EFFECT OF PIPING ARRANGEMENTS

ON THE

STEAM ENGINE INDICATOR DIAGRAM

BY

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THE EFFECT OF PIPING ARRANGEMENTS ON THE STEAM ENGINE INDICATOR DIAGRAM.

THE OBJECT OF THE EXPERIMENTS.

Within recent years engineers have been interested in the question of the effect of piping on the steam engine indicator diagrams, and many experiments have been made by engineers and engineering students. With but few exceptions it has been agreed that there is a difference due to different methods of piping to the indicator.

The following experiments were made for the purpose of adding to data already obtained, and to furnish data on some phases of the subject which have heretofore received but little attention from experimenters and writers on the subject.

APPARATUS.

The Ball Engine.- For an engine of high speed a Ball engine, used to furnish power to the shops and Mechanical Engineering Laboratory, was chosen. This engine is of the automatic cut-off type, having a cylinder eight inches in diameter and a ten inch stroke. It is belted to the line shaft and runs at an average speed of two hundred and ninety revolutions per minute. For these experiments a special cylinder head was made. The upper half of this cylinder head was tapped for three pipes, so as to allow of two or three pipes being connected to the head end of the cylinder at the same time. On the inside of the head these holes were counter-bored to make the opening large from the cylinder to the end of the pipe. With this head the clearance of the head end of the engine was 9.28 per cent. of the piston displacement. A sketch showing the head will be found on PLATE 4.

The larger number of experiments on this engine were performed under actual running conditions, during a part of the day when the load was nearly constant. During a vacation, a set of experiments was taken with the line shaft as a load, and to insure this being constant the shops were locked and no machines used. Further particulars will be given in the descriptions of the experiments.

The Robinson Engine.- For experiments with an engine of slow speed, an engine known in the Laboratory as the Robinson engine, was chosen. It is of the throttling governor type with a slide valve, built to run at about one hundred revolutions per minute. The cylinder is eight and one half inches in diameter and the stroke is sixteen inches. A special head was also made for this engine, similar to that described for the Ball engine. The clearance with this head was 3.91 per cent. of the piston displacement. The work done by this engine was absorbed by a rope friction brake. Different speeds were secured for these experiments and for the most part were sixty, one hundred and twelve, or one hundred and twenty revolutions per minute. In all experiments on this engine the speed was regulated by the throttle valve.

INDICATOR RIGS.

Ball Engine Indicator Rig.- This consisted of a pantograph of one parallelogram, as shown in the sketch. This was supported from the engine frame by a loop reaching from each side of the frame over the guides of the engine, and having a small angle piece with a pin-bearing for the pantograph, bolted to the loop. The entire rig was made of iron, and to insure still greater rigidity, an iron brace was run from the loop to the steam pipe. The fastening to the piston rod is shown in the sketch and consisted of two pieces which were clamped by a bolt around the rod, one-half having the pin-bearing for the pantograph. A pulley to give the cord a horizontal direction from the pantograph, was supported by a board clamped rigidly to the engine frame. The cord then made an angle of about twenty degrees from the horizontal to the indicators, as will be seen by the sketch. (PLATE 1.)

The Robinson Engine Rig.- This rig was of the lazy tongs type of three parallelograms. The rods were of wood with metal joints, all of which were well adjusted. This was fastened to the frame of the engine by a heavy iron upright bolted to the frame. The connection to the crosshead was made by using a brass bush which fitted the pin of the rig and was pipe-threaded on the outside and screwed into the crosshead. This rig as a whole was sufficiently rigid to insure good results. The cord from the rig passed to a pulley to give it a horizontal direction, and then made an angle of about ten degrees to the indicators. The pin to which the cord was fastened was in a direct line with the pins fastening the rig to the frame and crosshead.

THE INDICATORS.

The indicators used in these experiments were three Crosby instruments, two of which had been sent to the factory for repairs and another, a one and a half inch drum instrument, which was nearly new and in good adjustment. For experiments requiring two instruments the two, two inch drum indicators were used, and in experiments requiring only one indicator, the one and one half inch instrument was used.

THE ROPE BRAKE.

A rope brake was used on the Robinson engine to absorb the power. It was made by fastening the middle of a rope to a hook suspended from the ceiling and bringing both ends of the rope entirely around the fly wheel and down to a lever arm, on which was an adjustable weight to regulate the load. Wooden strips were fastened to the rope at short distances apart to keep it to its place on the wheel. (PLATE 3.)

THE PIPING.

The pipe used in these experiments was the common commercial iron pipe. This pipe was covered by a layer, one inch thick, of asbestos mixture and wraped with canvas, sewed on. The particular arrangements of the pipes had best be given under each experiment. The gate valve used was of the commercial pattern, having a full half inch circular opening. The three way cock was of the plug type, having an area in opening fully equal to the area of the cross section of the pipe. Tees, elbows and reducers used were all commercial fittings. In experiments to determine effect of long pipes, four lengths of pipe were used. These were cut to give the effect of $1\frac{1}{4}$ feet, $2\frac{1}{2}$ feet, 5 feet and 10 feet beyond the cylinder.

LONG PIPE EXPERIMENTS.

The object of these experiments was to determine the effect of the length of pipe connections to the indicator, on the diagram. The two engines described were used. Two methods of piping were used, one of which will be called the "Straight" pipe and the other the "Looped" pipe.

In the straight pipe experiments two indicators were used, one being connected to the cylinder by means of an elbow and a short nipple at a, PLATE , which will be called the short connected or cylinder indicator, the other being connected to the cylinder by an elbow and a long pipe, as shown at b. The long pipe in each case had a gate valve inserted close to the cylinder. In order to overcome the objections to a long indicator cord, in these experiments with long, straight pipes, a fine steel wire was used. It was tested by hanging an eight pound weight on a length of twenty feet of it for two days. This did not perceptibly lengthen the wire, which was found to be a light and inelastic connection from the rig to the indicator, and satisfactory in all respects. Having secured the desired conditions as to load, speed, &c., and having thoroughly warmed the pipes and indicators, three cards were taken; two were taken simultaneously from both connections and then a third card was immediately placed on the short connected indicator, the gate valve was closed to cut off the clearance effect of the long pipe, and then a third card taken. This diagram was assumed to be the true cylinder card representing the conditions and events taking place in the cylinder.

But little time was necessary to replace the card and close the gate valve and, as many experiments were performed, these cards were thought to give a good average result, even though it was impossible to take them simultaneously with those with which they were to be compared. The two cards taken at the same time are designated by the letters L.C. and S.C. Those diagrams which were taken on the long pipe were marked L.C. and those taken on the short connected indicator were marked S.C. The third card, taken on the short connected indicator with the gate valve in the long pipe closed, was marked G.V.C. The three cards taken together were each marked and numbered and the set marked on each. At least three diagrams from each connection were taken in each set. Then the indicators were interchanged, the one which was on the long connection being placed on the short connection, and vice versa. The cards then taken were marked as another set and the same number taken as in the corresponding set. These nine or twelve cards in each of the two sets, constituted the data for an experiment on the particular length of pipe used and for the speed at which the engine was running. In order to compare results and eliminate the errors due to indicators, an average card was platted for each connection. The method was: two cards marked L.C., set I, for example, were arranged with two cards marked L.C., set II, and platted on a blank card by means of closely drawn ordinates. Averages of cards marked S.C. and of cards marked G.V.C. were obtained in the same manner, cards being selected in each case which had the same card number. For example, if cards marked L.C., nos. 2 and 3, set I, and nos. 1 and 3, set II, were arranged, then S.C., nos. 2 and 3, set I, and S.C., nos. 1 and 3, set II, and G.V.C., nos. 2 and 3, set I, and G.V.C., nos. 1 and 3, set II, were also arranged. The three average cards thus obtained were measured with a planimeter and the card G.V.C. superposed upon the cards L.C. and S.C. for comparison, the card G.V.C. always being the full black line. In case the M.E.P. of the cards is given, the one written below is the M.E.P. for the card G.V.C. and the ratio gives the per cent. with the G.V.C. as the base. Results were obtained in this way for four different lengths of pipe which were cut to give the effect of 1½ feet, 2½ feet, 5 feet and 10 feet of pipe.

PLATE 5 shows the cards G.V.C. and L.C. as taken from the Robinson engine at a speed of sixty and one hundred and twelve revolutions per minute, the cards L.C. being the dotted lines and the cards G.V.C. being the full black, as before stated. PLATE 6 shows the cards G.V.C. superposed upon the cards S.C. PLATE 7 shows the form and M.E.P. of the cards G.V.C. and L.C. in the left hand column, and the cards G.V.C. and S.C. in the right side for four lengths of pipe. Pages A. and B. of cards show the twelve cards from which the average cards L.C.-S.C. and G.V.C. were obtained for the 1½ ft. pipe, the two upper cards in each column being taken with one position of the indicators and the lower two being taken after the indicators had been interchanged. Nos. 13, 14 and 15, page B, are cards taken at the same time on the 2½ ft. pipe on the Ball engine, Nos. 16, 17 and 18 are similar ones from the 5 ft. pipe, Nos. 19, 20 and 21 are from the 5 ft. pipe with the indicators exchanged. Cards 22, 23, 24 and 25, 26 and 27 were similarly taken on a 10 ft. pipe. This same order is observed on pages E., F., G., and H. of the cards. The speed of the Ball engine during the straight pipe experiments was two hundred and eighty five revolutions per minute.

THE "LOOPED" PIPE EXPERIMENTS.

In these experiments but one indicator was used, as will be seen in figure II, PLATE 4. The arrangement was as follows: a short nipple connected the gate valve to the cylinder, another short nipple connected a three way cock to the cylinder at a second point, the pipes which had been used in the straight pipe experiments were bent with an easy curve, as shown in PLATE 4, and one end secured at the gate valve and the other connected to the three way cock by a nipple and a right and left coupling. This enabled one to take cards with the long pipe open to the indicator, or by turning the plug, the short connection to the indicator could be opened and the long pipe left open to give extra clearance from the cylinder, or the gate valve could be closed, giving cards with only the short connection open from the cylinder. The three cards G.V.C., S.C. and L.C. could be taken one immediately after the other on the same card with the same indicator. As a rule, only two diagrams were taken on one card and most of these were to determine the difference in the diagrams with long connections and those with short ones, the gate valve being closed. In taking cards the pipes were allowed to warm and then a card was taken with the long connection to the indicator, this card being marked L.C. Then the three way cock was turned so as to give the short connection to the indicator and the gate valve was closed and a G.V.C. card taken. When it was desired to obtain a card which corresponded to the S.C. card of the straight pipe experiments, the diagram was taken with the cock turned to open the short connection to the indicator and the gate valve was left open, giving the effect of clearance of the long pipe. The results of these experiments are given in tables and cards are also shown on separate pages.

PLATE 8 shows in tabular form the results of experiments on both engines. In all cases the M.E.P. shown in the tables is the average M.E.P. of at least four cards which were taken under similar conditions. The per cent. of error was obtained by the G.V.C. card as a base. The minus and plus signs indicate that the M.E.P.'s of the cards S.C. and L.C. were greater or less than the M.E.P. of the card G.V.C.

OBSERVATIONS.

It may be noted here that the average cut-off of the Ball engine was about one-fourth, while that of the Robinson engine was about fifteen-sixteenths.

The most noticeable feature in the results of these experiments is, that the M.E.P. of all cards S.C. and L.C. taken from the Robinson engine are less than the M.E.P. of the corresponding G.V.C. cards, while the exact opposite is true of the experiments on the Ball engine.

While taken under apparently the same conditions two cards were seldom found which had the same M.E.P., or even the same per cent. of error, yet all cards taken from one engine agree in giving like errors due to long connections. The features that are most prominent in the form of the cards may be seen on pages A. to K. and plates 5, 6 and 7. Taking, for example, card no. one, PLATE 5, it will be seen that the card L.C. in dotted lines is almost wholly within the G.V.C. card where there is little or no cut-off. Beginning at the end of the stroke the exhaust line of L.C. lying above the exhaust line of G.V.C., may indicate three sources of error due to long pipe connections: (a) the kenetic energy of the steam when traveling to and from the indicator, (b) the effect of reevaporation due to heat stored up in the pipe during admission; (c) and to friction in the pipe. The compression line of L.C. outside of the compression line of G.V.C. indicates an error due to the time which it takes for a change of pressure in the cylinder to effect a change at the end of the pipe. The same cause, together with the excessive condensation in the long pipe at the beginning of the stroke, produces the

the curved line at the beginning of admission. The fact that the admission line of L.C. continues to be lower than that of G.V.C. may be accounted for by assuming that condensation continues to the end of the stroke. It will be seen that in all cards S.C. and L.C. taken on the Robinson engine, the drop at the beginning of exhaust is more gradual than that of the corresponding G.V.C. cards. This is probably due to the same causes that produce the curved line at the beginning of admission, except that reëvaporation occurs instead of condensation. As to the effect of increased clearance due to the long pipe, shown by cards S.C. and G.V.C., the same difference is noticed as in the cases of L.C. and G.V.C., except in a less degree, and the reëvaporation seems at a maximum at about midstroke, instead of at the beginning of exhaust.

In considering the errors due to a long pipe on the Ball engine we find that somewhat different conditions exist, the principal difference being that cut-off is less and compression greater. In general the errors may be attributed to the same causes as those in the Robinson engine. Referring to card 18 PLATE 7 it will be seen that all events of the stroke, as shown by the L.C. card, occur later than is actually the case. The steam lines of these cards are lower than those of the corresponding cards G.V.C., which is due to the excessive condensation in the long pipe. The steam and expansion lines of the L.C. card cross the corresponding lines of the G.V.C. card very near cut-off, which might indicate reëvaporation after cut-off, but on account of the shifting along of the expansion line, this can not be well shown on these cards.

However, cards S.C. and G.V.C., 21 to 24, PLATE 7, show this more clearly. The lower curved steam line of the S.C. card, resulting from condensation in the long pipe and its crossing the steam line at G.V.C. at or near cut-off, at once suggests reëvaporation. The fact that the exhaust lines of the two cards coincide so nearly as do the cards from the Ball engine, is explained when it is observed that little or no drop in pressure takes place at the end of the stroke, the reëvaporation having taken place just before, as is indicated by the dotted line above the full line between cut-off and this point. The effect of increased clearance is to reduce compression, and this is shown by the compression line of card S.C. falling below that of the card G.V.C.. These cards G.V.C. and S.C. show conclusively that a card taken from an indicator on a short connection can not be assumed to represent the true conditions as they exist in the cylinder if the clearance due to a long pipe be open from the cylinder when the cards are taken. They also show, together with the cards L.C. and G.V.C., that the error due to the use of a long pipe connection, is made up of at least three parts: (a) the error due to increased clearance space of pipe; (b) the error due to increased clearance surface; (c) and the error due to the time necessary to transmit a change of pressure from the cylinder to the indicator. In all experiments on long pipe connections the errors increased with the length of pipe and with the speed of the engine. The statement as to speed applies only to those experiments on the Robinson engine, as the Ball engine was run at a nearly constant speed.

The cards taken from the looped pipe are on pages I, J and K and may be considered as representing more accurately the actual errors, as the traced cards have slight errors due to the difficulties of tracing them accurately. Columns 13 and 14 of the tables are the averages of the per cent. of error of straight and looped pipe cards at the speeds of sixty and one hundred and twelve revolutions per minute. These values are averages which show what errors may be expected when taking cards under conditions similar to those in these experiments.

CONCLUSIONS.

1. If an indicator is expected to give accurate results the connections between it and the cylinder must be very short and direct.

2. The areas of cards taken on a long pipe from an engine having little or no expansion, are less than the areas taken on a short connection, the other conditions remaining the same.

3. The areas of cards taken on a long pipe connection from an engine having a large expansion, are larger than those of cards taken under the same conditions from short pipe connections.

4. From the last two observations it may be inferred that for a definite length of pipe there is a certain point of cut-off which will give a card equal in area from both the lont and short connections. From this it may be inferred that from this neutral point, for any length of pipe, the error increases or decreases as the number of expansions increase or decrease.

5. The errors in area increase with the length of pipe and with the piston speed.

6. The error in the form of the cards also increases with the length of pipe and with the piston speed.

7. The events of the stroke, as shown by a card taken from an indicator on a long pipe, occur later than, as shown by a card taken from a short connected indicator, when the other conditions are the same.

8. The error due to increased clearance space and surface in a one-half inch pipe, is a considerable portion of the total error due to the long pipe connections.

EXPERIMENTS WITH SHORT CONNECTIONS OF DIFFERENT SIZES OF PIPE.

Some experiments were made to determine, if possible, the difference due to short connections of different sizes of pipe. The sizes selected were three-eighths inch, one-half inch and three-fourths inch commercial pipe. It was necessary to use two indicators for these experiments and the diagrams were taken simultaneously. In order to eliminate errors due to the indicators, after three cards had been taken on each instrument, they were changed about and three more cards taken. These cards were averaged to determine the difference due to the pipes. The engines and rigs were the same as described for the other experiments. The piping was as follows: for the half inch connection one ½" nipple one and one half inches long, and one ½" elbow, were used; for the three-fourths inch connection one 3/4" nipple one and one-half inches long and 3/4" elbow, were used; for the three-eighths inch connection one reducing plug ½" to 3/8", one 3/8" nipple one and one-half inches long, one reducing plug 3/8" to ½" and one ½" elbow, were used. This arrangement gave the following lengths of connections from the cylinder to the indicator: one-half inch connection 2 3/8"; three-fourths inch connection 2 5/8"; three-eighths inch connection 2 3/4" connection to indicator. It will be seen from the tables that there was a slight difference in results in favor of the large connections. There appears to be but little difference between the half inch and the three-fourths inch connection. In fact, the error is less than that due to the two indicators, as will be seen in the table, for in one case one indicator gave larger results when on the one-half inch connection, and then when changed to the three-fourths inch connection it also gave the larger results. It would seem then, that, under ordinary conditions, the three-fourths inch short connection would not be considered better than the one-half inch connection.

These experiments cannot be regarded as satisfactory, owing to the inaccuracies of the instruments and the liability of error in the measurement of diagrams which are so nearly equal in area. However, they show that the error is not large, and in many cases might not be as great as that due to the instrument used. It would seem that the half inch connection should be used in preference to the three-eighths inch connection, because it insures better results, and in preference to the three-fourths inch connection, as a matter of convenience, the results being practically the same. See table on PLATE 9 and cards on page L.

EXPERIMENTS TO DETERMINE TEH EFFECT OF A CLEARANCE PIPE BEYOND THE INDICATOR.

Engines are often so piped than an open pipe extends on beyond the indicator. As long ago as 1878 Rigg, in his work "The Steam Engine," pointed out this source of error.

Experiments were made on both the Ball and the Robinson engines, to determine the effect of such a pipe. In all cases, except one which will be described further on, the piping was as follows: A short nipple and a tee formed the shortest possible connection from the cylinder to the indicator; a nipple connected the tee with a gate valve, beyond which extended the length of pipe to be used in the experiment. On the outer end of this pipe there was an elbow which carried an indicator cock to be used for draining the pipes if necessary. It was found that, with covered pipe, there was but little condensation. Four lengths of half inch pipe were used as in other experiments. In taking cards steam was first admitted to the long pipe, the pipe was allowed to warm and was drained, then a diagram was taken. Next, the gate valve was closed and a diagram taken, as quickly as possible, on the short connection, the long pipe being cut off by the gate valve. These cards, taken on the short connection, were assumed to be true base or cylinder cards. In some cases separate cards were taken, and in the others the cord would be shortened and two diagrams taken on one card for measurement with a planimeter. In many cases two diagrams, one taken over the other, were secured to show the difference in the diagrams in a graphical way. In the experiments on the Ball engine it will be noticed that the speed is not in all cases the same. During the time between the two series of experiments, the speed was slightly increased as it had been a little too slow for the purposes of the shops. Experiments were made on the Ball engine while it was running under actual conditions furnishing power to the shops. This will account for a slight change in the areas of similar cards. But as a part of the day was chosen when but little student labor was being done, the load was fairly constant. The two cards taken for comparison show differences nearly uniform, owing to the fact that with two operations the two cards could be taken in so short a time that but little change was liable to occur.

The experiments on the Robinson engine were exactly the same as on the Ball engine, except the speed was regulated to sixty and one hundred and twenty revolutions per minute, and the power was absorbed by a rope friction brake, which has been described.

Table A gives results of experiments on the Ball engine to determine the effect of clearance beyond the indicator. In this set of experiments the load was such as to give a short cut-off. The per centage of difference is based on the short connected or cylinder card. The cards were taken under actual running conditions of the engine, at a speed of two hundred and eighty five revolutions per minute, and with abboiler pressure which did not vary greatly from seventy pounds gage pressure.

Table B gives results of experiments on the Ball engine for the effect of clearance beyond the indicator. In these experiments the cut-offs were greater than in those in Table A. These were also taken under actual running conditions and the speed was two hundred and ninety revolutions per minute. By a comparison of Tables A and B it will be seen that the greater cut-offs give the greater relative differences in the diagrams.

Table C gives average results of three cards, taken under conditions similar to those which exist when the two ends of a cylinder are connected to one indicator by pipes leading to a tee placed near the middle of the side of the cylinder, with valves placed in the pipes close to the cylinder, or angle valves used at the bends near the cylinder. This is a method of piping frequently found when but one indicator is available, but it has given way somewhat of late to the better arrangement of using a three way cock, thus avoiding the additional error due to the open pipe beyond the indicator. In these experiments, instead of a short nipple, an eight inch length of half inch pipe lead from the cylinder to the tee, on which was placed the indicator and beyond which was the gate valve and clearance pipe, as in other experiments. Otherwise the experiments were like those in Table B.

Tables for the Robinson engine, giving effect of clearance beyond the indicator, are similar to those for the Ball engine. Experiments were performed with springs of a scale of forty pounds per inch and twenty pounds per inch. These results differ somewhat, as will be seen in the tables.

A few cards have been selected from each experiment. They represent well the average difference due to the pipes.

OBSERVATIONS AND CONCLUSIONS.

Experiments on effect of clearance pipe beyond the indicator.

In experiments on the Ball engine the cut-off evidently has an influence on the resulting diagrams. Greater cut-offs give the greater relative differences when other conditions are the same.

In all cases on the Robinson engine, and in most cases on the Ball engine, the effect of clearance pipe was to diminish the area of the diagram. But in two cases on the Ball engine, as will be seen in the tables, the resulting diagrams were larger with the clearance pipe beyond the indicator. In one of these cases a five foot clearance pipe was used, and in the other the connection to the indicator was eight inches in length and a clearance pipe two and one-half feet long was used beyond the indicator.

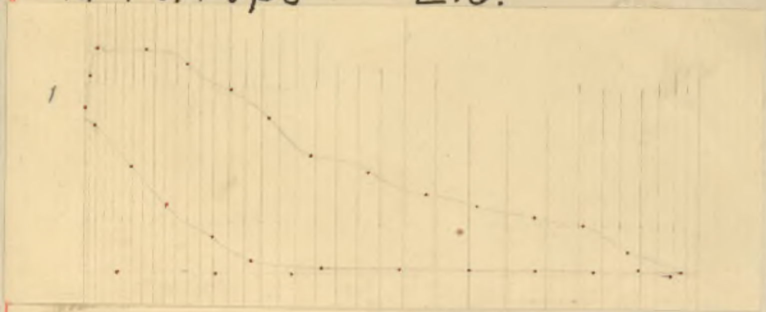
For comparatively short lengths of pipe the error in the mean effective pressure is not great, but the form of the card is changed. In cards on the Robinson engine it will be noticed that the clearance pipe card is entirely within the other.

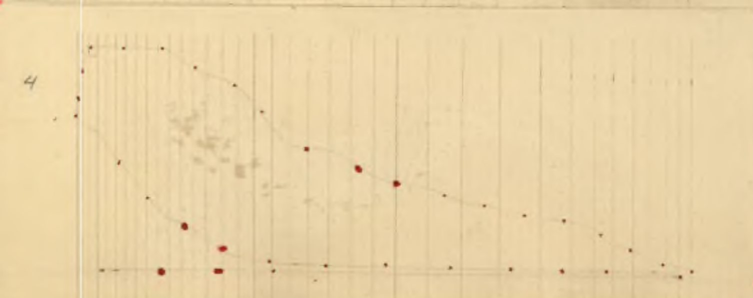
Since in nearly every case there is a difference due to a clearance pipe beyond the indicator, only direct connections should be used with no open pipe beyond the indicator.

A.

Straight Pipe Cards From Ball Engine

1¼ Ft. Pipe L.C.



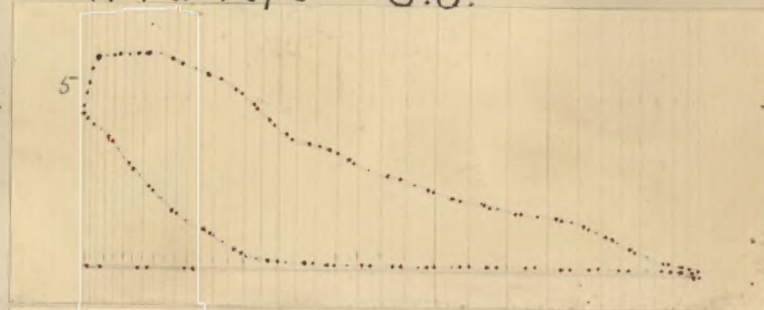


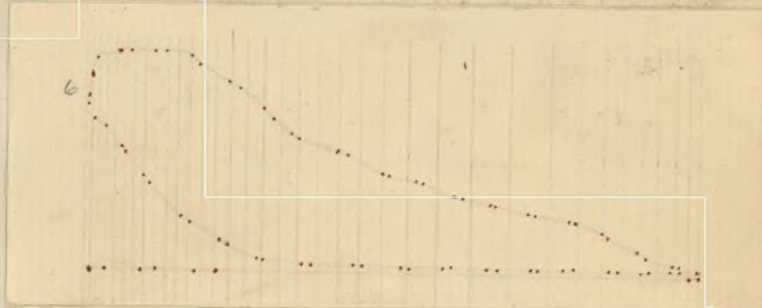
R.P.M. = 285

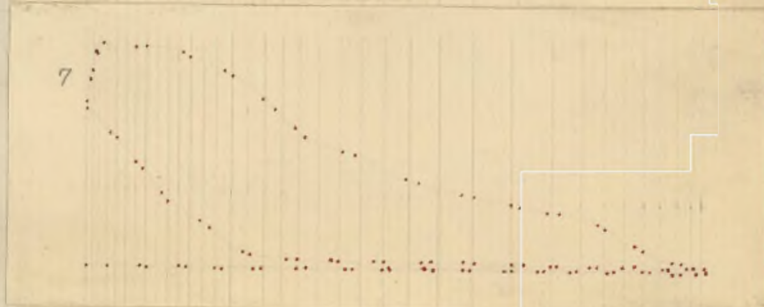
B.P. = 70 lbs.

Spring 50

1¼ Ft. Pipe S.C.



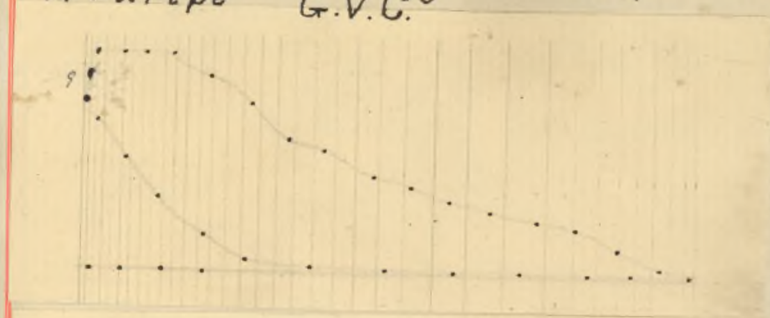




B.

Straight Pipe Cards From Ball Engine

1¼ Ft. Pipe G.V.C.

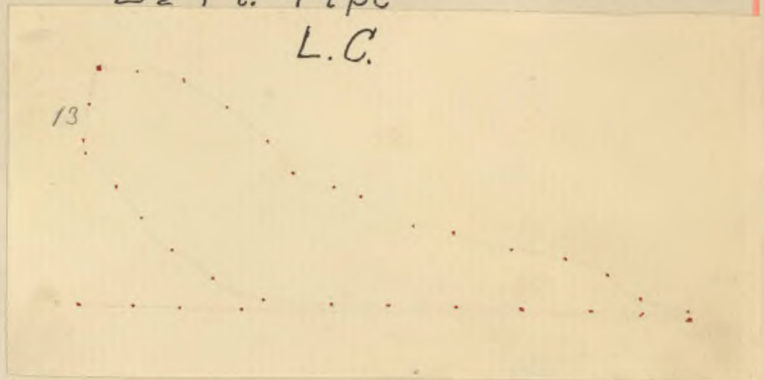


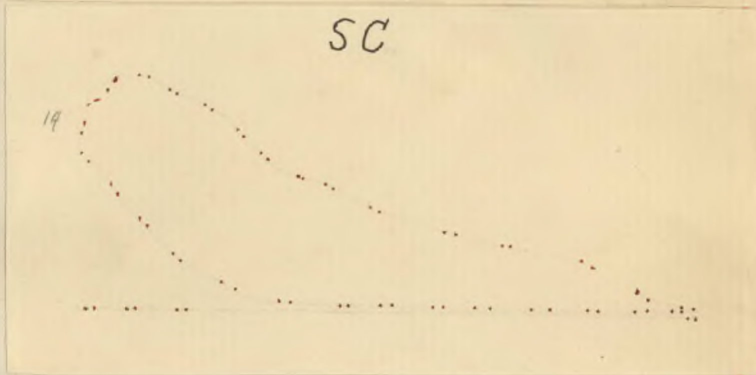
R.P.M. = 285

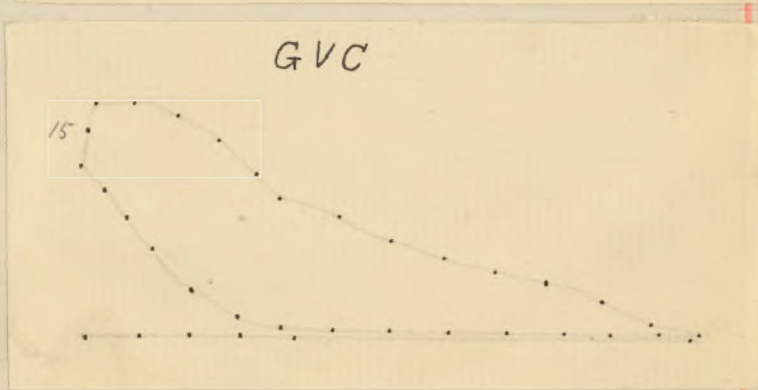
B.P. = 70 lbs.

50 Spring

2½ Ft. Pipe







Straight Pipe Cards From Ball Engine

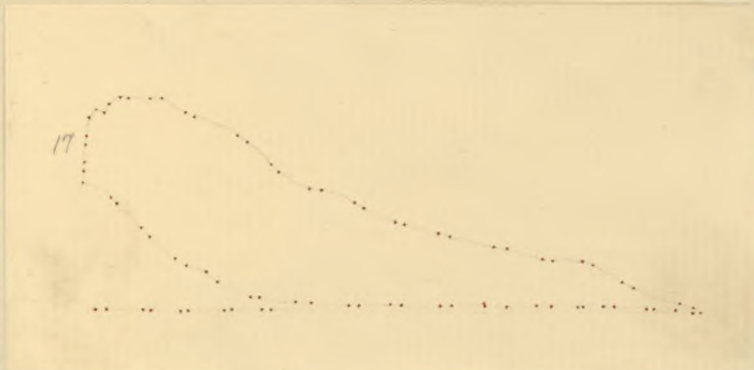
5 Ft. Pipe

RPM = 285

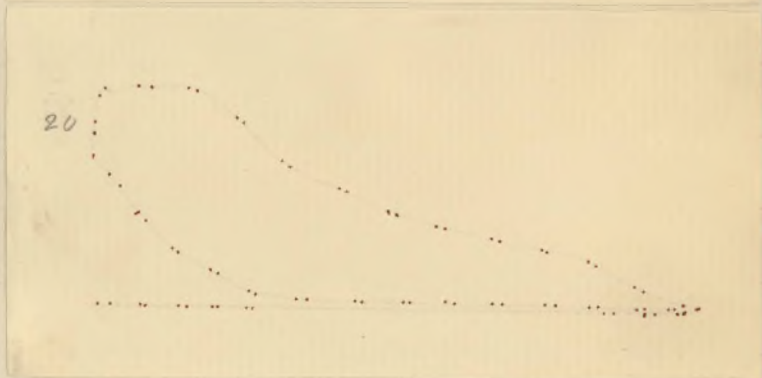
BP = 70 lbs.

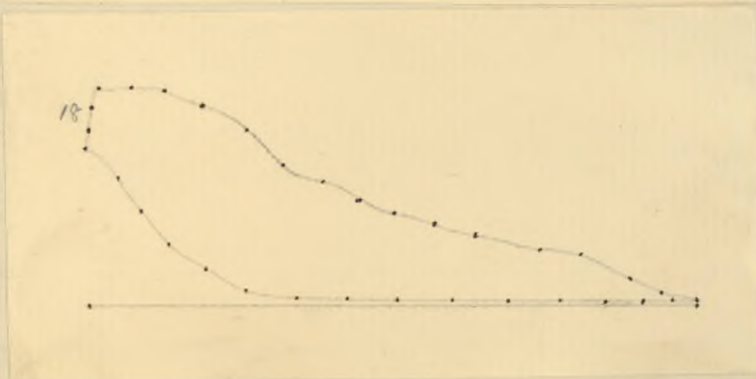
50 Spring

LC

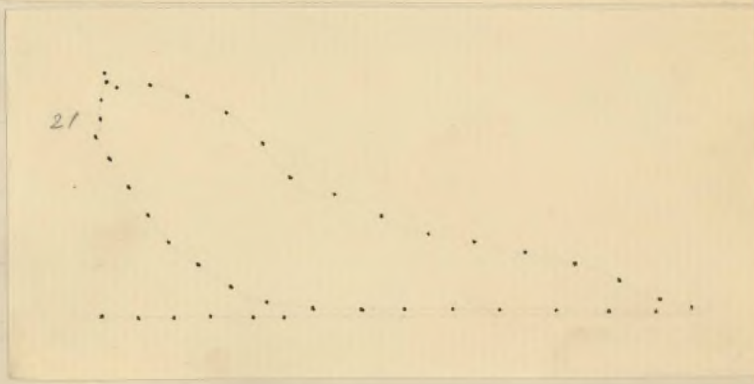


SC





GVC



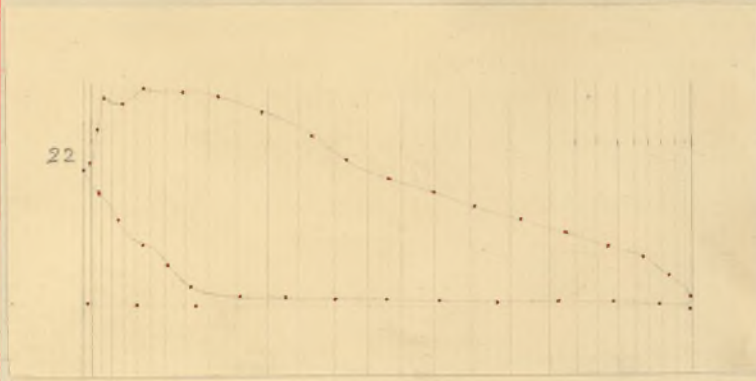
D.

Straight Pipe Cards From Ball Engine
10 Ft. Pipe

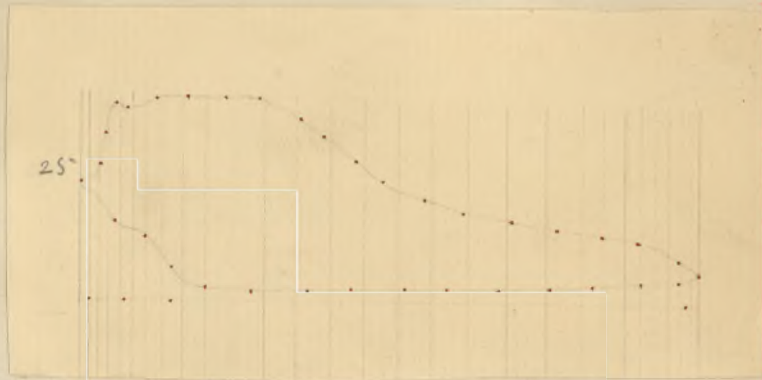
R.P.M. = 285

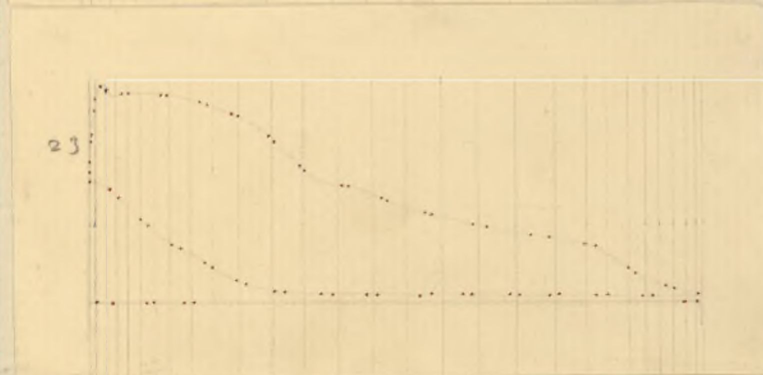
B.P. = 70 lbs.

50 Spring



L C





S C

G.V.C.

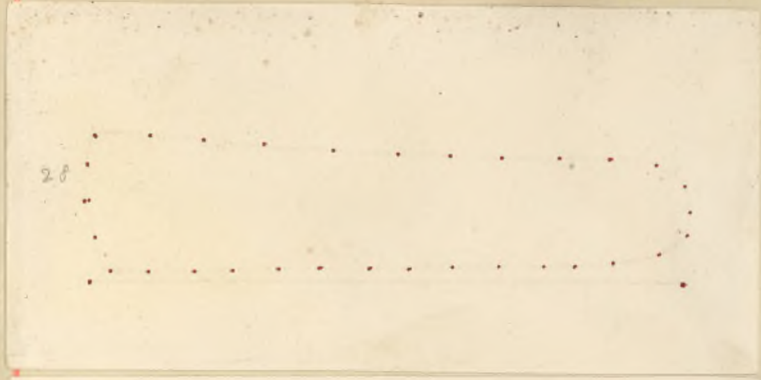
Straight Pipe Cards From Robinson Engine

$2\frac{1}{2}$ Ft. Pipe

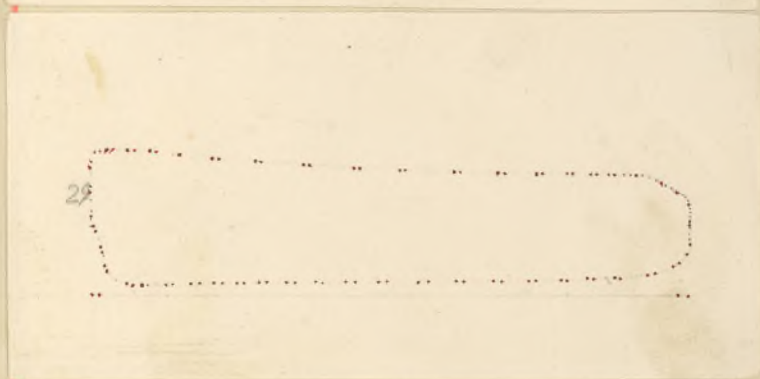
R.P.M. = 60

B.P. = 70 lbs.

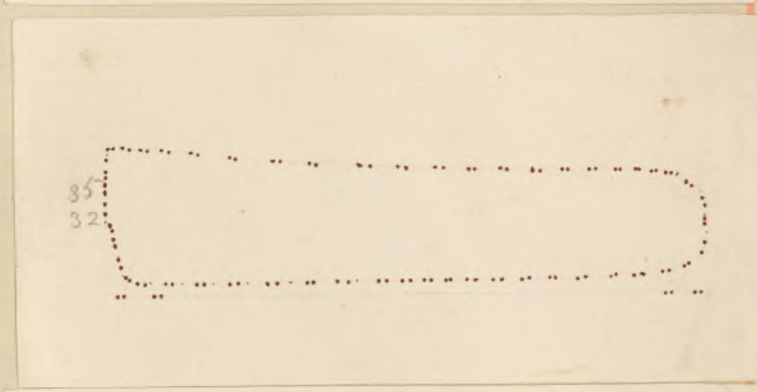
40 Spring

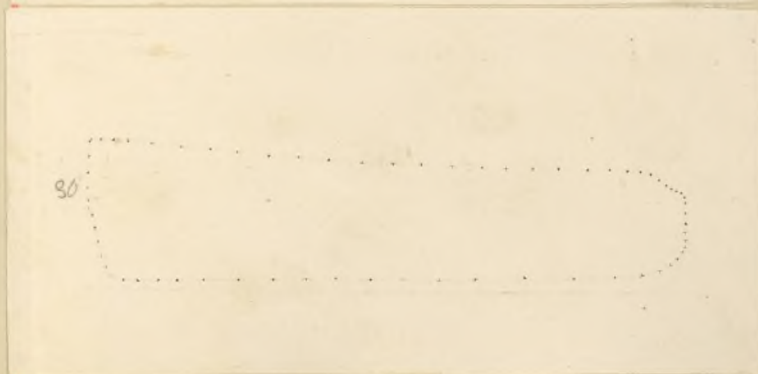


L.C.

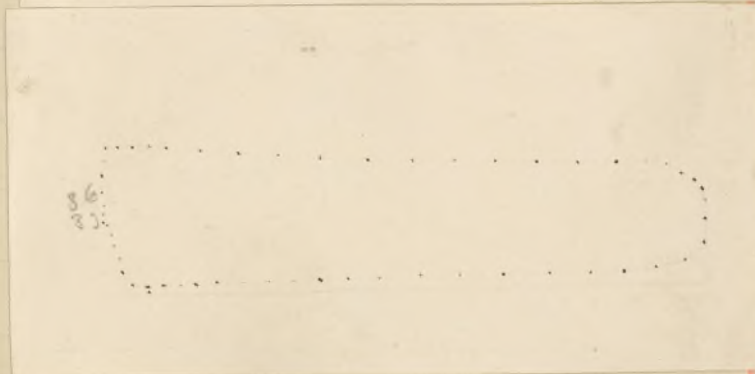


S.C.





G.V.C.

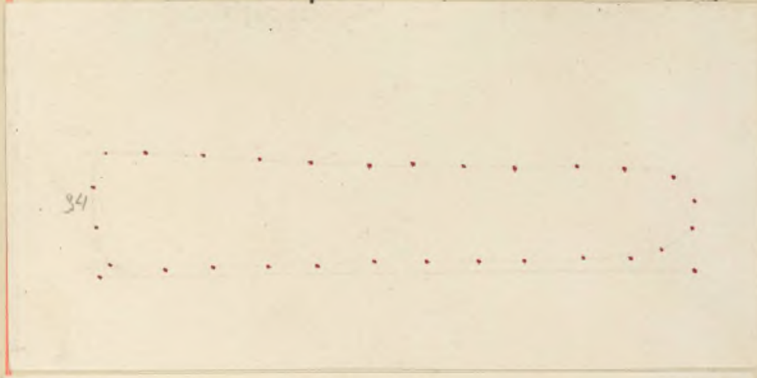


Straight Pipe Cards From Robinson Engine

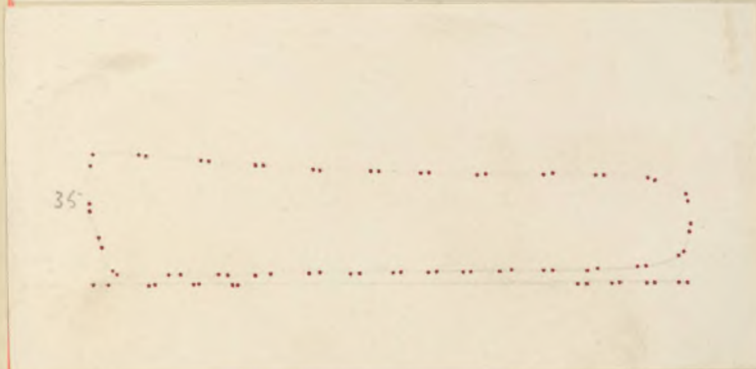
RPM = 60
BP = 70 lbs.
40 Spring

5 Ft. Pipe

LC



SC

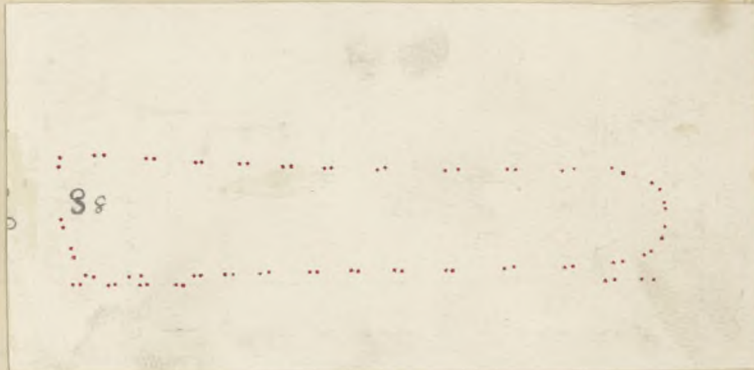


GVC

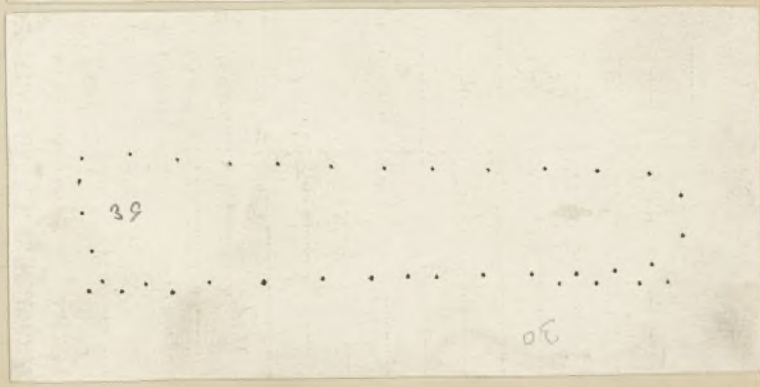
10 Ft Pipe

LC

SC



GVC



G.

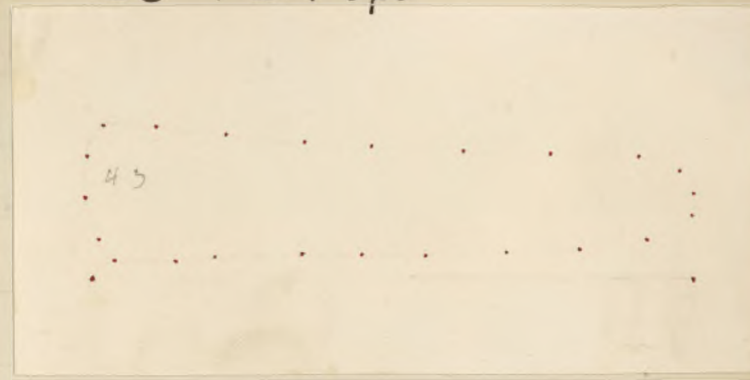
Straight Pipe Cards From Robinson Engine

1¼ Ft. Pipe — 2½ Ft. Pipe

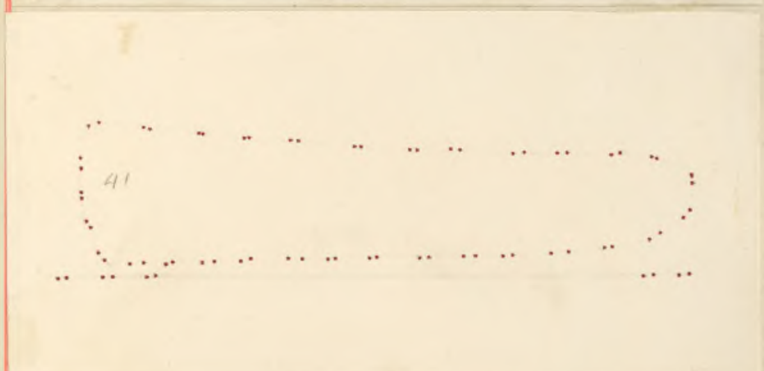
RPM = 112

BP = 70 lbs.

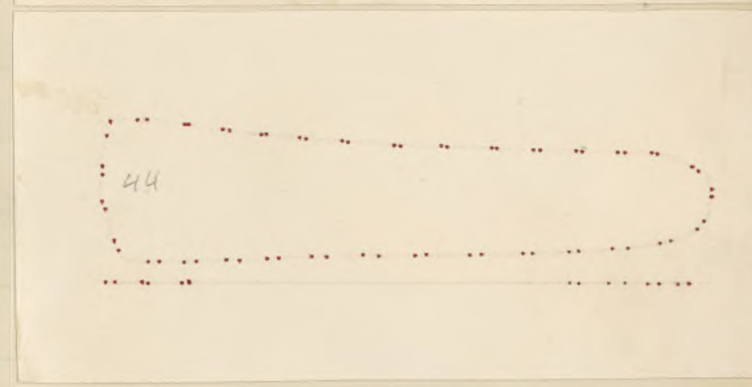
40 Spring

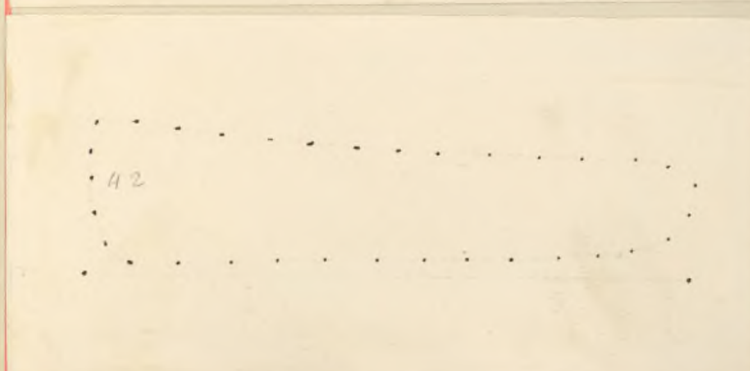


LC

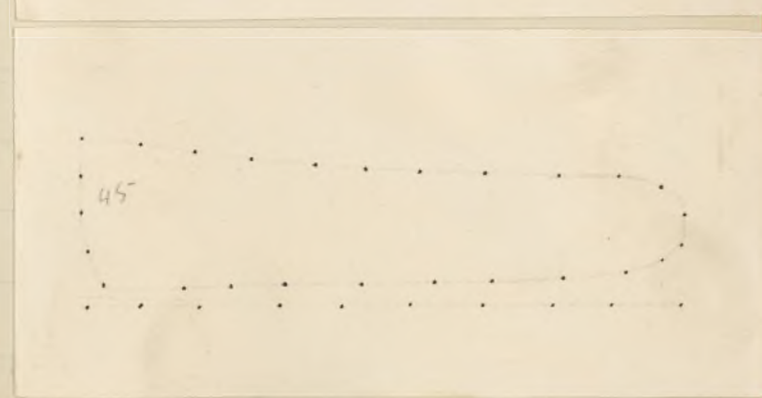


SC





GVC

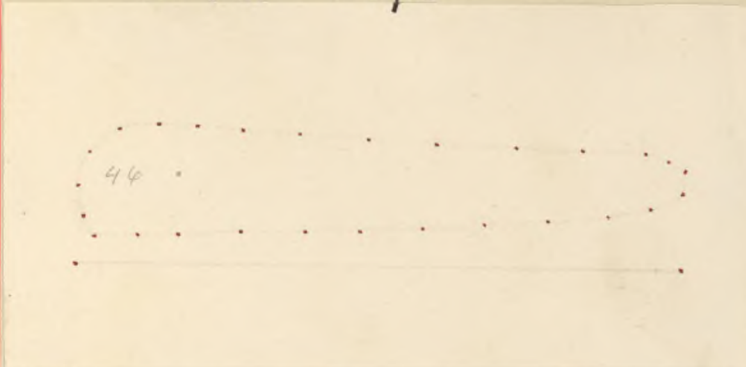


Straight Pipe Cards From Robinson Engine

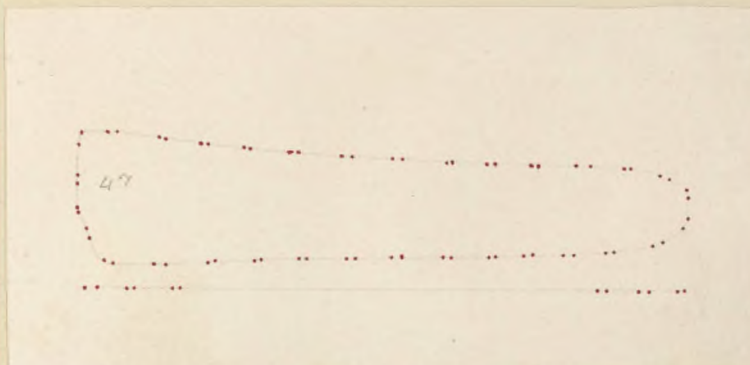
10 Ft. Pipe | 5 Ft. Pipe

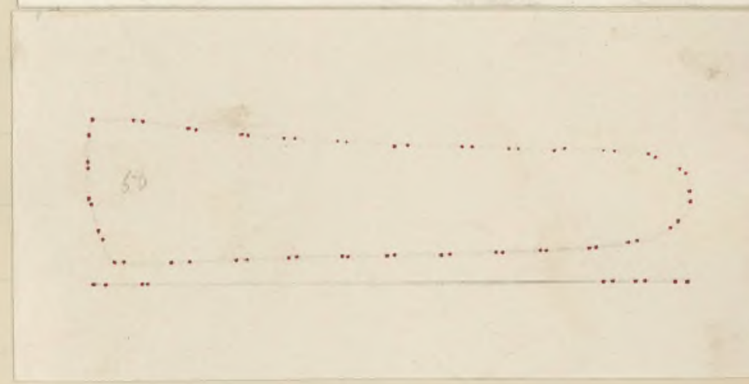
RPM = 112
BP = 70 lbs.
40 Spring

LC

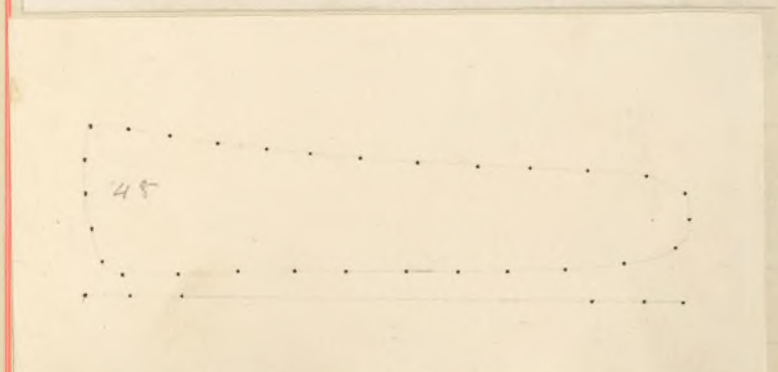


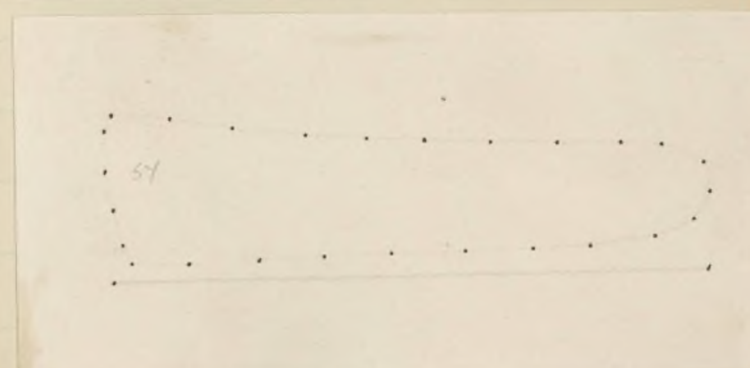
SC





GVC





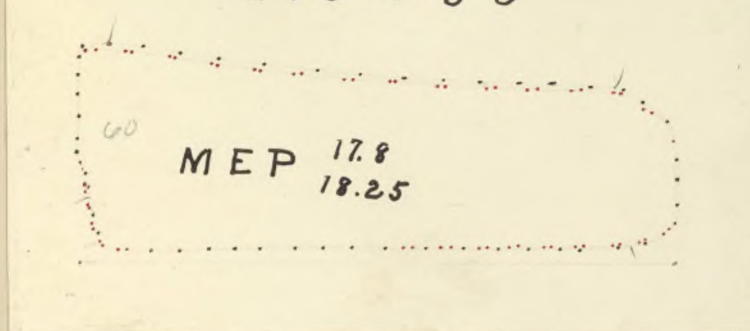
Looped Pipe Cards From Robinson Engine

RPM = 60 | RPM = 112

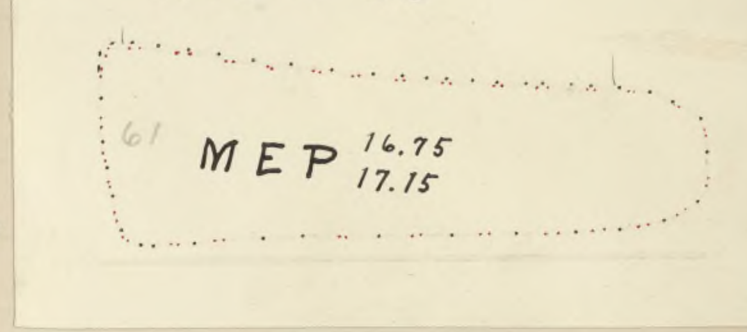
GVC & SC | GVC & SC

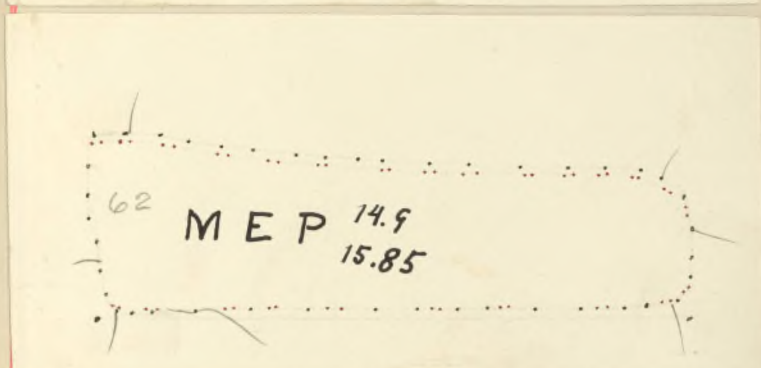
B P = 70 lbs.

20 Spring

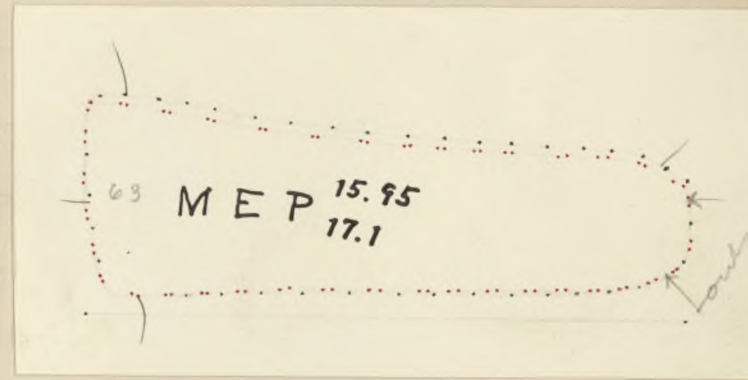


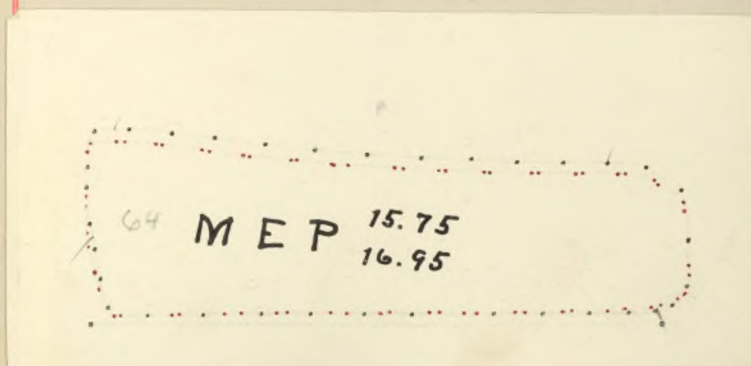
2½ Ft. Pipe



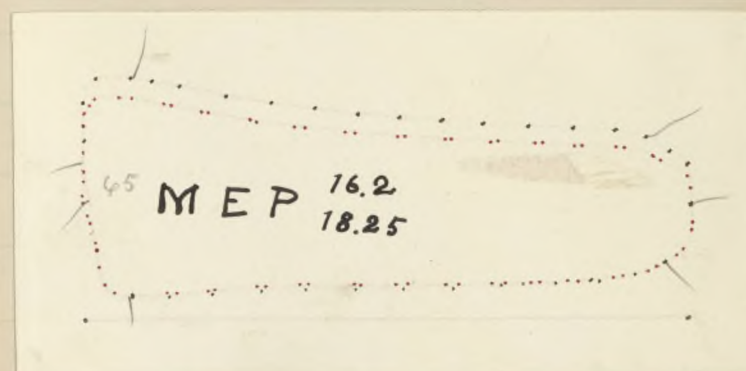


5 Ft. Pipe



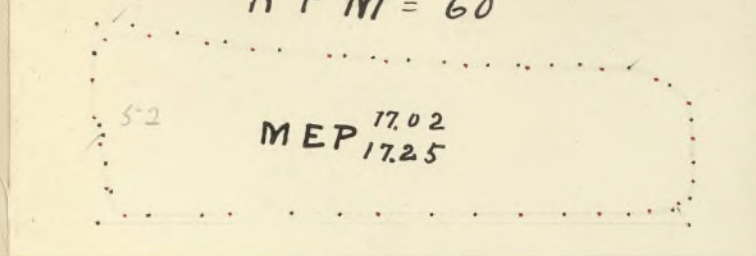


10 Ft. Pipe



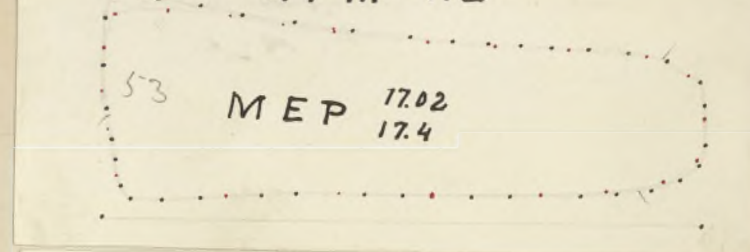
Looped Pipe Cards From Robinson Engine

GVC & LC
RPM = 60

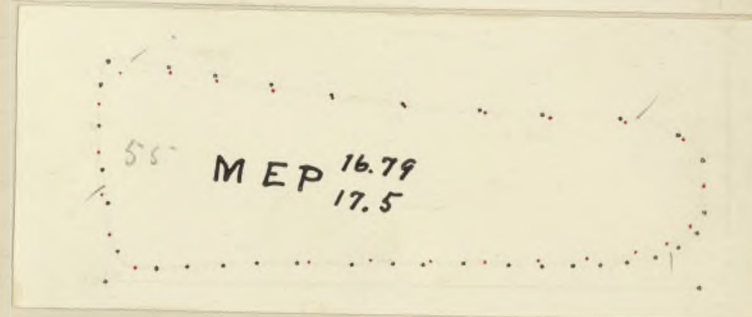


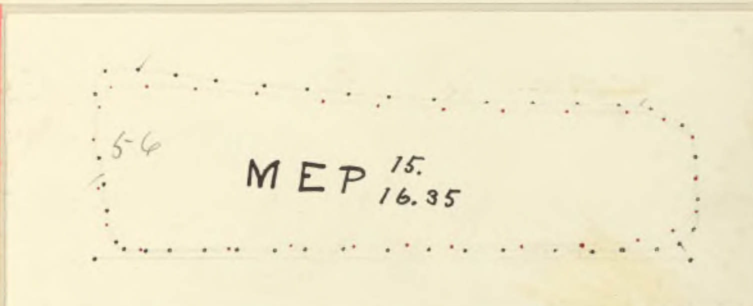
RPM = 60
BP = 70 lbs.
20 Spring
1¼ Ft. Pipe

GVC & LC
RPM = 112

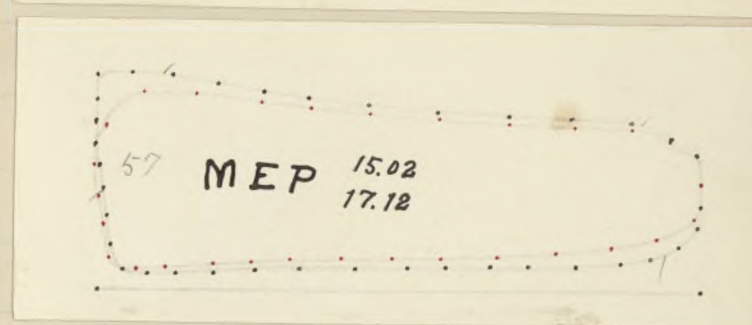


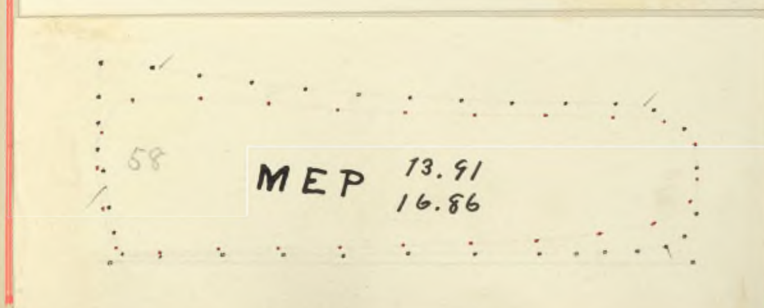
2½ Ft. Pipe



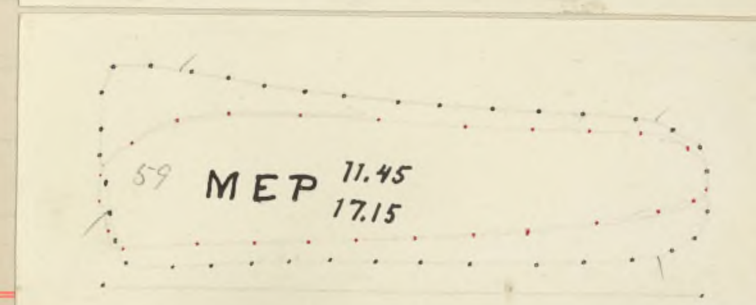


5 Ft. Pipe





10 Ft Pipe



Looped Pipe Cards From Ball Engine

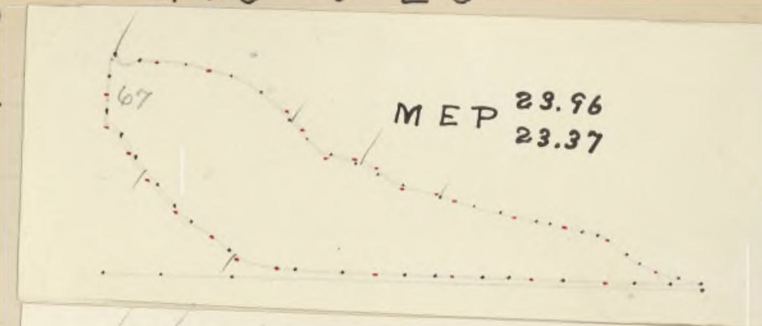
GVC & LC | GVC & LC

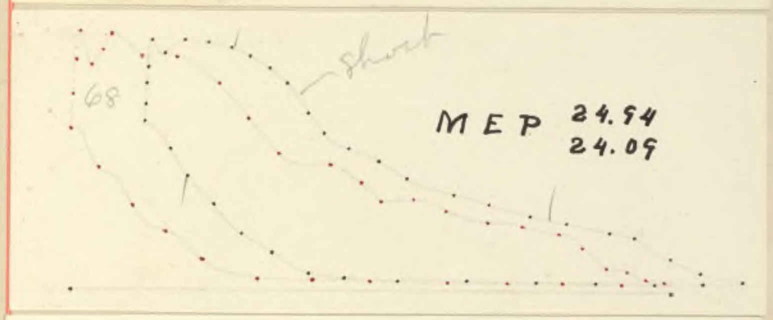
RPM = 290

BP = 70 lbs.

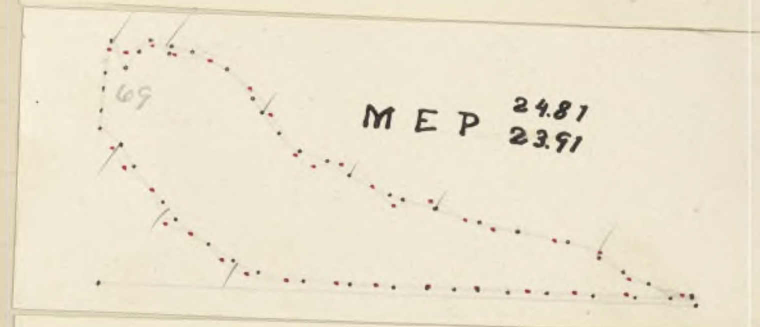
50 Spring

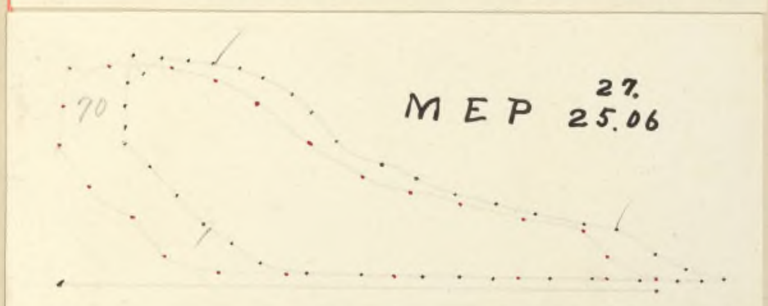
1¼ Ft. Pipe



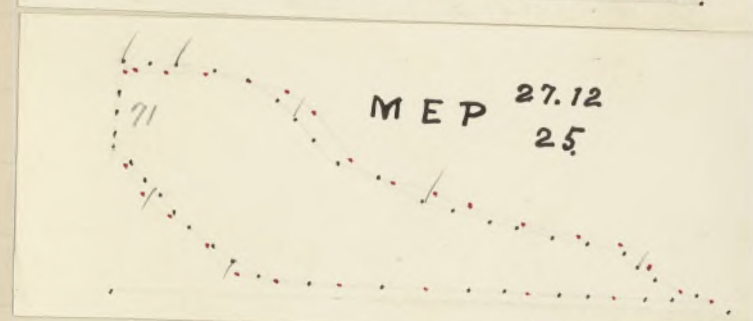


2½ Ft. Pipe

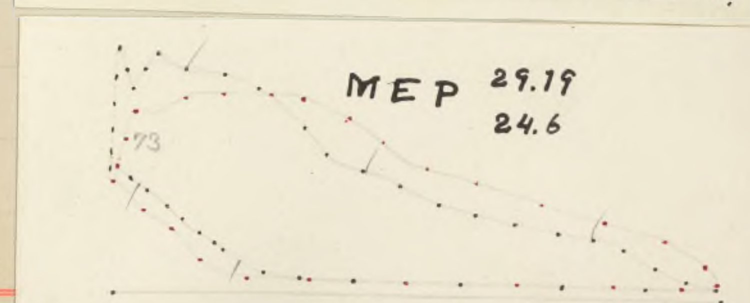




5 Ft. Pipe



10 Ft. Pipe



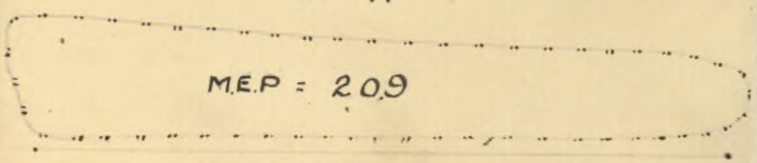
SHORT CONNECTIONS

DIFFERENT SIZES

R.P.M. = 100.

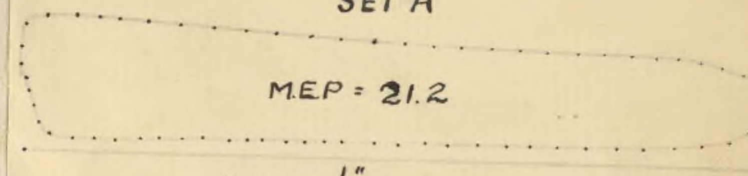
SCALE 1" = 40*

ROBINSON ENGINE
SET A



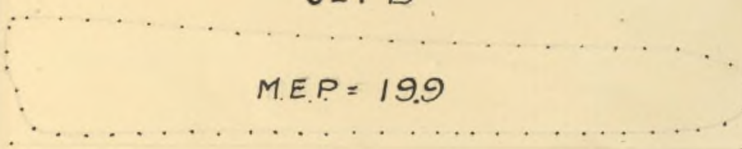
SHORT ¾" CON.

ROBINSON
SET A



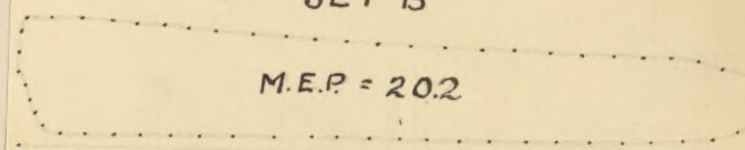
SHORT ½" CON.

ROBINSON
SET B



SHORT ½" CON.

ROBINSON
SET B

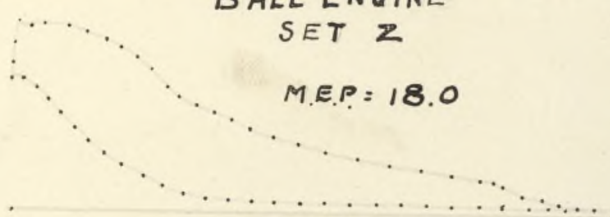


SHORT ¾" CON.

R.P.M. 290

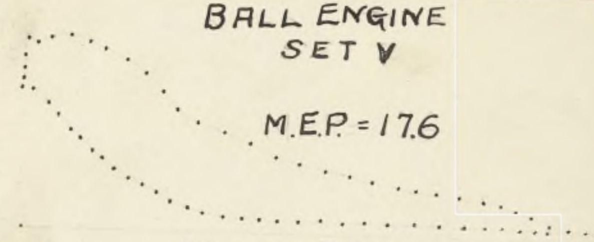
SCALE 1" = 60*

BALL ENGINE
SET Z



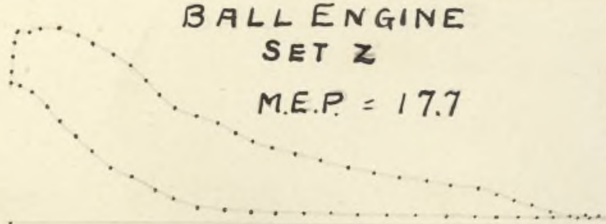
SHORT ¾" CON

BALL ENGINE
SET V



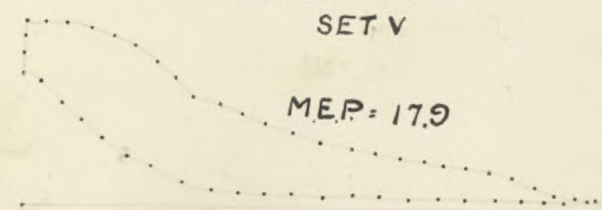
SHORT ¾" CON.

BALL ENGINE
SET Z



SHORT ½" CON

BALL ENGINE
SET V



SHORT ½" CON.

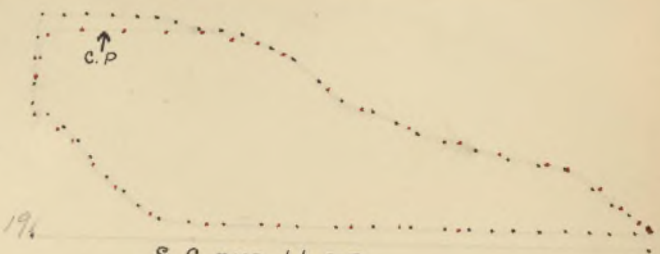
BALL ENGINE

DIAGRAMS — "SHORT CONNECTION" AND WITH CLEARANCE PIPE BEYOND INDICATOR

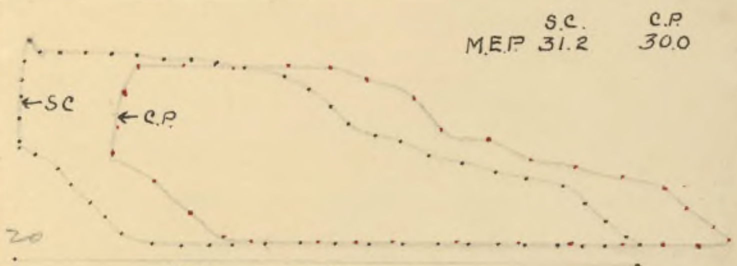
SCALE 1" = 50#

R.P.M. = 290

SC AND 1¼ C.P

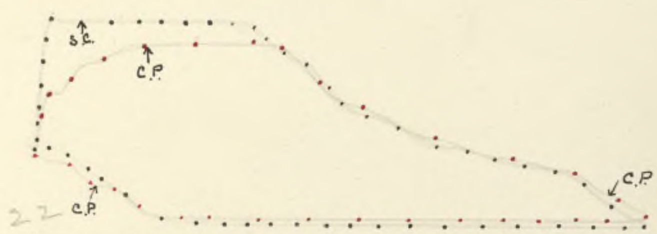


S. C AND 1¼ C.P

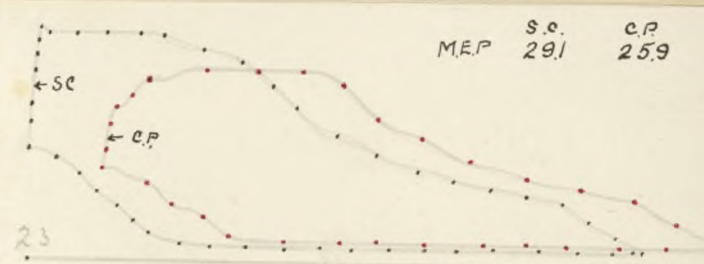


S.C. AND 2½ FT. C.P

SC AND 2½ FT. C.P

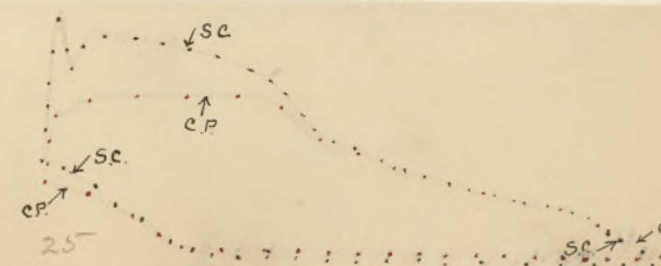


S.C. AND 5 FT. C.P



SC AND 5 FT. C.P.

S.C AND 10 FT. C.P



SC. — 10 FT. C.P.

N

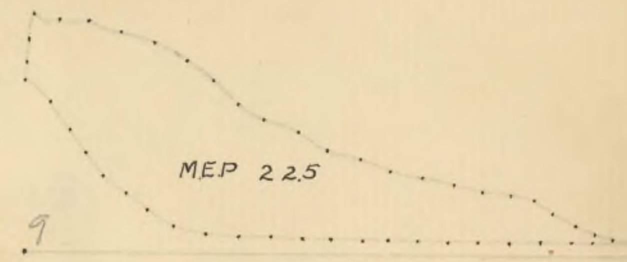
BALL ENGINE

DIAGRAMS — SHORT CONNECTION AND WITH CLEARANCE PIPE BEYOND THE INDICATOR.

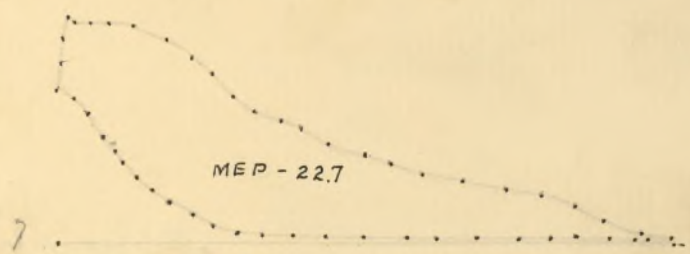
SCALE, 1" = 50#

R.P.M 285

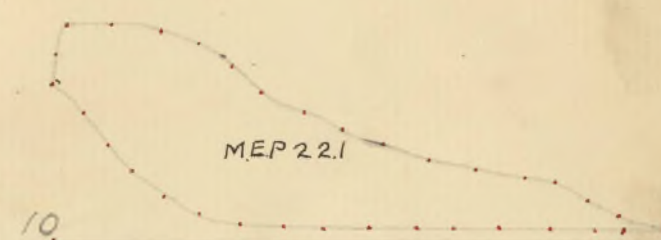
S.C. AND 1¼ FT. C.P.



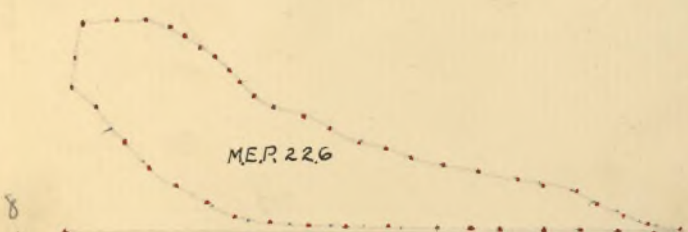
S. C SET 2



S. C. SET. 1.



2½ FT C.P. SET 2



1¼ FT C.P. SET. 1.

2½ FT C.P. AND S.C. 75# B.P.

BALL ENGINE

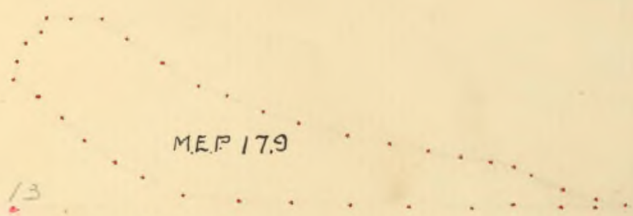
DIAGRAMS — SHORT CONNECTION AND WITH CLEARANCE PIPE BEYOND THE INDICATOR

SCALE 1" = 50#

R.P.M. 285

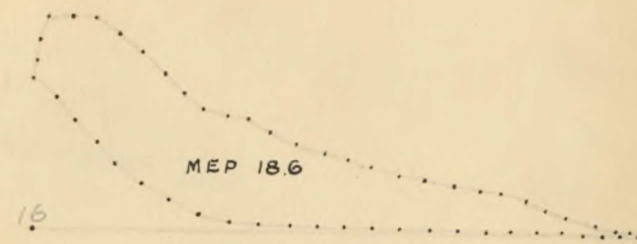
S.C. AND 5 FT. C.P.

S C AND 10 FT. C.P.



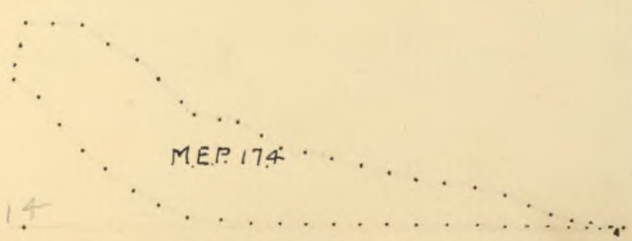
5-C.P.

SET 3



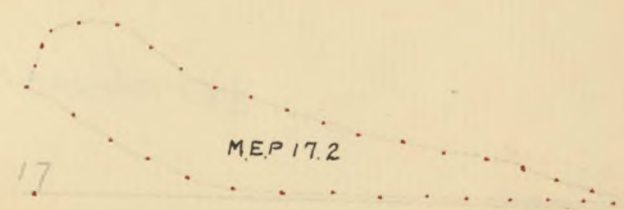
S C

SET 4



S.C.

SET 3

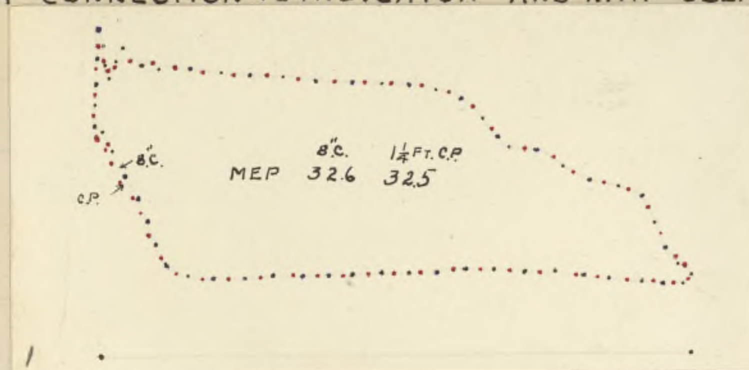


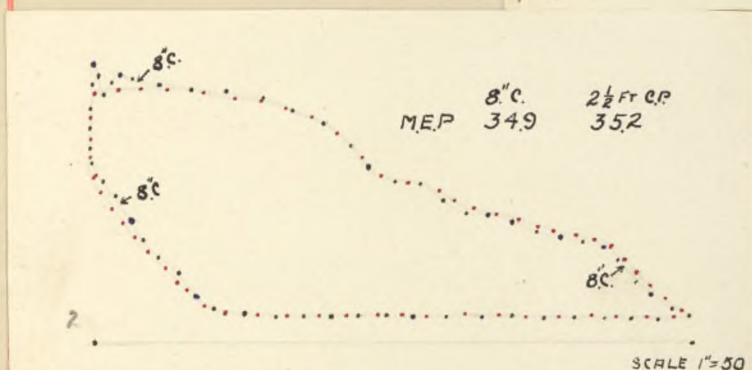
10 FT. C.P.

SET 4

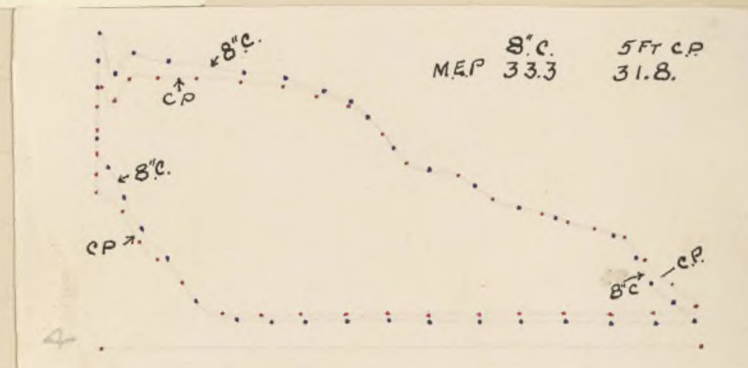
BALL ENGINE

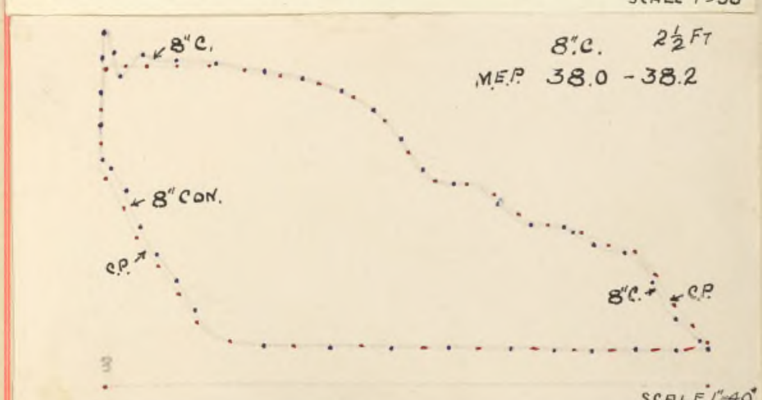
DIAGRAMS – 8 INCH CONNECTION TO INDICATOR AND WITH CLEARANCE PIPE BEYOND.

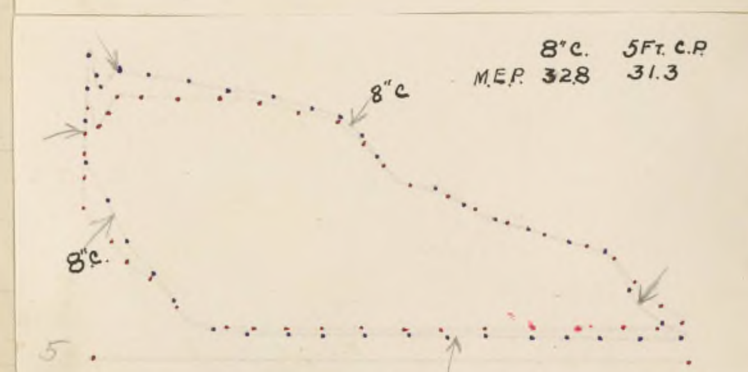




R.P.M. 290





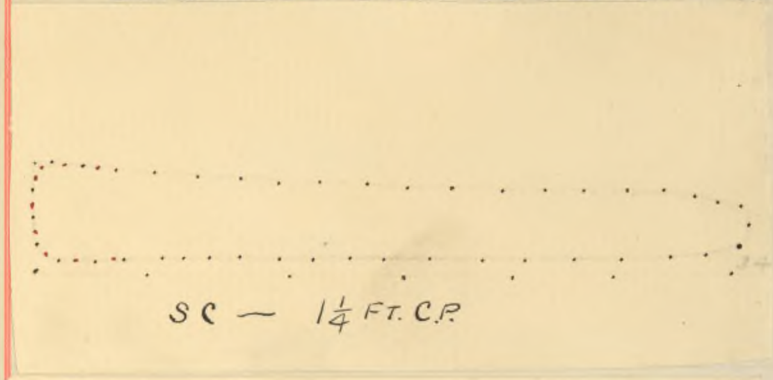


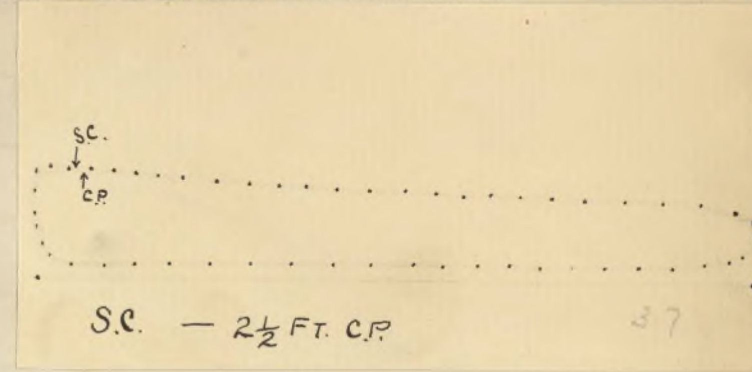
ROBINSON ENGINE

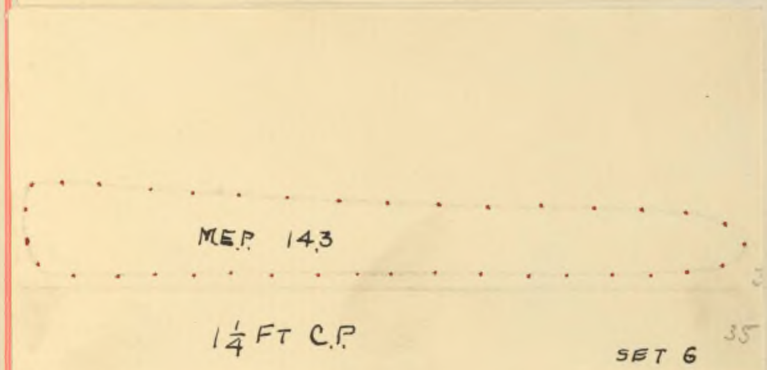
DIAGRAMS — SHORT CONNECTION — AND WITH CLEARANCE PIPE BEYOND THE INDICATOR

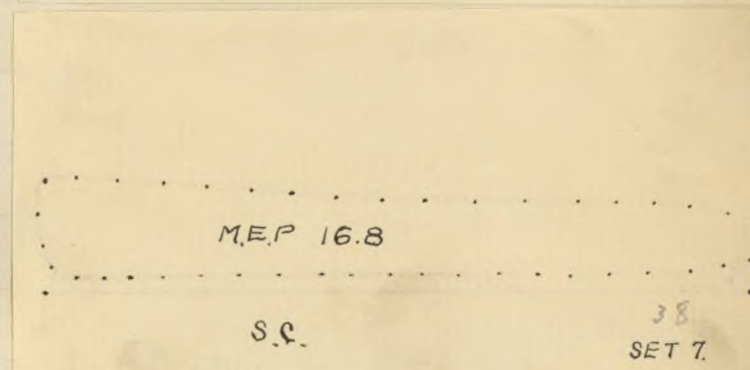
SCALE 1" = 40#

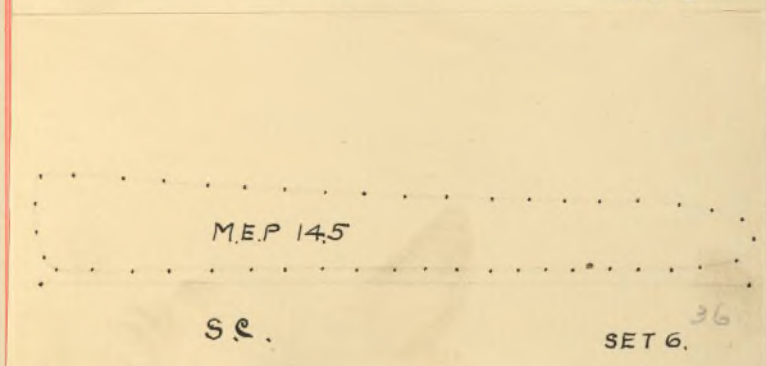
R.P.M = 120

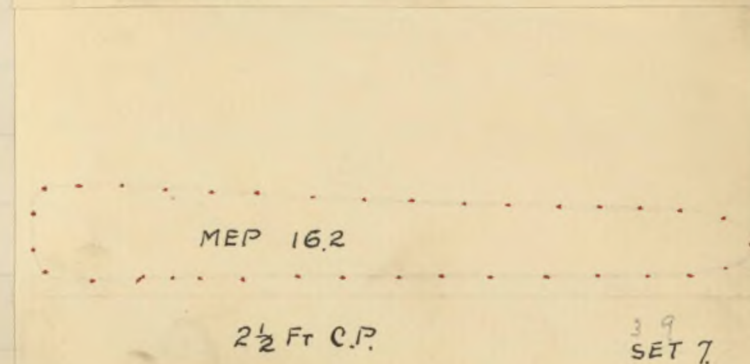












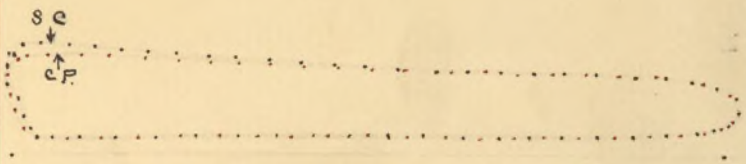
R

ROBINSON ENGINE

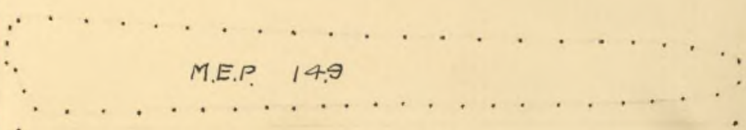
DIAGRAMS — SHORT CONNECTION AND WITH CLEARANCE PIPE BEYOND INDICATOR.

SCALE 1" = 40#

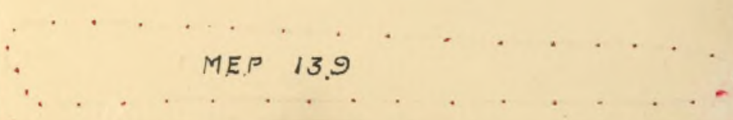
R.P.M = 120



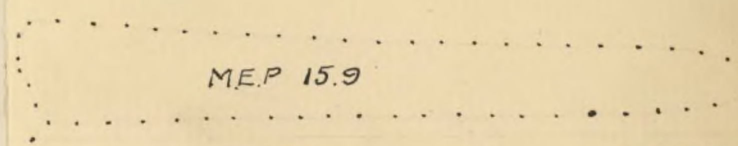
S.C. — 5 FT C.P 40



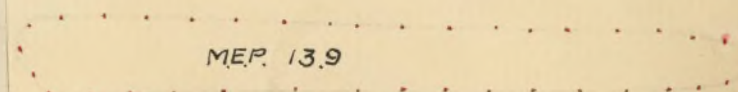
S.C. 41 SET 8



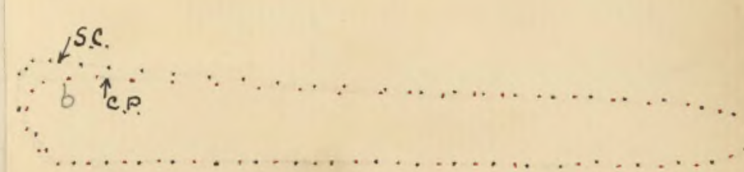
5 FT. C.P 42 SET 8.



S.C. 43a SET 9



10 FT. C.P 43 SET 9.



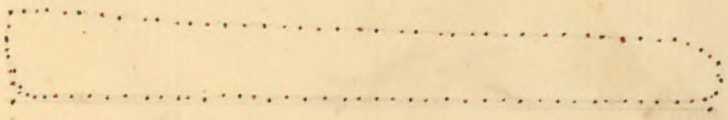
S.C. — 10 FT. C.P 44

ROBINSON ENGINE

DIAGRAMS — SHORT CONNECTION AND WITH CLEARANCE BEYOND THE INDICATOR

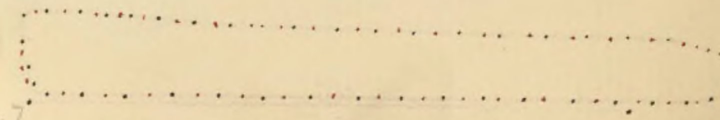
SCALE 1" = 40#

R.P.M. = 60



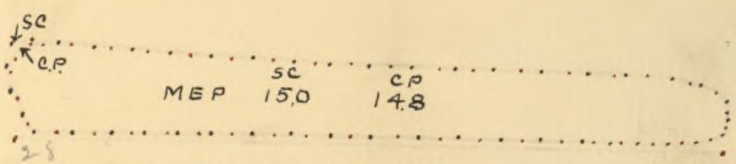
26

S.C. — 1¼ C.P.



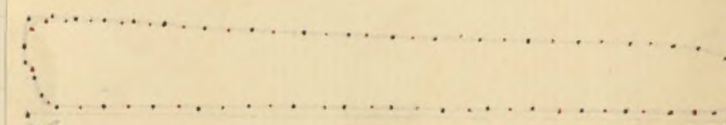
27

S.C. — 1¼ C.P.



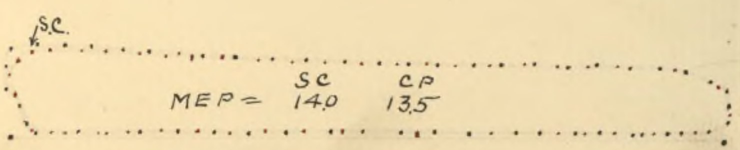
28

SC — 2½ FT C.P.



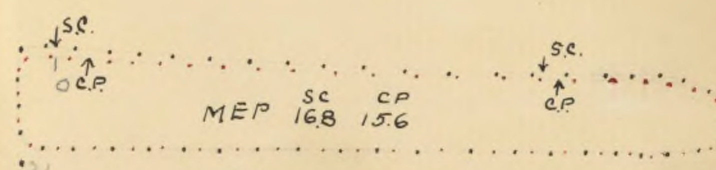
29

S.C. — 2½ FT. C.P.



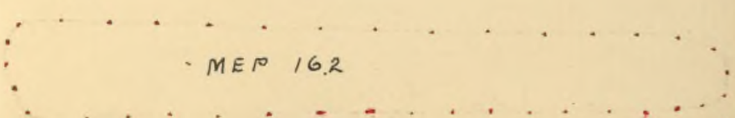
30

SC — 5 FT. C.P.



31

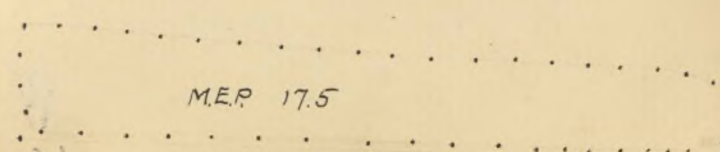
SC — 10 FT. C.P.



32

10 FT. C.P.

SET 5



33

S.C.

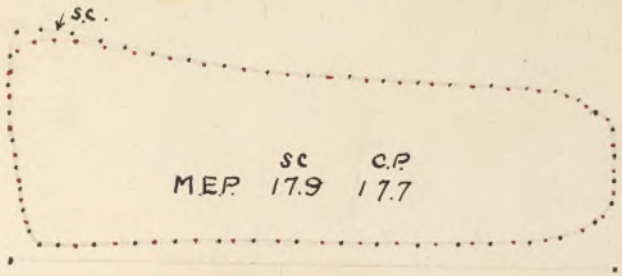
SET 5

ROBINSON ENGINE

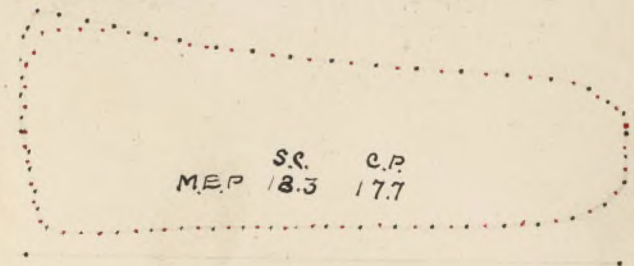
DIAGRAMS— SHORT CONNECTION AND WITH CLEARANCE PIPE BEYOND INDICATOR

SCALE 1" = 20#

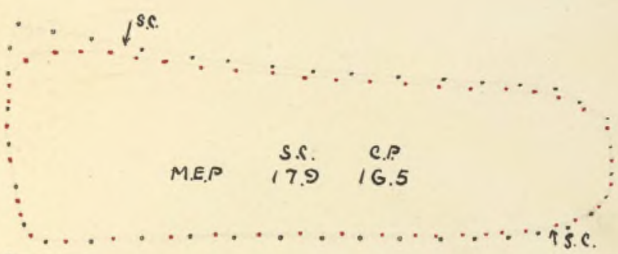
R.P.M = 120.



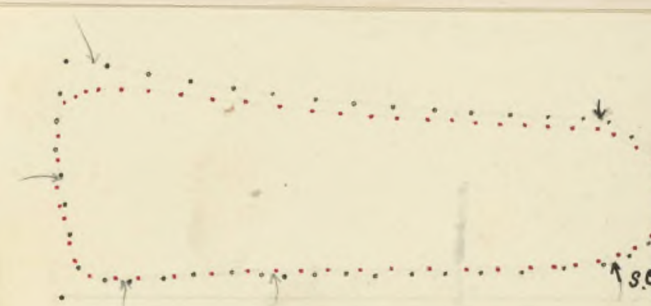
S.C. AND 1¼ FT. C.P.



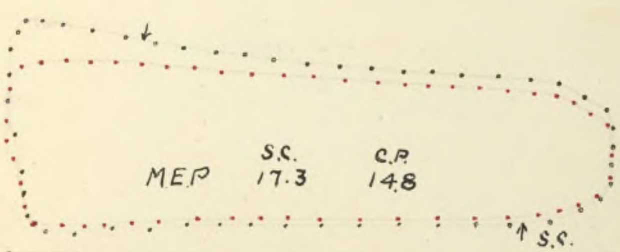
S.C. AND 2½ FT. C.P.



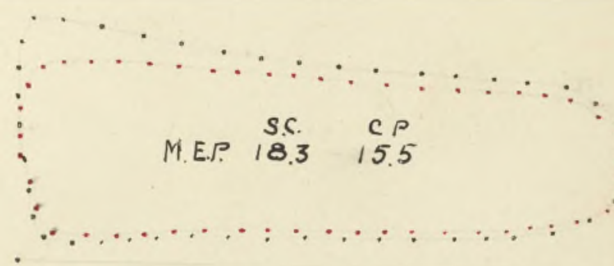
S.C. AND 5 FT C.P.



S.C. AND 5 FT. C.P.



S.C. AND 10 FT. C.P.



S.C. AND 10 FT. C.P.

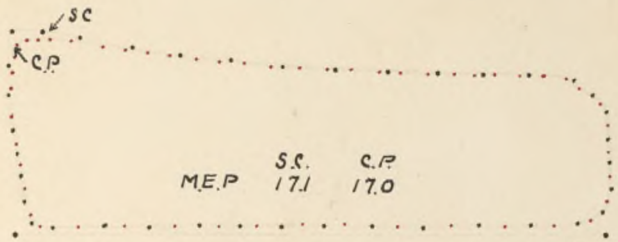
U

ROBINSON ENGINE

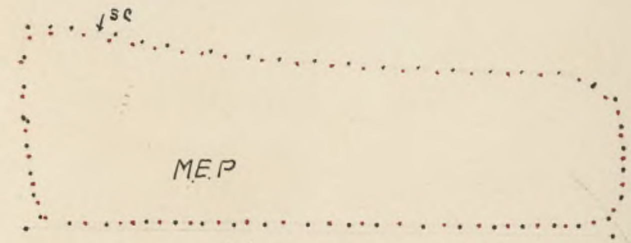
DIAGRAMS — SHORT CONNECTION, AND WITH CLEARANCE PIPE BEYOND THE INDICATOR.

SCALE 1" = 20#

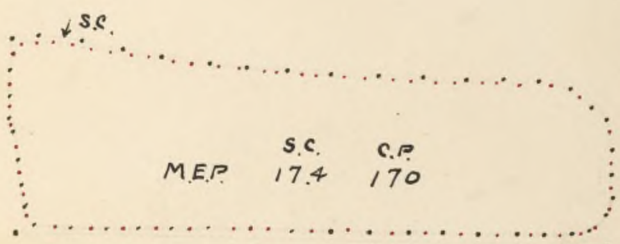
R.P.M. = 60



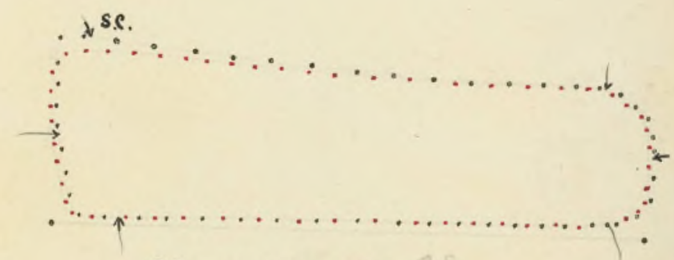
S.C. — 1¼ FT. C.P. 45



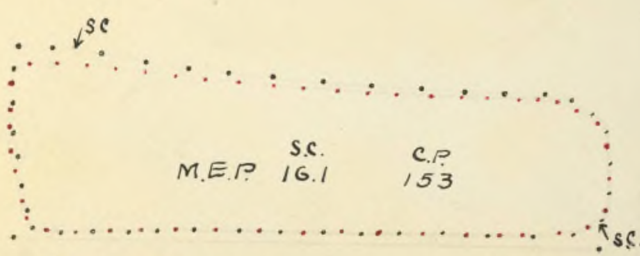
SC — 1¼ FT. C.P. 46



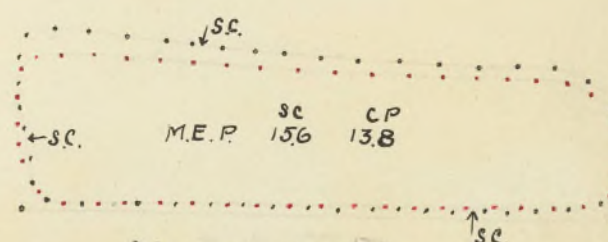
SC — 2½ C.P. 47



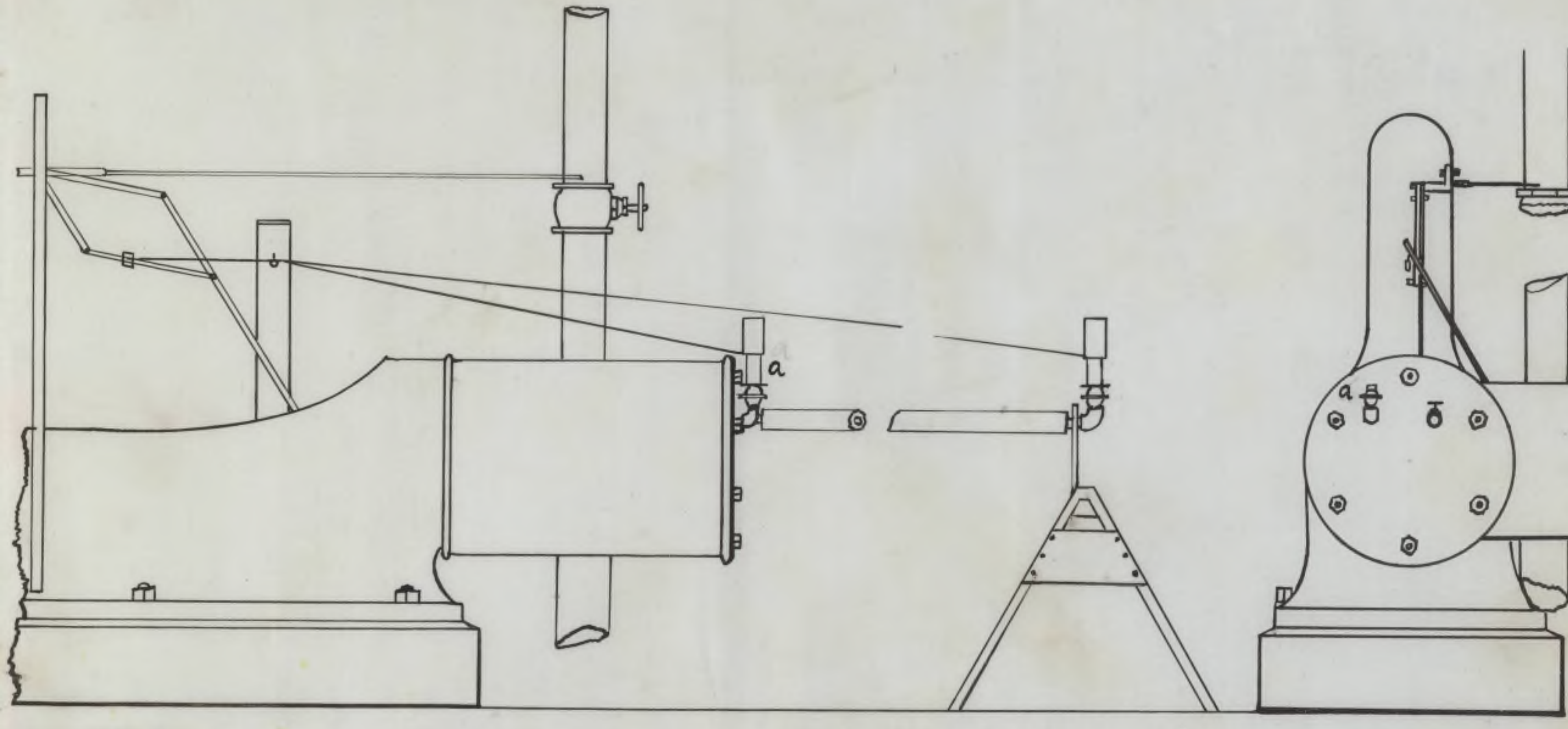
S.C. — 2½ FT. C.P. 48



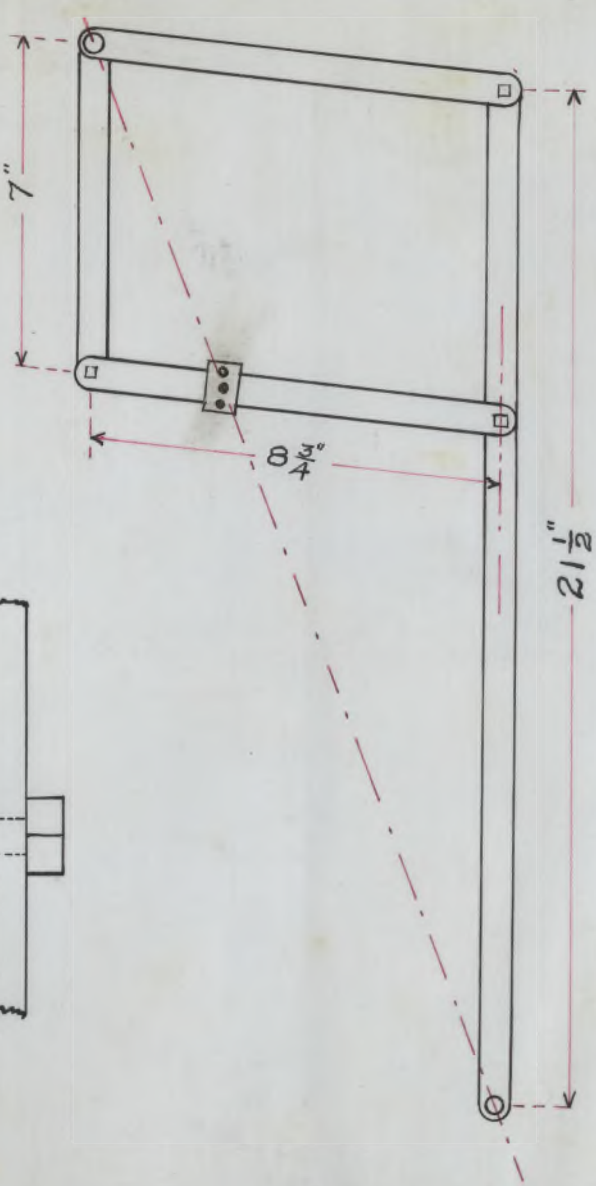
S.C. — 5 FT. C.P. 49

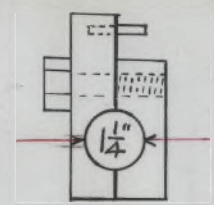


SC AND 10 FT C.P. 50

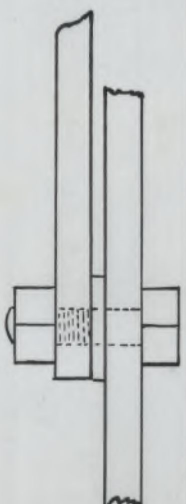


SKETCH OF RIG USED ON BALL ENGINE ~ LONG AND SHORT PIPES.~ END VIEW.





ATTACHMENT FOR PISTON ROD

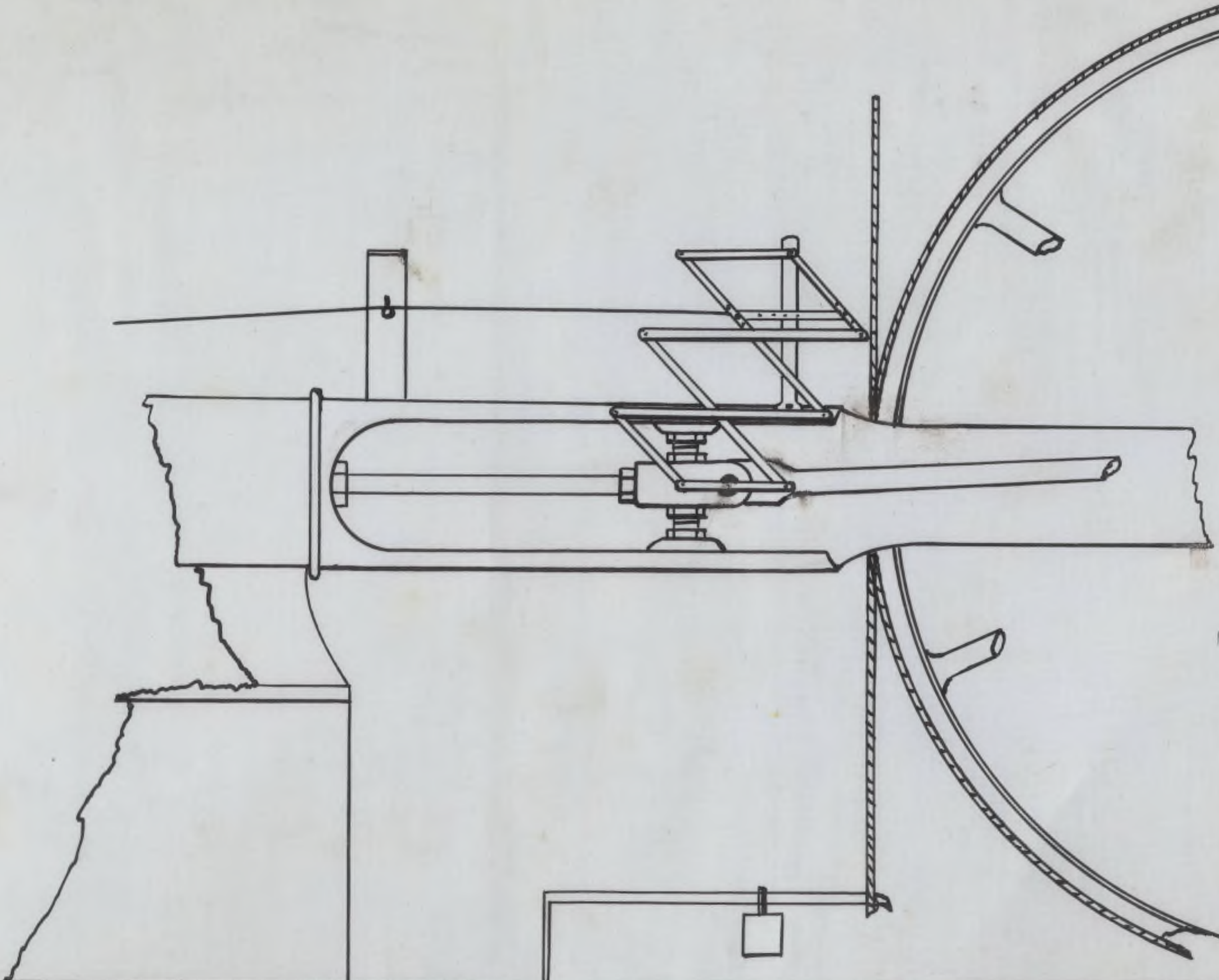


JOINT ~ FULL SIZE

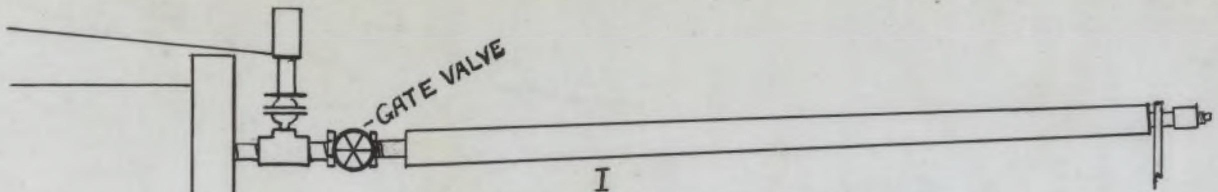
BALL ENGINE

INDICATOR RIG

SCALE 3" = 1 FT.

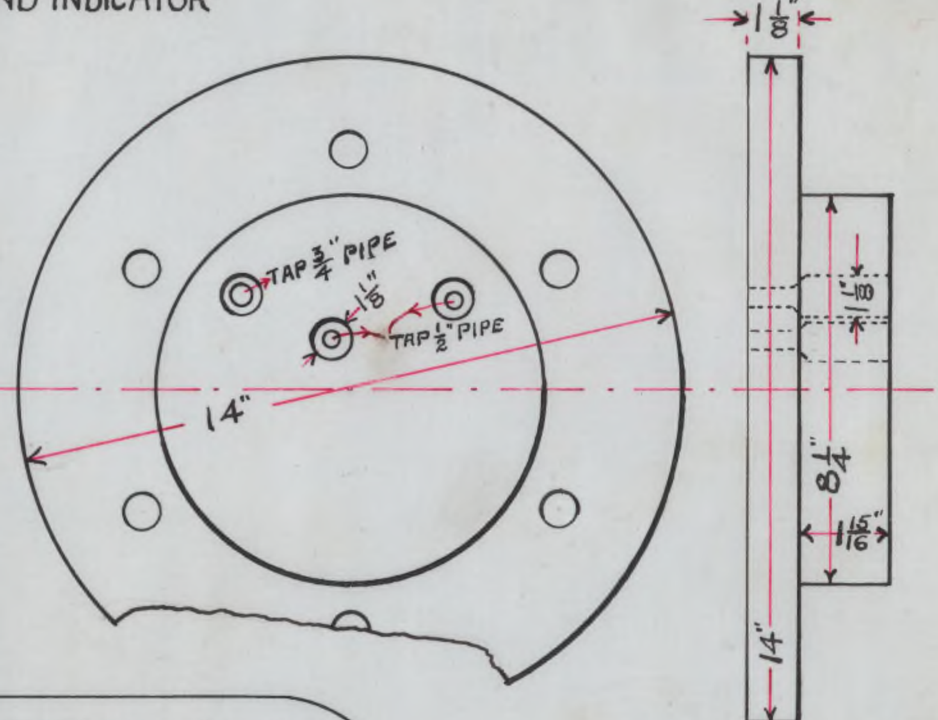


ROBINSON ENGINE RIG.



I

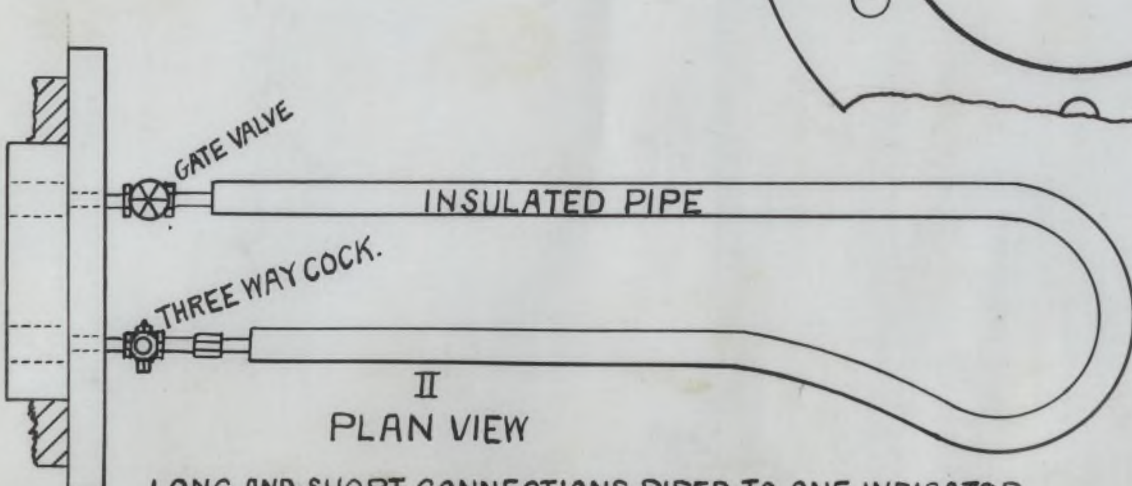
EEFFCT OF PIPE BEYOND INDICATOR



III

CYLINDER HEAD

SCALE 3"= 1 FOOT.



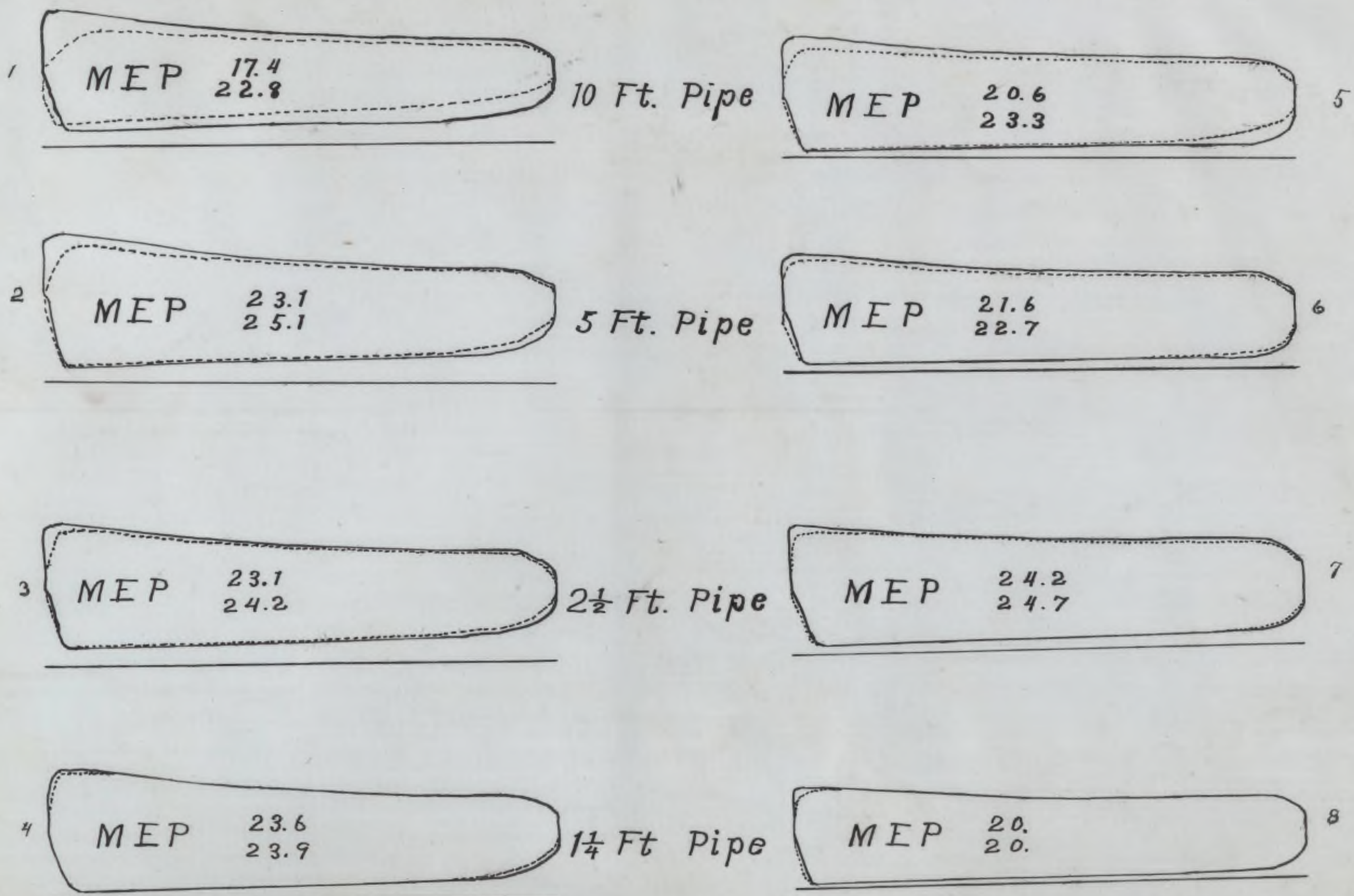
II

PLAN VIEW

LONG AND SHORT CONNECTIONS PIPED TO ONE INDICATOR.

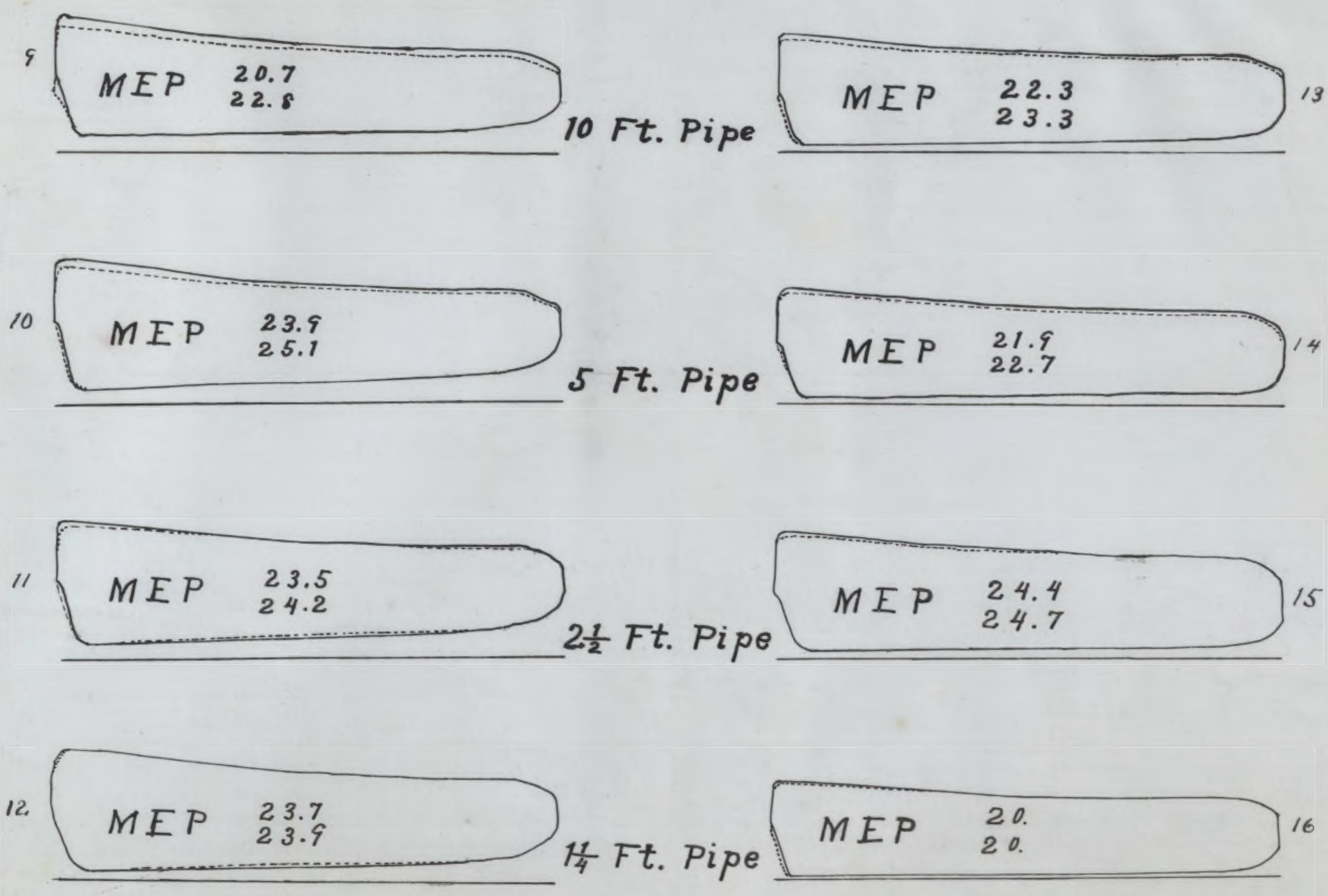
Straight Pipe Cards From Robinson Engine
GVC And LC

RPM = 112 RPM = 60



Straight Pipe Cards From Robinson Engine
GVC And SC

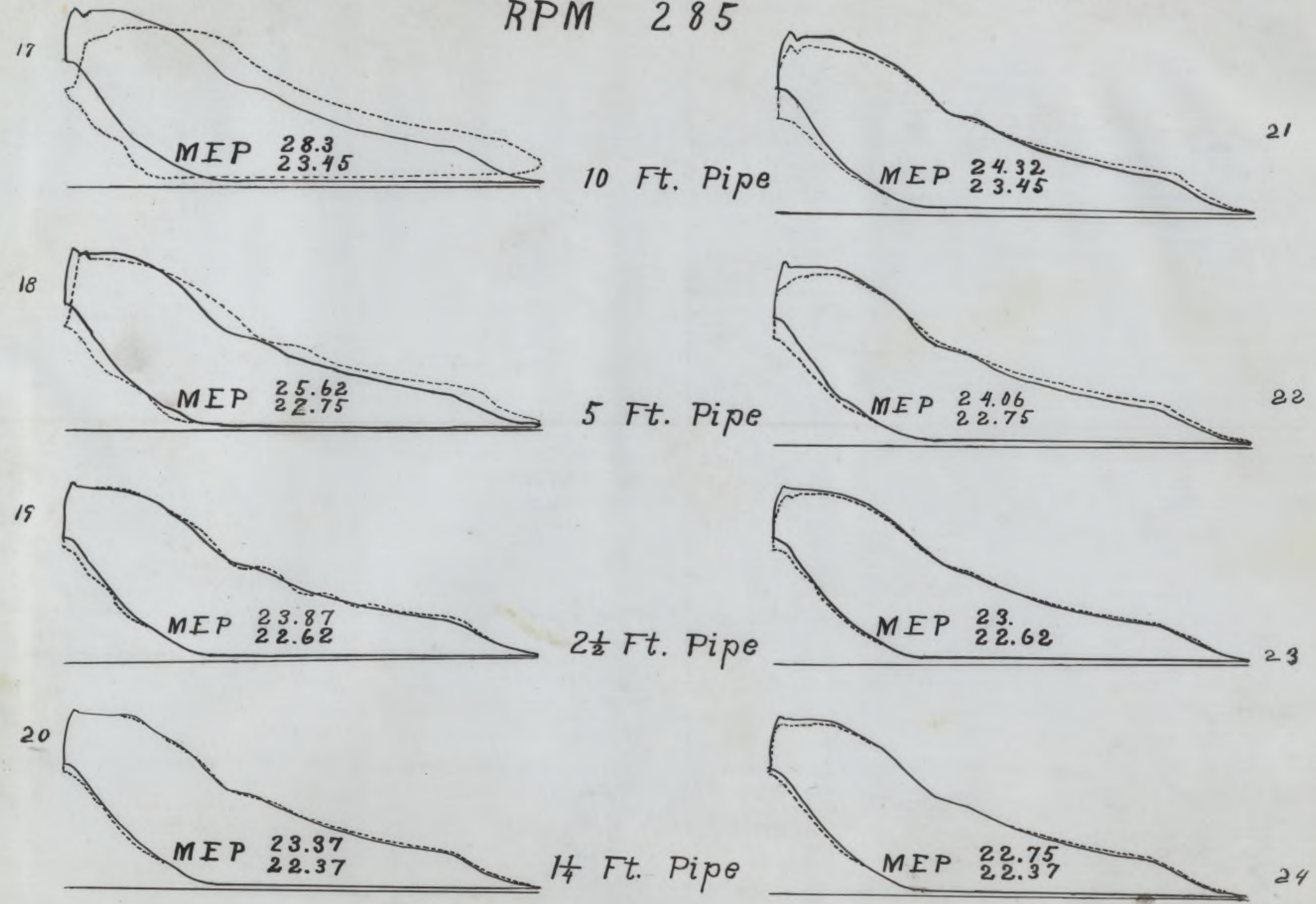
RPM 112 RPM 60



Straight Pipe Cards From Ball Engine

GVC And LC — GVC And SC

RPM 285



ROBINSON ENGINE — BOILER PRESSURE 70 lbs. — BALL ENGINE

Length of Pipe	Position of Indicator	Robinson Engine: Straight Pipe, RPM 60: MEP	Per Cent Error	Straight Pipe, RPM 112: MEP	Per Cent Error	Looped Pipe, RPM 60: MEP	Per Cent Error	Looped Pipe, RPM 112: MEP	Per Cent Error	Average of Columns 4 & 8	Average of Columns 6 & 10	Clearance: Per Cent Piston Displacement	Clearance: Surface Sq. in.	Ball Engine: Straight Pipe, RPM 285: MEP	Per Cent Error	Looped Pipe, RPM 290: MEP	Per Cent Error	Average of Columns 16 & 18	Clearance: Per Cent Piston Displacement	Clearance: Surface Sq. in.	
½ Ft.	GVC	20.		23.9		17.17		17.4				3.9	154	22.37		22.74			9.28	172	
	SC	20.		23.7	- 1.							4.39	183	22.75	+ 1.7				10.17	201	
	LC	20.		23.6	- 1.5	16.92	- 1.4	17.02	- 2.1	- .7	- 1.8	4.39	183	23.37	+ 4.5	23.56	+ 2.4	+ 4.05	10.17	201	
2½ Ft.	GVC	24.7		24.2		17.87		17.54				3.9	154	22.62		24.53			9.28	172	
	SC	24.4	-1.2	23.5	- 2.9		-2.5		-2.3	-1.85	-2.4	4.88	212	23.	+1.7				11.06	230	
	LC	24.2	- 2.	23.1	-4.6	17.03	- 4.7	16.73	-4.6	-3.35	-4.55	4.88	212	23.87	+5.5	25.49	+3.9	+4.7	11.06	230	
5 Ft.	GVC	22.7		25.1		16.25		17.06				3.9	154	22.75		25.12			9.28	172	
	SC	21.9	-3.6	23.9	- 4.8		- 5.1		- 5.4	-4.35	-5.1	5.87	270	24.06	+ 5.8				12.84	288	
	LC	21.6	-4.9	23.1	- 8.	14.94	- 9	15.15	- 11.2	-6.95	-9.6	5.87	270	25.62	+12.6	27.37	+ 8.9	+10.75	12.84	288	
10 Ft.	GVC	23.3		22.8		16.46		17.38				3.9	154	23.45		24.64			9.28	172	
	SC	22.3	-4.5	20.7	- 9.2		- 8.5		-10.5	-6.5	-9.85	7.84	386	24.32	+3.7				16.4	404	
	LC	20.6	-11.6	17.4	-23.7	13.71	-16.7	12.5	-28.1	-14.15	-25.9	7.84	386	28.8	+20.7	29.6	+20.1	+20.4	16.4	404	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22

SHORT CONNECTIONS – DIFFERENT SIZES

R.P.M.-100 — ROBINSON ENGINE — BOILER PRES. 75#

$\frac{3}{4}$" CON	SET A	$\frac{1}{2}$ CON	$\frac{3}{4}$" CON	SET B	$\frac{1}{2}$" CON
20.9	M.E.P.	21.2	20.2		19.9
21.0		21.5	21.4		20.7
20.7		21.2	21.0		20.4
TOTALS	$\frac{3}{4}$" CON. 125.2		$\frac{1}{2}$" CON 124.9		PER CENT DIF = 0.24%
	$\frac{3}{4}$" CON.	SETS – C AND D		$\frac{3}{8}$" CON.	
TOTALS	79.0	(4 CARDS)		78.3	
PER CENT DIF.					0.88%
	$\frac{1}{2}$ CON.	SETS E AND F		$\frac{3}{8}$" CON.	
TOTALS	113.6	(6 CARDS)		112.9	
PER CENT DIF.					0.62%
		BALL ENGINE			
	$\frac{1}{2}$" CON.	SETS G AND H		$\frac{3}{8}$" CON.	
TOTALS	88.2	(6 CARDS)		87.6	
PER CENT DIF.					0.69%
	$\frac{3}{4}$" CON.	SETS I AND J		$\frac{1}{2}$ CON.	
TOTALS	72.2	(6 CARDS)		72.0	
PER CENT DIF.					0.27%

BALL ENGINE
TABLE A

LENGTH OF CLEARANCE PIPE	APPARENT CUT-OFF SHORT CON.	M.E.P. SHORT CON. —TO— INDICATOR	M.E.P. CLEARANCE BEYOND-IND.	PER CENT DIFFERENCE SHORT CON-BASE
1 1/4 FT.	.40	31.0	30.9	-0.4%
	.39	29.7	29.6	
	.40	30.4	30.2	
2 1/2 FT.	.43	31.2	30.0	-4.4%
	.43	31.2	30.0	
	.43	31.9	30.1	
5 FT.	.33	29.4	25.9	- 11.1 %
	.33	29.3	26.2	
	.32	29.1	25.9	
10 FT.	.33	30.6	22.5	-24.9%
	.33	30.0	230	

CYLINDER 8"x10" R.P.M. 290. SCALE 1"= 50# BOILER PRES. 70#

BALL ENGINE

TABLE B

LENGTH OF CLEARANCE PIPE	APPARENT CUT-OFF SHORT CON.	M.E.P. SHORT CON. ~TO~ INDICATOR	M.E.P. CLEARANCE BEYOND IND.	PER-CENT DIFFERENCE SHORT CON-BASE
1 ¼ FT.	.21	22.2	22.1	
	.21	21.9	21.8	
	.21	22.7	22.6	−0.4 %
2 ½ FT.		22.5	22.1	
	.25	22.6	22.1	
		23.0	22.8	− 1.7 %
5 FT.	.13	17.4	17.9	
	.15	18.6	19.2	
	.13	17.2	17.7	+2.9 %
10 FT.	.11	18.6	17.2	
	.10	18.5	17.1	
	.11	18.6	17.1	− 7.5 %

CYLINDER 8"x10" R.P.M. 285 SCALE 1" = 50# BOILER PRES 70#

TABLE C

LENGTH OF CLEARANCE PIPE	APPARENT CUT-OFF SHORT CON.	M.E.P. 8 INCH CON. ~TO~ INDICATOR	M.E.P. CLEARANCE BEYOND-IND.	PER CENT DIFFERENCE 8 INCH CON.-BASE
1 ¼ FT	.62	32.6	32.5	−0.3 %
2 ½ FT	.40	34.9	35.2	+ 0.8 %
5 FT	.43	33.3	31.8	−4.5 %

R.P.M. 290 BOILER PRES. 70#

ROBINSON ENGINE

CYLINDER $8\frac{1}{2}'' \times 16''$ — 60 REV. PER MIN. — BOILER PRES. 70#

LENGTH OF CLEARANCE PIPE	SCALE OF SPRING 1" = 20# — M.E.P. SHORT CON. TO INDICATOR	SCALE OF SPRING 1" = 20# — M.E.P. CLEARANCE BEYOND IND.	SCALE OF SPRING 1" = 20# — PER CENT DIF.	SCALE OF SPRING 1" = 40# — M.E.P. SHORT CON. TO INDICATOR	SCALE OF SPRING 1" = 40# — M.E.P. CLEARANCE BEYOND IND.	SCALE OF SPRING 1" = 40# — PERCENT DIF.
$1\frac{1}{4}$ FT.	17.1	17.0		14.6	14.6	
	17.4	17.2		14.5	14.5	
	17.3	17.1	−0.6%	14.7	14.7	0. %
$2\frac{1}{2}$ FT.	17.4	17.0		15.1	14.9	
	17.4	17.1		15.0	14.8	
	17.2	16.8	−2.5%	15.0	14.9	−1.0%
5 FT.	16 2	15.5		13.0	12.6	
	16.1	15.3		14.0	13.5	
	16.1	15.3	−4.4%	13.5	13.0	−3.5%
10 FT.	15.6	13.8		17.5	15.8	
	15.6	13.7		17.5	16.2	
	16.0	14.1	−11.8%	17.0	15.6	−8.4%

Robinson Engine

Cylinder $8\frac{1}{2}'' \times 16''$ — 120 Rev. Per Min. — Boiler Pres. 70#

	Scale of Spring 1" = 20#			Scale of Spring 1" = 40#		
Length of Clearance Pipe	M.E.P. Short Con. To Indicator	M.E.P. Clearance Beyond Ind.	Per Cent Dif.	M.E.P. Short Con. To Indicator	M.E.P. Clearance Beyond Ind.	Per Cent Dif.
$1\frac{1}{4}$ Ft.	17.9	17.7		14.6	14.4	
	17.7	17.5		14.5	14.3	
	17.3	17.2	-0.9 %	14.7	14.6	-1.1 %
$2\frac{1}{2}$ Ft.	18.3	17.7		16.8	16.2	
	17.6	17.1		16.5	15.7	
	17.6	17.0	-3.1 %	16.6	16.3	-3.5 %
5 Ft.	17.9	16.7		16.0	14.8	
	17.9	16.5		15.0	14.0	
	17.6	16.2	-7.5 %	14.9	14.0	-6.8 %
10 Ft.	18.5	15.5		16.0	14.0	
	17.3	14.8		15.6	13.9	
	18.3	15.5	-15.3 %	15.5	14.0	-11.0 %