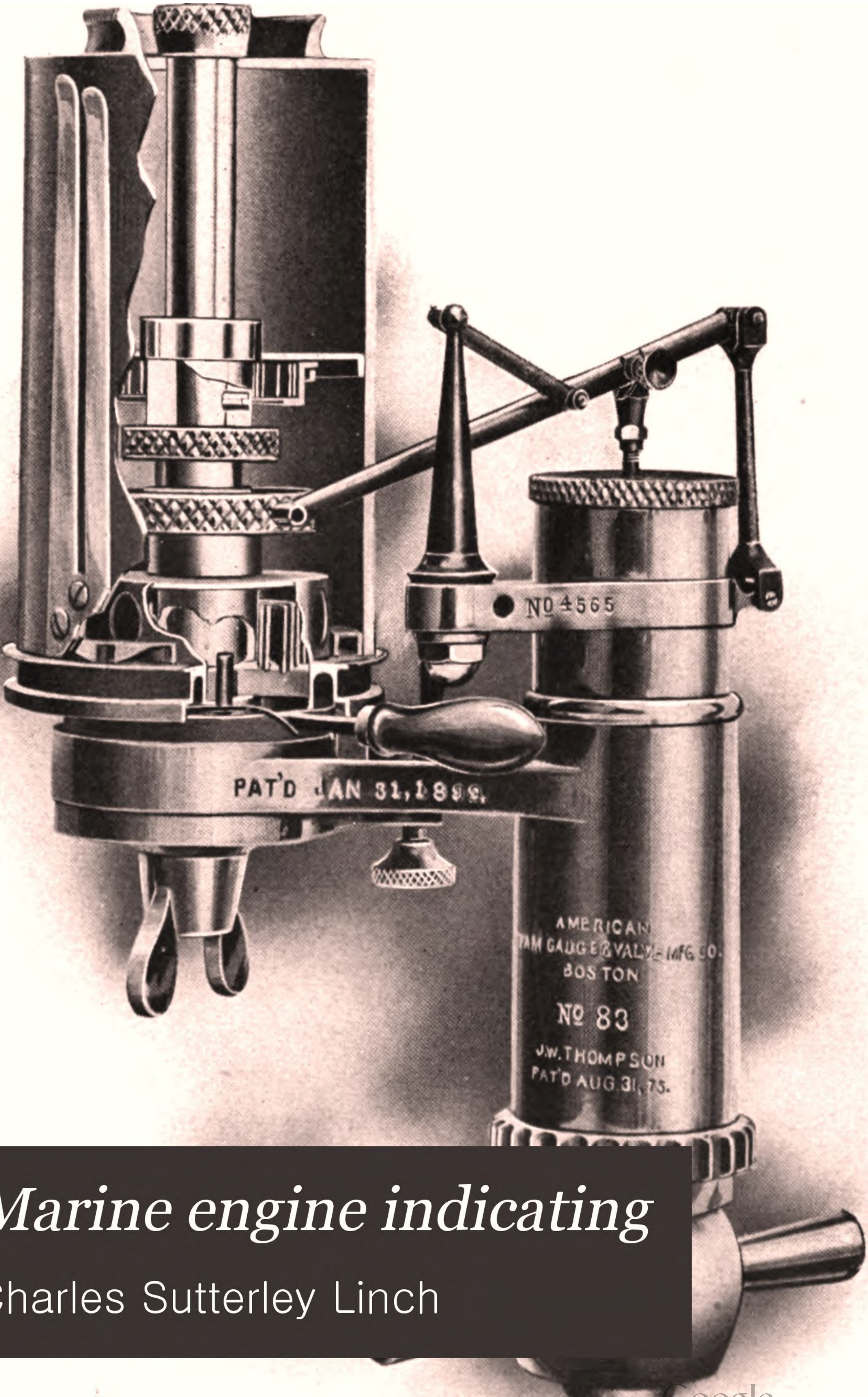
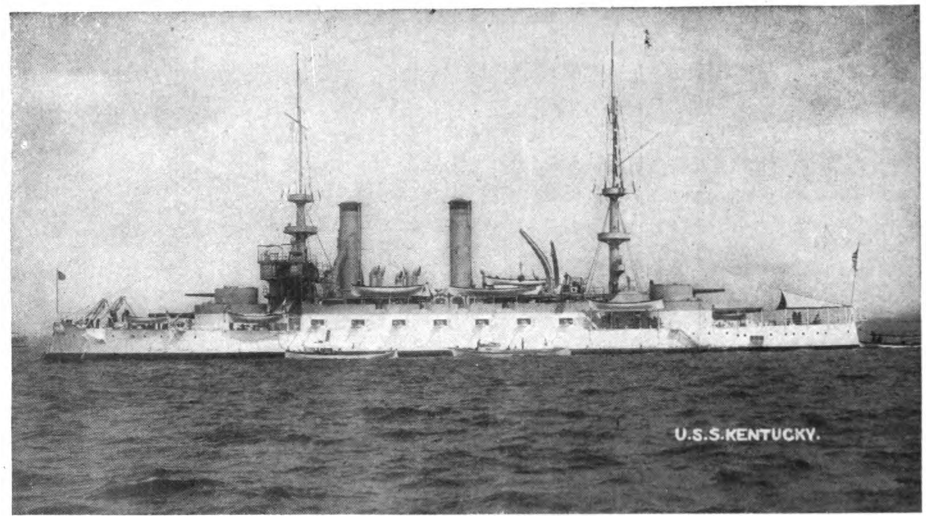



# *Marine engine indicating*

Charles Sutterley Linch


U.S.S. KENTUCKY.

# MARINE

# Engine Indicating

A Complete Treatise on the
Indicator and Indicator Diagrams,
as applied to Marine Engines

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By

C. S. LINCH

Consulting and Constructing Naval Architect
and Marine Engineer

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BOSTON:
AMERICAN STEAM GAUGE AND VALVE MFG. CO.
CAMDEN STREET
1910

# CONTENTS

THIS work is respectfully dedicated to my friend, R. B. Phillips, Treasurer and Manager of the American Steam Gauge & Valve Manufacturing Company, through whose Indicator, the American-Thompson, I have been able in all my professional work to accomplish most perfect results, and because it is my unqualified opinion that the facility and accuracy of this instrument is unequaled.

The importance of a perfect instrument in the expert work which I am constantly called upon to perform has compelled me to make this selection by thorough tests and the absence of all prejudice.

It is, therefore, in this same spirit that I give credit where credit is due.

CHARLES S. LINCH.

# *FOREWORD*

It has been the writer's observation—and doubtless the reader's as well—that text books written on the subject of indicators are invariably based on experiences with stationary engines.

That a thorough treatise on this all-important device, with special reference to its application to marine engines is greatly needed, is obvious to every marine engineer, and this work is undertaken expressly to meet that need, particular care being exercised, especially in all the analyses of diagrams, to be lucid and concise, rather than elaborately technical.

The history of the indicator has been purposely avoided, as being superfluous, the writer deeming it of far greater importance to confine himself especially to a complete description of the most accurate of the modern type.

In the analysis of diagrams it is important, when adjustment of valves must be made, to be able to construct and discuss the valve diagrams, and the object here has been to explain the methods in a clear manner, eliminating all geometrical proof.

All diagrams shown were taken, in actual practice, from modern marine engines.

If by writing this work I have been of help to those who are seeking this knowledge I shall feel amply repaid.

I am greatly indebted to Mr. Harry Vansciver, Division Superintendent, Merchants and Miners Transportation Company, for the analysis of the steamship "Tuscan."

THE AUTHOR.

# MARINE INDICATING

## CHAPTER I

The steam engine indicator is an instrument which, through the proper functioning of its various parts, depicts upon paper a diagram which should accurately represent the various changes of pressure on one side of the piston of the steam engine during both the forward and return strokes.

Not only does the diagram show these variations, but it shows defects of design and adjustment, enabling the engineer to rectify faulty adjustment, and to determine any changes which would be conducive to increased economy and efficiency.

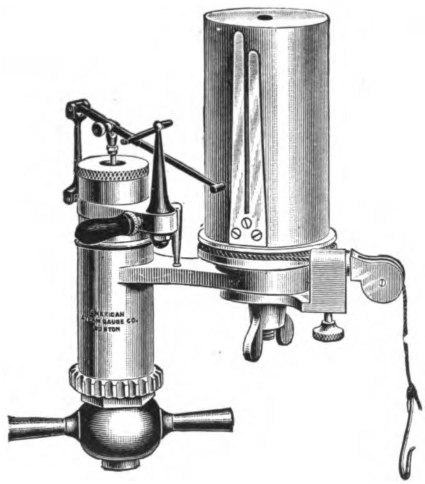


Fig. 1

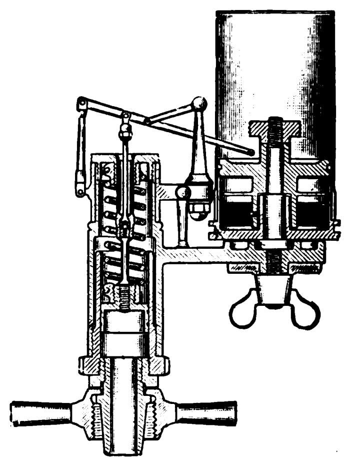
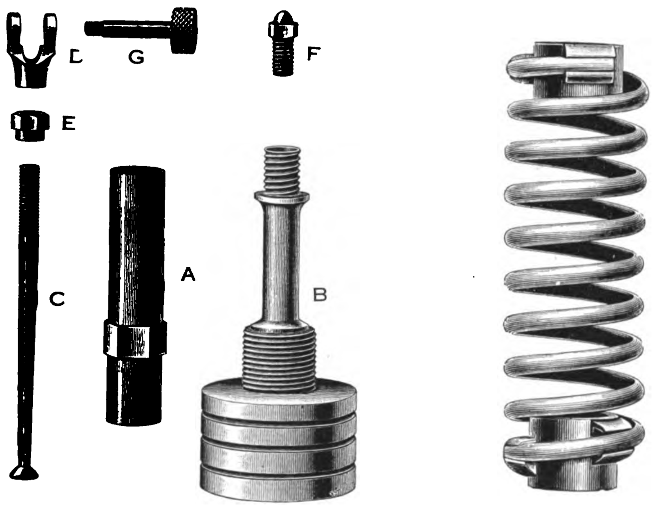


Fig. 2

Fig. 1 shows an outside view and Fig. 2 a section through the incased spring instrument manufactured by the American Steam Gauge and Valve Manufacturing Company of Boston, Mass., known to the engineering profession as the American Thompson Improved Indicator. This instrument consists of an outer cylinder or casing into which is secured the liner in which the piston travels. This liner is made of a special hard bronze composition, which differs slightly from the composition of which the piston is made. The object of having the liner and piston made of different compositions is to obtain a uniform expansion. The space between the outer casing and liner forms a suitable steam jacket. The bracket which carries the paper drum spindle and the casing are one casting. This bracket is of sufficient dimensions to form a very rigid and strong appendage, the distance between the center of cylinder and center of drum spindle being only sufficient to insure the pencil striking the proper position on the paper drum in a vertical plane. The pencil motion being three to one, this distance is therefore such that danger of bending with the light construction is eliminated.

The spindle is of steel and, as will be observed, is screwed into the bracket and shouldered; the end extending through the bracket carries the guide pulley bracket and wing nut.

The bearing surface for the paper drum pulley is large, insuring ample bearing surface.




## Piston

Fig. 2a

The piston Fig. 2*a* is of a special composition permitting a light construction yet possessing the requisite strength to prevent expansion from pressure, and is grooved for water packing.

The stem of the piston is constructed throughout of steel; the upper part consists of the sleeve "A" which acts as a guide passing through the cylinder cap. The piston "B" is connected with the pencil lever by a connecting rod "C" having a cross-head "D" at the upper end, which acts as a yoke, making connection with pencil lever by knurled-headed screw "G" connecting yoke with lever.

The cross-head is held in place by a small hexagonal lock nut "E." The top of the connecting rod is threaded, permitting the raising or lowering of the cross-head, thus securing adjustment of the atmospheric line on the diagram.

The lower end of the connecting rod forms a socket which rests on a ball stud "F," which, in turn, is adjustable in the piston stem. The result is a perfect ball and socket joint, and provides means for taking up any lost motion.

The parallel motion is made of drop-forged, compressed steel, and is carried on a sleeve, which is fitted to the upper end of the steam cylinder, being held in place by the milled cylinder cap. The pencil lever has a vertical motion in the ratio of three to one, and is guided by a short connecting link, which vibrates about a pin carried by the post. The post is carried by an arm cast with the sleeve. A link connecting the pencil lever and vibrating about a center carried also on the sleeve, acts as a fulcrum. The yoke as mentioned connects the piston with the pencil lever.

This construction insures an absolute straight line for pressure line; any inclination of this line in any diagram can therefore be attributed to other causes.

The end of the pencil lever is split, thus forming a spring sleeve to take the lead or German silver points.

Through the arm of the sleeve there is drilled and tapped a hole for the adjusting screw, as shown.

On the bracket carrying the paper drum there is fitted a stop to prevent injury to pencil lever, by introducing excessive friction on card, from too great pressure of lead against paper. The sleeve being free to turn, the adjustment of adjusting screw determines the pressure put on pencil.

The connection of the indicator to the straight or three-way cocks is through the medium of a swivel coupling, having a tailpiece which is secured into the lower end of the cylinder. This tailpiece is provided with a shoulder against which the inner flange of the coupling proper rests; this forms a perfect swivel coupling and is a decided improvement over those having right and left hand thread.

## Springs

The springs are made of the finest quality steel wire, and are wound on a mandrel and tempered in the most scientific manner. This mandrel on which all springs are wound is from four to four and one-half threads per inch. In the springs furnished with these instruments there is therefore more wire to each spring, and hence less strain than if wound on mandrels of two and three threads per inch. The heads of the springs are of brass, drilled and tapped to receive the piston and cylinder cap.

In securing the heads to the spring, no solder is used. The cut (Fig. 2*a*) shows clearly the construction.

## Paper Drum

The paper drum is of brass tubing, turned true, faced, capped and bored for pulley, and is light, yet possessing requisite strength.

The tension spring is carried by the drum pulley, the spring case forming an integral part of same. The tension of the spring is adjusted by turning the knurled cap, the cap is prevented from slipping by friction of the knurled lock nut. The construction is clearly shown in Fig. 3.

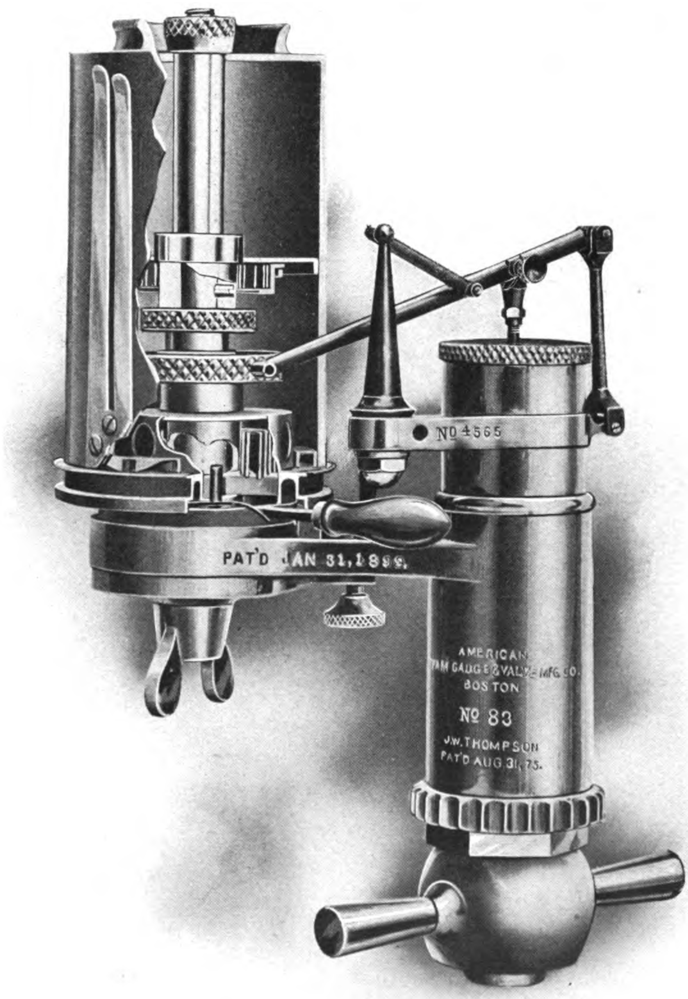



Fig. 3

Fig. 6 shows a section through the paper drum of an instrument fitted with detent motion.

## Leading Pulley

The leading pulley shown in Fig. 4 consists of a wheel which is carried on an adjustable bearing. This bearing as shown is carried by a stand which is cast with a palm, the palm is drilled so that it can pass over the extension of the paper drum spindle. This palm is clamped by the wing nut as shown in Figs. 1 and 2.

The cord from the grooved wheel of paper drum is passed through the hole in the pulley sleeve, thence passing over the pulley to the driving cord from reducing motion. After the leading pulley is adjusted it is clamped by the knurled head screw as shown. It will be noted that the cord from paper cylinder is always tangent to the groove in leading pulley.

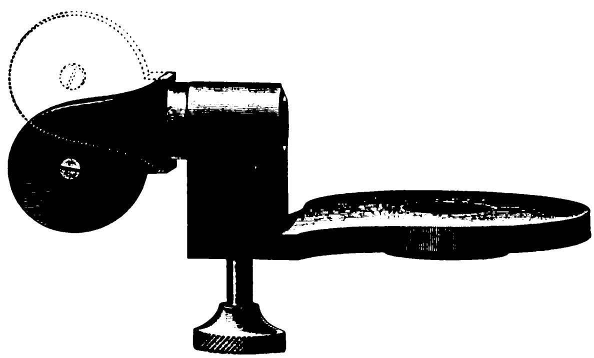


Fig. 4

## Detent Motion

Fig. 5 shows the instrument fitted with detent motion, and Fig. 6 shows a section through the paper drum of this instrument. It will be noticed that in order to stop the paper cylinder it is only necessary to move lever "A" in the direction traveled by the paper cylinder until the cylinder releases itself. The cylinder will then remain stationary, at which time the completed diagram can be removed and a new card substituted. The lever must be returned to its original position.

Looking now at Fig. 3 we see that the pin which is carried by spring when in position as shown, drives the paper cylinder. This spring is drawn down when lever is pushed over, hence withdrawing pin, thus disengaging the paper drum from pulley. When lever is again thrown back, the spring is free to push pin into position as soon as the hole in drum and drum pulley coincide. Therefore, when new card has been put on drum, turn the milled rim "B" on top of drum forward until it catches. The drum will then be in gear, and hence will revolve in usual manner.

## Outside Spring Instrument

The outside spring instrument shown in Fig. 6*a* is precisely the same as the incased spring instrument as far as construction and materials are concerned, except that the spring is not subject to variations of temperature, and is visible at all times. The pencil lever is yoked to straddle the spring, and two links are used from pencil lever to post, and to collar on piston rod, otherwise the details are the same.

It will be noted that the bracket which carries the paper drum is drilled and tapped for one of the standards of which there are two, and that there is a lug cast on the cylinder casing which carries the other standard. The standards are fitted at the top with a separator which is drilled and tapped for a long screw to which one end of the spring connects. The piston rod passes through the cylinder cap, and is flanged

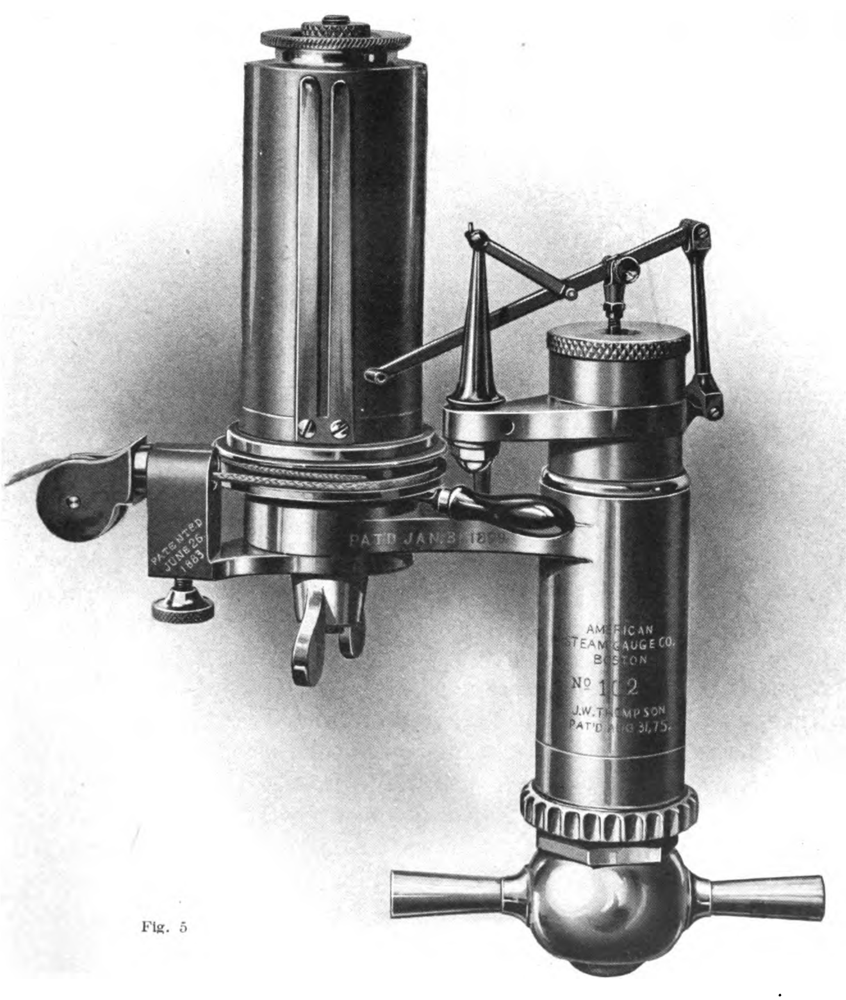



Fig. 5

at the upper end. This flange forms a shoulder on which the collar carrying the two links connecting the pencil lever rests. On top of this collar is carried the spring base which is provided with four holes in which is inserted a pin for holding piston-rod from turning when spring is to be inserted or removed.

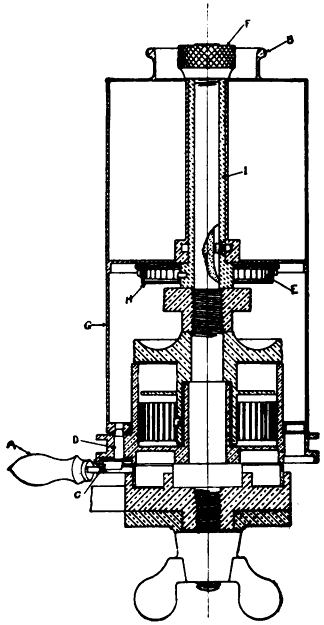



Fig. 6

## Reducing Wheel

It frequently happens that engines are not fitted with reducing motions, and when such cases occur we must resort to the use of reducing wheels.

The reducing wheel shown in Fig. 7 is made of aluminum, brass, and steel, combining lightness and strength, two very essential features. The wheel drum from which the cord passes to the cross-head arm or any other arrangement for driving, is $2\frac{3}{4}$ inches in diameter, and is made of aluminum. The coil spring for the take-up is in a separate case and connected by a three to one gear with the cord-wheel spindle, so that while the aluminum cord-wheel makes three revolutions, the spring makes but one. The spring can be adjusted to any desired tension to keep the cord taut on return stroke. The cord-wheel revolves on a steel screw, the thread of which has the same pitch as the cord, so that when the cord is drawn out the wheel travels as it revolves. Thus the cord is wound smoothly on the drum and passes straight through the guide pulley.

In using the reducing wheel on the indicator, remove the leading pulley (see Fig. 8) from the indicator and put the wheel on in place of it. Pass the drum cord around the small disk through the hole and under the holder. Observe that the cord is always wound round bushing or

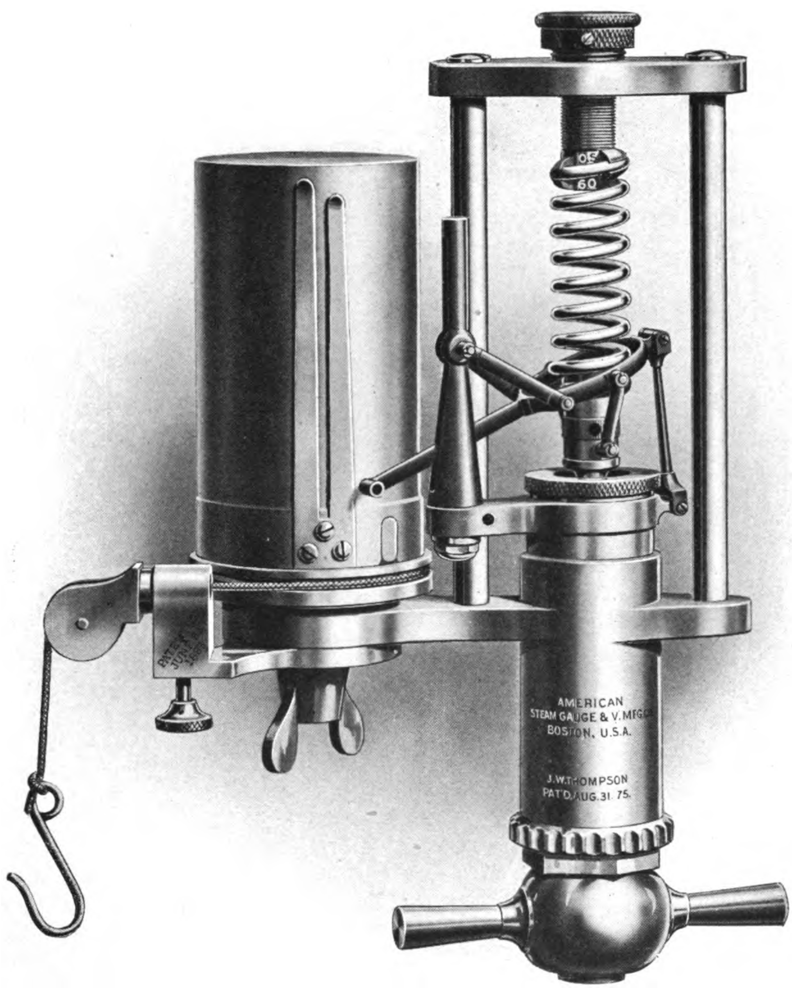



Fig. 6a

disk from the left. Before hooking in, see that cord on wheel and indicator is taut at shortest part of stroke and that it will pull out a little further than longest part of stroke.

The cord from reducing wheel to cross-head must run in a straight line.

In unhooking the cord do not permit it to run unchecked but allow it to run slowly until the stop reaches the guide pulley.

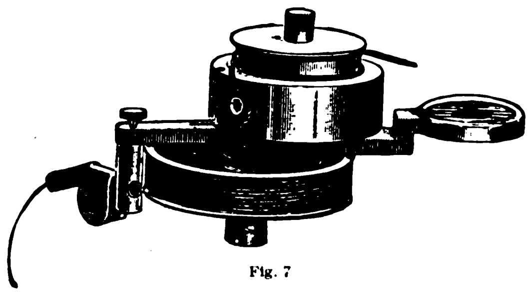


Fig. 7

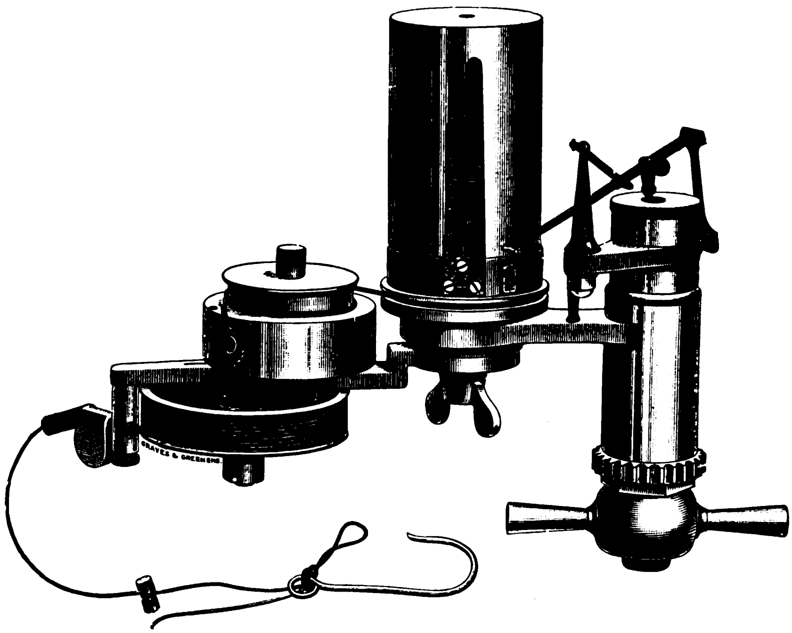


Fig. 8

Bushings are furnished of various sizes for small disks so that diagrams can be taken for any stroke up to 72″.

Having described the construction of the instrument we will now take up the subject of its care and adjustment.

## Care

Before using an indicator take it apart and thoroughly clean and oil it. Starting at the steam cylinder, remove the small knurled-head screw connecting the pencil lever with the connecting rod. Unscrew the cylinder cap and withdraw the piston and parallel motion by holding the instrument with one hand, and with thumb and finger lift up the sleeve. After the piston has been withdrawn, with one hand grasp the piston and with thumb and finger turn cylinder cap, unscrewing same from spring. Now unscrew spring from piston. Wipe out cylinder with clean waste, and see that all dirt, if any, is removed. Whilst the piston is out of instrument it is as well to look after the paper drum and its appendages.

Remove the knurled-nut "F" (see Fig. 6); take off the paper drum, then with the wire clip (which is furnished with each instrument fitted with detent motion) remove the auxiliary spring case "H" by catching the end of the clip in the notches; then remove the spring and inner sleeve "I." After cleaning and oiling, replace the inner sleeve "I" by inserting it into the drum so that the pin on the outside of the sleeve will enter the slot inside of drum bearing and turn it until it comes to a stop; then with the wire clip catch hold of the auxiliary spring holder "H" and give the auxiliary spring "E" a tension of about ½ turn, catching the points on the spring case "H" into the slots provided for them.

Whilst we have the auxiliary spring case and sleeve out it is necessary to be sure that the spindle is oiled, therefore, remove the lock nut, thus releasing the spring tension, then with screw driver (furnished with each instrument) remove the small screw on spindle, then remove lock nut, and lift off the paper drum pulley. Oil thoroughly and replace the pulley, and turn knurled cap, giving the spring the required tension and lock with lock nut; replace screw in spindle, thence replace paper drum, and finally the knurled nut "F."

Having selected the spring we wish to use, screw same to cylinder cap; next screw on the piston. Oil the piston with good cylinder oil and replace piston in cylinder; screw on the cylinder cap, and last, connect the pencil lever with connecting rod by inserting and gently screwing up the screw through yoke. Care must be exercised, and it is important to remember that the pencil lever must be disconnected first, and connected last. With the porpoise or watch oil (furnished with each instrument) oil the joints in the parallel motion. It is to be remembered that all parts of the instrument except the piston must not be oiled with any other oil except the kind furnished, and only a good cylinder oil is to be used on piston.

## Adjustment

Great care must be exercised in adjusting the instrument. For the adjustment of the paper drum spring, the tension on this must not be greater than is absolutely required. To determine just what this should be in any case, we must, with the engine turning very slow, take a diagram; then with engine turning maximum number of revolutions, take another diagram; with a pair of dividers measure the length of the diagrams; should the diagram taken with maximum turns show a difference in length the spring must be adjusted to give the same length. The tension on the spring will of course be greater for fast and less for slow turning engines, hence the necessity of adjusting to suit conditions.

The adjustment of the outside instrument is precisely the same as for incased spring.

The adjustment of the pencil is controlled by the adjusting screw, and should be such as to give as light a line consistent with clearness.

A diagram can very readily be distorted by excessive friction, and the data from same absolutely useless; beside the injury to the pencil lever.

After the instrument is removed from engine it should again be taken apart and all parts thoroughly cleaned and oiled; the cylinder thoroughly dried out and all water of condensation removed from jacket. The springs should be thoroughly cleaned, dried, and oiled with porpoise oil. The piston should be oiled with porpoise oil when instrument is to be put away. All parts which are concealed, such as the ball and socket joint, should be wiped out by forcing a thin piece of linen down the sleeve with a toothpick, and after same has been dried it should be oiled. The indicator is a very delicate instrument, and upon its proper care depends its accuracy, hence its value, and too much attention cannot be bestowed upon its care and adjustment.

## Testing the Instrument

Examine the instrument and try each part separately and see that it works smoothly. Put the instrument together without the spring. Hold the instrument by the steam cylinder in the right hand, and with thumb and finger raise the pencil lever very carefully to full extent of travel.

Place the thumb of right hand under the steam connection, release the pencil lever. Now slightly release the thumb over steam connection and note the fall of the piston. Repeat this until piston has traveled full stroke. The piston should fall freely every time the thumb is withdrawn. If however the piston moves in a sluggish manner, there is then excessive friction. If on the contrary it falls freely we know that the friction is a minimum. Now withdraw the piston in the manner above described and put in the desired spring. Oil piston and connect up the instrument. Before placing instrument on cylinder or indicator cocks, blow out thoroughly the pipes and connections; too much care cannot be exercised in making sure that the connections are thoroughly cleansed, as any grit or dirt is not only liable to cut the cylinder but it will affect the diagram as well.

## Changing Indicator Springs

The remarks made under the head of care and adjustment explain the method sufficiently, and in this connection it is only necessary to add: Care must be taken to see that the spring is shouldered in cap, and full down on piston. In removing the spring on the outside spring instrument unscrew the knurled nut at the top until the end of the spring is released. Then, turn the spring until it is free from the base. The piston is prevented from turning whilst removing the spring by inserting the pin (furnished with the instrument) in holes in the spring base.

The adjustment for atmospheric line when taking diagrams from condensing engine or low pressure cylinder of multiple expansion engines is made by the knurled nut at top.

Having described the instrument, its care and adjustment, we will now take up the connections to cylinders and reducing motions.

## Cylinder Connections

Cylinders of marine engines are as a rule fitted with pipes and 3-way cocks.

The cylinders have bosses cast on them both top and bottom. The bosses are drilled through into the counter bore of the cylinder. The outer end is tapped for 1″ pipe; short nipples are screwed into the bosses, and ells used to connect with the side pipes. There is a great mistake in using ordinary ells, and wherever possible long-turn ells should be used, as the friction of steam is greatly reduced, and short bends should in all cases be eliminated.

The side pipes connect with a 3-way cock. Frequently angle valves are used in place of ells. This is very bad practice, and should not under any circumstance be countenanced.

When the pipes are to remain permanent fixtures, the 3-way cock is fitted with a screw cap, and when the instrument is not in commission, this cap should be screwed on to prevent any dirt, etc., getting into pipes.

The following should be remembered: Angle valves should never be used. The steam should be led to the instrument without any abrupt change of flow having to be encountered. In case the cylinder is not fitted with bosses, and holes have to be drilled in cylinder, the location of same must be such that the flow will not be disturbed, such as would occur by having holes opposite steam ports, as the inertia effect of the steam would affect diagram. Care must be exercised to see that cylinder head does not block the openings.

Where the stroke is very long, or pipes require a bend, short nipples with long turn ells looking up should be used; the straight-way cocks can then be screwed into these ells, and the instrument will then be in a vertical plane. Never use the instrument in a horizontal plane, that is to say, do not screw straight-way cock into the boss.

Never if possible use ordinary ells, use only long turn ells, and close nipple, and use two instruments to each cylinder. If the engine is to be indicated then the data should be accurate, and if it is not worth assuring oneself that every precaution has been taken to make it so, then do not attempt to reason about the diagrams taken.

Never use any lead or litharge in connecting the pipes, as it is liable to get into the steam cylinder of the instrument and ruin it. In making up the connections, use oil on pipe threads. If after assembling there is a leak, same can be eliminated by winding strands of waste around the exposed thread. The distortion of diagrams caused by long pipes is clearly shown in diagrams taken from George W. Clyde and the pipe arrangement before and after alteration is shown in figs. 1 and 2 of insert.

## Reducing Motions

The reducing motion is as a rule, especially on the larger engines, a permanent fixture, and designed to give a length of diagram to suit the ideas of the designer. It should be designed to give a diagram not less than 4 inches long, except in high speed engines where the drum is a smaller diameter and hence a shorter diagram is a necessity.

The design of the motion is not a standard. Plate 1 shows the usual type of reducing motion. This is simply an arm or lever driven from the cross-head pin of the main engine through the medium of a short link. The lever is pivoted to the housings and pin for leading cord is located to give a certain length of diagram.

Another method of reducing the piston travel consists of a steel rod, pivoted to the cross-head pin; on the housing is bolted a bracket, to which is pivoted a brass sleeve; this sleeve carries an adjustable pin, to which the leading cord is attached by moving this pin in or out; the length of diagram can be varied. Still another method, and one which is in every way superior, is to drive a lever which is pivoted to either the housing or column, from the cross-head pin through the medium of a link. At the other end of the lever is connected a light vertical rod guided at its upper end by a guide bolted to the cylinder foot. This rod has on its upper end an eye into which the hook on the drum cord can be engaged or disengaged. This eliminates a long leading or driving cord, and the connection is therefore very short. This is an ideal motion, and as it can be made very light, and yet possess the requisite rigidity, the effect of inertia is too small to take account of.

## Taking Diagrams

Before putting instrument on straight or 3-way cocks, blow out the pipes thoroughly, make sure there is no dirt or grit left in them. Remove the piston and parallel motion and connect the instrument to cock. See that leads are correct, and after adjusting same, screw the instrument down tight.

Adjust now the length of leading or driving cord, exercising care to see that drum does not hit the stops in either up or down stroke. After this adjustment has been made, see that the hook on the drum cord is secured without any danger of slipping. See further that the loop or ring on driving cord is secured against slipping. Open now the steam connection and blow steam through the cylinder. After having done this make sure no dirt is in the cylinder. Oil the piston with good cylinder oil as directed, and insert it in cylinder, screw down the cylinder cap. Turn steam on the instrument and let it work until all condensation is eliminated, and instrument is thoroughly warmed. When dry steam blows through the reliefs we are prepared to take diagrams; see that the joints in parallel motion are oiled with porpoise oil, as explained in previous pages.

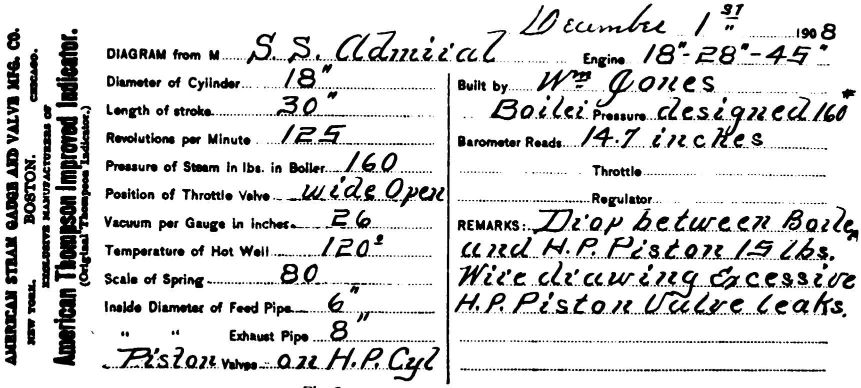
## Placing Cards on Drum

Take a blank card and turn over one end about ½ inch. Insert this under one of the clips on drum, then with thumb and finger draw card around drum and place the other end of card in the second clip. With thumb and finger pull card down on drum until it touches the shoulder at base of drum, flatten both edges out by passing the finger down the turned edges, exercise care and see that card is tight and smooth.

After the adjustment of the pencil has been made and the drum put in motion, press the adjusting screw against stop, and describe the atmospheric line first. Pull pencil away from paper and then open cock to steam, press screw against stop, and do not permit pencil to travel more than once around the card. In other words, hold only for one revolution as near as can be judged. If 3-way cock is used, mark on card whether taken from top or bottom. If top, then repeat the process for bottom. After diagrams have been taken the data should be inserted in their respective places on back of diagram as shown in fig. 9. Pressing adjusting screw against stop is the same as saying pressing pencil against card, as it is supposed that the adjustment has been made as directed.

Before taking diagrams it is well to try the instrument to determine whether drum spindle is true. This can be done, as follows:

Place card on paper drum, press adjusting screw against stop and pull drum cord slowly by hand, describing the atmospheric line, return drum to first position, open cock to steam, and with drum stationary describe the pressure line, with cock still open, again pull the paper drum, describing a line parallel with atmospheric line, with drum held in this position shut off steam, leaving the pencil to descend, open cock to atmosphere and we shall have described a rectangle. Now the admission line should be at right angles to the atmospheric line, and the steam line shall be parallel with atmospheric line. If the admission line is not at right angles with the atmospheric line, the drum spindle is not true. It is very important that this condition shall obtain. This test can be made before placing instrument on engine by removing the spring and raising the pencil lever by hand. The former


AMERICAN STEAM GAUGE AND VALVE MFG. CO.
NEW YORK. BOSTON. CHICAGO.
EXCLUSIVE MANUFACTURERS OF
American Thompson Improved Indicator.
(Original "Thompson" Indicator.)

December 1st 1908

DIAGRAM from M S. S. Admiral Engine 18"-28"-45"

Diameter of Cylinder 18"

Length of stroke 30"

Revolutions per Minute 125

Pressure of Steam in lbs. in Boiler 160

Position of Throttle Valve wide Open

Vacuum per Gauge in inches 26

Temperature of Hot Well 120°

Scale of Spring 80

Inside Diameter of Feed Pipe 6"

" " Exhaust Pipe 8"

Piston Valves on H.P. Cyl

Built by Wm Jones

Boiler Pressure designed 160

Barometer Reads 14.7 inches

Throttle

Regulator

REMARKS: Drop between Boiler and H.P. Piston 15 lbs. Wire drawing Excessive H.P. Piston Valve leaks.

Fig. 9

method is to be preferred as the instrument has been warmed and everything in condition. If a test gauge can be attached at a point close to instrument, we can then determine whether our springs are correct. It is a good method to make this test before taking diagrams, and keeping the test card with other records.

Before proceeding to take up the subject of indicator diagrams, it will be well to give a description of the planimeter and its use.

## Planimeter

The planimeter as its name implies is an instrument for the measuring the areas of irregular figures. There are several different types of instruments manufactured. We will, however, confine ourselves to the Amsler instrument as manufactured by the American Steam Gauge and Valve Manufacturing Company (see Fig. 10). This instrument consists of three essential parts, namely: A guide arm pivoted at "A" to the paper; a tracing arm which is hinged to the guiding-arm, and which carries the tracing point "B"; a measuring wheel "G," which carries a graduated cylindrical scale. There is also a vernier "E" for reading the scale on the wheel.

When in use the planimeter rests on the paper at three points. The pivot "A" which is a needle point pressed slightly into the paper; the edge of the measuring wheel "G," and the tracing point "B." A weight over the pivot "A" holds the needle point down, and gives the instrument stability.

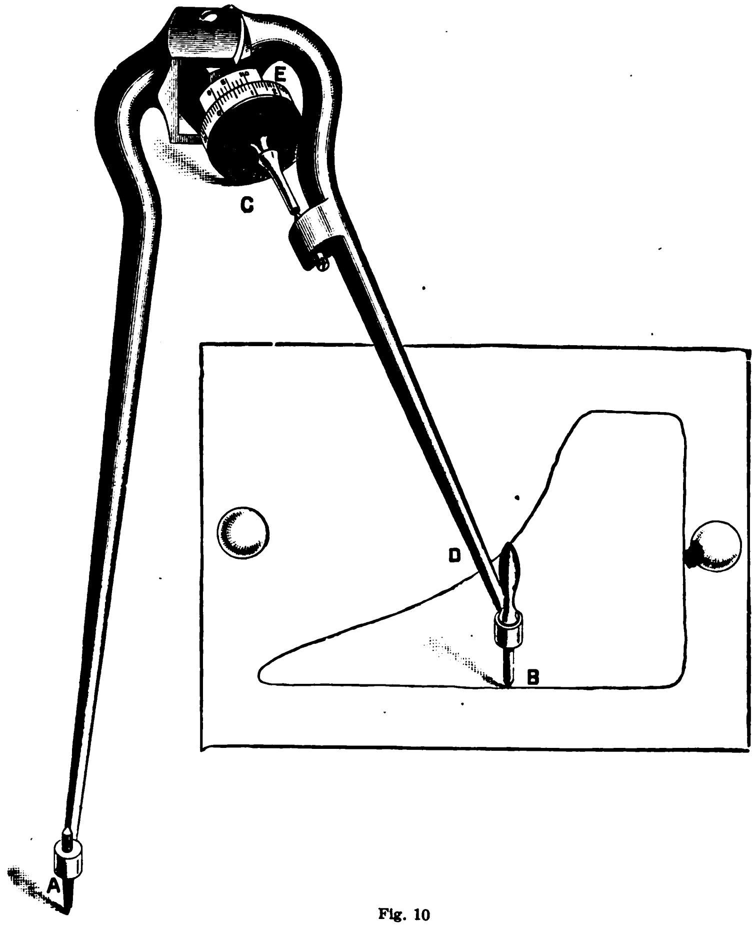



Fig. 10

To measure the area of any irregular figure like an indicator diagram the instrument is placed as in Fig. 10, so that the arm shall not take inconvenient positions when the outline of the diagram is traced. Take any point on the diagram as at "B" and set the measuring wheel to read zero, trace the diagram in a clockwise or right-hand direction.

Before proceeding to explain the method of reading, it will be as well to describe the vernier and measuring wheel.

Let Fig. 11 represent a scale of units numbered 1, 2, 3, 4, etc., which are sub-divided into tenths. The vernier U. V. is as long as nine of the sub-divisions, and is divided into ten parts. Thus the intervals of the vernier are 9/10ths as long as the interval of the scale, or we can say they are 1/10th of an interval shorter. As shown the index of the vernier reads 4.5 on the scale. It will be noted that the 4th division of the vernier coincides with a division of the scale, the 3d division of the vernier is 1/10th of an interval from the next mark on the scale, the 2nd division is 2/10ths, etc. Therefore, the reading of the vernier is 4.54 square inches, for if the measuring wheel is divided into ten equal parts, each to equal one square inch, then the sub-divisions enable us to read to hundredths of a square inch.

Therefore, starting at any desired point run tracing point "B" in clockwise direction, and trace around diagram until starting point

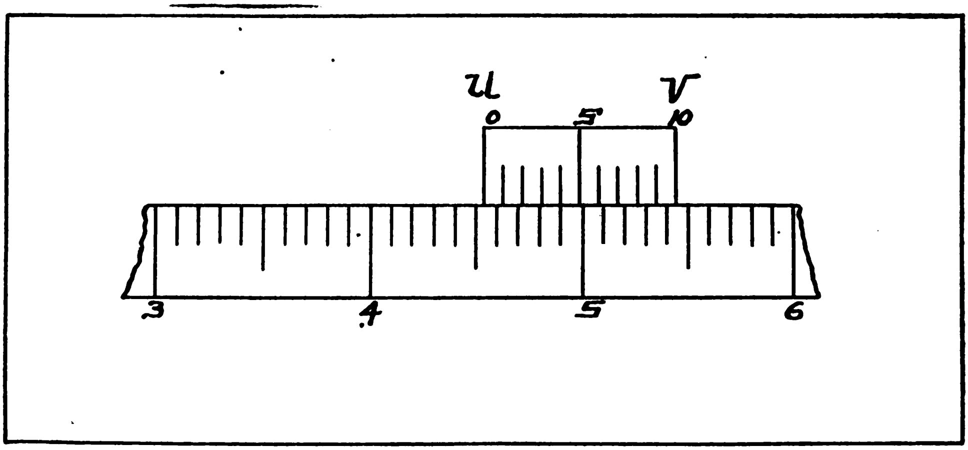



Fig. 11

is reached, find highest figure on measuring wheel which has passed the zero on vernier moving to the left, in this case 4. Find next the number of completed divisions between 4 on measuring wheel and zero on vernier, which is in this case 5. Find division on vernier which corresponds with some division on measuring wheel, and in this case it is 4. Therefore, the exact reading is 4.54 square inches.

After the operator becomes familiar with the instrument it is not necessary to set the wheel to zero, but take the reading before starting to trace outline of diagram, and subtract this from the final reading. Thus, suppose when instrument is in position we find the reading to be 1.64, the final reading is 6.18. Therefore, $6.18-1.64=4.54$ square inches, area of card.

The instrument can be used for finding areas of any irregular figures. If the area is large, divide it by lines into areas of less than 20 square inches and take separate measurements. If drawing be to scale multiply the reading of instrument by the square of the ratio number of the scale. Should it be required to find the area of an irregular figure containing 6 square inches drawn to a scale of 3 inches = 1 foot 3 inches = 1 foot is $\frac{1}{4}$ size. Therefore, $\frac{1}{4} \times \frac{1}{4} = \frac{1}{16}$ and $6 \times 16 = 96$ square inches.

## Definitions

Relating to indicator diagrams. (See Fig. 12.) Four phases of valve-motion occur during a complete revolution of the engine, and are as follows:

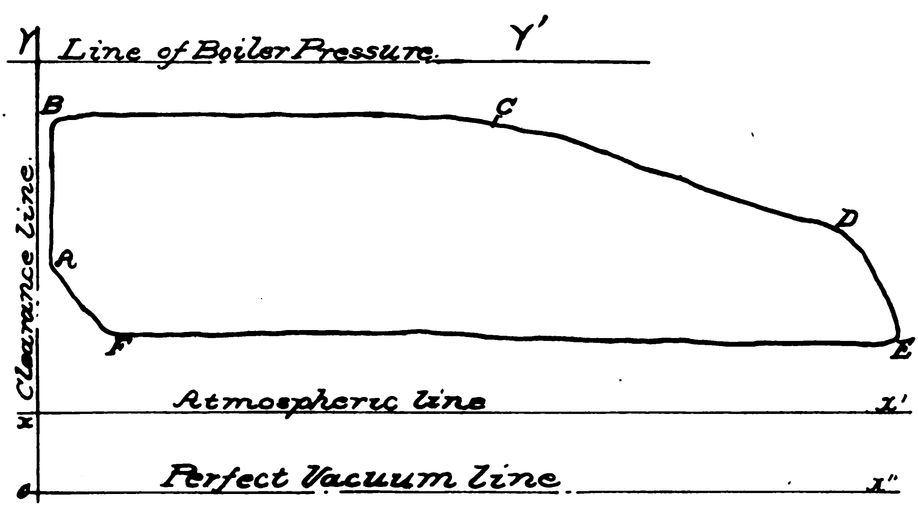



Fig. 12

Admission ABC. When valve is open, and steam passing into the cylinder.

Expansion CD. When valve has cut off the steam supply to cylinder, and hence steam is neither admitted or released, therefore, the piston is moved through this distance by the expansive force of the steam.

Exhaust DEF. When the valve closes the admission port, and the port to exhaust opened, and hence steam is escaping from cylinder into receiver, or condenser if condensing, or atmosphere if non-condensing.

Compression FA. When all ports are closed, and the remaining steam in the cylinder acts as a cushion to bring the piston gently to rest.

The atmospheric line XX′ is a line drawn by the pencil of the indicator when both sides of the piston are open to the atmosphere. The steam is of course shut off from instrument. The atmospheric line on the diagram represents the pressure of the atmosphere, the gauge reading being zero.

The vacuum line OX″ is a reference line drawn at a distance corresponding to barometer-pressure by scale below the atmospheric line. The barometric pressure which is usually 14.7 lbs. This line represents a perfect vacuum, or absence of pressure when drawn to scale to 15 lbs.

The clearance line OY is a reference line drawn at a distance from the end of the diagram equal to the same per cent. of its length as the clearance or volume not swept through by the piston is of the piston displacement. In other words, the distance between the clearance line and the end of diagram represents the volume of the clearance between piston and cylinder head, plus the volume of ports and passages at that end of cylinder.

Line of boiler pressure YY′ is a line drawn parallel to the atmospheric line, at a distance from it by scale equal to the boiler pressure shown by gauge.

Admission line AB is the line showing the rise of pressure due to admission of steam to the cylinder by the opening of steam valve.

Point of admission A indicates the pressure when the admission of steam begins at the opening of the valve.

Steam line BC is drawn when the steam-valve is open and steam is being admitted to the cylinder.

Point of cut-off C is the point where the admission of steam is stopped by the closing of the valve.

Expansion curve CD shows the fall in pressure as the steam in the cylinder expands.

Point of release D shows where the exhaust valve opens.

Exhaust line DE shows the change in pressure which takes place when the exhaust-valve opens.

Back pressure line EF shows the pressure acting against piston during its return stroke.

Point of exhaust closure F is the point where the exhaust valve closes. Point of compression F is where the exhaust valve closes, and compression begins. Compression curve FA shows the rise in pressure due to compression of the steam remaining in the cylinder after the exhaust valve has closed.

Initial pressure is the pressure acting on the piston at the beginning of the stroke.

Terminal pressure is the pressure above the line of perfect vacuum which would exist at the end of the stroke if the steam had not previously been released.

Admission pressure is the pressure acting on the piston at end of compression, and is as a rule less than the initial pressure.

Compression pressure is the pressure acting on the piston at beginning of compression; it is the least back pressure.

Cut-off pressure is the pressure acting on the piston at beginning of expansion.

Release pressure is the pressure acting on the piston at end of expansion.

Mean forward pressure is the average height of that part of the diagram traced on forward stroke.

Mean back pressure is the average height of that part of the diagram traced on the return stroke.

Mean effective pressure is the difference between the mean forward pressure and the mean back pressure during a forward and return stroke.

It is the height or length of the mean ordinate intercepted between the top and bottom lines of the diagram multiplied by the scale of spring used in instrument when diagram was taken. It is obtained without regard to atmospheric or vacuum lines.

Equivalent or referred mean effective pressure, often written as aggregate equivalent pressure referred to low pressure cylinder, is the mean effective pressure which would be required to produce the same indicated horse-power from a cylinder of the same dimensions as the low pressure cylinder of a multiple expansion engine.

Ratio of expansion is the ratio of the volume of steam in the cylinder at the end of stroke to that at cut-off.

Initial expansion is the fall of pressure during admission due to imperfect steam supply.

Wire drawing is the fall of pressure between admission and cut-off.

Horse-power. The unit employed to measure the rate at which work is done in a steam engine is the "horse-power," the power exerted in the performance of 33,000 foot pounds of work per minute.

A distinction must be made between the indicated horse-power, and the actual or brake horse-power. When we speak of indicated horse-power, the work done per minute by the steam on the piston of the engine, as computed from indicator diagrams, is understood. The friction of the shafting and pumps, as well as the reciprocating parts, friction of piston rods through stuffing boxes, glands, etc., valve gear and all working parts, absorb power and cause a loss which is termed frictional losses.

If, therefore, the sum of all these frictional losses is deducted from the indicated power we get the actual power available, which is delivered to the screw propeller, or in other words it is the rate at which useful work is done in turning the propeller.

The brake horse-power in very large engines is less, and in small engines considerably less than the indicated horse-power.

Now, brake horse-power ÷ indicated horse-power = efficiency of engine. Therefore, efficiency of engine multiplied by indicated horse-power = brake horse-power. Stated in form of an equation we have: $B.\ H.\ P. = N \times I.\ H.\ P.$ when $N =$ efficiency.

The following table (calculated from Middendorf, Scheffswiderstand und Maschinenleistung) gives values of efficiency N:

| I. H. P. | N | I. H. P. | N |
|---|---|---|---|
| 5 to 10 | 0.58 | 600 to 700 | 0.71 |
| 10 to 50 | 0.59 | 700 to 800 | 0.72 |
| 50 to 100 | 0.60 | 800 to 900 | 0.73 |
| 100 to 150 | 0.61 | 900 to 1,000 | 0.74 |
| 150 to 200 | 0.62 | 1,000 to 2,000 | 0.79 |
| 200 to 300 | 0.64 | 2,000 to 3,000 | 0.85 |
| 300 to 400 | 0.66 | 3,000 to 4,000 | 0.88 |
| 400 to 500 | 0.68 | 4,000 to 5,000 | 0.90 |
| 500 to 600 | 0.69 | 6,000 and over | 0.91 |

The determining of the brake horse-power has been, until recently, a difficult and in fact almost impossible procedure due to the fact that large powers had to be absorbed, and the difficulties of fitting a brake to absorb it very great. The values of the efficiency as shown above have been taken as approximate values, and until recently approximate values were the only ones available.

The torsion meter enables us to determine accurately the power delivered to the shaft. The latest trials made with the torsion meter have given the following values:

| I.H.P. | N | I.H.P. | H. |
|---|---|---|---|
| 1,630 | 0.885 | 2,370 | 0.920 |
| 1,640 | 0.091 | 2,690 | 0.911 |
| 1,940 | 0.911 | 4,500 | 0.935 |

Before entering upon the subject of the indicator diagram, it will be as well if we explain the rules of mean ordinates.

The simplest way of determining the M. E. P. is by the planimeter. It frequently happens that we are compelled to compute the pressure without the assistance of this instrument, hence we have to resort to some practical method of computation.

## "Rule of Mean Ordinates"

Divide the diagram into ten equal parts by lines at right angles to the atmospheric line, and measure the center of each division between the top and bottom lines forming the diagram. The mean height of the ten divisions, measured in inches and multiplied by scale of spring, is equal to the mean effective pressure in pounds per square inch. Greater accuracy is obtained by dividing diagram into 20 equal parts and measuring each ordinate, dividing the sum by 20 to obtain mean ordinate, then multiply by scale of spring. In the use of the planimeter we get the area of the diagram, and dividing it by the length of card we get the height of the mean ordinate, and multiplying this mean ordinate by scale of spring as explained gives us the M. E. P. in pounds per square inch.

Fig. 13 shows the method of obtaining the M. E. P. and dividing the card.

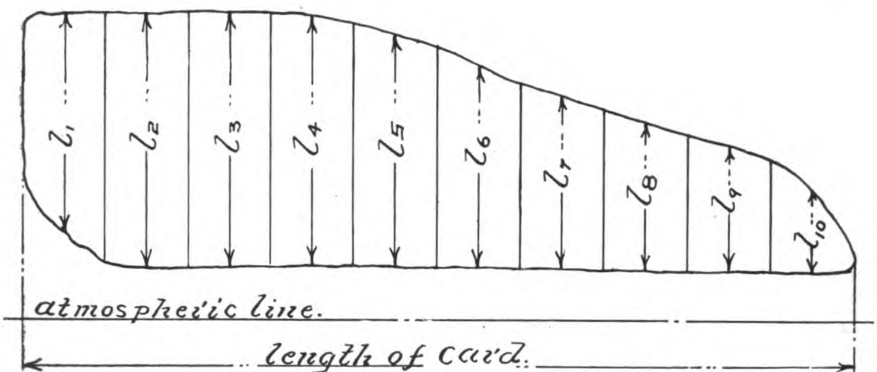



Fig. 13

| Numb. of Ord. | Length of Ord. |
|---|---|
| $L_1$ | 1.09375″ |
| $L_2$ | 1.3125 ″ |
| $L_3$ | 1.3125 ″ |
| $L_4$ | 1.3125 ″ |
| $L_5$ | 1.1875 ″ |
| $L_6$ | 1.0625 ″ |
| $L_7$ | .90625″ |
| $L_8$ | .40625″ |
| $L_9$ | .65625″ |
| $L_{10}$ | .4375 ″ |
| | Sum = 9.68750 |

Lgt. of Mean Ord. = 10)9.68750( = 0.96875

Scale of Spring = 60 lbs. per inch.

Mean Effective Pressure = 0.96875 × 60 = 58.125 lbs.

Mean Effective Pressure by Planimeter = 58.37 lbs.

## Simpson's Rule

Another method is by what is known as Simpson's Rule, and is as follows:

Divide the diagram into ten equal parts as before, and lettering the ordinate as shown, and take,

$Y_0 + Y_{10} = L_1$

$Y_1 + Y_3 + Y_5 + Y_7 + Y_9 = L_2$

$Y_2 + Y_4 + Y_6 + Y_8 = L_3.$

The mean effective pressure in pounds per square inch will therefore be,

$$\frac{L_1+4L_2+2L_3}{30}\times S$$

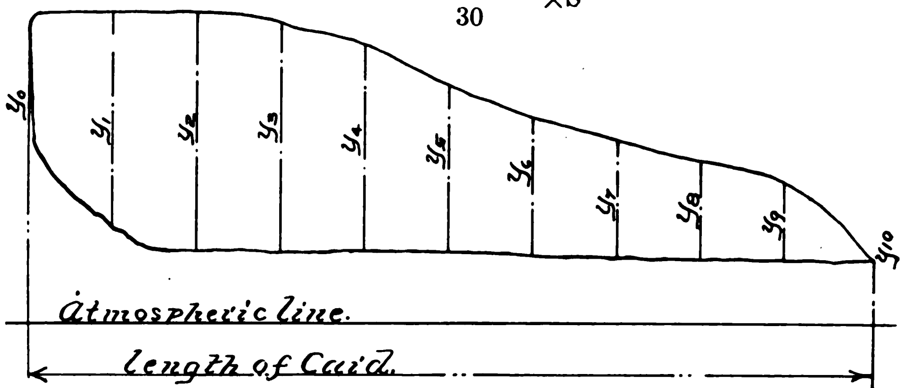



Fig. 14

Simpson's first rule is: To the sum of the first and last ordinate, add four times the even ordinates, plus twice the odd ordinates and multiply the sum by one-third the common interval gives area of figure. Now our interval is one-tenth, and one-third multiplied by one-tenth is equal to one-thirtieth, and this one-thirtieth multiplied by the scale of spring gives the divisor of our fraction. Therefore, the sum of $L_1+4L_2+2L_3$ divided by one-thirtieth multiplied by spring gives the mean effective pressure in pounds per square inch. Computation in full of Fig. 14.

| Numb. of Ord. | Length of Ord. | Multiplier | Function of Ord's. |
|---|---|---|---|
| $y_0$ | 0.25 ″ | 1 | 0.25 |
| $y_1$ | 1.125 ″ | 4 | 4.5 |
| $y_2$ | 1.218 ″ | 2 | 2.436 |
| $y_3$ | 1.1875 ″ | 4 | 4.75 |
| $y_4$ | 1.0625 ″ | 2 | 2.125 |
| $y_5$ | .875 ″ | 4 | 3.5 |
| $y_6$ | .71875″ | 2 | 1.4365 |
| $y_7$ | .625 ″ | 4 | 2.5 |
| $y_8$ | .5 ″ | 2 | 1. |
| $y_9$ | .375 ″ | 4 | 1.5 |
| $y_{10}$ | 0.0 | 1 | 0.0 |
| | | Sum of function, | 23.9975 |

Common interval $=\frac{1}{10}$.

$\frac{1}{3}$ " " $=\frac{1}{3}\times\frac{1}{10}=\frac{1}{30}$.

$23.9975\times\frac{1}{30}=30\overline{)23.9975}(=0.7999$.

Scale of Spring = 60 lbs. per inch.

Mean Effective Pressure = $0.7999\times60=47.994$ lbs.

Mean Effective Pressure by Planimeter = 48.7 lbs.

## Engine Types

Single-cylinder engines are those in which the whole work of the steam is performed in one cylinder. Twin cylinder engines are those in which each cylinder works in precisely the same way as a single-cylinder engine; the steam passing into both cylinders direct from the boilers, and exhausting from both cylinders into the atmosphere or condenser.

Compound engines are those in which the steam works successively in two or more cylinders placed close to each other.

In a two-cylinder compound engine the steam passes from the boiler into the high-pressure cylinder, exhausting from the high-pressure cylinder into the receiver and thence into the low-pressure cylinder. From the low-pressure cylinder it exhausts into the condenser.

In a triple expansion engine, the steam passes from the boiler into the high-pressure cylinder, exhausts from the high-pressure into the first receiver, from thence into the intermediate cylinder, exhausting from the intermediate cylinder into the second receiver, from thence into the low-pressure cylinder, and from low-pressure cylinder into the condenser.

In a quadruple expansion engine, the steam passes from the boiler into the high-pressure cylinder, exhausts from high-pressure into the first receiver, from thence into the first intermediate cylinder, exhausts from first intermediate cylinder into the receiver and from there into a second larger intermediate cylinder, exhausting from the second intermediate cylinder into the receiver, thence into the low-pressure cylinder, and from the low-pressure cylinder into the condenser.

As the steam decreases in pressure in passing through the various cylinders, its volume correspondingly increases; therefore the cylinder, from high-pressure onward, must increase in size, this increase depending upon the degree of expansion.

It frequently happens that the same degree of expansion may be divided between two cylinders, either two high-pressure or two low-pressure cylinders. This is resorted to for constructive reasons.

A triple expansion engine may have four cylinders high-pressure, intermediate-pressure, and two low-pressure cylinders of the same size.

A triple expansion engine having 5 cylinders, namely, two high-pressure, one intermediate, and two low-pressure cylinders, has been installed in large Atlantic liners.

Multiple expansion engines are computed in precisely the same manner as a single cylinder engine. The reasoning is the same as if all work of the steam were done in the low-pressure cylinder. This will be more readily understood when we take up the computations of Equivalent M. E. P. and Cylinder Dimensions.

# CHAPTER II

## Work of Steam

It is necessary that the work of the steam in the cylinder is comprehended thoroughly, and it will therefore be necessary to consider a hypothetical case. Let us assume that we have a vertical cylinder, open at the upper end to the atmosphere, and closed at the bottom. We will further assume that the cylinder is fitted with a piston without weight and frictionless.

If a certain quantity of water is introduced at the bottom of the cylinder and a fire is built under it to convert the water into steam, we will have the boiler and engine represented by one vessel; the piston and water being brought into direct contact.

Let us make the diameter of piston about 13½ inches; this will give us a sectional area of 1 square foot, equal to 144 square inches.

Let a quantity of water weighing 1 pound be poured into the cylinder, and let this stratum of water support the piston.

As the upper end of the cylinder is open to the atmosphere, the pressure of the atmosphere (here taken as 14.7 lbs.) acts upon the piston, amounting to 14.7 lbs. × 144 square inches = 2,116.8 lbs. on the square foot of surface of the piston. The temperature of the water under atmospheric pressure will be raised to 212° F, before any steam is generated. If now the heat of the fire be maintained, the temperature will remain stationary at 212° F, but steam will be formed, and disengaged under the piston. The piston supposed to be frictionless and without weight will be raised with its load of 2,116.8 pounds through consecutive stages, each, say, one foot, until it reaches an elevation of 26.6 feet above the bottom of the cylinder. When this point is reached we shall have found the whole one pound of water evaporated, the constant elasticity of the fluid having been measured by 14.7 pounds per square inch, and a temperature of 212° F.

What are we to understand by this? We see that the pound of water has been entirely evaporated into steam of atmospheric pressure, and occupies a volume of 26.6 cubic feet, for 1 square foot area × 26.6 feet = 26.6 cubic feet. The initial work consists in having lifted a weight of 2,116.8 pounds through a height of 26.6 feet, or, expressed in foot pounds, 2,116.8 pounds × 26.6 feet = 56,306.88 foot pounds.

The above demonstration affords a vivid conception of the expansive force of steam, or to be more exact, the force of water when converted into steam. Here we had a lamina of water not quite one-fifth of an inch in depth, lying at the bottom of a cylinder 13½ inches diameter. This water is converted into steam of atmospheric pressure of 1,602.4 times its original volume, for $\frac{1}{5}$ inch = 0.0166 feet, and 26.6 feet ÷ 0.0166 feet = 1,602.4.

As one heat unit is equivalent to 778 foot pounds, the value of the external work expressed in heat units is 56,306.88 foot pounds ÷ 778 heat units = 72.37 H. U. There is a small expenditure of energy in raising the mass of steam against the force of gravity. Thus, the average height to which the steam is raised is 26.6 ÷ 2 = 13.3 feet, and 1 pound × 13.3 feet = 13.3 foot pounds, or, 13.3 foot pounds ÷ 778 H. U = 0.017 H. U.

## British Thermal Unit

A British thermal unit or B. T. U. is the heat required to raise one pound of water from 62° F to 63° F. Heat is always measured in B. T. U.'s in the English system.

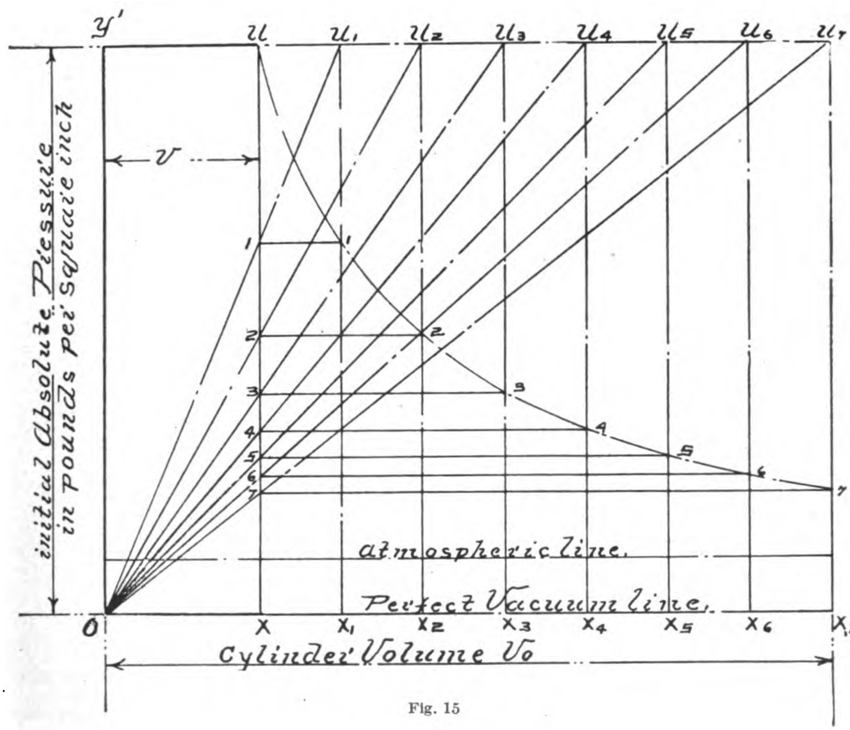



Fig. 15

## Expansion of Steam

The steam in the cylinder of a steam engine during expansion is supposed to follow substantially a law known as the law of Boyle and Mariotte. This law states that the pressure varies as the volume in an inverse ratio. That is to say: As the volume increases the pressure suffers a decrease.

Symbolically, if P = pressure, and V = volume, then P. V. = C.

We say substantially, because the actual changes of pressure do not follow the law exactly. The pressure may, and in the majority of cases it does fall more rapidly in the early stages of the expansion, and less rapidly in the latter portion than indicated by the law of inverse ratio. Therefore, the finial pressure is as a rule greater than that which would be deduced from the ratio of expansion.

Now the fullness of the expansion curve depicted on the indicator diagram, near the end, compensates for the hollowness near the beginning, and hence we find that the area bounded by the curve is practically equal to that bounded by a hyperbolic curve according to the law.

We, therefore, assume that for all practical purposes, and for general investigation, the steam expands according to the law, P. V. = C.

The curve which represents diminishing pressures due to increasing volume is a portion of a hyperbola.

The rectangular hyperbola used as a curve of expansion is constructed as follows: (See Fig. 15.)

Let OY′ = P, the initial pressure.

Let Y′U = V, the volume up to cut-off.

Let $OX_7 = V_o$, the volume at end of stroke.

Produce the line Y′U to $U_7$; divide $UU_7$ into any number of parts, say 7. Draw a series of radiating lines from O to $U_1$, $U_2$, $U_3$ . . . . . . $U_7$.

Now where the radiating lines $OU_1$, $OU_2$ . . . . . . $OU_7$ intersect the ordinate UX, such as points 1, 2, 3, etc., these points of intersection give points through which are drawn lines parallel to $OX_7$, as 1, 1,–2, 2, – 3, 3, etc.

Drawing a fair curve through the corresponding points of intersection with the ordinates $U_1$ $X_1$, $U_2$ $X_2$, $U_3$ $X_3$ . . . . . . $U_7$ $X_7$, we have the curve known as the rectangular hyperbola, or curve of P. V. = C.

To determine the pressure at any point of the expansion curve, say for volume $Y'U_3 = OX_3$. Draw the diagonal line $OU_3$, then through point 3 the intersection of U, X and $OU_3$ draw the horizontal line 3,3 parallel to $OX_7$. Point 3 is a point on the expansion curve and the vertical line 3, $X_3$ gives the absolute pressure corresponding to the volume $OX_3$.

Should we desire to obtain the finial pressure after expansion: Draw the diagonal line $OU_7$; then through the point 7, the intersection of UX and $OU_7$, draw the horizontal line 7, 7, parallel to $OX_7$. The vertical line 7, $X_7$ gives the required finial absolute pressure. We can conversely find the volume which a quantity of steam V. would occupy at the pressure P. if it were compressed to the pressure $P_a$. To obtain the volume, draw the diagonal line OU′ (see Fig. 16) now where OU′ intersects Y′U, draw A, A parallel to Y″O. The line Y″A gives the required volume.

It should be borne in mind that Y′U is volume without clearance, and $OX_7$ is vacuum line.

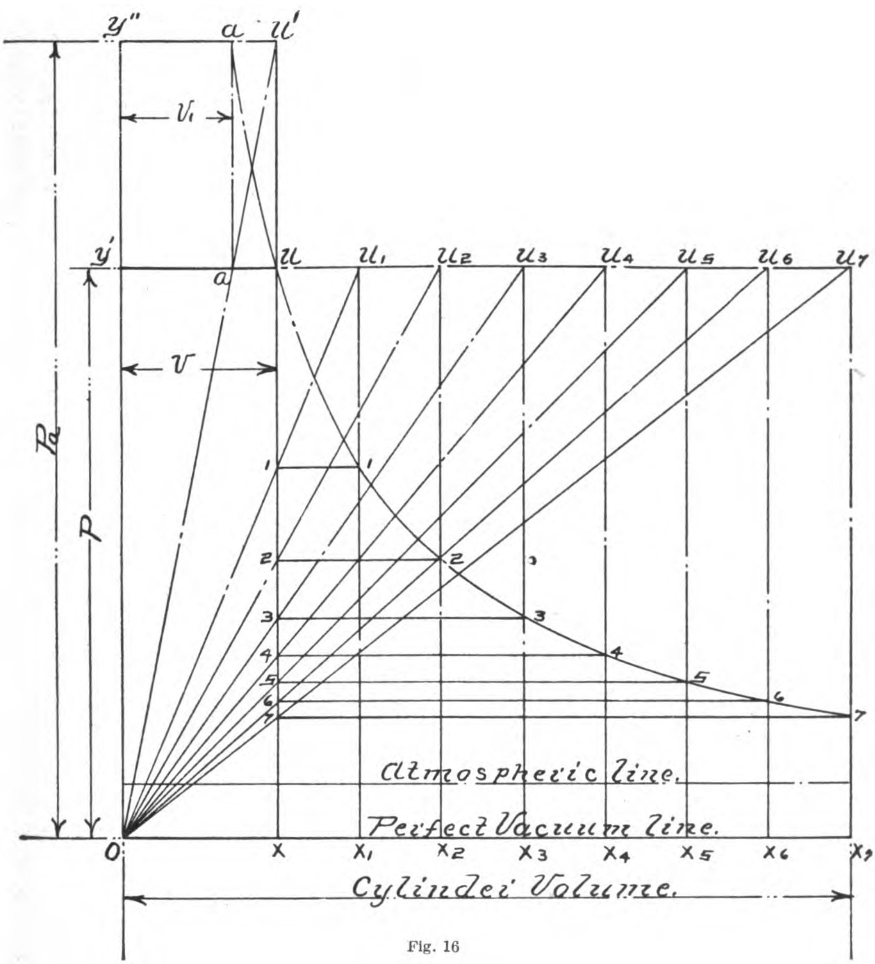



Fig. 16

To illustrate the application of the hyperbolic law of expansion, showing that the product of pressure and volume at any point of the expansion-curve is constant. Let the line XX1 (Fig. 17) represent the stroke of the piston and the corresponding volume described by it without clearance.

Assume steam of 160 pounds absolute pressure be admitted for a space 1 foot in length XA. The area of the rectangle is the product of the pressure and volume of the steam admitted. If the steam expands to double its volume XD the pressure will be one half, represented

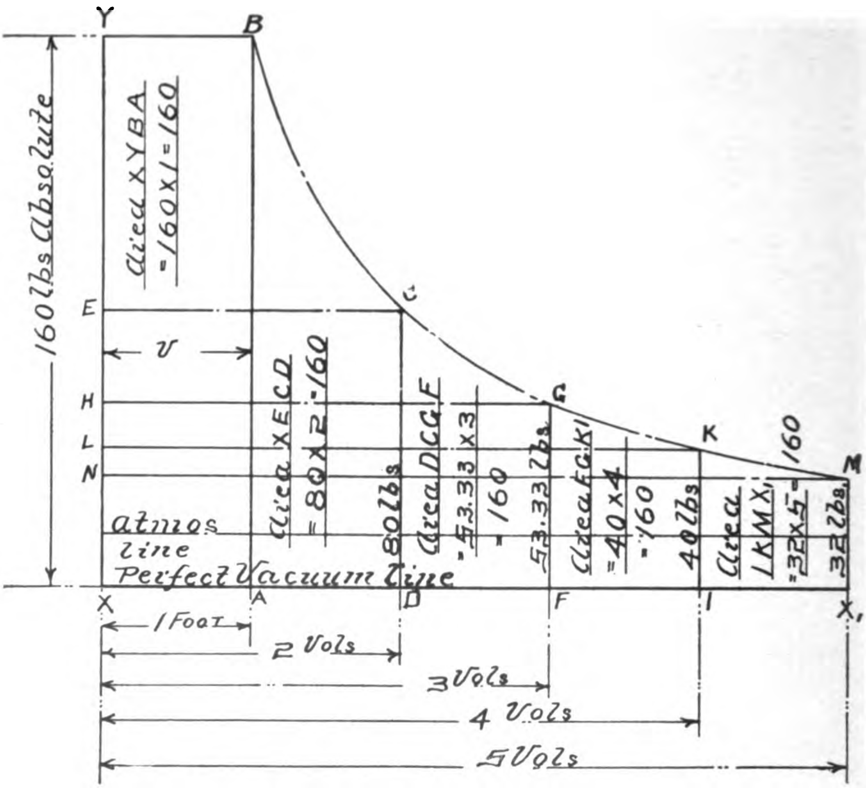



Fig. 17

by DC. The area of the rectangle XE×XD, is the product of pressure × volume, and this area will be equal to the area of the rectangle XY×XA.

Expanding further to any number of volumes we find the pressure multiplied by volume is equal to the initial pressure multiplied by initial volume. The area of each rectangle is therefore equal to the original rectangle. The hyperbolic curve containing these rectangles may be indefinitely extended at either end, embracing toward the left hand, high pressures and small volumes, and to the right hand, low pressures and large volume.

The area of the rectangle XYBA, being the product of pressure and volume, expresses the work done upon the piston by the steam on entering the cylinder and occupying a given volume. The area bounded by the hyberbolic curve BM, the ordinates $MX_1$, AB, and the base $AX_1$ expresses the work done by expansion of the steam after the communication with the steam supply has been cut off.

Let P = absolute initial pressure of steam.

Let V = volume up to cut-off.

The work done by the steam during admission is P.V. (See Fig. 18.)

Let S = whole stroke.

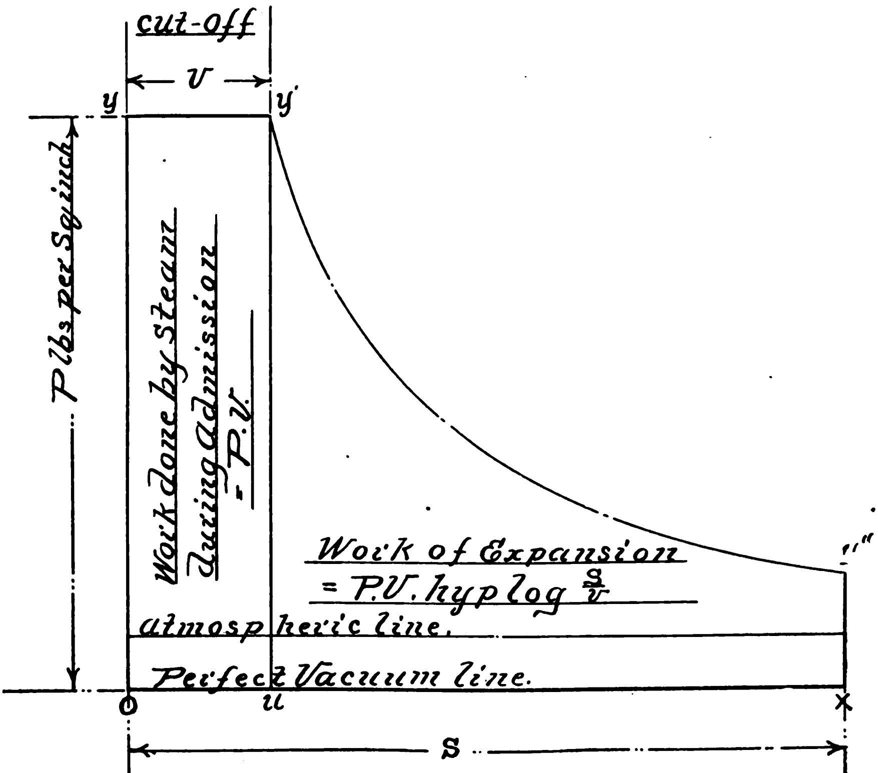



Fig. 18

The mean pressure during this period, in relation to the whole stroke S, is $p = P\frac{V}{S}$ where p = mean pressure.

The work of expansion is equal to the area Y′Y″XUY′. The area Y′Y″XUY′ = P V hyp log $\frac{S}{V}$. The mean pressure during the work of expansion in relation to whole stroke S is P $\frac{V}{S}$ hyp log $\frac{S}{V}$. Now $\frac{V}{S}$ = cut-off = C.

C is expressed either as a fraction or as a percentage of the volume of the cylinder. Thus, cut-off ¼ stroke = 4)1.00( = 0.25 or 25 per cent.

of stroke. $\frac{S}{V}$ is termed the ratio or degree of expansion. The ratio or degree of expansion is also equal to $\frac{1}{C}$ or 1 divided by the cut-off.

It should be clearly understood that in multiple expansion engines, that is, compound, triple and quadruple expansion engines, the term total cut-off is frequently used, and is understood to mean the ratio that the volume of steam admitted to the high-pressure cylinder bears to the volume of the low-pressure cylinder.

Total expansion means the ratio that the volume of the low-pressure cylinder bears to the volume of steam admitted to the high-pressure cylinder.*

As an example, suppose we have a triple expansion engine, the volume of the low-pressure cylinder is 7 times the volume of the high-pressure cylinder. The ratio of cylinder capacities are therefore 1:7.

Assume a cut-off in high-pressure cylinder of 75 per cent. of stroke. The ratio or degree of expansion is $\frac{7}{0.75}=75\rfloor 700\lfloor 9.33$.

And the total cut-off will be $\frac{1}{9.33}=\frac{.75}{7}=0.107$.

The cut-off in the high-pressure cylinder is equal to the ratio of cylinder capacities ÷ total expansion.

Thus $\frac{7}{9.33}=0.75$.

Let $C$ = total cut-off.

Let $C_h$ = cut-off in the high-pressure cylinder.

Let $R$ = ratio of the volume of low-pressure cylinder to that of the high pressure cylinder.

Then total cut-off $C=\frac{C_h}{R}$.

And total expansion $=\frac{1}{C}=R\frac{1}{C_h}$.

## Clearance

All engines have clearance, the space between the piston and cylinder-head when piston is at either end of its stroke. The steam passages between valve face and cylinder bore. This clearance space must be filled with steam of the initial pressure at the beginning of each stroke. The clearance is measured as a certain percentage of the cylinder volume. When so expressed it is termed volumetric clearance. For example, if we have a cylinder 12 inches in diameter by 12 inches stroke: The volume of the cylinder = area of cylinder in square inches × stroke in inches. Now the area of a 12″ circle = 113.10 square inches. 113.1 □″ × 12″ = 1357.2 cubic inches volume of cylinder.

Suppose the clearance between cylinder head and piston plus the clearance in port is equal to 95 cubic inches. The percentage is, therefore, 95 ÷ 1357.2 = 0.07 or 7 per cent. It is rather a tedious and sometimes impossible task to determine accurately the correct clearance, and

* The volume of a cylinder is equal to the area of the cylinder in square inches multiplied by the stroke of piston in inches.

where the data must be very accurate, the only way to determine it is from the cylinder drawings. The clearance may be measured in parts of the stroke and the clearance length added to the period of admission. It is evident that this sum represents or expresses the initial volume of steam for expansion.

Thus suppose that the clearance is 7 per cent. of the volume of the cylinder or piston displacement, which is one and the same thing, and let us further assume cut-off at half stroke = 50 per cent.

We readily see that the effective cut-off is not 50 per cent., but it is more than this by the amount of clearance, and hence we have the

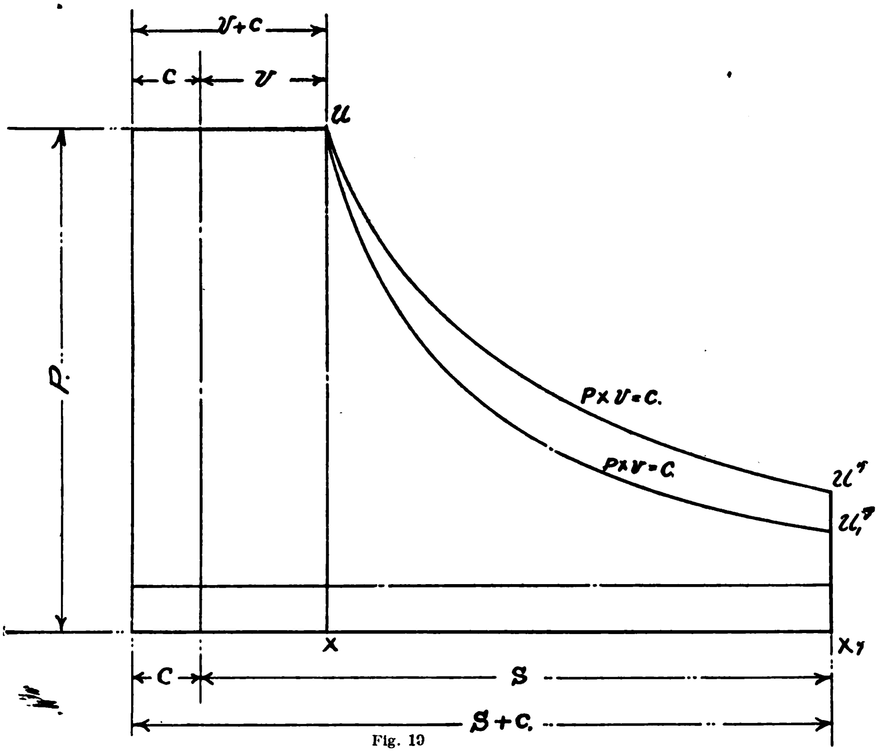



Fig. 19

expansion of a volume of steam equal to 50 per cent. plus 7 per cent. = 57 per cent. instead of only 50 per cent. This practially amounts to making the cylinder 7 per cent. longer and cutting off at 50 per cent. of the stroke without clearance.

The mean pressures in practice are greatly effected by clearance. Before the incoming steam can force the piston out, it has to fill the clearance space. Now this space being filled alternately with admission steam of a high temperature, and the cooler exhaust steam having a lower temperature causes considerable loss by condensation during admission. It matters not how accurately the engine is designed, the clearance spaces are large, and the superficial areas, exposed to extreme variations of temperature, are likewise large. It will therefore readily be seen that clearance affects expansion prejudicially due to the fact that it raises the terminal pressure, and affects compression, because it reduces the finial pressure of compression.

Diagram (Fig. 19) shows first the work of expansion is increased by clearance. Thus area $XUU^7X_7X$ is greater than $XUU,^7\ X_7X$, area $XUU,^7\ X_7X$ representing work done during expansion without clearance. "Second," showing that compression must be increased to obtain a given terminal pressure if there is clearance.

The rate of expansion taken without clearance is termed nominal rate of expansion.

The rate of expansion taken with clearance is termed the actual rate of expansion.

When the clearance can be accurately determined it is better to use it, and obtain the actual instead of the nominal rate of expansion.

Then if $V_n$ = nominal rate of expansion.

$V_a$ = actual rate of expansion.

$C$ = clearance as a fraction of the cylinder capacity.

We have $\frac{1}{V_a}=\frac{\frac{1}{V_n}+C}{1+C}$. $V_a=V_n\frac{1+C}{1+CV_n}$.

$\frac{1}{V_n}+C$ is the volume of steam at cut-off between the piston and valve.

This steam expands to the volume $1+C$ at the end of the stroke. If there is no compression of the steam before admission the whole space $\frac{1}{V_n}+C$ must be filled with fresh steam at each stroke.

In some cases there is sufficient compression to fill the clearance space with steam of initial pressure. The volume of steam used during each stroke will then be that swept by the piston up to cut-off only. This will then be equal to $\frac{1}{V_n}$.

Whilst clearance serves to increase the mean pressure beyond that due to the nominal rate of expansion, it cannot be considered as a source of loss, unless the equivalent cut-off is taken to obtain the rate of expansion. With the use of higher steam-pressures and higher rates of expansion the disadvantageous influence of clearance is diminished.

With good steam distribution and proper compression, the drawbacks due to clearance may be lessened. As the actual total cut-off deviates less from the theoretical; the limit of total expansion due to clearance can be arranged to fall in more favorable position. The clearance should however in any case be made as small as possible.

## Losses in Cylinders

The principal causes of loss of pressure in the cylinders of a marine engine are the following:

Friction in boiler stop valve.
Friction in throttle valve on cylinder.
Losses by friction in main steam pipe.
Friction or wire drawing of the steam during admission.
Liquification during expansion.
Compression and back-pressure.
Friction in the ports and pipes.

The loss by friction in the stop-valves, throttle-valve, and main steam pipe does not show on the indicator diagram, but the loss is manifest in the fall of pressure or drop between boiler and piston.

The loss by friction or wire drawing is as a rule due to defective design and adjustment. Defective design embracing small steam ports. Valve chest too small, causing thereby expansion of steam into cylinder when valve opens without being replaced with sufficient rapidity by steam from boiler.

Adjustment embracing valves, not permitting a sufficiently large opening for the quantity of steam required. Valves not cutting-off with quickness. This latter is a defect inherent in a link motion.

Liquification during expansion, due in part to the cooling action of the cylinder walls.

In multiple expansion engines, liquification losses are less than in single-cylinder engines. Exhausting before the piston reaches end of its stroke, whilst conducive to good working of fast running engines, nevertheless shows a loss in the indicator diagram.

## The Steam Jacket

The steam jacket is seldom used except for warming the engine cylinders. The value of the steam jacket decreases with the diameter of the cylinder and high piston speeds. The wet steam supplied by the average water tube boiler neutralizes the good effects.

Again it is only the innermost layers of the cylinder walls that are affected by the fluctuation of temperature taking place in the cylinder. The variations will be less in the outer layers of metal; each concentric layer has a mean temperature, diminishing toward the exterior surface of the walls. It is readily seen that the outer layers approximate to the surrounding temperature of the atmosphere. The higher the temperature the less far will the variations of temperature extend outward through the walls and hence the exchange of heat during one revolution will be smaller.

## Effective Mean Pressure With Clearness

Assume steam pressure = 100 pounds gauge or 100 + 15 = 115 pounds absolute.

Let clearance space equal one-ninth of the cylinder volume.

Back-pressure assumed at 16 pounds absolute.

Nominal cut-off = $\frac{1}{4}$ the stroke.

Assume no compression.

The actual cut-off $V_a = V_n \dfrac{1+C}{1+CV_n}$.

$V_n = 4$. Hence $4\dfrac{1+\frac{1}{9}}{1+\frac{4}{9}} = \dfrac{\frac{10}{9}}{\frac{13}{9}} = \frac{10}{13} \times 4 = 3$.

The mean pressure will be $115 \times \dfrac{1 + \text{hyp log } V_a}{V_a} =$

$115 \times 0.6993 = 80.42$ pounds.

Effective mean pressure = 80.42 − 16 = 64.42 pounds.

Let us assume that we now compress the steam to full pressure = 115 pounds.

Then $\frac{115}{16} = 7$ = rate of compression.

Then the mean pressure = 80.42 pounds as obtained before.

The effective mean pressure $= (80.42 - 16)\,(1 + \frac{1}{9}) + \frac{115}{9}(1 - 2.95) = \frac{10}{9} \times 64.42 - \frac{224.25}{9} = 46.66$ pounds.

If there was no clearance the mean effective pressure would have been 68.59 − 16 = 52.59 pounds.

We see that the steam used in the case with full compression is the same as if there had been no clearance. The effective pressure was only 46.66 pounds. There is consequently a loss due to clearance of 52.59 pounds − 46.66 pounds, or say 5.93 pounds, or about 11 per cent.

In the first case the quantity of steam used is $\frac{13}{16}$ the volume of cylinder per stroke or one-ninth of the volume in excess of the quantity with no clearance. If with this increase of steam there was no clearance and the rate of expansion of 4 there should be an increase in the work done, and the increased work will be to the work done by the smaller quantity of steam as 13 is to 9.

We, therefore, see that the equivalent mean effective pressure is then $\frac{13}{9}$ of 52.59 or 75.96 pounds. Against 64.42 pounds, which shows a loss of 11.54 pounds or 15 per cent. This case will show the loss due to clearance, and whilst it may be considered one rarely met with in practice, yet it is sufficient to demonstrate what has been said before on this subject.

Before leaving this subject, another case will be quoted. From data of a compound engine in the author's possession we have the following:

Steam pressure, 120 pounds gauge or 135 absolute.

Receiver pressure, 25 pounds absolute.

Cut-off high-pressure cylinder, 60 per cent.

Nominal rate of expansion, 1.66.

Clearance, $\frac{1}{9}$ the cylinder volume.

We will take the first case with no compression.

Now actual rate of expansion $= 1.66 \frac{1+\frac{1}{9}}{1+\frac{1.66}{9}} = 1.66 \frac{\frac{10}{9}}{\frac{10.66}{9}} = \frac{1.66 \times 10}{10.66} =$ 1.55.

The mean pressure will be $135 \frac{1+\text{hyp log } 1.55}{1.55} =$ $0.9292 \times 135 = 125.44$ pounds.

The effective mean pressure $= 125.44 - 25 = 100.44$ pounds.

When $\frac{3}{5}+\frac{1}{9}$ or $\frac{32}{45}$ of the volume of the cylinder of steam is used, the equivalent effective mean pressure will be $\frac{10.66}{9}$ of $97.39 = 115.35$ pounds.

The loss by clearance is, therefore, $115.35 - 100.44 = 14.91$ pounds or 13 per cent.

Now assume we compress the steam to initial pressure.

The effective mean pressure is 103.06 pounds.

The loss is, therefore, $115.35 - 103.06 = 12.29$ pounds or 10.64 per cent.

In conclusion, it is unnecessary to say the loss from clearance in a compound engine is not so serious as in a simple engine. If the clearance in the low-pressure cylinder of multiple expansion engines is large, considerable loss will occur. Otherwise, if the clearance in low-pressure cylinder is small, the losses from clearance are of no consequence. This is due to the fact, that whereas in the simple engine the cut-off is earlier, the clearance is from constructive reasons much the same. Again the ratio of clearance to volume at cut-off will be much higher. In the multiple expansion engine, the steam passing from high-pressure cylinder to the other cylinders will do more work. The exhaust steam passing to the condenser in a single cylinder condensing engine is at a higher pressure when there is clearance than when there is no clearance.

## Mean Pressure in Multiple Expansion Engines

In the compound engine, if the effective mean pressure in the high pressure cylinder be divided by the ratio of the volume of low-pressure cylinder to that of the high-pressure cylinder, plus the effective mean pressure in the low-pressure cylinder the sum is termed the equivalent or referred effective mean pressure.

This referred effective mean pressure is the pressure necessary to obtain from the low-pressure cylinder alone the whole work of both cylinders.

If the effective mean pressure in the high-pressure cylinder be divided by the ratio of the volume of low-pressure cylinder to the volume of high-pressure cylinder; the quotient is the pressure required to do the same work in the low-pressure cylinder as is effected in the high-pressure cylinder.

Thus if the ratio of $\frac{\text{L. P. Cyl.}}{\text{H. P. Cyl.}}=4$ say.

If the effective mean pressure in high-pressure cylinder = 90 pounds.

Then the effective mean pressure in the low-pressure cylinder to do the same work as effected in high-pressure cylinder $=\frac{90}{4}=22.5$ pounds.*

If the effective mean pressure in the high-pressure cylinder is as before 90 pounds, and the effective mean pressure in the low-pressure cylinder is 15 pounds, then the equivalent or referred effective mean pressure is equal to $\frac{90}{4}+15=37.5$ pounds.

The referred effective pressure in multiple expansion engines should be the same as the effective mean pressure in a single cylinder engine having the same total rate of expansion. This, however, is never realized owing to drop in receivers, and other causes which will be taken up later.

The equivalent or referred effective mean pressure in a triple expansion engine is obtained in the same way. That is to say, the referred effective mean pressure is equal to the sum of the effective mean pressure in high-pressure cylinder divided by the ratio of the volume of low-pressure cylinder to the volume of high-pressure cylinder, plus the effective mean pressure in mean-pressure cylinder divided by the ratio of the volume of low-pressure cylinder to the volume of mean-pressure cylinder plus the effective mean pressure in low-pressure cylinder, or, placed in the form of an equation we have

If $P'_m$ = Effective mean pressure in H. P. Cyl.
$P''_m$ = Effective mean pressure in M. P. Cyl.
$P'''_m$ = Effective mean pressure in 2nd M. P. Cyl.
$P''''_m$ = Effective mean pressure in L. P. Cyl.
$R$ = The ratio of the volume of L. P. to H. P. Cyl.
$R'$ = The ratio of the volume of L. P. to M. P. Cyl.
$R''$ = The ratio of the volume of L. P. to 2nd M. P. Cyl.

Then referred effective mean pressure is $\frac{P'_m}{R}+P'''_m$ for compound.

$\frac{P'_m}{R}\pm\frac{P''_m}{R'}+P''''_m$ for triple expansion.

$\frac{P_m'}{R}+\frac{P''_m}{R'}+\frac{P'''_m}{R''}+P_m''''$ for quadruple expansion.

* The same reasoning applies to triple and quadruple engines.

## Actual Effective Mean Pressures

The actual mean pressures in practice are less than those computed for a given initial pressure and rate of expansion.

Now the effective mean pressure is equal to the absolute initial pressure multiplied by the quotient obtained by dividing 1 plus the hyperbolic logarithm of the rate of expansion by the rate of expansion minus the absolute back pressure.

Thus if $P_i$ = initial absolute pressure per□″ in any cylinder.
$P_b$ = absolute back pressure per□″ in any cylinder.
$R$ = total rate of expansion.
$R_h$ = rate of expansion in H. P. Cyl.
$R_m$ = rate of expansion in M. P. Cyl.
$R_{m1}$ = rate of expansion in 2d M. P. Cyl.
$R_l$ = rate of expansion in L. P. Cyl.

Then $P_i \times \frac{1 + \text{hyp log } R}{R} - P_b$ = effective mean pressure due to the initial pressure $P_i$ and a total rate of expansion R.*

As stated above, this pressure is, however, that which would obtain in a perfect engine, and hence is only a theoretical effective mean pressure.

In an actual engine, however, carefully designed, there will be causes of loss, and hence the actual indicator diagram will show an effective mean pressure much less than computed. The causes of loss have been treated in this chapter.

Now the ratio of the actual effective mean pressure to the theoretical effective mean pressure expresses the efficiency of the system and is termed the design or card factor.

## Card Factor

The card factors vary not only for the various types of engines, but for engines of the same type, and different powers.

The following table gives a fair average:

| | |
|---|---|
| For single engines not allowing for clearance | 0.75 to 0.85 |
| For single engines allowing for clearance | 0.6 to 0.68 |
| For compound engines not allowing for clearance | 0.7 to 0.85 |
| For compound engines allowing for clearance | 0.55 to 0.7 |
| Triple expansion engines not allowing for clearance | 0.67 to 0.75 |
| Triple expansion engines allowing for clearance | 0.5 to 0.54 |
| Quadruple expansion engines not allowing for clearance | 0.65 to 0.7 |
| Quadruple expansion engines allowing for clearance | 0.55 to 0.7 |

In determining the card factors, it is best whenever possible to make a note of engine's performance, deducting the card factor and tabulating

* The E M. P. for any cylinder can be found by substituting the literal quantities in the equation.

same. As an example, suppose we have a triple expansion engine the ratio of the volume of L. P. cylinder to H. P. cylinder is 1:7.

Assume cut-off in H. P. cylinder=75 per cent.

The total rate of expansion or R=7÷0.75=0.75)7.00(=
075)700.00(9.33

675

250

225

250

Assume steam pressure 160 lbs absolute.

Assume back pressure 5 lbs. absolute.

$$\text{Now } 160\times\frac{1+\text{hyp log } 9.33}{9.33}=160\times0.3473=55.57 \text{ lbs.}$$

The mean pressure = 55.57 lbs.

The effective mean pressure = 55.57 − 5 = 50.57 lbs.

Now suppose from the indicator diagrams we have a referred effective mean pressure of 34 lbs.

The card factor would be the ratio of 34 lbs to 50.57 lbs. = 0.672.

Now, conversely, suppose we were designing a triple expansion engine, the ratio of the volume of L.P. cylinder to H.P. cylinder=1:7.

Cut-off in H. P. cylinder 0.75.

All conditions the same as before.

The theoretical referred effective mean pressure we found to be 50.57 lbs.

Now suppose we select a card factor of say 0.67.

Then the actual pressure would be 50.57×0.67=33.88, say 34 pounds.

In designing a multiple expansion engine the referred effective mean pressure is used, and after that has been determined the diam. of the low-pressure cylinder is determined.

From the remarks made before on the definition of equivalent or referred pressure, we reason about it as though the power was to be developed in the L. P. cylinder only.

With a single cylinder engine, condensing or non-condensing, the cut-off would be total cut-off, thus with a total rate of expansion of 6 and a cut-off of 75 per cent in the H. P. cylinder of a multiple expansion engine, the total cut-off would be $\frac{0.75}{6}=0.125$.

The total rate of expansion, being the reciprocal of the total cut-off would therefore be $\frac{1}{0.125}=8$. We therefore see that with a multiple expansion engine cutting-off at 75 per cent in the H. P. Cyl. the total rate of expansion with a ratio of L. P. to H. P. Cyl. of 6 would be 8, while to effect this rate of expansion in a single cylinder we would cut-off at one-eighth the stroke. It is at once apparent that the great temperature range would prohibit the use of a single cylinder aside from other losses.

An example of the application of the principles enunciated in this chapter will perhaps be of benefit in aiding to comprehend fully those principles.

From data in the author's possession we will select a triple expansion engine which was designed to develop 1530 I. H. P.

The following data will be used:

Designed I. H. P. = 1530.

Steam pressure at H. P. cylinder = 150 pounds gauge.

Steam pressure at H. P. cylinder 165 pounds absolute.

Back pressure 5 pounds absolute.

Cut-off in H. P. cylinder = 0.75 = 75 per cent. of stroke.

Total rate of expansion decided upon = 8.

The theoretical referred effective mean pressure is

$$\left[165\# \times \frac{1 + \text{hyp log } 8}{8} - 5\#\right].$$

But $\frac{1 + \text{hyp log } 8}{8} = 0.3849.$

Theoretical mean pressure = 165# × 0.3849 = 63.5 pounds.

Theoretical effective mean pressure = 63.5# − 5# = 58.5 pounds.

From diagrams of a similar engine the design factor of 0.583 was obtained.

Using this factor for our present computation we obtain:

The expected effective mean pressure = 58.5# × 0.583 = 34.1 pounds.

As the designed horse power is to be 1530, the foot pounds of work per minute is therefore 1530 × 33000 = 50,490,000.

The stroke of piston is to be 2.75 feet = 33".

Designed piston speed = 580.8 feet.

Revolutions = 105.6.

Computing the diameter of the L. P. cylinder we have

$$\text{Area L. P. Cyl.} = \frac{1530 \times 33000}{34.1 \times 580.8} = 2550 \text{ square inches.}$$

The nearest practical diameter is 57 inches, and the corresponding area is 2551.8 square inches.

The ratio of the volume of L. P. cylinder to H. P. cylinder must be equal to cut-off in H. P. cylinder multiplied by total rate of expansion or $0.75 = \frac{R}{8} \therefore R = 6.$

The diameter of the H. P. cylinder will be obtained, thus:

$$\text{Area H. P. cylinder} = \frac{\text{Area L. P. cylinder}}{\text{Cut-off H. P. Cyl.} \times \text{total rate of expansion}}$$

$$= \frac{2551.8\square''}{0.75 \times 8} = \frac{2551.8\square''}{6} = 425.3 \text{ square inches.}$$

The nearest practical diameter is 23.27 inches.

The area and therefore diameter of the M. P. cylinder is a subject upon which no two designers agree. It should be in the ratio of the square root of the ratio of L. P. to H. P. cylinder; this, however, gives a cylinder too large, as the temperature range is too great, and the power unequal, hence putting up excessive strains on crank shaft.

From a list of engines showing a fair distribution of power, it is found that the square root of the ratio of L. P. to H. P. cylinder is multiplied by a constant factor ranging from 1.05 to 1.1.

The diameter of the M. P. cylinder will be obtained, thus:

$$\text{Area M. P. cylinder} = \frac{\text{Area L. P. cylinder}}{F\sqrt{\text{Ratio of L. P. to H. P. Cyl.}}}$$

This engine as built had cylinders of the following dimensions:

H. P. cylinder diameter = $23\frac{1}{2}$ inches.
M. P. cylinder diameter = 35 inches.
L. P. cylinder diameter = 57 inches.
Stroke common to all cylinders = 33 inches.

The ratio of $\frac{\text{L. P.}}{\text{H. P.}} = \frac{2551.8}{433.73} = 5.88.$

The ratio of $\frac{\text{M. P.}}{\text{H. P.}} = \frac{962.11}{433.73} = 2.21.$

The ratio of $\frac{\text{L. P.}}{\text{M. P.}} = \frac{2551.8}{962.11} = 2.65.$

The effective mean pressure H. P. Cyl. = 56.7 pounds.
The effective mean pressure M. P. Cyl. = 31.1 pounds.
The effective mean pressure L. P. Cyl. = 12.8 pounds.

The actual referred effective mean pressure is

$$\frac{56.7\#}{5.88} + \frac{31.1\#}{2.65} + 12.8\# = 34.17 \text{ pounds.}$$

The I. H. P. developed in H. P. cylinder = 432.82
The I. H. P. developed in M. P. cylinder = 526.92
The I. H. P. developed in L. P. cylinder = 574.86
The total I. H. P. = 1534.70

*Note.*—It is usual in designing the cylinders to be guided by temperature range, and distribution of power, etc., and as this involves a treatment which has no place in a book of this kind, as it is too abstruse, and is fully treated in the author's book on marine engine design.

## Horse Power

The unit of horse power is 33,000 foot pounds per minute. This is equivalent to 33,000 pounds raised 1 foot or 1 pound raised 33,000 feet per minute.

The power to be exerted is, therefore, expressed in foot pounds. We had 1530 horse power as the desired number; we multiplied this by 33,000 foot pounds because 1 horse power is equal to 33,000 foot pounds of work per minute. Now this is the numerator of our fraction. As the horse power varies directly as the piston speed in feet per minute and as the effective mean pressure, we see that this is the denominator of our fraction.

Now the formula for horse power is $\frac{PLA2N}{33000}$.

Where P = effective mean pressure.
L = length of stroke in feet.
A = area piston in square inches.
N = number of revolutions per minute.

Now as $I.H.P. = \frac{PLA2N}{33000}$.

The area of cylinder will be given by $\frac{I.H.P \times 33000}{PL2N}$.

It must be clearly borne in mind that the effective mean pressure is the mean of the effective pressures. If the power is to be determined for each end of the cylinder separately, then the formula is $\frac{PLAN}{33000}$ and top and bottom must be added to obtain the total horse power.

Again it is readily seen that the mean pressure for each cylinder is evidently equal to the initial pressure in that cylinder, multiplied by $\frac{I + \text{hyp log of rate,}}{\text{rate}}$ where rate is the rate of expansion in that cylinder. The back pressure has to be deducted to obtain the effective mean pressure. As this is the theoretical pressure it must be multiplied by a factor. This factor like other factors must be determined from the ratio of the actual effective mean pressure to the theoretical effective mean pressure. What has been said before about the reasoning on multiple expansion engines, namely, that the low pressure is treated as though all the work was to be done in that cylinder is now sufficiently clear.

In computing the horse power developed in the cylinder or cylinders of an engine, the net area of piston is understood. That is to say, the area of piston-rod, and tail-rod, if any, must be deducted from area of piston. As an example, suppose we have an engine of the following dimensions:

| | |
|---|---|
| Diameter of cylinder, - - - | 10 inches |
| Stroke of piston, - - - - | 24 inches |
| Revolutions, - - - - - - - | 100 per minute |
| Diameter of piston-rod, - - | 2 inches |
| M. E. P. top from diagram, - | 40 pounds |
| M. E. P. bottom from diagram, | 36 pounds |

Area of piston $=10^2 \times .7854 = 78.54$ square inches

$$\text{Therefore, I. H. P. top} = \frac{PLAN}{33000} = \frac{40 \times 2 \times 78.54 \times 100}{33000} = 19.04.$$

$$\text{Now I. H. P. bottom} = \frac{36 \times 2 \times (10^2 - 2^2) \times 0.7854 \times 100}{33000} = 16.45.$$

Total I. H. P. $= 19.04 + 16.45 = 35.49$.

We can if desirable proceed thus:

The M. E. P. top was 40 pounds.

The M. E. P. bottom was 36 pounds.

The average M. E. P. is therefore 38 pounds.

Area of piston top $= 78.54$ square inches.

Area of piston bottom $= 78.54$ square inches $- 3.14$ square inches $= 75.4$ square inches.

Mean area $= (78.54\square'' + 75.4\square'') \div 2 = 76.97\square''$.

$$\text{The I. H. P.} = \frac{PLA2N}{33000} = \frac{38 \times 2 \times 76.97 \times 2 \times 100}{33000} = 35.49.$$

If a tail rod is fitted to the piston of any cylinder, its area must be deducted from area of piston.

# CHAPTER III

## Combining Indicator Diagrams

Before taking up the subject of indicator diagrams in general, we will describe the method of combining same.

The object of combining the diagrams is to present in a graphical manner the losses suffered in multiple expansion engines, and to study their effects, and by proper analysis to determine the best methods for their reduction. In multiple expansion engines certain large losses appertaining to the expansive engine and not shown by the indicator diagrams are avoided. Other losses are, however, introduced which consists of those between the cylinders due to sudden expansion, wire drawing, friction, etc. It is very important to reduce all losses to the smallest possible extent; hence the value of combining and analyzing the diagrams.

The indicator diagrams which we will combine were taken from a triple expansion engine, having cylinders of the following dimensions:

Diameter of H. P. cylinder = 19″
Diameter of M. P. cylinder = 30″
Diameter of L. P. cylinder = 50″
Stroke common to all cylinders = 30″.

Fig. 20 shows the indicator diagrams from the 3 cylinders. The top and bottom diagrams are on one card.

The top diagrams only will be treated.

Taking now the diagram from high-pressure cylinder top, we divide the diagram into twenty equal spaces.* Erect ordinates perpendicular to the line of perfect vacuum. Measure the pressure at each ordinate. The pressure up to steam line and expansion line, we will call plus or positive. Measure likewise the pressure between back-pressure line and vacuum line; call this pressure minus, or negative. If a scale for pressures corresponding with spring used in instrument when diagrams were taken is not at hand, we can measure each ordinate in inches and convert same into pounds, per square inch. Thus, if the ordinate is $1\frac{3}{4}''$ long and the scale used was, say, 80 pounds, the pressure would be $1.75 \times 80 = 140$ pounds per square inch.

In using 20 ordinates the work is more tedious, but the result amply repays for any extra work, as the enlarged diagram is more accurate. After having divided the high-pressure diagram as described, we pro-

* Some prefer to divide diagram into 10 equal spaces; 20, however, are more accurate.

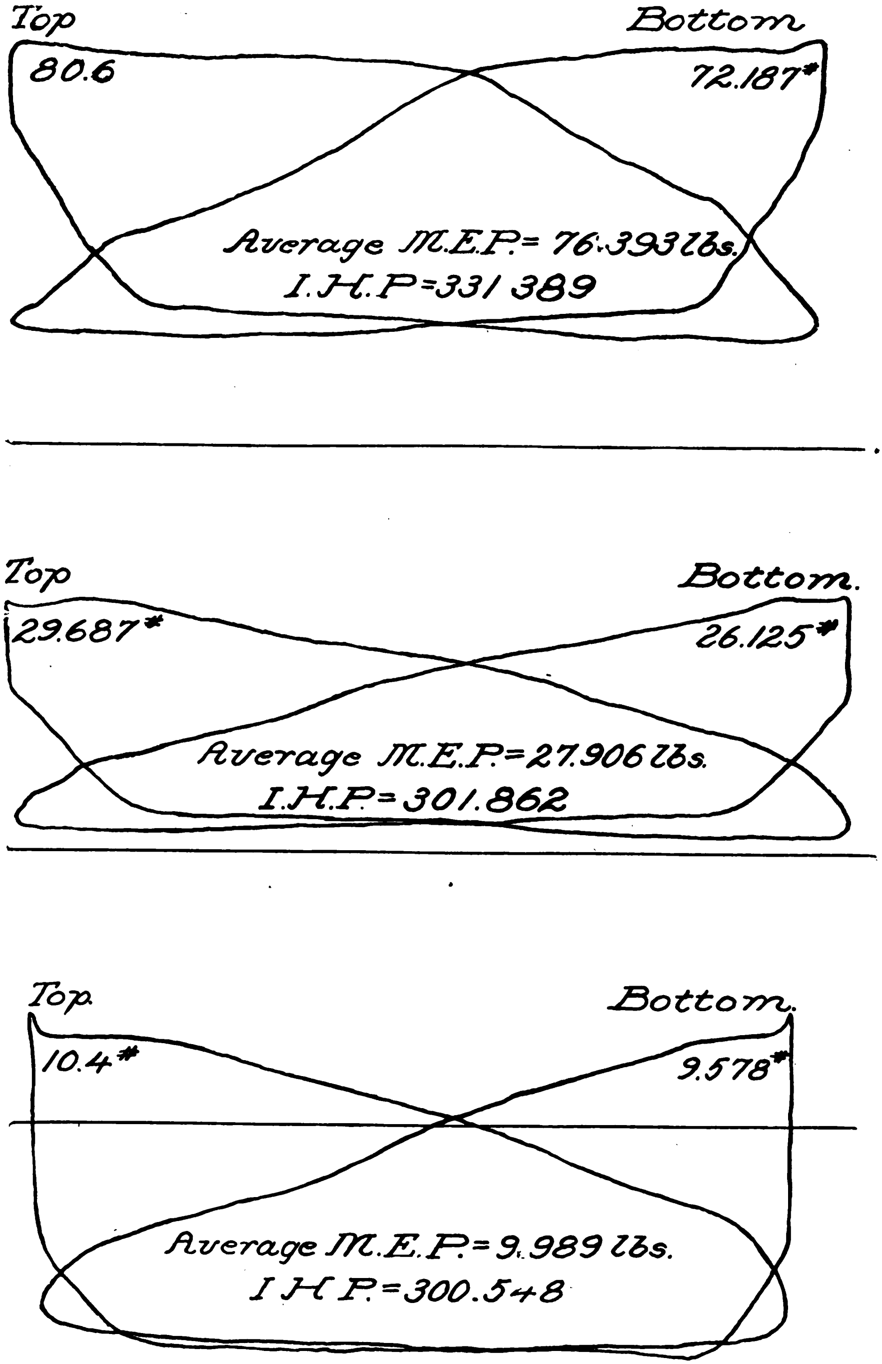

Top
Bottom
80.6
72.187#
Average M.E.P.= 76.393 lbs.
I.H.P=331 389
Top
Bottom.
29.687#
26.125#
Average M.E.P.=27.906 lbs.
I.H.P.=301.862
Top.
Bottom.
10.4#
9.578#
Average M.E.P.= 9.989 lbs.
I H P.=300.548

Fig. 20

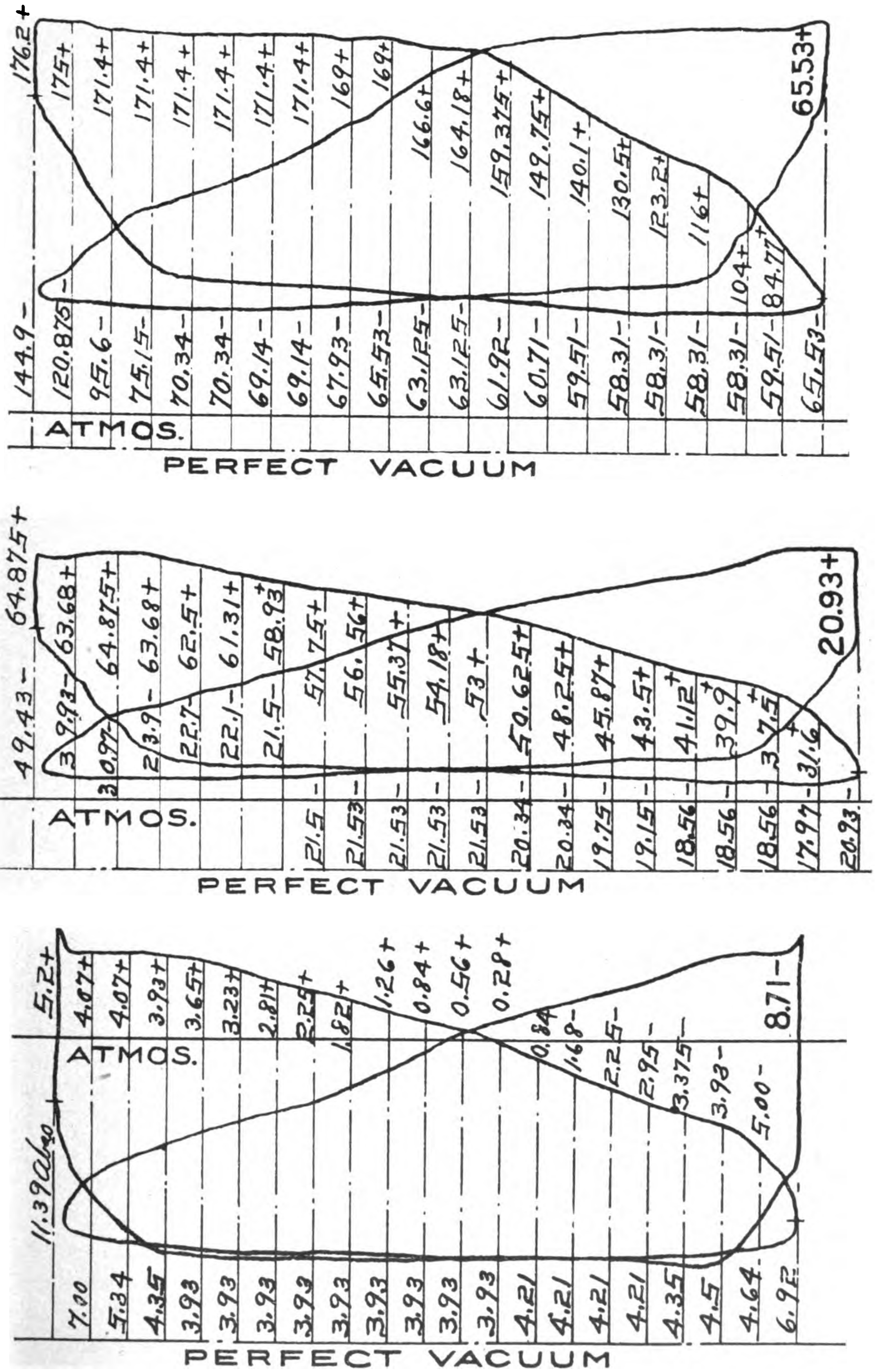

176.2+
175+
171.4+
171.4+
171.4+
171.4+
171.4+
171.4+
169+
169+
166.6+
164.18+
159.375+
149.75+
140.1+
130.5+
123.2+
116+
104+
84.77+
65.53+
144.9-
120.875-
95.6-
75.15-
70.34-
70.34-
69.14-
69.14-
67.93-
65.53-
63.125-
63.125-
61.92-
60.71-
59.51-
58.31-
58.31-
58.31-
58.31-
59.51-
65.53-
ATMOS.
PERFECT VACUUM
64.875+
63.68+
64.875+
63.68+
62.5+
61.31+
58.93+
57.75+
56.56+
55.37+
54.18+
53+
50.625+
48.25+
45.87+
43.5+
41.12+
39.9+
37.5+
31.6+
20.93+
49.43-
39.93-
30.97-
23.9-
22.7-
22.1-
21.5-
21.5-
21.53-
21.53-
21.53-
21.53-
20.34-
20.34-
19.75-
19.15-
18.56-
18.56-
18.56-
17.97-
20.93-
ATMOS.
PERFECT VACUUM
5.2+
4.07+
4.07+
3.93+
3.65+
3.23+
2.81+
2.25+
1.82+
1.26+
0.84+
0.56+
0.28+
0.84
1.68-
2.25-
2.95-
3.375
3.93-
5.00-
8.71-
ATMOS.
11.39
7.00
5.34
4.35
3.93
3.93
3.93
3.93
3.93
3.93
3.93
3.93
3.93
4.21
4.21
4.21
4.21
4.35
4.5
4.64
6.95
PERFECT VACUUM

Fig. 21

ceed to treat the diagram from M. P. cylinder and L. P. cylinder, in precisely the same manner. Fig. 21 shows the diagrams of Fig. 20 divided, and the corresponding pressure inserted.

The combined diagram is shown on plate 2.

The method of construction is as follows: Draw a horizontal line OX, and a vertical line OY, intersecting OX in O. The horizontal line OX is a line of volume; the vertical line OY is a line of pressure, or perhaps more correctly the line on which pressures are set off.

The line OX is also the line of perfect vacuum. In combining diagrams the volumes of the different cylinders are set off in their proper volumetric ratios; whilst the pressures are all set off to the same scale.

For pressures we will use a scale of 10 pounds to the inch; thus every inch in height on line OY represents 10 pounds pressure per square inch on piston.

Set off from O on OY pressures up to the absolute boiler pressure, thus 0, 10, 20,......187 as shown.

The boiler pressure at the time these diagrams were taken was 172 pounds gauge or 187 pounds absolute. Line OY is not only a line of pressure, but it is also the line from which the clearance in each cylinder is measured. We must know the volumetric clearance in each cylinder before we can combine the diagrams. As mentioned in chapter II, this is a very difficult undertaking after engines are erected and in the ship. It is then necessary to obtain this information from the builders. The clearances for this engine was determined from the drawings of the cylinders and was found to be as follows:

Volumetric clearance H. P. cylinder = 14 per cent.
Volumetric clearance M. P. cylinder = 14 per cent.
Volumetric clearance L. P. cylinder = 9 per cent.

From the line OY set off parallel with OX, and to the right a distance equal to the clearance in H. P. cylinder. Before doing this, however, we must decide upon what length to make the H. P. cylinder diagram. The length of diagram is entirely optional and depends upon the whim of the engineer. 2 inches makes a good length of diagram, as then each ordinate is $\frac{1}{10}''$ apart, that is to say, the interval is 0.1 inch.

We will adopt a length of 2 inches. Now 14 per cent. of 2 inches is equal to $0.14 \times 2 = 0.28$ inch. Set off, therefore, from OY a distance of 0.28 inch and draw a vertical line parallel with OY. Draw a horizontal line parallel with OX, at a height corresponding to the initial absolute pressure in H. P. cylinder, which is in this case 176.2 pounds absolute. Set off a distance from OY on the horizontal line mentioned, a distance of 2.28 inches, or 2 inches from the clearance line. Now divide the

2 inches into 20 equal parts, drawing ordinates parallel with OY. Set off on these ordinates the pressures corresponding to the similar ordinates on the indicator diagram (Fig. 21).

After these pressures are all set off on their respective ordinates for both the forward and return stroke, we trace a curve through the points and obtain the contour of diagram. It is best in all cases when dealing with pressures to deal with absolute pressures, because pressures are set off from vacuum. In taking pressures from the diagram it it better to take from vacuum line also. This line can be drawn on each card, by setting off below the atmospheric line a distance corresponding to 15 pounds to the scale with which diagram was taken.

## Intermediate Cylinder Diagram

The diameter of the M. P. cylinder is 30 inches.

The area of a 30-inch cylinder is 706.86 square inches.

The diameter of the H. P. cylinder is 19 inches.

The area of a 19-inch cylinder is 283.53 square inches. The ratio of the volume of M. P. to H. P. is, therefore, $706.86 \div 283.53 = 2.49$.

The high pressure diagram having been made 2 inches in length, the length of the M. P. diagram will, therefore, be $2.49 \times 2 = 4.98$ inches.

The clearance in M. P. cylinder was found to be 14 per cent.; therefore, 14 per cent. of $4.98 = 4.98'' \times 0.14 = 0.697$ inch. Set off from OY a distance equal to 0.697 inch, draw a line parallel with OY. Draw a horizontal line parallel with OX, at a height corresponding to the initial absolute pressure, in this cylinder, which in this case is 64.875 pounds absolute. Set off from OY on the horizontal line just described, a distance of 5.677 inches or 4.98 inches from the clearance line. Now divide the 4.98 inches into 20 equal parts, drawing ordinates parallel with OY. Set off on these ordinates the pressures corresponding to the similar ordinates on the indicator diagram (Fig. 21). After these pressures are all set off on their respective ordinates, as explained for the H. P. diagram. and the curves drawn in, we have the contour of the M. P. cylinder diagram.

## Low-pressure Diagram

The diameter of the L. P. cylinder is 50 inches.

The area of a 50-inch cylinder is 1963.5 square inches.

The diameter of the H. P. cylinder is 19 inches.

The area of a 19″ cylinder is 283.53 square inches.

The ratio of the volume of L. P. to H. P. is therefore, $1963.5 \div 283.53 = 6.92$.

The high-pressure diagram having been made 2 inches in length, the length of the L. P. diagram will therefore be $6.92 \times 2 = 13.84$ inches.

The clearance in L. P. cylinder was found to be 9 per cent.; therefore, 9 per cent. of $13.84 = 13.84 \times 0.09 = 1.24$ inches. Set off from OY a distance equal to 1.24 inches; draw a line parallel with OY. Draw a horizontal line parallel with OX, at a height corresponding to the initial absolute pressure in this cylinder, which is in this case 20.2 pounds absolute. Set off from OY on the horizontal line just described, a distance of 15.08 inches, or 13.84 inches from the clearance line. Now divide the 13.84 inches into 20 equal parts, drawing ordinates parallel with OY. Set off on these ordinates the pressures corresponding to the similar ordinates on the indicator diagram, Fig. 21. After these pressures are all set off on their respective ordinates as explained for the H. P. and M. P. diagrams, and the curves drawn in, we have the contour of the L. P. cylinder diagram.*

We now have the three diagrams drawn to the same scale of pressures, and each diagram set out in its proper volumetric ratio, and with their proper clearances.

The next step is to draw the $PV = C$ curve.

The method of doing this has been described in a previous chapter, and need not be treated here. Any of the curves can be drawn, and they are of interest, and should be practiced by the student.

Drawing the curve $PV = C$ through the point of cut-off as shown, we note that, producing this curve to the maximum initial pressure, the cut-off is slightly reduced. This is known as the reduced cut-off, for we see that the cut-off on the indicator diagram of H. P. cylinder is 59 per cent. This is the nominal cut-off. The actual cut-off is nominal cut-off + clearance $= 0.59 + 0.14 = 73$ per cent. The reduced cut-off should be $\frac{(0.59+0.14) \times 161.52}{176.2} = 0.67$ or 67 per cent.

Measuring the combined diagram we see that it measures just 67 per cent. for $1\frac{1}{16}'' \div 2 = 53$ per cent.

$0.53 + 0.14 = 0.67$ or 67 per cent.

161.52 pounds is the cut-off pressure.

176.2 pounds is the initial pressure on H. P. piston.

## Back Pressure Line

The assumed back pressure is 4 pounds absolute. From O on OY, set off a distance equal to 4 pounds, draw a horizontal line parallel with the perfect vacuum line OX.

## Atmospheric Line

The atmospheric line should be drawn after pressure and vacuum lines are established. Therefore, from O on OY, set off a distance

* It may be found by some to be more desirable to work from the atmospheric line for H. P. and M. P. diagrams and above and below atmospheric line for L. P. diagram. This is optional.

equal to 15 pounds, draw a horizontal line parallel with the perfect vacuum line OX.

Looking at the combined diagrams, plate 2, we note that there is a drop of 10.8 pounds between boiler and piston of H. P. cylinder.

The boiler pressure was 187 pounds absolute.

The initial pressure by indicator diagram is 176.2 pounds absolute. Therefore, $187-176.2=10.8$ pounds.

There is also a drop between the initial pressure and cut-off pressure. The cut-off pressure is 161.52 pounds, and the difference between 176.2 pounds and 161.52 pounds $=14.68$ pounds.

The pressure in first receiver was 67 pounds. The initial pressure in M. P. cylinder was 64.875 pounds.

There is a drop in this receiver of 67 pounds $-$ 64.875 pounds $=2.125$ pounds.

The pressure in second receiver was 21 pounds.

The initial pressure in L. P. cylinder was 20.2 pounds.

There is a drop in this receiver of 21 pounds $-$ 20.2 pounds $=0.8$ pounds.

The theoretical diagram is that represented by OY, OX, and the curve $PV=C$.

The effective mean pressure of the ideal diagram is obtained as follows:

The initial steam pressure is 176.2 pounds absolute.

The reduced cut-off was 67 per cent. This is an actual and not a nominal cut-off.

The ratio of the volume of the L. P. cylinder to the H. P. cylinder is 6.92.

Now $0.67=\frac{6.92}{X}$. Therefore, the total rate of expansion $X=6.92\div0.67=10.32$.

Now $\frac{1+\text{hyp log } 10.32}{10.32}=0.3224$.

The theoretical mean pressure $=176.2\times0.3224=56.8$ pounds.

The theoretical effective mean pressure $=56.8$ pounds $-$ 4 pounds $=$ 52.8 pounds.

The effective mean pressure shown by H. P. diagram $=80.6$ pounds.

The effective mean pressure shown by M. P. diagram $=29.687$ pounds.

The effective mean pressure shown by L. P. diagram $=10.4$ pounds.

Then the effective mean pressure referred is as before equal to $\frac{80.6}{6.92}+\frac{29.687}{2.77}+10.4=11.64$ pounds $+$ 10.71 pounds $+$ 10.4 pounds $=32.75$ pounds.

Now, as explained before, the card factor is a ratio, and represents the percentage of returns for investment. The card factor in this case is, therefore, $32.75 \div 52.8 = 0.62$. That is to say, the actual pressure is 62 per cent. of the theoretical. If the theoretical diagram is to be considered from initial pressure H. P. cylinder to perfect vacuum, then the card factor would be $32.75\# \div 56.8\# = 0.576$.

In all engineering investigations, accuracy should be the prime factor. Not only in the analysis and computations, but the instruments with which the data is obtained should be accurate, and should the instrument be in error, this error must be determined and allowed for. It will be found profitable, after all measurements of the diagrams have been made and recorded, to determine the effective mean pressures, from the measurements made, before combining, as the measurements are many, and having previously found the effective mean pressure of the diagrams by planimeter, it is a good check.

An example will make these remarks clear.

The effective mean pressure of the top indicator diagram of H. P. cylinder was found to be 80.6 pounds; from the ordinates we have 80.18 pounds. It is shown by Fig. 21 that measuring between the limits of the diagram the following pressures are obtained.

| | | | |
|---|---|---|---|
| 1st | Ordinate | 31.3 | pounds. |
| 2d | " | 54.125 | " |
| 3rd | " | 75.8 | " |
| 4th | " | 96.25 | " |
| 5th | " | 101.06 | " |
| 6th | " | 101.06 | " |
| 7th | " | 101.06 | " |
| 8th | " | 101.06 | " |
| 9th | " | 101.07 | " |
| 10th | " | 103.47 | " |
| 11th | " | 103.475 | " |
| 12th | " | 101.055 | " |
| 13th | " | 97.455 | " |
| 14th | " | 89.04 | " |
| 15th | " | 80.59 | " |
| 16th | " | 72.19 | " |
| 17th | " | 64.97 | " |
| 18th | " | 57.69 | " |
| 19th | " | 45.69 | " |
| 20th | " | 25.26 | " |
| 21st | " | 0. | " |
| | Sum = | 1603.67 | |

th
is
is
b
th

f
n
th
f
h
f
a
t

c

c

And 1603.67 ÷ 20 = 80.18 pounds effective mean pressure. Showing a difference = 80.6 − 80.18 = 0.42 pounds, or .5 per cent. That is ½ of 1 per cent. less.

Treating the M. P. and L. P. diagrams in a similar manner we obtain for the top diagram of M. P. cylinder 29.25 pounds. The effective mean pressure of the same diagram by planimeter is 29.687 pounds. Showing a difference of 29.687 − 29.25 = 0.437 pounds, or 1.4 per cent. less.

For the top diagram of L. P. cylinder 10.81 pounds. The effective mean pressure of the same diagram by planimeter is 10.4. Showing a difference of 10.81 − 10.4 = 0.41 pounds or nearly 4 per cent. greater.

This is sufficient to prove the accuracy of the different pressures. It will be noticed that in each diagram of the combined diagram, the effective mean pressure is inserted. Each diagram was carefully traced over with the planimeter and the pressures inserted obtained.

It may have been noted that the remarks upon the combined diagram took no account of the clearance in the L. P. cylinder. The diagrams and the combined diagrams, fig. 21a, are from the same engine as those shown on plate 2, but at a different time. Now taking into consideration the clearance in L. P. cylinder, our computations would be as follows: The nominal cut-off in H. P. cylinder is 75 per cent. The clearance in H. P. cylinder is equal to 14 per cent. of the cylinder volume.

The initial pressure as shown by H. P. cylinder diagram is 165.38 pounds absolute.

The pressure at cut-off H. P. cylinder as shown by diagram is 157.88 pounds absolute.

The equivalent cut-off from measurement is 84.5 per cent.

Thus nominal equivalent cut-off from measurement = 70.5 per cent. 70.5 + 14 = 84.5 per cent.

The actual equivalent cut-off by computation is

$$\frac{(75+14)\times 157.88}{165.38} = 0.849 = 84.9 \text{ per cent.}$$

Initial volume for expansion is therefore 84.9 per cent.

The finial volume will therefore be (100 + 9) × 6.92 where 6.92 = the ratio of $\frac{\text{L. P.}}{\text{H. P.}}$

Clearance in L. P. cylinder = 9 per cent. of the cylinder volume. Now 109 × 6.92 = 754.28

$$\text{The cut-off is therefore} = \frac{\text{initial volume}}{\text{finial volume}} = \frac{84.9}{754.28} = 0.112.$$

$$\text{The total rate of expansion} = \frac{1}{R} = \frac{1}{0.112} = 8.92.$$

If we take and divide the distance OX into volumes equal to OU, we see that it contains OU just 8.92 times. By the shorter method, as previously described, we have

Equivalent cut-off = 0.845.

Ratio $\frac{\text{L. P.}}{\text{H. P.}} = 6.92.$

Total ratio of expansion $= \frac{6.92}{0.845} = 8.18.$

The mean pressure per pound for 8.920 = .358.

The mean pressure per pound for 8.180 = .3759.

Taking initial pressure 165.38 pounds in both cases, we have

$165.38 \times 0.358 = 59.2$ pounds.

$165.38 \times 0.3759 = 62.16$ pounds.

Deducting 4 pounds back pressure in both cases, we have for effective mean pressure:

$59.2 - 4 = 55.2$ pounds.

$62.16 - 4 = 58.16$ pounds.

The difference = 2.96 pounds, or 5 per cent.

The effective referred mean pressure from diagrams = 33.7 pounds.

The card factor in the former case is $\frac{35.91}{55.2} = 0.65.$

The card factor in the latter case is $\frac{35.91}{58.16} = 0.617.$

Some designers do not deduct an assumed back pressure, treating the area between initial pressure and a vacuum.

The card factor then becomes in the first case: $\frac{35.91}{59.2} = 0.6.$

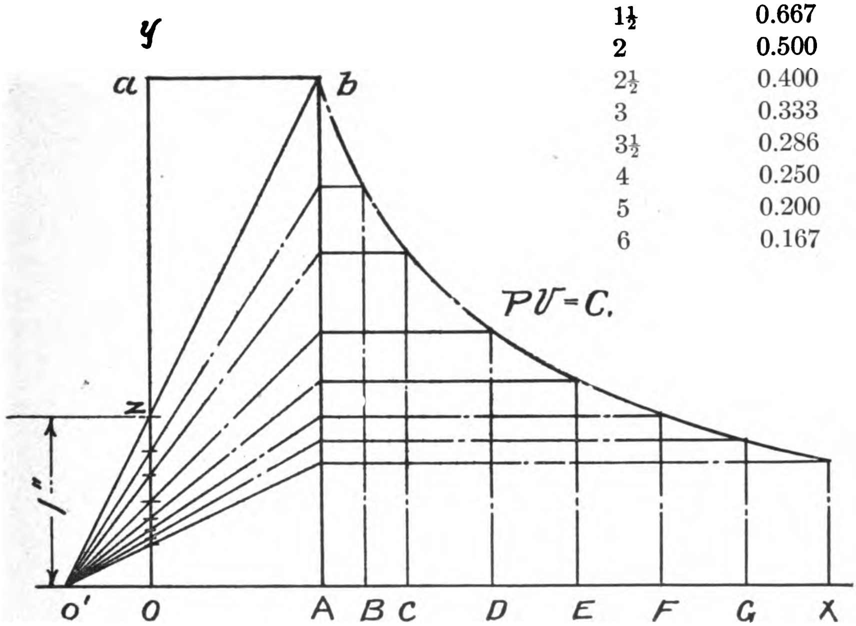
In the latter case the card factor is: $\frac{35.91}{62.16} = 0.577.$

It is thus seen that when the first value is taken or the first method, the cylinders would be slightly smaller than with the second method. That is to say, in designing with a referred, effective mean pressure the cylinders would be slightly smaller with the clearance in L. P. cylinder taken into consideration. It is, therefore, better to deal with the actual values from similar engines, and in computing the effective theoretical mean pressure, from the combined diagram the clearance in L. P. cylinder must be considered. Computing from actual data the card factor for several types of engines, the following gives a fair mean when determining the mean referred pressure without taking a theoretical back-pressure into consideration.

COMPOUND ENGINES

Large engines up to 100 revolutions per minute....0.6 to 0.68
Small engines ..................................0.5 to 0.6
Triple expansion 3-cylinder engines
Mercantile ships ................................0.55 to 0.58
Triple expansion 4-cylinder engines ..............0.5 to 0.54
Quadruple expansion ...........................0.52

| Volume | Decimal |
|---|---|
| 1¼ | 0.800 |
| 1½ | 0.667 |
| 2 | 0.500 |
| 2½ | 0.400 |
| 3 | 0.333 |
| 3½ | 0.286 |
| 4 | 0.250 |
| 5 | 0.200 |
| 6 | 0.167 |




Equilateral Hyperbola

Fig. 22

It is absolutely necessary to exercise the greatest care in not only taking diagrams, but in computing the data, for unless the data is reliable it is simply a waste of time to analyze results. The value to the designer as well as to the practical engineer of the information to be derived from the indicator diagram cannot be over-estimated.

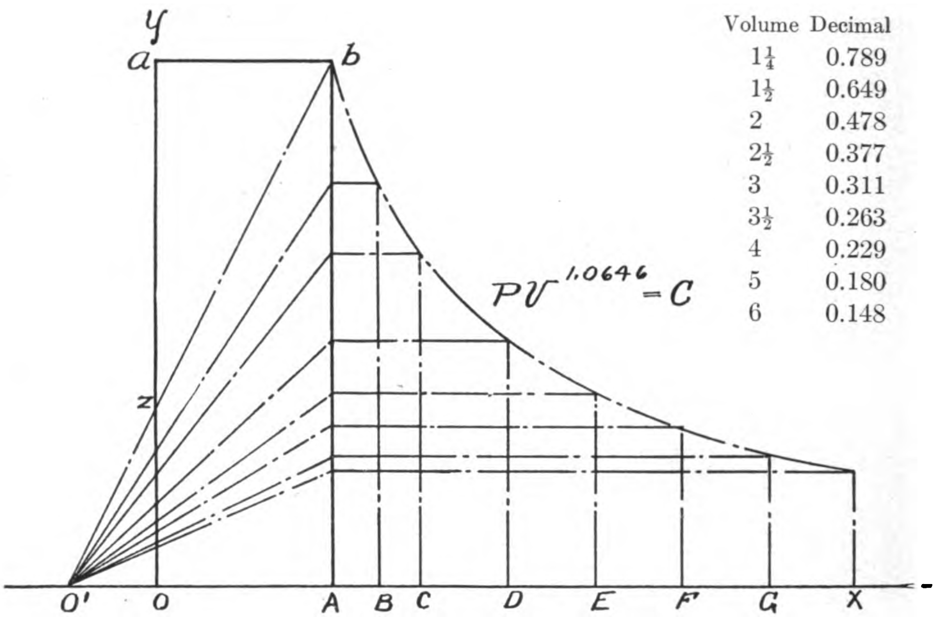
Before closing this subject we will consider some other curves, and describe the method of constructing them. It was at one time customary to plot what was termed the saturation curve when cards were combined. Others treated the PV = C curve as the curve of saturation.

The PV=C curve is and has been repeatedly referred to as the theoretical curve of expansion. In previous remarks, we see how absurd such reference is. The equation to the saturation curve is $PV^k=C$.

Now the exponent k for this curve is 1.0646, whilst the exponent for the hyperbola is 1.

The adiabatic curve is $PV^k=C$. The exponent k for this curve is 1.13.

It is interesting to plot these curves on a combined indicator diagram, to see their variations and peculiar features, and the exercise is highly instructive.




| Volume | Decimal |
|---|---|
| 1¼ | 0.789 |
| 1½ | 0.649 |
| 2 | 0.478 |
| 2½ | 0.377 |
| 3 | 0.311 |
| 3½ | 0.263 |
| 4 | 0.229 |
| 5 | 0.180 |
| 6 | 0.148 |

Saturation Curve.

Fig. 23

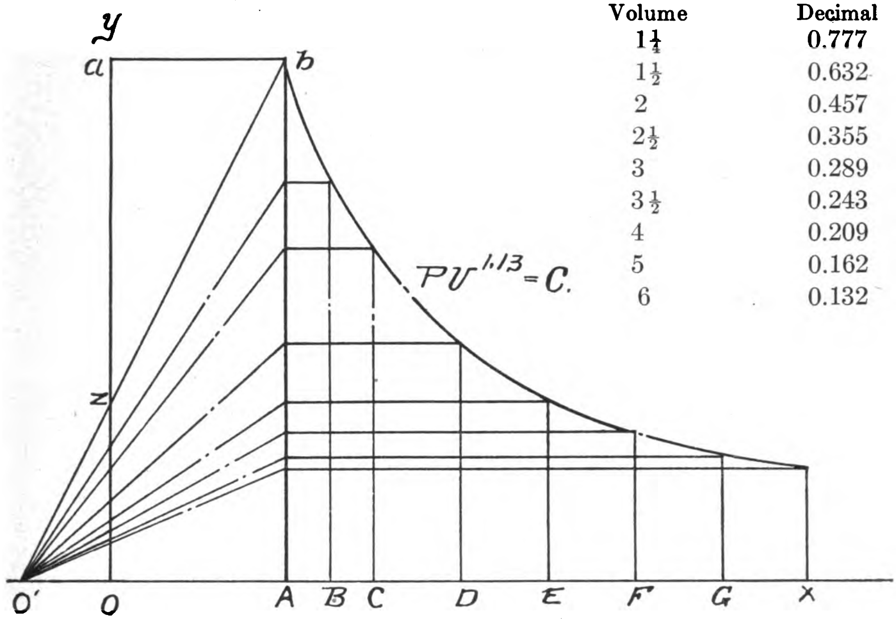
## Curves of Expansion

With each figure there is given a table of the constants used in constructing the respective curves.

Fig. 22 shows a practical method of plotting the PV=C curve, and its construction is as follows: Let OY represent the absolute initial pressure; from O set off on OY a distance of 1 inch represented by OZ. Now set off on the line OX a distance equal to the volume up to cut-off. Complete the rectangle OYBA.

Draw a diagonal line from B passing through Z, and produce same to pass through O′ on the line of perfect vacuum produced. Set off on OX, a distance OB = $1\frac{1}{4}$ OA, OC = $1\frac{1}{2}$ OA, OD = 2 OA, OE, = $2\frac{1}{2}$ OA, OF = 3OA, OG = $3\frac{1}{2}$ OA, etc.

Now from O set off on OY a distance = 0.8 inch for $1\frac{1}{4}$ vols. 0.667 for $1\frac{1}{2}$ vols., 0.5 for 2 vols., 0.4 for $2\frac{1}{2}$ vols., 0.333 for 3 vols., 0.286 for $3\frac{1}{2}$ vols. and 0.25 for 4 vols. Now pass diagonals through the corresponding points from O′ intersecting AB. From these points of intersection pass horizontal lines parallel with OX. The horizontals intersecting the ordinates erected on OX, as shown, locate points of the




| Volume | Decimal |
|---|---|
| $1\frac{1}{4}$ | 0.777 |
| $1\frac{1}{2}$ | 0.632 |
| 2 | 0.457 |
| $2\frac{1}{2}$ | 0.355 |
| 3 | 0.289 |
| $3\frac{1}{2}$ | 0.243 |
| 4 | 0.209 |
| 5 | 0.162 |
| 6 | 0.132 |

Adiabatic Curve

Fig. 24

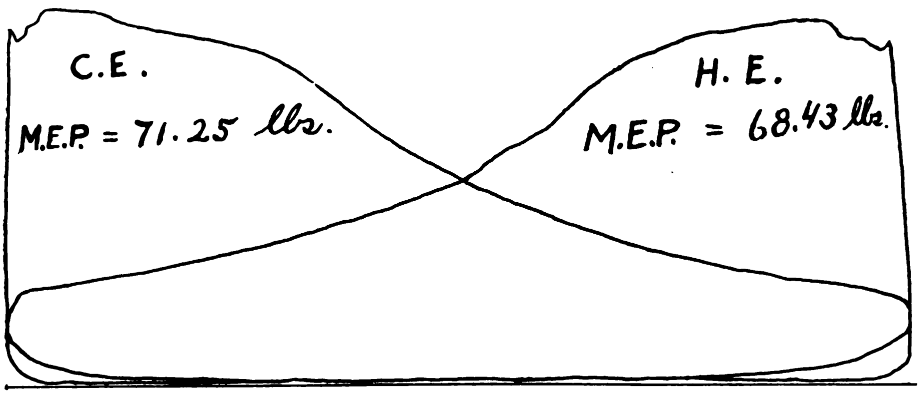
curve; passing a fair curve through these points gives us a curve known as the equilateral hyperbola, or PV = C curve. Taking the combined indicator diagrams, the volume is 73 per cent. and proceeding as just described we obtain the curve as there plotted.

Fig. 23 shows the saturation curve. This curve is constructed in precisely the same manner as the PV = C curve. The decimal corresponding to the volume is given in figure.

Fig. 24 shows the adiabatic curve of expansion. Constructed the same as explained for the two preceding curves. The decimal corresponding to the volume is given in the figure.

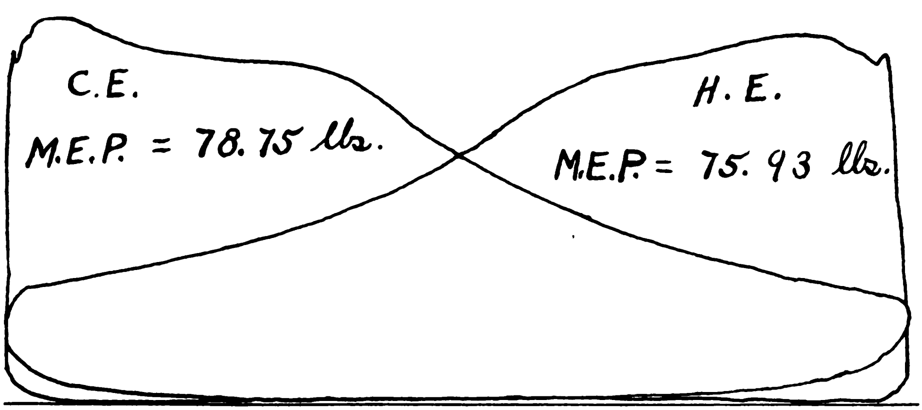
**Indicator Diagrams**

The following four diagrams are taken from the steam tug "Baltic." Diameter cylinder 16 inches; stroke of piston 16 inches.



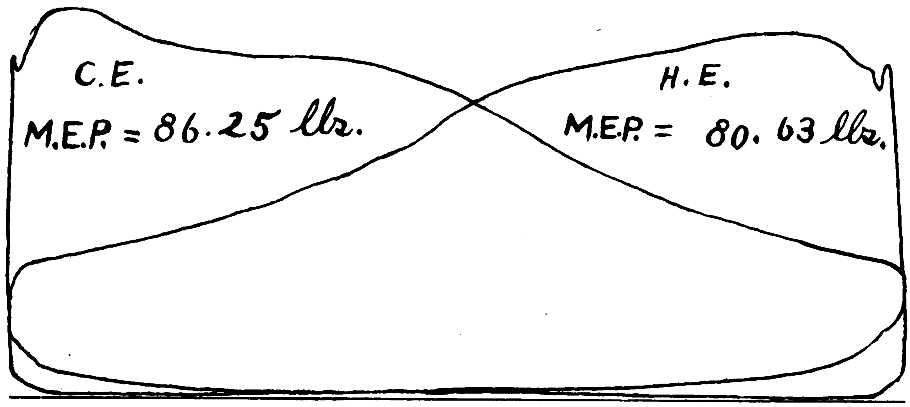

Average M. E. P., 69.84 lbs.

6″ Cut-off. Steam, 120 lbs. 118 Revo.
133.561 I. H. P.
Scale of Spring, 60



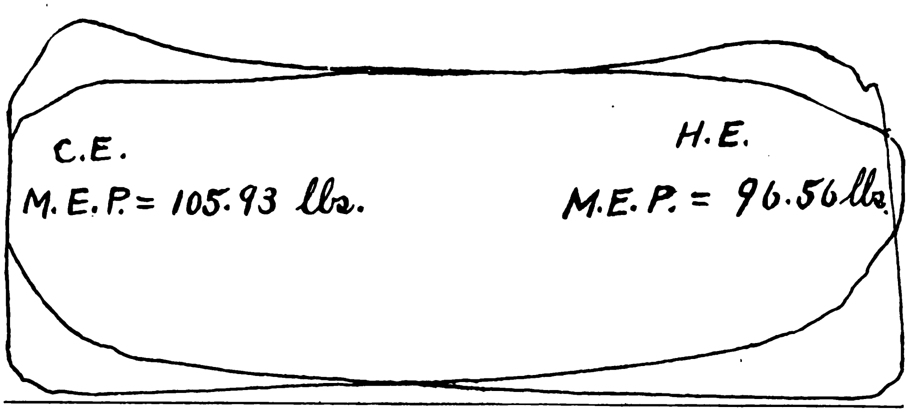

Average M. E. P., 77.34 lbs.

7″ Cut-off Steam, 120 lbs. 120 Revo.
150.325 I. H. P.
Scale of Spring, 60




Average M. E. P., 83.44 lbs.

8″ Cut-off Steam, 120 lbs. 126 Revo.
170.317 I. H. P.
Scale of Spring, 60




Average M. E. P., 101.245 lbs.

Full Stroke of Valve Steam, 120 lbs. 132 Revo.
216.502 I. H. P.
Scale of Spring, 60

The following diagrams are from the first compound engine built in America.

This engine has cylinders of the following dimensions

High pressure cylinder 24 inches.

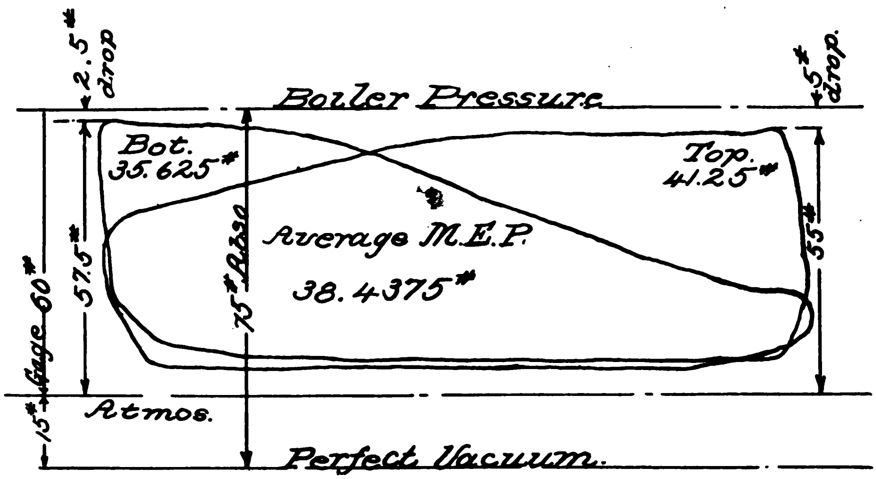
Low pressure cylinder 38 inches.

Stroke common to both 36 inches.

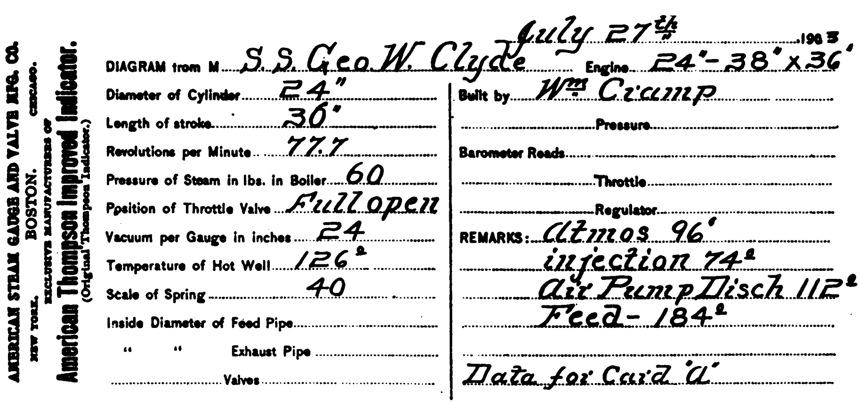
In the first chapter I stated that the defects incident to long indicator pipes would be discussed later.

Diagrams "a" and "b" are from the H. P. and L. P. cylinders respectively. The indicator pipe was arranged as shown in inset facing page 66 in fig. 1.

Looking at card "a,"




Card "a"



AMERICAN STEAM GAUGE AND VALVE MFG. CO.
NEW YORK. BOSTON. CHICAGO.
EXCLUSIVE MANUFACTURERS OF
American Thompson Improved Indicator.
(Original Thompson Indicator.)

July 27th 1903,

DIAGRAM from M S. S. Geo W. Clyde Engine 24"-38"x36"

| | |
|---|---|
| Diameter of Cylinder 24" | Built by Wm Cramp |
| Length of stroke 36" | Pressure |
| Revolutions per Minute 77.7 | Barometer Reads |
| Pressure of Steam in lbs. in Boiler 60 | Throttle |
| Position of Throttle Valve Full open | Regulator |
| Vacuum per Gauge in inches 24 | REMARKS: Atmos 96° |
| Temperature of Hot Well 126° | injection 74° |
| Scale of Spring 40 | Air Pump Disch 112° |
| Inside Diameter of Feed Pipe | Feed - 184° |
| " " Exhaust Pipe | |
| Valves | Data for Card "a" |

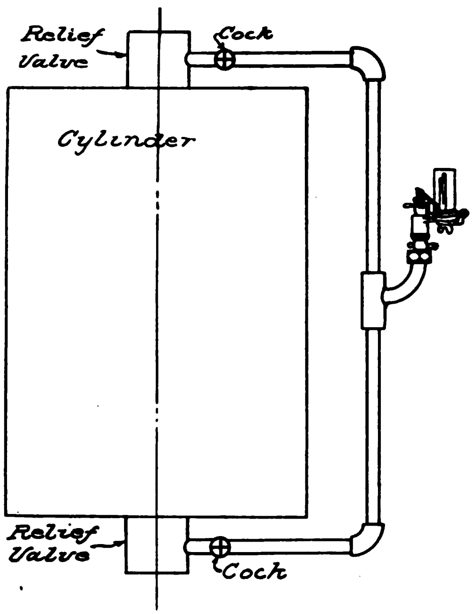

Relief Valve
Cock
Cylinder
Relief Valve
Cock

Fig .1

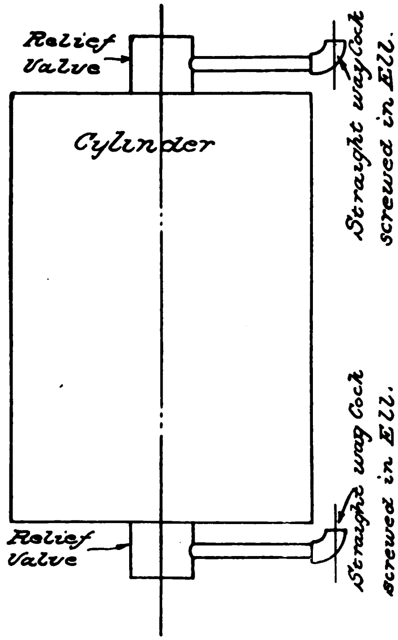
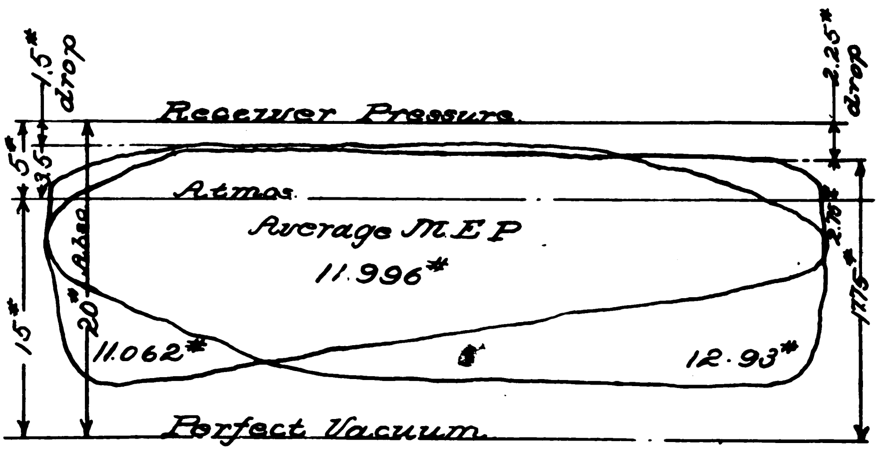

Relief Valve
Straight way Cock screwed in Ell.
Cylinder
Relief Valve
Straight way Cock screwed in Ell.

Fig. 2

we see the drop between boiler and H. P. piston is 5 lbs. for top, 2.5 lbs. for bottom. The initial steam pressure top is 55 lbs. gauge or 70 lbs. absolute. For the bottom the initial pressure is 57.5 lbs. gauge or 72.5 lbs absolute. The absolute steam pressure is 75 lbs. The M. E. P. top is 41.25 lbs. M. E. P. bottom is 35.625 lbs. Giving a difference between top and bottom of 5.625 lbs. The average M. E. P. is 41.25#+35.625#=76.875 lbs. 76.875÷2=38.4375 lbs.

For card "b,"




Card "b"

AMERICAN STEAM GAUGE AND VALVE MFG. CO.
NEW YORK. BOSTON. CHICAGO.
EXCLUSIVE MANUFACTURERS OF
American Thompson Improved Indicator.
(Original Thompson Indicator.)

July 27th 1903

DIAGRAM from M S. S. Geo W. Clyde Engine 24"-38"x36"

| | |
|---|---|
| Diameter of Cylinder 38" | Built by Wm Cramp |
| Length of stroke 36" | Pressure |
| Revolutions per Minute 777 | Barometer Reads |
| Pressure of Steam in lbs. in Boiler 60 | Throttle |
| Position of Throttle Valve Full Open | Regulator |
| Vacuum per Gauge in inches 24 | REMARKS: Atmos 96° |
| Temperature of Hot Well 126° | injection 74° |
| Scale of Spring 12 | Air Pump Disch 112° |
| Inside Diameter of Feed Pipe | Feed 184° |
| " " Exhaust Pipe | |
| Valves | Data for Card "b" |

we have a receiver pressure of 5 lbs. gauge or 20 lbs. absolute. The drop in receiver is for top 2.25 lbs. and 1.5 lbs. for bottom. The initial steam pressure top is 2.75 lbs. gauge of 17.75 lbs. absolute. For the bottom the initial pressure is 3.5 lbs. gauge or 18.5 lbs. absolute.

The M. E. P. top is 12.93 lbs. M. E. P. bottom is 11.0625 lbs., giving a difference of 1.8675 lbs. The average M. E. P. is 12.93# + 11.062# = 23.992 lbs. 23.992 ÷ 2 = 11.996 lbs.

The constant for the H. P. cylinder $= \frac{PLA2N}{33000}$.

Let the M. E. P. pressure = 1 pound.

Piston speed in feet = 1 foot per minute.

Then the constant for 1 lb. M. E. P and one foot of piston speed = $\frac{1 \times 1 \times 452.39 \times 2 \times N}{33000} = \frac{904.78}{33000} = 0.02741.$

The constant for L. P. cylinder $= \frac{1134.1 \times 2}{33000} = \frac{22682}{33000} = 0.06873.$

The average M. E. P. H. P. cylinder = 38.4375

The average revolutions = 77.7

The stroke of piston = 3 feet.

The indicated horse power developed in H. P. cylinder is, therefore, $C \times$ M. E. P. $\times N \times L = 0.02741 \times 38.4375 \times 77.7 \times 3 = 245.571$ horse power.

The indicated horse power developed by L. P. cylinder is, therefore, $C \times$ M. E. P. $\times N \times L = 0.06873 \times 11.996 \times 77.7 \times 3 = 192.189$ horse power.

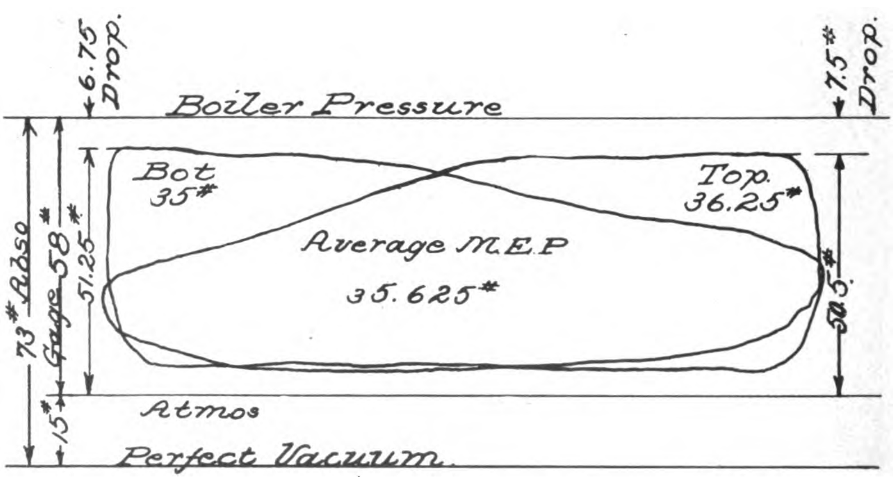
The collective I. H. P. = 245.571 + 192.189 = 437.76.

The ratio of cylinder capacities = area L. P. cylinder ÷ area H. P. cylinder = 1134.1 ÷ 452.59 = 2.56.

The aggregate equivalent M. P. referred to L. P. piston is, therefore,

$$\frac{\text{M. E. P. H. P. Cyl.}}{\text{Ratio } \frac{\text{L. P.}}{\text{H. P.}}} + \text{M. E. P. L. P. Cyl.} = \frac{38.4375}{2.56} + 11.996 =$$

15.01# + 11.996# = 27 lbs.




Card "c"

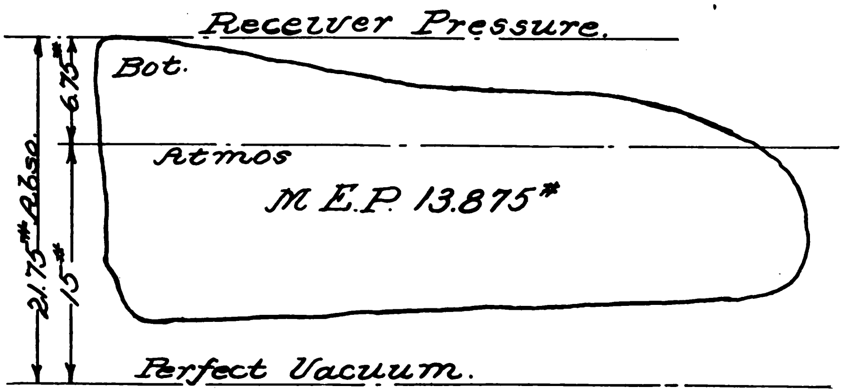
Diagrams "c," "d" and "e" are from the same engine but with short connections (see fig. 2 of inset facing page 66).

AMERICAN STEAM GAUGE AND VALVE MFG. CO.
NEW YORK. BOSTON. CHICAGO.
EXCLUSIVE MANUFACTURERS OF
**American Thompson Improved Indicator.**
(Original Thompson Indicator.)

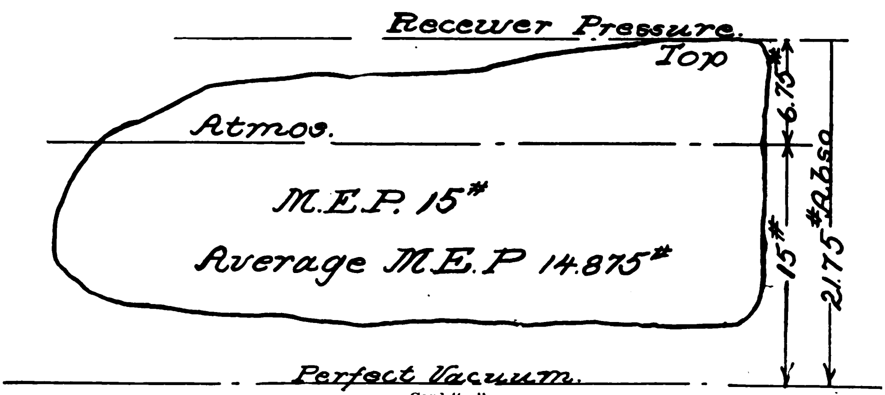
August 10th 1903

DIAGRAM from M S. S. Geo W. Clyde Engine

| | |
|---|---|
| Diameter of Cylinder 24" | Built by |
| Length of stroke 36" | Pressure |
| Revolutions per Minute 75 | Barometer Reads |
| Pressure of Steam in lbs. in Boiler 58 | Throttle |
| Position of Throttle Valve Full Open | Regulator |
| Vacuum per Gauge in Inches 22.75 | REMARKS: |
| Temperature of Hot Well 126° | Conditions same as |
| Scale of Spring 40 | July 27th 1903 |
| Inside Diameter of Feed Pipe | |
| " " Exhaust Pipe | |
| Valves | |

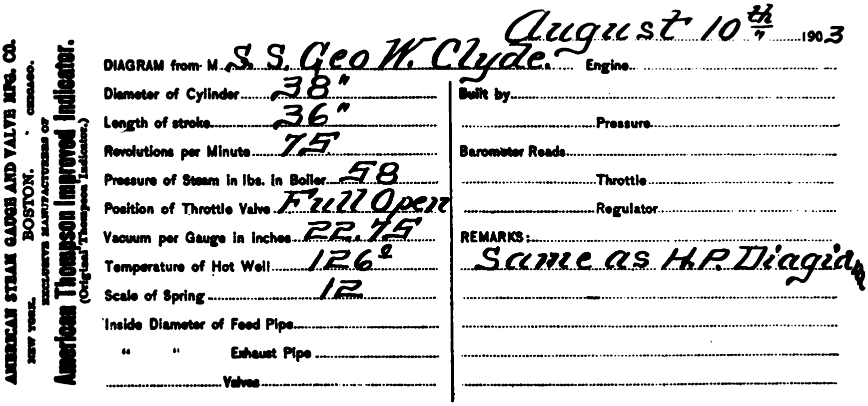



Card "d"




Card "e"

Taking diagram "c" we see that the drop between boiler and H. P. piston is 7.5 lbs. for top, 6.75 for bottom. The initial steam pressure top is 50.5 lbs. or 65.5 lbs. absolute. For the bottom the initial pressure is 51.25 lbs. gauge or 66.25 lbs. absolute. The absolute steam pressure is 73 lbs. The M. E. P. top is 36.25 lbs., M. E. P. bottom is 35 lbs., giving a difference between top and bottom of 1.25 lbs.


AMERICAN STEAM GAUGE AND VALVE MFG. CO.
NEW YORK. BOSTON. CHICAGO.
EXCLUSIVE MANUFACTURERS OF
American Thompson Improved Indicator.
(Original "Thompson Indicator.")

August 10th 1903
DIAGRAM from M. S. S. Geo W. Clyde. Engine
Diameter of Cylinder 38"
Length of stroke 36"
Revolutions per Minute 75
Pressure of Steam in lbs. in Boiler 58
Position of Throttle Valve Full Open
Vacuum per Gauge in inches 22.75
Temperature of Hot Well 126°
Scale of Spring 12
Inside Diameter of Feed Pipe
" " Exhaust Pipe
Valves
Built by
Pressure
Barometer Reads
Throttle
Regulator
REMARKS: Same as H.P. Diagram

The average M. E. P. is 36.25# + 35# = 71.25 lbs. 71.25 ÷ 2 = 35.625 lbs.

For diagrams "d" and "e" we have no drop in receiver. The receiver pressure is 6.75 lbs. gauge or 21.75 lbs. absolute. The M. E. P. of L. P. top is 15 lbs. The M. E. P. of L. P. bottom is 13.875 lbs.

The average M. E. P. is 15# + 13.875# = 28.875 lbs. 28.875 ÷ 2 = 14.875 lbs.

The constant for H. P. cylinder we found to be 0.02741.

Now for H. P. cylinder the I. H. P. is thus found to be $0.02741 \times 35.625 \times 75 \times 3 = 219.712$ I. H. P.

The constant for L. P. cylinder was 0.06873.

The I. H. P. L. P. cylinder is thus found to be $0.06873 \times 14.875 \times 75 \times 3 = 229.95$ I. H. P., say 230.

The collective I. H. P. = 219.712 + 230 = 449.712.

The aggregate equivalent M. P. referred to L. P. piston is, therefore,

$$\frac{35.625}{2.56} + 14.875 = 13.91\# + 14.875\# = 28.785 \text{ lbs.*}$$

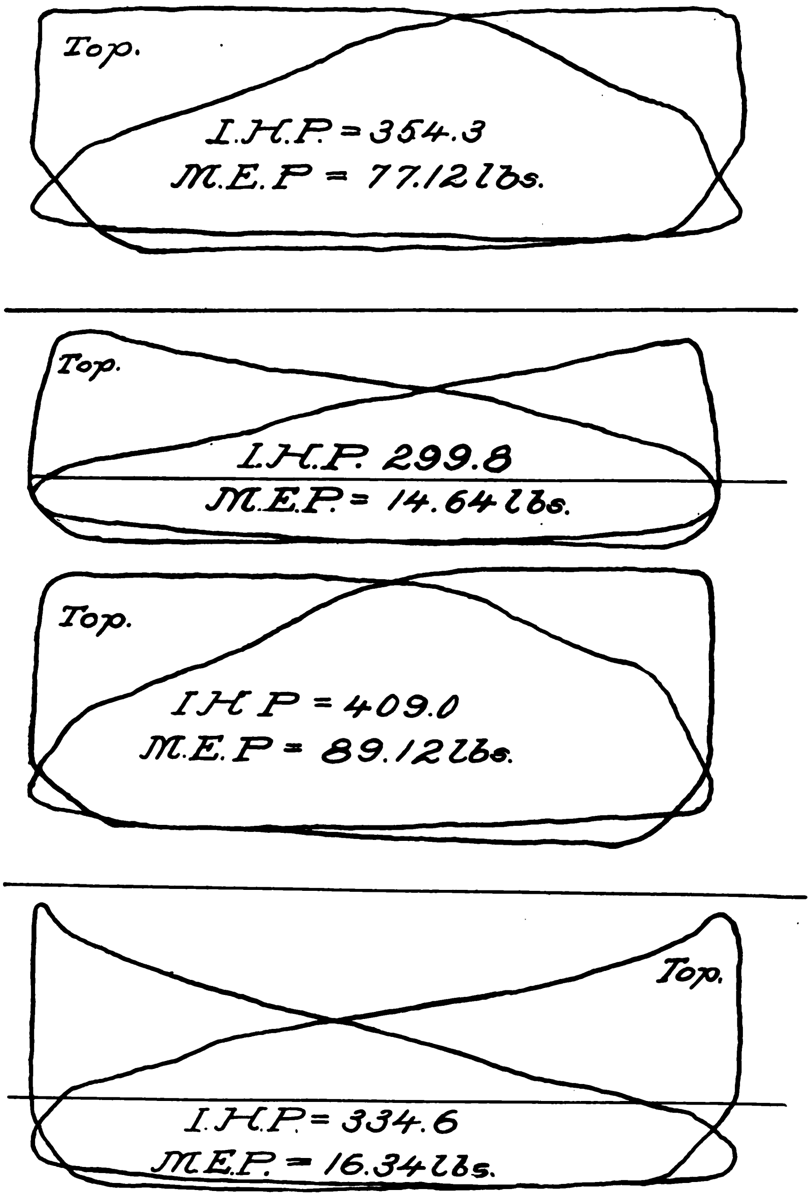
Following are two series of indicator diagrams. Taken from a double screw ferryboat, whose cylinders measure

$$\frac{18'' \times 38''}{28''} \text{ and } \frac{18'' \times 38''}{28''}$$

| RUN | REV. | RUN | REV. |
|---|---|---|---|
| 1 and 2 | 128¼ | 5 and 6 | 128½ |
| 3 and 4 | 130 | Average of all Runs | 128.9 |

* A close perusal of the diagrams from the G. W. Clyde will prove the uncertainty and, in fact, unreliability of ordinary indicator pipes as fitted. If on trial trip the ordinary method of one instrument to each cylinder is insisted upon, then before any data is taken, diagrams with short connections should be made, and hence a correction factor is determined. After this has been done, we have a check for the diagrams, and no error need be introduced.

SERIES 1




RUN No. 1A

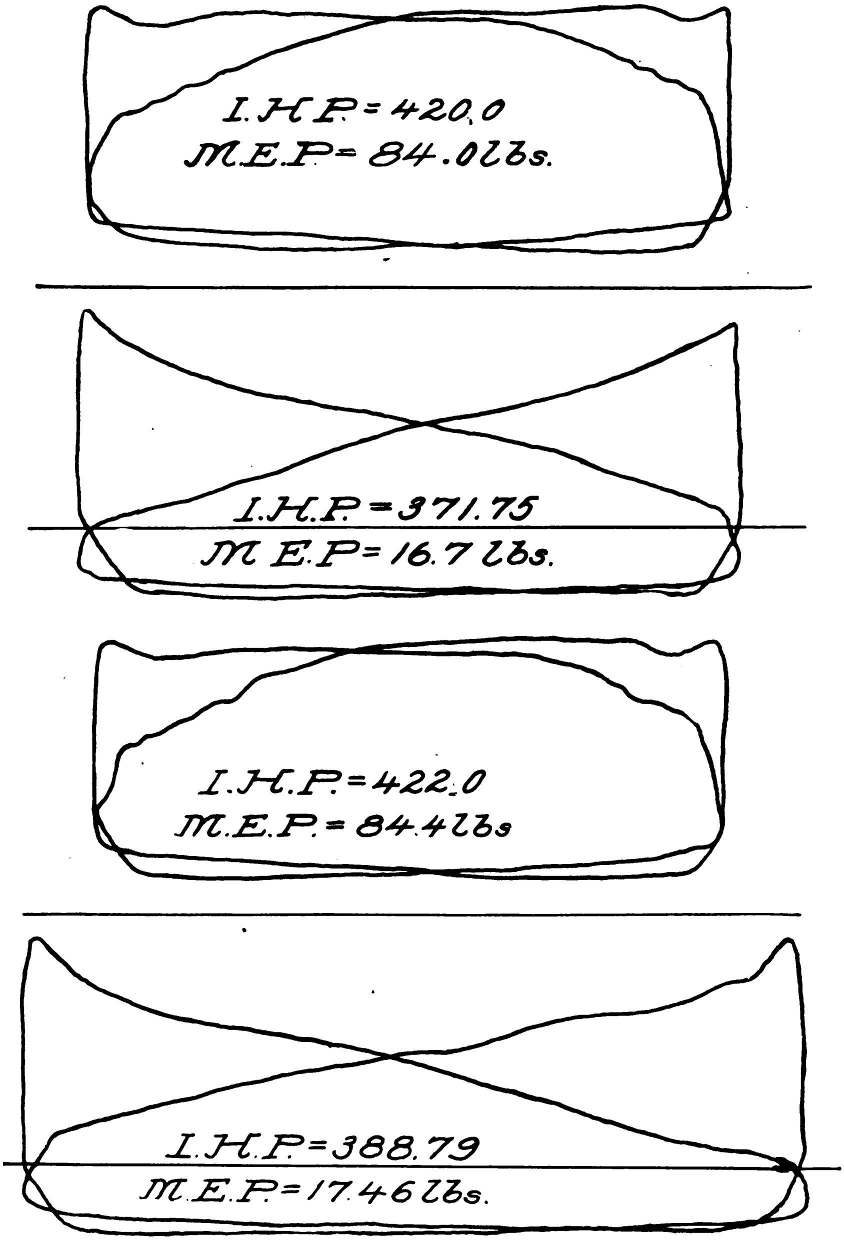
Steam 150 For'd Rec. 24 Aft. Rec. 24 Vac. 24″ Rev. 127

I. H. P., F. H. P. 354.3 I. H. P., F. L. P. 299.8

I. H. P., A. H. P. 409.0 I. H. P., A. L. P. 334.6 Total, I. H. P. 1397.7

Throttle wide open. Gear: { F. H. P. linked in $3\frac{3}{16}''$. A. H. P. linked in $2\frac{11}{16}''$.
F. L. P. linked full out. A. L. P. linked full out. }

SERIES 2




RUN NO. 2B

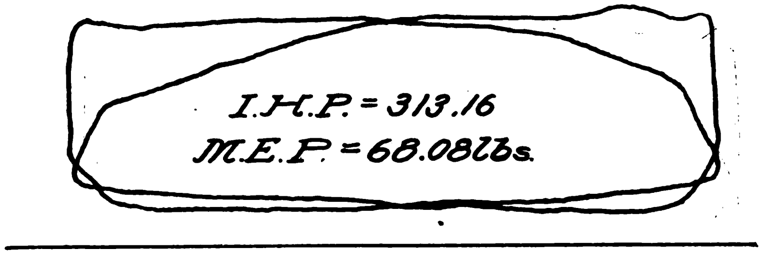
Steam $132\frac{1}{2}$ L. P. Rec. 23 Vac. $24\frac{1}{2}''$ Rev. 139

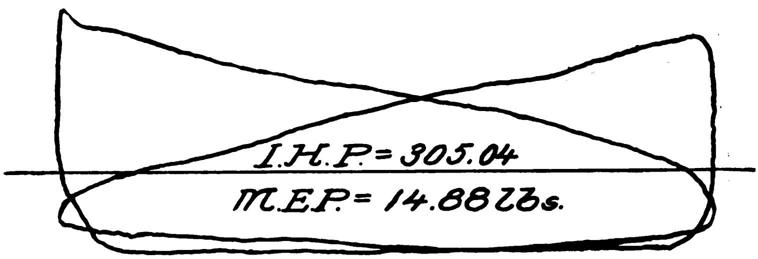
I. H. P., F. H. P. 420.0 I. H. P., F. L. P. 371.75

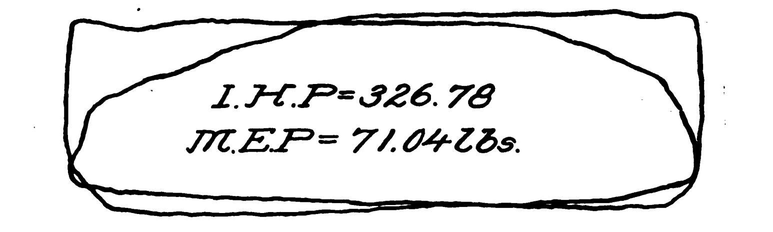
I. H. P., A. H. P. 422.0 I. H. P., A. L. P. 388.79 Total, I. H. P. 1602.54

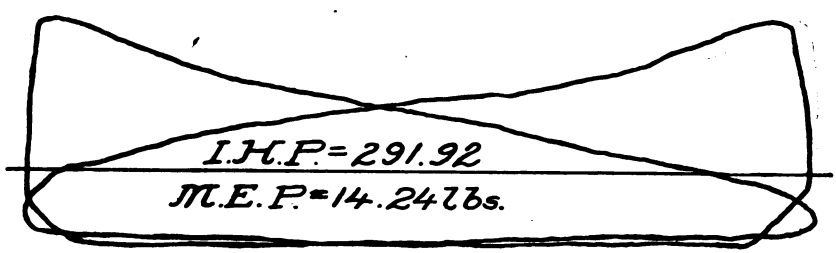
Throttle wide open. Full Gear.

SERIES 2




RUN NO. 3A

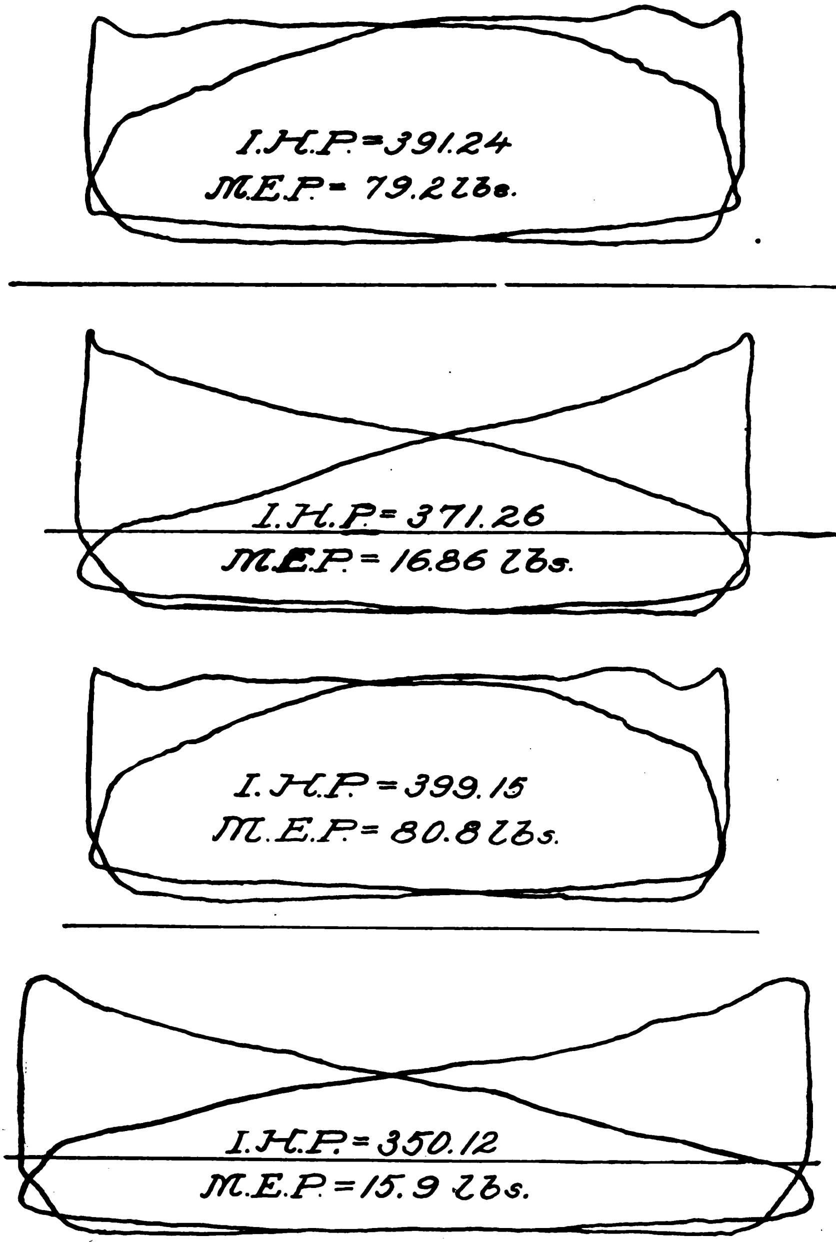
Steam 112 L. P. Rec. 18 Vac. 25″ Rev. 128

I. H. P., F. H. P. 313.16 I. H. P., F. L. P. 305.04

I. H. P., A. H. P. 326.78 I. H. P., A. L. P. 291.92 Total, I. H. P. 1236.90

Throttle wide open. Full Gear.

Series 2




Run No. 4A

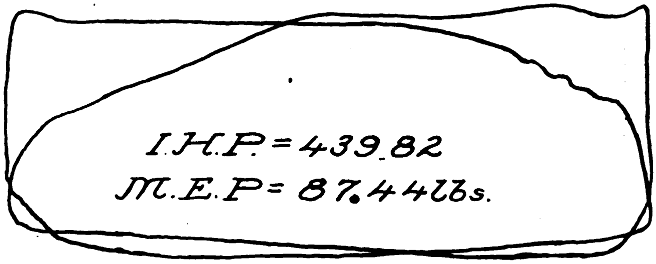
Steam 122 L. P. Rec. $19\frac{1}{2}$ Vac. $25\frac{3}{4}''$ Rev. $137\frac{1}{2}$

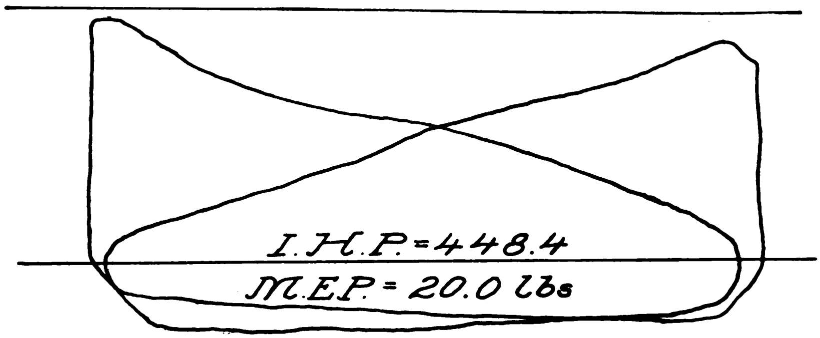
I. H. P., F. H. P. 391.24 I. H. P., F. L. P. 371.26

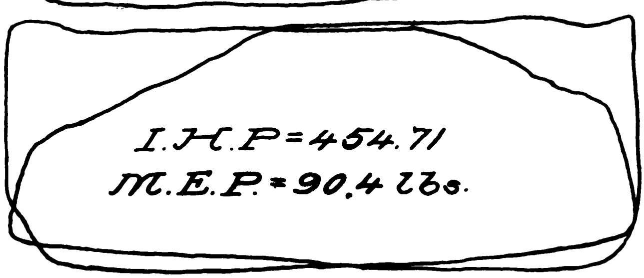
I. H. P., A. H. P. 399.15 I. H. P., A. L. P. 350.12 Total, I. H. P. 1511.77

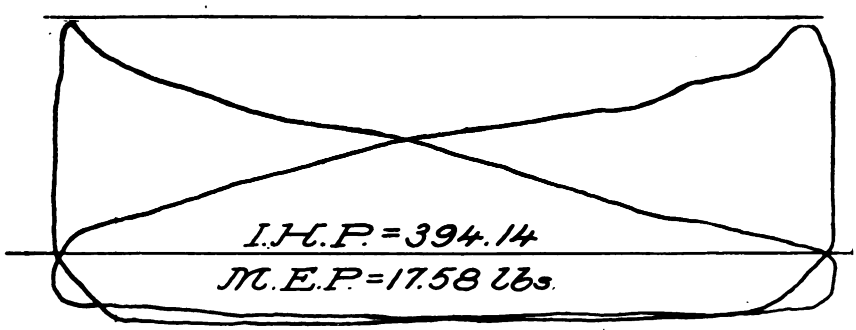
Throttle wide open. Full Gear.

SERIES 2




RUN No. 5B

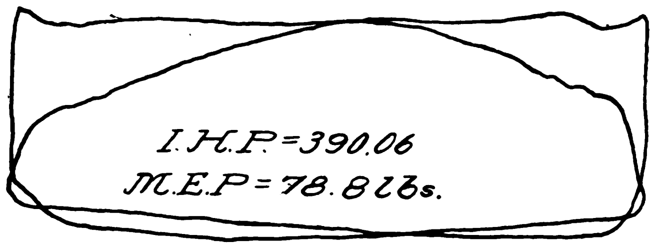
Steam 150 L. P. Rec. 28 Vac. 24″ Rev. 140

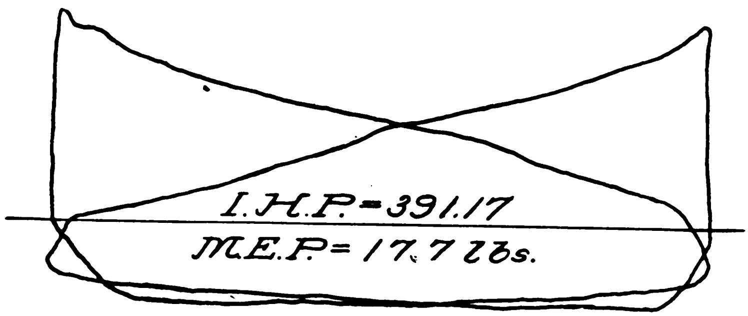
I. H. P., F. H. P. 439.82 I. H. P., F. L. P. 448.4

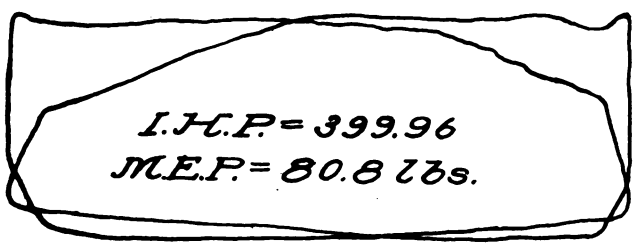
I. H. P., A. H. P. 454.71 I. H. P., A. L. P. 394.14 Total, I. H. P. 1737.07.

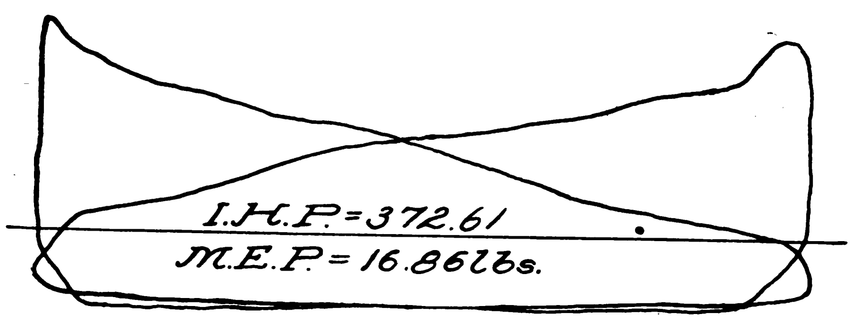
Throttle wide open. All linked up ¾.

SERIES 2




RUN No. 6B

Steam 125  L. P. Rec. 23  Vac. 27″  Rev. 138½

I. H. P., F. H. P. 390.06  I. H. P., F. L. P. 391.17

I. H. P., A. H. P. 399.96  I. H. P., A. L. P. 372.61  Total, I. H. P. 1553.80

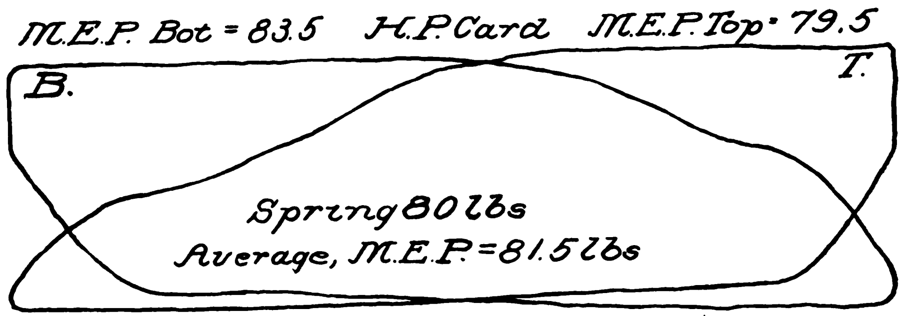
Throttle wide open.  All linked up ¾.

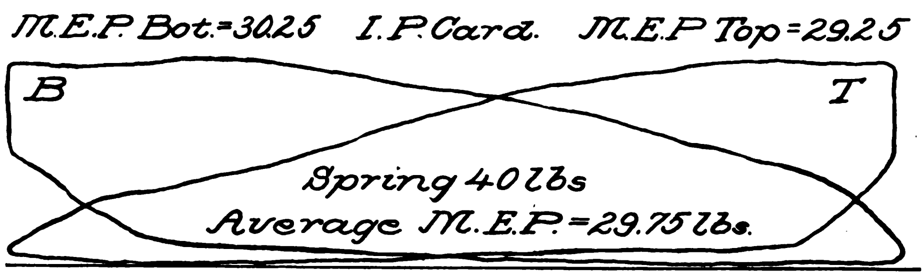
SERIES 3

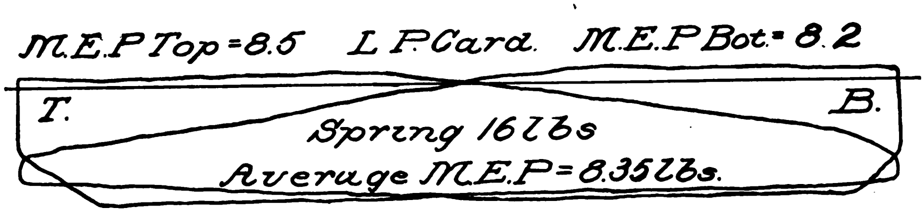
ENGINE $\dfrac{25'' \times 41\frac{1}{2}'' \times 68''}{42''}$

Steam Pressure, 170 lbs. per square inch designed. Boiler Pressure, 150 lbs. on trial. 1st Receiver 44 lbs. 2d Receiver 6½ lbs. Vacuum, 26 inches.

Revolutions 86 lbs.



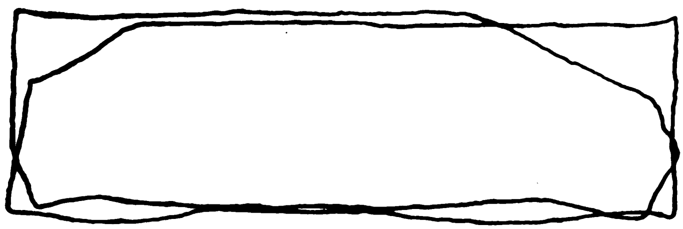



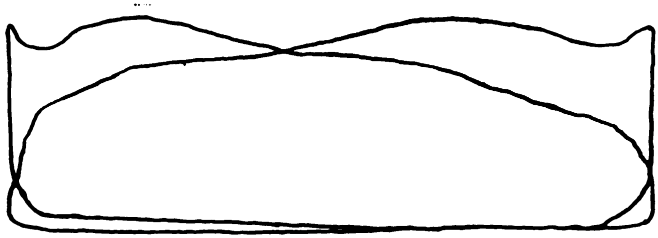

I. H. P. 710.68 H. P. Cyl. I. H. P. 551.10 L. P. Cyl.
I. H. P. 727.09 I. P. Cyl. Total, 1,988.87
Mean Pressure, Ref. D. to L. P. Cyl. = 28.62 lbs.
Throttle full open. All valves linked up to cut-off 29¾″ top, 26½″ bot.

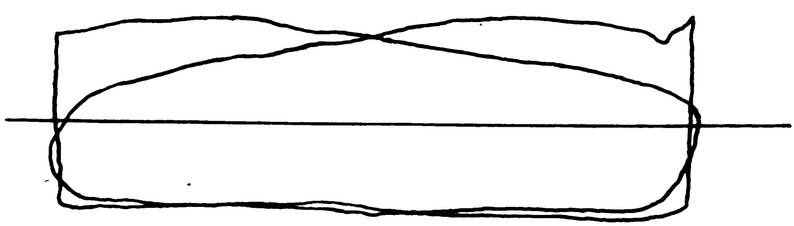
### Series 4

ENGINE $\frac{34'' \times 57'' \times 104''}{63''}$

| HIGH PRESSURE | INTERMEDIATE PRESSURE | LOW PRESSURE |
|---|---|---|
| Diam. Cylinder....34″ | Diam. Cylinder....57″ | Diam. Cylinder...104″ |
| Diam. Piston Rod...9″ | Diam. Piston Rod...9″ | Diam. Piston Rod...9″ |
| Stroke............63″ | Stroke...........63″ | Stroke............63″ |
| Scale of Spring...120 | Scale of Spring.....60 | Scale of Spring.10 & 20 |
| I. H. P. Constant .2787 | I. H. P. Constant..8019 | I.H.P. Constant 2.6928 |

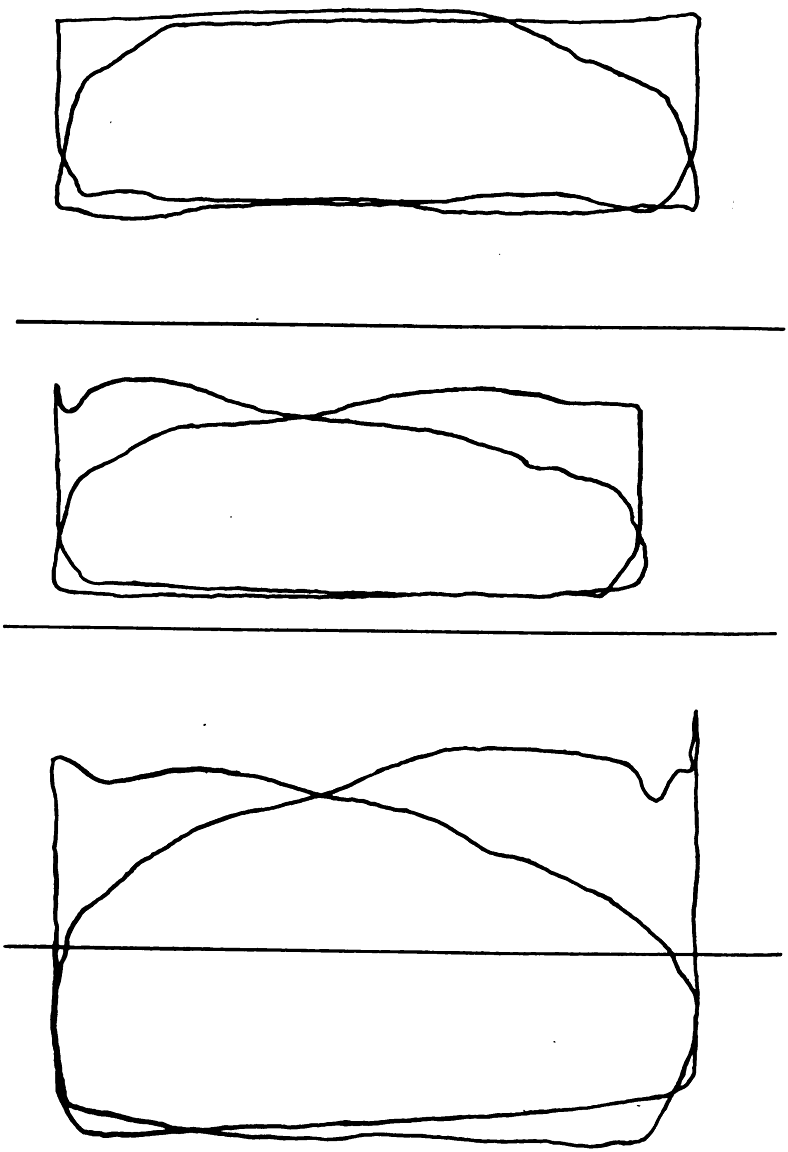






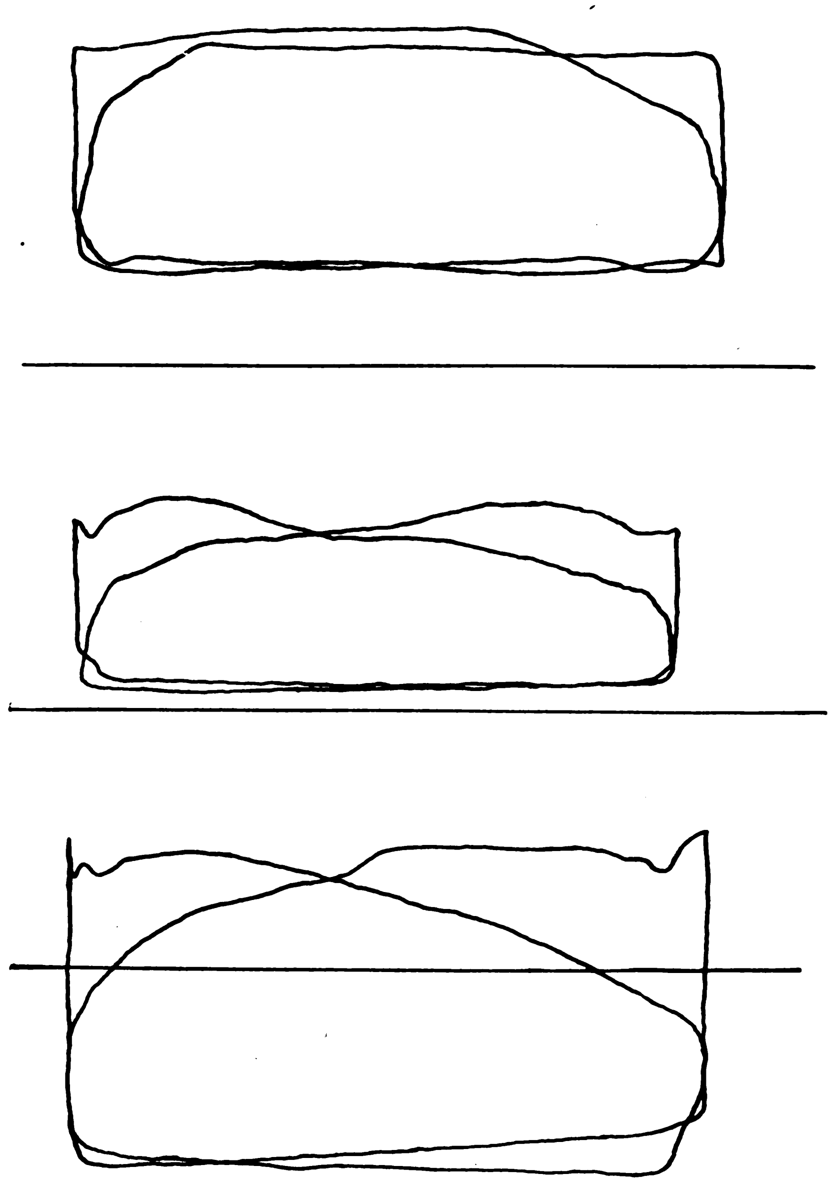
| M. E. P. | I. H. P. | | |
|---|---|---|---|
| H = 115.05 | H = 2,661.35 | Steam.............. | 232. |
| M = 52.95 | M = 3,524.23 | M. P. Rec........... | 81. |
| L = 17.07 | L = 3,815.19 | L. P. Rec............ | 19. |
| | Total, 10,000.77 | Vacuum............ | 25.5″ |
| | | R. P. M............. | 83. |
| | | Piston Speed........ | 871.5 |
| | | Cut Off............. | Full |

SERIES 4



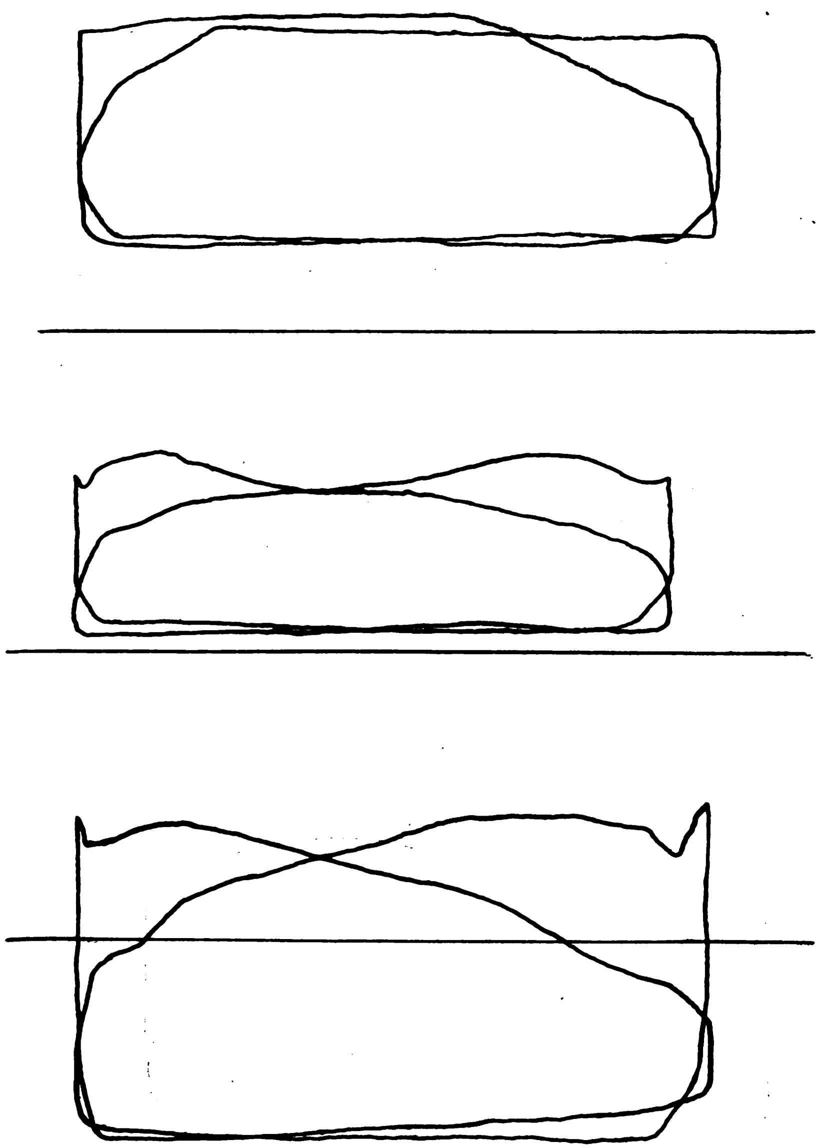
| M. E. P. | I. H. P. | | |
|---|---|---|---|
| H = 110.4 | H = 2,524. | Steam | 230. |
| M = 54.3 | M = 3,570. | M. P. Rec. | 79. |
| L = 16.43 | L = 3,630. | L. P. Rec. | 16. |
| | Total, 9,724. | Vacuum | 24.5″ |
| | | R. P. M. | 82. |
| | | Piston Speed | 861. |
| | | Cut off | Full |

**Series 4**



| M. E. P. | I. H. P. | | |
|---|---|---|---|
| H = 130.99 | H = 2,885. | Steam | 232. |
| M = 48.15 | M = 3,050. | M. P. Rec. | 65. |
| L = 13.71 | L = 2,917. | L. P. Rec. | 12.5 |
| | Total, 8,852. | Vacuum | 25.″ |
| | | R. P. M. | 79. |
| | | Piston Speed | 829.5 |
| | | Cut off | Full |

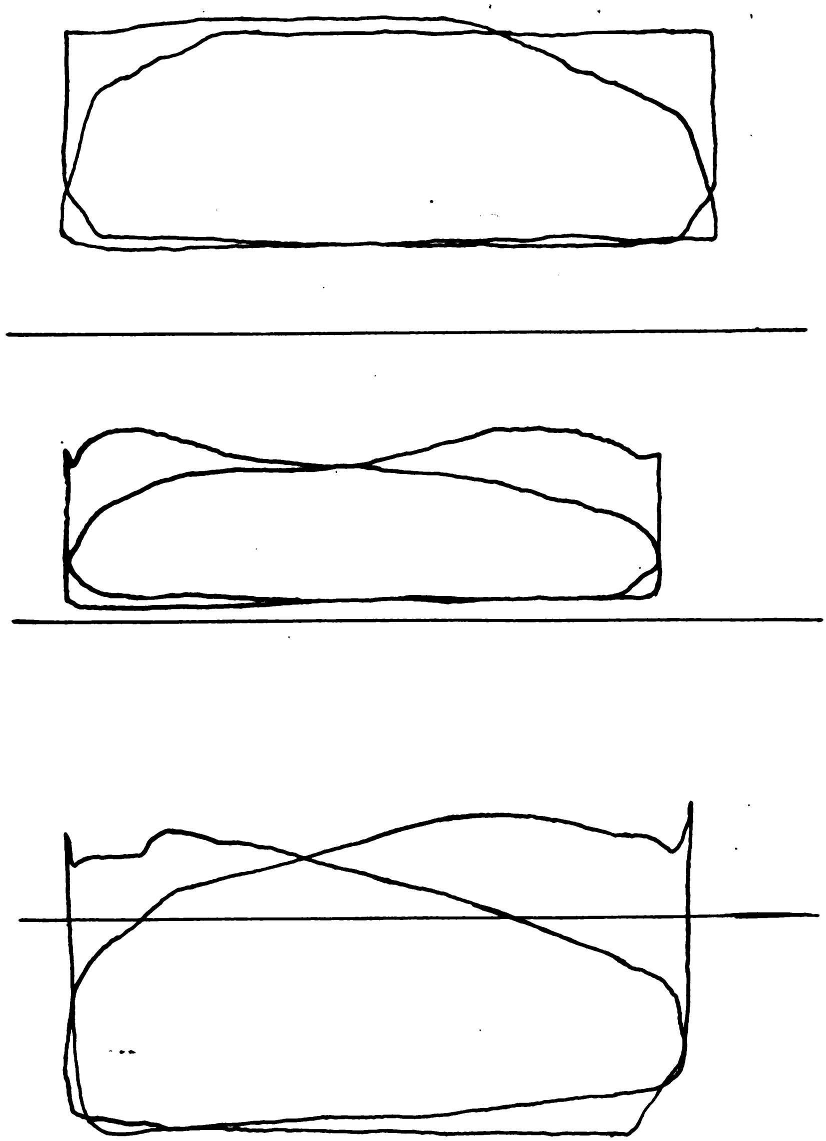
SERIES 4



| M. E. P. | I. H. P. | Steam | 225. |
|---|---|---|---|
| H = 126.15 | H = 2,707.4 | M. P. Rec. | 62. |
| M = 41.55 | M = 2,565.3 | L. P. Rec. | 11.25 |
| L = 13.50 | L = 2,799.1 | Vacuum | 24.″ |
| | Total, 8,071.8 | R. P. M. | 77. |
| | | Piston Speed | 808.5 |

Cut off: H. P. = .71, M. P. = .732, L. P. = Full

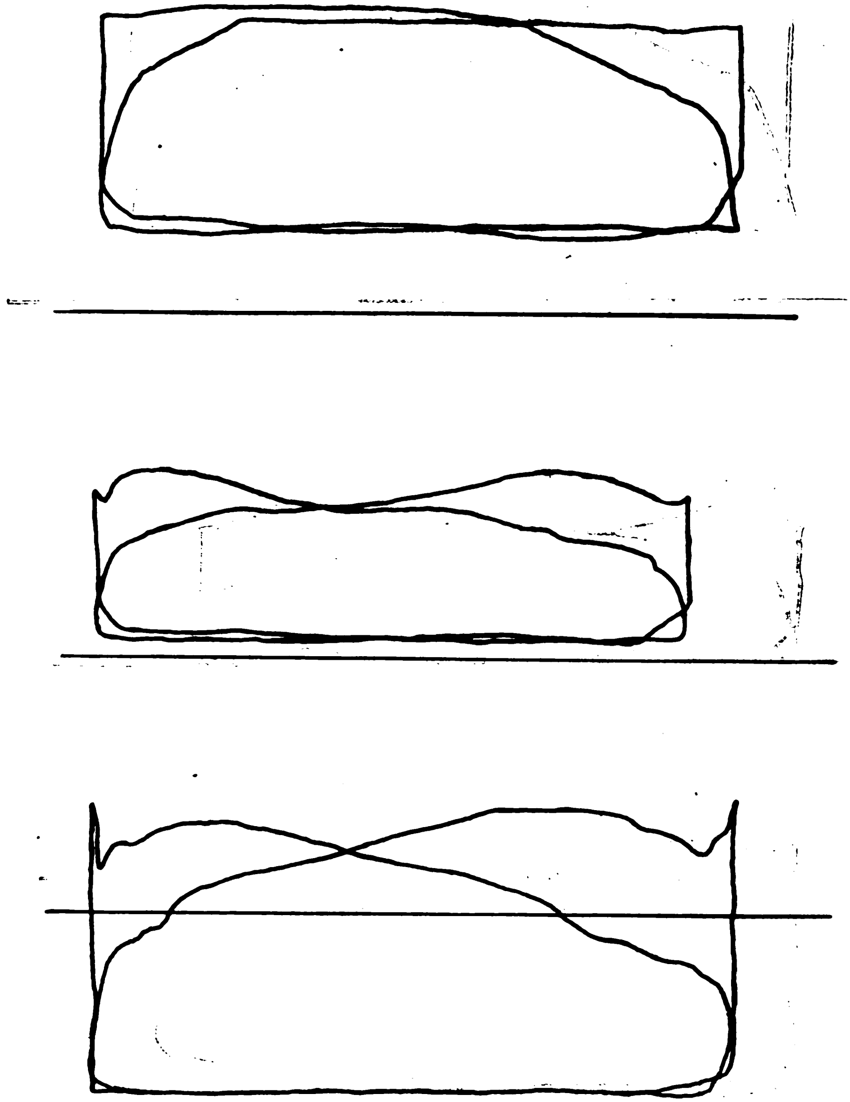
**Series 4**



| M. E. P. | I. H. P. | | |
|---|---|---|---|
| H = 123.6 | H = 2,602. | Steam................. | 220. |
| M = 41.7 | M = 2,525. | M. P. Rec. ............ | 59. |
| L = 12.81 | L = 2,605. | L. P. Rec. ............ | 10.5 |
| | Total, 7,732. | Vacuum .............. | 25.5″ |
| | | R. P. M. ............... | 75.5 |
| | | Piston Speed .......... | 79.3 |

Cut off: H. P. = .71, M. P. & L. P. = Full

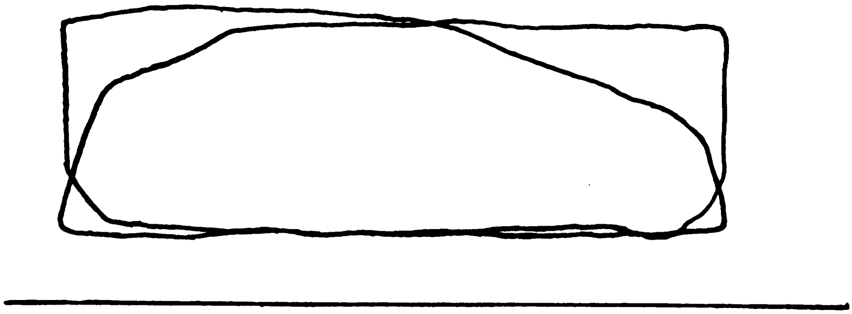
SERIES 4

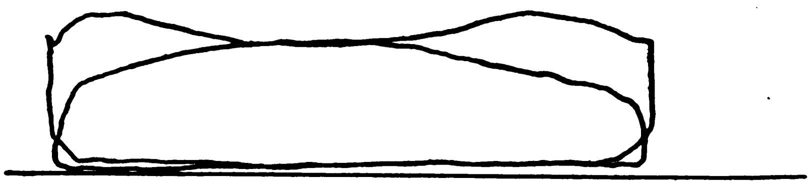


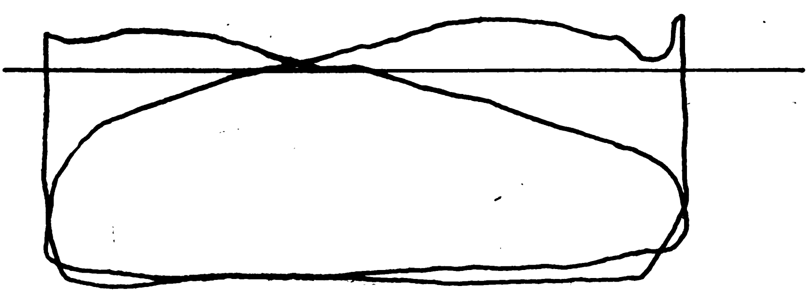
| M. E. P. | I. H. P. | | |
|---|---|---|---|
| H = 122.55 | H = 2,561.84 | Steam | 220. |
| M = 41.10 | M = 2,471.60 | M. P. Rec. | 61. |
| L = 11.74 | L = 2,360.95 | L. P. Rec. | 10.5 |
| | Total, 7,394.39 | Vacuum | 25." |
| | | R. P. M. | 75. |
| | | Piston Speed | 787.5 |

Cut off: H. P.=.69, M. P. & L. P.=.75

SERIES 4



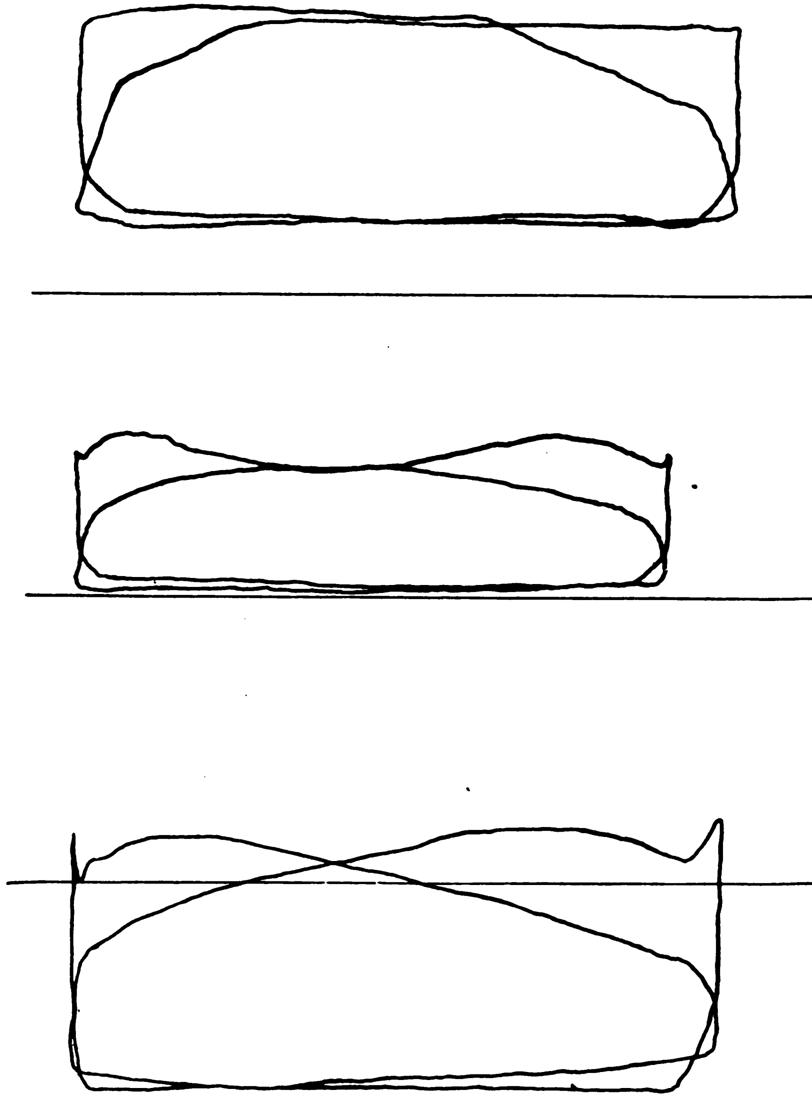




| M. E. P. | I. H. P. | | |
|---|---|---|---|
| H = 125.1 | H = 2,553.7 | Steam.............. | 210. |
| M = 36.9 | M = 2,167.5 | M. P. Rec. .......... | 49.5 |
| L = 10.48 | L = 2,067.2 | L. P. Rec. ........... | 8.0 |
| | | Vacuum ........... | 25.″ |
| | Total, 6,788.4 | R. P. M.............. | 73.25 |
| | | Piston Speed ....... | 769.125 |

Cut off: H. P.=.66, M. P.—.75, L. P.=.735

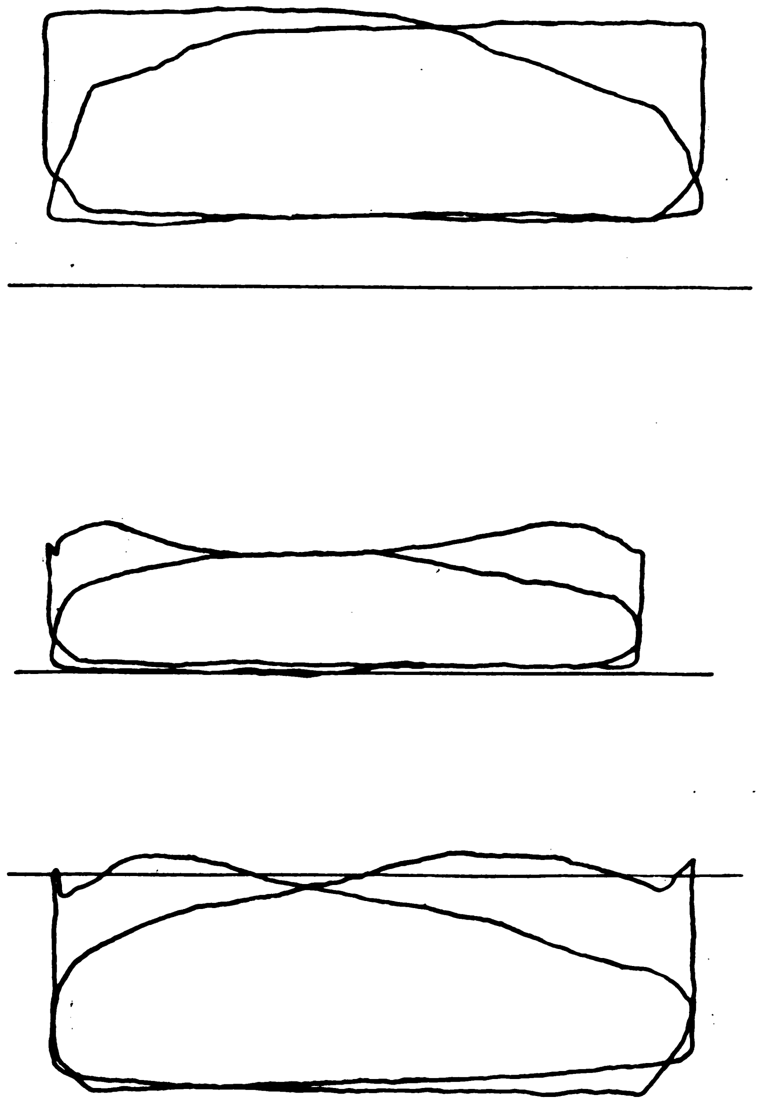
SERIES 4



| M. E. P. | I. H. P. | | |
|---|---|---|---|
| H = 114.3 | H = 2,301.66 | Steam | 202. |
| M = 36.0 | M = 2,085.48 | M. P. Rec. | 50. |
| L = 10.77 | L = 2,095.41 | L. P. Rec. | 8. |
| | Total, 6,482.55 | Vacuum | 25.″ |
| | | R. P. M. | 72.25 |
| | | Piston Speed | 758.6 |

Cut off: H. P. = .69, M. P. = .73, L. P. = .75

SERIES 4



| M. E. P. | I. H. P. | | |
|---|---|---|---|
| H = 110.55 | H = 2,141.3 | Steam | 204. |
| M = 34.42 | M = 1,918.3 | M. P. Rec. | 45. |
| L = 9.75 | L = 1,828.4 | L. P. Rec. | 6.5 |
| | | Vacuum | 25.5″ |
| | Total, 5,888.0 | R. P. M. | 69.5 |
| | | Piston Speed | 729.75 |

Cut off: H. P. = Normal, Throttled, M. P. & L. P. = Full

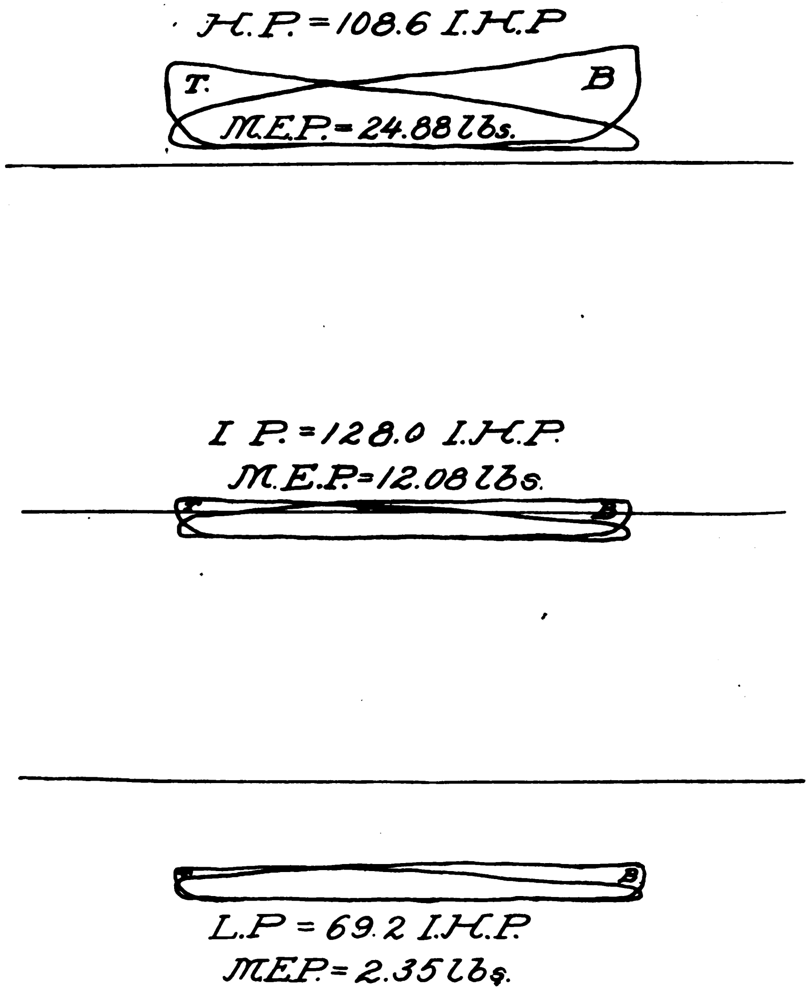
## TRIAL TRIP OF PASSENGER STEAMER AT DELAWARE BREAKWATER

| NO. OF RUN | STARBOARD ENGINE | | | | | | PORT ENGINE | | | | | | TOTAL I. H. P. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | STEAM | 1ST REC. | 2D REC. | VAC. INS. | REV. | I. H. P. | STEAM | 1ST REC. | 2D REC. | VAC. INS. | REV. | I. H. P. | |
| 1 | 145 | 18 | –9 | 26 | 99 | 305.8 | 145 | 17 | –7½ | 26½ | 96 | 308.4 | 614.2 |
| 2 | 144 | 17 | –8½ | 25½ | 96½ | 392.5 | 145 | 16½ | –7½ | 26½ | 97½ | 305.2 | 697.7 |
| 3 | 133 | 33½ | 0 | 25 | 118 | 739.2 | 133 | 35 | 1 | 26 | 119 | 656.5 | 1,395.7 |
| 4 | 137 | 34½ | 0 | 26 | 122 | 711.8 | 137 | 33½ | 0 | 27 | 123 | 740.1 | 1,451.9 |
| 5 | 147 | 51 | 5½ | 25½ | 136 | No Cards | 147 | 54 | 3 | 26½ | 136 | No cards | Taken |
| 6 | 150 | 52 | 6 | 26 | 136 | No Cards | 150 | 54 | 3 | 26 | 137 | No cards | Taken |
| 7 | 155 | 55 | 7 | 26 | 142 | 1,126.1 | 155 | 56 | 5 | 26 | 143 | 1,111.5 | 2,237.6 |
| 8 | 158 | 57 | 10 | 26 | 146½ | 1,192.3 | 158 | 57 | 7 | 26 | 146½ | 1,216.9 | 2,409.2 |

Scale of Springs used: H. P. = 80 lbs. M. P. = 30 lbs. L. P. = 16 lbs.
Length of course = 1.261 nautical miles.

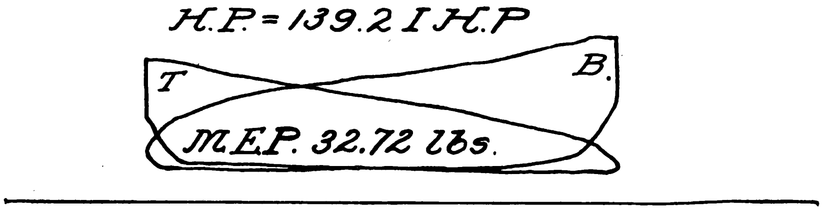
Engine $\frac{19\frac{1}{4}'' \times 30'' \times 50''}{30''}$

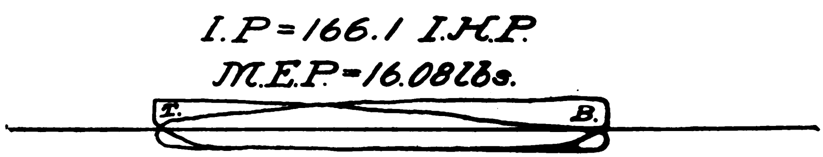
SERIES 5

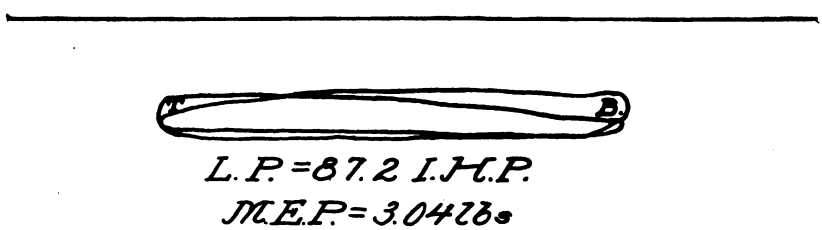



No. 1 STARBOARD

SERIES 5

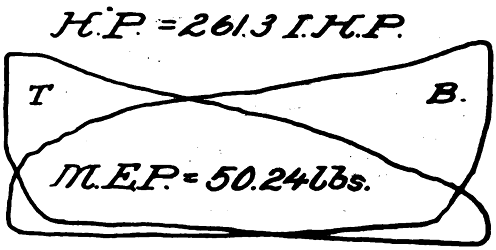


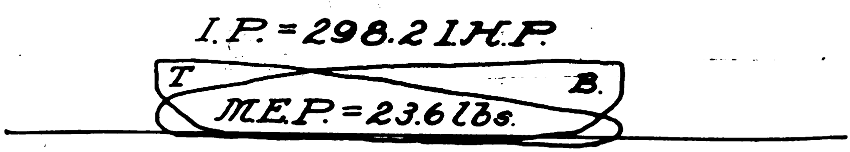



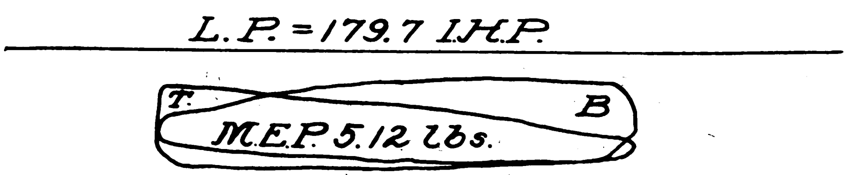




No. 2 STARBOARD

SERIES 5

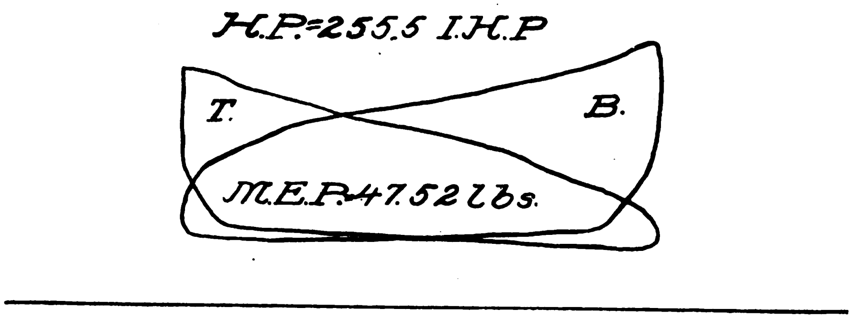


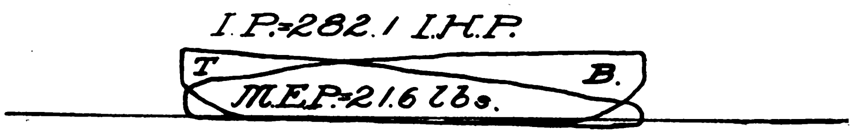



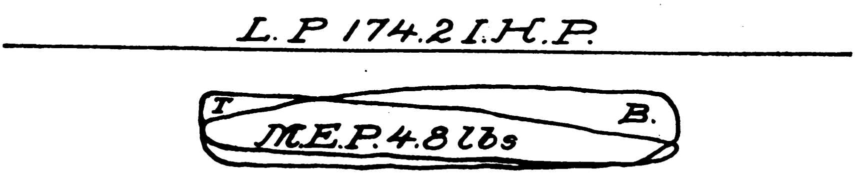




NO. 3 STARBOARD

SERIES 5

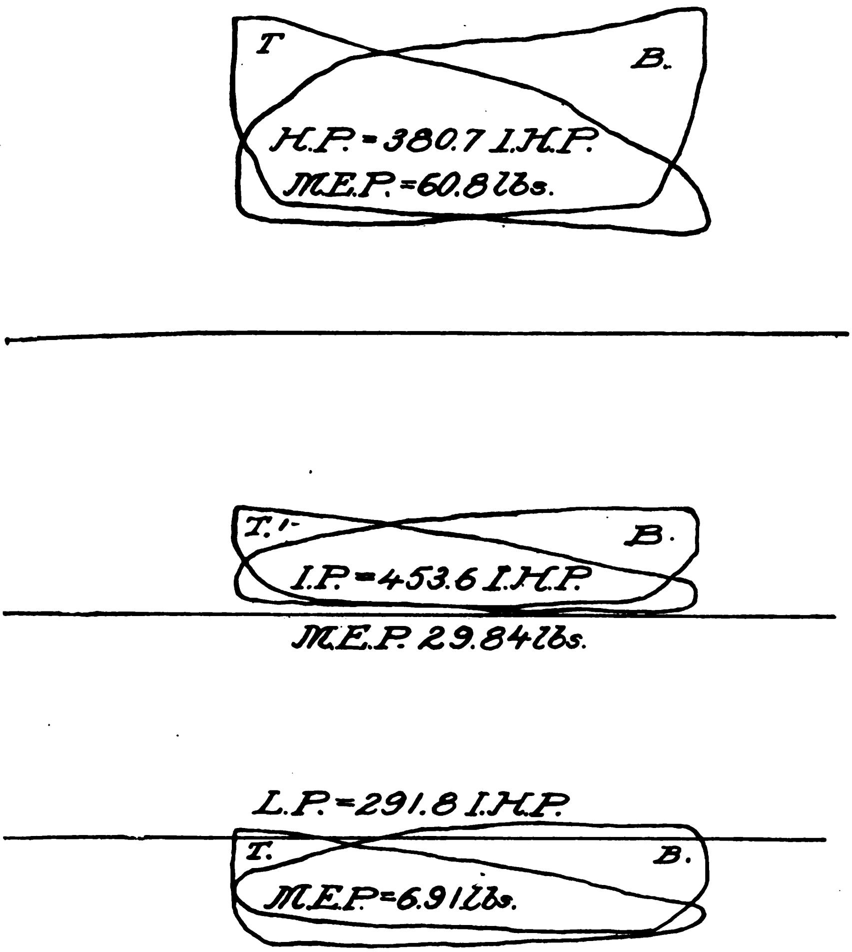


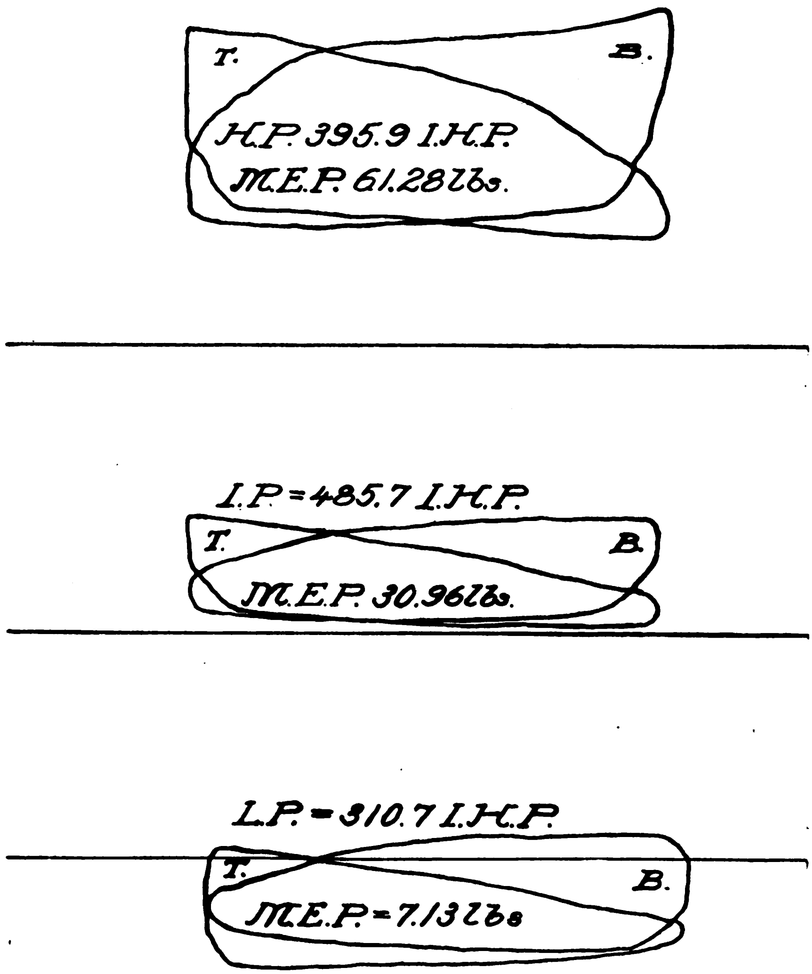

No. 4 STARBOARD

## Series 5



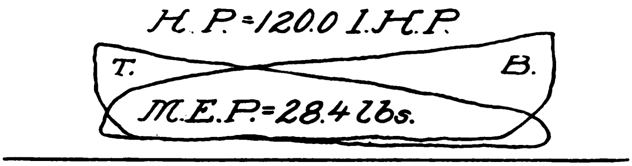

No. 7 Starboard

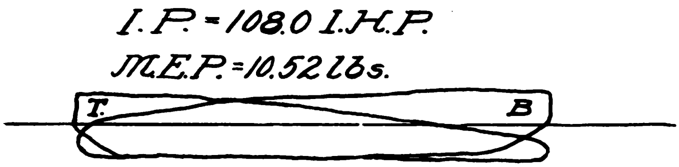
SERIES 5

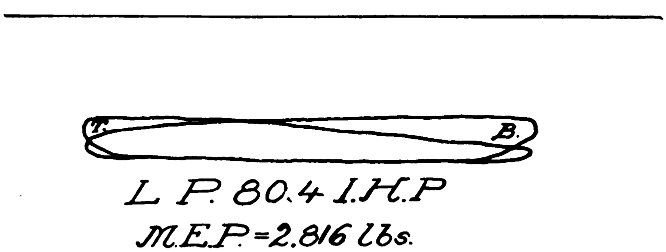



No. 8 STARBOARD

Series 5

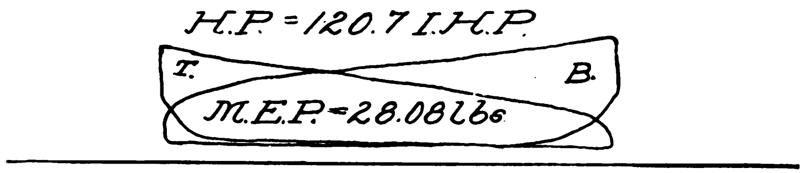


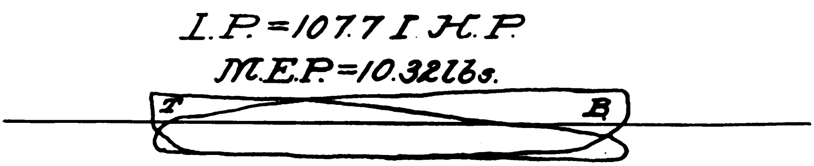



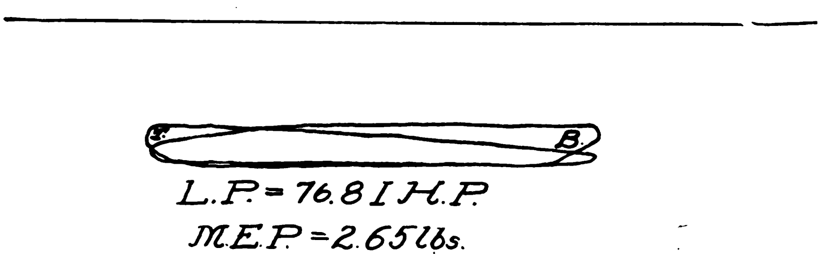




No. 1 Port

SERIES 5

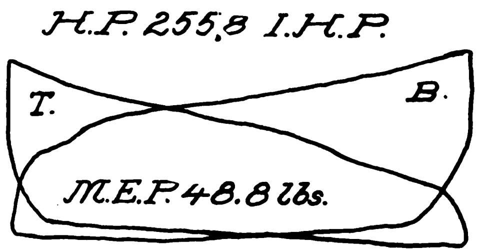


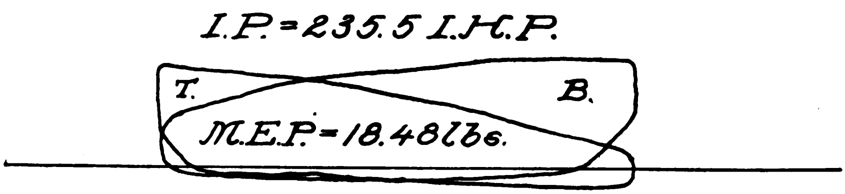



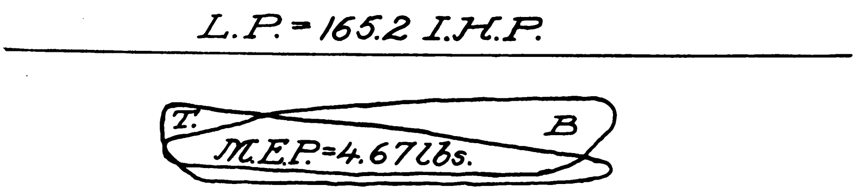




No. 2 PORT

SERIES 5

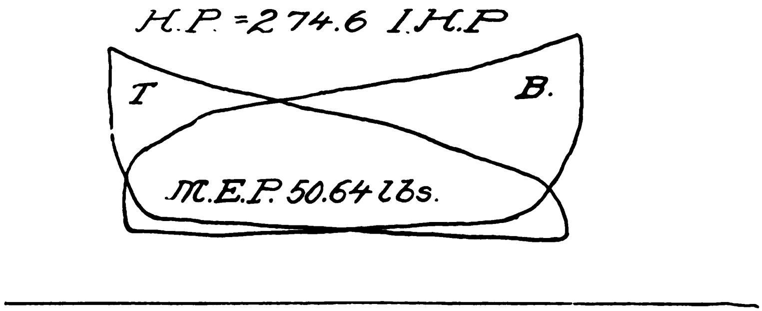


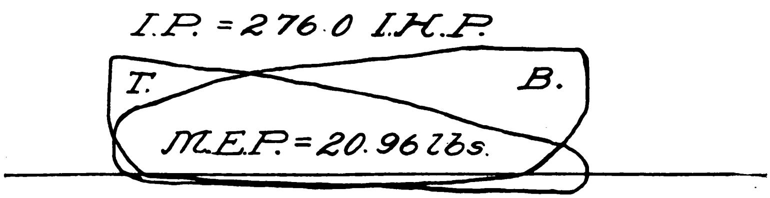



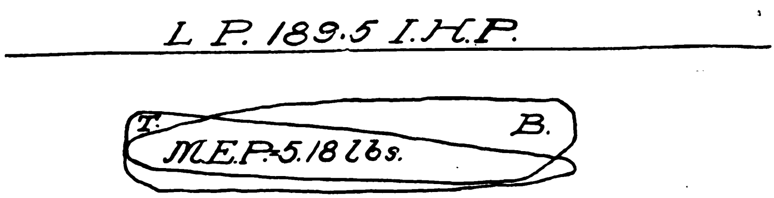




No. 3 PORT

Series 5

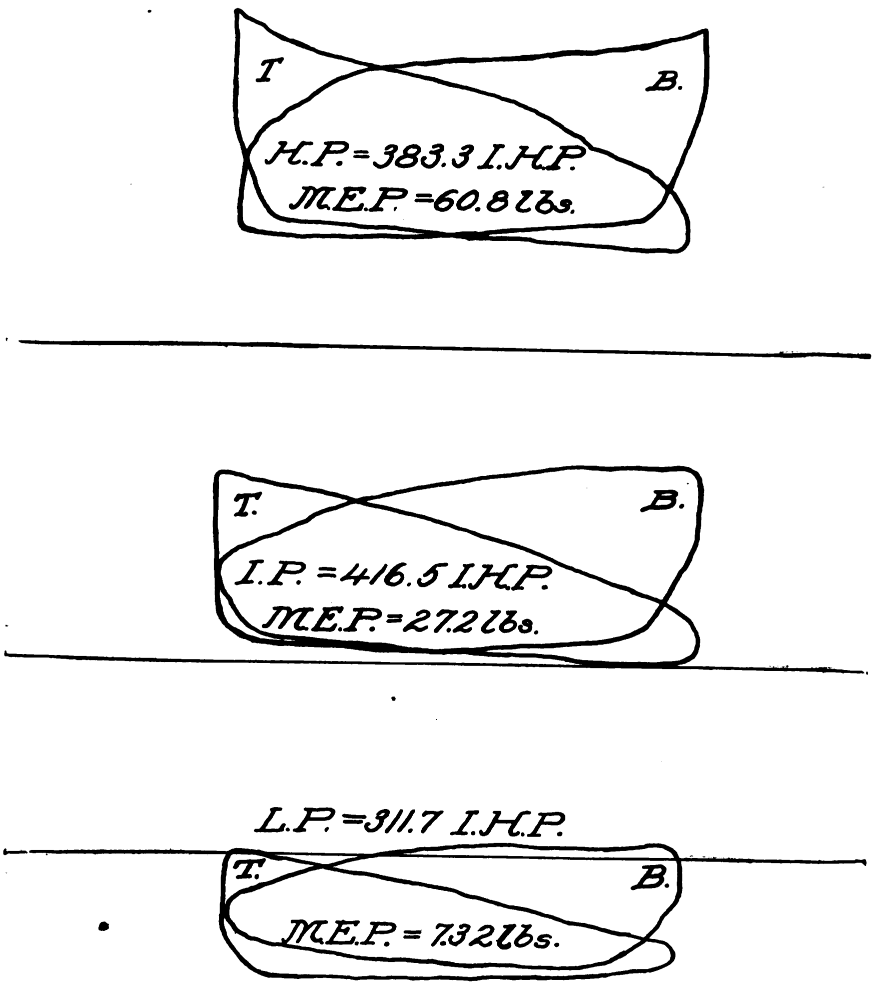


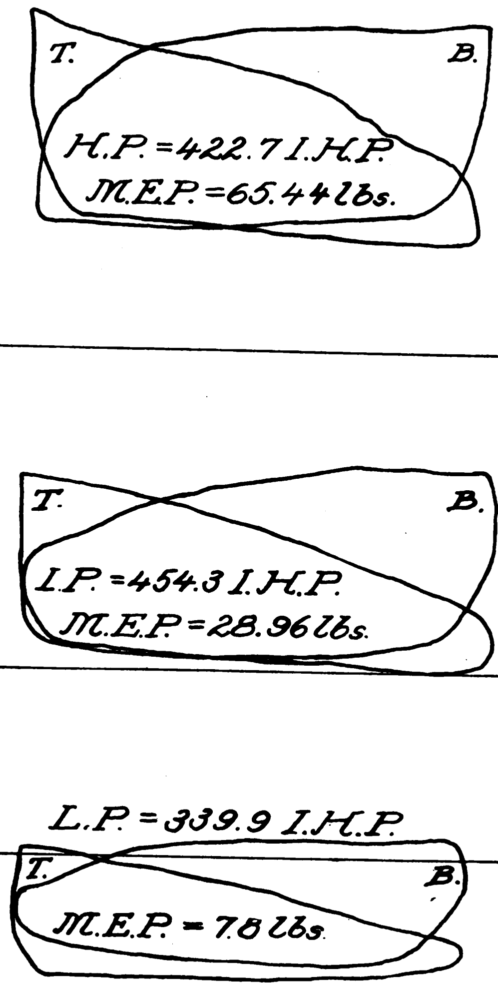

No. 4 Port

SERIES 5




No. 7 PORT

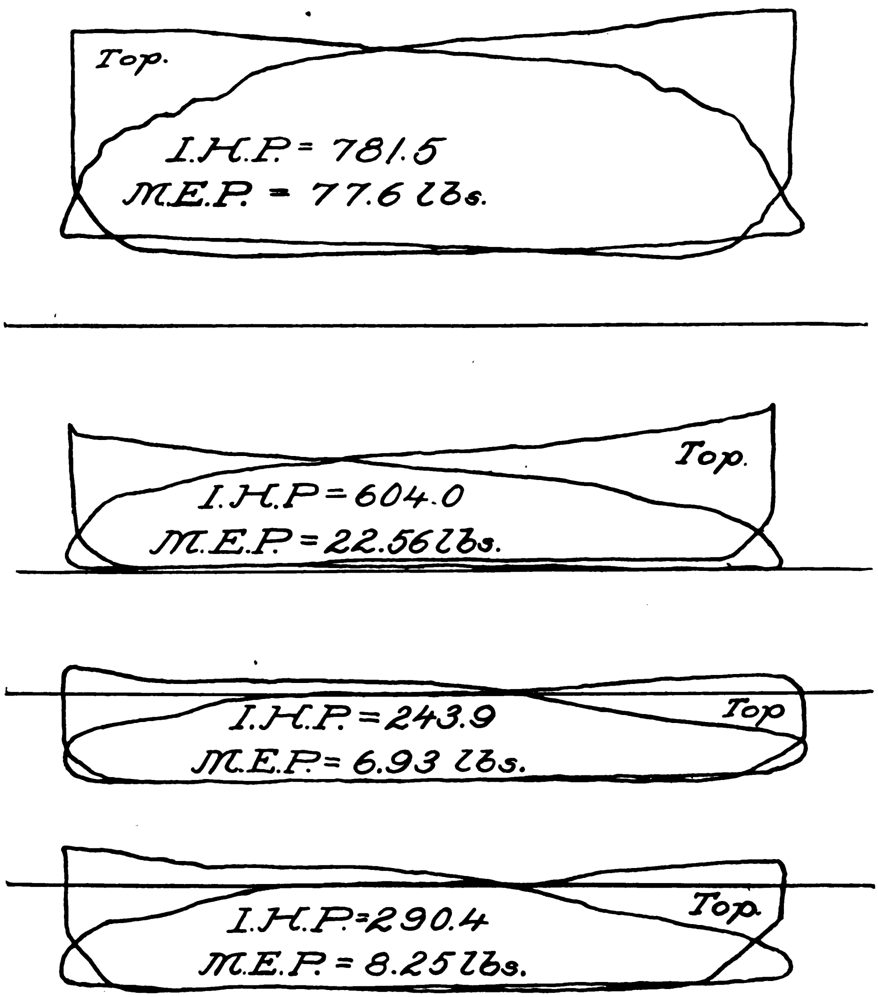
Series 5




No. 8 Port

### Series 6

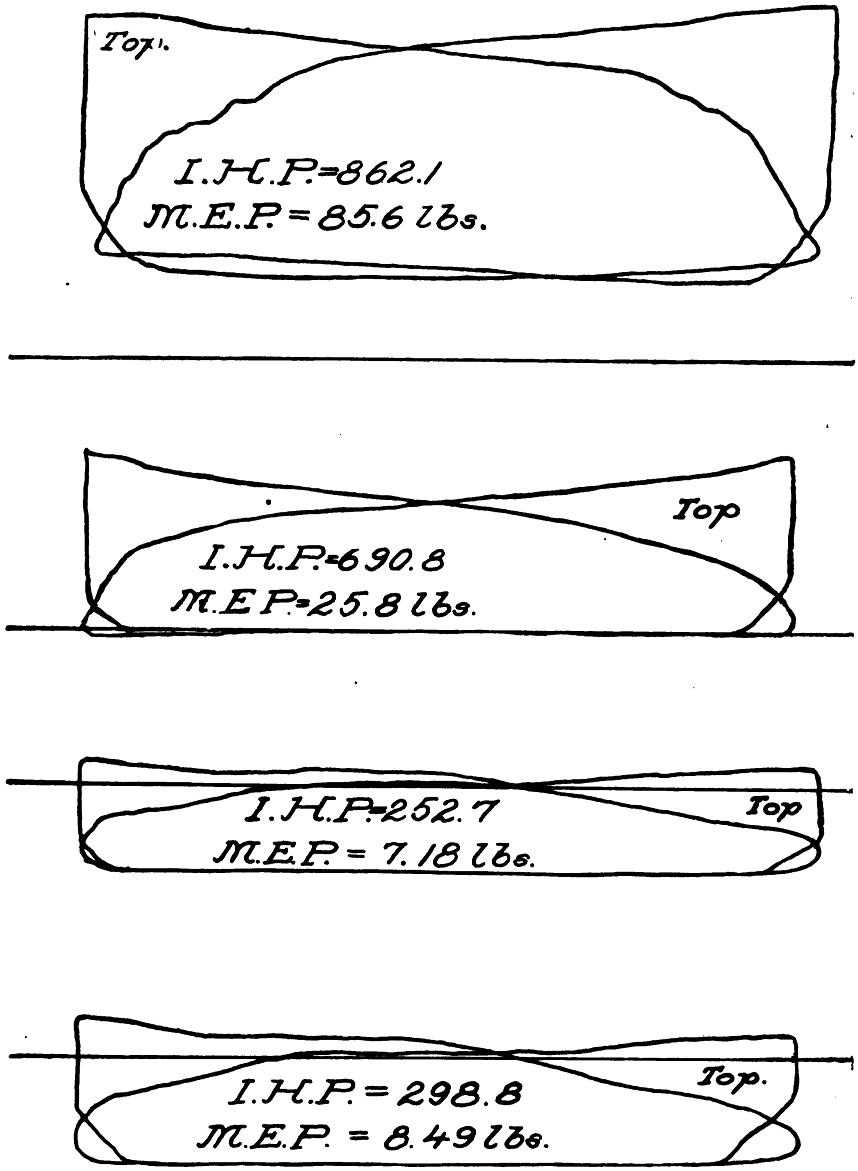
## INDICATOR DIAGRAMS TAKEN FROM ENGINE $\frac{23'' \times 37\frac{1}{2}'' \times 43'' \times 43''}{30''}$




No. 1 Starboard

Steam 145 lbs. 1st Rec. 38 lbs. 2d Rec. 3 lbs. Vac. 22″ Rev. 160
I. H. P., H. P. 781.5 I. H. P., I. P. 604.0
I. H. P., F. L. P. 243.9 I. H. P., A. L. P. 290.4 Total I. H. P.1919.8
Scale of springs used: H. P. = 80 lbs., M. P. = 30 lbs., L. P. = 16 lbs.

SERIES 6

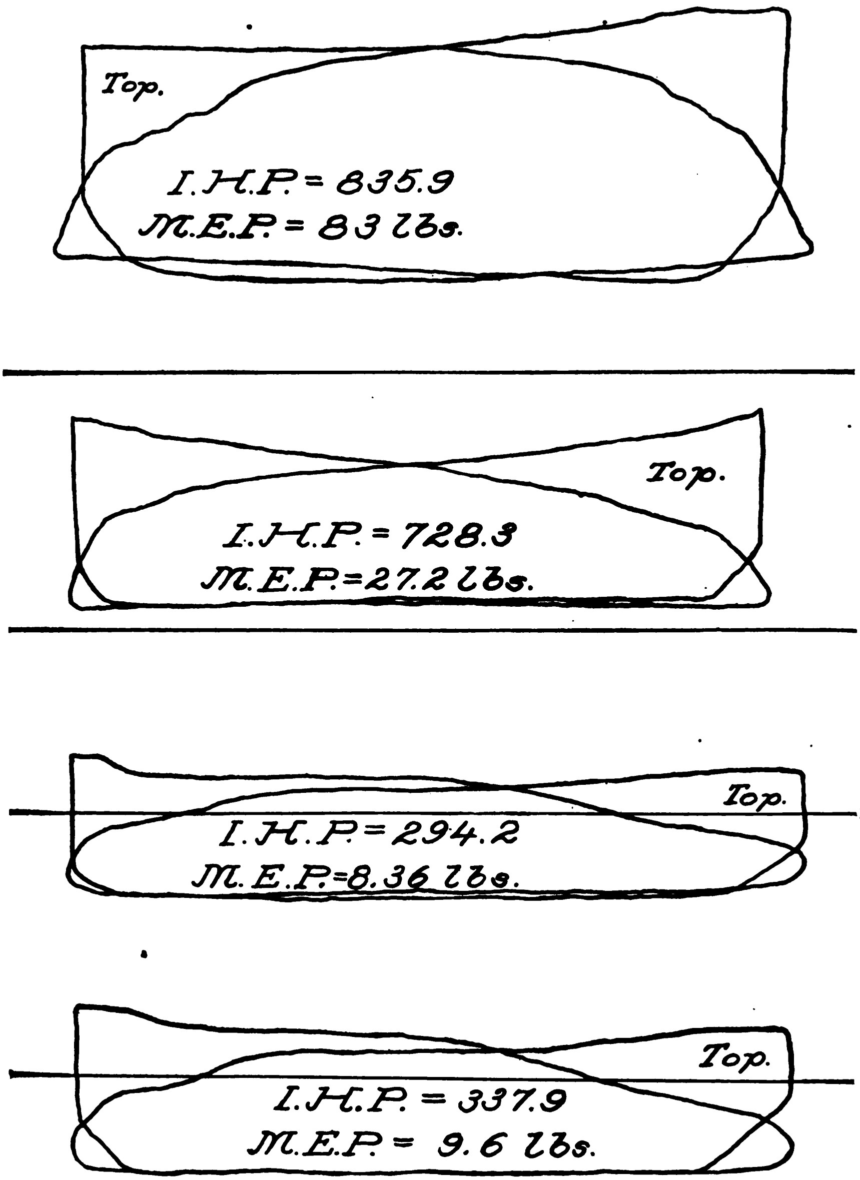



No. 2 STAR. ENG.

Rev. 160

| | | |
|---|---|---|
| I. H. P., H. P. 862.1 | I. H. P., I. P. 690.8 | |
| I. H. P., F. L. P. 252.7 | I. H. P., A. L. P. 298.8 | Total, 2,104.4 |

Series 6



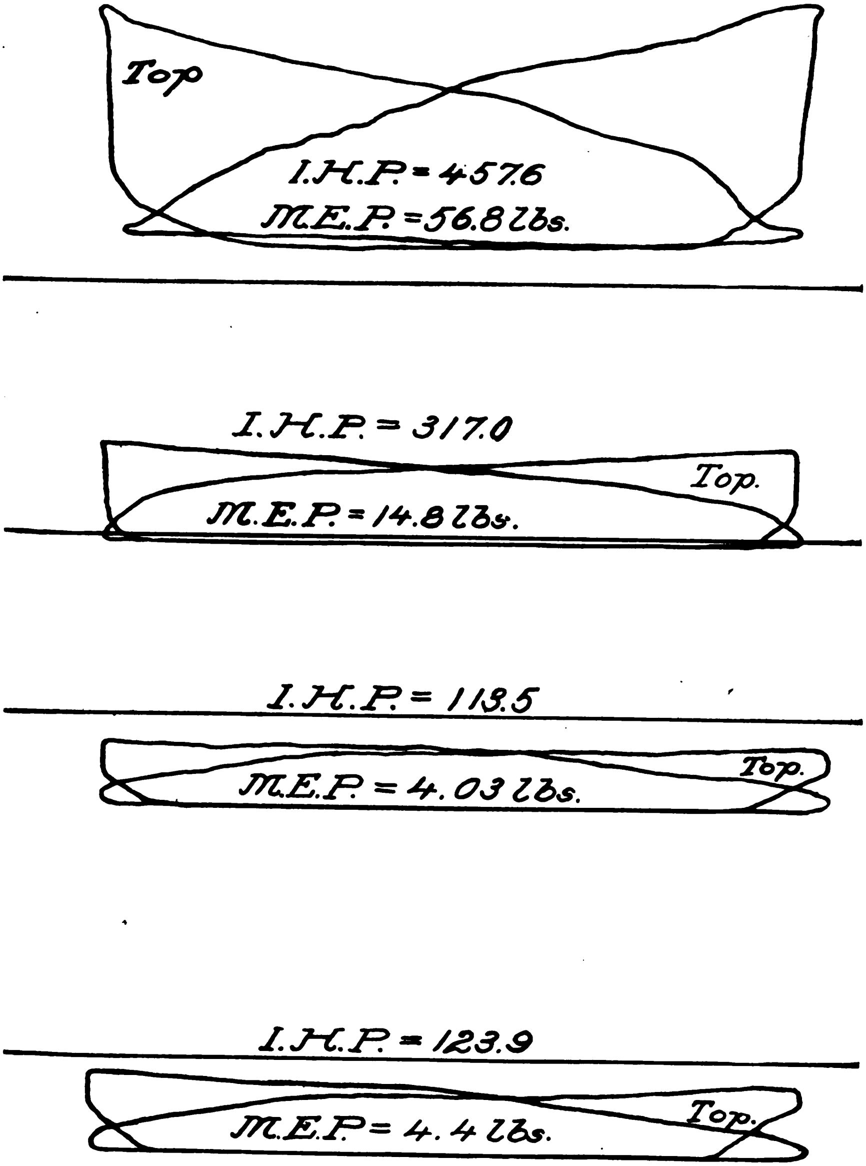

No. 3 Star. Eng.

Rev. 160

I. H. P., H. P. 835.9 — I. H. P., I. P. 728.3

I. H. P., F. L. P. 294.2 — I. H. P., A. L. P. 337.9 — Total, 2,196.3

SERIES 6



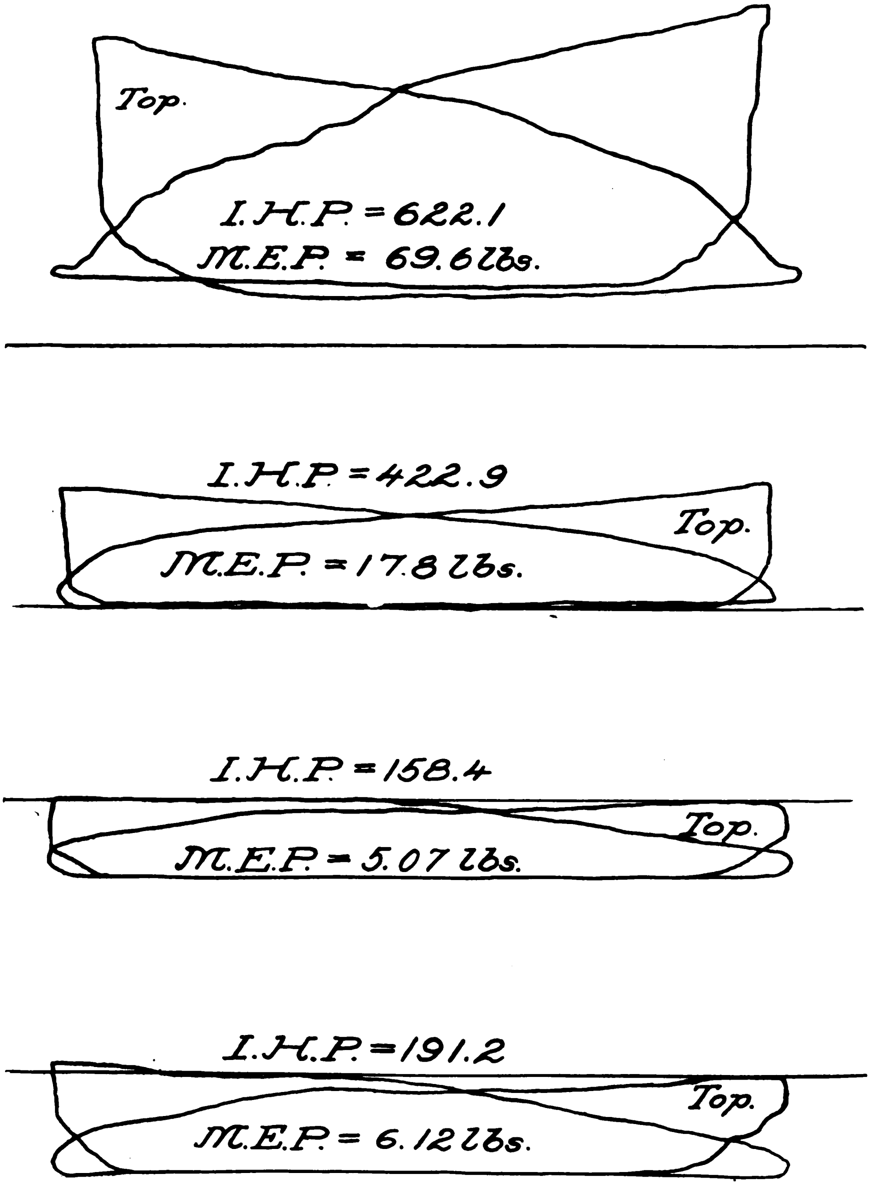

No. 4 STAR ENG.

Steam 150 1st Rec. 20 2d Rec. –5 Vac. 21″ Rev. 128

I. H. P., H. P. 457.6 I. H. P., I. P. 317.0

I. H. P., F. L. P. 113.5 I. H. P., A. L. P. 123.9 **Total, 1,012.0**

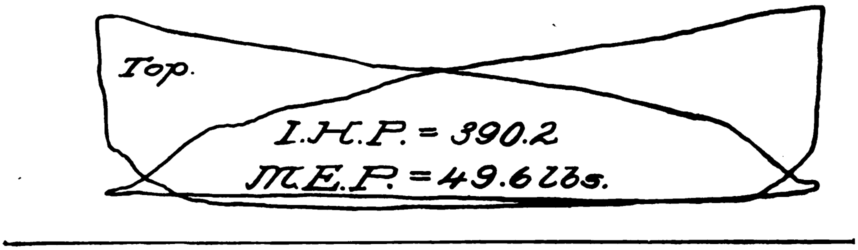
SERIES 6

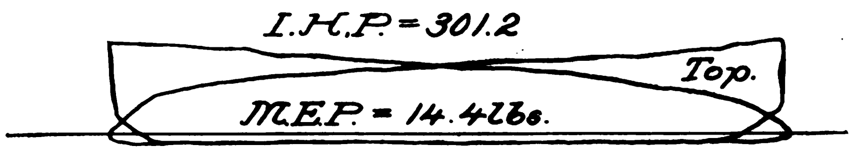


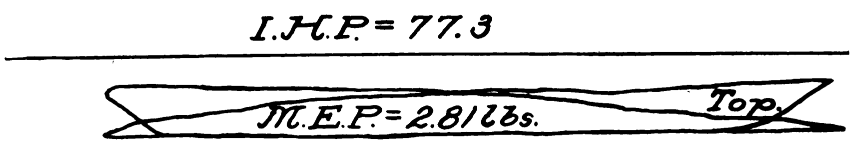

No. 5 STAR. ENG.

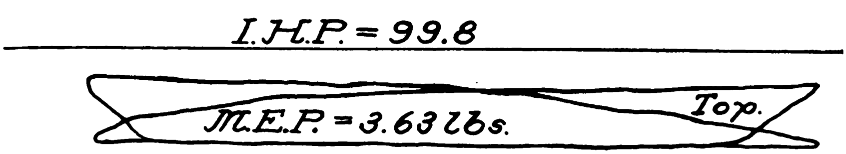
Steam 149  1st Rec. 30  2d Rec. 2  Vac. 21″  Rev. 142
I. H. P., H. P. 622.1  I. H. P., I. P. 422.9
I. H. P., F. L. P. 158.4  I. H. P., A. L. P. 191.2  Total, 1,394.6

SERIES 6



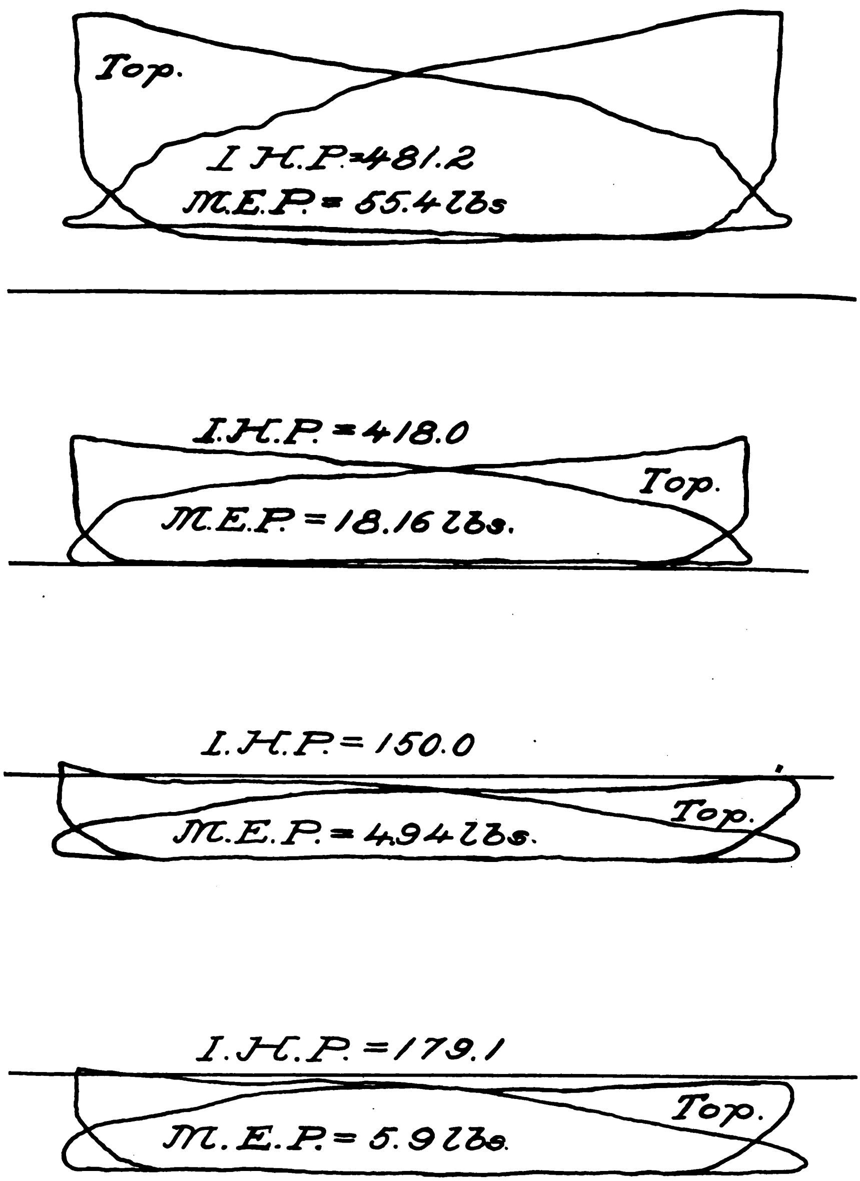

NO. 6 PORT ENG.

Steam 125 1st Rec. 20 2d Rec. 6 Vac. 21″ Rev. 125

I. H. P., H. P. 390.2 I. H. P., I. P. 301.2

I. H. P., F. L. P. 77.3 I. H. P., A. L. P. 99.8 Total, 868.5

Series 6



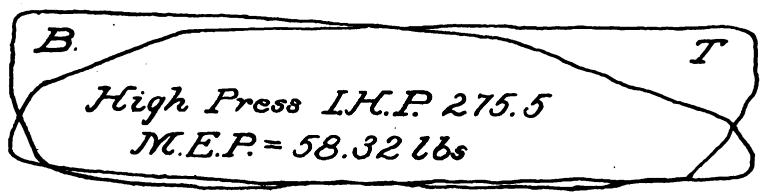

No. 7 Port Engine

Steam 143 1st Rec. 30 2d Rec. 2 Vac. 21″ Rev. 138

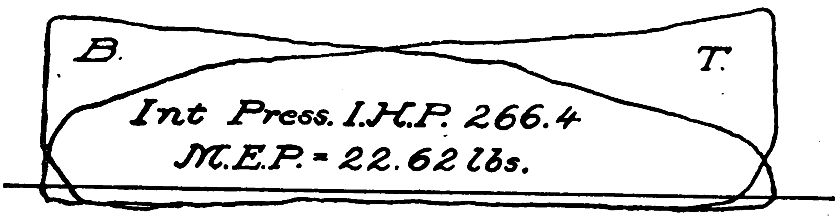
I. H. P., H. P. 481.2 I. H. P., I. P. 418.0

I. H. P., F. L. P. 150.0 I. H. P., A. L. P. 179.1 Total, 1228.3

SERIES 7

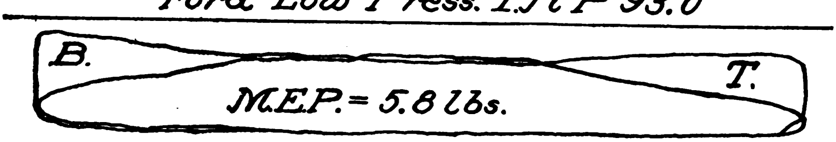



80 lbs. Spring.



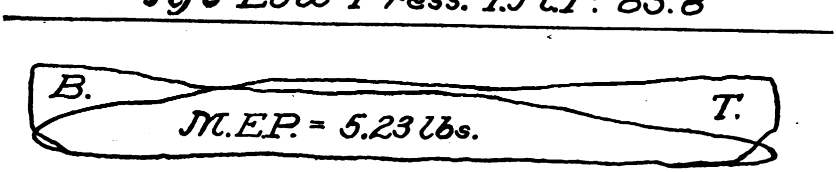

30 lbs. Spring.

Ford Low Press. I.H.P 93.0




16 lbs. Spring.

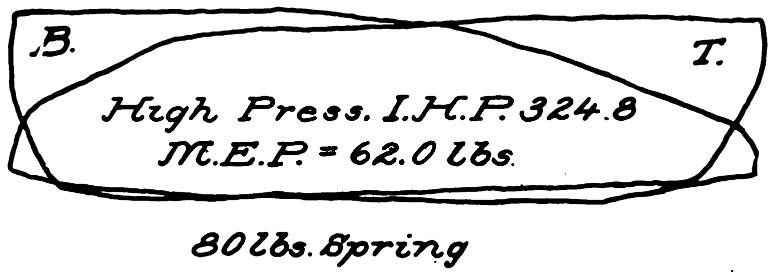
Aft Low Press. I.H.P. 83.8

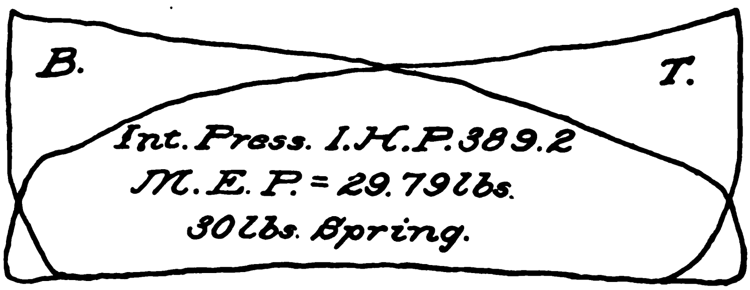


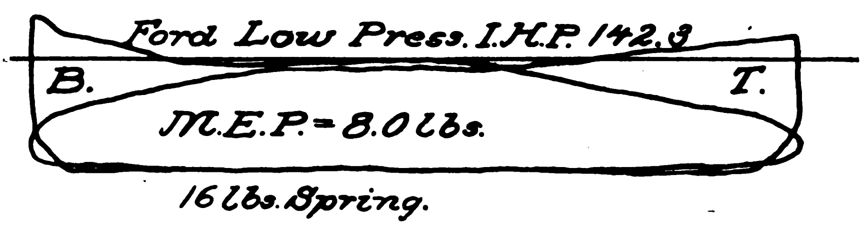

16 lbs. Spring.

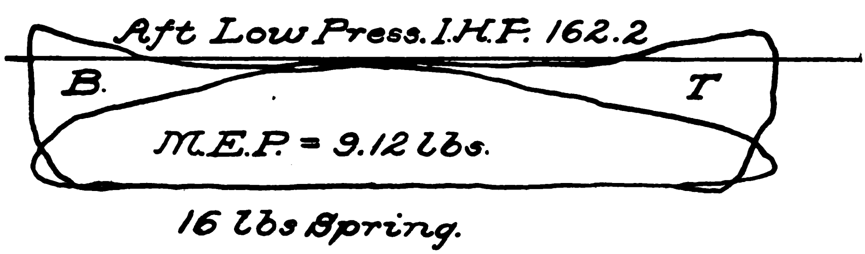
| No. of Run | Steam | 1st Rec. | 2d Rec. | Vac. | Rev. |
|---|---|---|---|---|---|
| 1 | 115 | 33 | −1 | 24½″ | 110 |

SERIES 7



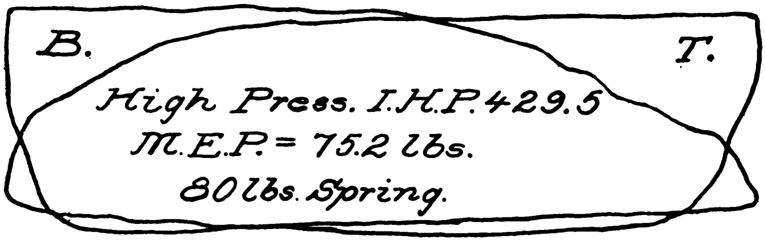



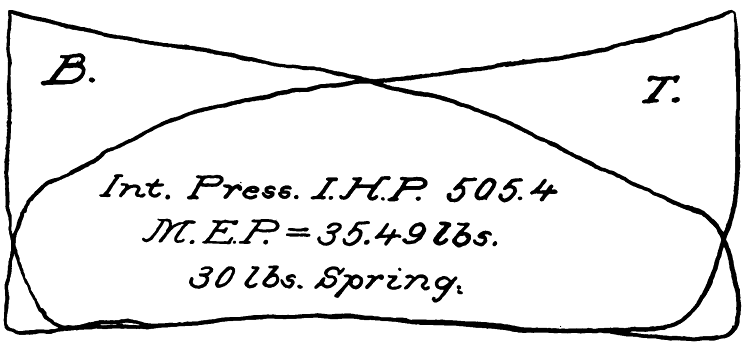



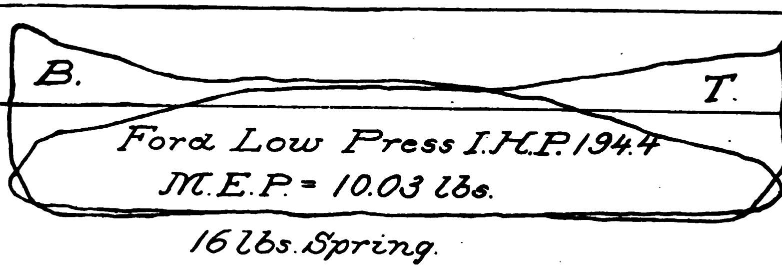



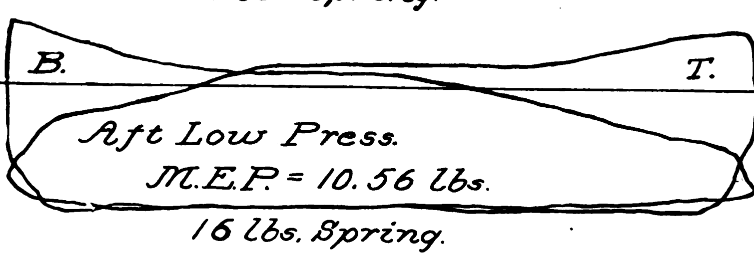

| No of Run | Steam | 1st Rec. | 2d Rec. | Vac. | Rev. |
|---|---|---|---|---|---|
| 4 | 135 | $46\frac{1}{2}$ | $3\frac{3}{4}$ | $24\frac{1}{2}''$ | 122 |

SERIES 7



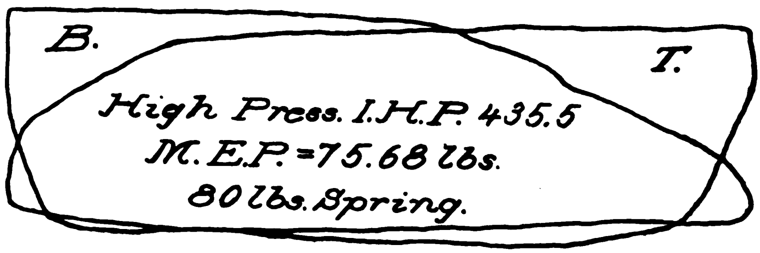



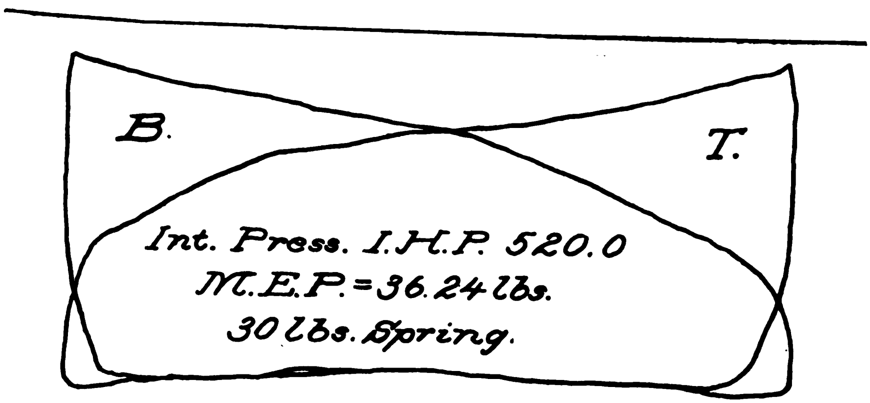



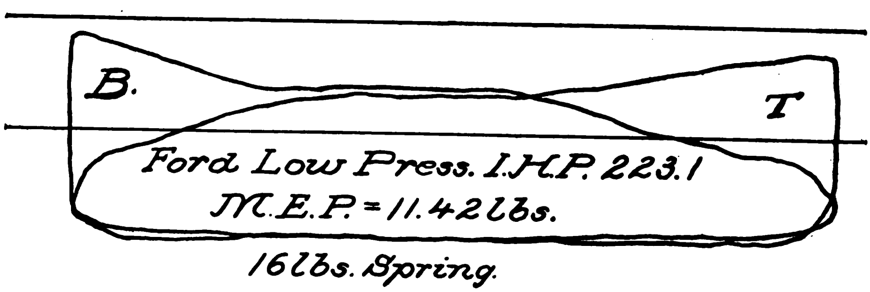



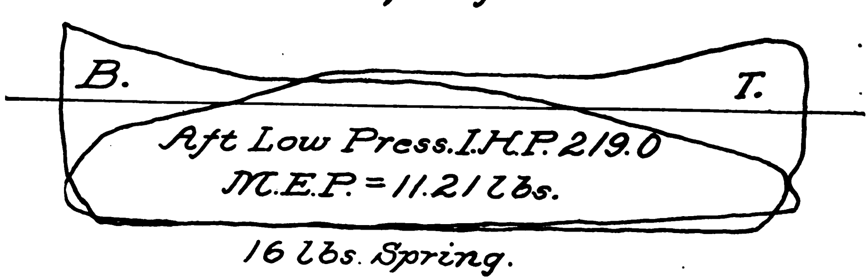

| No. of Run | Steam | 1st Rec. | 2d Rec. | Vac. | Rev. |
|---|---|---|---|---|---|
| 5 | 168 | 57 | 8 | 24″ | 133 |

SERIES 7




| No. of Run | Steam | 1st Rec. | 2d Rec. | Vac. | Rev. |
|---|---|---|---|---|---|
| 6 | 170 | 59 | 10 | 25″ | 134 |

# LOG OF TRIAL TRIP OF JANUARY 24, 1907

| FREIGHT STEAMER "TUSCAN" | POINTS DOWN | TIME | Elapsed Time Minutes | Nautical Miles | Statute Miles | Speed Knots | Speed Miles | Mean Rev's | Mean Steam | Mean I.H.P | % |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Place, Patapsco River and Chesapeake Bay | Passed Sandy Point ....... | 11-12-13 | | | | | | | | | |
| | | | 32′, 2″ | 7.4 | 8.5 | 13.8 | 15.87 | 81.6 | 182.6 | 2838 | 21 |
| 270 Tons Coal | " Thomas Point ...... | 11-44-15 | | | | | | | | | |
| | | | 14′, 14″ | 3.25 | 3.74 | 13.68 | 15.73 | | | | |
| F. W. Tanks Full | " Bloody Point ...... | 11-58-29 | | | | | | | | | |
| Draft on Trial { For'd.... 9′, 9″<br>Aft......13′, 6″<br>Mean ...11′, 7½″ | " Bloody Point ...... | 12-07-00 | | | | | | | | | |
| | | | 11′, 45″ | 3.25 | 3.74 | 16.6 | 19.0 | | | | |
| | " Thomas Point ...... | 12-18-45 | | | | | | | | | |
| | | | 27′, 15″ | 7.4 | 8.5 | 16.26 | 18.69 | 86.4 | 185.3 | 3079 | 13 |
| Wetted Surface, 12,800 Square Feet | " Sandy Point ....... | 12-46-00 | | | | | | | | | |
| I.H.P. per 100 square inches, W. S. @ 10 knots, 6.6 | " Sandy Point ....... | 12-55-00 | | | | | | | | | |
| | | | 30′, 03″ | 7.4 | 8.5 | 14.76 | 16.97 | 83.5 | 176.5 | 3059 | 19 |
| Displacement, 2,260 Tons | " Thomas Point ...... | 1-25-03 | | | | | | | | | |
| Admirality Co-eff., 200.9 | " Thomas Point ...... | 1-35-00 | | | | | | | | | |
| | | | 28′, 15″ | 7.4 | 8.5 | 15.72 | 18.07 | 84.6 | 170.3 | 2983 | 14 |
| Fore Peak Tank Full to 1 ft. of Lower Deck | " Sandy Point ....... | 2-03-15 | | | | | | | | | |
| | " Sandy Point ....... | 2-10-00 | | | | | | | | | |
| | | | 30′, 15″ | 7.4 | 8.5 | 14.64 | 16.83 | 85.5 | 184 | 3252 | 20 |
| Aft. Tank Full | " Thomas Point ...... | 2-40-15 | | | | | | | | | |
| | Thomas Point ...... | 2-59-30 | | | | | | | | | |
| | | | 27′, 30″ | 7.4 | 8.5 | 16.14 | 18.56 | 83.3 | 180.6 | 2928 | 15 |
| | Sandy Point ....... | 3-27-00 | | | | | | | | | |

| | No. Card | Time | Steam | Vac. | M. P. Rec. | L. P. Rec. | Rev. | M. R. P. | I. H. P. H. P. | I. H. P. M. P. | I. H. P. L. P. | I. H. P. Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C | 1 | 10–45 | 180 | 27 | 66 | 14 | 83.3 | 33.0 | 823.27 | 870.21 | 1090.91 | 2784.39 |
| C | 2 | 11–00 | 186 | 27 | 67 | 16 | 83.3 | 34.0 | 840.66 | 805.72 | 1216.79 | 2863.17 |
| O | 3 | 11–15 | 184 | 27 | 70 | 19 | 85 | 34.2 | 780.91 | 855.05 | 1305.84 | 2941.80 |
| C | 4 | 11–30 | 185 | 27 | 67 | 16 | 82 | 33.4 | 821.84 | 793.15 | 1156.50 | 2771.49 |
| C | 5 | 11–45 | 183 | 27¼ | 65 | 14 | 84.5 | 32.8 | 846.89 | 749.11 | 1106.63 | 2802.63 |
| O | 6 | 12–00 | 188 | 27 | 72 | 19 | 85 | 35.5 | 798.66 | 904.38 | 1348.66 | 3051.70 |
| O | 7 | 12–15 | 183 | 27 | 72 | 20 | 83 | 34.4 | 693.22 | 867.04 | 1421.44 | 2981.70 |
| O | 8 | 12–30 | 188 | 27 | 80 | 22½ | 85.6 | 35.2 | 643.50 | 894.20 | 1509.08 | 3046.78 |
| O | 9 | 12–45 | 185 | 27 | 78 | 21½ | 85 | 37.4 | 615.26 | 1118.14 | 1477.10 | 3210.50 |
| O | 10 | 1–00 | 178 | 27 | 74 | 20 | 82.5 | 37.0 | 597.17 | 1089.50 | 1412.89 | 3099.56 |
| O | 11 | 1–15 | 175 | 27 | 72 | 20 | 83.3 | 35.8 | 602.96 | 1031.32 | 1384.62 | 3018.90 |
| O | 12 | 2–15 | 178 | 27 | 77 | 23 | 85 | 37.4 | 427.11 | 1141.03 | 1541.32 | 3209.46 |
| O | 13 | 2–30 | 190 | 27 | 77 | 21 | 86 | 37.9 | 682.36 | 1098.02 | 1516.13 | 3296.51 |
| C | 14 | 2–45 | 182 | 27 | 66 | 16 | 82.6 | 33.6 | 773.86 | 894.82 | 1141.15 | 2809.83 |
| C | 15 | 3–00 | 176 | 27¼ | 63 | 14½ | 82.6 | 31.9 | 735.87 | 846.89 | 1081.76 | 2664.52 |
| O | 16 | 3–15 | 183 | 27 | 72 | 20½ | 84 | 35.6 | 689.88 | 942.49 | 1396.26 | 3028.73 |
| O | 17 | 3–30 | 183 | 27 | 73 | 21 | 83.5 | 36.6 | 627.67 | 991.49 | 1472.06 | 3091.22 |

Card marked "C" by pass closed. Cards marked "O" by pass open.

| 1st Mean | | | | | 2nd Mean | | | | | 3rd Mean | | | | | 4th Mean | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Steam | Rev. | I.H.P. | Speed Knots | Speed Miles | Steam | Rev. | I.H.P. | Speed Knots | Speed Miles | Steam | Rev. | I.H.P. | Speed Knots | Speed Miles | Steam | Rev. | I.H.P. | Speed Knots | Speed Miles |
| 182.6 | 81.6 | 2838 | 13.8 | 15.87 | 183.9 | 84 | 2958 | 15.03 | 17.28 | | | | | | | | | | |
| 185.3 | 86.4 | 3079 | 16.26 | 18.69 | | | | | | 178.6 | 84 | 2989 | 15.13 | 17.40 | | | | | |
| 176.5 | 83.5 | 3059 | 14.76 | 16.97 | 173.4 | 84 | 3021 | 15.24 | 17.52 | | | | | | 178.2 | 84.1 | 3022 | 15.22 | 17.51 |
| 170.3 | 84.6 | 2983 | 15.72 | 18.07 | | | | | | 177.8 | 84.2 | 3055 | 15.31 | 17.63 | | | | | |
| 184 | 85.5 | 3252 | 14.64 | 16.83 | 182.3 | 84.4 | 3090 | 15.39 | 17.74 | | | | | | | | | | |
| 180.6 | 83.3 | 2928 | 16.14 | 18.56 | | | | | | | | | | | | | | | |

## LOG OF TRIP OF JANUARY 28 AND 29, 1907—BALTIMORE TO PHILADELPHIA

| Freight Steamer "Tuscan" | Points Down | Time | Elapsed Time Minutes | Nautical Miles | Statute Miles | Speed Knots | Speed Miles | Mean Rev's | Mean Steam | Mean I.H.P. | Slip % |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Place, Patapsco River and Chesapeake Bay | Passed Sandy Point ....... | 3-14-45 | | | | | | | | | |
| 310 Tons Coal | " Thomas Point ...... | 3-45-30 | 30′, 43″ | 7.4 | 8.5 | 14.44 | 16.60 | 81.6 | 170 | 2480 | 18 |
| F. W. Tanks Full | " Sharps Island ....... | 4-52-20 | 66′, 50″ | 15.3 | 17.6 | 13.72 | 15.79 | 79.2 | 171 | 2472 | 20 |
| Draft { For'd.....10′, 4″ | " Coye Point ........ | 5-52-50 | 60′, 30″ | 15.2 | 17.5 | 14.76 | 16.97 | 80.4 | 174 | | 14 |
| Aft.......13′, 8″ Mean ....12′, 0″ | " Cedar Point ........ | 6-13-30 | 20′, 40″ | 5.2 | 6.0 | 15.05 | 17.30 | 81.6 | 178.3 | | 15 |
| Wetted Surface, 13,000 Square Inches | " Point Lookout ..... | 7-17-00 | 63′, 30″ | 15.4 | 17.7 | 14.54 | 16.72 | 81. | 180 | | 17 |
| I.H.P. per 100 square inches, W. S., @ 10 knots, 6.6 | " Smith's Point ....... | 8-00-50 | 43′, 50″ | 10.7 | 12.3 | 14.62 | 16.81 | 77.4 | 170.6 | | 15 |
| Displacement, 2,340 Tons | " Wind Mill ......... | 9-11-00 | 70′, 10″ | 17.0 | 19.5 | 14.51 | 16.69 | 78.6 | 165 | | 15 |
| Admiralty Co-eff., 202.2 | " Wolf Trap ......... | 10- 5-45 | 54′, 45″ | 12.2 | 14.0 | 13.36 | 15.36 | 79.2 | 175 | | 22 |
| Fore Peak Tank Full to 1 ft. of Lower Deck | " York Spit ......... | 10-53-20 | 47′, 35″ | 10.6 | 12.2 | 13.21 | 15.19 | 80.4 | 179 | | 23 |
| Aft. Tank Full | | | | | | | | | | | |

## READINGS OF TRIP, JANUARY 28 AND 29, 1907

| No. Card | Time | Steam | Vac. | M. P. Rec. | L. P. Rec. | Rev. | M.R.P. | I. H. P. H. P. | I. H. P. M. P. | I. H. P. L. P. | I. H. P. Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 3–25 | 170 | 26½ | 62 | 11 | 79 | 30.6 | 758.78 | 733.56 | 955.02 | 2447.36 |
| 2 | 3–40 | 170 | 26½ | 63 | 11 | 79 | 31.5 | 775.28 | 764.13 | 974.91 | 2514.32 |
| 3 | 4–35 | 170 | 26¼ | 63 | 12 | 79 | 30.4 | 742.98 | 733.56 | 955.02 | 2431.56 |
| 4 | 6–00 | 180 | 26 | 65 | 13½ | 81.5 | 32.1 | 822.50 | 788.31 | 1046.81 | 2657.62 |
| 5 | 7–40 | 172 | 26 | 60 | 11 | 79.5 | 31.5 | 763.57 | 768.96 | 1001.10 | 2533.63 |
| 6 | 10–00 | 180 | 25½ | 68 | 14 | 80.3 | 31.9 | 793.52 | 807.77 | 990.95 | 2592.24 |
| 7 | 11–00 | 178 | 25¼ | 70 | 15½ | 81 | 33.3 | 749.80 | 877.49 | 1102.40 | 2729.69 |
| 8 | 11–45 | 175 | 25¾ | 70 | 15 | 81 | 31.8 | 738.53 | 846.15 | 1019.99 | 2604.67 |

NOTE—Cards 1 to 5 inclusive taken January 28, 1907. Cards 6, 7, 8, taken with coal test, January 29, 1907.

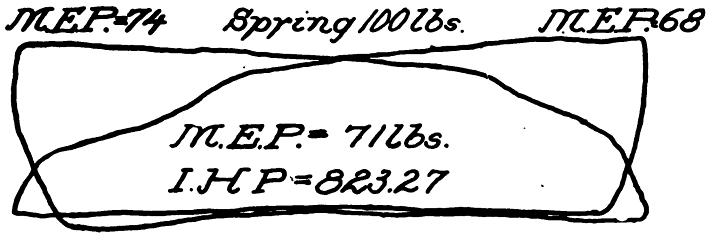
Coal used from 9.30 A. M. to 12.00 M., 14763 lbs.

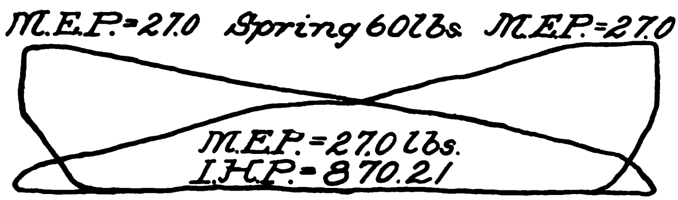
Coal used per hour, 5905 lbs.

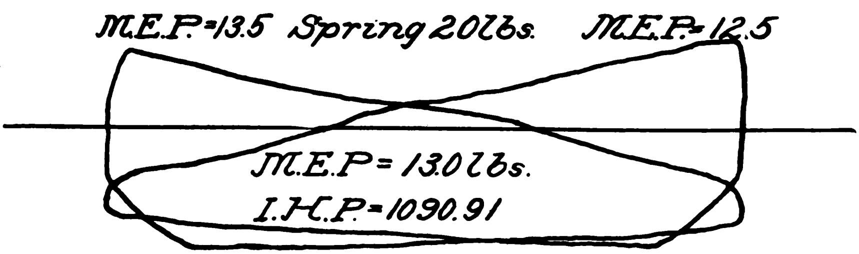
Coal used per I. H. P., per hour, 2.29 lbs.

Coal used per sq. foot of grate per hour, 20.9 lbs.

TUSCAN




By Pass Closed.

Time-10 45 A.M. Date, 1-24-1907.

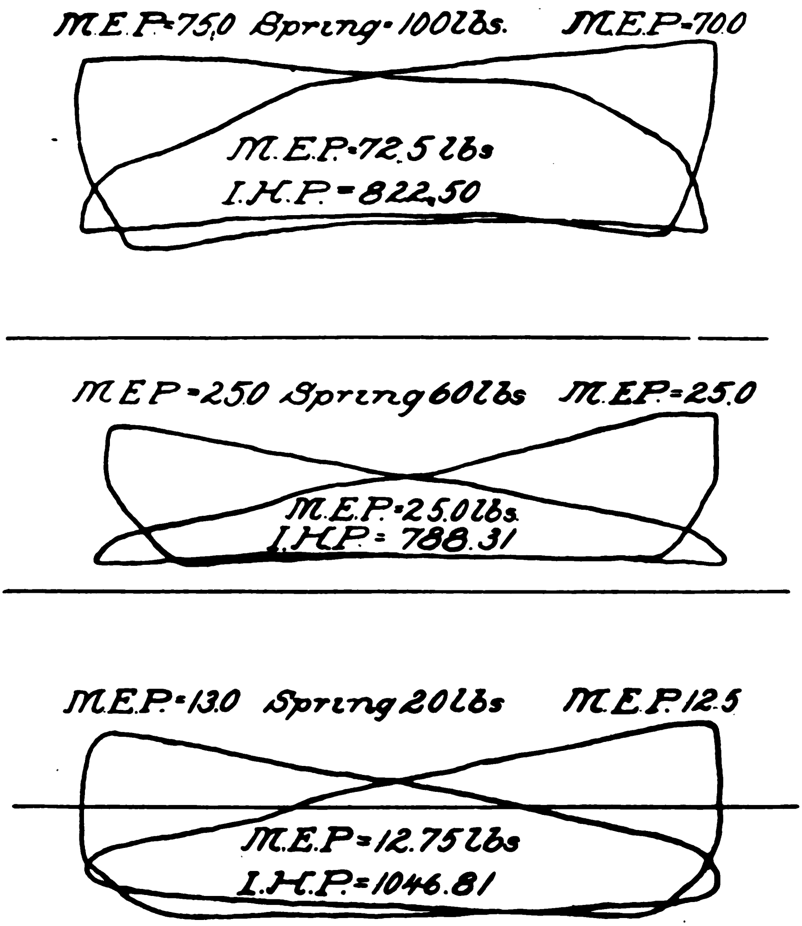
Card No. 1. Vac.-27.5

Steam-180 lbs. M.R.P.-330

M.P.Rec. 66 L.P.Rec. 140

R.P.M.=83.3 I.H.P.=2784.39

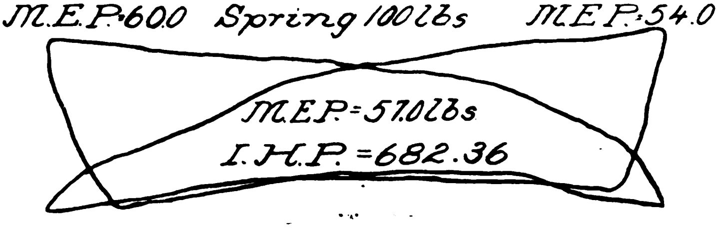
TUSCAN

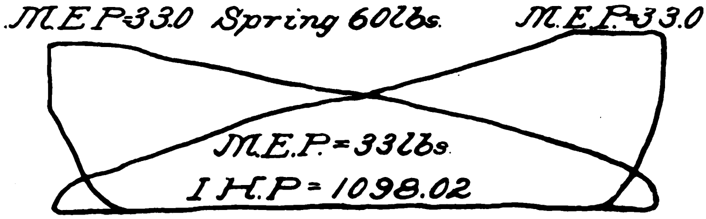


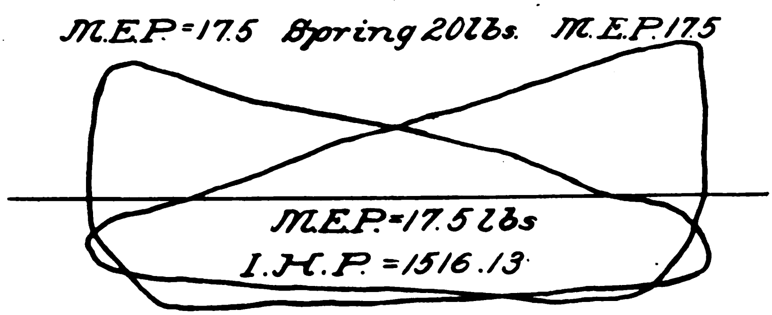

By Pass Closed.

| | |
|---|---|
| Time 6⁰⁰ P.M. | Date, 1-28-1907 |
| Card No. 4 | Vac- 26.0 |
| Steam- 180 lbs. | M.R.P. 32.1 |
| M.P. Rec. 65 | L.P. Rec. 13.5 |
| R.P.M.- 81.5 | I.H.P.=2657.62 |

TUSCAN




By Pass Open.

| | |
|---|---|
| Time - 2.30 P.M. | Date - 1-24-1907. |
| Card No. 13 | Vac - 27 |
| Steam - 190 lbs. | M.R.P. 37.9 |
| M.P. Rec. 77. | L.P. Rec. 21. |
| R.P.M. - 86. | I.H.P. 3296.51. |

The preceding series of diagrams are representative of modern marine engine practice. The data is sufficiently full to enable a thorough analysis to be made. They are worthy of close and careful study, and, being exact reproductions, can therefore be measured.

Further comment is unnecessary.

# CHAPTER IV

## Valve Diagrams

We will first describe the construction of the Zeuner diagram, and then the construction of the diagram for Marshall valve gear.

On plate 3 is shown valve diagrams for each cylinder of the engine shown on plate 1, the indicator diagrams of which are shown on page 95.

The construction will be made for top only (see plate 4), as the method for bottom is precisely the same.

Draw the horizontal line XX, and produce it to a sufficient length to take in the length of connecting rod between centers to same scale as selected for crank pin circle. Draw the vertical line YY, intersecting XX, in O. With O as center and radius equal to throw of crank, or half stroke, describe the crank pin circle A, B, C, D. This circle is drawn to any convenient scale; as shown it is drawn 3″=1 foot. Divide the diameter C, A, into 10 equal parts, each division representing $\frac{1}{10}$ of the stroke. With O as center, and radius equal to the eccentricity or half travel of the valve, describe the circle E, F, G, H. Now mark the end which is to be taken as top, and which one for bottom, selecting the right hand of diagram for top, as shown, and with G as center describe an arc i equal to the lead. It is better to make the valve diagram twice full size, as then the intersections of the different lines are shown with more distinctness.

Now set off from C a distance equal to the cut-off either in inches or percentage, and with a radius equal to connecting rod length as before, describe an arc, intersecting the crank pin circle in K. From O draw a diagonal line passing through K and cutting the circle of valve-travel in $K_1$. From $K_1$ draw a diagonal line tangent to the lead arc i and cutting the circle at L.

Through O draw a line OM perpendicular to $K_1$ L, cutting it in N. With O as center and ON as radius, describe an arc; ON is then the steam lap, and NM the maximum port opening.

Bisect the line OM, and with P as center describe the valve circles Q, R, S, and $Q_1$, $R_1$, $S_1$.

Through O draw a line parallel with $K_1$ L, and at the points of intersection with the travel circle T $U_1$ as centers describe arcs equal to the exhaust lap. If the exhaust lap is negative the circle will lie in the upper valve-cirlce, Q, R, S, and if positive it will lie in the lower valve-circle $Q_1$, $R_1$, $S_1$. The reason for describing the arc at points T and $U_1$ is due to the fact that the intersection of the arc representing exhaust lap, with the valve-circle as at V, is rather difficult to exactly determine, and may cause variation.

From O draw diagonals tangent to the circles, and at the points where they cut the crank pin circle as at W, $W_1$, drop arcs with radius equal to radius of connecting rod, upon the diameter C, A. This gives the point of stroke at which release and compression takes place. With O as center and a radius equal to port opening plus exhaust lap describe an arc, cutting the lower valve-circle in Z, $Z_1$; from O draw diagonal lines through the points of intersection. This gives us the points between which the exhaust valve is full open.

Upon examining the diagram we see that the crank has to pass through the angle G, O, $K_1$, to arrive at the point where the steam is cut off; this point is shown at 1 where the lap-circle cuts the valve-circle.

Angle M, O, F, is the angle of advance. That is to say, when engine is turning over, the center of the eccentric sheave leads the center line of crank by 90 degrees plus the angle of advance; hence having the required lead, and point of cut-off we can by the construction determine the required angle.*

If the exhaust lap is negative, then the point of intersection of the lap circle with the valve-circle, point 2, shows where the valve opens to release the expanded steam. If, therefore, we desire to determine the point of release, we see that if it is desired to release later in the stroke the lap may have to be positive and if on the other hand we desire it earlier we need negative lap.

The distance between the intersection of the lap-circle with the diameter GE, and where the valve-circle cuts the diameter GE, is equal to the lead.

Again at point 3, where the lap-circle intersects the valve-circle this point of intersection shows where the valve starts to open for lead.

The analysis of the valve diagram enables us to determine the effects of any changes we may desire to make. Thus suppose we desire to cut off longer in the stroke, in other words to permit the steam to follow longer, the lead to remain unchanged. It is evident that to maintain the same lead, the steam lap must be reduced. Suppose, however, the lap is required to remain unchanged. It is evident that the lead must be reduced. The other changes involved will be left for the student to work out, and only by working out these different

* If engine turns under, the angle which the center of eccentric sheave makes with crank is 90 degrees—the angle of advance.

problems, in other words, constructing the diagram and discussing it, can he ever expect to be able to properly analyze it as it is impossible by mere reading to perform, and further, the subject is so broad and interesting that it is only by actual performance that one is able to grasp the details. There are several different diagrams used for analyzing the slide-valve operated by eccentrics, but the Zeuner is the most beautiful.

The diagrammatic work to the right of the diagram is only given to make the subject if possible more clear, and as before mentioned the diagrams shown on plate 3 should be very carefully studied.

## The Marshall Valve Gear

The Marshall valve gear is one of the types of radial valve gears, which is used more extensively in marine practice than any other radial gear.

The diagram for Marshall valve gear and a valve diagram are shown on plate 5.

We will take a concrete case, and lay down the diagram, from the following data:

Travel of valve, $6\frac{13}{16}''$.
Lap of valve top, $1\frac{5}{16}''$.
Lap of valve bottom, $1\frac{1}{4}''$.
Lead top, $\frac{7}{16}''$.
Lead bottom, $\frac{1}{2}''$.
Maximum port opening, top $1\frac{1}{2}''$.
Maximum port opening, bottom $2\frac{3}{4}''$.
Cut-off top, 75.8 per cent. $=22\frac{3}{4}''$.
Cut-off bottom, 77.9 per cent. $=23\frac{3}{8}''$.
Stroke of piston $=30''$.
Eccentricity $=2\frac{1}{2}''$.
Length of stiff eccentric rod, 23.13″.
Length of prolongation of eccentric rod, 16.03″.

Draw the horizontal line $XX_1$, and the vertical line $YY_1$, intersecting the horizontal line $XX_1$ in O.

Lay off a distance OC such that $OC=\sqrt{L^2-R^2}$, where L is the length of the stiff eccentric rod. OC in this case is given, namely, 23″, therefore, $L=\sqrt{OC^2+R^2}=23.13''$, and R is the eccentricity. From C lay-off a distance CD, and draw the vertical line $UU_1$.

With O as center and eccentricity as radius $2\frac{1}{2}''$ in this diagram, describe a circle, to any convenient scale. This diagram is drawn half size except where otherwise marked.

Now 5″ diameter circle drawn half size corresponds with 30″, the stroke of piston to a scale of 1″ = 1 foot. Therefore, with a scale of 1″ = 1 foot, set up on $YY_1$, produced, the stroke of engine as shown, and with a radius equal to the length of connecting rod between centers, in this case 5′ − 7½″, describe arcs cutting the circle in points 2, 4, 6, 8......30, etc., as shown. Now with C as center, and radius of length of radius rod, describe the arc A, B, in this case 12½″. With A and B as centers and the radius of 12½″ describe arcs E and F. With $O_1$, 2, 4, 6, 8, etc., as centers, and L as radius describe arcs on arc E, for one complete revolution in a head gear repeating the same process on arc F for astern gear. Now the distance CD is equal to the length of the prolongation of the stiff eccentric rod, "M." Therefore, from the points 0, 2, 4, 6, 8, etc., draw lines passing through the intersection of the arcs, on arc E and F as previously described. Measuring off from the points of intersection along the lines representing M, we get a series of points through which a fair curve is drawn, this elongated figure represents the oscillations of the point D, or the point of attachment of the valve-rod. The writer uses a beam compass with an extra attachment, placing needle point on points 0, 2, 4, 6, 8, etc., and the middle leg of compass on C, the other leg taken equal to the length of M; hence when arc is described on arc E, a corresponding arc is described at its proper distance, hence passing a line through the latter arc, a point is obtained; numbering these points as shown prevents confusion to one not accustomed to laying down the diagram, and until one is thoroughly acquainted with construction, it will pay to mark them; proceeding thus for one complete revolution we obtain points through which a fair curve is passed, giving us the elongated figure as shown.

Only the ahead motion has been considered. The astern motion is treated in precisely the same manner. If the student has not a beam compass handy, then a straight edge can be used, made as follows: Measure off the length L, and scrive marks upon the straight edge corresponding to the length $O_1$ C = L. Scrive a distance corresponding to $CD_1$ = M, therefore, the points of intersection can be accurately located. To the left of the diagram is drawn the stroke of piston to a scale of 1″ = 1 foot. This is divided into 15 equal parts representing 2 inch intervals of same.

The lap is laid off $1\frac{5}{16}$″ for top, 1¼″ for bottom.

With a pair of dividers the points for 2, 4, 6, 8, etc., of the elongated figure is laid off on the respective piston position. Connecting these points we obtain the figure as shown. Measuring the port opening for top we find 1½″ as required, for bottom we find 2¾″ as required. On the diagram we lay off as shown, the lead, lap, and port opening. Observe that the point $D_1$ intersects the lead line for both top and bottom; this is as it should be, for when the crank is on top or bottom center the valve has opened for lead.

This engine is worked from the starboard side. If worked from the port side, the ahead position would be reversed, that is to say, ahead would be to the right and astern to the left of center line.

The eccentric coincides in this gear with the crank. The stiff eccentric-rod L is jointed at C to the radius rod AC, which swings on A. The gudgeon is attached to the radius arm, shown on plate 5, which is movable on fixed centers.

The prolongation M of the eccentric-rod L may form a slight angle with L if desirable. Conditions of design, however, control this.

It can be readily observed from diagram that the amount of lead is proportionate to the length M, and hence the term lead arm is frequently applied. The valve rod is joined at $D_1$ and the distance traversed represents the oscillations of the valve. The angle at which the radius-arm deviates on either side from the vertical through the fixed center is termed the deviation angle.

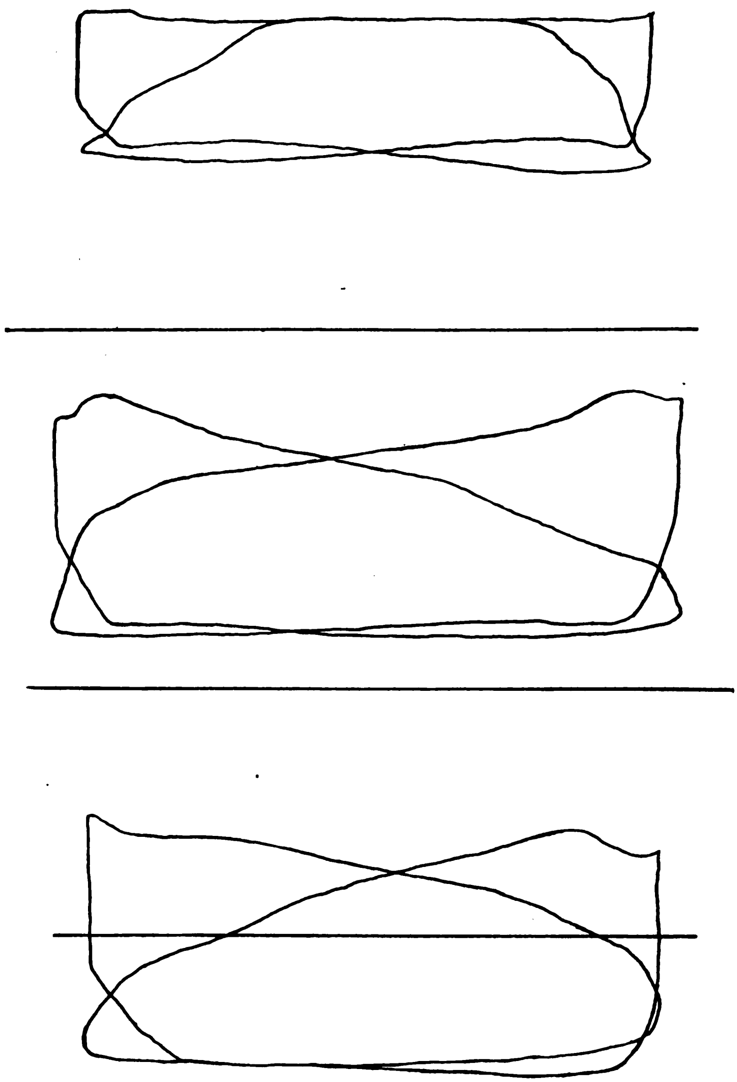
The crank-shaft revolves in the same direction in which the radius-arm deviates from the vertical.

As the center C travels through an arc described by the radius-rod AC the oscillations are greater above than below the center line, as will be noted. This difference between upper and lower oscillations has the following advantages:

The valve-openings are less for down stroke.
The cut-off is earlier.
The compression is earlier.
For the up stroke, the cut-off is later.
The valve-opening is greater.
The compression is later.
The momentum of the moving parts are, therefore, better balanced.

The difference between oscillations is effected by the length of radius-rod, and radius-arm.

The diagram has been marked to make its construction as clear as possible.



The set of diagrams shown above is from a triple expansion engine fitted with Marshall Valve Gear. These diagrams are fair types of those obtained with this gear, and same should be closely studied and compared with the other diagrams shown, as all other diagrams were taken from engines fitted with link-motion.

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The publishing of peculiarly formed diagrams, showing variou contours, has been purposely avoided, as it would be impossible to show the very many forms of diagrams, and as it is only by a thorough grasp of the principles fundamental combined with practice that one can ever become proficient in analysis, it has been the author's aim to present these.

Plate 6 shows a section through the cylinders and valve chest of a triple expansion engine, and shows clearly the passages through which the steam travels from throttle valve to condenser. The H. P. and M. P. take steam on inside of valve and the L. P. on outside of valve. The receivers are cast with cylinders and are shown dotted. In this engine the H. P. crank leads.

It may be well to say in conclusion: Let the student take diagrams from either a compound or triple expansion engine with first H. P. crank leading, then if possible, diagrams from same type of engine with L. P. crank leading. Combine the diagrams, and note the difference under the various conditions. This way and this alone can he properly analyze.

If by writing this work I have been of help to those who are seeking this knowledge and who are willing to work hard for a clear understanding of this most interesting and vital subject, I shall feel amply repaid.

## TABLE OF $\frac{1 + \text{Hyp log } r}{r}$

Let $r$ = Rate of expansion.

$\frac{1}{r}$ = Cut-off.

| $r$ | $\frac{1}{r}$ | $\frac{1+\text{Hyp log } r}{r}$ | $r$ | $\frac{1}{r}$ | $\frac{1+\text{Hyp log } r}{r}$ |
|---|---|---|---|---|---|
| 1.33 | 0.752 | 0.9657 | 8.0 | 0.125 | 0.3849 |
| 1.4 | 0.714 | 0.9546 | 8.25 | 0.121 | 0.377 |
| 1.5 | 0.667 | 0.937 | 8.5 | 0.118 | 0.3694 |
| 1.6 | 0.625 | 0.9188 | 8.75 | 0.114 | 0.3622 |
| 1.7 | 0.588 | 0.9003 | 9.00 | 0.111 | 0.3552 |
| 1.75 | 0.571 | 0.8911 | 9.25 | 0.108 | 0.3486 |
| 1.8 | 0.556 | 0.882 | 9.5 | 0.105 | 0.3422 |
| 1.9 | 0.526 | 0.8641 | 9.75 | 0.103 | 0.3361 |
| 2.0 | 0.500 | 0.8465 | 10.00 | 0.100 | 0.3302 |
| 2.1 | 0.476 | 0.8294 | 10.25 | 0.097 | 0.3246 |
| 2.2 | 0.455 | 0.8129 | 10.50 | 0.095 | 0.3191 |
| 2.25 | 0.444 | 0.8048 | 10.75 | 0.093 | 0.315 |
| 2.75 | 0.364 | 0.7315 | 11.00 | 0.091 | 0.3088 |
| 3.00 | 0.333 | 0.6995 | 11.25 | 0.089 | 0.304 |
| 3.25 | 0.308 | 0.6703 | 11.50 | 0.087 | 0.2994 |
| 3.75 | 0.267 | 0.6191 | 11.75 | 0.0851 | 0.2947 |
| 4.0 | 0.25 | 0.5965 | 12.00 | 0.0833 | 0.2904 |
| 4.25 | 0.235 | 0.5757 | 12.25 | 0.0816 | 0.2861 |
| 4.5 | 0.222 | 0.5564 | 12.5 | 0.08 | 0.2821 |
| 5.0 | 0.200 | 0.5219 | 12.75 | 0.0784 | 0.2781 |
| 5.25 | 0.190 | 0.5063 | 13. | 0.0769 | 0.2741 |
| 5.5 | 0.182 | 0.4917 | 13.25 | 0.0755 | 0.2705 |
| 5.75 | 0.174 | 0.4781 | 13.5 | 0.0741 | 0.2668 |
| 6. | 0.167 | 0.4652 | 13.75 | 0.0727 | 0.2633 |
| 6.25 | 0.160 | 0.4532 | 14. | 0.0714 | 0.2599 |
| 6.5 | 0.154 | 0.4418 | 15. | 0.0667 | 0.2472 |
| 6.75 | 0.148 | 0.431 | 16. | 0.0625 | 0.2358 |
| 7.0 | 0.143 | 0.4208 | 17. | 0.0588 | 0.2255 |
| 7.25 | 0.138 | 0.4111 | 18. | 0.055 | 0.2161 |
| 7.5 | 0.133 | 0.4019 | 20. | 0.050 | 0.1998 |
| 7.75 | 0.129 | 0.3932 | | | |

# TABLE

CONTAINING THE

# COMMON LOGARITHMS OF NUMBERS

## FROM 1 TO 10,000

To obtain the hyperbolic logarithm of a number
multiply the common logarithm of
the number by 2.302585

| N. | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | D. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 100 | 00 0000 | 00 0434 | 00 0868 | 00 1301 | 00 1734 | 00 2166 | 00 2598 | 00 3029 | 00 3461 | 00 3891 | 432 |
| 101 | 4321 | 4751 | 5181 | 5609 | 6038 | 6466 | 6894 | 7321 | 7748 | 8174 | 428 |
| 102 | 8600 | 9026 | 9451 | 9876 | 01 0300 | 01 0724 | 01 1147 | 01 1570 | 01 1993 | 01 2415 | 424 |
| 103 | 01 2837 | 01 3259 | 01 3680 | 01 4100 | 4521 | 4940 | 5360 | 5779 | 6197 | 6616 | 420 |
| 104 | 7033 | 7451 | 7868 | 8284 | 8700 | 9116 | 9532 | 9947 | 02 0361 | 02 0775 | 416 |
| 105 | 02 1189 | 02 1603 | 02 2016 | 02 2428 | 02 2841 | 02 3252 | 02 3664 | 02 4075 | 02 4486 | 02 4896 | 412 |
| 106 | 5306 | 5715 | 6125 | 6533 | 6942 | 7350 | 7757 | 8164 | 8571 | 8978 | 408 |
| 107 | 9384 | 9789 | 03 0195 | 03 0600 | 03 1004 | 03 1408 | 03 1812 | 03 2216 | 03 2619 | 03 3021 | 404 |
| 108 | 03 3424 | 03 3826 | 4227 | 4628 | 5029 | 5430 | 5830 | 6230 | 6629 | 7028 | 400 |
| 109 | 7426 | 7825 | 8223 | 8620 | 9017 | 9414 | 9811 | 04 0207 | 04 0602 | 04 0998 | 397 |
| 110 | 04 1393 | 04 1787 | 04 2182 | 04 2576 | 04 2969 | 04 3362 | 04 3755 | 04 4148 | 04 4540 | 04 4932 | 393 |
| 111 | 5323 | 5714 | 6105 | 6495 | 6885 | 7275 | 7664 | 8053 | 8442 | 8830 | 390 |
| 112 | 9218 | 9606 | 9993 | 05 0380 | 05 0766 | 05 1153 | 05 1538 | 05 1924 | 05 2309 | 05 2694 | 386 |
| 113 | 05 3078 | 05 3463 | 05 3846 | 4230 | 4613 | 4996 | 5378 | 5760 | 6142 | 6524 | 383 |
| 114 | 6905 | 7286 | 7666 | 8046 | 8426 | 8805 | 9185 | 9563 | 9942 | 06 0320 | 379 |
| 115 | 06 0698 | 06 1075 | 06 1452 | 06 1829 | 06 2206 | 06 2582 | 06 2958 | 06 3333 | 06 3709 | 06 4083 | 376 |
| 116 | 4458 | 4832 | 5206 | 5580 | 5953 | 6326 | 6699 | 7071 | 7443 | 7815 | 373 |
| 117 | 8186 | 8557 | 8928 | 9298 | 9668 | 07 0038 | 07 0407 | 07 0776 | 07 1145 | 07 1514 | 370 |
| 118 | 07 1882 | 07 2250 | 07 2617 | 07 2985 | 07 3352 | 3718 | 4085 | 4451 | 4816 | 5182 | 366 |
| 119 | 5547 | 5912 | 6276 | 6640 | 7004 | 7368 | 7731 | 8094 | 8457 | 8819 | 363 |
| 120 | 07 9181 | 07 9543 | 07 9904 | 08 0266 | 08 0626 | 08 0987 | 08 1347 | 08 1707 | 08 2067 | 08 2426 | 360 |
| 121 | 08 2785 | 08 3144 | 08 3503 | 3861 | 4219 | 4576 | 4934 | 5291 | 5647 | 6004 | 357 |
| 122 | 6360 | 6716 | 7071 | 7426 | 7781 | 8136 | 8490 | 8845 | 9198 | 9552 | 355 |
| 123 | 9905 | 09 0258 | 09 0611 | 09 0963 | 09 1315 | 09 1667 | 09 2018 | 09 2370 | 09 2721 | 09 3071 | 352 |
| 124 | 09 3422 | 3772 | 4122 | 4471 | 4820 | 5169 | 5518 | 5866 | 6215 | 6562 | 349 |
| 125 | 09 6910 | 09 7257 | 09 7604 | 09 7951 | 09 8298 | 09 8644 | 09 8990 | 09 9335 | 09 9681 | 10 0026 | 346 |
| 126 | 10 0371 | 10 0715 | 10 1059 | 10 1403 | 10 1747 | 10 2091 | 10 2434 | 10 2777 | 10 3119 | 3462 | 343 |
| 127 | 3804 | 4146 | 4487 | 4828 | 5169 | 5510 | 5851 | 6191 | 6531 | 6871 | 341 |
| 128 | 7210 | 7549 | 7888 | 8227 | 8565 | 8903 | 9241 | 9579 | 9916 | 11 0253 | 338 |
| 129 | 11 0590 | 11 0926 | 11 1263 | 11 1599 | 11 1934 | 11 2270 | 11 2605 | 11 2940 | 11 3275 | 3609 | 335 |
| 130 | 11 3943 | 11 4277 | 11 4611 | 11 4944 | 11 5278 | 11 5611 | 11 5943 | 11 6276 | 11 6608 | 11 6940 | 333 |
| 131 | 7271 | 7603 | 7934 | 8265 | 8595 | 8926 | 9256 | 9586 | 9915 | 12 0245 | 330 |
| 132 | 12 0574 | 12 0903 | 12 1231 | 12 1560 | 12 1888 | 12 2216 | 12 2544 | 12 2871 | 12 3198 | 3525 | 328 |
| 133 | 3852 | 4178 | 4504 | 4830 | 5156 | 5481 | 5806 | 6131 | 6456 | 6781 | 325 |
| 134 | 7105 | 7429 | 7753 | 8076 | 8399 | 8722 | 9045 | 9368 | 9690 | 13 0012 | 323 |
| 135 | 13 0334 | 13 0655 | 13 0977 | 13 1298 | 13 1619 | 13 1939 | 13 2260 | 13 2580 | 13 2900 | 13 3219 | 321 |
| 136 | 3539 | 3858 | 4177 | 4496 | 4814 | 5133 | 5451 | 5769 | 6086 | 6403 | 318 |
| 137 | 6721 | 7037 | 7354 | 7671 | 7987 | 8303 | 8618 | 8934 | 9249 | 9564 | 316 |
| 138 | 9879 | 14 0194 | 14 0508 | 14 0822 | 14 1136 | 14 1450 | 14 1763 | 14 2076 | 14 2389 | 14 2702 | 314 |
| 139 | 14 3015 | 3327 | 3639 | 3951 | 4263 | 4574 | 4885 | 5196 | 5507 | 5818 | 311 |
| 140 | 14 6128 | 14 6438 | 14 6748 | 14 7058 | 14 7367 | 14 7676 | 14 7985 | 14 8294 | 14 8603 | 14 8911 | 309 |
| 141 | 9219 | 9527 | 9835 | 15 0142 | 15 0449 | 15 0756 | 15 1063 | 15 1370 | 15 1676 | 15 1982 | 307 |
| 142 | 15 2288 | 15 2594 | 15 2900 | 3205 | 3510 | 3815 | 4120 | 4424 | 4728 | 5032 | 305 |
| 143 | 5336 | 5040 | 5943 | 6246 | 6549 | 6852 | 7154 | 7457 | 7759 | 8061 | 303 |
| 144 | 8362 | 8664 | 8965 | 9266 | 9567 | 9868 | 16 0168 | 16 0469 | 16 0769 | 16 1068 | 301 |
| 145 | 16 1368 | 16 1667 | 16 1967 | 16 2266 | 16 2564 | 16 2863 | 16 3161 | 16 3460 | 16 3758 | 16 4055 | 299 |
| 146 | 4353 | 4650 | 4947 | 5244 | 5541 | 5838 | 6134 | 6430 | 6726 | 7022 | 297 |
| 147 | 7317 | 7613 | 7908 | 8203 | 8497 | 8792 | 9086 | 9380 | 9674 | 9968 | 295 |
| 148 | 17 0262 | 17 0555 | 17 0848 | 17 1141 | 17 1434 | 17 1726 | 17 2019 | 17 2311 | 17 2603 | 17 2895 | 293 |
| 149 | 3186 | 3478 | 3769 | 4060 | 4351 | 4641 | 4932 | 5222 | 5512 | 5802 | 291 |
| 150 | 17 6091 | 17 6381 | 17 6670 | 17 6959 | 17 7248 | 17 7536 | 17 7825 | 17 8113 | 17 8401 | 17 8689 | 289 |
| 151 | 8977 | 9264 | 9552 | 9839 | 18 0126 | 18 0413 | 18 0699 | 18 0986 | 18 1272 | 18 1558 | 287 |
| 152 | 18 1844 | 18 2129 | 18 2415 | 18 2700 | 2985 | 3270 | 3555 | 3839 | 4123 | 4407 | 285 |
| 153 | 4691 | 4975 | 5259 | 5542 | 5825 | 6108 | 6391 | 6674 | 6956 | 7239 | 283 |
| 154 | 7521 | 7803 | 8084 | 8366 | 8647 | 8928 | 9209 | 9490 | 9771 | 19 0051 | 281 |
| 155 | 19 0332 | 19 0612 | 19 0892 | 19 1171 | 19 1451 | 19 1730 | 19 2010 | 19 2289 | 19 2567 | 19 2846 | 279 |
| 156 | 3125 | 3403 | 3681 | 3959 | 4237 | 4514 | 4792 | 5069 | 5346 | 5623 | 278 |
| 157 | 5900 | 6176 | 6453 | 6729 | 7005 | 7281 | 7556 | 7832 | 8107 | 8382 | 276 |
| 158 | 8657 | 8932 | 9206 | 9481 | 9755 | 20 0029 | 20 0303 | 20 0577 | 20 0850 | 20 1124 | 274 |
| 159 | 20 1397 | 20 1670 | 20 1943 | 20 2216 | 20 2488 | 2761 | 3033 | 3305 | 3577 | 3848 | 272 |
| N. | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | D. |

| N. | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | D. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 160 | 20 4120 | 20 4391 | 20 4663 | 20 4934 | 20 5204 | 20 5475 | 20 5746 | 20 6016 | 20 6286 | 20 6556 | 271 |
| 161 | 6826 | 7096 | 7365 | 7634 | 7904 | 8173 | 8441 | 8710 | 8979 | 9247 | 269 |
| 162 | 9515 | 9783 | 21 0051 | 21 0319 | 21 0586 | 21 0853 | 21 1121 | 21 1388 | 21 1654 | 21 1921 | 267 |
| 163 | 21 2188 | 21 2454 | 2720 | 2986 | 3252 | 3518 | 3783 | 4049 | 4314 | 4579 | 266 |
| 164 | 4844 | 5109 | 5373 | 5638 | 5902 | 6166 | 6430 | 6694 | 6957 | 7221 | 264 |
| 165 | 21 7484 | 21 7747 | 21 8010 | 21 8273 | 21 8536 | 21 8798 | 21 9060 | 21 9323 | 21 9585 | 21 9846 | 262 |
| 166 | 22 0108 | 22 0370 | 22 0631 | 22 0892 | 22 1153 | 22 1414 | 22 1675 | 22 1936 | 22 2196 | 22 2456 | 261 |
| 167 | 2716 | 2976 | 3236 | 3496 | 3755 | 4015 | 4274 | 4533 | 4792 | 5051 | 259 |
| 168 | 5309 | 5568 | 5826 | 6084 | 6342 | 6600 | 6858 | 7115 | 7372 | 7630 | 258 |
| 169 | 7887 | 8144 | 8400 | 8657 | 8913 | 9170 | 9426 | 9682 | 9938 | 23 0193 | 256 |
| 170 | 23 0449 | 23 0704 | 23 0960 | 23 1215 | 23 1470 | 23 1724 | 23 1979 | 23 2234 | 23 2488 | 23 2742 | 255 |
| 171 | 2996 | 3250 | 3504 | 3757 | 4011 | 4264 | 4517 | 4770 | 5023 | 5276 | 253 |
| 172 | 5528 | 5781 | 6033 | 6285 | 6537 | 6789 | 7041 | 7292 | 7544 | 7795 | 252 |
| 173 | 8046 | 8297 | 8548 | 8799 | 9049 | 9299 | 9550 | 9800 | 24 0050 | 24 0300 | 250 |
| 174 | 24 0549 | 24 0799 | 24 1048 | 24 1297 | 24 1546 | 24 1795 | 24 2044 | 24 2293 | 2541 | 2790 | 249 |
| 175 | 24 3038 | 24 3286 | 24 3534 | 24 3782 | 24 4030 | 24 4277 | 24 4525 | 24 4772 | 24 5019 | 24 5266 | 248 |
| 176 | 5513 | 5759 | 6006 | 6252 | 6499 | 6745 | 6991 | 7237 | 7482 | 7728 | 246 |
| 177 | 7973 | 8219 | 8464 | 8709 | 8954 | 9198 | 9443 | 9687 | 9932 | 25 0176 | 245 |
| 178 | 25 0420 | 25 0664 | 25 0908 | 25 1151 | 25 1395 | 25 1638 | 25 1881 | 25 2125 | 25 2368 | 2610 | 243 |
| 179 | 2853 | 3096 | 3338 | 3580 | 3822 | 4064 | 4306 | 4548 | 4790 | 5031 | 242 |
| 180 | 25 5273 | 25 5514 | 25 5755 | 25 5996 | 25 6237 | 25 6477 | 25 6718 | 25 6958 | 25 7198 | 25 7439 | 241 |
| 181 | 7679 | 7918 | 8158 | 8398 | 8637 | 8877 | 9116 | 9355 | 9594 | 9833 | 239 |
| 182 | 26 0071 | 26 0310 | 26 0548 | 26 0787 | 26 1025 | 26 1263 | 26 1501 | 26 1739 | 26 1976 | 26 2214 | 238 |
| 183 | 2451 | 2688 | 2925 | 3162 | 3399 | 3636 | 3873 | 4109 | 4346 | 4582 | 237 |
| 184 | 4818 | 5054 | 5290 | 5525 | 5761 | 5996 | 6232 | 6467 | 6702 | 6937 | 235 |
| 185 | 26 7172 | 26 7406 | 26 7641 | 26 7875 | 26 8110 | 26 8344 | 26 8578 | 26 8812 | 26 9046 | 26 9279 | 234 |
| 186 | 9513 | 9746 | 9980 | 27 0213 | 27 0446 | 27 0679 | 27 0912 | 27 1144 | 27 1377 | 27 1609 | 233 |
| 187 | 27 1842 | 27 2074 | 27 2306 | 2538 | 2770 | 3001 | 3233 | 3464 | 3696 | 3927 | 232 |
| 188 | 4158 | 4389 | 4620 | 4850 | 5081 | 5311 | 5542 | 5772 | 6002 | 6232 | 230 |
| 189 | 6462 | 6692 | 6921 | 7151 | 7380 | 7609 | 7838 | 8067 | 8296 | 8525 | 229 |
| 190 | 27 8754 | 27 8982 | 27 9211 | 27 9439 | 27 9667 | 27 9895 | 28 0123 | 28 0351 | 28 0578 | 28 0806 | 228 |
| 191 | 28 1033 | 28 1261 | 28 1488 | 28 1715 | 28 1942 | 28 2169 | 2396 | 2622 | 2849 | 3075 | 227 |
| 192 | 3301 | 3527 | 3753 | 3979 | 4205 | 4431 | 4656 | 4882 | 5107 | 5332 | 226 |
| 193 | 5557 | 5782 | 6007 | 6232 | 6456 | 6681 | 6905 | 7130 | 7354 | 7578 | 225 |
| 194 | 7802 | 8026 | 8249 | 8473 | 8696 | 8920 | 9143 | 9366 | 9589 | 9812 | 223 |
| 195 | 29 0035 | 29 0257 | 29 0480 | 29 0702 | 29 0925 | 29 1147 | 29 1369 | 29 1591 | 29 1813 | 29 2034 | 222 |
| 196 | 2256 | 2478 | 2699 | 2920 | 3141 | 3363 | 3584 | 3804 | 4025 | 4246 | 221 |
| 197 | 4466 | 4687 | 4907 | 5127 | 5347 | 5567 | 5787 | 6007 | 6226 | 6446 | 220 |
| 198 | 6665 | 6884 | 7104 | 7323 | 7542 | 7761 | 7979 | 8198 | 8416 | 8635 | 219 |
| 199 | 8853 | 9071 | 9289 | 9507 | 9725 | 9943 | 30 0161 | 30 0378 | 30 0595 | 30 0813 | 218 |
| 200 | 30 1030 | 30 1247 | 30 1464 | 30 1681 | 30 1898 | 30 2114 | 30 2331 | 30 2547 | 30 2764 | 30 2980 | 217 |
| 201 | 3196 | 3412 | 3628 | 3844 | 4059 | 4275 | 4491 | 4706 | 4921 | 5136 | 216 |
| 202 | 5351 | 5566 | 5781 | 5996 | 6211 | 6425 | 6639 | 6854 | 7068 | 7282 | 215 |
| 203 | 7496 | 7710 | 7924 | 8137 | 8351 | 8564 | 8778 | 8991 | 9204 | 9417 | 213 |
| 204 | 9630 | 9843 | 31 0056 | 31 0268 | 31 0481 | 31 0693 | 31 0906 | 31 1118 | 31 1330 | 31 1542 | 212 |
| 205 | 31 1754 | 31 1966 | 31 2177 | 31 2389 | 31 2600 | 31 2812 | 31 3023 | 31 3234 | 31 3445 | 31 3656 | 211 |
| 206 | 3867 | 4078 | 4289 | 4499 | 4710 | 4920 | 5130 | 5340 | 5551 | 5760 | 210 |
| 207 | 5970 | 6180 | 6390 | 6599 | 6809 | 7018 | 7227 | 7436 | 7646 | 7854 | 209 |
| 208 | 8063 | 8272 | 8481 | 8689 | 8898 | 9106 | 9314 | 9522 | 9730 | 9938 | 208 |
| 209 | 32 0146 | 32 0354 | 32 0562 | 32 0769 | 32 0977 | 32 1184 | 32 1391 | 32 1598 | 32 1805 | 32 2012 | 207 |
| 210 | 32 2219 | 32 2426 | 32 2633 | 32 2839 | 32 3046 | 32 3252 | 32 3458 | 32 3665 | 32 3871 | 32 4077 | 206 |
| 211 | 4282 | 4488 | 4694 | 4899 | 5105 | 5310 | 5516 | 5721 | 5926 | 6131 | 205 |
| 212 | 6336 | 6541 | 6745 | 6950 | 7155 | 7359 | 7563 | 7767 | 7972 | 8176 | 204 |
| 213 | 8380 | 8583 | 8787 | 8991 | 9194 | 9398 | 9601 | 9805 | 33 0008 | 33 0211 | 203 |
| 214 | 33 0414 | 33 0617 | 33 0819 | 33 1022 | 33 1225 | 33 1427 | 33 1630 | 33 1832 | 2034 | 2236 | 202 |
| 215 | 33 2438 | 33 2640 | 33 2842 | 33 3044 | 33 3246 | 33 3447 | 33 3649 | 33 3850 | 33 4051 | 33 4253 | 202 |
| 216 | 4454 | 4655 | 4856 | 5057 | 5257 | 5458 | 5658 | 5859 | 6059 | 6260 | 201 |
| 217 | 6460 | 6660 | 6860 | 7060 | 7260 | 7459 | 7659 | 7858 | 8058 | 8257 | 200 |
| 218 | 8456 | 8656 | 8855 | 9054 | 9253 | 9451 | 9650 | 9849 | 34 0047 | 34 0246 | 199 |
| 219 | 34 0444 | 34 0642 | 34 0841 | 34 1039 | 34 1237 | 34 1435 | 34 1632 | 34 1830 | 2028 | 2225 | 198 |
| N. | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | D. |

| N. | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | D. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 220 | 34 2423 | 34 2620 | 34 2817 | 34 3014 | 34 3212 | 34 3409 | 34 3606 | 34 3802 | 34 3999 | 34 4196 | 197 |
| 221 | 4392 | 4589 | 4785 | 4981 | 5178 | 5374 | 5570 | 5766 | 5962 | 6157 | 196 |
| 222 | 6353 | 6549 | 6744 | 6939 | 7135 | 7330 | 7525 | 7720 | 7915 | 8110 | 195 |
| 223 | 8305 | 8500 | 8694 | 8889 | 9083 | 9278 | 9472 | 9666 | 9860 | 35 0054 | 194 |
| 224 | 35 0248 | 35 0442 | 35 0636 | 35 0829 | 35 1023 | 35 1216 | 35 1410 | 35 1603 | 35 1796 | 1989 | 193 |
| 225 | 35 2183 | 35 2375 | 35 2568 | 35 2761 | 35 2954 | 35 3147 | 35 3339 | 35 3532 | 35 3724 | 35 3916 | 193 |
| 226 | 4108 | 4301 | 4493 | 4685 | 4876 | 5068 | 5260 | 5452 | 5643 | 5834 | 192 |
| 227 | 6026 | 6217 | 6408 | 6599 | 6790 | 6981 | 7172 | 7363 | 7554 | 7744 | 191 |
| 228 | 7935 | 8125 | 8316 | 8506 | 8696 | 8886 | 9076 | 9266 | 9456 | 9646 | 190 |
| 229 | 9835 | 36 0025 | 36 0215 | 36 0404 | 36 0593 | 36 0783 | 36 0972 | 36 1161 | 36 1350 | 36 1539 | 189 |
| 230 | 36 1728 | 36 1917 | 36 2105 | 36 2294 | 36 2482 | 36 2671 | 36 2859 | 36 3048 | 36 3236 | 36 3424 | 188 |
| 231 | 3612 | 3800 | 3988 | 4176 | 4363 | 4551 | 4739 | 4926 | 5113 | 5301 | 188 |
| 232 | 5488 | 5675 | 5862 | 6049 | 6236 | 6423 | 6610 | 6796 | 6983 | 7169 | 187 |
| 233 | 7356 | 7542 | 7729 | 7915 | 8101 | 8287 | 8473 | 8659 | 8845 | 9030 | 186 |
| 234 | 9216 | 9401 | 9587 | 9772 | 9958 | 37 0143 | 37 0328 | 37 0513 | 37 0698 | 37 0883 | 185 |
| 235 | 37 1068 | 37 1253 | 37 1437 | 37 1622 | 37 1806 | 37 1991 | 37 2175 | 37 2360 | 37 2544 | 37 2728 | 184 |
| 236 | 2912 | 3096 | 3280 | 3464 | 3647 | 3831 | 4015 | 4198 | 4382 | 4565 | 184 |
| 237 | 4748 | 4932 | 5115 | 5298 | 5481 | 5664 | 5846 | 6029 | 6212 | 6394 | 183 |
| 238 | 6577 | 6759 | 6942 | 7124 | 7306 | 7488 | 7670 | 7852 | 8034 | 8216 | 182 |
| 239 | 8398 | 8580 | 8761 | 8943 | 9124 | 9306 | 9487 | 9668 | 9849 | 38 0030 | 181 |
| 240 | 38 0211 | 38 0392 | 38 0573 | 38 0754 | 38 0934 | 38 1115 | 38 1296 | 38 1476 | 38 1656 | 38 1837 | 181 |
| 241 | 2017 | 2197 | 2377 | 2557 | 2737 | 2917 | 3097 | 3277 | 3456 | 3636 | 180 |
| 242 | 3815 | 3995 | 4174 | 4353 | 4533 | 4712 | 4891 | 5070 | 5249 | 5428 | 179 |
| 243 | 5606 | 5785 | 5964 | 6142 | 6321 | 6499 | 6677 | 6856 | 7034 | 7212 | 178 |
| 244 | 7390 | 7568 | 7746 | 7923 | 8101 | 8279 | 8456 | 8634 | 8811 | 8989 | 178 |
| 245 | 38 9166 | 38 9343 | 38 9520 | 38 9698 | 38 9875 | 39 0051 | 39 0228 | 39 0405 | 39 0582 | 39 0759 | 177 |
| 246 | 39 0935 | 39 1112 | 39 1288 | 39 1464 | 39 1641 | 1817 | 1993 | 2169 | 2345 | 2521 | 176 |
| 247 | 2697 | 2873 | 3048 | 3224 | 3400 | 3575 | 3751 | 3926 | 4101 | 4277 | 176 |
| 248 | 4452 | 4627 | 4802 | 4977 | 5152 | 5326 | 5501 | 5676 | 5850 | 6025 | 175 |
| 249 | 6199 | 6374 | 6548 | 6722 | 6896 | 7071 | 7245 | 7419 | 7592 | 7766 | 174 |
| 250 | 39 7940 | 39 8114 | 39 8287 | 39 8461 | 39 8634 | 39 8808 | 39 8981 | 39 9154 | 39 9328 | 39 9501 | 173 |
| 251 | 9674 | 9847 | 40 0020 | 40 0192 | 40 0365 | 40 0538 | 40 0711 | 40 0883 | 40 1056 | 40 1228 | 173 |
| 252 | 40 1401 | 40 1573 | 1745 | 1917 | 2089 | 2261 | 2433 | 2605 | 2777 | 2949 | 172 |
| 253 | 3121 | 3292 | 3464 | 3635 | 3807 | 3978 | 4149 | 4320 | 4492 | 4663 | 171 |
| 254 | 4834 | 5005 | 5176 | 5346 | 5517 | 5688 | 5858 | 6029 | 6199 | 6370 | 171 |
| 255 | 40 6540 | 40 6710 | 40 6881 | 40 7051 | 40 7221 | 40 7391 | 40 7561 | 40 7731 | 40 7901 | 40 8070 | 170 |
| 256 | 8240 | 8410 | 8579 | 8749 | 8918 | 9087 | 9257 | 9426 | 9595 | 9764 | 169 |
| 257 | 9933 | 41 0102 | 41 0271 | 41 0440 | 41 0609 | 41 0777 | 41 0946 | 41 1114 | 41 1283 | 41 1451 | 169 |
| 258 | 41 1620 | 1788 | 1956 | 2124 | 2293 | 2461 | 2629 | 2796 | 2964 | 3132 | 168 |
| 259 | 3300 | 3467 | 3635 | 3803 | 3970 | 4137 | 4305 | 4472 | 4639 | 4806 | 167 |
| 260 | 41 4973 | 41 5140 | 41 5307 | 41 5474 | 41 5641 | 41 5808 | 41 5974 | 41 6141 | 41 6308 | 41 6474 | 167 |
| 261 | 6641 | 6807 | 6973 | 7139 | 7306 | 7472 | 7638 | 7804 | 7970 | 8135 | 166 |
| 262 | 8301 | 8467 | 8633 | 8798 | 8964 | 9129 | 9295 | 9460 | 9625 | 9791 | 165 |
| 263 | 9956 | 42 0121 | 42 0286 | 42 0451 | 42 0616 | 42 0781 | 42 0945 | 42 1110 | 42 1275 | 42 1439 | 165 |
| 264 | 42 1604 | 1768 | 1933 | 2097 | 2261 | 2426 | 2590 | 2754 | 2918 | 3082 | 164 |
| 265 | 42 3246 | 42 3410 | 42 3574 | 42 3737 | 42 3901 | 42 4065 | 42 4228 | 42 4392 | 42 4555 | 42 4718 | 164 |
| 266 | 4882 | 5045 | 5208 | 5371 | 5534 | 5697 | 5860 | 6023 | 6186 | 6349 | 163 |
| 267 | 6511 | 6674 | 6836 | 6999 | 7161 | 7324 | 7486 | 7648 | 7811 | 7973 | 162 |
| 268 | 8135 | 8297 | 8459 | 8621 | 8783 | 8944 | 9106 | 9268 | 9429 | 9591 | 162 |
| 269 | 9752 | 9914 | 43 0075 | 43 0236 | 43 0398 | 43 0559 | 43 0720 | 43 0881 | 43 1042 | 43 1203 | 161 |
| 270 | 43 1364 | 43 1525 | 43 1685 | 43 1846 | 43 2007 | 43 2167 | 43 2328 | 43 2488 | 43 2649 | 43 2809 | 161 |
| 271 | 2969 | 3130 | 3290 | 3450 | 3610 | 3770 | 3930 | 4090 | 4249 | 4409 | 160 |
| 272 | 4569 | 4729 | 4888 | 5048 | 5207 | 5367 | 5526 | 5685 | 5844 | 6004 | 159 |
| 273 | 6163 | 6322 | 6481 | 6640 | 6799 | 6957 | 7116 | 7275 | 7433 | 7592 | 159 |
| 274 | 7751 | 7909 | 8067 | 8226 | 8384 | 8542 | 8701 | 8859 | 9017 | 9175 | 158 |
| 275 | 43 9333 | 43 9491 | 43 9648 | 43 9806 | 43 9964 | 44 0122 | 44 0279 | 44 0437 | 44 0594 | 44 0752 | 158 |
| 276 | 44 0909 | 44 1066 | 44 1224 | 44 1381 | 44 1538 | 1695 | 1852 | 2009 | 2166 | 2323 | 157 |
| 277 | 2480 | 2637 | 2793 | 2950 | 3106 | 3263 | 3419 | 3576 | 3732 | 3889 | 157 |
| 278 | 4045 | 4201 | 4357 | 4513 | 4669 | 4825 | 4981 | 5137 | 5293 | 5449 | 156 |
| 279 | 5604 | 5760 | 5915 | 6071 | 6226 | 6382 | 6537 | 6692 | 6848 | 7003 | 155 |
| N. | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | D. |

| N. | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | D. |
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| **280** | 44 7158 | 44 7313 | 44 7468 | 44 7623 | 44 7778 | 44 7933 | 44 8088 | 44 8242 | 44 8397 | 44 8552 | 155 |
| **281** | 8706 | 8861 | 9015 | 9170 | 9324 | 9478 | 9633 | 9787 | 9941 | 45 0095 | 154 |
| **282** | 45 0249 | 45 0403 | 45 0557 | 45 0711 | 45 0865 | 45 1018 | 45 1172 | 45 1326 | 45 1479 | 1633 | 154 |
| **283** | 1786 | 1940 | 2093 | 2247 | 2400 | 2553 | 2706 | 2859 | 3012 | 3165 | 153 |
| **284** | 3318 | 3471 | 3624 | 3777 | 3930 | 4082 | 4235 | 4387 | 4540 | 4692 | 153 |
| **285** | 45 4845 | 45 4997 | 45 5150 | 45 5302 | 45 5454 | 45 5606 | 45 5758 | 45 5910 | 45 6062 | 45 6214 | 152 |
| **286** | 6366 | 6518 | 6670 | 6821 | 6973 | 7125 | 7276 | 7428 | 7579 | 7731 | 152 |
| **287** | 7882 | 8033 | 8184 | 8336 | 8487 | 8638 | 8789 | 8940 | 9091 | 9242 | 151 |
| **288** | 9392 | 9543 | 9694 | 9845 | 9995 | 4601 | 46 0296 | 46 0447 | 46 0597 | 46 0748 | 151 |
| **289** | 46 0898 | 46 1048 | 46 1198 | 46 1348 | 46 1499 | 1649 | 1799 | 1948 | 2098 | 2248 | 150 |
| **290** | 46 2398 | 46 2548 | 46 2697 | 46 2847 | 46 2997 | 46 3146 | 46 3296 | 46 3445 | 46 3594 | 46 3744 | 150 |
| **291** | 3893 | 4042 | 4191 | 4340 | 4490 | 4639 | 4788 | 4936 | 5085 | 5234 | 149 |
| **292** | 5383 | 5532 | 5680 | 5829 | 5977 | 6126 | 6274 | 6423 | 6571 | 6719 | 149 |
| **293** | 6868 | 7016 | 7164 | 7312 | 7460 | 7608 | 7756 | 7904 | 8052 | 8200 | 148 |
| **294** | 8347 | 8495 | 8643 | 8790 | 8938 | 9085 | 9233 | 9380 | 9527 | 9675 | 148 |
| **295** | 46 9822 | 46 9969 | 47 0116 | 47 0263 | 47 0410 | 47 0557 | 47 0704 | 47 0851 | 47 0998 | 47 1145 | 147 |
| **296** | 47 1292 | 47 1438 | 1585 | 1732 | 1878 | 2025 | 2171 | 2318 | 2464 | 2610 | 146 |
| **297** | 2756 | 2903 | 3049 | 3195 | 3341 | 3487 | 3633 | 3779 | 3925 | 4071 | 146 |
| **298** | 4216 | 4362 | 4508 | 4653 | 4799 | 4944 | 5090 | 5235 | 5381 | 5526 | 146 |
| **299** | 5671 | 5816 | 5962 | 6107 | 6252 | 6397 | 6542 | 6687 | 6832 | 6976 | 145 |
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| **301** | 8566 | 8711 | 8855 | 8999 | 9143 | 9287 | 9431 | 9575 | 9719 | 9863 | 144 |
| **302** | 48 0007 | 48 0151 | 48 0294 | 48 0438 | 48 0582 | 48 0725 | 48 0869 | 48 1012 | 48 1156 | 48 1299 | 144 |
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| **305** | 48 4300 | 48 4442 | 48 4585 | 48 4727 | 48 4869 | 48 5011 | 48 5153 | 48 5295 | 48 5437 | 48 5579 | 142 |
| **306** | 5721 | 5863 | 6005 | 6147 | 6289 | 6430 | 6572 | 6714 | 6855 | 6997 | 142 |
| **307** | 7138 | 7280 | 7421 | 7563 | 7704 | 7845 | 7986 | 8127 | 8269 | 8410 | 141 |
| **308** | 8551 | 8692 | 8833 | 8974 | 9114 | 9255 | 9396 | 9537 | 9677 | 9818 | 141 |
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| **310** | 49 1362 | 49 1502 | 49 1642 | 49 1782 | 49 1922 | 49 2062 | 49 2201 | 49 2341 | 49 2481 | 49 2621 | 140 |
| **311** | 2760 | 2900 | 3040 | 3179 | 3319 | 3458 | 3597 | 3737 | 3876 | 4015 | 139 |
| **312** | 4155 | 4294 | 4433 | 4572 | 4711 | 4850 | 4989 | 5128 | 5267 | 5406 | 139 |
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| **314** | 6930 | 7068 | 7206 | 7344 | 7483 | 7621 | 7759 | 7897 | 8035 | 8173 | 138 |
| **315** | 49 8311 | 49 8448 | 49 8586 | 49 8724 | 49 8862 | 49 8999 | 49 9137 | 49 9275 | 49 9412 | 49 9550 | 138 |
| **316** | 9687 | 9824 | 9962 | 50 0099 | 50 0236 | 50 0374 | 50 0511 | 50 0648 | 50 0785 | 50 0922 | 137 |
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| **318** | 2427 | 2564 | 2700 | 2837 | 2973 | 3109 | 3246 | 3382 | 3518 | 3655 | 136 |
| **319** | 3791 | 3927 | 4063 | 4199 | 4335 | 4471 | 4607 | 4743 | 4878 | 5014 | 136 |
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| **322** | 7856 | 7991 | 8126 | 8260 | 8395 | 8530 | 8664 | 8799 | 8934 | 9068 | 135 |
| **323** | 9203 | 9337 | 9471 | 9606 | 9740 | 9874 | 51 0009 | 51 0143 | 51 0277 | 51 0411 | 134 |
| **324** | 51 0545 | 51 0679 | 51 0813 | 51 0947 | 51 1081 | 51 1215 | 1349 | 1482 | 1616 | 1750 | 134 |
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| 352 | 6543 | 6666 | 6789 | 6913 | 7036 | 7159 | 7282 | 7405 | 7529 | 7652 | 123 |
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| 367 | 4666 | 4784 | 4903 | 5021 | 5139 | 5257 | 5376 | 5494 | 5612 | 5730 | 118 |
| 368 | 5848 | 5966 | 6084 | 6202 | 6320 | 6437 | 6555 | 6673 | 6791 | 6909 | 118 |
| 369 | 7026 | 7144 | 7262 | 7379 | 7497 | 7614 | 7732 | 7849 | 7967 | 8084 | 118 |
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| 371 | 9374 | 9491 | 9608 | 9725 | 9842 | 9959 | 57 0076 | 57 0193 | 57 0309 | 57 0426 | 117 |
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| 402 | 4226 | 4334 | 4442 | 4550 | 4658 | 4766 | 4874 | 4982 | 5089 | 5197 | 108 |
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| 407 | 9594 | 9701 | 9808 | 9914 | 61 0021 | 61 0128 | 61 0234 | 61 0341 | 61 0447 | 61 0554 | 107 |
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| 433 | 6488 | 6588 | 6688 | 6789 | 6889 | 6989 | 7089 | 7189 | 7290 | 7390 | 100 |
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| 478 | 9428 | 9519 | 9610 | 9700 | 9791 | 9882 | 9973 | 68 0063 | 68 0154 | 68 0245 | 91 |
| 479 | 68 0336 | 68 0426 | 68 0517 | 68 0607 | 68 0698 | 68 0789 | 68 0879 | 0970 | 1060 | 1151 | 91 |
| 480 | 68 1241 | 68 1332 | 68 1422 | 68 1513 | 68 1603 | 68 1693 | 68 1784 | 68 1874 | 68 1964 | 68 2055 | 90 |
| 481 | 2145 | 2235 | 2326 | 2416 | 2506 | 2596 | 2686 | 2777 | 2867 | 2957 | 90 |
| 482 | 3047 | 3137 | 3227 | 3317 | 3407 | 3497 | 3587 | 3677 | 3767 | 3857 | 90 |
| 483 | 3947 | 4037 | 4127 | 4217 | 4307 | 4396 | 4486 | 4576 | 4666 | 4756 | 90 |
| 484 | 4845 | 4935 | 5025 | 5114 | 5204 | 5294 | 5383 | 5473 | 5563 | 5652 | 90 |
| 485 | 68 5742 | 68 5831 | 68 5921 | 68 6010 | 68 6100 | 68 6189 | 68 6279 | 68 6368 | 68 6458 | 68 6547 | 89 |
| 486 | 6636 | 6726 | 6815 | 6904 | 6994 | 7083 | 7172 | 7261 | 7351 | 7440 | 89 |
| 487 | 7529 | 7618 | 7707 | 7796 | 7886 | 7975 | 8064 | 8153 | 8242 | 8331 | 89 |
| 488 | 8420 | 8509 | 8598 | 8687 | 8776 | 8865 | 8953 | 9042 | 9131 | 9220 | 89 |
| 489 | 9309 | 9398 | 9486 | 9575 | 9664 | 9753 | 9841 | 9930 | 69 0019 | 69 0107 | 89 |
| 490 | 69 0196 | 69 0285 | 69 0373 | 69 0462 | 69 0550 | 69 0639 | 69 0728 | 69 0816 | 69 0905 | 69 0993 | 89 |
| 491 | 1081 | 1170 | 1258 | 1347 | 1435 | 1524 | 1612 | 1700 | 1789 | 1877 | 88 |
| 492 | 1965 | 2053 | 2142 | 2230 | 2318 | 2406 | 2494 | 2583 | 2671 | 2759 | 88 |
| 493 | 2847 | 2935 | 3023 | 3111 | 3199 | 3287 | 3375 | 3463 | 3551 | 3639 | 88 |
| 494 | 3727 | 3815 | 3903 | 3991 | 4078 | 4166 | 4254 | 4342 | 4430 | 4517 | 88 |
| 495 | 69 4605 | 69 4693 | 69 4781 | 69 4868 | 69 4956 | 69 5044 | 69 5131 | 69 5219 | 69 5307 | 69 5394 | 88 |
| 496 | 5482 | 5569 | 5657 | 5744 | 5832 | 5919 | 6007 | 6094 | 6182 | 6269 | 87 |
| 497 | 6356 | 6444 | 6531 | 6618 | 6706 | 6793 | 6880 | 6968 | 7055 | 7142 | 87 |
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| 500 | 69 8970 | 69 9057 | 69 9144 | 69 9231 | 69 9317 | 69 9404 | 69 9491 | 69 9578 | 69 9664 | 69 9751 | 87 |
| 501 | 9838 | 9924 | 70 0011 | 70 0098 | 70 0184 | 70 0271 | 70 0358 | 70 0444 | 70 0531 | 70 0617 | 87 |
| 502 | 70 0704 | 70 0790 | 0877 | 0963 | 1050 | 1136 | 1222 | 1309 | 1395 | 1482 | 86 |
| 503 | 1568 | 1654 | 1741 | 1827 | 1913 | 1999 | 2086 | 2172 | 2258 | 2344 | 86 |
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|---|---|---|---|---|---|---|---|---|---|---|---|
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| 522 | 7671 | 7754 | 7837 | 7920 | 8003 | 8086 | 8169 | 8253 | 8336 | 8419 | 83 |
| 523 | 8502 | 8585 | 8668 | 8751 | 8834 | 8917 | 9000 | 9083 | 9165 | 9248 | 83 |
| 524 | 9331 | 9414 | 9497 | 9580 | 9663 | 9745 | 9828 | 9911 | 9994 | 72 0077 | 83 |
| 525 | 72 0159 | 72 0242 | 72 0325 | 72 0407 | 72 0490 | 72 0573 | 72 0655 | 72 0738 | 72 0821 | 72 0903 | 83 |
| 526 | 0986 | 1068 | 1151 | 1233 | 1316 | 1398 | 1481 | 1563 | 1646 | 1728 | 82 |
| 527 | 1811 | 1893 | 1975 | 2058 | 2140 | 2222 | 2305 | 2387 | 2469 | 2552 | 82 |
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| 544 | 5599 | 5679 | 5759 | 5838 | 5918 | 5998 | 6078 | 6157 | 6237 | 6317 | 80 |
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| 549 | 9572 | 9651 | 9731 | 9810 | 9889 | 9968 | 74 0047 | 74 0126 | 74 0205 | 74 0284 | 79 |
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| 551 | 1152 | 1230 | 1309 | 1388 | 1467 | 1546 | 1624 | 1703 | 1782 | 1860 | 79 |
| 552 | 1939 | 2018 | 2096 | 2175 | 2254 | 2332 | 2411 | 2489 | 2568 | 2647 | 79 |
| 553 | 2725 | 2804 | 2882 | 2961 | 3039 | 3118 | 3196 | 3275 | 3353 | 3431 | 78 |
| 554 | 3510 | 3588 | 3667 | 3745 | 3823 | 3902 | 3980 | 4058 | 4136 | 4215 | 78 |
| 555 | 74 4293 | 74 4371 | 74 4449 | 74 4528 | 74 4606 | 74 4684 | 74 4762 | 74 4840 | 74 4919 | 74 4997 | 78 |
| 556 | 5075 | 5153 | 5231 | 5309 | 5387 | 5465 | 5543 | 5621 | 5699 | 5777 | 78 |
| 557 | 5855 | 5933 | 6011 | 6089 | 6167 | 6245 | 6323 | 6401 | 6479 | 6556 | 78 |
| 558 | 6634 | 6712 | 6790 | 6868 | 6945 | 7023 | 7101 | 7179 | 7256 | 7334 | 78 |
| 559 | 7412 | 7489 | 7567 | 7645 | 7722 | 7800 | 7878 | 7955 | 8033 | 8110 | 78 |
| 560 | 74 8188 | 74 8266 | 74 8343 | 74 8421 | 74 8498 | 74 8576 | 74 8653 | 74 8731 | 74 8808 | 74 8885 | 77 |
| 561 | 8963 | 9040 | 9118 | 9195 | 9272 | 9350 | 9427 | 9504 | 9582 | 9659 | 77 |
| 562 | 9736 | 9814 | 9891 | 9968 | 75 0045 | 75 0123 | 75 0200 | 75 0277 | 75 0354 | 75 0431 | 77 |
| 563 | 75 0508 | 75 0586 | 75 0663 | 75 0740 | 0817 | 0894 | 0971 | 1048 | 1125 | 1202 | 77 |
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| 567 | 3583 | 3660 | 3736 | 3813 | 3889 | 3966 | 4042 | 4119 | 4195 | 4272 | 77 |
| 568 | 4348 | 4425 | 4501 | 4578 | 4654 | 4730 | 4807 | 4883 | 4960 | 5036 | 76 |
| 569 | 5112 | 5189 | 5265 | 5341 | 5417 | 5494 | 5570 | 5646 | 5722 | 5799 | 76 |
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| 573 | 8155 | 8230 | 8306 | 8382 | 8458 | 8533 | 8609 | 8685 | 8761 | 8836 | 76 |
| 574 | 8912 | 8988 | 9063 | 9139 | 9214 | 9290 | 9366 | 9441 | 9517 | 9592 | 76 |
| 575 | 75 9668 | 75 9743 | 75 9819 | 75 9894 | 75 9970 | 76 0045 | 76 0121 | 76 0196 | 76 0272 | 76 0347 | 75 |
| 576 | 76 0422 | 76 0498 | 76 0573 | 76 0649 | 76 0724 | 0799 | 0875 | 0950 | 1025 | 1101 | 75 |
| 577 | 1176 | 1251 | 1326 | 1402 | 1477 | 1552 | 1627 | 1702 | 1778 | 1853 | 75 |
| 578 | 1928 | 2003 | 2078 | 2153 | 2228 | 2303 | 2378 | 2453 | 2529 | 2604 | 75 |
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| 582 | 4923 | 4998 | 5072 | 5147 | 5221 | 5296 | 5370 | 5445 | 5520 | 5594 | 75 |
| 583 | 5669 | 5743 | 5818 | 5892 | 5966 | 6041 | 6115 | 6190 | 6264 | 6338 | 74 |
| 584 | 6413 | 6487 | 6562 | 6636 | 6710 | 6785 | 6859 | 6933 | 7007 | 7082 | 74 |
| 585 | 76 7156 | 76 7230 | 76 7304 | 76 7379 | 76 7453 | 76 7527 | 76 7601 | 76 7675 | 76 7749 | 76 7823 | 74 |
| 586 | 7898 | 7972 | 8046 | 8120 | 8194 | 8268 | 8342 | 8416 | 8490 | 8564 | 74 |
| 587 | 8638 | 8712 | 8786 | 8860 | 8934 | 9008 | 9082 | 9156 | 9230 | 9303 | 74 |
| 588 | 9377 | 9451 | 9525 | 9599 | 9673 | 9746 | 9820 | 9894 | 9968 | 77 0042 | 74 |
| 589 | 77 0115 | 77 0189 | 77 0263 | 77 0336 | 77 0410 | 77 0484 | 77 0557 | 77 0631 | 77 0705 | 0778 | 74 |
| 590 | 77 0852 | 77 0926 | 77 0999 | 77 1073 | 77 1146 | 77 1220 | 77 1293 | 77 1367 | 77 1440 | 77 1514 | 74 |
| 591 | 1587 | 1661 | 1734 | 1808 | 1881 | 1955 | 2028 | 2102 | 2175 | 2248 | 73 |
| 592 | 2322 | 2395 | 2468 | 2542 | 2615 | 2688 | 2762 | 2835 | 2908 | 2981 | 73 |
| 593 | 3055 | 3128 | 3201 | 3274 | 3348 | 3421 | 3494 | 3567 | 3640 | 3713 | 73 |
| 594 | 3786 | 3860 | 3933 | 4006 | 4079 | 4152 | 4225 | 4298 | 4371 | 4444 | 73 |
| 595 | 77 4517 | 77 4590 | 77 4663 | 77 4736 | 77 4809 | 77 4882 | 77 4955 | 77 5028 | 77 5100 | 77 5173 | 73 |
| 596 | 5246 | 5319 | 5392 | 5465 | 5538 | 5610 | 5683 | 5756 | 5829 | 5902 | 73 |
| 597 | 5974 | 6047 | 6120 | 6193 | 6265 | 6338 | 6411 | 6483 | 6556 | 6629 | 73 |
| 598 | 6701 | 6774 | 6846 | 6919 | 6992 | 7064 | 7137 | 7209 | 7282 | 7354 | 73 |
| 599 | 7427 | 7499 | 7572 | 7644 | 7717 | 7789 | 7862 | 7934 | 8006 | 8079 | 72 |
| 600 | 77 8151 | 77 8224 | 77 8296 | 77 8368 | 77 8441 | 77 8513 | 77 8585 | 77 8658 | 77 8730 | 77 8802 | 72 |
| 601 | 8874 | 8947 | 9019 | 9091 | 9163 | 9236 | 9308 | 9380 | 9452 | 9524 | 72 |
| 602 | 9596 | 9669 | 9741 | 9813 | 9885 | 9957 | 78 0029 | 78 0101 | 78 0173 | 78 0245 | 72 |
| 603 | 78 0317 | 78 0389 | 78 0461 | 78 0533 | 78 0605 | 78 0677 | 0749 | 0821 | 0893 | 0965 | 72 |
| 604 | 1037 | 1109 | 1181 | 1253 | 1324 | 1396 | 1468 | 1540 | 1612 | 1684 | 72 |
| 605 | 78 1755 | 78 1827 | 78 1899 | 78 1971 | 78 2042 | 78 2114 | 78 2186 | 78 2258 | 78 2329 | 78 2401 | 72 |
| 606 | 2473 | 2544 | 2616 | 2688 | 2759 | 2831 | 2902 | 2974 | 3046 | 3117 | 72 |
| 607 | 3189 | 3260 | 3332 | 3403 | 3475 | 3546 | 3618 | 3689 | 3761 | 3832 | 71 |
| 608 | 3904 | 3975 | 4046 | 4118 | 4189 | 4261 | 4332 | 4403 | 4475 | 4546 | 71 |
| 609 | 4617 | 4689 | 4760 | 4831 | 4902 | 4974 | 5045 | 5116 | 5187 | 5259 | 71 |
| 610 | 78 5330 | 78 5401 | 78 5472 | 78 5543 | 78 5615 | 78 5686 | 78 5757 | 78 5828 | 78 5899 | 78 5970 | 71 |
| 611 | 6041 | 6112 | 6183 | 6254 | 6325 | 6396 | 6467 | 6538 | 6609 | 6680 | 71 |
| 612 | 6751 | 6822 | 6893 | 6964 | 7035 | 7106 | 7177 | 7248 | 7319 | 7390 | 71 |
| 613 | 7460 | 7531 | 7602 | 7673 | 7744 | 7815 | 7885 | 7956 | 8027 | 8098 | 71 |
| 614 | 8168 | 8239 | 8310 | 8381 | 8451 | 8522 | 8593 | 8663 | 8734 | 8804 | 71 |
| 615 | 78 8875 | 78 8946 | 78 9016 | 78 9087 | 78 9157 | 78 9228 | 78 9299 | 78 9369 | 78 9440 | 78 9510 | 71 |
| 616 | 9581 | 9651 | 9722 | 9792 | 9863 | 9933 | 79 0004 | 79 0074 | 79 0144 | 79 0215 | 70 |
| 617 | 79 0285 | 79 0356 | 79 0426 | 79 0496 | 79 0567 | 79 0637 | 0707 | 0778 | 0848 | 0918 | 70 |
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| 622 | 3790 | 3860 | 3930 | 4000 | 4070 | 4139 | 4209 | 4279 | 4349 | 4418 | 70 |
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| 624 | 5185 | 5254 | 5324 | 5393 | 5463 | 5532 | 5602 | 5672 | 5741 | 5811 | 70 |
| 625 | 79 5880 | 79 5949 | 79 6019 | 79 6088 | 79 6158 | 79 6227 | 79 6297 | 79 6366 | 79 6436 | 79 6505 | 69 |
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| 627 | 7268 | 7337 | 7406 | 7475 | 7545 | 7614 | 7683 | 7752 | 7821 | 7890 | 69 |
| 628 | 7960 | 8029 | 8098 | 8167 | 8236 | 8305 | 8374 | 8443 | 8513 | 8582 | 69 |
| 629 | 8651 | 8720 | 8789 | 8858 | 8927 | 8996 | 9065 | 9134 | 9203 | 9272 | 69 |
| 630 | 79 9341 | 79 9409 | 79 9478 | 79 9547 | 79 9616 | 79 9685 | 79 9754 | 79 9823 | 79 9892 | 79 9961 | 69 |
| 631 | 80 0029 | 80 0098 | 80 0167 | 80 0236 | 80 0305 | 80 0373 | 80 0442 | 80 0511 | 80 0580 | 80 0648 | 69 |
| 632 | 0717 | 0786 | 0854 | 0923 | 0992 | 1061 | 1129 | 1198 | 1266 | 1335 | 69 |
| 633 | 1404 | 1472 | 1541 | 1609 | 1678 | 1747 | 1815 | 1884 | 1952 | 2021 | 69 |
| 634 | 2089 | 2158 | 2226 | 2295 | 2363 | 2432 | 2500 | 2568 | 2637 | 2705 | 68 |
| 635 | 80 2774 | 80 2842 | 80 2910 | 80 2979 | 80 3047 | 80 3116 | 80 3184 | 80 3252 | 80 3321 | 80 3389 | 68 |
| 636 | 3457 | 3525 | 3594 | 3662 | 3730 | 3798 | 3867 | 3935 | 4003 | 4071 | 68 |
| 637 | 4139 | 4208 | 4276 | 4344 | 4412 | 4480 | 4548 | 4616 | 4685 | 4753 | 68 |
| 638 | 4821 | 4889 | 4957 | 5025 | 5093 | 5161 | 5229 | 5297 | 5365 | 5433 | 68 |
| 639 | 5501 | 5569 | 5637 | 5705 | 5773 | 5841 | 5908 | 5976 | 6044 | 6112 | 68 |

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| **641** | 6858 | 6926 | 6994 | 7061 | 7129 | 7197 | 7264 | 7332 | 7400 | 7467 | 68 |
| **642** | 7535 | 7603 | 7670 | 7738 | 7806 | 7873 | 7941 | 8008 | 8076 | 8143 | 68 |
| **643** | 8211 | 8279 | 8346 | 8414 | 8481 | 8549 | 8616 | 8684 | 8751 | 8818 | 67 |
| **644** | 8886 | 8953 | 9021 | 9088 | 9156 | 9223 | 9290 | 9358 | 9425 | 9492 | 67 |
| **645** | 80 9560 | 80 9627 | 80 9694 | 80 9762 | 80 9829 | 80 9896 | 80 9964 | 81 0031 | 81 0098 | 81 0165 | 67 |
| **646** | 81 0233 | 81 0300 | 81 0367 | 81 0434 | 81 0501 | 81 0569 | 81 0636 | 0703 | 0770 | 0837 | 67 |
| **647** | 0904 | 0971 | 1039 | 1106 | 1173 | 1240 | 1307 | 1374 | 1441 | 1508 | 67 |
| **648** | 1575 | 1642 | 1709 | 1776 | 1843 | 1910 | 1977 | 2044 | 2111 | 2178 | 67 |
| **649** | 2245 | 2312 | 2379 | 2445 | 2512 | 2579 | 2646 | 2713 | 2780 | 2847 | 67 |
| **650** | 81 2913 | 81 2980 | 81 3047 | 81 3114 | 81 3181 | 81 3247 | 81 3314 | 81 3381 | 81 3448 | 81 3514 | 67 |
| **651** | 3581 | 3648 | 3714 | 3781 | 3848 | 3914 | 3981 | 4048 | 4114 | 4181 | 67 |
| **652** | 4248 | 4314 | 4381 | 4447 | 4514 | 4581 | 4647 | 4714 | 4780 | 4847 | 67 |
| **653** | 4913 | 4980 | 5046 | 5113 | 5179 | 5246 | 5312 | 5378 | 5445 | 5511 | 66 |
| **654** | 5578 | 5644 | 5711 | 5777 | 5843 | 5910 | 5976 | 6042 | 6109 | 6175 | 66 |
| **655** | 81 6241 | 81 6308 | 81 6374 | 81 6440 | 81 6506 | 81 6573 | 81 6639 | 81 6705 | 81 6771 | 81 6838 | 66 |
| **656** | 6904 | 6970 | 7036 | 7102 | 7169 | 7235 | 7301 | 7367 | 7433 | 7499 | 66 |
| **657** | 7565 | 7631 | 7698 | 7764 | 7830 | 7896 | 7962 | 8028 | 8094 | 8160 | 66 |
| **658** | 8226 | 8292 | 8358 | 8424 | 8490 | 8556 | 8622 | 8688 | 8754 | 8820 | 66 |
| **659** | 8885 | 8951 | 9017 | 9083 | 9149 | 9215 | 9281 | 9346 | 9412 | 9478 | 66 |
| **660** | 81 9544 | 81 9610 | 81 9676 | 81 9741 | 81 9807 | 81 9873 | 81 9939 | 82 0004 | 82 0070 | 82 0136 | 66 |
| **661** | 82 0201 | 82 0267 | 82 0333 | 82 0399 | 82 0464 | 82 0530 | 82 0595 | 0661 | 0727 | 0792 | 66 |
| **662** | 0858 | 0924 | 0989 | 1055 | 1120 | 1186 | 1251 | 1317 | 1382 | 1448 | 66 |
| **663** | 1514 | 1579 | 1645 | 1710 | 1775 | 1841 | 1906 | 1972 | 2037 | 2103 | 65 |
| **664** | 2168 | 2233 | 2299 | 2364 | 2430 | 2495 | 2560 | 2626 | 2691 | 2756 | 65 |
| **665** | 82 2822 | 82 2887 | 82 2952 | 82 3018 | 82 3083 | 82 3148 | 82 3213 | 82 3279 | 82 3344 | 82 3409 | 65 |
| **666** | 3474 | 3539 | 3605 | 3670 | 3735 | 3800 | 3865 | 3930 | 3996 | 4061 | 65 |
| **667** | 4126 | 4191 | 4256 | 4321 | 4386 | 4451 | 4516 | 4581 | 4646 | 4711 | 65 |
| **668** | 4776 | 4841 | 4906 | 4971 | 5036 | 5101 | 5166 | 5231 | 5296 | 5361 | 65 |
| **669** | 5426 | 5491 | 5556 | 5621 | 5686 | 5751 | 5815 | 5880 | 5945 | 6010 | 65 |
| **670** | 82 6075 | 82 6140 | 82 6204 | 82 6269 | 82 6334 | 82 6399 | 82 6464 | 82 6528 | 82 6593 | 82 6658 | 65 |
| **671** | 6723 | 6787 | 6852 | 6917 | 6981 | 7046 | 7111 | 7175 | 7240 | 7305 | 65 |
| **672** | 7369 | 7434 | 7499 | 7563 | 7628 | 7692 | 7757 | 7821 | 7886 | 7951 | 65 |
| **673** | 8015 | 8080 | 8144 | 8209 | 8273 | 8338 | 8402 | 8467 | 8531 | 8595 | 64 |
| **674** | 8660 | 8724 | 8789 | 8853 | 8918 | 8982 | 9046 | 9111 | 9175 | 9239 | 64 |
| **675** | 82 9304 | 82 9368 | 82 9432 | 82 9497 | 82 9561 | 82 9625 | 82 9690 | 82 9754 | 82 9818 | 82 9882 | 64 |
| **676** | 9947 | 83 0011 | 83 0075 | 83 0139 | 83 0204 | 83 0268 | 83 0332 | 83 0396 | 83 0460 | 83 0525 | 64 |
| **677** | 83 0589 | 0653 | 0717 | 0781 | 0845 | 0909 | 0973 | 1037 | 1102 | 1166 | 64 |
| **678** | 1230 | 1294 | 1358 | 1422 | 1486 | 1550 | 1614 | 1678 | 1742 | 1806 | 64 |
| **679** | 1870 | 1934 | 1998 | 2062 | 2126 | 2189 | 2253 | 2317 | 2381 | 2445 | 64 |
| **680** | 83 2509 | 83 2573 | 83 2637 | 83 2700 | 83 2764 | 83 2828 | 83 2892 | 83 2956 | 83 3020 | 83 3083 | 64 |
| **681** | 3147 | 3211 | 3275 | 3338 | 3402 | 3466 | 3530 | 3593 | 3657 | 3721 | 64 |
| **682** | 3784 | 3848 | 3912 | 3975 | 4039 | 4103 | 4166 | 4230 | 4294 | 4357 | 64 |
| **683** | 4421 | 4484 | 4548 | 4611 | 4675 | 4739 | 4802 | 4866 | 4929 | 4993 | 64 |
| **684** | 5056 | 5120 | 5183 | 5247 | 5310 | 5373 | 5437 | 5500 | 5564 | 5627 | 63 |
| **685** | 83 5691 | 83 5754 | 83 5817 | 83 5881 | 83 5944 | 83 6007 | 83 6071 | 83 6134 | 83 6197 | 83 6261 | 63 |
| **686** | 6324 | 6387 | 6451 | 6514 | 6577 | 6641 | 6704 | 6767 | 6830 | 6894 | 63 |
| **687** | 6957 | 7020 | 7083 | 7146 | 7210 | 7273 | 7336 | 7399 | 7462 | 7525 | 63 |
| **688** | 7588 | 7652 | 7715 | 7778 | 7841 | 7904 | 7967 | 8030 | 8093 | 8156 | 63 |
| **689** | 8219 | 8282 | 8345 | 8408 | 8471 | 8534 | 8597 | 8660 | 8723 | 8786 | 63 |
| **690** | 83 8849 | 83 8912 | 83 8975 | 83 9038 | 83 9101 | 83 9164 | 83 9227 | 83 9289 | 83 9352 | 83 9415 | 63 |
| **691** | 9478 | 9541 | 9604 | 9667 | 9729 | 9792 | 9855 | 9918 | 9981 | 84 0043 | 63 |
| **692** | 84 0106 | 84 0169 | 84 0232 | 84 0294 | 84 0357 | 84 0420 | 84 0482 | 84 0545 | 84 0608 | 0671 | 63 |
| **693** | 0733 | 0796 | 0859 | 0921 | 0984 | 1046 | 1109 | 1172 | 1234 | 1297 | 63 |
| **694** | 1359 | 1422 | 1485 | 1547 | 1610 | 1672 | 1735 | 1797 | 1860 | 1922 | 63 |
| **695** | 84 1985 | 84 2047 | 84 2110 | 84 2172 | 84 2235 | 84 2297 | 84 2360 | 84 2422 | 84 2484 | 84 2547 | 62 |
| **696** | 2609 | 2672 | 2734 | 2796 | 2859 | 2921 | 2983 | 3046 | 3108 | 3170 | 62 |
| **697** | 3233 | 3295 | 3357 | 3420 | 3482 | 3544 | 3606 | 3669 | 3731 | 3793 | 62 |
| **698** | 3855 | 3918 | 3980 | 4042 | 4104 | 4166 | 4229 | 4291 | 4353 | 4415 | 62 |
| **699** | 4477 | 4539 | 4601 | 4664 | 4726 | 4788 | 4850 | 4912 | 4974 | 5036 | 62 |
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| 705 | 84 8189 | 84 8251 | 84 8312 | 84 8374 | 84 8435 | 84 8497 | 84 8559 | 84 8620 | 84 8682 | 84 8743 | 62 |
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| 707 | 9419 | 9481 | 9542 | 9604 | 9665 | 9726 | 9788 | 9849 | 9911 | 9972 | 61 |
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| 732 | 4511 | 4570 | 4630 | 4689 | 4748 | 4808 | 4867 | 4926 | 4985 | 5045 | 59 |
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| 774 | 8741 | 8797 | 8853 | 8909 | 8965 | 9021 | 9077 | 9134 | 9190 | 9246 | 56 |
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| 777 | 89 0421 | 89 0477 | 89 0533 | 0589 | 0645 | 0700 | 0756 | 0812 | 0868 | 0924 | 56 |
| 778 | 0980 | 1035 | 1091 | 1147 | 1203 | 1259 | 1314 | 1370 | 1426 | 1482 | 56 |
| 779 | 1537 | 1593 | 1649 | 1705 | 1760 | 1816 | 1872 | 1928 | 1983 | 2039 | 56 |
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| 781 | 2651 | 2707 | 2762 | 2818 | 2873 | 2929 | 2985 | 3040 | 3096 | 3151 | 56 |
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| 783 | 3762 | 3817 | 3873 | 3928 | 3984 | 4039 | 4094 | 4150 | 4205 | 4261 | 55 |
| 784 | 4316 | 4371 | 4427 | 4482 | 4538 | 4593 | 4648 | 4704 | 4759 | 4814 | 55 |
| 785 | 89 4870 | 89 4925 | 89 4980 | 89 5036 | 89 5091 | 89 5146 | 89 5201 | 89 5257 | 89 5312 | 89 5367 | 55 |
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| 815 | 91 1158 | 91 1211 | 91 1264 | 91 1317 | 91 1371 | 91 1424 | 91 1477 | 91 1530 | 91 1584 | 91 1637 | 53 |
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| 830 | 91 9078 | 91 9130 | 91 9183 | 91 9235 | 91 9287 | 91 9340 | 91 9392 | 91 9444 | 91 9496 | 91 9549 | 52 |
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| 850 | 92 9419 | 92 9470 | 92 9521 | 92 9572 | 92 9623 | 92 9674 | 92 9725 | 92 9776 | 92 9827 | 92 9879 | 51 |
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| 870 | 93 9519 | 93 9569 | 93 9619 | 93 9669 | 93 9719 | 93 9769 | 93 9819 | 93 9869 | 93 9918 | 93 9968 | 50 |
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| 872 | 0516 | 0566 | 0616 | 0666 | 0716 | 0765 | 0815 | 0865 | 0915 | 0964 | 50 |
| 873 | 1014 | 1064 | 1114 | 1163 | 1213 | 1263 | 1313 | 1362 | 1412 | 1462 | 50 |
| 874 | 1511 | 1561 | 1611 | 1660 | 1710 | 1760 | 1809 | 1859 | 1909 | 1958 | 50 |
| 875 | 94 2008 | 94 2058 | 94 2107 | 94 2157 | 94 2207 | 94 2256 | 94 2306 | 94 2355 | 94 2405 | 94 2455 | 50 |
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| 877 | 3000 | 3049 | 3099 | 3148 | 3198 | 3247 | 3297 | 3346 | 3396 | 3445 | 49 |
| 878 | 3495 | 3544 | 3593 | 3643 | 3692 | 3742 | 3791 | 3841 | 3890 | 3939 | 49 |
| 879 | 3989 | 4038 | 4088 | 4137 | 4186 | 4236 | 4285 | 4335 | 4384 | 4433 | 49 |

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|---|---|---|---|---|---|---|---|---|---|---|---|
| 880 | 94 4483 | 94 4532 | 94 4581 | 94 4631 | 94 4680 | 94 4729 | 94 4779 | 94 4828 | 94 4877 | 94 4927 | 49 |
| 881 | 4976 | 5025 | 5074 | 5124 | 5173 | 5222 | 5272 | 5321 | 5370 | 5419 | 49 |
| 882 | 5469 | 5518 | 5567 | 5616 | 5665 | 5715 | 5764 | 5813 | 5862 | 5912 | 49 |
| 883 | 5961 | 6010 | 6059 | 6108 | 6157 | 6207 | 6256 | 6305 | 6354 | 6403 | 49 |
| 884 | 6452 | 6501 | 6551 | 6600 | 6649 | 6698 | 6747 | 6796 | 6845 | 6894 | 49 |
| 885 | 94 6943 | 94 6992 | 94 7041 | 94 7090 | 94 7140 | 94 7189 | 94 7238 | 94 7287 | 94 7336 | 94 7385 | 49 |
| 886 | 7434 | 7483 | 7532 | 7581 | 7630 | 7679 | 7728 | 7777 | 7826 | 7875 | 49 |
| 887 | 7924 | 7973 | 8022 | 8070 | 8119 | 8168 | 8217 | 8266 | 8315 | 8364 | 49 |
| 888 | 8413 | 8462 | 8511 | 8560 | 8609 | 8657 | 8706 | 8755 | 8804 | 8853 | 49 |
| 889 | 8902 | 8951 | 8999 | 9048 | 9097 | 9146 | 9195 | 9244 | 9292 | 9341 | 49 |
| 890 | 94 9390 | 94 9439 | 94 9488 | 94 9536 | 94 9585 | 94 9634 | 94 9683 | 94 9731 | 94 9780 | 94 9829 | 49 |
| 891 | 9878 | 9926 | 9975 | 95 0024 | 95 0073 | 95 0121 | 95 0170 | 95 0219 | 95 0267 | 95 0316 | 49 |
| 892 | 95 0365 | 95 0414 | 95 0462 | 0511 | 0560 | 0608 | 0657 | 0706 | 0754 | 0803 | 49 |
| 893 | 0851 | 0900 | 0949 | 0997 | 1046 | 1095 | 1143 | 1192 | 1240 | 1289 | 49 |
| 894 | 1338 | 1386 | 1435 | 1483 | 1532 | 1580 | 1629 | 1677 | 1726 | 1775 | 49 |
| 895 | 95 1823 | 95 1872 | 95 1920 | 95 1969 | 95 2017 | 95 2066 | 95 2114 | 95 2163 | 95 2211 | 95 2260 | 48 |
| 896 | 2308 | 2356 | 2405 | 2453 | 2502 | 2550 | 2599 | 2647 | 2696 | 2744 | 48 |
| 897 | 2792 | 2841 | 2889 | 2938 | 2986 | 3034 | 3083 | 3131 | 3180 | 3228 | 48 |
| 898 | 3276 | 3325 | 3373 | 3421 | 3470 | 3518 | 3566 | 3615 | 3663 | 3711 | 48 |
| 899 | 3760 | 3808 | 3856 | 3905 | 3953 | 4001 | 4049 | 4098 | 4146 | 4194 | 48 |
| 900 | 95 4243 | 95 4291 | 95 4339 | 95 4387 | 95 4435 | 95 4484 | 95 4532 | 95 4580 | 95 4628 | 95 4677 | 48 |
| 901 | 4725 | 4773 | 4821 | 4869 | 4918 | 4966 | 5014 | 5062 | 5110 | 5158 | 48 |
| 902 | 5207 | 5255 | 5303 | 5351 | 5399 | 5447 | 5495 | 5543 | 5592 | 5640 | 48 |
| 903 | 5688 | 5736 | 5784 | 5832 | 5880 | 5928 | 5976 | 6024 | 6072 | 6120 | 48 |
| 904 | 6168 | 6216 | 6265 | 6313 | 6361 | 6409 | 6457 | 6505 | 6553 | 6601 | 48 |
| 905 | 95 6649 | 95 6697 | 95 6745 | 95 6793 | 95 6840 | 95 6888 | 95 6936 | 95 6984 | 95 7032 | 95 7080 | 48 |
| 906 | 7128 | 7176 | 7224 | 7272 | 7320 | 7368 | 7416 | 7464 | 7512 | 7559 | 48 |
| 907 | 7607 | 7655 | 7703 | 7751 | 7799 | 7847 | 7894 | 7942 | 7990 | 8038 | 48 |
| 908 | 8086 | 8134 | 8181 | 8229 | 8277 | 8325 | 8373 | 8421 | 8468 | 8516 | 48 |
| 909 | 8564 | 8612 | 8659 | 8707 | 8755 | 8803 | 8850 | 8898 | 8946 | 8994 | 48 |
| 910 | 95 9041 | 95 9089 | 95 9137 | 95 9185 | 95 9232 | 95 9280 | 95 9328 | 95 9375 | 95 9423 | 95 9471 | 48 |
| 911 | 9518 | 9566 | 9614 | 9661 | 9709 | 9757 | 9804 | 9852 | 9900 | 9947 | 48 |
| 912 | 9995 | 96 0042 | 96 0090 | 96 0138 | 96 0185 | 96 0233 | 96 0280 | 96 0328 | 96 0376 | 96 0423 | 48 |
| 913 | 96 0471 | 0518 | 0566 | 0613 | 0661 | 0709 | 0756 | 0804 | 0851 | 0899 | 48 |
| 914 | 0946 | 0994 | 1041 | 1089 | 1136 | 1184 | 1231 | 1279 | 1326 | 1374 | 48 |
| 915 | 96 1421 | 96 1469 | 96 1516 | 96 1563 | 96 1611 | 96 1658 | 96 1706 | 96 1753 | 96 1801 | 96 1848 | 47 |
| 916 | 1895 | 1943 | 1990 | 2038 | 2085 | 2132 | 2180 | 2227 | 2275 | 2322 | 47 |
| 917 | 2369 | 2417 | 2464 | 2511 | 2559 | 2606 | 2653 | 2701 | 2748 | 2795 | 47 |
| 918 | 2843 | 2890 | 2937 | 2985 | 3032 | 3079 | 3126 | 3174 | 3221 | 3268 | 47 |
| 919 | 3316 | 3363 | 3410 | 3457 | 3504 | 3552 | 3599 | 3646 | 3693 | 3741 | 47 |
| 920 | 96 3788 | 96 3835 | 96 3882 | 96 3929 | 96 3977 | 96 4024 | 96 4071 | 96 4118 | 96 4165 | 96 4212 | 47 |
| 921 | 4260 | 4307 | 4354 | 4401 | 4448 | 4495 | 4542 | 4590 | 4637 | 4684 | 47 |
| 922 | 4731 | 4778 | 4825 | 4872 | 4919 | 4966 | 5013 | 5061 | 5108 | 5155 | 47 |
| 923 | 5202 | 5249 | 5296 | 5343 | 5390 | 5437 | 5484 | 5531 | 5578 | 5625 | 47 |
| 924 | 5672 | 5719 | 5766 | 5813 | 5860 | 5907 | 5954 | 6001 | 6048 | 6095 | 47 |
| 925 | 96 6142 | 96 6189 | 96 6236 | 96 6283 | 96 6329 | 96 6376 | 96 6423 | 96 6470 | 96 6517 | 96 6564 | 47 |
| 926 | 6611 | 6658 | 6705 | 6752 | 6799 | 6845 | 6892 | 6939 | 6986 | 7033 | 47 |
| 927 | 7080 | 7127 | 7173 | 7220 | 7267 | 7314 | 7361 | 7408 | 7454 | 7501 | 47 |
| 928 | 7548 | 7595 | 7642 | 7688 | 7735 | 7782 | 7829 | 7875 | 7922 | 7969 | 47 |
| 929 | 8016 | 8062 | 8109 | 8156 | 8203 | 8249 | 8296 | 8343 | 8390 | 8436 | 47 |
| 930 | 96 8483 | 96 8530 | 96 8576 | 96 8623 | 96 8670 | 96 8716 | 96 8763 | 96 8810 | 96 8856 | 96 8903 | 47 |
| 931 | 8950 | 8996 | 9043 | 9090 | 9136 | 9183 | 9229 | 9276 | 9323 | 9369 | 47 |
| 932 | 9416 | 9463 | 9509 | 9556 | 9602 | 9649 | 9695 | 9742 | 9789 | 9835 | 47 |
| 933 | 9882 | 9928 | 9975 | 97 0021 | 97 0068 | 97 0114 | 97 0161 | 97 0207 | 97 0254 | 97 0300 | 47 |
| 934 | 97 0347 | 97 0393 | 97 0440 | 0486 | 0533 | 0579 | 0626 | 0672 | 0719 | 0765 | 46 |
| 935 | 97 0812 | 97 0858 | 97 0904 | 97 0951 | 97 0997 | 97 1044 | 97 1090 | 97 1137 | 97 1183 | 97 1229 | 46 |
| 936 | 1276 | 1322 | 1369 | 1415 | 1461 | 1508 | 1554 | 1601 | 1647 | 1693 | 46 |
| 937 | 1740 | 1786 | 1832 | 1879 | 1925 | 1971 | 2018 | 2064 | 2110 | 2157 | 46 |
| 938 | 2203 | 2249 | 2295 | 2342 | 2388 | 2434 | 2481 | 2527 | 2573 | 2619 | 46 |
| 939 | 2666 | 2712 | 2758 | 2804 | 2851 | 2897 | 2943 | 2989 | 3035 | 3082 | 46 |
| N. | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | D. |

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|---|---|---|---|---|---|---|---|---|---|---|---|
| **940** | 97 3128 | 97 3174 | 97 3220 | 97 3266 | 97 3313 | 97 3359 | 97 3405 | 97 3451 | 97 3497 | 97 3543 | 46 |
| **941** | 3590 | 3636 | 3682 | 3728 | 3774 | 3820 | 3866 | 3913 | 3959 | 4005 | 46 |
| **942** | 4051 | 4097 | 4143 | 4189 | 4235 | 4281 | 4327 | 4374 | 4420 | 4466 | 46 |
| **943** | 4512 | 4558 | 4604 | 4650 | 4696 | 4742 | 4788 | 4834 | 4880 | 4926 | 46 |
| **944** | 4972 | 5018 | 5064 | 5110 | 5156 | 5202 | 5248 | 5294 | 5340 | 5386 | 46 |
| **945** | 97 5432 | 97 5478 | 97 5524 | 97 5570 | 97 5616 | 97 5662 | 97 5707 | 97 5753 | 97 5799 | 97 5845 | 46 |
| **946** | 5891 | 5937 | 5983 | 6029 | 6075 | 6121 | 6167 | 6212 | 6258 | 6304 | 46 |
| **947** | 6350 | 6396 | 6442 | 6488 | 6533 | 6579 | 6625 | 6671 | 6717 | 6763 | 46 |
| **948** | 6808 | 6854 | 6900 | 6946 | 6992 | 7037 | 7083 | 7129 | 7175 | 7220 | 46 |
| **949** | 7266 | 7312 | 7358 | 7403 | 7449 | 7495 | 7541 | 7586 | 7632 | 7678 | 46 |
| **950** | 97 7724 | 97 7769 | 97 7815 | 97 7861 | 97 7906 | 97 7952 | 97 7998 | 97 8043 | 97 8089 | 97 8135 | 46 |
| **951** | 8181 | 8226 | 8272 | 8317 | 8363 | 8409 | 8454 | 8500 | 8546 | 8591 | 46 |
| **952** | 8637 | 8683 | 8728 | 8774 | 8819 | 8865 | 8911 | 8956 | 9002 | 9047 | 46 |
| **953** | 9093 | 9138 | 9184 | 9230 | 9275 | 9321 | 9366 | 9412 | 9457 | 9503 | 46 |
| **954** | 9548 | 9594 | 9639 | 9685 | 9730 | 9776 | 9821 | 9867 | 9912 | 9958 | 46 |
| **955** | 98 0003 | 98 0049 | 98 0094 | 98 0140 | 98 0185 | 98 0231 | 98 0276 | 98 0322 | 98 0367 | 98 0412 | 45 |
| **956** | 0458 | 0503 | 0549 | 0594 | 0640 | 0685 | 0730 | 0776 | 0821 | 0867 | 45 |
| **957** | 0912 | 0957 | 1003 | 1048 | 1093 | 1139 | 1184 | 1229 | 1275 | 1320 | 45 |
| **958** | 1366 | 1411 | 1456 | 1501 | 1547 | 1592 | 1637 | 1683 | 1728 | 1773 | 45 |
| **959** | 1819 | 1864 | 1909 | 1954 | 2000 | 2045 | 2090 | 2135 | 2181 | 2226 | 45 |
| **960** | 98 2271 | 98 2316 | 98 2362 | 98 2407 | 98 2452 | 98 2497 | 98 2543 | 98 2588 | 98 2633 | 98 2678 | 45 |
| **961** | 2723 | 2769 | 2814 | 2859 | 2904 | 2949 | 2994 | 3040 | 3085 | 3130 | 45 |
| **962** | 3175 | 3220 | 3265 | 3310 | 3356 | 3401 | 3446 | 3491 | 3536 | 3581 | 45 |
| **963** | 3626 | 3671 | 3716 | 3762 | 3807 | 3852 | 3897 | 3942 | 3987 | 4032 | 45 |
| **964** | 4077 | 4122 | 4167 | 4212 | 4257 | 4302 | 4347 | 4392 | 4437 | 4482 | 45 |
| **965** | 98 4527 | 98 4572 | 98 4617 | 98 4662 | 98 4707 | 98 4752 | 98 4797 | 98 4842 | 98 4887 | 98 4932 | 45 |
| **966** | 4977 | 5022 | 5067 | 5112 | 5157 | 5202 | 5247 | 5292 | 5337 | 5382 | 45 |
| **967** | 5426 | 5471 | 5516 | 5561 | 5606 | 5651 | 5696 | 5741 | 5786 | 5830 | 45 |
| **968** | 5875 | 5920 | 5965 | 6010 | 6055 | 6100 | 6144 | 6189 | 6234 | 6279 | 45 |
| **969** | 6324 | 6369 | 6413 | 6458 | 6503 | 6548 | 6593 | 6637 | 6682 | 6727 | 45 |
| **970** | 98 6772 | 98 6817 | 98 6861 | 98 6906 | 98 6951 | 98 6996 | 98 7040 | 98 7085 | 98 7130 | 98 7175 | 45 |
| **971** | 7219 | 7264 | 7309 | 7353 | 7398 | 7443 | 7488 | 7532 | 7577 | 7622 | 45 |
| **972** | 7666 | 7711 | 7756 | 7800 | 7845 | 7890 | 7934 | 7979 | 8024 | 8068 | 45 |
| **973** | 8113 | 8157 | 8202 | 8247 | 8291 | 8336 | 8381 | 8425 | 8470 | 8514 | 45 |
| **974** | 8559 | 8604 | 8648 | 8693 | 8737 | 8782 | 8826 | 8871 | 8916 | 8960 | 45 |
| **975** | 98 9005 | 98 9049 | 98 9094 | 98 9138 | 98 9183 | 98 9227 | 98 9272 | 98 9316 | 98 9361 | 98 9405 | 45 |
| **976** | 9450 | 9494 | 9539 | 9583 | 9628 | 9672 | 9717 | 9761 | 9806 | 9850 | 44 |
| **977** | 9895 | 9939 | 9983 | 99 0028 | 99 0072 | 99 0117 | 99 0161 | 99 0206 | 99 0250 | 99 0294 | 44 |
| **978** | 99 0339 | 99 0383 | 99 0428 | 0472 | 0516 | 0561 | 0605 | 0650 | 0694 | 0738 | 44 |
| **979** | 0783 | 0827 | 0871 | 0916 | 0960 | 1004 | 1049 | 1093 | 1137 | 1182 | 44 |
| **980** | 99 1226 | 99 1270 | 99 1315 | 99 1359 | 99 1403 | 99 1448 | 99 1492 | 99 1536 | 99 1580 | 99 1625 | 44 |
| **981** | 1669 | 1713 | 1758 | 1802 | 1846 | 1890 | 1935 | 1979 | 2023 | 2067 | 44 |
| **982** | 2111 | 2156 | 2200 | 2244 | 2288 | 2333 | 2377 | 2421 | 2465 | 2509 | 44 |
| **983** | 2554 | 2598 | 2642 | 2686 | 2730 | 2774 | 2819 | 2863 | 2907 | 2951 | 44 |
| **984** | 2995 | 3039 | 3083 | 3127 | 3172 | 3216 | 3260 | 3304 | 3348 | 3392 | 44 |
| **985** | 99 3436 | 99 3480 | 99 3524 | 99 3568 | 99 3613 | 99 3657 | 99 3701 | 99 3745 | 99 3789 | 99 3833 | 44 |
| **986** | 3877 | 3921 | 3965 | 4009 | 4053 | 4097 | 4141 | 4185 | 4229 | 4273 | 44 |
| **987** | 4317 | 4361 | 4405 | 4449 | 4493 | 4537 | 4581 | 4625 | 4669 | 4713 | 44 |
| **988** | 4757 | 4801 | 4845 | 4889 | 4933 | 4977 | 5021 | 5065 | 5108 | 5152 | 44 |
| **989** | 5196 | 5240 | 5284 | 5328 | 5372 | 5416 | 5460 | 5504 | 5547 | 5591 | 44 |
| **990** | 99 5635 | 99 5679 | 99 5723 | 99 5767 | 99 5811 | 99 5854 | 99 5898 | 99 5942 | 99 5986 | 99 6030 | 44 |
| **991** | 6074 | 6117 | 6161 | 6205 | 6249 | 6293 | 6337 | 6380 | 6424 | 6468 | 44 |
| **992** | 6512 | 6555 | 6599 | 6643 | 6687 | 6731 | 6774 | 6818 | 6862 | 6906 | 44 |
| **993** | 6949 | 6993 | 7037 | 7080 | 7124 | 7168 | 7212 | 7255 | 7299 | 7343 | 44 |
| **994** | 7386 | 7430 | 7474 | 7517 | 7561 | 7605 | 7648 | 7692 | 7736 | 7779 | 44 |
| **995** | 99 7823 | 99 7867 | 99 7910 | 99 7954 | 99 7998 | 99 8041 | 99 8085 | 99 8129 | 99 8172 | 99 8216 | 44 |
| **996** | 8259 | 8303 | 8347 | 8390 | 8434 | 8477 | 8521 | 8564 | 8608 | 8652 | 44 |
| **997** | 8695 | 8739 | 8782 | 8826 | 8869 | 8913 | 8956 | 9000 | 9043 | 9087 | 44 |
| **998** | 9131 | 9174 | 9218 | 9261 | 9305 | 9348 | 9392 | 9435 | 9479 | 9522 | 44 |
| **999** | 9565 | 9609 | 9652 | 9696 | 9739 | 9783 | 9826 | 9870 | 9913 | 9957 | 43 |
| N. | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | D. |