3

INDICATING OIL ENGINES.

The merits and demerits of the indicator as a practical means of obtaining the best results from an internal combustion engine are, to some extent, a matter of opinion, which is, in many cases, unduly influenced by particular experiences. The plain facts appear to be that a suitable instrument, properly installed, and given the essential time, skilled attention and manipulation, is almost the only means whereby the sequence of events in the cylinder can be closely followed. On the other hand, if these *desiderata* are not all complied with, the indicator may be widely misleading, and so, for ordinary practical purposes, it is usually preferable to employ simpler means of obtaining the essential data, even if these do not provide the complete information that is given by the indicator diagram.

The practical engineer, who is attempting to obtain the best results out of a given engine, is not in general greatly concerned with the finer points of the diagram, but is mainly interested in one aspect only—that is in obtaining a certain power from each cylinder and ensuring that reasonable similarity exists in this respect between the various cylinders comprising the engine. Various approximate methods may be used for this purpose (*vide* pp. 8 and 9 of Papers No. IX), and these will, in general, give more rapid and more reliable results than can be obtained from the indicator by relatively unskilled operators. Occasions do arise, however, when some more searching investigation into the behaviour of an engine is necessary, and for this purpose the indicator may well be the only available tool. This article has been written by an experienced and expert operator of the indicator, with the object of drawing attention to the essential points that must be observed if success is to be achieved : an account is also given of methods of indicating which, while perhaps not widely known in H.M. Navy, may, on occasion, prove to be of service. The matter is given in its original form, the opinions expressed being those of the writer, whose experience is, however, a sufficient recommendation for their adoption and trial. It must be borne in mind that the complete observance of all the suggestions given, can, in general, only be carried out in a well-equipped laboratory ; this, however, does not detract from the value of this article, which sets up an ideal to be aimed at. The skill and training necessary before diagrams, similar to those accompanying this article, can be produced need hardly be stressed when it is realised that these are not theoretical results, but are the actual diagrams obtained from a laboratory engine by an expert.

In conclusion, it may be well to stress the following points, mentioned by the author :—

(1) The indicator connections should be arranged so that the diagram can be taken as comfortably as possible, and so that the instrument can be readily fixed and removed.

(2) The error due to the stretch of the cord is often greater than is supposed. Keep the cord as short as possible, using light steel rods to effect this.

(3) Keep the indicator as cool as possible, only opening the cock *when required,* and maintaining it gas-tight.

1. Foreword.

In view of the general increase in the use of diesel engines in H.M. ships, and in recognition of the desirability to obtain better performance from this type of engine, the following remarks on indicating have been compiled.

The intention has been to deal with the practical use of the indicator, to expose some of the failings, and to assist the engineer officer in maintaining his diesel plant in a condition which will give him the greatest satisfaction.

2. Manipulation of the indicator.

(*a*) *Adjusting and cleaning for use.*—An indicator which is out of adjustment or dirty is worse than useless ; a misleading diagram does more harm than good.

In most indicators it is a simple matter to remove the piston, immerse it in paraffin and clean with a non-fluffy material. The cylinder can then be cleaned with a suitable wad of the same material, which should be held up to the light in order to see that every trace of carbon is removed. A spot of a high-grade oil is now required to be rubbed on the piston before replacing.

So much for the cleaning. Now the question as to how often this should be done depends upon the conditions inside the cylinder *i.e.*, the amount of carbon or coke suspended in the gases during the expansion stroke. Under conditions of clear exhaust, it is generally possible to take from 6 to 10 good diagrams, if the indicator cock is not left open longer than absolutely necessary. After taking a few diagrams under favourable exhaust conditions, the indicator piston becomes dry and begins to darken near the bottom—at this stage a spot of castor oil wiped round the piston is all that is required for the next few diagrams.

There is little adjustment which can be made in the engine-room to the instrument other than to the pencil stop. This should be adjusted to give a faint but discernible line, in order to eliminate pencil friction on the diagram.

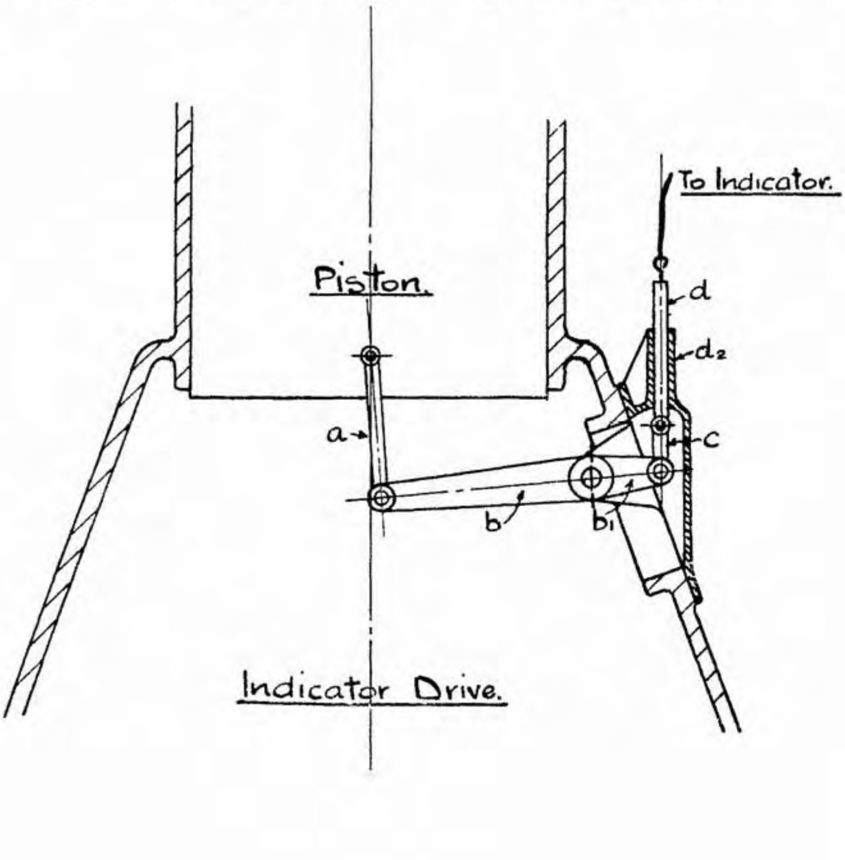
An examination of the indicator on the bench should be made periodically. Remove the spring from the instrument ; then replace the piston and connect up completely ; the piston should fall by its own weight when the instrument is held vertically or upside down. Occasionally, a new instrument after being in use once develops a sticky piston and will fail under the above test. In such a case, the piston may be touched when bright with the finest oil stone until free ; on no account should an abrasive be used between the piston and cylinder.

With the spring still removed the vertical motion of the pencil arm may now be checked. Place a card on the drum and, having first drawn an atmospheric line, move the piston up and down with the pencil touching the card. If this line is not at right angles, the instrument must be rejected.

The pencil mechanism should be examined for slackness ; this frequently appears in the swivel joint in one popular make of indicator. For light spring work the slackness permissible is very small, say, a sixty-fourth of an inch as a maximum. When dealing with power diagrams double that amount would have but a slight effect on the M.I.P., since the error is in the descending stroke only. There would be, however, an error of, say, 10 to 15 lbs. per sq. in. in measuring the compression pressure or maximum pressure unless the atmospheric lines were drawn with light finger pressure under the pencil arm.

Arranging the drive.—In a single-cylinder engine the correct reduced piston motion may be produced by a working scale model of the crankpin, connecting rod and piston arranged at the end of the crankshaft. In a multi-cylinder engine, however, this would involve a rotating shaft throughout the length of the engine driven by a chain from the crankshaft or camshaft (if this be driven through ground gears) ; for the purpose of timing the engine this system is both unnecessarily elaborate and costly.

A suitable drive for multi-cylinder engines consists of a link *a* connected to the piston, a lever bb^1 mounted on a crankcase door, a link *c* connecting the lever bb^1 to a plunger *d* guided by d_2.



The guide d_2 is mounted parallel to the engine cylinder, and preferably vertically under the indicator pulley, so that the cord connecting the hook to the indicator is parallel to the plunger d. In this arrangement the two halves of the lever bb^1 should bear the same ratio to one another as the links a and c; *i.e.*, $ab^1 = bc$. In some cases it is not possible to arrange the guide d_2 directly beneath the indicator, then it is necessary to provide a pulley directly over the guide d_2 so that the cord attached to the hook is parallel to the plunger d, between the hook and the pulley. After leaving the pulley the cord may be led in any direction to the indicator.

In order to be strictly accurate, the link c and the plunger d should be pointing downwards, so that the included angles between links and lever would be equal. In practice this is generally inconvenient, on account of the slope of the crankcase door, and again it would involve another change of direction of the cord or tape leading to the indicator.

The error introduced by the arrangement shown in the sketch is small, and does not affect the tuning of a multicylinder engine.

Taking the diagram.—Before attaching the indicator, presumably cleaned and ready for use, open the cock to blow out any grit or carbon accumulation from the indicator passage. Fix the indicator to the cock in such a manner as to give the most direct lead for the cord on to the drum, *i.e.*, wherever possible avoid using the small swivelled pulley except as a guide. The cord will require adjustment for length so that the drum does not touch the limit of travel at either end of the stroke. See that the card fits tightly to the drum, then draw on an atmospheric line, which will also define the length of the stroke. Open the indicator cock, take the diagram as quickly and lightly as possible, *then shut the cock*. It is common to see an indicator cock allowed to remain open twice as long as necessary; it means more frequent cleaning and sometimes inferior diagrams.

The pencil line should be sufficiently intense to be legible. Avoid the thick dark line which gives a more attractive diagram, but an inflated mean pressure, as a result of a lag on the compression stroke and another lag on the expansion stroke, both caused by friction.

3. Defects.

(*a*) *Due to faulty indicator.*—The most common defect in the indicator is probably slackness in the joints of the pencil arm mechanism; of these joints the swivel at the top of the piston rod usually becomes loose first of all. Depending upon the purpose for which the indicator is being used, so a moderate degree of slackness in this mechanism is permissible; for example, in tuning a multi-cylinder engine, the results would be comparative, provided that the same indicator were used throughout. For light spring work, when it is desired to measure volumetric efficiency, or when $0 \cdot 5$ lb. per sq. in. has to be measured, obviously an indicator in very good condition must be used. The subject of light spring diagrams will be dealt with later.

Another indicator defect, not so common but by no means unknown, is when the pencil does not move parallel to the axis of the drum. In this case the diagram records pressures at any given time lower than those actually obtaining.

Springs become strained which results in their appearing too strong when tested. As a general guide a spring should not be used for a pressure of more than one and a-half times the rate per inch of the spring. Occasional tests on springs should be made by some reliable method. (A simple deadweight tester is described elsewhere).

Too many turns of cord on the indicator drum sometimes produce a mysterious kink in a diagram, due to one turn overriding another and then slipping down to the drum ; thus a sudden change of speed is produced.

Lack of adjustment of drum spring load may produce a lag at one end of the stroke. The load must be sufficient to overcome the inertia of the drum and thus keep the cord taut ; going to the other extreme, a very strong spring causes a delay at the beginning of the stroke in which the cord pulls, due to a slight stretch.

A sticky indicator piston gives a " stepped " diagram most noticeable on the expansion line. The diagram is distinct from that caused by spring oscillations, which take the form of a wave. A sticky piston when returning to atmospheric pressure stops for an instant until the spring pressure has overcome the friction, mean while a flat step has been formed on the diagram.

Other defects may arise as result of an accident or fall ; these include a bent piston rod, or drum rotating out of truth, etc., the cause and effect of which is usually obvious. The defects dealt with above refer to condition and not design of the indicator.

(*b*) *Due to faulty drive.*—This subject is partly dealt with under Section 2 (*vide also* Papers No. 6, p. 98), so far as the hook at the end of plunger *d* ; this hook is given a motion proportional to that of the piston. The cord attached to this hook should be parallel to the motion of the hook so far as the first pulley ; any obliquity in this lead to the pulley will result in a shorter diagram and a rate of travel not proportional to that of this piston.

From the first pulley, the cord should be, whenever possible, a tangent to the indicator drum, *i.e.*, any further change of direction should be avoided in order to reduce errors due to cord stretch. Theoretically these further changes of direction in the cord are of no consequence.

The effect of the cord stretch on the length of the diagram may be observed by taking a " barred round " length and comparing it with the length obtained when running. If these lengths are nearly equal, there is not much at fault with the drive in general. The length of the diagram is not necessarily equal to the travel of the hook. Though the card drum diameter may be equal to that over which the cord passes, the thickness of the cord has to be reckoned, so there is a reduction in length of the diagram by about 3 per cent.

(*c*) Other defects in diagrams include those caused by the cock being insufficiently open, or, by a restricted passage from the cylinder to the cock. Both of these give a diagram with a low maximum and high mean pressures. An example is given marked T.

It is of interest to note that considerable restriction to an indicator is necessary before any effect is produced on the diagram. An experiment was conducted employing a steel distance piece between an engine cylinder and the indicator cock; the distance piece was provided with a moveable washer, $\frac{7}{16}$ in. thick, through the centre of which a $\frac{1}{32}$-in. hole was drilled. The engine, which was running normally at 98 M.I.P. and 625 maximum pressure, was then indicated. The result was to increase the M.I.P. by 15 per cent., and to reduce the maximum pressure to 480 lbs./sq. in. The washer was removed and opened out in several stages up to $\frac{1}{16}$ in., diagrams being taken at each step. With a $\frac{1}{16}$-in. hole in the washer the M.I.P. was but 3 per cent. above normal, and the maximum pressure 625 lbs./sq. in.

The above experiment removes any doubt about a $\frac{1}{4}$-in. hole of considerable length having any misleading effect on a diagram. Incidentally, it was carried further, using a distance piece having a passage of about 6-in. total length, $\frac{3}{16}$ in. diameter, with two sharp right angle bends (*i.e.*, holes drilled at right angles to one another). This arrangement had no discernible effect whatever upon the diagram.

A variation up to 3 per cent. may be expected from a high-speed engine giving a smooth diagram. In cases where there is considerable lag between injection and the commencement of combustion, or generally, where detonation is present, then considerably more than 3 per cent. difference in M.I.P. may be expected between two diagrams. Isolated diagrams, therefore, should not be accepted, *an average of at least three is advisable in order to arrive at a mean pressure for comparative purposes.*

Adjustment of the cord between the indicator hook and the driving hook is important. When the length is much too great the effect is most marked by the flat end of the diagram. Any doubt about this point may be removed by drawing an atmospheric line on the card, pulling the cord by hand to the full extent of travel, after which take a running diagram; the latter should fall short of the hand-drawn atmospheric line at either end.

Unsatisfactory atmospheric lines are usually caused by slack in the pencil mechanism, but when the latter is in good order, look for a spring not securely screwed home, or a leaky indicator cock. When the last-named is suspected, remove the indicator and draw the atmospheric line by hand.

4. Indicating Air Compressors.

The ordinary engine indicator is suitable for this purpose, a special range of springs only being required. The three-stage compressor usually requires 1/40 for the first stage, 1/200 for the second, and 1/800 for the final or third stage.

Apart from obtaining diagrams from which the power absorbed may be worked out, the value of indicating air compressors is in the detection of faulty valves, etc.

There are only two strokes to consider in general, namely, the compression and delivery combined stroke, and the stroke during which air is received. From one end of the stroke, compression should begin at once—(if it does not, then there is something wrong; probably the suction valve shuts too slowly or leaks, or else the piston rings are defective). Compression takes place until the delivery valve is overbalanced, at which point it ceases, delivery at constant pressures beginning. At the end of the stroke the delivery valve is open, but should shut as soon as the piston begins to move back; for an instant, both valves remain closed until the delivery pressure of the stage previous becomes greater than that in the cylinder under consideration.

The most desirable characteristic of a compressor diagram is the almost vertical drop in pressure at the end of the compression stroke. It is an indication that the delivery valve does not leak and that it closes quickly; it further indicates that the clearance volume is small; and, in cases where the cylinder in question is a low-pressure cylinder having an H.P. one above it, it indicates that there is no leakage from the upper cylinder to the lower one, via the rings of the upper piston. Compare examples U and V, the former one being ideal and the later showing some of the air returned before receiving air from the previous cylinder. Diagram W, with a rounded top, is an example of the delivery valve being slow to open, and shows the pressure higher than necessary for delivery to the stage above. It involves slightly more work done on the air than the ideal diagram would require, otherwise the quantity received and delivered is the same as in the diagram U.

5. Light Spring Diagrams.

Springs up to 1/100 may be regarded as light springs. Those of 1/40 to 1/100 are useful when examining the exhaust pressure from the point of opening of the exhaust port or valve down to the end of the stroke.

1/16 and 1/8 springs are used to detect any restriction of flow through the air passages, to obtain volumetric efficiency and to detect any delayed closing of the induction valve. Diagrams taken with these springs are often worthless owing to the momentum of the pencil arm and the moving parts of the indicator.

A good method of obtaining reliable and consistent results with these light springs is that of fitting a distance piece inside the spring in order to limit the travel of the piston to give, say, 3 lbs./sq. in. maximum pressure. By this means the momentum of the moving parts is so considerably reduced that the wave usually present in the ordinary light spring diagram is entirely eliminated. (See diagram marked " X ".)

Having obtained a satisfactory diagram by this method, it remains to draw an atmospheric line in the correct position. An error of 1/32 here means ½ lb./sq. in. in the case of a 1/16 spring; this may render valueless an otherwise useful diagram.

A satisfactory method of placing a correct atmospheric line is as follows:—Remove the indicator from the engine, clean thoroughly the piston and cylinder, assemble the parts again, and place a card on the drum. Draw an atmospheric line on the card by hand, and then press the spring up to the limit of pressure; when in this position draw another line parallel to the atmospheric line. Now measure the distance accurately between these lines. The true atmospheric line may then be drawn on all the diagrams with drawing instruments on the desk, measuring from the upper line or " stop " line, which is constant and free from inaccuracy, whether running or not.

6. Tuning a multi-cylinder engine.

6. The object in view is to produce similar maximum and mean pressures on all the cylinders. Furthermore, those pressures are to be suited to the engine, and not excessive at any load at which the engine may be required to run.

The variables under consideration are chiefly as follows:—

1. Quantity of fuel injected.
2. The rate of injection of the fuel.
3. The time of injecting the fuel.
4. The compression pressure.
5. The air and exhaust valve settings (in a 4-cycle engine).
6. The blast pressure in an air injection engine.

It is assumed here that the engine is not in the experimental stage and that suitable fuel nozzles, toepieces, etc., have been fitted.

Beginning with item 1 above, there is no hope of tuning a multi-cylinder engine if for a given load varying quantities of fuel are being supplied to the respective cylinders. It is, therefore, of the first importance to start with all suction and delivery valves in perfect condition, and then to check the closing of the suction valves in relation to the position of the plunger near the top of the delivery stroke for each cylinder. On air injection engines, several plungers generally work together fixed to one crosshead, thus the work of checking the position of each is reduced.

The test for the closing of the suction valves should be made in " full fuel " position, and may be checked at about half-fuel position, if there should be any doubt about the effective pump stroke being reduced proportionally in the two or more batches of cylinders.

The suction valve closing may be conveniently checked by means of feelers inserted between the tappets and the valves; it should be remembered that there is only a light spring on the suction valves and that false readings may be obtained with feelers if these are not carefully used.

When all suction valves are adjusted to close at the same degree of the plunger delivery stroke, then the pumps should deliver equal quantities of fuel. To obtain the maximum pumping result, these valves should close from 3 to 5 per cent. down the delivery stroke, according to the speed of the engine.

The rate of injection of the fuel is bound up with the period and height of the valve lift, the nozzle orifice being constant. This rate of injection has a tremendous effect upon the type of diagram obtained, the maximum pressure, and the efficiency of the combustion. It is assumed that a suitable toepiece has been determined, and that all the toepieces are identical; a method of checking this is explained later, should any doubt arise.

With the control in full fuel position, a minimum working clearance should be given between each roller and the neutral portion of the toepiece, *i.e.*, before lift commences. If the toepieces at each end are flush with the cam disc (which should be the case), then the roller clearance may be set to the cam disc.

The actual timing of the injection may be set now to a figure in degrees before top centre given by the engine builders. This figure may be anything from 6° to 26° before top centre, according to the type of cycle employed, and the initial acceleration of the fuel cam. There are generally facilities provided on every engine for independent adjustment of timing on each cylinder; this adjustment should be used until a dial indicator placed on the top of the needle valve shows intital movement at the same degree before top centre for each cylinder.

It is necessary now to run the engine in order to check the compression pressures of each cylinder; by running at a very light load with the timing gear fully retarded, the ordinary indicator diagram will usually show the compression pressure quite clearly; should doubt arise, however, it will be necessary to cut out the cylinder in question by not admitting fuel.

It is preferable to use the same indicator throughout for this purpose, since it is desired to obtain comparative results. The compression pressures should be adjusted as necessary to within 3 per cent. of one another as a general guide (*vide* Papers No. 9, page 5). If there appears any discrepancy about the compression it is as well to ascertain whether this is due to the legitimate cause, *i.e.*, the clearance volume being different, or whether it is due to a leaky valve or faulty piston rings. A variation of compression due to the first cause can be tolerated to a greater extent without disastrous results.

The blast pressure is generally common to all cylinders and does not call for any independent adjustment. The shape of the diagram is materially altered by blast pressure, an increase tending to produce a peaky diagram when running, whilst excessive blast on starting, delays ignition slightly and produces rapid pressure rise. The minimum blast pressure which gives clear exhaust, is desirable.

Having made the above adjustments, one might reasonably expect the engine to run in tune, all cylinders giving similar mean and maximum pressures. Should this not be the case, a careful examination of the diagrams from all the cylinders should be made, tabulating therefrom the maximum and mean pressures. There is no doubt about the accuracy of the settings recently checked, but one cylinder persistently produces a peaky diagram, another one perhaps produces a low maximum pressure with a round top to the diagram.

The probability is, in such cases, that the previous assumption that all the toepieces were identical does not hold good. A few thousandths of an inch difference, particularly on the opening side of the fuel cam, can make a vast difference to the initial burning. Retarding the toepiece which gives the peaky diagram, would reduce the maximum pressure, but it would not always improve the shape. The clearance should be reduced to a minimum in such cases and the individual timing retarded. Where the clearance cannot be reduced the toepiece can be modified on the opening side by a medium grade half-round carborundum stone so as to obtain a more gradual rate of opening.

It might appear from the above facts that the oil engine is a sensitive and difficult one to adjust. On the contrary, the onus is on the manufacturer ; if these vital parts are made and fitted with extreme initial accuracy, then the adjustment and setting becomes a simple matter, one over which the operator has considerable control.

A diagram plotted from the fuel valve lift will help considerably to enable the operator to form a clear conception of what is taking place. In the absence of a special indicator for the purpose, a ready means of obtaining such diagrams is as follows :—Set a dial indicator on the needle valve to read the valve lift in thousandths, turn the engine to the point of valve opening, then take readings every 5° until the closing of the valve. Plot the figures obtained on a crank angle base. The results obtained from the various cylinders are for comparison, therefore, plot always on the same scale and have the controls always in the same position, either full fuel or at a position at which the engine is usually run. Trace the diagram from the cylinder, which gives the desired indicator diagram, then superimpose it on any which appears faulty ; it will show if the trouble lies with the valve lift.

The above procedure is not advocated for ordinary tuning of an engine, but as a means for detecting where trouble lies when ordinary methods are of no avail.

The air and exhaust valve settings are easily adjusted and require correction comparatively seldom. Inaccuracies in these settings may be tolerated to a wide extent. At maximum powers all the air obtainable is required, therefore the makers' settings for the air or induction valves should be adhered to, in order to get the best volumetric efficiency. Excessive clearance on the exhaust valve reduces the overlap or scavenging period at the end of the exhaust stroke and for that reason should be avoided. With these valves the operator is dealing with a lift of about ten times that of the fuel valve, consequently, the same accuracy is not called for.

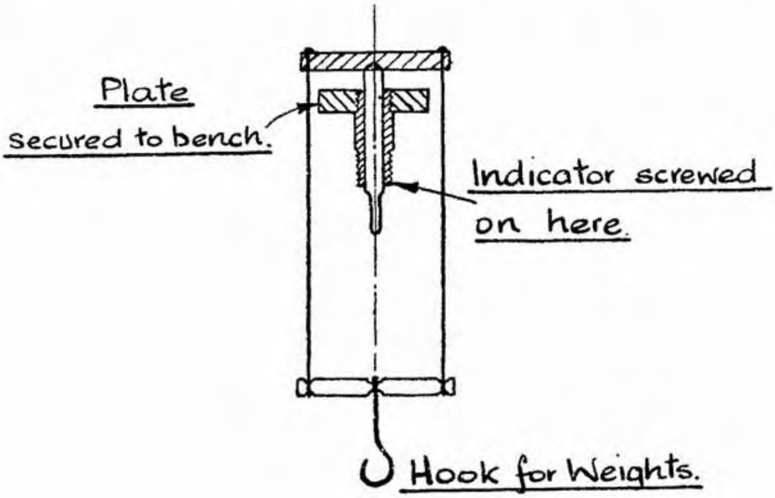
A Simple Dead-weight Spring Tester.—It is useful to have a means for testing the accuracy of indicator springs from time to time. In this connection the indicator itself may be used to form the main part of a simple apparatus. All that is required is a substantial plate about 9 in. long, 3 in. wide by ⅜-in. or ½-in. thick ; to the underside of the plate, near one end, is screwed an adaptor made from 1¼ in. Hex. bar about 3 in. long, suitably threaded on the bottom end to take the indicator. The adaptor and plate are then drilled ½-in. concentrically with the thread and finally reamered. A steel plunger (having the lower end spherical and the upper end conical) is then made a working fit in this hole, the length being determined by the indicator when screwed on the adaptor, so that whilst the spherical end rests on the underside of the indicator piston the conical end projects at least ½-in. above the plate. It will be necessary to reduce the diameter of the lower end of the plunger to ¼-in. for a length of 1-in. or so to clear the indicator cylinder.

The loading on the plunger is arranged by an arm 4 in. long, countersunk in the centre and carrying from each end a tie rod, on the bottom of which is supported a cross bar and hook.

The indicator is fixed down to the adaptor and a card is fixed to the drum in the usual manner.

The zero line is then drawn on the card by pulling the cord by hand. The load can then be put on the hook and a line drawn after each weight is attached. It is advisable to tap the plate lightly at each loading in order to get the true reading and to overcome friction on the side of the guide, etc.

If the piston area is $\frac{1}{8}$ of a square inch, 50 lbs. will be required to load a 1/400 spring to 1 in., and so in proportion for other springs.

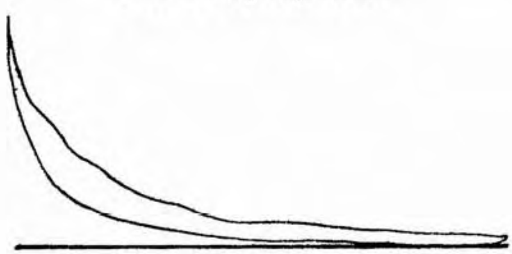


Deadweight Spring Tester.

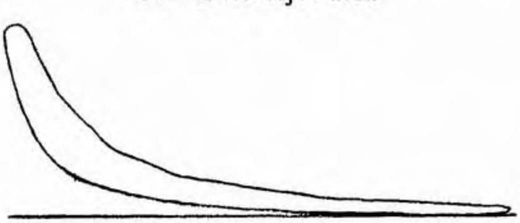
7. Examples.

Diagrams A, B, and C, are from the same engine at the same load, the speed being 350 R.P.M. They show the following characteristics :—

A. Early injection.



B. Late injection.



C. Shortage of fuel.

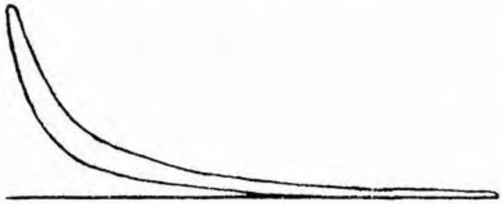


Diagram D shows violent burning with late injection and high blast. This same effect can be produced by using an unsuitable fuel.

The tendency to detonate thus can be reduced by raising compression and by decreasing the rate of lift of the spray valve cam.

D.

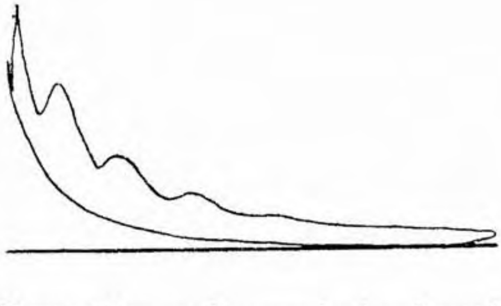


Diagram E was taken at the same load and speed on the same engine as diagram D after correct adjustment had been made.

E.

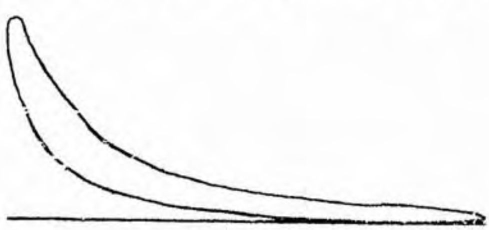


Diagram F is from the same cylinder as diagram E at half load.

F.

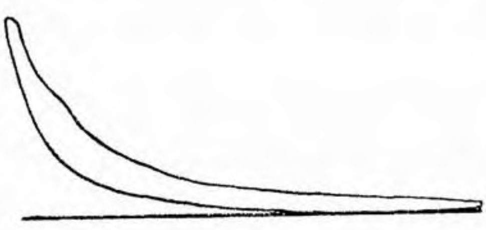


Diagram G is a simple case of late injection with an indicator piston sticking slightly.

G.

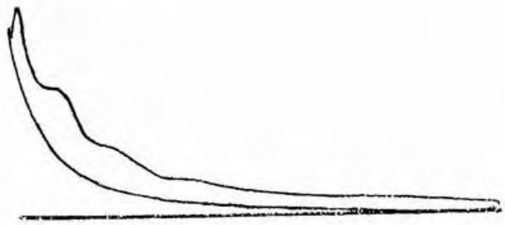


Diagram H is taken with a 1/50 spring, and shows the effects of restricted exhaust.

H.

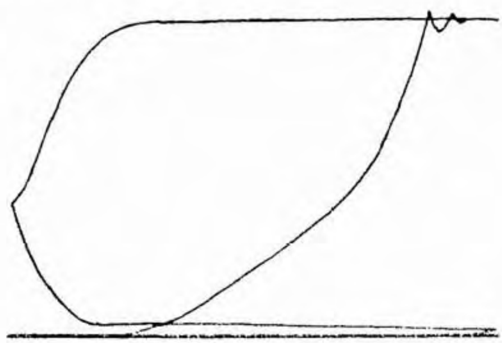
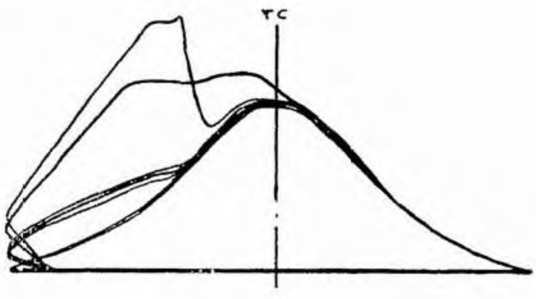


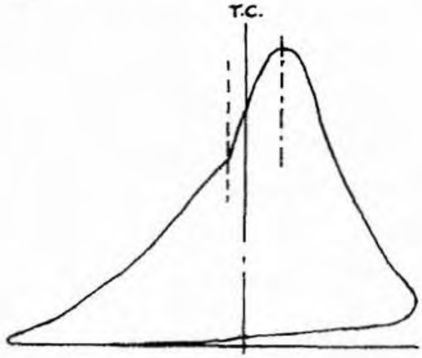
Diagram J is an out of phase starting diagram showing the starting air and the first two firing strokes.

J.



Diagrams K and L are taken with the indicator gear 90° out of phase. The object was to show the different rate of burning of two distinct fuels, namely, shale and American distillate. The latter, it will be seen, is slightly later to ignite, but reaches the maximum pressure in a shorter time. From these examples the value of the out of phase diagram can be seen readily, more particularly in experimental work.

K.



L.

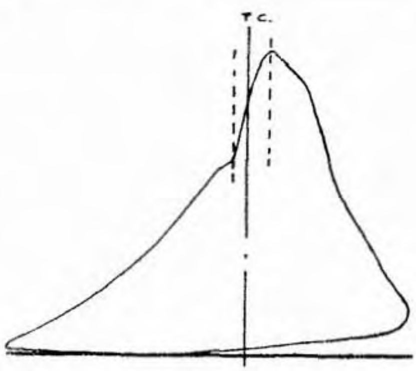


Diagram M is an example of Tarakan fuel used on a solid injection L class engine without suitable modification. The rapid rise in pressure sets up oscillation in the spring clearly shown in both the " in phase " and " out phase " diagrams.

M.

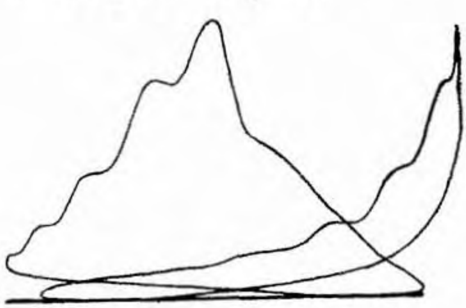


Diagram N shows the same cylinder working on Shale oil.

N.

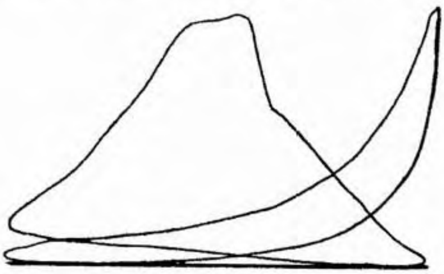


Diagram O is from an opposed piston blast injection two-cycle engine working at 144 M.I.P.

O.

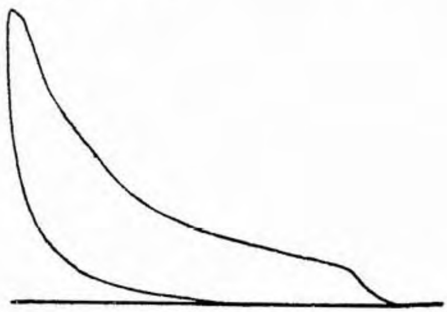
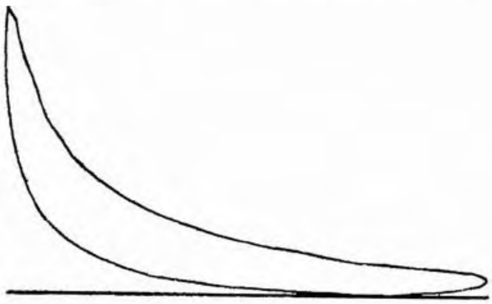


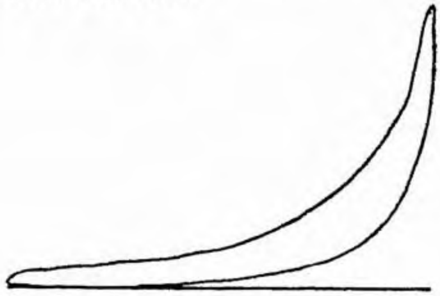
Diagram P is from a four-cycle double acting engine at 102 M.I.P.

P.

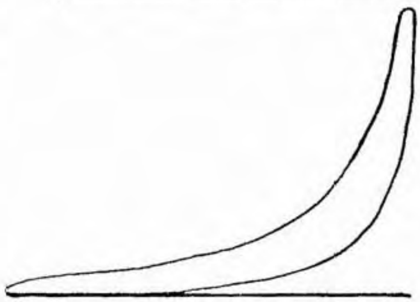


The next five diagrams are taken from a solid injection engine working at high compression and maximum pressure. Q is the normal diagram of the series, whilst R was taken with too many turns of cord on the drum, giving a shorter diagram and wider top. Diagram S was taken under the same conditions as Q except that a gummy " lubricant " was smeared on the indicator piston. The increase in area is most marked.

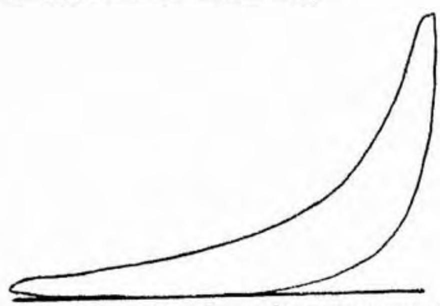
Q.



R.

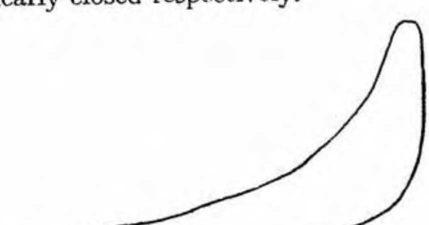


S.



The same effect but with reduced maximum pressure is produced in diagrams T1 and T2 which were taken with the indicator cock partially and nearly closed respectively.

T1.

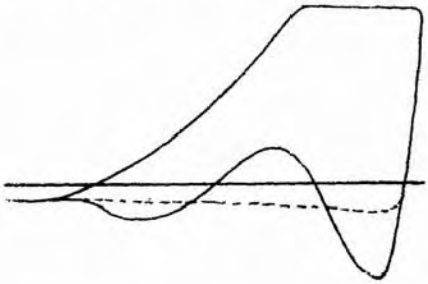


T2.

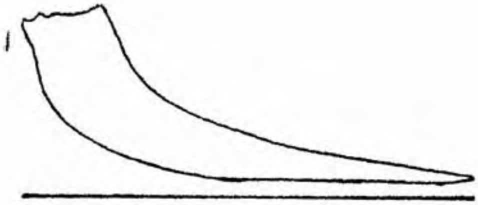
Compressor diagrams are U, V, and W, reference to which has been made under Chapter 5. Diagram U shows the effect of the very sudden drop in pressure at the end of the stroke, producing a wavy line due to the momentum of the moving parts. The dotted line shows approximately where this line should be with the wave eliminated.

(Most of the above diagrams were taken with a Dobbie McInnes Design 1.G. Instrument.)

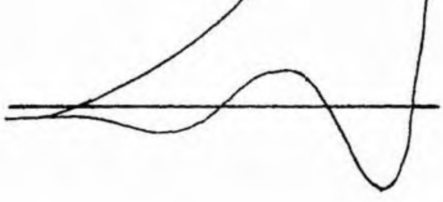
U.



V.

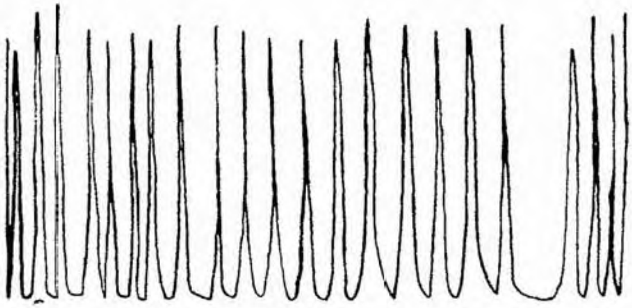


W.



X.

Y.



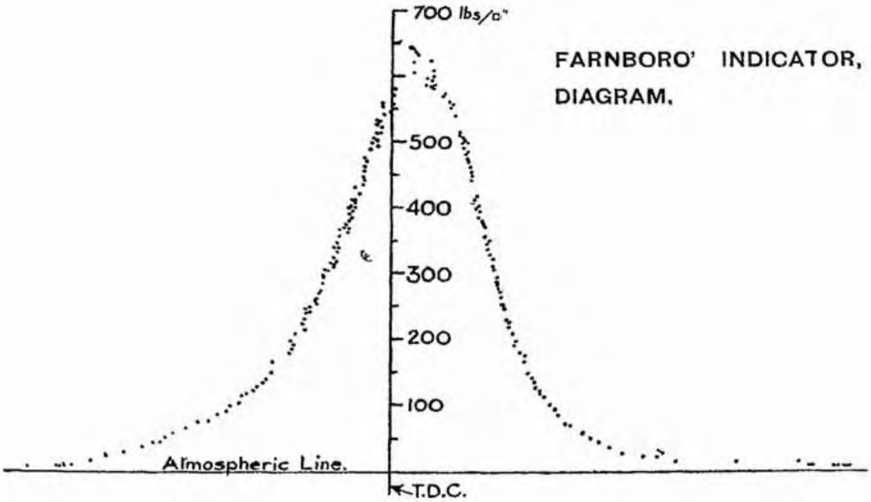
8. Out of phase diagrams are taken with the indicator gear set 90° away from the normal setting so that the top centre is in the middle of the diagram, *i.e.*, when the drum is travelling at the maximum speed. The advantage of this type is in examining the point of ignition as compared with the point of injection, also in detecting the rate of pressure rise—(Examples *K* and *L*).

9. Other Indicators.

The "Mathot" type of indicator has a large drum which is rotated at a constant speed by clockwork. Each pressure stroke is recorded at regular intervals, when the engine speed is constant. The use of the instrument is limited to detecting any variation in pressure during successive cycles.

The type of diagram obtained is shown in example Y. This diagram was actually obtained from an ordinary indicator the drum being slowly rotated by pulling the cord by hand. The variations in maximum pressure in this instance are very marked.

The "Farnboro'," indicator is one in which the drum revolves directly coupled to the crankshaft, and so produces a crank angle base. The pressure at the various points of the stroke is indicated by an electric spark perforating the card on the drum. The spark is produced when the pressure in the cylinder balances a controlled pressure from an air bottle, by means of a disc valve, the movement of which breaks the primary current of an electric circuit.



The operator raises the opposing pressure from atmospheric to maximum in the course of a few seconds during which time the pressures have been recorded on the card by the spark over a number of cycles. Only two points are plotted during one cycle, *i.e.*, on the rise and fall of cylinder pressure.

This type of indicator eliminates the trouble arising from fast moving parts; it is chiefly useful for high speed work and for finding the pressure accurately at a certain crank angle.

The " Okill " Indicator is an instrument for obtaining maximum pressures only. It consists mainly of a cylinder and spring loaded piston, the loading being varied by turning a knurled cap. A pointer indicates when the maximum cylinder pressure is just balanced by the spring loading; the pressure can then be read on a dial. The instrument affords a quick method of levelling up the maximum pressures in a multi-cylinder engine.