CHAPTER XL.—THE INDICATOR.

THE indicator is an instrument which marks or draws a figure, or diagram as it is called, which shows the pressure there is in the cylinder at every point in the piston stroke, while it also shows the resistance offered by the same body of steam to the piston on its return stroke. From the form of this figure or diagram, the engineer is enabled to discover whether those parts of the engine whose operation regulates the admission of the steam to and its exhaust from the cylinder are correctly adjusted.

From the diagram the engineer may find the average or mean effective pressure of steam on the piston throughout the stroke, for use in calculating the power of the engine.

He may also locate the point of cut off, of release, the amount of back pressure, the degree of perfection of the vacuum in a condensing engine, and the amount of compression.

From the area of the diagram the engineer may also estimate the quantity of steam that is used, and supposing it to be dry

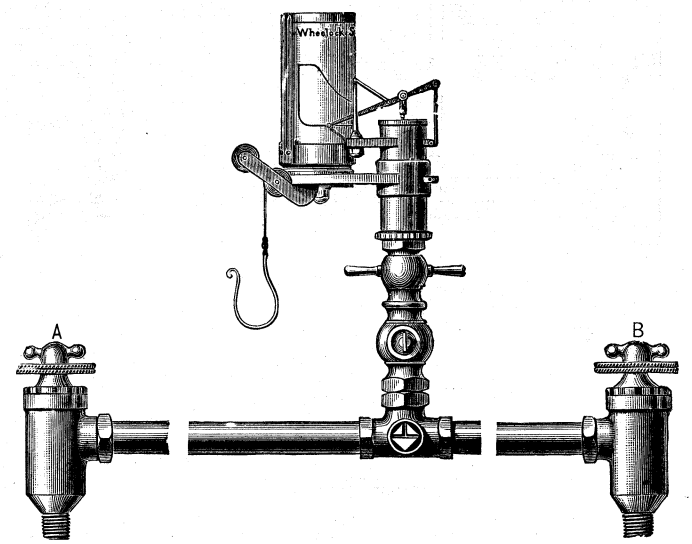

Fig. 3358.

steam, he may calculate the amount of water used to make the steam, and assuming one pound of coal to evaporate so much water, he may calculate the amount of coal used to produce the steam.

The indicators commonly used upon steam cylinders contain two principal mechanical movements; first, a drum revolving the piece of paper upon which the diagram is to be marked, and second, a piston and parallel motion for moving the pencil to mark the diagram upon the revolving paper.

The drum is given a motion that, to insure a correct diagram, is exactly timed with the piston motion.

The pencil is given a vertical movement; this movement must bear a constant and uniform relation to the pressure of the steam in the engine cylinder.

An indicator may be attached to each end of the cylinder or in the middle, with a pipe passing to each end of the cylinder, as in Fig. 3358, but an indicator of the usual construction and such as here referred to, can take a diagram, or *card* as it is sometimes called, from but one end of the cylinder at a time. The stop valves A and B are used, so that the communication between the indicator and one end of the cylinder may be shut off while a diagram is being taken from the other end, while both ends may be shut off when the indicator is not being used.

In the figure a piece of paper (or card, as it is commonly called) is shown in place upon the drum with a diagram upon it.

The Thompson Indicator is shown in Fig. 3359, and in section in Fig. 3360.

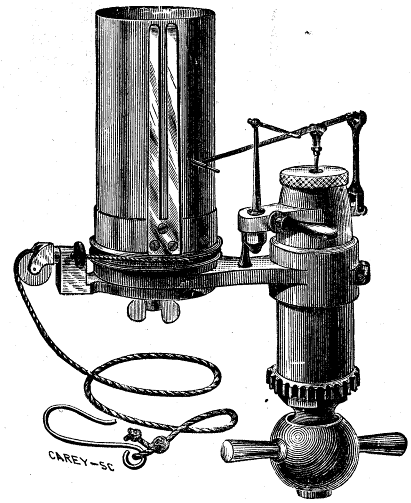

Fig. 3359.

The Tabor Indicator is shown in Fig. 3361, and in section in Fig. 3362.

Both are made with the piston and parallel motion as light as possible, in order to enable the taking of diagrams at as high a speed of engine revolution as possible.

Each consists of a cylinder and piston, the bottom surface of the latter being in communication with the bore of the engine cylin-

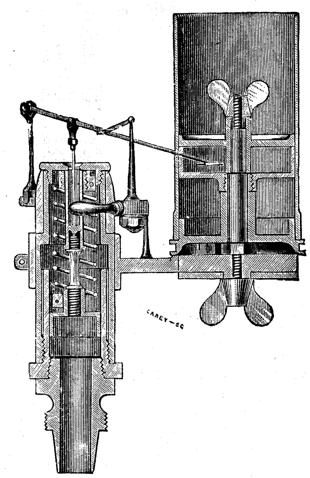

Fig. 3360.

der, so as to receive whatever steam pressure there may be in the cylinder.

This indicator piston receives, on its upper surface, the pressure of a spiral spring, which acts to resist the steam pressure.

The indicator piston rod actuates an arm or line on the end of which is a pencil, which, by means of a parallel motion, is caused to move in a straight line.

The paper or *card* being in place upon the drum, and steam let into the indicator, the pencil lever is moved until the pencil touches the paper as lightly as possible, and as a result of the combined movements of the pencil and drum, the diagram is marked, its

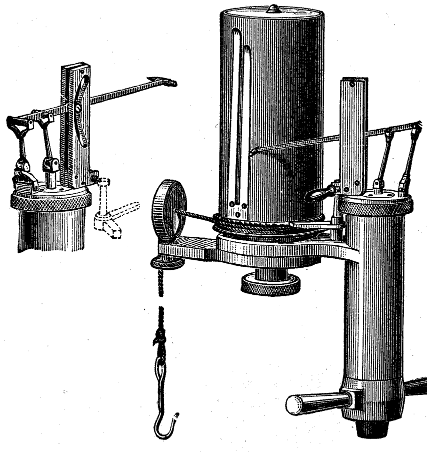

Fig. 3361.

form being illustrated in Fig. 3363, which represents a diagram placed above a cylinder, and the engine piston in three positions; first at the beginning of the stroke; second, at the point of cut off (which is supposed to be at one-third of the stroke); and third, at the point of release where the valve first opens the port for the exhaust. For convenience, the diagram is shown as long as the cylinder, but the actual diagram usually measures about 2½ inches high and 4¼ inches long.

Supposing the cylinder to be filled with air, and the engine piston in position 1, and the indicator piston would be at the corner A of the diagram; but if steam were admitted, the pencil would rise vertically, marking the line from A to B, which is therefore called the *admission line*, or by some, the *induction line*.

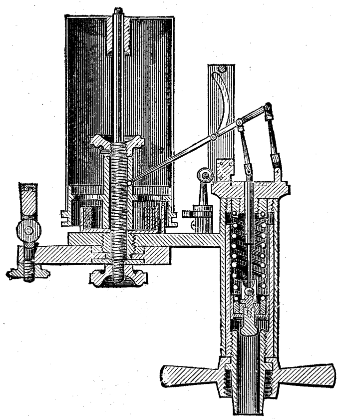

Fig. 3362.

If on reaching B the pressure was enough to move the engine piston, that piston and the indicator drum would move simultaneously, and as long as live steam was admitted the line from B to C would be drawn, hence this is called the *steam line*, its length denoting the live steam period.

The cut off occurs when the engine piston is in position 2, and the indicator pencil at C.

From this point the pencil will fall, in proportion as the steam pressure falls from expansion until the exhaust begins, the piston then being in position 3, and the pencil at D.

The line from C to D is therefore called the *expansion line* or *expansion curve*, and the point D the *point of release* or *point of exhaust*.

We have now to explain that in reality the whole of the remainder of the line of the diagram is, in reality, the exhaust line, yet there is a difference between the part of the line from point D to the end E of the diagram, and that part from E to A, inasmuch as that during the period of exhaust from D to E, the pressure is helping to propel the piston, while after E is reached, whatever steam pressure there may remain in the cylinder acts to retard the piston.

The line from D to E is therefore the exhaust line, and that from E to A is the *back pressure line* or *counter pressure line*.

In this example it has been supposed that while the piston was moving from position 3 to the end of its stroke, and the pencil from D to E, the indicator piston would have a steam pressure on it equal to atmospheric pressure, hence the line from E to A, in this case, represents the atmospheric line, and also the back pressure line.

The atmospheric line is a line drawn when there is no steam admitted to the indicator, and represents a pressure above a perfect vacuum equal to the pressure of the atmosphere. Its use is

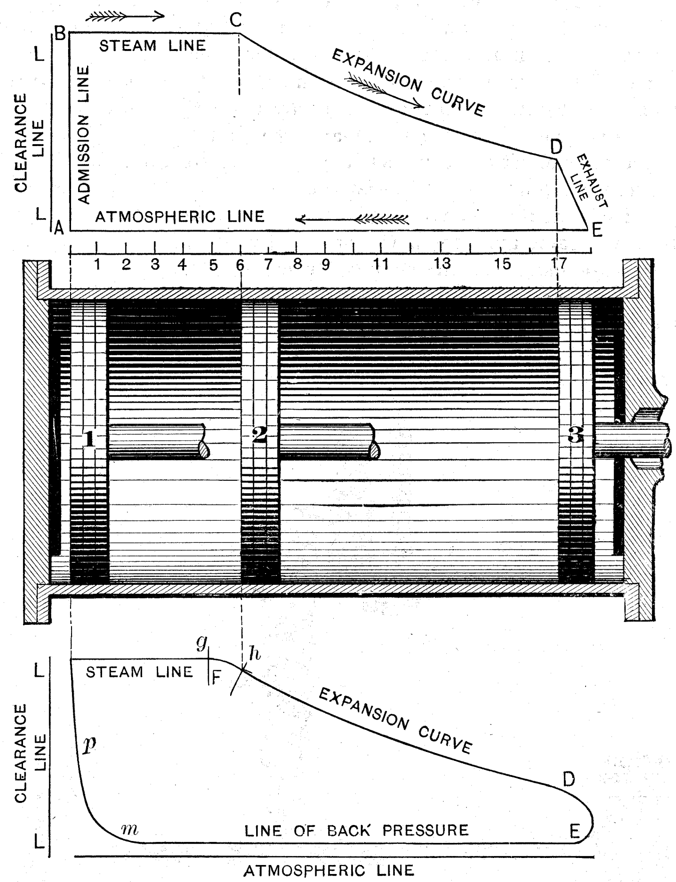

Fig. 3363.

to show the amount of back pressure, and in a condensing engine to show the degree of vacuum obtained.

It also forms a line wherefrom the line of perfect vacuum, or that of full boiler pressure, may be marked.

The steam pressure at any point in the stroke is denoted by the height of the diagram above the atmospheric line, but the steam pressure thus taken is obviously above atmospheric, and is thus the same as the pressure of a steam gauge, which is also above the atmospheric pressure, and therefore represents the pressure that produces useful effect in a non-condensing engine.

This is what may be called a theoretical diagram, because, first, it supposes the steam not to be admitted to the cylinder until the piston was at the end of its stroke, and to attain its full pressure in the cylinder before the piston lead begins to move, whereas, in order to attain a full steam pressure at the beginning of the stroke, the valve must have lead.

Second, it supposes the cut off to be effected simultaneously, whereas the valve must have time to move and close the port, and during this time the steam pressure will fall, and the curve C of the diagram will therefore be rounded more or less according to the rapidity with which the valve closed.

Third, it supposes the steam to have exhausted down to atmospheric pressure by the time the piston had reached the end of the stroke, whereas the piston will have moved some part of the back or return stroke before the steam will have had time to exhaust down to atmospheric pressure ; and,

Fourth, it supposes the steam to remain at atmospheric pressure until the piston arrives at the end of its return stroke, whereas the valve will begin to close the port and cause the steam remaining in the cylinder to compress before the piston has completed its return stroke.

In practice the diagram will, under favorable conditions, accord nearer to the shape shown in the lower part of Fig. 3363, in which the closure of the port for the cut off is shown by the curve at F. At the point denoted by *g* the valve began to close, and at the point denoted by *h* the cut off was completely effected, and the expansion curve began.

The curve beginning at D is caused by the gradual opening of the exhaust port.

The height of the line of back pressure above the atmospheric line shows the amount of back pressure.

At the point *m*, where the back pressure line rises into a curve, the valve had closed, shutting in the cylinder a portion of the exhaust steam, which is afterwards compressed by the piston.

This curve is therefore called the *compression line* or *compression curve*. The point at which it begins cannot be clearly seen when the exhaust port is closed slowly.

The compression curve ends at *p*, where it merges into the admission line, but the exact point where the compression ends and the admission begins cannot always be located, this being the case when the port is opened slowly or the compression extends through a large portion of the stroke.

The admission line is, however, in most cases nearly vertical when the valve has lead, because the valve opens the port quickly while the engine piston is moving at its slowest.

A diagram as drawn by the indicator does not account for all the steam that is used in the cylinder, however, as will be seen from Fig. 3363, because, as the paper drum of the indicator receives its motion from the engine cross head, its length represents the length of the piston stroke, whereas, there is a part of the cylinder bore between the piston (when it is at the end of the stroke) and the cylinder cover that is filled with steam as is also the steam passage.

This steam performs no useful work during the live steam period, but obviously expands during the expansion period, and therefore affects the expansion curve, and must be taken account of in calculating the consumption of steam, of water, or of coal from the diagram, or in marking in the true expansion curve.

In calculating the horse power, however, it may be neglected, as it does not enter into that subject.

But in any calculation involving the amount of steam used, the clearance must be marked in by a line at a right angle to the admission line and distant from the nearest point of the admission line to an amount that bears the same proportion to the whole length of the diagram as the clearance does to the whole contents of the cylinder.

The clearance line is shown at L, L', in Fig. 3363, its distance from the admission line representing the amount of clearance which includes the contents of the steam port and passage, as well as that of the cylinder bore that is between the cylinder cover and the piston, when the latter is at the end of the stroke.

A method of measuring the amount of clearance has already been given with reference to stationary steam engines.

A diagram for a condensing engine is shown in Fig. 3364, which corresponds to Fig. 3363, except that the line of perfect vacuum or no pressure is marked in.

It represents a perfect vacuum, and must be marked on all diagrams from which the consumption of steam is to be calculated, because the quantity of steam used obviously includes that which is used in counter balancing the pressure of the atmosphere.

Learners often get confused on this point, hence it may be more fully explained as follows :

Suppose the engine piston to be blocked in the middle of the cylinder, and has on one side of it a pressure of 20 lbs. of steam by steam gauge, and on the other the pressure of the atmosphere, and we might pump out the steam, thus leaving the cylinder empty on that side of the piston.

The atmosphere would then exert a pressure of about 14½ lbs. per square inch on one side of the piston, and if we slowly admitted steam again, it would have to get up a pressure of 14½ lbs. per square inch before the atmospheric pressure would be counterbalanced and the piston be in equilibrium.

But the steam gauge would at this time stand at zero, and not show that there was any steam in the cylinder, because the zero of the steam gauge is atmospheric pressure.

When, therefore, the steam gauge showed a pressure of 20 lbs. of steam in the cylinder, there would actually be a pressure of 34½ lbs. of steam per square inch.

The clearance line and the vacuum line must both, therefore, be marked on the diagram when the quantity of steam used is to

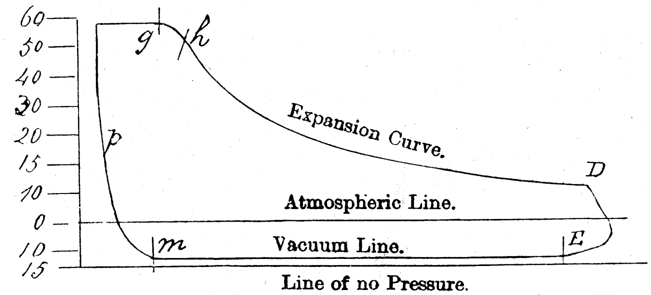

Fig. 3364.

be computed from the diagram, and also when the proper or theoretical expansion curve is to be marked on the diagram.

This is clear, because in finding the expansion curve for a given volume of steam the whole of its volume must be taken into account, and this whole volume is represented by the area inclosed within the clearance line, the steam line, the expansion curve, the exhaust line, and the line of perfect vacuum, or line of no pressure.

The atmospheric line should be drawn after the diagram has been taken, and while the indicator is hot, as the expansion of the indicator affects the position of this line. It is drawn with the steam shut entirely off from the indicator, whose piston therefore has atmospheric pressure on both sides of it.

Whether the engine is condensing or non-condensing, the same amount of steam (all other things being equal) is used, the only difference being that in a condensing engine a greater portion of the steam is available for driving the piston.

If the condenser produced a perfect vacuum, the whole of the steam would be utilized in propelling the piston.

The "line of no pressure," or of perfect vacuum, is marked as far below the atmospheric line as will represent the pressure of the atmosphere, which is, at the sea level, about 14.7 lbs. per square inch when the barometer stands at 29.99 inches.

THE BAROMETER.

A barometer is an instrument for denoting the pressure or weight of the atmosphere, which it does by means of a column of mercury inclosed in a tube, in which there is a vacuum, which may be produced as follows :

A tube having a parallel bore and closed at one end is filled with mercury, and while the finger is placed over the open end of the tube, it is turned upside down and inverted in a cup of mercury that is open to receive the pressure of the atmosphere.

The finger is then removed from the end of the tube and the mercury will fall, leaving a vacuum at its upper end.

The pressure of the atmosphere on the surface of the mercury in the cup forces the mercury up the tube, because the surface of the mercury in the tube has no atmospheric pressure on it, the action being the same as that already described with reference to the principles of action of a pump.

The weight of the atmosphere is equal to the weight of that part of the column of mercury that is above the surface of the mercury in the cup, hence lines may be drawn at different heights representing the weight of the atmosphere, or of any other gas, when the column of mercury stands at the heights denoted by the respective lines.

But as mercury expands by heat, a definite degree of temperature must be taken in marking a column, to represent the weight, this temperature being 32° Fahrenheit.

Similarly, as the weight of the atmosphere varies, according to the height at which it is taken from the surface of the earth, a definite height must be taken.

The sea level is that usually taken, the mean or average atmosphere (at that level) being 14.7 lbs. per square inch.

For higher altitudes, the mean atmospheric pressure in lbs. per square inch may be found by multiplying the altitude or height above sea level by .00053, and subtracting the product from 14.7.

Each pound on the square inch is represented by a height of 2.036 inches of mercury, hence the height of a column of mercury at a temperature of 32° that will balance the mean weight of the atmosphere is 29.92 inches, and to avoid fractions, it is usual (for purposes not requiring to be very exact) to say that the atmospheric pressure at sea level is represented by 30 inches of mercury.

The atmospheric pressure is also, to avoid using fractions, taken roughly at 15 lbs. per square inch at sea level.

Each 2 inches of mercury will, under these conditions, represent 1 lb. of pressure.

Vacuum gauges are based upon the same principles and subject to the same variations as to altitude as mercury gauges or the barometer.

To find the absolute pressure, or pressure above zero, or a perfect vacuum, we may add the pressure of the boiler steam gauge to that shown by the mercury gauge or barometer.

In Fig. 3364 the line of no pressure is marked at 15 lbs. per square inch below the atmospheric line of the diagram, the atmospheric pressure being for convenience taken as 15 lbs. above a perfect vacuum.

The line of no pressure serves as a guide in showing the effectiveness of the condenser, as well as for computing the volume of steam used, but is not necessary in computing the horse power of a non-condensing engine, because the gauge pressure has its zero marked to correspond with the atmospheric pressure.

In computing the consumption of steam or water from the diagram, therefore, both the clearance line and the line of no pressure must be marked on the diagram, and lines of the diagram extended so as to include them, thus accounting for all the steam that leaves the steam chest from the piston stroke.

Indicator springs are varied in strength to suit the pressure of steam they are to be used for.

The scale of the spring is the number of lbs. pressure per square inch represented by a vertical motion of the pencil; thus, a 40 lb. spring is one in which a pressure of steam of 40 lbs. per square inch would cause the piston to rise an inch above the atmospheric line of the diagram.

The strength or tension of the spring is so adjusted as to cause the diagram to be about 2½ inches high, let the steam pressure be what it may. The following are the scales of springs of the Thompson and Tabor indicator.

THOMPSON INDICATOR.

Scale of spring.	Used for pressure above atmosphere if not more than
15 lbs.	21 lbs. per square inch.
20 "	38 " " " "
30 "	94 " " " "
40 "	90 " " " "
60 "	143 " " " "

TABOR INDICATOR.

10 lbs.	14 " " " "
12 "	20 " " " "
16 "	30 " " " "
20 "	40 " " " "
24 "	48 " " " "
30 "	60 " " " "
32 "	64 " " " "
40 "	80 " " " "
48 "	96 " " " "
50 "	100 " " " "
60 "	120 " " " "
64 "	128 " " " "
80 "	160 " " " "

A spring that is strong enough for a given pressure may be used for any less pressure.

The height of the diagram will, however, be less, and accuracy is best secured by having the diagram up to the limit of about 2½ inches, using a spring that is light enough to secure this result.

Diagrams of high speed engines, however, will have their lines more regular in proportion as a stronger spring is used.

This occurs because the spring, being under more tension, is less liable to vibration.

An indicator requires careful cleaning and oiling with the best of oil, as the slightest undue friction seriously impairs the working of the instrument.

Instructions upon the care of the instrument, and how to take it apart, etc., are usually given by the makers of the indicator.

There are various methods of giving to the paper drum of the indicator a motion coincident with that of the engine piston, but few of them give correct results.

Reducing levers, such as shown in Fig. 3365, are constructed as follows:

Fig. 3365 represents a reducing lever with the indicators attached. A C is a strip of pine board three or four inches wide and about one and one-half times as long as the stroke of the engine.

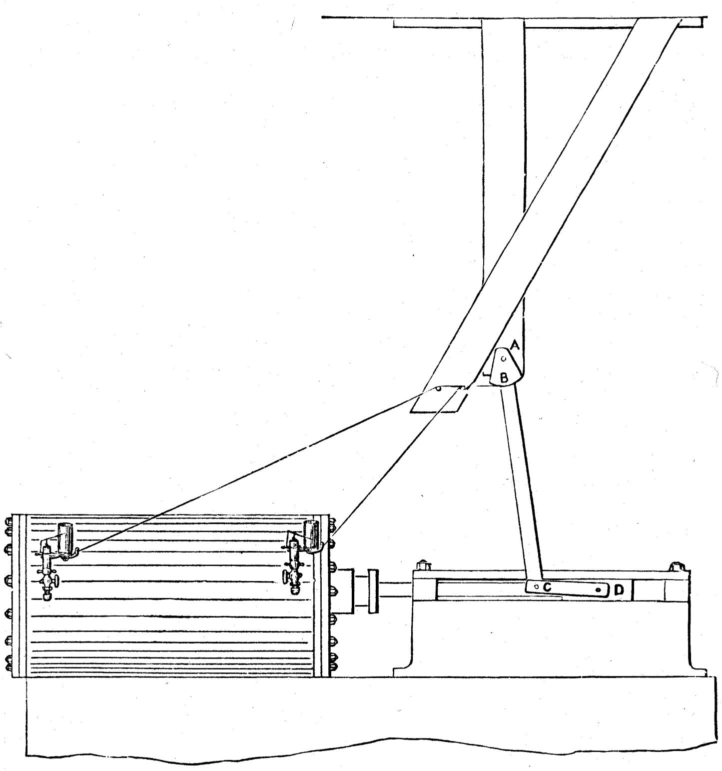

Fig. 3365.

It is hung by a screw or small bolt to a wooden frame attached overhead. A link C one-third as long as the stroke is attached at one end to the lever, and at the other end to a stud screwed into the cross head, or to an iron clamped to the cross head by one of the nuts that adjust the gibs, or to any part of the cross head that may be conveniently used. The lever should stand in a vertical position when the piston is at the middle of the stroke. The connecting link C, when at that point, should be as far below a horizontal position as it is above it at either end of the stroke. The cords which drive the paper drums may be attached to a screw inserted in the lever near the point of suspension; but a better plan is to provide a segment, A, B, the centre of which coincides with the point of suspension, and allow the cord to pass around the circular edge. The distance from edge to centre should bear the same proportion to the length of the reducing lever as the desired length of diagram bears to the length of the stroke. On an engine having a stroke of 48 inches, the lever should be 72 inches, and the link C 16 inches in length, in which case, to obtain a diagram 4 inches long, the radius of the segment would be 6 inches. It is immaterial what the actual length of the diagram is, except as it suits the operator's fancy, but 4 inches is a length that is usually satisfactory. It may be reduced to advantage to 3 inches at very high speeds. The cords should leave the segment in a line parallel with the axis of the engine cylinder.

The pulleys over which they pass should incline from a vertical plane and point to the indicators wherever they may be located. If the indicators and the reducing lever can be placed so as to be in line with each other, the pulleys may be dispensed with and the cords carried directly from the segment to the instruments, a longer arc being provided for this purpose. The arm which holds the carrier pulleys on each indicator should be adjusted so as to point in the direction in which the cord is received.

In all arrangements of this kind the reduced motion is not mathematically exact, because the leverage is not constant at all points of the stroke.

Pantagraph motions have been devised for overcoming these defects. Two forms have been successfully used, which, if well made, well cared for, and properly handled, reproduce the motion on the reduced scale with perfect accuracy. They are shown in working position in Figs. 3366 and 3367.

Fig. 3366 represents the manner of attaching the pantagraph motion, or *lazy tongs*, as it is sometimes called, when the indicators

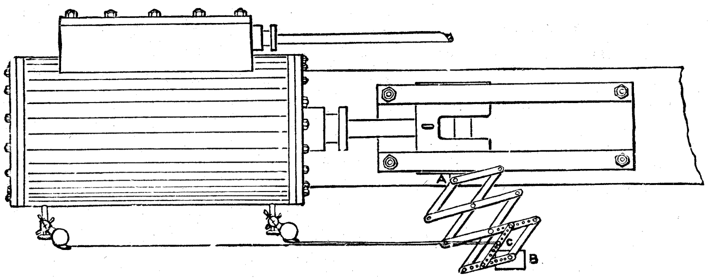

Fig. 3366.

are applied to the side of the cylinder. It works in a horizontal plane, the pivot end being supported by a post B erected in front of the guides, and the working end receiving motion from an iron attached to the cross head.

By adjusting the post to the proper height and at a proper distance in front of the cross head, the cords may be carried from the cord pin C to the indicators, without the intervention of carrier pulleys.

If the indicators are attached to the side of the cylinder, the simplest form of pantagraph shown in Fig. 3367 may be used. The working end A receives motion from the cross head, and the front piece B is attached to the floor. The cord pin D is fixed in line be-

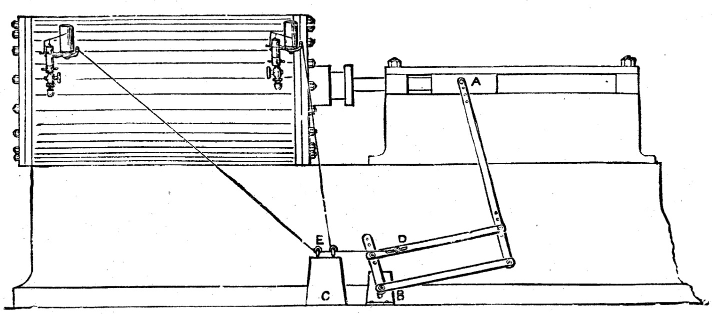

Fig. 3367.

tween the pivot and the working end, and the pulleys E, attached to the block C, guide the cords to the indicators.

The indicator rigging that gives the best results at high speeds is a plain reducing lever like that first described, provided at the lower end with a slot that receives a stud, screwed into the cross head. The length of the lever should be one and one-half times the engine stroke, as given on the preceding page.

Whatever plan is followed, it is desirable to avoid the use of long stretches of cord. If the motion must be carried a long distance, strips of wood may often be arranged in their place and operated with direct connections. Braided linen cord, a little in excess of one-sixteenth of an inch in diameter, is a suitable material for indicator work.

To take a diagram, a blank card is stretched smoothly upon the paper drum, the ends being held by the spring clips. The driving cord is attached and so adjusted that the motion of the drum is central.

For convenience two diagrams, one from each end of the cylinder, may be made on the same card, as shown in Fig. 3368.

TESTING THE EXPANSION CURVE.

The usual manner of testing the expansion curve of a diagram is to compare it with a curve representing Marriotte's law for the expansion of a perfect gas.

A theoretic expansion curve that will accord with Marriotte's law may be constructed on the diagram by the following method :

The diagram, as drawn by the indicator, will have the atmos-

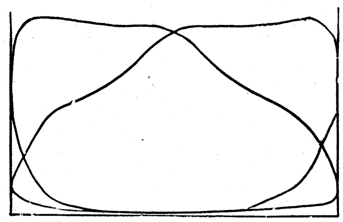

Fig. 3368.

pheric line upon it, and from this as a basis we may mark in the line of no pressure or line of perfect vacuum.

To do this we draw, beneath the atmospheric line, a line as far beneath it as will represent the atmospheric line, on the same scale as the spring used, in the indicator, to draw the diagram.

Suppose, for example, that a 30 lb. spring was used, and assuming the atmospheric pressure to be 15 lbs. per inch, then the line of no pressure would be drawn half an inch below the atmospheric line, because 15 lbs. pull on the spring would cause it to distend half an inch.

The clearance line must then be drawn in, according to directions that have already been given.

The next thing to do is to divide the length of the diagram into any convenient number of equal parts, by vertical lines parallel to, and beginning at, the clearance line, as shown in Fig. 3369. These lines are numbered as shown, ten of them being used because that is a convenient number, but any other number would do.

We next decide at which part of the diagram its expansion curve and the test curve shall touch, and in this example we have chosen that it shall be at line 10.

We have now to find what pressure the length of line 10 represents on the scale of the indicator spring, which in this case we will suppose to be 25 lbs., the line measuring $\frac{25}{30}$ of an inch, and a 30 lb. spring having been used to draw the diagram. Next multiply the pressure (25 lbs.) by the number of the line (10), and divide the product (250) by the number of each of the other lines in succession, and the quotient will be the pressures to be represented by the lines.

For example, for line 9 we have that 250 divided by 9 gives 27.7, hence line 9 must be long or high enough to represent a pressure of 27.7 lbs. above a perfect vacuum, or in this case $\frac{27.7}{30}$ of an inch.

For line 8 we have that 250 divided by 8 gives 31.25 lbs., hence line 8 must be high enough to represent a pressure of 31.25 lbs. above a perfect vacuum.

The atmospheric line is, in this case, of no other service than to form a guide wherefrom to mark in the line of no pressure, or of perfect vacuum.

Now take the case of line 5, and 250 divided by 5 gives 50, hence the height of line 5 must represent a pressure above vacuum of 50 lbs.

Having carried this out for all the lines from line 10 to line 1,

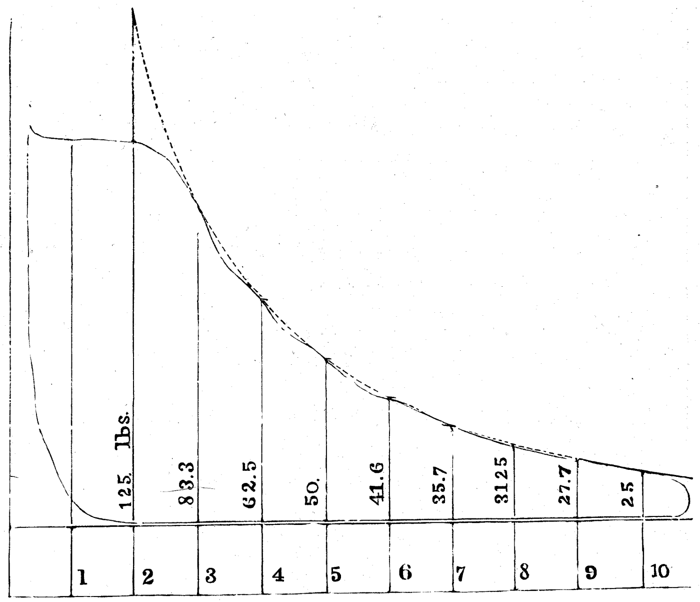

Fig. 3369.

we draw in the true expansion curve, which will touch the tops of all the lines.

Another method of drawing this curve is shown in Fig. 3370. Having drawn the clearance line B C, and vacuum line D C, as before and chosen where the curves shall touch (as at *a*), then draw from *a* a perpendicular *a* A.

Draw line A B, parallel to the vacuum line, and at any convenient height above or near the top of the diagram.

From A draw A C, and from *a* draw *a b* parallel to D C, then from its intersection with A C, erect the perpendicular *b c*, locating on A B, the theoretical point (*c*) of cut-off.

From a number of points on A, B (which may be located without regard to equally spacing them), such as E, F, G and H, draw lines to C, and also drop perpendicular lines, as E *e*, F *f*, G *g*, H *h*.

From the intersection of E C with *b c*, draw a horizontal line to *e*. From the intersection of F C with *b c*, draw a horizontal line, and so on; and where these horizontals cut the verticals (as at *e*, *f*, *g*, *h*) are points in the curve, which begins at *c*, and passes through *e*, *f*, *g*, *h*, to *a*.

But this curve does not correctly represent the expansion of steam. It would do so if the steam remained or was maintained at a uniform temperature; hence it is called the isothermal curve, or curve of same temperature. But in fact steam and all other elastic fluids fall in temperature during their expansion, and rise during compression, and this change of temperature slightly affects the pressure.

A curve in which the combined effects of volume and resulting temperatures is represented is called the *adiabatic* curve, or curve of no transmission; since, if no heat is transmitted to or from the fluid during change of volume, its sensible temperature will change according to a fixed ratio, which will be the same for the same fluid in all cases.

A sufficiently close approximation to the adiabatic curve to enable the non-professional engineer to form an idea of the difference between the two may be produced by the following process:

Taking a similar diagram to that used for the foregoing illustrations, as in Fig. 3371. Fix on a point A near the terminal, where the total pressure is 25 pounds. As before, this point is chosen in order that the two curves may coincide there.

Any other point might have been chosen for the point of coincidence; but a point in that vicinity is generally chosen, so that the result will show the amount of power that should be obtained from the existing terminal. This point is 3.3 inches from the clearance line, and the volume of 25 pounds 996, that is, steam of that pressure has 996 times the bulk of water.

Now if we divide the distance of A from the clearance line by 996, and multiply the quotient by each of the volumes of the other pressures indicated by similar lines, the products will be the respective lengths of the lines measured from the clearance line; the desired curve passing through their other ends. Thus, the quotient of the first or 25 lb. pressure line divided by 996 is .003313; this, multiplied by 726, the volume of 35 lbs. pressure, gives 2.4, the length of the 35 lb. pressure line; and so on for all the rest.

The application of either of the above curves will show that some diagrams are much more accurate than others, even though taken from engines of the same design and quality of workmanship.

As a general rule, those from large engines will be more correct than from small ones, and those from high more correct than from low speeds, and in either case efficiently covering the steam pipes and jacketing the cylinder, to prevent condensation, will improve the diagram.

The character of the imperfection in the expansion curve, shown by the application of a test curve, is generally too high a terminal pressure for the point of cut off, the first part of the curve being generally the most correct, and nearly all the inaccuracy appearing in the last half.

The usual explanation of this is, that the steam admitted during the live steam period condenses because of having to heat the cylinder, and that this water of condensation re-evaporates during the latter part of the stroke when this water of condensation is at a higher temperature than the expanded steam, and thus increases the pressure.

A leaky admission valve may generally, however, be looked for (or else wet steam), if the expansion curve rises much during its lower half.

TO CALCULATE THE HORSE POWER FROM A DIAGRAM.

In calculating the horse power of an engine, the only assistance given by the indicator is, that it provides a means of obtaining

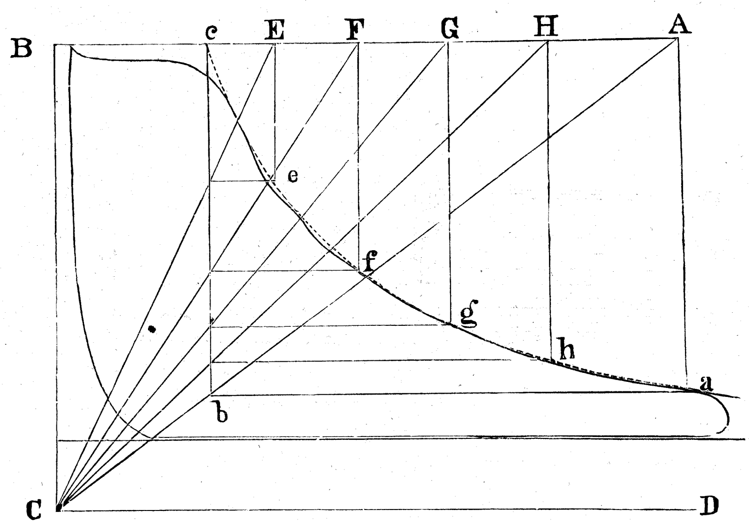

Fig. 3370.

the average pressure of the steam throughout the piston stroke.

There are two methods of doing this, one by means of a planimeter or averaging instrument, and the other by means of lines called *ordinates*.

The ordinates or lines are drawn at a right angle to the atmospheric line, as shown in Fig. 3372, and each line is taken to represent the average height or length of one-half of the space between itself and the next lines.

Suppose, for example, that we require to get the area of that part of the diagram that lies between the dotted lines in the figure, and it is clear that the average height of this part of the diagram is represented by the height of the full line between them.

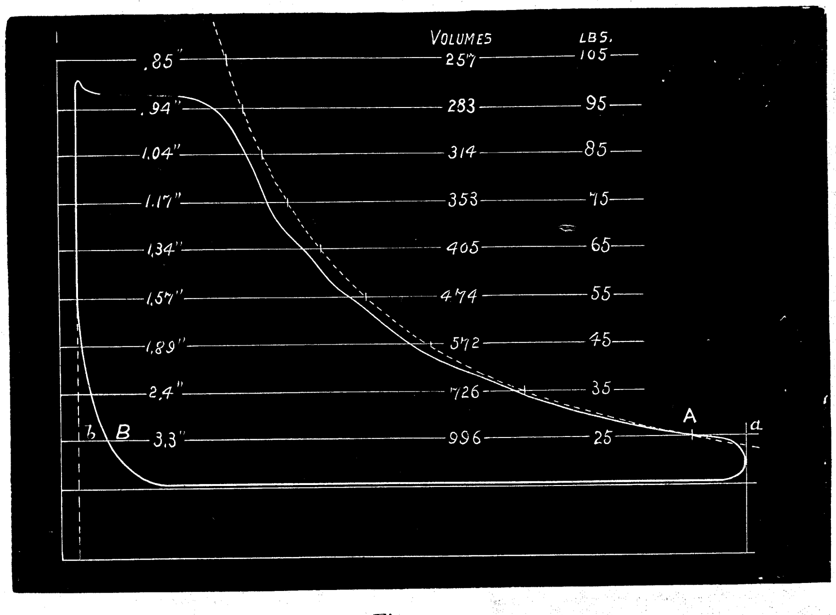

Fig. 3371.

Any number of ordinates may be used, and the greater their number the greater the accuracy obtained. It is, however, usual to draw 10.

The end ordinates A and D, in the figure, should be only half the distance from the ends of the diagram that they are from the next ordinate, as will be seen when it is considered that the ordinate is in the middle of the space it represents.

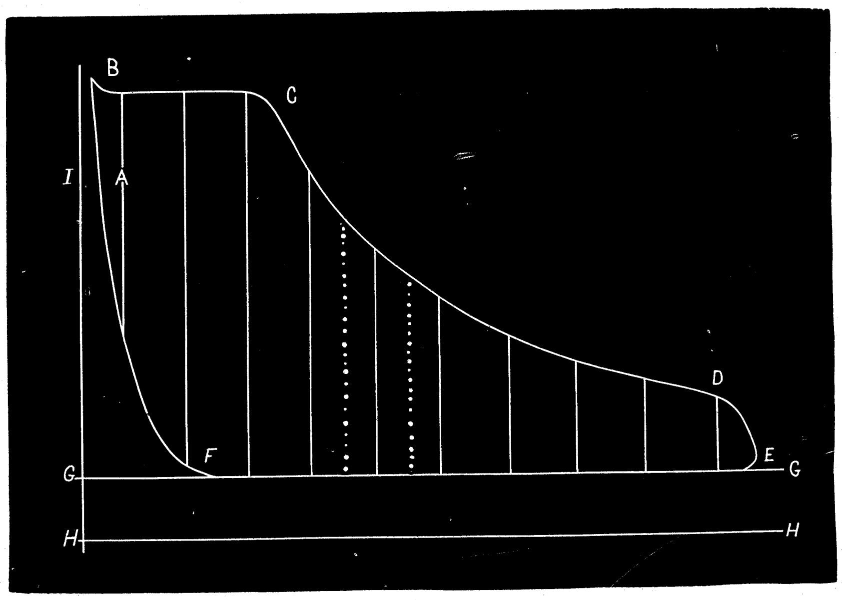

Fig. 3372.

The ordinates being drawn their lengths, are added together, and the sum so obtained is divided by the number of ordinates, which gives the average height of the ordinates.

Suppose, then, that the average height of the ordinate is two inches, and that the scale of the spring of the indicator that took the diagram was 30 lbs., then the average pressure, shown by the diagram, will be 60 lbs. per square inch. Or in other words, each inch in the height of the ordinate represents 30 lbs. pressure per square inch.

The mean effective pressure having been found, the indicated horse power (or I. H. P. as it is given in brief) is found by multiplying together the area of the piston (minus half the area of the piston rod when great accuracy is required) and the travel of the piston in feet per minute, and dividing the product by 33,000, an example having been already explained.

It is to be observed, however, that when great accuracy is required a diagram should be taken from each end of the cylinder, as the mean effective pressure at one end of the cylinder may vary considerably from that at the other.

This will be the case when a single valve is used with equal lap, because, in this case, the point of cut off will vary on one stroke as compared with the other, which occurs by reason of the angularity of the connecting rod.

When cut off valves or two admission valves are used, it may occur from improper adjustment of the valves. It occurs in all engines, because on one side of the piston the piston rod excludes the steam from the piston face, unless, indeed, the piston rod passes through both covers, in which case the rod area must be subtracted from the piston area.

If the expansion curve in a diagram from a non-condensing engine should pass below the atmospheric line, then the mean effective pressure of that part of the card that is below the atmospheric line must be subtracted from the mean effective pressure of that part that is above the atmospheric line, because the part below represents back pressure or pressure resisting the piston motion.

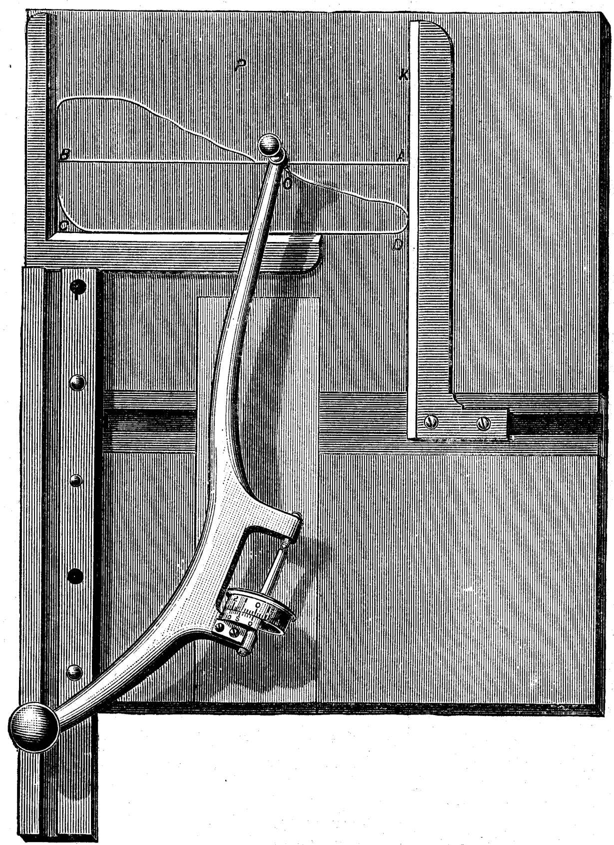

Fig. 3373.

The planimeter affords a much quicker and more accurate method of obtaining the average steam pressure from a diagram.

Coffin's averaging instrument or planimeter is shown in Fig. 3373. The diagram is traced by the point O, and the register wheel gives the area of the diagram.

A quick method of approximating the mean effective pressure (or M. E. P. as it is called) of a diagram is to draw a line *a b*, in Fig. 3374, touching the expansion curve at *a*, and so inclined that the space *e* is, as near as the eye can judge, equal to the space *d*. Then the line *f* drawn in the middle of the diagram, and measured on the scale of the spring that was used to take the diagram, represents the mean effective pressure, or M. E. P. of the diagram.

CALCULATING THE AMOUNT OF STEAM OR WATER USED.

The amount of water evaporated in the boiler is not accounted for by an indicator diagram or card, and the full reasons for this are not known.

It is obvious, however, that the loss, from the steam being unduly wet or containing water held in suspension, is not shown by the diagram, and this amount of loss will vary with the conditions.

Thus the loss from this cause will be less in proportion as the point of cut off occurs earlier in the stroke, because, as the water is at the same temperature as the steam, it will, as the temperature of the steam reduces from the expansion, evaporate more during the expansion period, doing so to a greater extent in proportion as the cut off is early, on account of there being a wider variation between the temperature of the steam at the point of cut off and at the end of the stroke. On the other hand, however, in proportion as the cut off is earlier, the proportionate loss from condensation during the live steam period is greater, because a greater length of the cylinder bore is cooled during the expansion period, and it has more time to cool in.

Whatever steam is saved by the compression, from the exhaust, must be credited to the engine in calculating the water consumption from the indicator card or diagram, since it fills, or partly fills, the clearance space.

In engines which vary the point of cut off, by varying the travel of the induction or admission valve, the amount of compression is variable with the point of cut off, and increases in proportion as the live steam period diminishes; hence to find the actual water or steam consumption per horse power per hour, diagrams would require to be taken continuously from both ends of the cylinder during the hour; assuming, however, that the point of cut off remains the same, that the amount of compression is constant, that the steam is saturated, and neither wet nor superheated, steam and the water consumption may be computed from the diagram as follows:

WATER CONSUMPTION CALCULATIONS.—An engine driven by water instead of steam, at a pressure of 1 lb. per square inch, would require 859,375 lbs. per horse power per hour; the water being of such temperature and density that 1 cubic foot would weigh 62½ lbs. If the mean pressure were more than 1 lb., the consumption would be proportionately less; and, if steam were used, the consumption would be as much less as the volume of steam used was greater than an equal weight of water. Hence, if we divide the number 859,375 by the mean effective pressure and by the volume of the terminal pressure, the result will be the theoretical rate of water consumption in pounds per I. H. P. per hour.

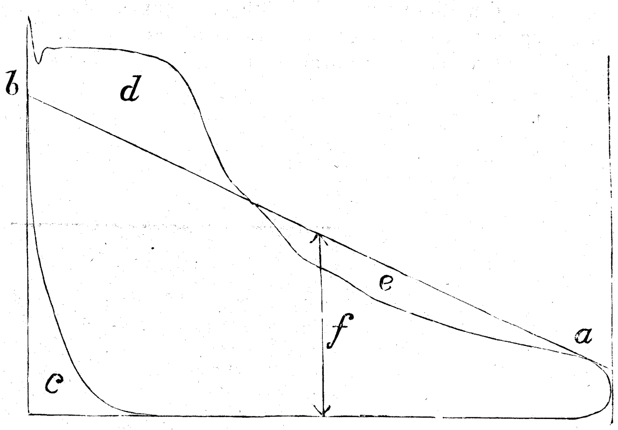

Fig. 3374.

For the terminal pressure we may take the pressure at any convenient point in the expansion curve near the terminal, as at A, Fig. 3375, in which case the result found must be diminished in the proportion that the portion of stroke remaining to be made, A *a*, bears to the whole length of the stroke *a b*; and it may also be diminished by the proportion of stroke remaining to be made after the pressure at A has been reached in the compression curve at B. In other words, A B is the portion of the stroke *a b*, during which steam at the pressure at A is being consumed. Hence the result obtained by the above rule is multiplied by A B, and the product divided by *a b*.

To illustrate, suppose the mean effective pressure of the diagram to be 37.6 lbs., and the pressure at A, 25 lbs., of which the volume is 996.

Then $\frac{859{,}375}{37.6 \times 996} = 22.94$ pounds water per I. H. P. per hour, the rate that would be due to using an entire cylinder full of steam at 25 pounds pressure every stroke. But as the period of consumption is represented by B A (*b a* being the stroke), the following correction is required:

$\frac{22.94 \times 3.03}{3.45''} = 20.15$; 3.03 inches being the portion B A, and 3.45 inches being the whole length *b*, *a*. This correction allows for the effects of clearance as well as compression, since, if more clearance had existed, the pressure at A would not have been reached till later in the stroke, and the consumption line B A would have been longer.

But such a rate can never be realized in practice. Under the best attainable conditions, such as about the load indicated on the diagram, or more on a large engine with steam tight valves and piston, and well protected cylinder and pipes, the unindicated loss will seldom be less than 10 per cent., and it will be increased by departure from any of the above conditions to almost any extent. It will increase at an accelerating ratio as the load is diminished, so that such calculations applied to light load diagrams would be deceptive and misleading; in fact, they have but little practical value, except when made for comparison with tests of actual consumption for the purpose of determining the amount of loss under certain given conditions.

DEFECTIVE DIAGRAMS.

In seeking the causes that may produce a defective diagram, the following points should be remembered:

caused by a leaky piston, by a valve that leaks on the exhaust side but not on the steam side, or if the exhaust valve is separate from the steam valve, it may leak while the steam valve is tight.

It may also be caused by the cylinder being unduly cooled, as from water accumulating in a steam jacket.

There are many defects in the adjustment of the valve gear, or of improper proportion in the parts, that may be clearly shown by a diagram, while there are defects which might exist and that would not be shown on the diagram.

It is possible, for example, that a steam valve and the engine piston may both leak to the same amount, and as a result the expansion curve may appear correct and not show the leak.

Insufficient valve lead would be shown by the piston moving a certain portion of its stroke before the steam line attained its greatest height in Fig. 3376, in which from A upwards, the admission line, instead of rising vertically, is at an angle to the right, showing that the piston had moved a certain portion of its stroke before full pressure of steam was admitted.

That too small a steam port or steam pipe did not cause this defect may be known from the following reasoning:

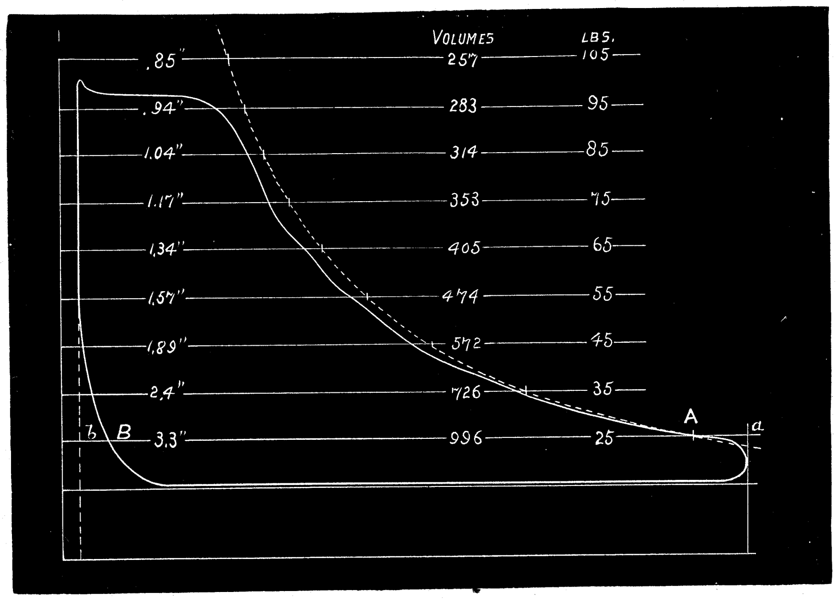

Fig. 3375.

The indicator must be kept in perfect order, thoroughly clean and well lubricated, so that its parts will move freely. It should always be cleaned throughout after using.

The motion of the indicator drum should be an exact copy, on a reduced scale, of that of the piston at every point in the stroke.

The steam pipes from the cylinder to the indicator, if any are used, must be large enough to give a free and full pressure of steam, and care must be taken that the water of condensation does not obstruct them or enter the indicator.

The cord should be as strong as possible, or if long, fine wire should be substituted.

The pencil should be held to the card with just sufficient force to make a fine line with a sharp pencil.

The diagram should be as long as the atmospheric line, any difference in this respect showing unequal tension of the cord, probably from unequal pressure of the pencil to the paper or card.

A fall in the steam line could arise from too small a steam pipe, and this could be tested by a diagram taken from the steam chest. It could also occur from too small a steam port or an obstructed steam passage as well as from a leaky piston.

An expansion curve that is higher than it should be may arise from a leaky valve, letting in steam after the cut off had occurred, or if at the later point of expansion curve, it may be caused by the steam being wet or containing water, which evaporates as the temperature falls from the expansion.

An expansion curve that is lower than it should be may be

The port opened when the pencil was at A, which shows that the valve had lead. At this time the piston was near the dead centre and moving slower than it was when the pressure reached its highest point on the diagram, and since the steam line is fairly parallel with the atmospheric line, it shows that the port was large enough to maintain the pressure when the piston was travelling fast, and therefore ample when the piston was moving slow.

The remedy in this case is to set the eccentric back.

With less compression the point A would be lower.

Excessive lead is shown in Fig. 3377 by the loop at A, where the compression curve extends up to the steam line, and the lead carries the admission line above it, because of the piston moving against the incoming steam.

To mark in the theoretical compression curve, the vacuum line and the clearance line must be drawn in as in the figure, and ordinates must be drawn.

According to the diagram, in Fig. 3377, the compression is clearly defined to have begun at C, and at that time the space filled by steam is represented by the distance from C to the clearance line. The pressure above vacuum (or total pressure) of the steam in the cylinder when the compression began is represented by the length or height of the dotted line 1.

Now suppose the piston to have moved from the point C, where compression began, to line 2 (which is midway between line 1 and the clearance line), and as the compressed steam occupies one-half the space it did when the piston was at C, therefore the steam pressure will be doubled, and line 2 may be drawn making it twice as high as line 1.

Line 2 is now the starting point for getting the next ordinate, and line 3, must be marked midway between line 2 and the clearance line, and twice as high as line 2, because at line 3 the steam will occupy half the space it did at line 2. Line 4 is obviously midway between line 3 and the clearance line.

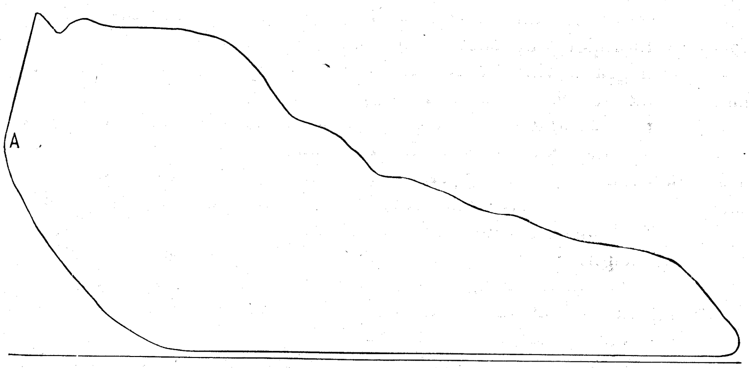

Fig. 3376.

Through the tops of these lines we may draw the theoretical compression curve, which is shown dotted in.

To find the amount of steam actually saved by the compression, we have to consider the compression curve only, beginning at the point of the diagram where it is considered that the compression actually began, and ending where the compression line joins the admission line, and the horizontal distance between these two points represents the length of the cylinder bore filled by the compression.

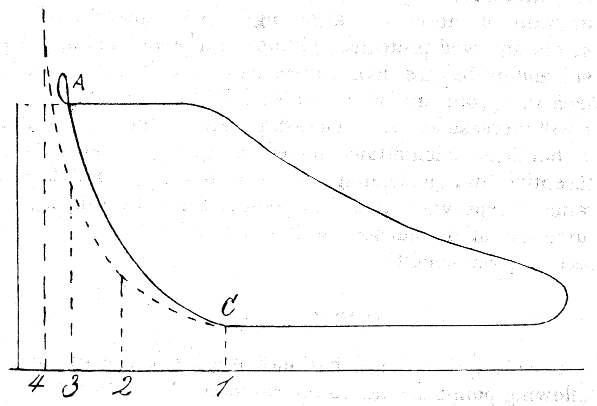

Fig 3377.

To find the average amount to which the steam is compressed, we must draw within this length of the diagram, and within the boundaries of the compression curve, and the line of no pressure ordinates corresponds to those given for finding the average shown pressure of a diagram, as explained with reference to that subject, taking care to have the end ordinates spaced half as wide as the intermediate ones, as explained with reference to Fig. 3372.