Inches.
53½	2.248.01	68½	3.685.29	92	6,647.62
54	2,290.22	69	3,739.28	93	6,792.92
54½	2,332 83	69½	3.793.67	94	6,939.79
55	2,375.83	70	3,848.46	95	7,088.23
55½	2,419.22	70½	3,903.63	96	7,238 24
56	2,463.01	71	3,959.20	97	7,389.80
56½	2,507.19	71½	4,015.16	98	7,542.96
57	2,551.76	72	4,071.51	99	7,697.68
57½	2.596.72	72½	4,128.25	100	7.854,00
58	2,642.08	73	4,185.39	101	8,011.85
58½	2,687.83	73½	4.242.92	102	8,171.28
59	2.733.97	74	4,300.85	103	8,332.29
59½	2.780.51	74½	4,359.16	104	8,494.87
60	2.827.44	75	4,417.87	105	8,659.01
60½	2.874.76	76	4,536.47	106	8,824.73
61	2,922 47	77	4,656.63	107	8,992.02
61½	2,970.57	78	4,778.37	108	9,160.88
62	3,019.07	79	4,901.68	109	9,331.32
62½	3,067.96	80	5,026.56	110	9,503.32
63	3,117.25	81	5,153.00	111	9,676.89
63½	3,166.92	82	5,281.02	112	9,852.03
64	3.216.99	83	5,410.62	113	10,028.75
64½	3.267.46	84	5,541.78	114	10,207.03
65	3,318.31	85	5,674.51	115	10,386.89
65½	3,369.56	86	5,808.81	116	10,568.32
66	3,421.20	87	5,944 69	117	10,751.32
66½	3,473.23	88	6.082 13	118	10,935.88
67	3,525.62	89	6,221.15	119	11,122.02
67½	3,578.47	90	6.361.74	120	11,309.73
68	3,631.68	91	6,503 89		

TABLE No. 2.

HORSE-POWER CONSTANTS.

1 LB. M.E.P., 1 FT. PER MIN.

Diameter in Inches. Cylinder.	Diameter in Inches. Rod.	H.-P. Constants.	Diameter in Inches. Cylinder.	Diameter in Inches. Rod.	H.-P. Constants.
10	1.75	.00234	40	5.5	.03772
11	1.87	.00284	41	5.62	.03963
12	2.00	.00338	42	5.75	.04159
13	2.12	.00397	43	5.87	.04360
14	2.25	.00460	44	6.00	.04565
15	2.37	.00529	46	6.75	.0498
16	2.5	.00602	48	7.00	.05424
17	2.62	.0068	50	7.25	.05888
18	2.75	.00762	52	7.5	.06368
19	2.87	.00849	54	7.75	.06868
20	3.00	.00941	56	8.00	.07388
21	3.12	.01038	58	8.25	.07924
22	3.25	.01139	60	8.5	.08484
23	3.37	.01245	62	8.75	.09056
24	3.5	.01356	64	9.00	.09652
25	3.62	.01472	66	9.25	.10264
26	3.75	.01592	68	9.5	.10896
27	3.87	.01717	70	9.75	.11548
28	4.00	.01847	75	10.37	.1326
29	4.12	.01981	80	11.00	.15088
30	4.25	.02121	85	12.00	.17024
31	4.37	.02264	90	13.00	.19077
32	4.5	.02413	95	13.75	.21255
33	4.62	.02566	100	14.5	.23552
34	4.75	.02724	120	17.00	.31696
35	4.87	.02887			
36	5.	.03055			
37	5.12	.03227			
38	5.25	.03404			
39	5.37	.03585			

TABLE No. 3.

HORSE-POWER DEVELOPED FOR VARIOUS CYLINDERS AND PISTON SPEEDS.

Diameter of Cylinder, in.	Diameter of Piston Rod, in.	Speed of Piston in Feet per Minute.											
		400 ft.			500 ft.			600 ft.			700 ft.		
		Mean Effective Pressure in Lbs. per Square Inch.											
		1 lb.	10 lbs.	50 lbs.	1 lb.	10 lbs.	50 lbs.	1 lb.	10 lbs.	50 lbs.	1 lb.	10 lbs.	50 lbs.
10	1.75	.936	9.36	46.8	1.17	11.70	58.5	1.404	14.04	70.2	1.638	16.38	81.9
11	1.87	1.136	11.36	56.8	1.42	14.20	71.0	1.704	17.04	85.2	1.988	19.88	99.4
12	2.0	1.352	13.52	67.6	1.69	16.90	84.5	2.028	20.28	101.4	2.366	23.66	118.3
13	2.0	1.588	15.88	79.4	1.985	19.85	99.25	2.382	23.82	119.1	2.779	27.79	138.95
14	2.25	1.84	18.4	92.0	2.30	23.0	115.0	2.76	27.60	138.0	3.22	32.2	161.0
15	2.37	2.116	21.16	105.8	2.645	26.45	132.25	3.174	31.74	158.7	3.703	37.03	185.15
16	2.5	2.408	24.08	120.4	3.01	30.1	150.5	3.612	36.12	180.6	4.214	42.14	210.7
17	2.62	2.72	27.2	136.0	3.4	34.0	170.0	4.08	40.8	204.0	4.76	47.6	238.0
18	2.75	3.048	30.48	152.4	3.81	38.1	190.5	4.572	45.72	228.6	5.334	53.34	266.7
19	2.87	3.396	33.96	169.8	4.245	42.45	212.25	5.094	50.94	254.7	5.943	59.43	297.15
20	3.0	3.764	37.64	188.2	4.705	47.05	235.25	5.646	56.46	282.3	6.587	65.87	329.35
21	3.12	4.152	41.52	207.6	5.19	51.9	259.5	6.228	62.28	311.4	7.266	72.66	363.3
22	3.25	4.556	45.56	227.8	5.695	56.95	284.75	6.834	68.34	341.7	7.973	79.73	398.65
23	3.37	4.98	49.80	249.0	6.225	62.25	311.25	7.47	74.7	373.5	8.115	87.15	435.75
24	3.5	5.424	54.24	271.2	6.78	67.8	339.0	8.136	81.36	406.8	9.492	94.92	474.6
25	3.62	5.888	58.88	294.4	7.36	73.6	368.0	8.832	88.32	441.6	10.304	103.04	515.2
26	3.75	6.368	63.68	318.4	7.96	79.6	398.0	9.552	95.52	477.6	11.144	111.44	557.2
27	3.87	6.868	68.68	343.4	8.585	85.85	429.25	10.302	103.02	515.1	12.019	120.19	600.95
28	4.0	7.388	73.88	369.4	9.235	92.35	461.75	11.082	110.82	554.1	12.929	129.29	646.45
29	4.12	7.924	79.24	396.2	9.905	99.05	495.25	11.886	118.86	594.3	13.867	138.67	693.35

30	4.25	8.484	84.84	424.2	10.605	106.05	530.25	12.726	127.26	636.3	14.847	148.47	742.35
31	4.37	9.056	90.56	452.8	11.32	113.2	566.0	13.584	135.84	679.2	15.848	158.48	792.4
32	4.5	9.652	96.52	482.6	12.065	120.65	603.25	14.478	144.78	723.9	16.891	168.91	844.55
33	4.62	10.264	102.64	513.2	12.83	128.3	641.5	15.396	153.96	769.8	17.962	179.62	898.1
34	4.75	10.896	108.96	544.8	13.62	136.2	681.0	16.344	163.44	817.2	19.068	190.68	953.4
35	4.87	11.548	115.48	577.4	14.435	144.35	721.75	17.322	173.22	866.1	20.209	202.09	1010.45
36	5.0	12.22	122.20	611.0	15.275	152.75	763.75	18.33	183.3	916.5	21.385	213.85	1069.25
37	5.12	12.908	129.08	645.4	16.135	161.35	806.75	19.362	193.62	968.1	22.589	225.89	1129.45
38	5.25	13.616	136.16	680.8	17.02	170.2	851.0	20.424	204.24	1021.2	23.828	238.28	1191.4
39	5.37	14.34	143.40	717.0	17.925	179.25	896.25	21.51	215.1	1075.5	25.095	250.95	1254.75
40	5.5	15.088	150.88	754.4	18.86	188.6	943.0	22.632	226.32	1131.6	26.404	264.04	1320.20
41	5.62	15.852	158.52	792.6	19.815	198.15	990.75	23.778	237.78	1188.9	27.741	277.41	1387.05
42	5.75	16.636	166.36	831.8	20.795	207.95	1039.75	24.954	249.54	1247.7	29.113	291.13	1455.65
43	5.87	17.44	174.40	872.0	21.80	218.0	1090.0	26.16	261.6	1308.0	30.52	305.2	1526.0
44	6.0	18.26	182.60	913.0	22.825	228.25	1141.25	27.39	273.9	1369.5	31.955	319.55	1597.75
46	6.75	19.92	199.2	996.0	24.9	249.0	1245.0	29.88	298.8	1494.0	34.86	348.6	1743.0
48	7.0	21.696	216.96	1084.8	27.12	271.2	1356.0	32.544	325.44	1627.2	37.968	379.68	1898.4
50	7.25	23.552	235.52	1177.6	29.44	294.4	1472.0	35.328	353.28	1766.4	41.216	412.16	2060.8
52	7.5	25.472	254.72	1273.6	31.84	318.4	1592.0	38.208	382.08	1910.4	44.576	445.76	2228.8
54	7.75	27.472	274.72	1373.6	34.34	343.4	1717.0	41.208	412.08	2060.4	48.076	480.76	2403.8
56	8.0	29.552	295.52	1477.6	36.94	369.4	1847.0	44.328	443.28	2216.4	51.716	517.16	2585.8
58	8.25	31.696	316.96	1584.8	39.62	396.2	1981.0	47.544	475.44	2377.2	55.468	554.68	2773.4
60	8.5	33.936	339.36	1696.8	42.42	424.2	2121.0	50.904	509.04	2545.2	59.388	593.88	2969.4
62	8.75	36.224	362.24	1811.2	45.28	452.8	2264.0	54.336	543.36	2716.8	63.392	633.92	3169.6
64	9.0	38.608	386.08	1930.4	48.26	482.6	2413.0	57.912	579.12	2895.6	67.564	675.64	3378.2
66	9.25	41.056	410.56	2052.8	51.32	513.2	2566.0	61.584	615.84	3079.2	71.848	718.48	3592.4
68	9.5	43.584	435.84	2179.2	54.48	544.8	2724.0	65.376	653.76	3268.8	76.272	762.72	3813.6
70	9.75	46.192	461.92	2309.6	57.74	577.4	2887.0	69.288	692.88	3464.4	80.836	808.36	4041.8
75	10.37	53.04	530.4	2652.0	66.3	663.0	3315.0	79.56	795.6	3978.0	92.82	928.2	4641.0
80	11.0	60.352	603.52	3017.6	75.44	754.4	3772.0	90.528	905.28	4526.4	105.616	1056.16	5280.8
85	12.0	68.096	680.96	3404.8	85.12	851.2	4256.0	102.144	1021.44	5107.2	119.168	1191.68	5958.4
90	13.0	76.308	763.08	3815.4	95.385	953.85	4769.25	114.462	1144.62	5723.1	133.539	1335.39	6676.95
95	13.75	85.020	850.2	4251.0	106.275	1062.75	5313.75	127.53	1275.3	6376.5	148.785	1487.85	7439.25
100	14.5	94.208	942.08	4710.4	117.76	1177.6	5888.0	141.312	1413.12	7065.6	164.864	1648.64	8243.2
120	17.0	126.784	1267.84	6339.2	158.48	1584.8	7924.0	190.176	1901.76	9508.8	221.872	2218.72	11093.6

TABLE No. 4.

TABLE OF COEFFICIENTS, $\frac{13750}{M.E.P.}$.

M.E.P.	13750 / M.E.P.	M.E.P.	13750 / M.E.P.	M.E.P.	13750 / M.E.P.	M.E.P.	13750 / M.E.P.
10.0	1375.0	17.0	808.8	24.0	572.9	31.0	443.5
.2	1348.	.2	799.4	.2	568.2	.2	440.7
.4	1322.1	.4	790.2	.4	563.5	.4	437.9
.6	1297.1	.6	781.2	.6	558.9	.6	435.1
.8	1273.1	.8	772.5	.8	554.4	.8	432.4
11.0	1250.	18.0	763.9	25.0	550.	32.0	429.7
.2	1227.7	.2	755.5	.2	545.6	.2	427.
.4	1206.1	.4	747.3	.4	541.3	.4	424.4
.6	1185.4	.6	739.2	.6	537.1	.6	421.8
.8	1165.3	.8	731.4	.8	532.9	.8	419.2
12.0	1145.8	19.0	723.7	26.0	528.8	33.0	416.7
.2	1127.1	.2	716.1	.2	524 8	.2	414.1
.4	1108.9	.4	708.8	.4	520.8	.4	411.7
.6	1091.3	.6	701.5	.6	516.9	.6	409.2
.8	1074.2	.8	694.4	.8	513.	.8	406.8
13.0	1057.7	20.0	687.5	27.0	509.2	34.0	404.4
.2	1041.7	.2	680.7	.2	505.5	.2	402.
.4	1026.1	.4	674.0	.4	501.8	.4	399.7
.6	1011.	.6	667.5	.6	498.2	.6	397.4
.8	996.4	.8	661.1	.8	494.6	.8	395.1
14.0	982.1	21.0	654.8	28.0	491.1	35.0	392.8
.2	968.3	.2	648.6	.2	487.6	.2	390.6
.4	954.9	.4	642.5	.4	484.2	.4	388.4
.6	941.8	.6	636.6	.6	480.8	.6	386.2
.8	929.0	.8	630.7	.8	477.4	.8	384.1
15.0	916.7	22.0	625.0	29.0	474.1	36.0	381.9
.2	904.6	.2	619.4	.2	470.9	.2	379.8
.4	892.9	.4	613.8	.4	467.7	.4	377.7
.6	881.4	.6	608.4	.6	464.5	.6	375.7
.8	870.2	.8	603 1	.8	461.4	.8	373.6
16.0	859.4	23.0	597.8	30.0	458.3	37.0	371.6
.2	848.8	.2	592.7	.2	455.3	.2	369.6
.4	838.4	.4	587.6	.4	452.3	.4	367.6
.6	828.3	.6	582.6	.6	449.3	.6	365.7
.8	818.4	.8	577.7	.8	446.4	.8	363.7

TABLE No. 4. — (*Continued.*)

M.E.P.	13750 / M.E.P.	M.E.P.	13750 / M.E.P.	M.E.P.	13750 / M.E.P.	M.E.P.	13750 / M.E.P.
38.0	361.8	46.0	298.9	54.0	254.6	62.0	221.8
.2	359.9	.2	297.6	.2	253.6	.2	221.1
.4	358.1	.4	296.3	.4	252.7	.4	220.3
.6	356.2	.6	295.0	.6	251.8	.6	219.6
.8	354 4	.8	293.8	.8	250.9	.8	218.9
39.0	352.6	47.0	292.5	55.0	250.0	63.0	218.2
.2	350.8	.2	291.3	.2	249.1	.2	217.6
.4	349.0	.4	290.0	.4	248.2	.4	216.9
.6	347.2	.6	288.8	.6	247.3	.6	216.2
.8	345.5	.8	287.6	.8	246.4	.8	215.5
40.0	343.8	48.0	286.4	56.0	245.5	64.0	214.8
.2	342.0	.2	285.2	.2	244.6	.2	214.2
.4	340.3	.4	284.1	.4	243.8	.4	213.5
.6	338.7	.6	282.9	.6	242.9	.6	212.8
.8	337.	.8	281.7	.8	242.1	.8	212.2
41.0	335.3	49.0	280.6	57.0	241.2	65.0	211.5
.2	333.7	.2	279.4	.2	240.4	.2	210.9
.4	332.1	.4	278.3	.4	239.5	.4	210.2
.6	330.5	.6	277.2	.6	238.7	.6	209.6
.8	328.9	.8	276.1	.8	237.8	.8	208.9
42.0	327.4	50.0	275.0	58.0	237.0	66.0	208.3
.2	325.8	.2	273.9	.2	236.2	.2	207.7
.4	324.3	.4	272 8	.4	235.4	.4	207.1
.6	322.8	.6	271.7	.6	234.6	.6	206.4
.8	321.3	.8	270.6	.8	233 8	.8	205.8
43.0	319.8	51.0	269.6	59.0	233.0	67.0	205.2
.2	318.3	.2	268.5	.2	232.2	.2	204.6
.4	315.8	.4	267.5	.4	231.4	.4	204.0
.6	315.4	.6	266.4	.6	230.7	.6	203.4
.8	313.9	.8	265.4	.8	229.9	.8	202.8
44.0	312.5	52.0	264.4	60.0	229.2	68.0	202.2
.2	311.1	.2	263.4	.2	228.4	.2	201.6
.4	309.7	.4	262.4	.4	227.6	.4	201.0
.6	308.3	.6	261.4	.6	226.9	.6	200.4
.8	306.9	.8	260.4	.8	226.1	.8	199.8
45.0	305.6	53.0	259.4	61.0	225.4	69.0	199 3
.2	304.2	.2	258.4	.2	224.7	.2	198.7
.4	302.9	.4	257.5	.4	223.9	.4	198.1
.6	301.5	.6	256 5	.6	223.2	.6	197.6
.8	300.2	.8	255.5	.8	222.5	.8	197.0

TABLE No. 4. — (*Continued.*)

M.E.P.	13750 / M.E.P.	M.E.P.	13750 / M.E.P.	M.E.P.	13750 / M.E.P.	M.E.P.	13750 / M.E.P.
70.0	196.4	78.0	176.3	86.0	159.9	94.0	146.3
.2	195.9	.2	175.8	.2	159.5	.2	146.
.4	195.3	.4	175 4	.4	159.1	.4	145.6
.6	194.7	.6	174.9	.6	158.7	.6	145.3
.8	194.2	.8	174.5	.8	158.4	.8	145.
71.0	193.6	79.0	174.1	87.0	158.0	95.0	144.7
.2	193.1	.2	173.6	.2	157.7	.2	144.4
.4	192.5	.4	173.2	.4	157.3	.3	144.1
.6	192.0	.6	172.7	.6	157.0	.6	143.8
.8	191.5	.8	172.3	.8	156.6	.8	143.5
72.0	191.0	80.0	171.9	88.0	156.2	96.0	143.2
.2	190.4	.2	171.4	.2	155.9	.2	142.9
.4	189.9	.4	171.0	.4	155.5	.4	142.6
.6	189.4	.6	170.6	.6	155.2	.6	142.3
.8	188.9	.8	170.2	.8	154.8	.8	142.
73.0	188.3	81.0	169.7	89.0	154.5	97.0	141.7
.2	187.8	.2	169.3	.2	154.1	.2	141.4
.4	187.3	.4	168.9	.4	153.8	.4	141.2
.6	186.8	.6	168.5	.6	153.5	.6	140.9
.8	186.3	.8	168.1	.8	153.1	.8	140.6
74.0	185.8	82.0	167.7	90.0	152.8	98.0	140.3
.2	185.3	.2	167.2	.2	152.4	.2	140.
.4	184.8	.4	166.9	.4	152 1	.4	139.7
.6	184.3	.6	166.4	.6	151.7	.6	139.4
.8	183.8	.8	166.1	.8	151.4	.8	139.1
75.0	183.3	83.0	165.6	91.0	151.1	99.0	138.9
.2	182.8	.2	165.3	.2	150.8	.2	138.6
.4	182.3	.4	164.8	.3	150.5	.4	138.3
.6	181.9	.6	164.5	.6	150.1	.6	138.
.8	181.4	.8	164.1	.8	149.8	.8	137.8
76.0	180.9	84.0	163.7	92.0	149.5	100	137.5
.2	180.4	.2	163.3	.2	149.2	1	136.14
.4	180.0	.4	162.9	.4	148.8	2	134.8
.6	179.5	.6	162.5	.6	148.5	3	133.5
.8	179.0	.8	162 1	.8	148.2	4	132.21
77.0	178.6	85.0	161.7	93.0	147.9	105	130.95
.2	178.1	.2	161.4	.2	147.5	6	129.71
.4	177.6	.4	161.0	.4	147.2	7	128.5
.6	177.2	.6	160.6	.6	146.9	8	127.31
.8	176.7	.8	160.2	.8	146.6	9	126.15

TABLE No. 4. — (*Continued.*)

M.E.P.	$\frac{13750}{M.E.P.}$	M.E.P.	$\frac{13750}{M.E.P.}$	M.E.P.	$\frac{13750}{M.E.P.}$	M.E.P.	$\frac{13750}{M.E.P.}$
110	125.	123	103.38	156	88.14	179	76.82
1	123.88	4	102.61	7	87.59	180	76.39
2	122.77	135	101.85	8	87.03	1	75.97
3	121.68	6	101.10	9	86.48	2	75.55
4	120.61	7	100.36	160	85.94	3	75.14
115	119.57	8	99 64	1	85.40	4	74.73
6	118.54	9	98.92	2	84.88	185	74.32
7	117.52	140	98.21	3	84.36	6	73.93
8	116.53	1	97.52	4	83.84	7	73.53
9	115.55	2	96.83	165	83.33	8	73.14
120	114.58	3	96.15	6	82.83	9	72.75
1	113.64	4	95.49	7	82.34	190	72.37
2	112.71	145	94.83	8	81.85	1	71.99
3	111.79	6	94.18	9	81.36	2	71.62
4	110.89	7	93.54	170	80.88	3	71.25
125	110.	8	92.91	1	80.41	4	70.88
6	109.13	9	92 28	2	79.94	195	70.51
7	108.27	150	91.67	3	79.48	6	70.15
8	107.42	1	91.06	4	79.02	7	69.80
9	106.59	2	90.46	175	78.57	8	69.44
130	101.77	3	89.87	6	78.13	9	69.10
1	104.96	4	89.29	7	77.68	200	68.75
2	104.17	155	88.71	8	77.25		

TABLE No. 5.

Steam Tables.

Pressure Above 0 Lbs.	Temperature Fahr.	Total Heat Above 0° Fahr. B. T. U.		Weight per Cu. Ft. in Lbs.	
		Steam.	Water.	Steam.	Water.
.25	59.5	1132.	59.5	.00081	62.37
.50	79.7	8.3	79.7	.00157	
.75	92.5	1142.1	92 6	.00229	
1.	102.1	5.1	102.1	.00299	62.00
2.	126.3	1152.5	126.4	.00577	
3.	141.6	7.1	141.9	.00848	
4.	153.1	1160.6	153.4	.01112	61.12
5.	162.3	3.4	162.7	.01373	
6.	170.1	5.8	170.6	.01631	
7.	176.9	7.9	7.4	.01887	60.62
8.	182.9	9.7	183.5	.02140	
9.	188.3	1171.4	8.9	.02391	
10.	193.2	2.9	193.9	.02641	60.24
11.	197 8	4.3	8.5	.02889	
12.	202.0	5.5	202.7	.03136	
13.	205.9	6.9	6.7	.03381	
14.	209.6	7.9	210.4	.03625	
14.7	212.	8.6	2.9	.03794	59.76
15.	213.0	.9	3.9	.03868	
16.	216.3	9.9	7.3	.04110	
17.	219.4	1180.9	220.4	.04352	
18.	222.4	1.8	3.4	.04592	
19.	225.2	2.6	6.3	.04831	
20.	227.9	3.5	9.0	.05070	
21.	230.5	4.2	231 7	.05308	
22.	233.0	5.0	4.2	.05545	
23.	235.4	.7	6.7	.05782	
24.	237 8	6.5	9.0	.06018	
25.	240.0	7.1	241.3	.06253	59.10
26.	242.2	.8	3.5	.06487	
27.	244.3	8.4	5.7	.06721	
28.	246.3	.1	7.7	.06955	
29.	248.3	9.7	9.8	.07188	

TABLE No. 5. — (*Continued.*)

Pressure Above 0 Lbs.	Temperature Fahr.	Total Heat Above 0° Fahr. B. T. U.		Weight per Cu. Ft. in Lbs.	
		Steam.	Water.	Steam.	Water.
30.	250.2	1190.3	251.7	.07420	
31.	252.1	.8	3.6	.07652	
32.	254.0	1.4	5.5	.07884	
33.	255.7	.9	7.3	.08115	
34.	257.5	2.5	9.1	.08346	
35.	259.2	3.0	260.8	.08576	
36.	260.8	.5	2.5	.08806	
37.	262.5	4.0	4.1	.09035	
38.	264.0	.5	5.8	.09264	
39.	265.6	.9	7.4	.09493	
40.	267.1	5.4	8.9	.09721	
41.	268.6	.9	270.5	.09949	
42.	270.1	6.3	2.0	.1018	
43.	271.5	.7	3.4	.1040	
44.	272.9	7.2	4.9	.1063	
45.	274.3	.6	6.3	.1086	58.08
46.	275.7	8.0	7.7	.1108	
47.	277.0	.4	9.0	.1131	
48.	278.3	.8	280.4	.1153	
49.	279.6	9.2	1.7	.1176	
50.	280.9	.6	3.0	.1198	
51.	282.1	1200.0	4.2	.1221	
52.	283.3	.4	5.5	.1243	
53.	284.5	.7	6.7	.1266	
54.	285.7	1.1	8.0	.1288	
55.	286.9	.4	9.2	.1311	
56.	288.1	.8	290.3	.1333	
57.	289.1	2.1	1.5	.1355	
58.	290.3	.5	2.7	.1377	
59.	291.4	.8	3.8	.1400	
60.	292.5	3.2	4.9	.1422	
61.	293.6	.5	6.0	.1444	
62.	294.7	.8	7.1	.1466	
63.	295.7	4.1	8.2	.1488	
64.	296.8	.4	9.2	.1511	

TABLE No. 5.— (*Continued.*)

Pressure Above 0 Lbs.	Temperature Fahr.	Total Heat Above 0° Fahr. B. T. U.		Weight per Cu. Ft. in Lbs.	
		Steam.	Water.	Steam.	Water.
65.	297.8	1204.8	300.3	.1533	57.33
66.	298.8	5.1	1.3	.1555	
67.	299.8	.4	2.4	.1577	
68.	300.8	.7	3.4	.1599	
69.	301.8	6.0	4.4	.1621	
70.	302.7	.3	5.4	.1643	
71.	303.7	.6	6.4	.1665	
72.	304.6	.8	7.3	.1687	
73.	305.6	7.1	8.3	.1709	
74.	306.5	.4	9.2	.1731	
75.	307.4	.7	310.2	.1753	
76.	308.3	8.0	1.1	.1775	
77.	309.2	.2	2.0	.1797	
78.	310.1	.5	2.9	.1819	
79.	310.9	.8	3.8	.1840	
80.	311.8	9.0	4.7	.1862	
81.	312.7	.3	5.6	.1884	
82.	313.5	.6	6.5	.1906	
83.	314.4	.8	7.3	.1928	
84.	315.2	1210.1	8.2	.1950	
85.	316.0	.3	9.0	.1971	56.72
86.	316.8	.6	.9	.1993	
87.	317.7	.8	320.7	.2015	
88.	318.5	1.1	1.5	.2036	
89.	319.3	.3	2.4	.2058	
90.	320.0	.6	3.2	.2080	
91.	320.8	.8	4.0	.2102	
92.	321.6	2.0	.8	.2123	
93.	322.4	.3	5.6	.2145	
94.	323.1	.5	6.4	.2166	
95.	323.9	.7	7.1	.2188	
96.	324.6	3.0	.9	.2210	
97.	325.4	.2	8.7	.2231	
98.	326.1	4	9.4	.2253	
99.	326.8	.6	330.2	.2274	

TABLE No. 5. — (*Continued.*)

Pressure Above 0 Lbs.	Temperature Fahr.	Total Heat Above 0° Fahr. B. T. U.		Weight per Cu. Ft. in Lbs.	
		Steam.	Water.	Steam.	Water.
100.	327.6	1213.8	330.9	.2296	
101.	328.3	4.1	1.7	.2317	
102.	329.0	.3	2.4	.2339	
103.	329.7	.5	3.1	.2360	
104.	330.4	.7	.9	.2382	
105.	331.1	.9	4.6	.2403	56.20
106.	331.8	5.1	5.3	.2425	
107.	332.5	.4	6.4	.2446	
108.	333.2	.6	.7	.2467	
109.	333.9	.8	7.4	.2489	
110.	334.5	6.0	8.1	.2510	
111.	335.2	.2	.8	.2531	
112.	335.9	.4	9.5	.2553	
113.	336.5	.6	340.2	.2574	
114.	337.2	.8	.8	.2596	
115.	337.8	7.0	1.5	.2617	
116.	338.5	.2	2.2	.2638	
117.	339.1	.4	.8	.2660	
118.	339.7	.6	3.5	.2681	
119.	340.4	.8	4.1	.2703	
120.	341.0	.9	.8	.2724	
121.	341.6	8.1	5.4	.2745	
122.	342.2	.3	6.1	.2766	
123.	342.9	.5	.7	.2788	
124.	343.5	.7	7.3	.2809	
125.	344.1	.9	8.0	.2830	55.73
126.	344.7	9.1	.6	.2851	
127.	345.3	.3	9.2	.2872	
128.	345.9	.4	.8	.2894	
129.	346.5	.6	350.4	.2915	
130.	347.1	.8	1.1	.2936	
131.	347.6	1220 0	.7	.2957	
132.	348.2	.2	2.3	.2978	
133.	348.8	.3	.8	.3000	
134.	349.4	.5	3.5	.3021	

TABLE No. 5.— (*Continued.*)

Pressure Above 0 Lbs.	Temperature Fahr.	Total Heat Above 0° Fahr. B. T. U.		Weight per Cu. Ft. in Lbs.	
		Steam.	Water.	Steam.	Water.
135.	350.0	1220.7	354.1	.3042	
136.	350.5	.9	.6	.3063	
137.	351.1	1.0	5.2	.3084	
138.	351.8	.2	.8	.3105	
139.	352.2	.4	6.4	.3126	
140.	352.8	.5	7.0	.3147	
141.	353.3	.7	.5	.3169	
142.	353.9	.9	8.1	.3190	
143.	354.4	2.0	.7	.3211	
144.	355.0	.2	9.2	.3232	
145.	355.5	.4	.8	.3253	55.32
146.	356.0	.5	360.4	.3274	
147.	356.6	.7	.9	.3295	
148.	357.1	.9	1.5	.3316	
149.	357.6	3.0	2.0	.3337	
150.	358.2	.2	.6	.3358	
151.	358.7	.3	3.1	.3379	
152.	359.2	.5	.6	.3400	
153.	359.7	.7	4.2	.3421	
154.	360.2	.8	.7	.3442	
155.	360.7	4.0	5.2	.3463	
156.	361.3	.1	.8	.3483	
157.	361.8	.3	6.3	.3504	
158.	362.3	.4	.8	.3525	
159.	362.8	.6	7.3	.3546	
160.	363.3	.7	.9	.3567	
161.	363.8	.9	8.4	.3588	
162.	364.3	5.0	.9	.3609	
163.	364.8	.2	9.4	.3630	
164.	365.3	.3	.9	.3650	
165.	365.7	.5	370.4	.3671	54.96
166.	366.2	.6	.9	.3692	
167.	366.7	.8	1.4	.3713	
168.	367.2	.9	.9	.3734	
169.	367.7	6.1	2.4	.3754	

TABLE No. 5. — (*Continued.*)

Pressure Above 0 Lbs.	Temperature Fahr.	Total Heat Above 0° Fahr. B. T. U.		Weight per Cu. Ft. in Lbs.	
		Steam.	Water.	Steam.	Water.
170.	368.2	1226.2	372.9	.3775	
171.	368.6	.4	3.4	.3796	
172.	369.1	.5	.9	.3817	
173.	369.6	.7	4.4	.3838	
174.	370.0	.8	.9	.3858	
175.	370.5	.9	5.4	.3879	
176.	371.0	7.1	.9	.3900	
177.	371.4	.2	6.3	.3921	
178.	371.9	.4	.8	.3942	
179.	372.4	.5	7.3	.3962	
180.	372.8	.7	.8	.3983	
181.	373.3	.8	8.3	.4004	
182.	373.7	.9	.7	.4025	
183.	374.2	8.1	9.2	.4046	
184.	374.6	.2	.7	.4066	
185.	375.1	.3	380.1	.4087	54.60
186.	375.5	.5	.6	.4108	
187.	375.9	.6	1.1	.4129	
188.	376.4	.7	.5	.4150	
189.	376.9	.9	2.0	.4170	
190.	377.3	9.0	.4	.4191	
191.	377.7	.1	.9	.4212	
192.	378.2	.3	3.3	.4233	
193.	378.6	.4	.8	.4254	
194.	379.0	.5	4.2	.4275	
195.	379.5	.7	.7	.4296	
196.	380.0	.8	5.1	.4317	
197.	380.3	.9	.6	.4337	
198.	380.7	1230.1	6.0	.4358	
199.	381.2	.2	.4	.4379	
200.	381.6	.3	.9	.4400	
201.	382.0	.4	7.3	.4420	
202.	382.4	.6	.8	.4441	
203.	382.8	.7	8.2	.4462	
204.	383.2	.8	.6	.4482	

TABLE No. 5. — (*Continued.*)

Pressure Above 0 Lbs.	Temperature Fahr.	Total Heat Above 0° Fahr. B. T. U.		Weight per Cu. Ft. in Lbs.	
		Steam.	Water.	Steam.	Water.
205.	383.7	1231.0	389.1	.4503	54.27
206.	384.1	.1	.5	.4523	
207.	384.5	.2	.9	.4544	
208.	384.9	.3	390.3	.4564	
209.	385.3	.5	.8	.4585	
210.	385.7	.6	1.2	.4605	
211.	386.1	.7	.6	.4626	
212.	386.5	.8	2.0	.4646	
213.	386.9	.9	.4	.4667	
214.	387.3	2.1	.9	.4687	
215.	387.7	.2	3.3	.4707	
220.	389.7	.8	4.2	.4852	
225.	391.7	3.4	6.2	.4957	53.96
230.	393.6	4.0	8.2	.5061	
235.	395.5	.5	400.1	.5165	
240.	397.3	5.1	2.0	.5270	
245.	399.1	.6	3.9	.5374	53.68
250.	400.9	6.2	5.8	.5478	
260.	404.4	7.3	9.4	.5686	
270.	407.8	8.3	412.9	.5894	
280.	411.	9.3	6.3	.6101	53.22
290.	414.2	1240.3	9.7	.6308	
300.	417.4	1.2	422.9	.6515	
350.	432.	5.7	438.3	.7545	
400.	444.9	9.7	452.8	.8572	51.87
500.	467.4	1256.5	475.5	1.062	
600.	486.9	1262.5	496.2	1.266	
700.	504.1	1267.7	514.4	1.470	
800.	519.6	1272.3	530.9	1.674	48.80
900.	533.7	1276.7	546.0	1.878	
1000.	546.8	1280.7	560.3	2.082	