T H E S I S

THE CORLISS ENGINE

Under

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By

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1919.

THE CORLISS ENGINE.

The Corliss engine owes its popularity to its valve motion. Up to the time of the Corliss valve, all steam engines possessed the evil of admitting fresh steam to the cylinder through the passages which had been cooled down by the low temperature of the exhaust steam. Amother design of weakness up to that time was that of the extra power required to overcome the friction due to the sliding of the valves. In order to overcome these difficulties, the Corliss valve was designed.

The principal peculiarities of the Corliss gear are that there are four steam ports and four valves, the two of the latter which control the steam admission and cut-off being driven by a special mechanism which insures a very sharp closing of the steam ports when the cut-off takes place. The two upper ports are intended solely for the admission of the steam, the remaining two serving for the exhaust. Thanks to this arrangement, the fresh steam on entering the cylinder does not come in contact with surfaces which have just been cooled down by the passage of the comparatively cold exhaust steam. The valves do not belong to the class of D slides, but are formed of portions of cylinders AA, BB, fig. 2, which oscillate on a cylindrical surface. The valves are so arranged that the pressure of the steam forces them against their seats only when the port is closed. In all other positions there is but little friction due to the steam pressure, consequently the operation of these valves absorbs but little power of the engine. Fig. 1 is a general view of the mechanism by which the valves are operated. The disc L is caused to oscillate in an arc of a circle around its own center by means of the eccentric and the eccentric rod. To the disc or spider are connected four valve rods, b, b, and H, H, which are also attached to the four valves. The two belonging to the lower valves BB are perfectly simple; their function is to open the exhaust ports at the proper moment, and keep them open during the required fixed period of the stroke. The function of the two upper rods is more complicated. Their work is, not only to open the steam ports at the proper moment, but also to keep them open during whatever period of the stroke is required by the rate of expansion, and then to liberate the valve so as to permit of its being closed sharply by an independent piece of mechanism which will be described hereafter.

The mechanism referred to above is the Reynolds hook. The steam arm is keyed to the valve spindle which passes loosely through a bracket on which the bell-crank lever turns, and the spindle is packed to make a steam-tight joint where it enters the cylinder. Motion of the steam rod towards the right will turn the bell-crank lever and raise the hook stud. The hook pivoted on this stud has at one end, a small steel block with a rounded face. As the hook rises, the hook disengages the stud die which is fastened to the steam arm, and one end of the steam arm is thus raised. This turns the valve in its seat and admits steam. As the hook continues to rise, its stud moves in an arc above the valve spindle, and the round-faced block at its left-hand end strikes the knock-off cam which causes the hook to turn about its stud and disengage the hook die from the stud die. In raising the steam arm, the dash-pot rod also is raised and a partial vacuum is created in the dash-pot. As soon, therefore, as the dies become disengaged, the dash-pot rod quickly drops under the force of this vacuum, thus turning the steam arm and closing the valve. The striking of the left-hand end of the hook against the knockoff cam determines the point of cut-off, by releasing the valve at that instant.

This cam is a part of the knock-off lever to which the governor cam rod is fastened. Any action of the governor which would cause the cam rod to move toward the right would cause the knock-off lever to turn on its axis, the steam arm, and consequently lower the position of the knock-off cam. This would cause an earlier contact between the cam and end of the hook and consequently an earlier cut-off. By lengthening or shortening the governor rod, the point of cut-off can be adjusted to suit the engine load without changing speed.

There is a limit to this adjustment, for it can be shown that a Corliss gear operated by a single eccentric cannot be arranged to cut-off later than half-stroke. Suppose the eccentric is set just 90° ahead of the crank. Then it will reach its position just as the piston gets to half stroke. If by that time the hook which was rising and opening the admission valve, has not yet struck the knock-off cam, it cannot strike it at all, for any further motion will cause the hook to descend to its original position, that is its position at the beginning of the stroke; the hook will not disengage from the steam arm stud at all and the bell-crank will return, closing the valve in the same manner in which it opened it. Cut-off will then take place near the end of the stroke, but it will not be the sharp cut-off produced by the sudden drop when the dies disengaged.

The safety cam is an important feature of the Corliss gear. If for any reason the engine governor should fail to act, due for instance to the breaking of the governor belt, the governor would drop to its lowest position, supply more steam to the engine and allow it to run away. The safety cam prevents this by moving so far to the right that it strikes the hook when it descends to pick up the steam arm. The hook is consequently turned toward the right and then lifted without engaging the stud die; the valve consequently remains closed and the engine stops.

We may summarize the distinguishing features of the Corliss engine as follows:

(1) The use of four oscillating valves so placed one at each corner of the cylinder as to reduce the clearance to a minimum.

(2). The use of the wrist plate which is given an oscillating motion by an eccentric, and to which are connected each of the four valves in such a manner that their motions of opening and closing take place rapidly, holding the valves open and closed for a certain period of time at each end of the wrist plate stroke. This causes an excellent economical distribution of the steam in its passage through the cylinder.

(3). An effective and very simple method of detaching the steam valves from the driving mechanism, insuring their rapid and sudden closing at any desired point of the stroke.

(4). The connection of the governor to the valve mechanism so that the variation of speed with changing loads is reduced to a minimum. This is accomplished in such a manner that the least possible work is put on the governor, thus making it extremely sensitive.

(5). A form of frame which gives a maximum of strength and rigidity with a minimum of weight.

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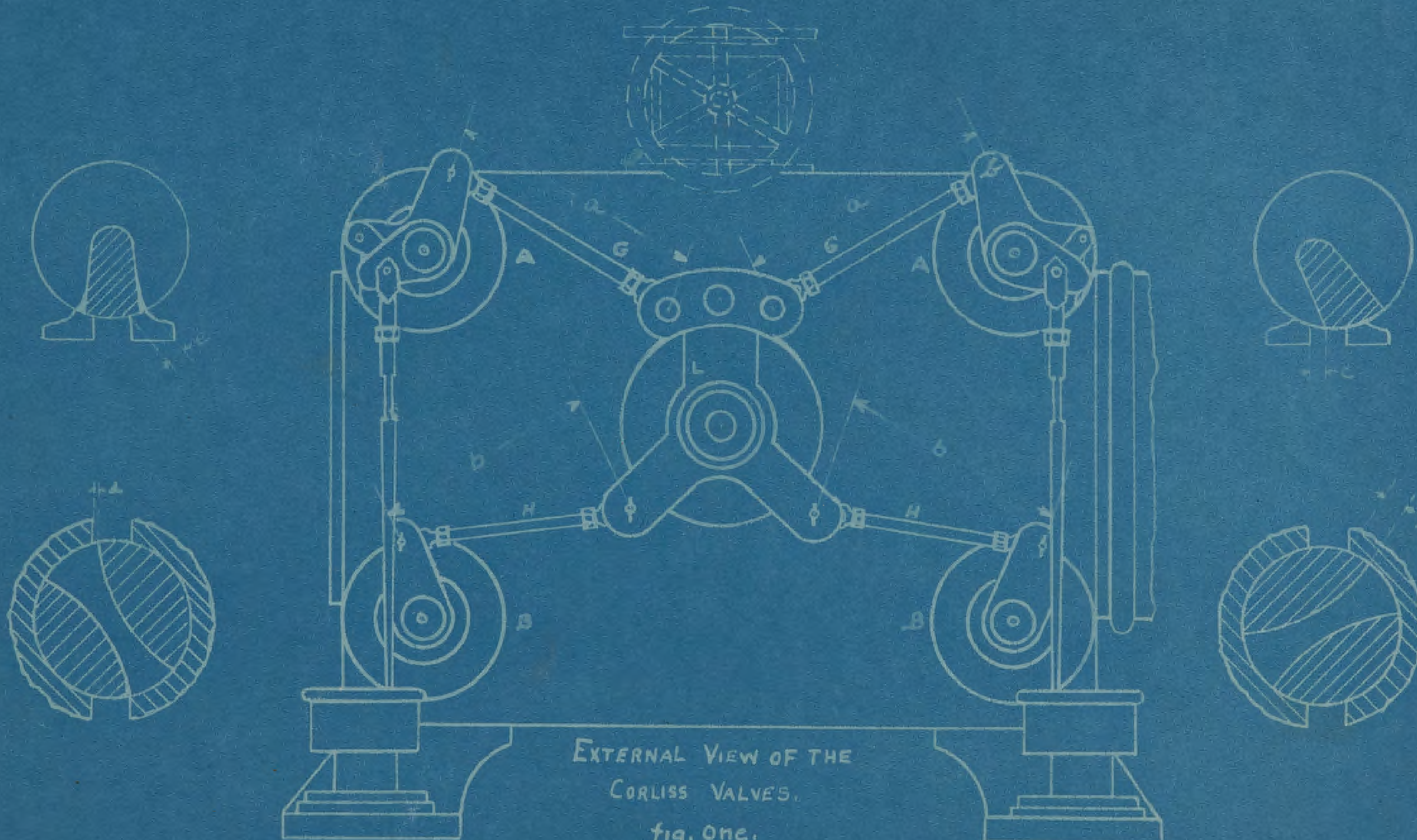
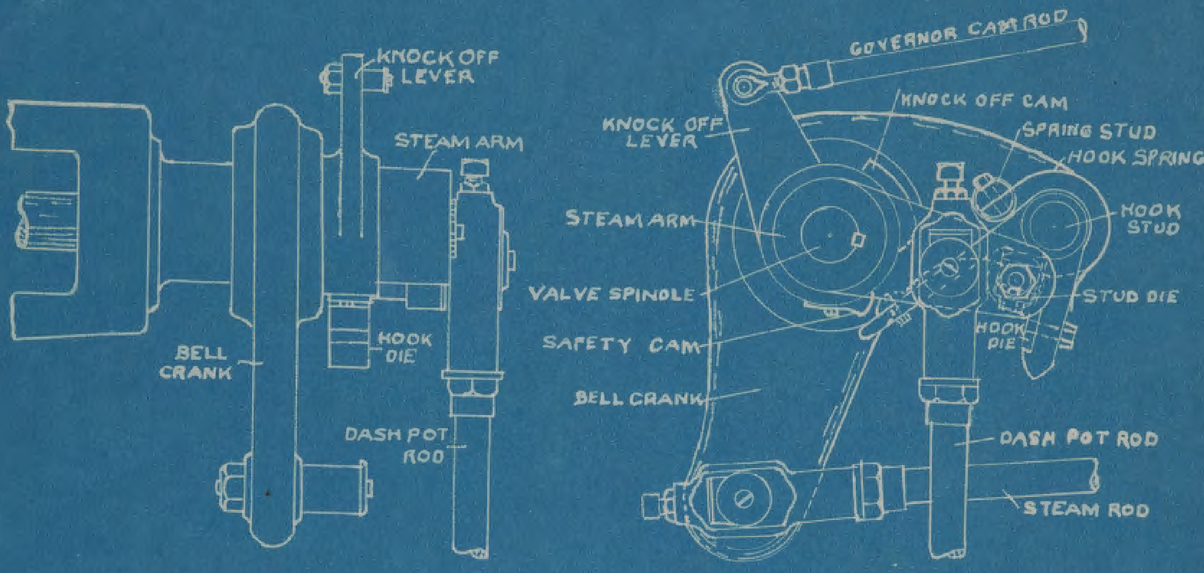
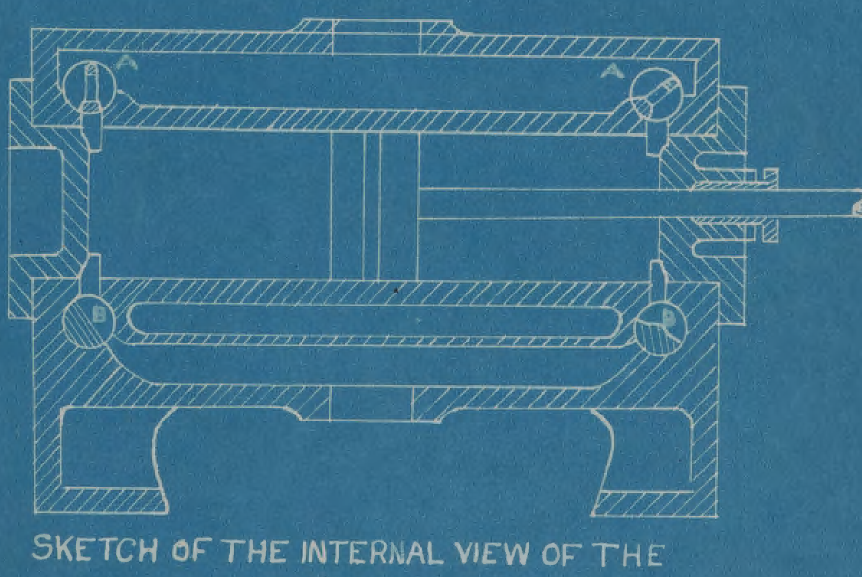


EXTERNAL VIEW OF THE
CORLISS VALVES.
fig. one.



SKETCH OF THE REYNOLDS HOOK.



SKETCH OF THE INTERNAL VIEW OF THE CORLISS VALVE.

My first experience with the Corliss engine was to set the valves according to specifications. The setting of a Corliss valve gear is a much longer process than the setting of a plain slide valve, but is nevertheless a simple matter, for the various adjustments are nearly all independent of one another. My first step was to see that the length of the eccentric rod was of such a length that the carrier arm swings equal distances on each side of a vertical line thru its pivot, and secondly I adjusted the carrier rod until the wrist plate oscillated symmetrically about a vertical line thru its pivot. The engine in question had one mark on the wrist plate hub and three on the wrist plate stand, and the wrist plate should swing so that its mark moves to and from the two outer marks on the wrist plate stand, but not beyond either one. The valves are then not in their exact mid-position, but it is customary to regard them as being in mid-position, and to speak of the lap as the amount the valve covers the port when the wrist plate is in mid-position.

To set the valves, the bonnets of the valve chambers are removed on the side opposite the gear. On the end, in line with the finished edge of the valve, and on the seat in line with the edge of the steam port are marks. When these marks coincide, the valve is either just opening or just closing, and when in any other position, the amount of opening or the amount by which the port is closed is shown directly by the distance between the marks. The wrist plate is blocked in mid-position, and by means of the right and left threads the length of the steam rods ~~is~~ are so adjusted as to cover the ports with the amount of lap called for in the specifications.

Next, the exhaust rods were adjusted until the exhaust ports were opened an amount equal to the clearance given in the specifications. The engine is now set on its head end dead point, the carrier rod is hooked onto the wrist plate and in the direction in which the engine is to run, the eccentric turned enough to open the head-end admission valve by a proper amount of lead; then the eccentric is 90° plus the angular advance ahead of the crank. The proper amount of lead having been obtained, on the one end of the stroke this is compared with the lead at the other dead center position. If they are equal and correct the eccentric is fastened on the shaft by means of the set screw, and it is made sure by trial that the wrist plate moves to its extreme of travel. When making adjustments on the Corliss engine, always see to it that the dash-pot rods are so adjusted that when the dash-pot piston is at its lowest position, the hooks descend just far enough for the hook dies to snap over the stud dies with about 1/32" to spare.

Summary of Corliss Valve setting without steam:

(1) Remove the bonnets covering the ends of the valves. Reference marks will be found on the ends of the valves and seats giving the positions of the working edges of the valves and ports.

(2) Adjust the length of the eccentric rod so that the rocker arm swings equal angles on each side of the vertical through its shaft.

(3) Reference marks will be found on the wrist-plate and on the supporting stud. Turn the eccentric around the shaft and adjust the length of the gab-rod so that the wrist-plate swings properly.

(4) Place the wrist plate in mid-position with the dash-pot plungers hooked up. Adjust the length of the wrist-plate rods so that the steam valves and the exhaust valves have the proper laps.

(5) Place the wrist-plate in one extreme position with the dash-pot plunger resting on its seat. Adjust the length of the dash-pot rod so that the claw catches the hook block with about one thirty-second of an inch distance. Repeat for the other extreme position.

(6) Put the engine on either dead-point and connect the gab-rod to the wrist-plate having the proper steam valve hooked up. Turn the eccentric on the shaft until it is about ninety degrees ahead of the crank and then move it ahead until the steam valve has the proper lead. Fasten the eccentric on the shaft and turn the engine to the other dead-point. If the lead is not correct make it so by adjusting the length of the steam-rod.

(7) Block the governor half way up and move the engine ahead until it reaches the point at which cut-off is desired. Adjust the length of the proper governor reach-rod until the valve is released. Repeat for the other end.

(8) With the governor in the lowest position and with the wrist plate in one extreme position, adjust the safety stop so that the hook-block will not be caught when the wrist-plate swings back. Repeat for the other extreme position.

The specifications given on our specific engine were as follows: Refer to Fig. 1.

Length of steam rod "a" . . . . 9 7/16"
Length of exhaust rod "b" . . . . . 8 3/16"

Engine on dead center.

Steam rod "c" . . . . 1/32"

Wrist plate central.

Steam lap "e" . . . . 1/8"
Exhaust lap "f" . . . . 1/2"

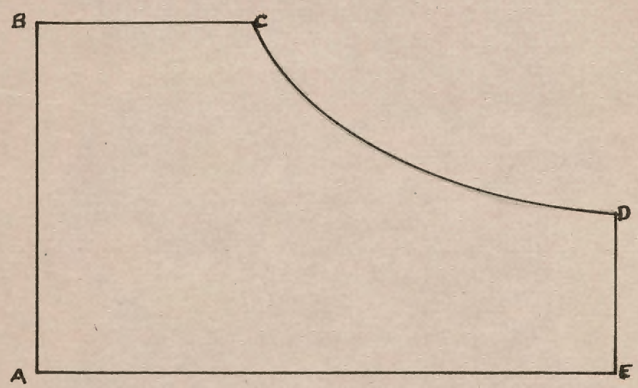
Having set my valves my next step was to take an indicator card of the valves in such positions. The card taken is card No. I. As will be noticed by reference to this card that it is not a perfect card by any means, as would be expected. This probably is due to the age of the engine, and to the fact that the conditions under which it was running varied from those under which it was meant to run.

It was designed for:	Our conditions were:
100 lbs. gauge pressure	85 lbs.
125 revolutions per minute	165
17 lbs. back pressure absolute	15.7 lbs.

The diagram shows a very late admission of steam, the maximum pressure not being attained until the piston has traversed a portion of the stroke represented by a a'. The fault is evidently due to the valve having been badly set, or else through the eccentric not having been given sufficient advance, as both indicate the same trouble, it must be due to the eccentric. Also the cut-off is not sharp enough, this can be remedied by adjusting the cut-off rods. It will also be noticed that the compression on the head end is too early and that on the crank end is too late. This can be adjusted by charging the exhaust rods. There is a leakage shown by the diagram which is either due to the valves or to a lost motion in my reducing motion.

My next step was to obtain a correct setting of the valves by means of the indicator. The indicator is screwed into a pipe which is connected to both ends of the cylinder. The cock on this pipe is furnished with a three-way plug and is also provided with a small hole communicating with the outside air. By means of the three-way plug the under side of the indicator piston can be placed in communication with the atmosphere, or with the engine cylinder, or can be shut off from either. Firstly, let it be placed in communication with the atmosphere; the spring above the indicator piston is then neither in tension nor compression. Let the pencil now be pressed against the paper on the barrel and the pencil will trace the line of atmospheric pressure. Let the cock now be turned so that the indicator piston shall be placed in communication with the steam cylinder at the commencement of the stroke. The piston will immediately rise, compressing the spiral spring above it, through a space proportional to the steam pressure, tracing the line A B. As the piston moves forward, let the steam continue to enter at undiminished pressure, say for one-third of the stroke, and let it then be sharply cut off. During this period the pencil will remain at the same height and will, consequently, as the drum of the indicator revolves beneath it, trace out the horizontal straight line B C, proportional in length to one-third of the stroke of the piston.

When the steam is cut off it will commence to expand, and the pressure will consequently drop. The point of the pencil drops as the pressure diminishes, and as at the same time the drum revolves, a curve C D will be traced which will approximate a portion of a rectangular hyperbola. When the piston has reached the end of its stroke, let the exhaust valve open fully and sharply; then if there be no condenser, the pressure will fall to that of the atmosphere, and the pencil will descend, describing the straight line D E. The piston will now commence its return stroke, during which there is no pressure of steam, but only the pressure of the atmosphere opposing its return, and the pencil will consequently trace the horizontal line E A, till the piston reaches its original position, when the same series of operations re-commences.



The diagram records the following facts:

1. The exact position of the stroke at which steam is admitted.
2. The way in which the initial pressure is maintained or otherwise during the period of expansion.
3. The point of cut-off.
4. The point of release, i.e. when the exhaust is opened.
5. The rapidity with which the exhaust takes place, as shown by the nature of the exhaust curve.
6. The period when the exhaust is closed.

7. The nature of the curve of compression.
The diagram gives several other things, but the above are those in which we are interested.

Now we understand the diagram, and we wish to set the valves by taking diagrams, making adjustments shown needed by each diagram until a perfect or as near perfect, as possible, a diagram is secured. Referring to indicator card No.1 we see that the eccentric needs to be adjusted. This adjustment will be made first. The first eight cards (two to ten) were taken at different positions of the eccentric only. Each card representing an advance of one-fourth of an inch forward. It will be noticed from card nine that the admission on the crank end is correct, while that on the head end is still a little late due to the valve on that end. Our next step will be to improve the compression which in both cases is too early. This is done by adjusting the exhaust rods as given below:

Card	10 -	lengthened	lead	exhaust	rod.
"	11 -	"	crank	"	"
"	12 -	"	head	"	"
"	13 -	shortened	"	"	"
"	14 -	"	both	"	"
"	15 -	"	"	"	"

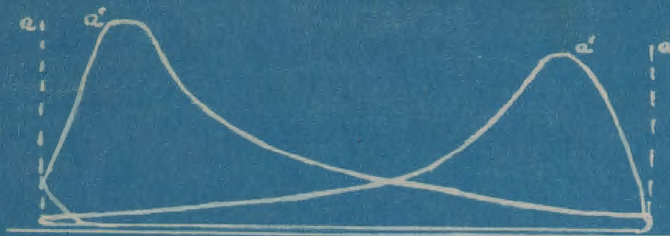
We next turn our attention to the admission on the piston end, this is adjusted by the admission rod to the admission valve on the piston end.

Card	16 -	lengthened	steam	rod	on	lead	end.
"	17 -	shortened	"	"	"	"	"
"	18 -	"	"	"	"	"	"

Our last step towards a very good card is the adjustment of the cut-off on the crank end.

Card	19 -	shortened	crank (long rod)	cut-off	one	revolution
"	20 -	lengthened	"	"	two	"
"	21 -	shortened	"	"	additional $\frac{1}{4}$"	
"	22 -	lengthened	"	"	a fraction	
"	24 -	"	"	"	1/2	revolution
"	25 -	shortened	"	"	one	"
"	26 -	shortened crank cut-off a fraction and other minor corrections.				

The setting of the valves by indicator is, as seen, just a cut and try method, but a very accurate and positive manner. Of course, there was nothing to keep me from making all those adjustments above at the same time, which would have been quicker. But we adopted the other method to give a clearer idea of what was being done and the effect each adjustment had, - a moving picture effect.



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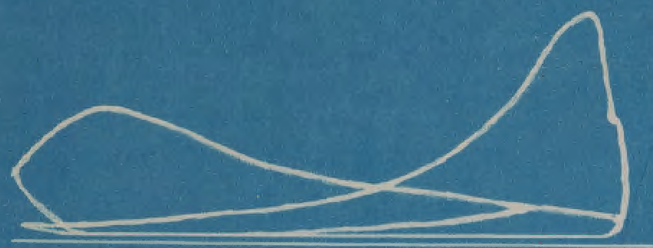

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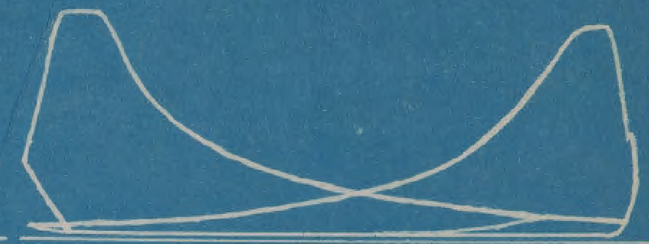

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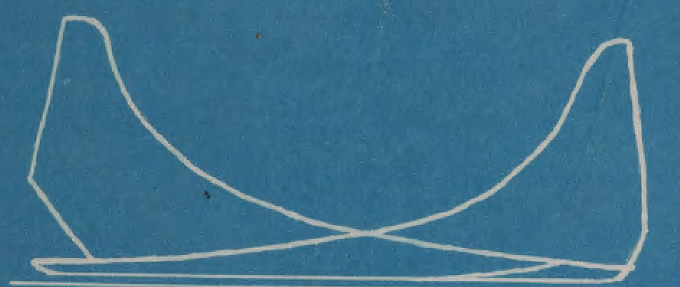

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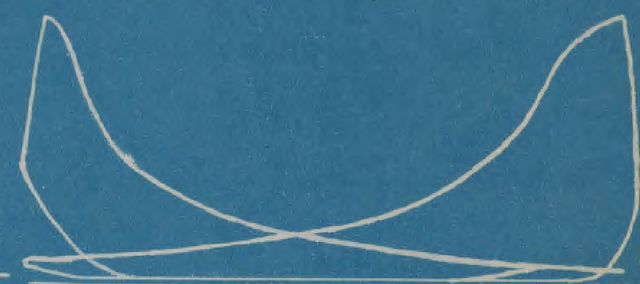

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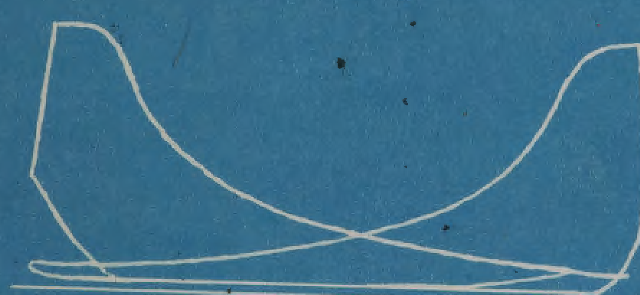

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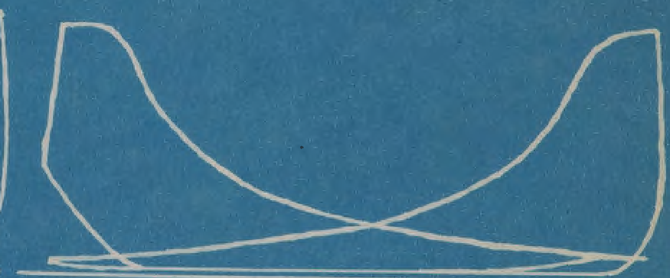

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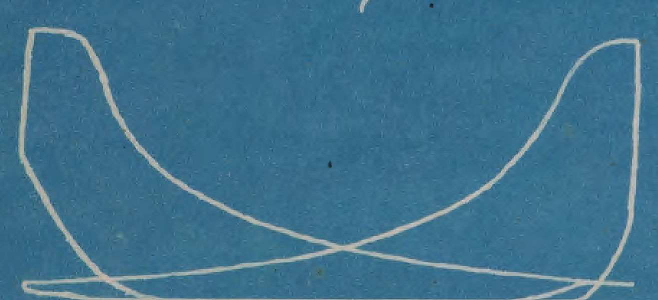

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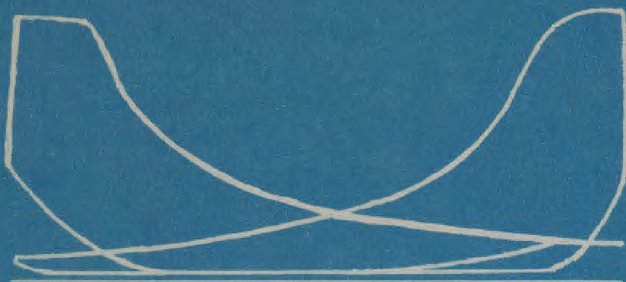

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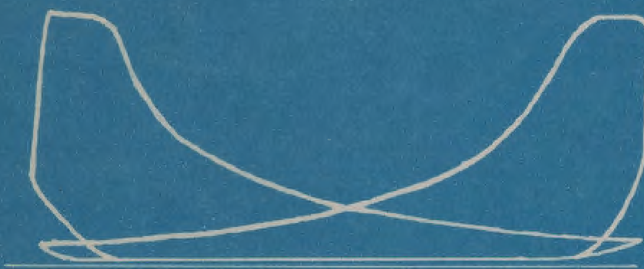

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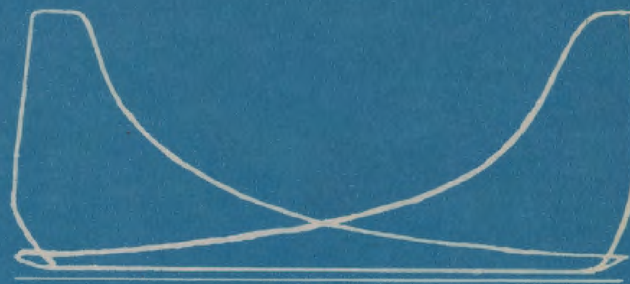

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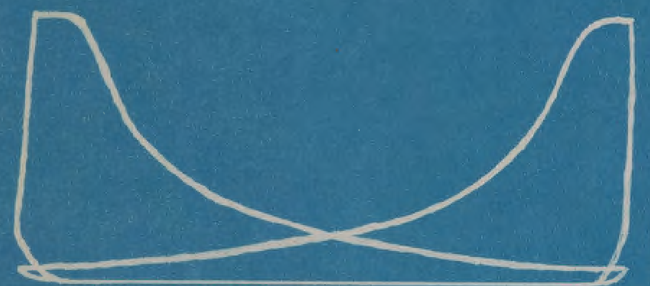

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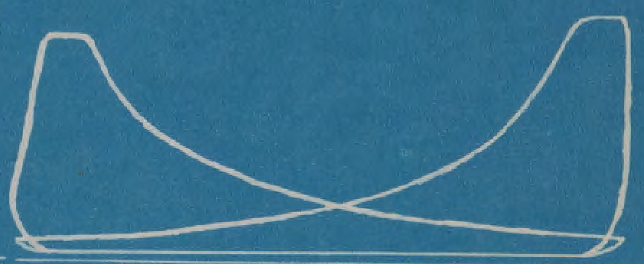

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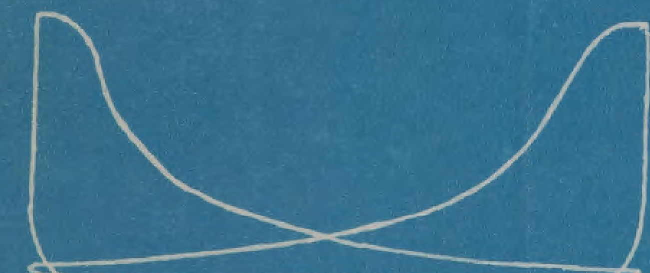

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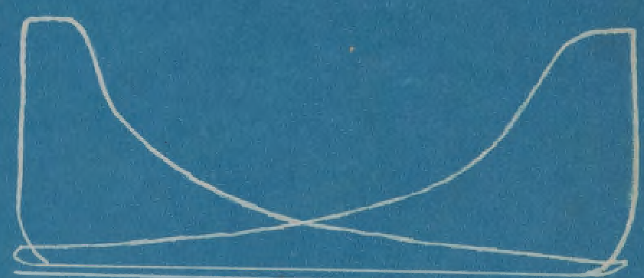

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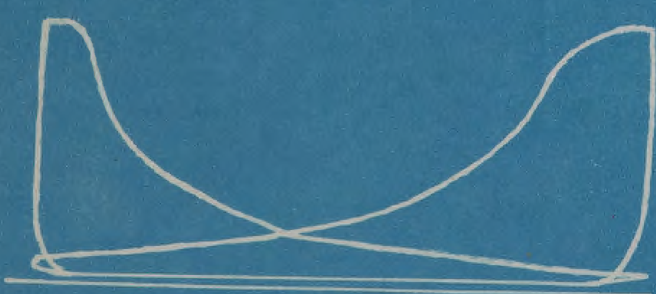

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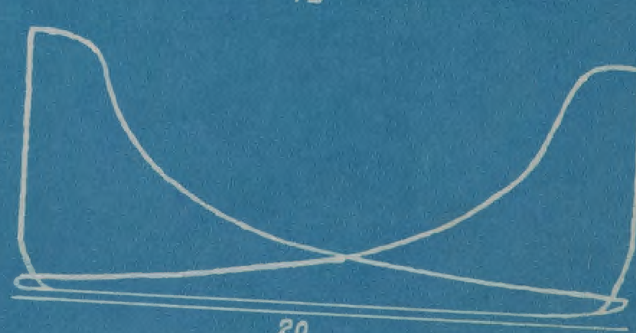

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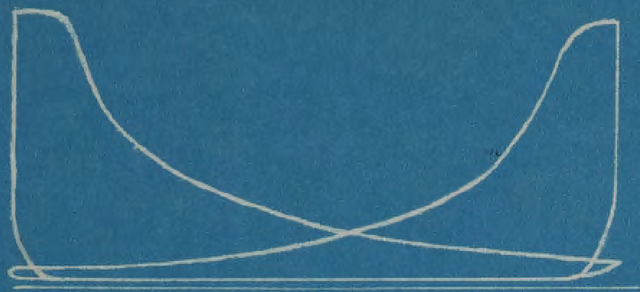

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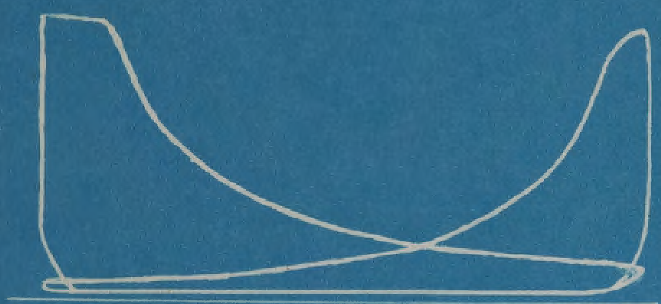

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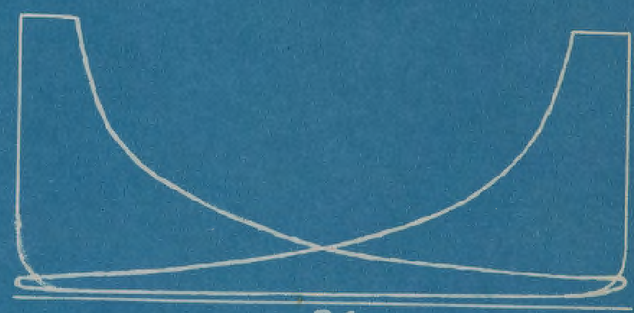

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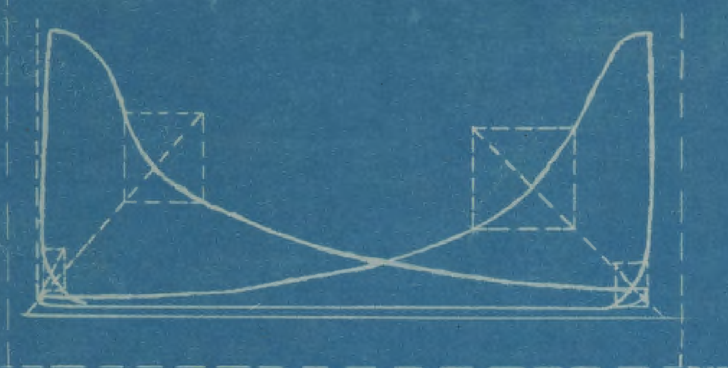
(The clearance in an engine is usually determined by measuring the volume inside of a cylinder not swept through by the piston, or in other words, the length of the inside of the cylinder minus the stroke of the piston times the area of the cylinder gives the clearance volume. The ratio of this volume to the volume of the piston displacement is the clearance. This gives the total clearance, so dividing by two would give one end clearance. It is often impossible to measure this clearance exactly, in which case some engineers recommend the clearance to be obtained from the indicator card by a method to be explained later. I wish to prove or disprove this method as the case may be from an actual experiment. My first step towards my investigation was to determine the head and crank end clearancesby direct measurements by filling the ports with water. The clearances obtained in this manner are represented by the lines A B and C D in our diagrams. (refer to diagram 86).

To determine the clearance from the indicator diagrams, the procedure is as follows: (refer to diagram 86). First, the vacuum line O X is laid out parallel to the atmospheric line K L. Take two points a d on the expansion line and e g on the compression line and draw horizontal and vertical lines through these points, completing the rectangles a b c d and e f g h. Draw diagonals through these rectangles and the points where they cross the vacuum line determine the clearance. As will be seen I have treated eight cards in this manner and in no one of them has this method checked out with the actual clearance. The conclusion reached that the method of obtaining the clearance from the indicator diagram is very inaccurate. (Refer to diagrams 85 thru 92).



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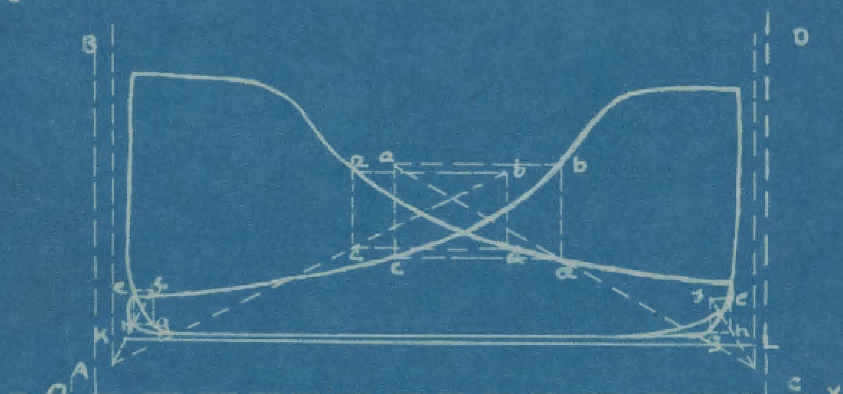

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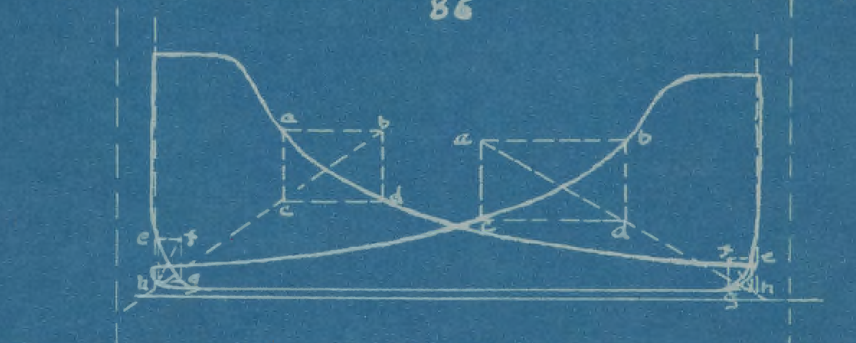

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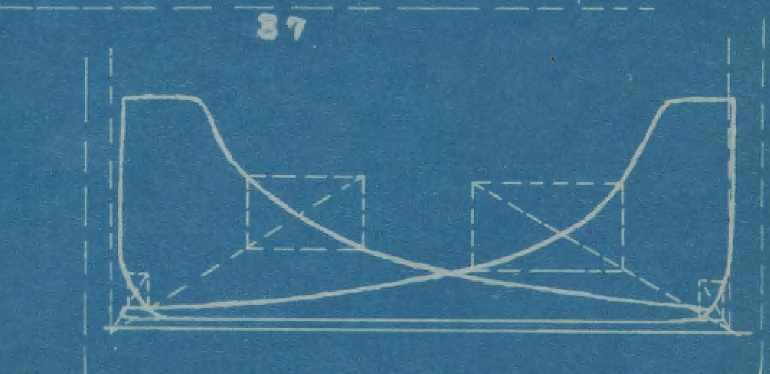

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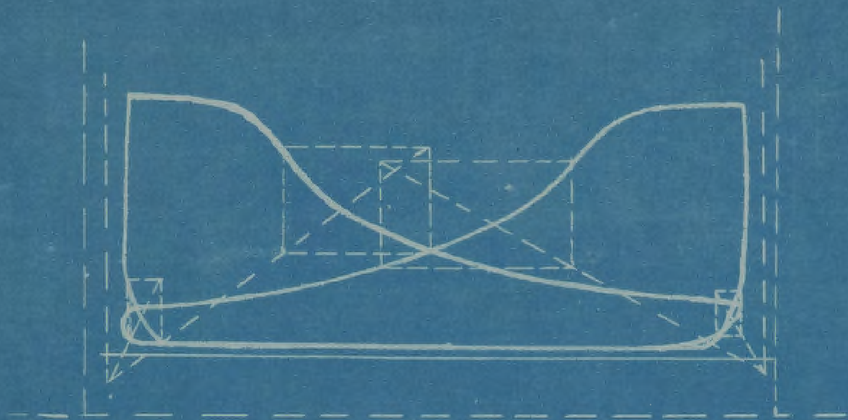

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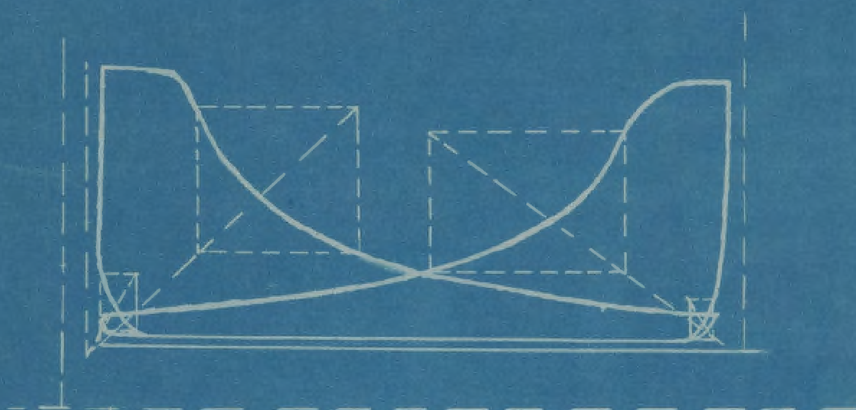

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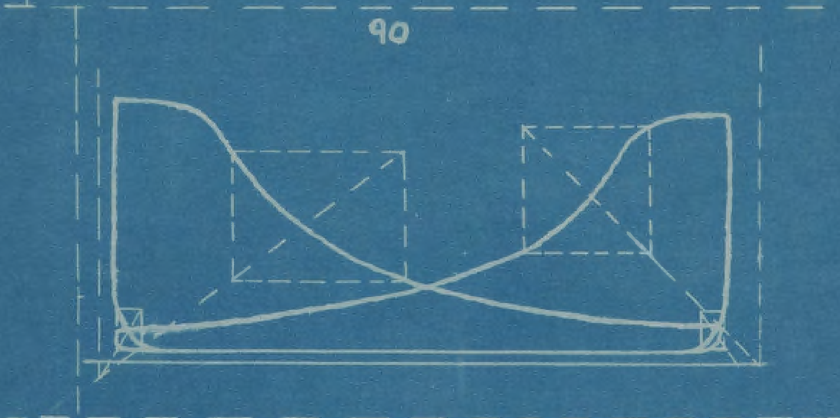

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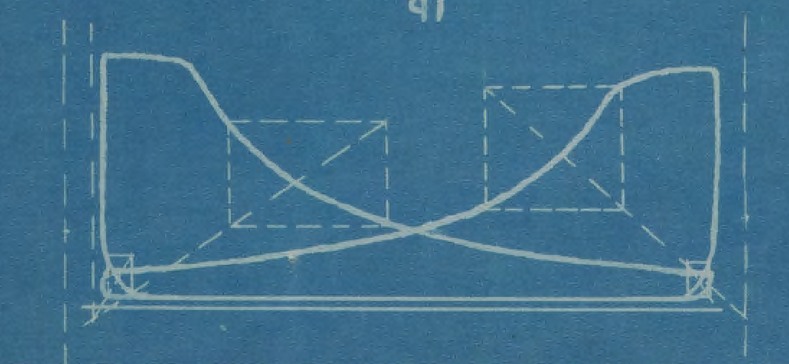

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There are two methods for determining the quality of steam which the engine is using, namely, the calorimeter method, and the indicator method. It is my purpose to determine how these two methods check by experiment. To do this a calorimeter was put on the steam line and the quality of steam as given by it observed. This quality was 99 %. My next move was to take a few indicator cards and determine from them the quality. (Refer to cards 93 thro 96.) The expansion line on an indicator card from the point of cut-off to the point of release should be an adiabatic curve, that is a curve which represents neither gain or loss in heat. But this ideal condition never exists, during expansion, the condition that heat shall not be supplied to, or abstracted from, the steam is not fulfilled, because the metals of which cylinders are constructed render the fulfillment of this condition impossible. The metal being a good conductor is rapidly heated by the steam, and parts with its heat to surrounding bodies by radiation and conduction, thus causing the steam to be cooled during its passage thro the cylinder, so that the expansion line falls below the proper adiabatic curve. Upon this is based the determining of the quality of the steam from the indicator diagram.

To determine this we must construct our ideal line of expansion:-the adiabatic curve. This is done as follows: select any number of pressures along the admission line (refer to card 93 and table 1).

Pressure	Volume	Vol.per water rate	Theoretical Displacement of piston	Displacement reduced to curve scale
84	5.23	.240	.685 cu.ft.	1.529"
72	6.05	.278	.800 "	1.562"
60	7.18	.330	.957 "	2.136"
48	8.86	.407	1.162 "	2.593"
36	11.60	.533	1.522 "	3.397"
24	16.95	.779	2.225 "	4.966"

The clearance line is plotted and also the line of absolute zero from which the pressures are measured. Having obtained the pressures, the volume of one pound of dry saturated steam at that respective pressure is obtained from the steam tables. The weight of the steam used per hour is measured and the strokes per hour being known, the volume of steam used per stroke is easily obtained, being in this particular case .046. Multiply this "water rate" by the volume and the "volume per water rate" is obtained. The volume per water rate "divided by the area of the piston head gives the theoretical displacement of piston" in cubic feet, which can be at once reduced to inches, giving the adiabatic curve. That is we plot our last column from the clearance line for each respective pressure, the curve determined by these points being the adiabatic expansion curve. From which the quality may be had by dividing the actual volume of steam for any pressure by the theoretical volume, as measured on our respective curves.

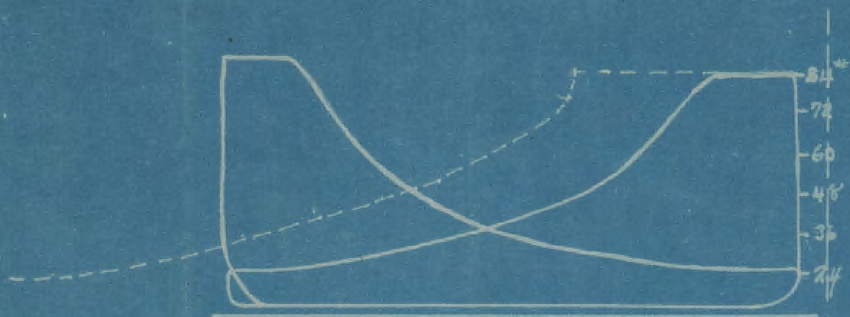
It will be seen that these values differ considerably from our calorimeter quality. This may be explained by the fact that the calorimeter was about twenty feet distance from the entrance to the cylinder, the steam condensing considerable along this distance. Also the cylinder of a steam engine acts to a great extent both as a steam generator and condenser; and, moreover, it exercises these functions precisely at the wrong times, for, as will be shown presently, the metal sides and ends abstract heat from the entering steam, causing a partial condensation at the moment when it is most desirable to maintain the temperature; while on the other hand, the steam thus condensed is partly re-evaporated during the whole period of expansion, when it can only give out a fraction of its original energy, and partly during the exhaust period, when it not only gives out no useful energy whatever, but also tends to impair the vacuum and to increase the back pressure. It is this performance which accounts for the difference in our two qualities.

The calorimeter, no doubt, is correct for the quality of steam at its position. But, from the above discussion it can be plainly seen the quality of the steam in the cylinder can by no means be judged from the calorimeter statement. If the quality of the steam in the cylinder is desired, the only accurate way for its determination is from the indicator diagram and water rate. This method has another advantage over the calorimeter as the quality at any portion of the stroke may be determined. So the statement may be made, that in engines which work expansively, the amount of steam used, calculated from the diagrams, is nearly always considerably less than that supplied by the boiler. This proves that besides the steam which issues at exhaust and which is accounted for by the indicator diagram, there is also present in the cylinder a quantity of water which must continue to evaporate during the period of exhaust, and which may partly be carried over mechanically into the condenser, and which has no more useful effect than if it were to pass straight from the boiler to the condenser.

This peculiarity of engines which use steam expansively is accounted for by the great difference which exists between the initial and final temperatures of the steam in the cylinder. Then take card 93, the entering steam had a pressure of 84 lbs. per square inch, and which expanded down to 18.75 lbs. absolute, the initial temperature would be 315°, and the final 225°, showing a difference of 90°, and as our engine was condensing this fall would be increased because the cylinder would be exposed, during the whole exhaust. During the whole period of expansion and exhaust, the surface of the metal forming the sides and ends of the cylinder and piston is being cooled down by the combined effects of radiation to the moist steam - which readily absorbs radiant heat - and conduction to the condensed steam, which is re-evaporated from the metallic surfaces. The result is, that when the fresh steam re-enters the cylinder, it comes in contact with the relatively cool surfaces, and a large portion of it is condensed; the latent heat of the steam condensed raising the temperature of the sides up to that of the entering steam. In order to make up for the steam condensed, fresh steam rushes in from the boiler and thus much more steam enters during the period of admission than is required to fill the cubic contents of this portion of the cylinder.

When the steam is cut off and commences to expand, its pressure and temperature fall, but during the early period of expansion, its temperature is generally still higher than that of the sides of the cylinder and more condensation takes place. At the same time, however, the reduction in pressure allows a portion of the water formed by condensation during the admission period to re-evaporate; for this water has, when formed, the temperature of the entering steam and therefore, when the pressure in the cylinder falls, it possesses too much heat to remain in the state of water, and part of it boils off, the evaporation being added and increased by the supply of heat forthcoming from the hot sides and end of the admission portion. Thus, during the whole period of expansion, both condensation and re-evaporation go on. During the earlier period of the stroke the condensation predominates, but towards the middle and the end of the stroke, as the temperature of the expanding steam approximates more closely to that of the sides of the cylinder, the condensation becomes less and less, and the re-evaporation becomes more active, and consequently the latter predominates, while during the exhaust, in consequence of the very low pressure, the circumstances are most favorable for re-evaporation.

This in justice to the calorimeter as well as to the indicator diagram the final conclusion is that the quality as given by the calorimeter by no means applies to the steam in the cylinder. The only correct method for obtaining the quality of the steam in the cylinder is by the indicator card. These statements are based upon the previous discussion.

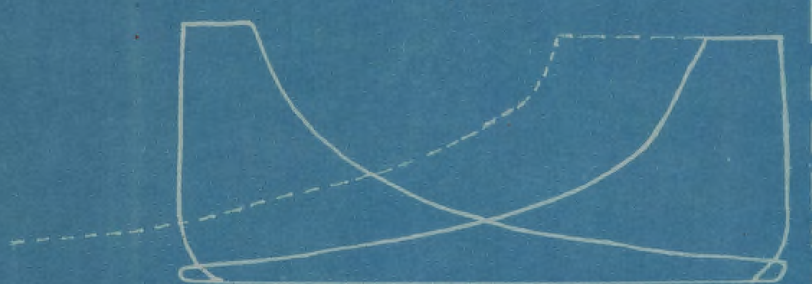


Quality at admission: 43.0
" " Exhaust: 73.6

93

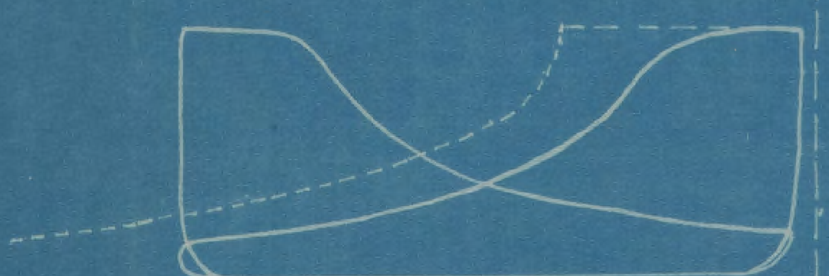
Quality at Admission: 37.5
" " Exhaust: 75.0

94



Quality at Admission: 41.9
" " Exhaust: 75.0

95



Quality at Admission: 48.0
" " Exhaust: 78.0

96

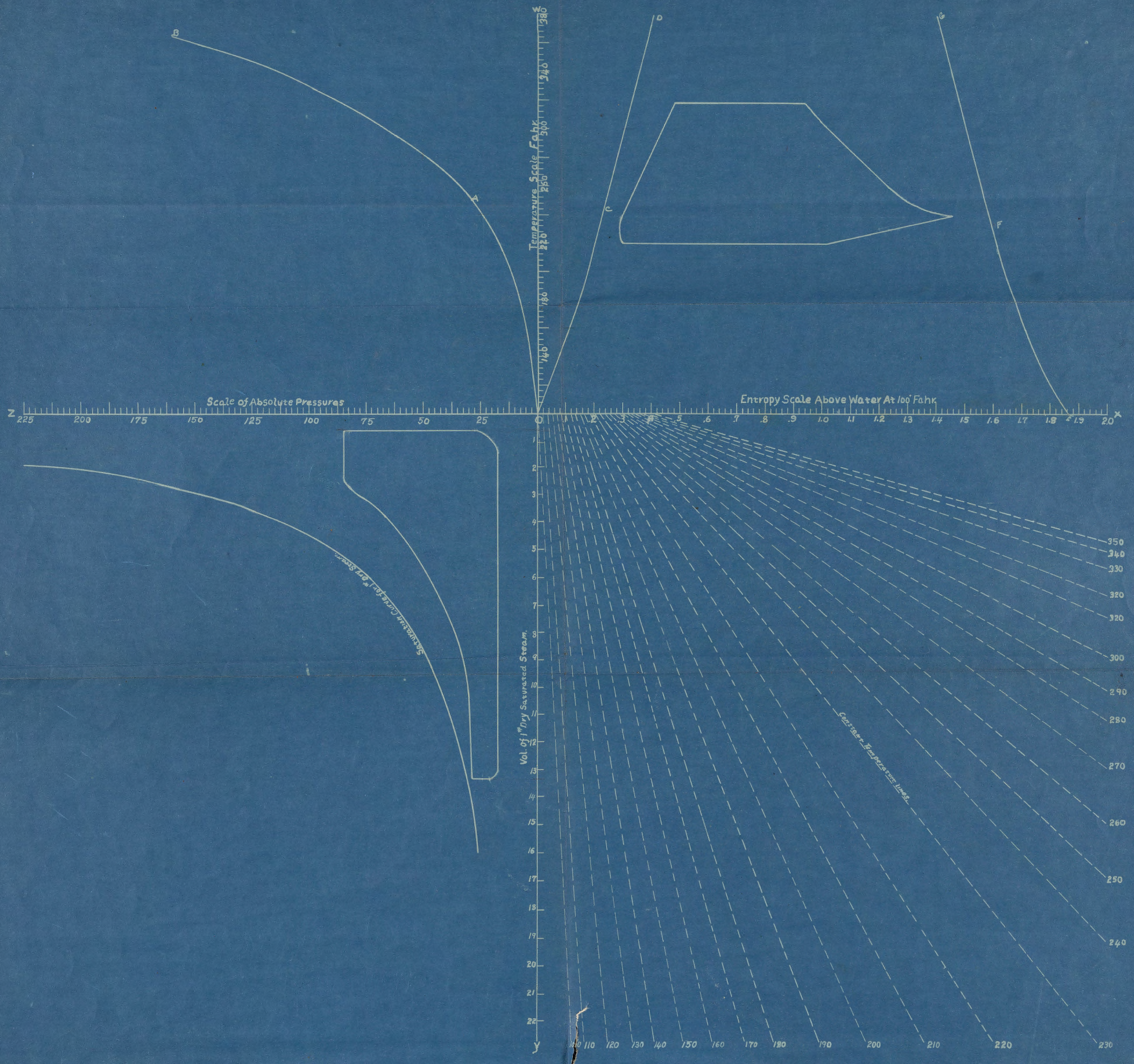
The Complete Entropy Diagram: Referring to the diagram I will begin with the first quadrant and follow them through explaining just how each is constructed. First with O, in the center of the diagram, as the initial point, a temperature scale is plotted vertically upwards on the line O W, starting with any convenient minimum temperature as 100 deg. Fahr., and adopting any convenient scale. A scale of entropy O X is drawn horizontally to the right to any convenient scale, the entropy given being above that contained in one pound of water at a temperature equal to the zero adopted in the temperature scale. Volumes are plotted vertically downward on the axis O Y, to a scale to be afterward determined; and pressures (absolute) are measured horizontally to the left, as shown by the line O Z, to any convenient scale.

Starting with the first quadrant the curve O A B, representing the relation between temperature and pressure of dry saturated steam, can be plotted direct from the steam tables, using the temperature and pressure scales already decided upon. In the second quadrant we first construct the curve of entropy of water, curve O C D. To get a point on the curve suppose we commence with water heated from 100° Fahr. to 125° Fahr., the heat given to one pound of water to raise its temperature from 560° Fahr., absolute to 585° will be (92.92 - 68) or 24.92 B.T.U. That is we subtract the heat content of vapor at 100° from that at 125° to get the heat given to one pound of water to raise its temperature 25°. Therefore, the increase in entropy would be $\frac{24.92}{572.5}$ or .0425. Similarly the value of entropy can be calculated for any temperature, giving us a series of points thro which a curve is drawn, the curve of entropy of water. The curve E F G, or the entropy curve of steam, is drawn by adding an amount of entropy $\frac{V}{T}$ to the entropy curve of water, where V is the latent heat of one lb. of steam at T degrees absolute temperature. The values of V for any temperature T may be determined from the steam tables.

To determine the volume scale O Y, take any point on the temperature pressure curve, say A at 250 degrees Fahr., at which point a tangent is drawn. At the point C, where the 250° projection intersects the curve of entropy of water drop a perpendicular to the O X axis. Now from this point draw a line parallel to the tangent at A, and the constant temperature line for 250° is determined. In this manner the constant temperature lines for any degree of temperature may be determined. These lines in the third quadrant represent the increasing volume of one lb. of steam in being generated at constant temperature, and are therefore called for brevity "constant temperature lines." If at the point where the 250°

projection intersects the curve of entropy of steam, a perpendicular is dropped until it strikes the 250° constant temperature line; the vertical distance from its point of intersection on the O X axis to its intersection of the constant temperature line represent to scale the volume occupied by one lb. of dry saturated steam at the temperature indicated, and with other such constructions for other temperatures furnish the necessary data for constructing the volume scale O Y.

The saturation curve for one lb. of dry steam is plotted in the fourth quadrant directly from the steam tables. Also an indicator card is plotted, as shown, to the pressure and volume scales as given in the fourth quadrant. Now our last step is to plot our indicator card in the entropy diagram. This is done by doing with several points what I will describe for one. Suppose we take 260° on our temperature scale and project horizontally until it intersects our curve O A B,at this point of intersection drop a perpendicular down until it intersects our indicator diagram. From this point of intersection project horizontally until the constant temperature line of 260° is intersected and from that point project vertically upward until the 260° degree horizontal project is met. This point is one point of our diagram. By following this method for other points we can complete our entropy diagram.



Temperature Scale Fahr.
Scale of Absolute Pressures
Entropy Scale Above Water At 100° Fahr.
Vol. of 1# Dry Saturated Steam.
Saturation Curve for 1# Dry Steam.
Constant Temperature Lines.
W
X
Y
Z
B
C
D
F
G
380
340
300
260
220
180
140
225
200
175
150
125
100
75
50
25
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2.0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
350
340
330
320
320
300
290
280
270
260
250
240
230
220
210
200
190
180
170
160
150
140
130
120
110
100

Our next step is a study of the effects on the indicator diagram for different settings of the different valves, taking a diagram for each event. This will enable us to see the effect that each respective setting has. But before we take up this study, perhaps it would be well to discuss a few faulty diagrams with explanations of the fault of each. (Taken from a handbook of the Trill Indicator Co.)

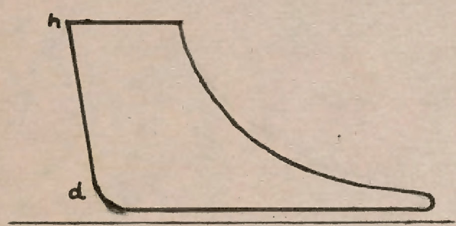


fig. 1.

Fig. one. The line (nd) slants backward instead of being perpendicular. It will be noticed that in a single-valve engine, the cut-off, release and compression also will be too early, but in a Corliss engine these parts may not be affected, as shown. To remedy this the lap of the admission valve should be increased. Admission is too early.

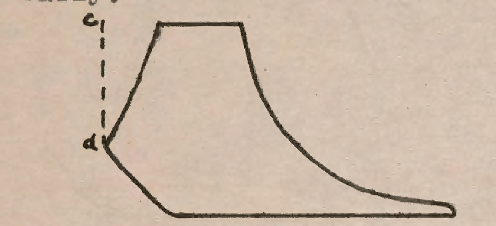


fig. 2.

Fig. two. The admission line (cd) slants forward instead of being nearly perpendicular. With the Corliss it results from the valves becoming misplaced or badly set. Admission may be made earlier by reducing the lap of admission valves. Admission is too late.

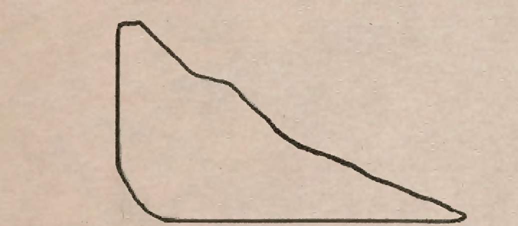


fig. 3.

Fig. three. The steam line drops instead of being horizontal, indicating that the steam port is not open for a sufficient time. Steam is throttled during admission.

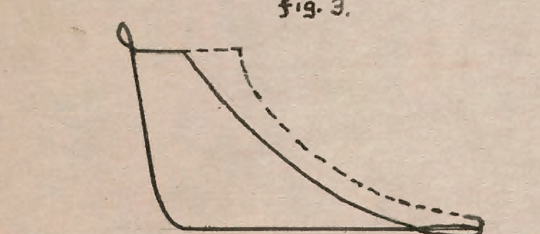


fig. 4.

Fig. four. Steam expands until its pressure is less than the back pressure, and the expansion line crosses the back pressure line to form the loop (y). It is caused by too high steam pressure and wastes steam for the amount of work done, besides causing reversal of pressure and pounding. The steam must be throttled, the back pressure lowered by running condensing, or the engine run slower to remedy this condition.

The dotted line shows the result of slowing down the engine and cutting off later. This diagram also shows the result of too early compression. The steam is compressed in the clearance space until the pressure rises above that in the steam chest. Cut-off is too early.

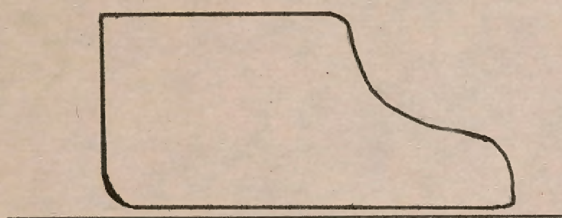


fig. 5

Fig. five. This is characterized by a high pressure at release and means a big waste of steam due to its inability to do work by expansion before the exhaust opens. The boiler pressure should be raised so that a diagram of equal area may be obtained with an earlier cut-off, or the revolutions of the engine increased, and the cut-off made earlier. Cut-off too late.

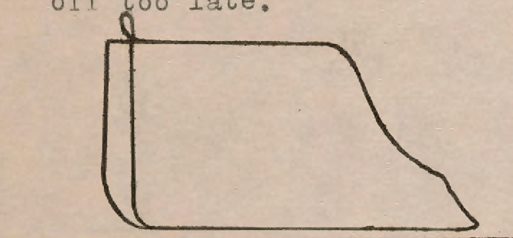


fig. 6

Fig. six. The pressure in the cylinder rises above that in the steam chest and may cause chattering of the valve, pounding and heating, in addition to reducing the effective work of the steam. The dotted area plus the loop indicate the additional work obtained by setting the valves for proper compression. A similar loop may be caused by the absence of load on the steam valve, but when this fault occurs, the loop comes to a sharp point on top. Compression is too early.

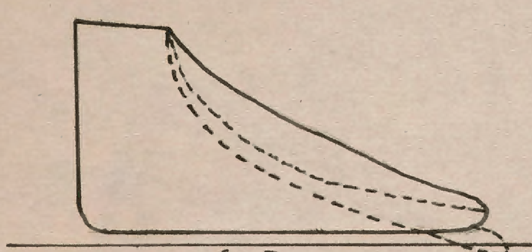


fig. 7

Fig. seven. If the expansion line is noticeably above the theoretical adiabatic expansion line, steam enters the cylinder thro a leakage valve after cut-off. If the expansion line falls below the theoretical, steam leaks past the piston, or gets out thro a leaky exhaust valve. Leaks indicated by expansion line.

fig. 8

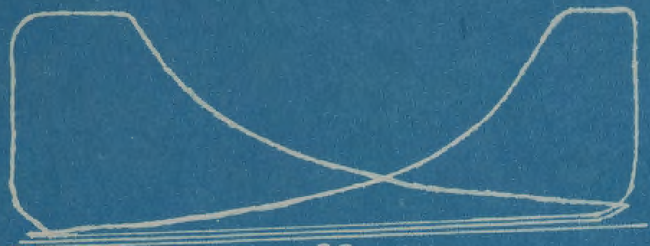
Fig. eight. The curvature of the compression line changes as the piston nears the end of the stroke, sometimes even forming a hook, as shown. This indicates the escape of steam from the compression space, either through the exhaust or past the piston. Leaks are indicated by compression line.

My first changes dealt with the cut-off. Referring to cards 28 through 35, my settings were as follows:

28: Both cut-off rods lengthened one revolution from original position,
29: Both cut-off rods lengthened two revolutions from original position,
30: Both cut-off rods lengthened three revolutions from original position,
31: Both cut-off rods lengthened four revolutions from original position,
32: Both cut-off rods shortened one revolution from original position,
33: Both cut-off rods shortened two revolutions from original position,
34: Crank cut-off lengthened three revolutions, piston cut-off 2½ from original position,
35: Crank cut-off lengthened four revolutions, piston cut-off 2½ from original position.

From a study of the first four cards we see the effect of our changes is a lengthening of the admission line of the head end and a shortening of the same for the crank end. The cut-off of the head end becomes later in each case while that of the crank end becomes earlier. It will also be noticed that the mean effective pressure for the head end increases for the piston end, while that of the crank end decreases. The admission of the crank end also decreases a little for each change, until in card 31 it is quite noticeable. The point of release becomes later, and the point of exhaust becomes earlier on the head end, while it becomes later for the crank end.

For the remainder of the cards the reverse of the above is true.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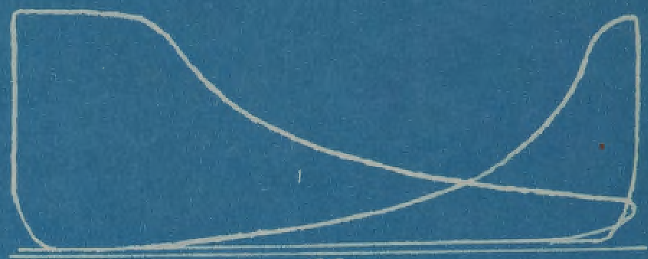
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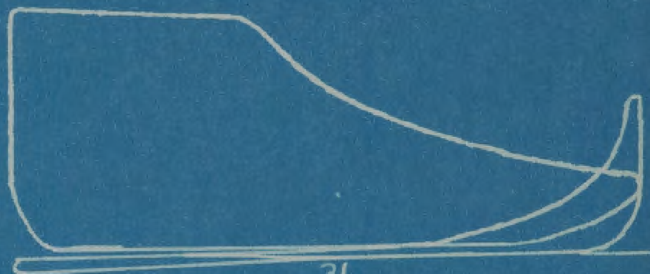
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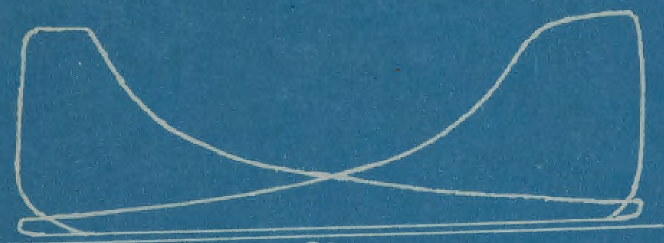
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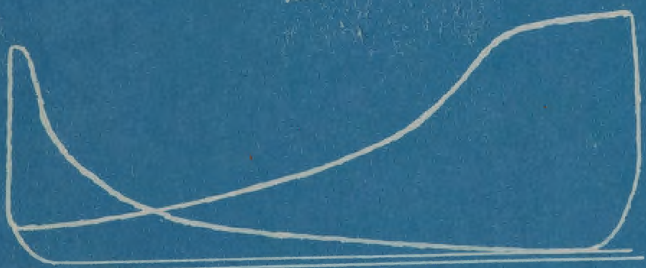
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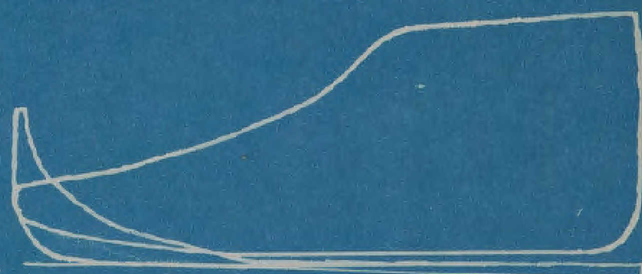

35

Cards 38 to 48 inclusive are from the effects of various settings of the exhaust rods.

Card 38: Shortened both rods one-half revolution from original position,
" 39: Shortened both rods one revolution from original position,
" 40: Shortened both rods one & half revolutions from original position,
" 41: Shortened head exhaust rod three & half, Crank $1\frac{1}{2}$ revolutions from original position,
" 42: Lengthened both rods one half revolutions from original position,
" 43: Lengthened both rods one revolution from original position,
" 44: Lengthened both rods $1\frac{1}{2}$ revolutions from original position,
" 45: Lengthened both rods two revolutions from original position,
" 46: Lengthened both rods three revolutions from original position,
" 47: Lengthened both rods $3\frac{1}{2}$ revolutions from original position,
" 48: Lengthened both rods out to limit from original position.

In the first four cards the effect is to make the exhaust close later for each successive setting. In the remainder of the cards the exhaust closes earlier for each successive setting and the point of release later, until as will be noticed the point of exhaust comes before expansion is completed. It is interesting to note in card 47 of the leak indicated by the compression line of the crank end digram. This indicates the escape of steam from the compression space, either thru the exhaust or past the piston. Card 48 is a very notable one for here we have a case where admission occurs before the exhaust is completed. That is, steam remains in the exhaust port causing a high back pressure. When the engine is set to give such a card as this, it is impossible for it to give very efficient work.

Cards 49 to 58 inclusive deal with changes of the eccentric setting.

Card	49	Eccentric	moved	1"	forward	from	original	position.
"	50	"	"	2"	"	"	"	"
"	51	"	"	3"	"	"	"	"
"	52	"	"	to original position.				
"	53	"	"	1"	backward	from	original	position.
"	54	"	"	2"	"	"	"	"
"	55	"	"	3"	"	"	"	"

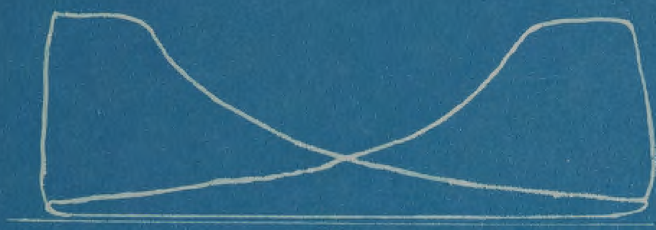
Card 56 Eccentric moved 4" backward from original position.
" 57 " " 5" " " " "
" 58 " " 6" " " " "

In the first three cards, 49, 50, 51 the admission line slants backwards, showing a very early admission. It also seems to have the effect of causing the exhaust to come earlier, and the point of exhaust closure to come later or we have a longer compression. It is also interesting to note in cards 50 and 51 theloop; this is caused by too long compression which interferes with the admission. That is, when the admission is open instead of the steam entering at once, steam is leaving the cylinder for a moment.

In the remainder of the cards the admission line slants forward, denoting a late admission. The steam pressure during admission is injuriously affected, becoming more serious with each card; this is due to the insufficient opening or area of the port. The cut-off comes earlier with each successive card, the point of exhaust opening comes before expansion is completed, or before the end of the stroke. The point of release comes later with each card. Cards 57 and 58 are very interesting, all events are late, there is no compression at all and it will be noticed of the large leakage of steam indicated by the compression line.

Cards 59 to 65 inclusive deal with the various settings of the admission rods.
Card 59 Both rods lengthened ½ revolutions from original position,
" 60 " " " 1 " " " "
" 61 Original position
" 62 Both lengthened ½ revolutions from original position,
" 63 " " 1 " " " "
" 64 " " 1½ " " " "
" 65 " " 2 " " " "

To lengthen both rods the admission for both ends becomes longer. To shorten the rods the admission while the piston is moving becomes shorter, the admission line slants forward, showing a late admission also that the valves are badly set. The compression line of the crank end of card 65 shows a leakage somewhere.



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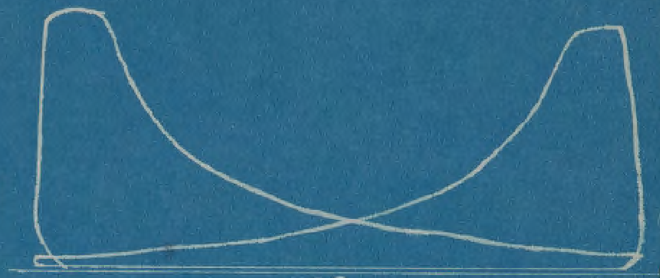

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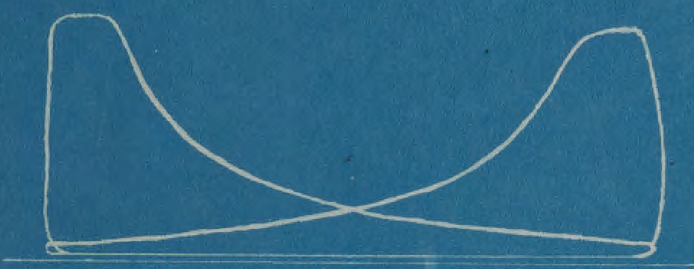

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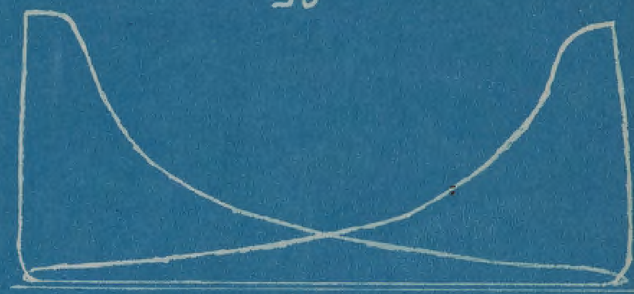

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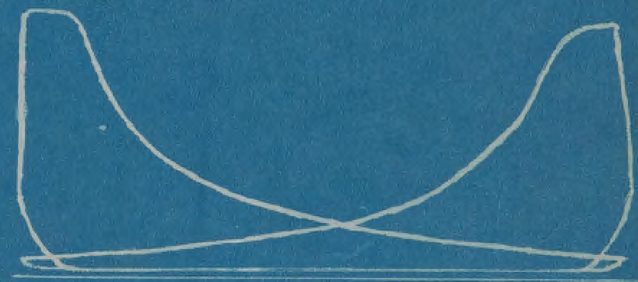

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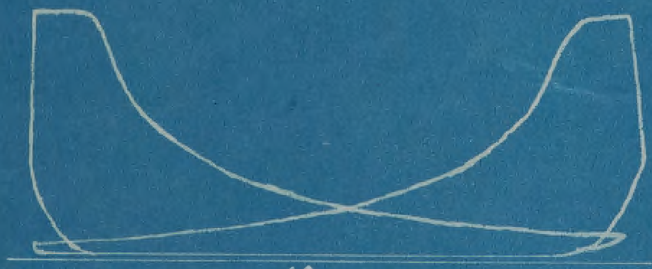

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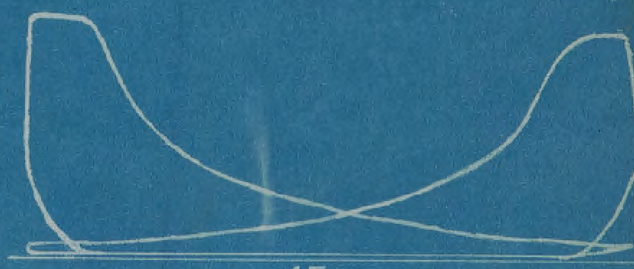

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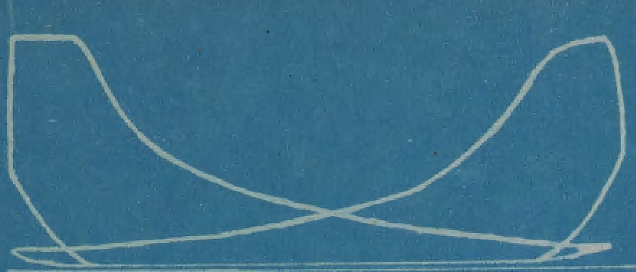

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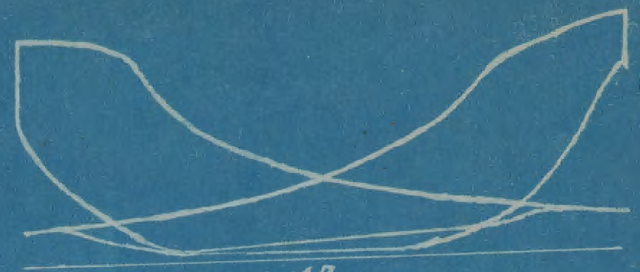

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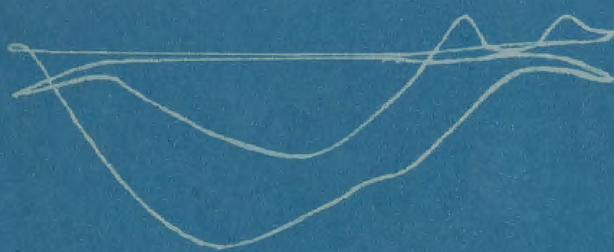

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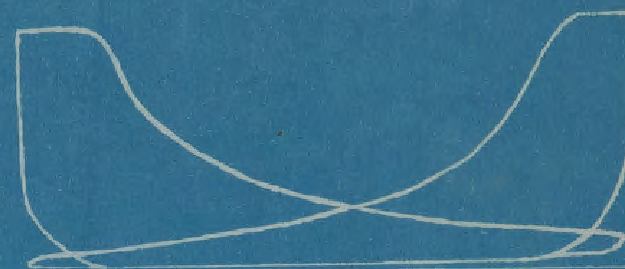

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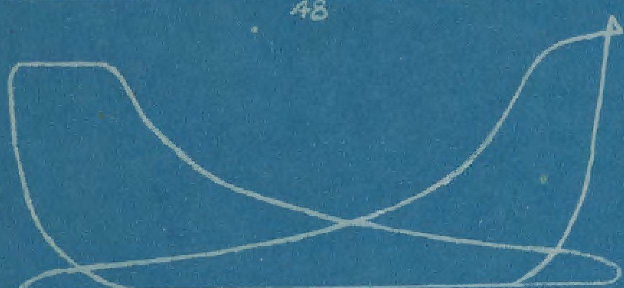

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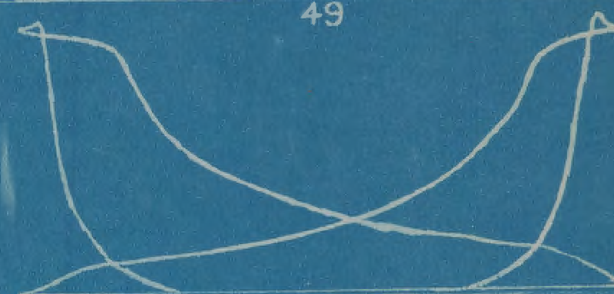

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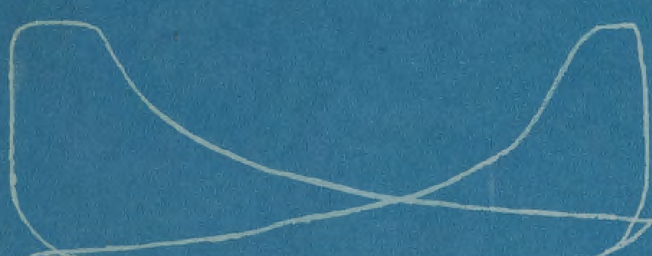

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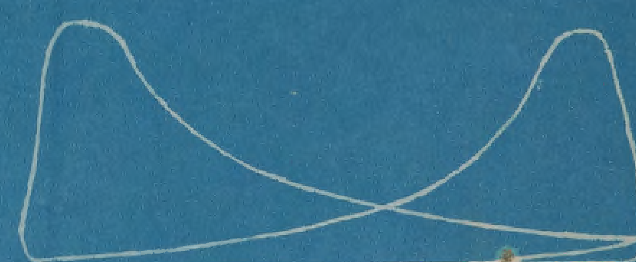

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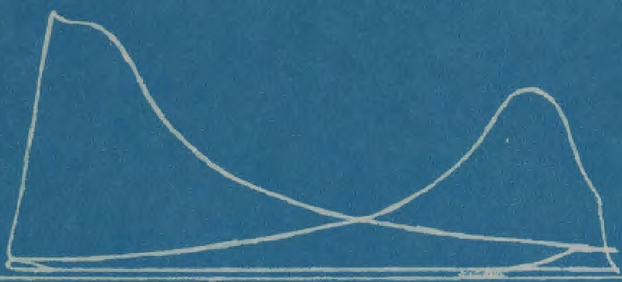

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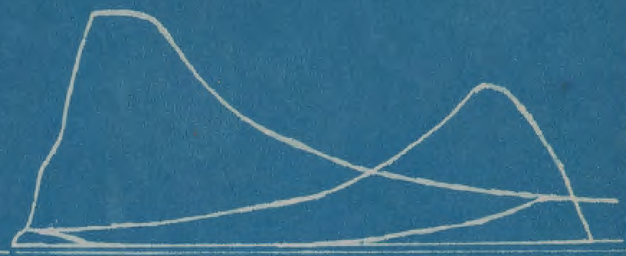

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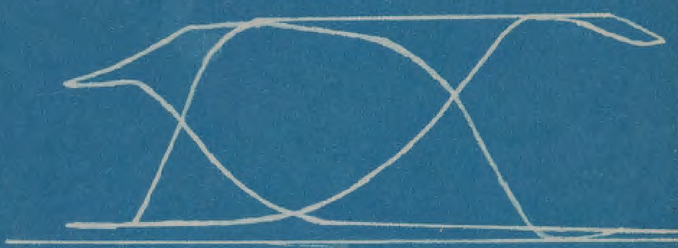

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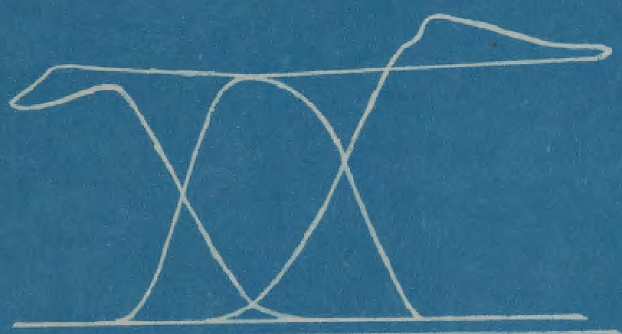

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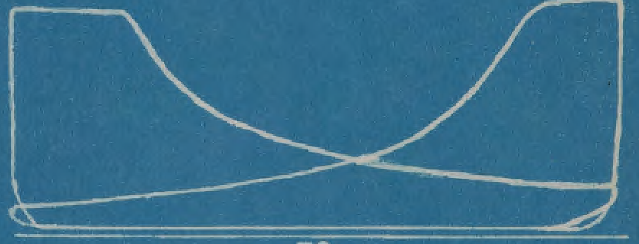

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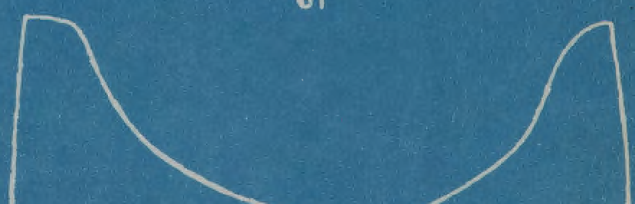

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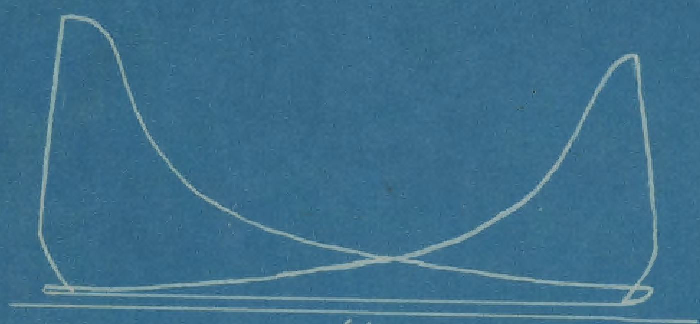

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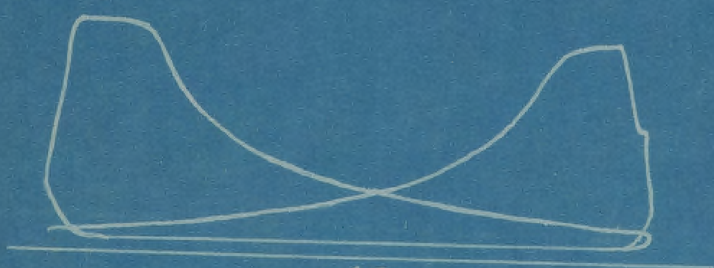

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Suppose we were to take a few cards with throttled admission, what would be the result? The result would be that the steam line would drop instead of being horizontal.

If we had sluggish dash-pots the cut-off would be effected. There would be a round curve instead of a sharp well defined point. In the extreme case where the dash-pots are working very bad, the expansion line might be found with zigzags in it.

In conclusion, the following results have been brought forth:

1. The indicator method of setting Corliss engine valves is superior to all other methods. The valves may first be set according to specifications, but if so should be checked and finally adjusted with the aid of the indicator.

2. The only accurate method of obtaining the clearance of an engine is by calculation or measurement. The indicator diagram method can not be relied upon.

3. To obtain the quality of steam in the cylinder of an engine, the method of obtaining it from the diagram is the only true method since the calorimeter only gives it on the point of its position. The indicator card gives the quality of the steam at any point desired in the cylinder.

4. The graphical method of drawing the entropy diagram is more accurate and convenient than the calculation method.

5. From a study of the indicator cards taken for different settings of the valves, anyone may be able to glance at a card and tell what is wrong and what must be done to remedy this evil. Thus a complete understanding of the working of the Corliss valves is obtained.