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The Development of the Internal Combustion Engine

READ AT
THE SHIPPING EXHIBITION, OLYMPIA.

BY MR. CHARLES BAXTER (Member).

On Tuesday, October 7th, at 7.15 p.m.

CHAIRMAN: MR. JAS. SHANKS (Vice-President).

DISCUSSION ADJOURNED TO TUESDAY, DECEMBER 23, 6.30 p.m.

The CHAIRMAN: The subject of this paper is an important one and is of very great interest to us all in view of the gradual introduction of the internal combustion engine to sea-going vessels. Marine engineers are fully investigating the details of this type of engine and seeking to gain knowledge and experience of the different kinds. The author has kept this fact before him in the preparation of his paper, which is illustrated with that object, and is thus rendered of additional value as a contribution to our Transactions. After it has been read and studied, the discussion at a future date will no doubt bring forth many valuable comments based upon experience.

Introduction.—In marine engineering the steam reciprocating engine has in the past held undisputed sway, and along with the steam turbine will undoubtedly hold a prominent position in the future.

Signs are not lacking, however, that at the present time the internal combustion engine is receiving considerable attention in marine circles, and what is more, shows every indication of becoming a serious rival to the two previously mentioned prime movers, it being at last looked upon by engineers as a serious proposition.

In the early days of the development of this new prime mover, wild statements were made by its over energetic sponsers in order to cover up the many faults it then possessed.

It was stated that the reliability was at least equal to the reciprocating steam engine and on most other points with perhaps the exception of the starting difficulty it was said to outrival its opponent. There is therefore no getting away from the fact that these irresponsible statements did an infinite amount of harm, for when the purchaser found that they could not be substantiated, the pendulum swung the other way and a period of unnecessary scepticism prevailed which took many years to dispel.

Early engines of this type were very unsatisfactory in many ways, all of which, directly or indirectly, affected their reliability and due to the small sizes in which they were then built, no attempt was made to boom them from a marine point of view, which is perhaps very fortunate for the marine engineer as the development through which all prime movers have to pass to reach the commercial stage, then took place on shore which was in this case a far safer proceeding.

Problem after problem was solved, however, by close application, which incidentally enabled larger sizes to be built, until now we find successful ships of reasonable size, engined with this prime mover running with a regularity which was only previously associated with steam.

These ships although not very large in either size or number are rapidly growing in both directions and it is undoubtedly a sign of the times, which augurs well for their success, that marine engineers are beginning to be interested.

The development taking place upon shore put marine engineers rather at a disadvantage, as it was only at intervals that many of them got the opportunity of coming into contact with these engines. They were therefore left rather in the dark as to the historical and development side of the study, and when this branch of engineering is taken up it is found that it has already grown to almost gigantic proportions; engines differing widely from each other being used for all manner of purposes ranging from the propulsion of ships to the propulsion of aeroplanes and motor cycles.

Now although the members of the Institute are chiefly interested in the propulsion of ships it is a fact that the development of this engine in its different branches all went to form the whole, it being impossible to say where the discoveries and development in one branch cease to influence another, the illustrations appended indicating the diversity in design.

It will therefore be found upon taking up the study of this prime mover that the particular knowledge required is scattered over innumerable text books and technical journals, the perusal of which is truly a formidable task, and it is with a view to helping engineers interested in the subject that the author has been tempted to offer this paper.

The information given has been carefully compiled during the past few years, and if it saves some of the time usually spent in wading through ancient and modern literature upon the subject, this effort will be amply repaid.

The present paper is not the first one before the Institute upon the internal combustion engine, many valuable ones preceding it, which are well worth the time spent in perusal, and if the discussion upon the present one is as practical and enlightening as those on its predecessors much valuable information will come to light, the views of members always meriting considerable respect

Historical.—The very early history or origin of this engine is rather obscure and seems to have begun with a period of speculation, before anything was done, the Abbe Hautefeuile described an engine in the year 1678; a partial vacuum caused by burning gunpowder in a cylinder, raising water, the resulting gasses being cooled. Gunpowder in small quantities was exploded in a cylinder, the pressure being allowed to escape through non-return valves; upon the gasses cooling and the pressure falling below that of the atmosphere the piston was forced down by atmospheric pressure.

According to patent records which are something of a guide in the matter, a Robert Street, of this country, in May, 1794, described an engine which worked by turpentine.

Other atmospheric type engines such as that by Samuel Brown, 1823, a beam engine, were made, in which the working depended upon the exploded charge being cooled and so forming a vacuum, allowing the atmosphere to do the work.

The first engine to attain any success however was that of Lenoir, 1860, a diagrammatic sketch of which is shown in Fig. 1 along with its diagram.

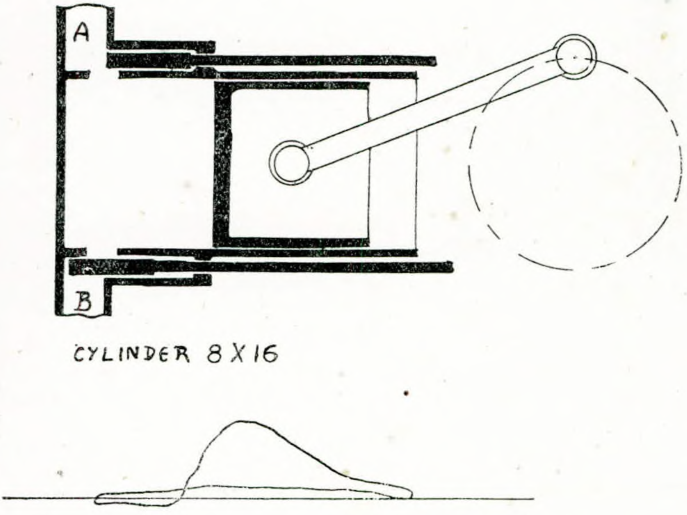


FIG 1

Cylinder 8 inch Bore by 16 inch Stroke.

This is shown as single acting, but in reality it was a double acting engine, very similar to the steam engines of that day.

A slide valve A, after the style of the usual D valve, uncovered the inlet port as the piston began to move outward and a charge of gas and air was inducted for about half the stroke, the valve then closing; the charge was ignited by means of an electric spark, the resulting pressure propelling the piston. At the end of the stroke the exhaust valve B opened and the piston on returning swept out the burnt charge. The impetus thus given to the fly-wheel allowed the engine to give off a certain amount of power and tided it over the idle stroke. The maximum pressure was in the region of 50lbs. per sq. inch and the consumption is said to have been 95 cubic feet per indicated horse-power hour.

An engine afterwards made by Hugan seems to have been of better mechanical construction, as the consumption was reduced to 85 cubic feet per indicated horse-power hour, whilst an atmospheric type engine by Otto and Langen further reduced the consumption to 44ft. by allowing the mixture to come in below a slightly raised piston and exploding it, the piston being rapidly sent upwards like a projectile, thus giving favourable conditions by rapid expansion, the weight of the returning piston along with the atmosphere, doing the work. The feature of Otto and Langen's engine was that the piston was free on its upward stroke and was connected to the crankshaft on its return stroke by a free wheel clutch. The maximum pressure was about 56lbs. per square inch, the consumption in large sizes falling to 30 cubic feet. Fig. 2 shows the diagram.

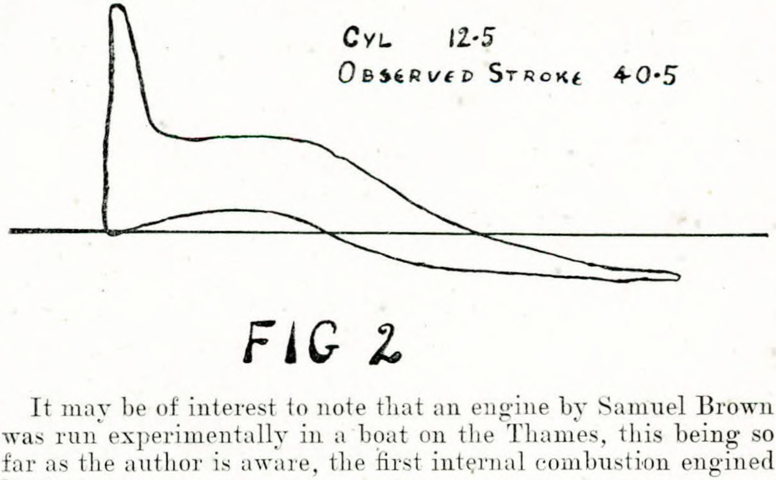


FIG 2

It may be of interest to note that an engine by Samuel Brown was run experimentally in a boat on the Thames, this being so far as the author is aware, the first internal combustion engined boat.

The next step of any note in the chain of events was the discovery that if a charge of mixture be drawn into the cylinder, compressed by the piston, exploded, thus doing work upon the piston and driven out on the pistons return, that this formed a much more efficient cycle.

Four Stroke Cycle.—The cycle of events was thus completed in four strokes, from whence it derives its name, it being without doubt the point at which the real history of the internal combustion engine began.

This type shown in Fig. 3 was patented by Beau de Roches in 1862 and made by Otto in 1876. Referring to point A on the diagram, the inlet valve opened and the piston proceeded upon its outward stroke drawing in a charge of mixture, the inlet valve then closing at B and the piston returning compressed the mixture to C, where it was ignited on the inner dead centre. The rise in pressure due to the explosion propelled the piston on the power stroke, the exhaust valve opening at D, and the piston returning driving out the burnt gas, starting the cycle again at A.

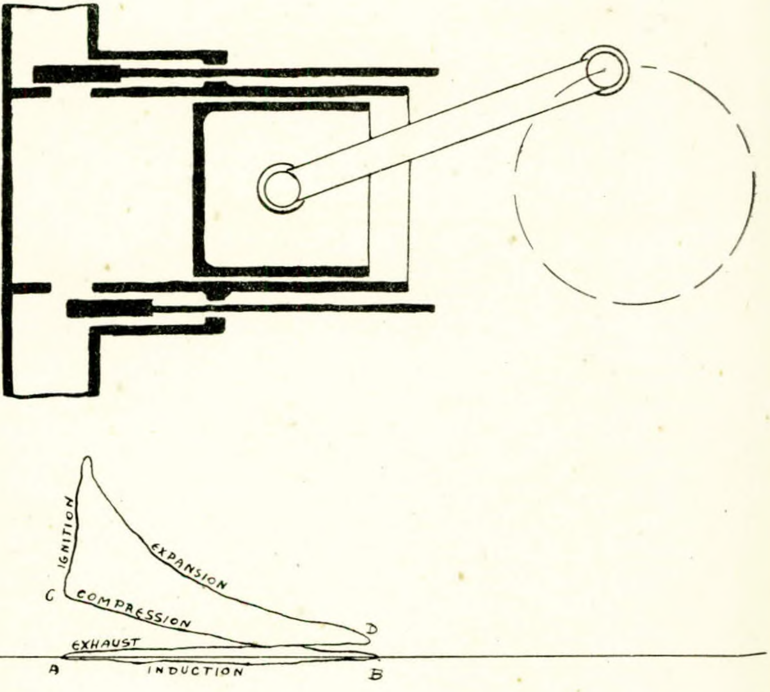


FIG 3

At first sight it may seem strange that anything can be gained by compressing the mixture previous to ignition, but it is found in practice that there is a great gain in efficiency, the mixture in modern engines being compressed to as high a pressure as practicable, as will be explained later.

Two Stroke Cycle.—The two cycle engines also compresses its mixture previous to exploding it and is now in extensive use, the cycle of operations being thought out by Sir Dugald Clerk. The engine is shown in Fig. 4 and functions as follows, completing its cycle of course in two strokes.

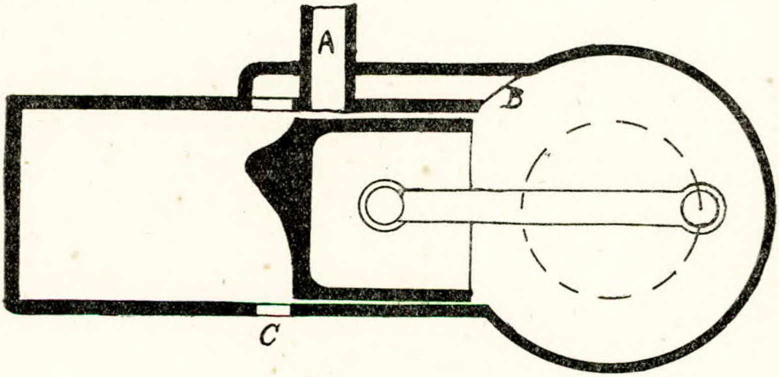


FIG 4

The piston on its in-stroke causes a vacuum in the crank chamber which fills with mixture when the piston uncovers the inlet port A. It also compresses the previous charge in the top of the cylinder which is ignited upon the inner dead centre, thus propelling the piston and compressing the charge beneath it, previously drawn into the crank case. Near the end of the stroke the exhaust port C is uncovered and the transfer port B, the new mixture driving out the products of combustion and filling the cylinder, the piston crown being shaped to facilitate this. It will be seen that the engine has its expansion, exhaust and inlet strokes all in one so to speak, the other stroke being for compressing the charge. These engines can be made without valves and are simple and reliable, being used in great numbers for small craft and motor cycles.

It should be borne in mind that they give more power than the four cycle, exploding twice as often, but not twice the power, as a proportion of the stroke is taken up in uncovering ports. These engines will also run in either direction, but as the very small ones are not self-starting, this is not of much consequence and a reversing gear is provided. They are also not as efficient as the four stroke, due to some of the inlet charge going out with the exhaust, although where the scavanging is done by air this does not of course apply. The uncommon feature about the engine is that the inlet charge drives out the exhaust, but this is found in practice to be quite satisfactory, the only precaution being the placing of a wire gauze in the transfer port to prevent accidental explosion in the crank chamber. Another point is that when running upon a partially closed throttle the cylinder is not quite filled with mixture and miss-fires, the next charge filling it and allowing the explosion to take place. It is possible for this to happen with great regularity, the explosion every other stroke being known as four stroking, but normal functioning is at once resumed when more throttle is given.

Four Cycle Diesel.—In this type a charge of air is drawn in on the induction stroke and compressed on the compression stroke to give it a temperature in the region of 1,000° F., which is higher than that required to burn the fuel.

At the end of the compression stroke the fuel valve opens and oil is injected by compressed air, thus burning automatically, the expansion and exhaust strokes taking place as in all four cycle engines. The fuel is injected by air in order to pulverise it and the extended burning period gives a diagram more like that of the steam engine, see Fig. 5.

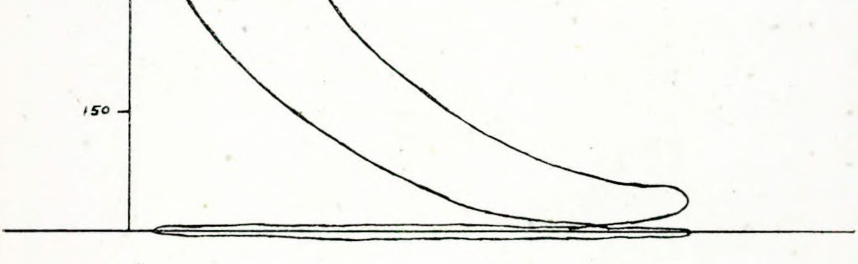


FIG 5

All kinds of heavy fuel are used successfully in these engines and no ignition apparatus is required, but the heavy strains set up have been a formidable obstacle to designers.

Two Cycle Diesel.—This is identical with the two cycle engine previously described, but on the Diesel system. Assuming the piston to be at the end of the expansion stroke a charge of air is admitted under pressure, driving out the burnt gasses and filling the cylinder, the piston then compresses the air to give the high temperature required, the fuel being admitted, burnt, expanded and then driven out by the next charge of air.

Semi Diesel.—This is an engine coming into extensive use, because it practically works upon the Diesel principle but avoids the higher compression pressure. It is also sometimes named by its makers the "Hot Bulb Engine," this term being considered by some to be more appropriate, the Diesel cycle being slightly modified.

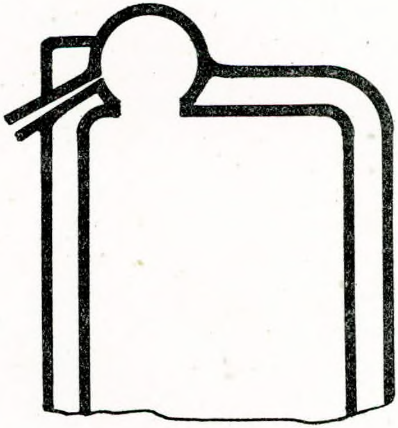


FIG 6

In Fig. 6 it will be seen that the cylinder is water jacketed in the usual way with the exception of the hot bulb, which is thus allowed to attain considerable temperature. A charge of air is taken in on the induction stroke and compressed on the next stroke to quite a reasonable pressure, the ignition of the oil taking place by it being injected into the bulb, the heat of which augmented by the heat of compression is sufficient to burn the oil.

These engines may of course be constructed to operate upon either the two or four cycle principle, but by far the greater number operate upon the two cycle principle, the fuel being injected on the solid system, i.e., by pump without compressed air.

Review.—It will be found that although the engines met with differ widely in detail and arrangement of parts, they may all be classed under one of the previously described headings. It is difficult to classify them according to their uses as certain types of engines are found in many spheres, but the following will give some idea of their arrangement in this respect.

Two Cycle Engines.—Motor cycles, small craft, large engines operating upon blast furnace gas, lighting sets, etc.

Four Cycle Engines.—Motor cycles, cars, stationary engines, aeroplanes and airships.

Two and Four Cycle Diesel Engines.—Marine and generating station work.

Semi Diesel Engines.—Small craft, etc., where simple operation is imperative and the speed is fairly constant.

Other Cycles.—From time to time other cycles make their appearance, such as the Six Cycle, where a charge of mixture is inducted, compressed, exploded, exhausted, then a charge of clean air inducted and then exhausted, the idea of course being to get rid of all products of combustion. These however do not seem to be put to any commercial use, but a cycle proposed by Mr. Durtnall, one of our members, is interesting and should be noted. Fig. 7 shows the diagram and it will be seen that air at atmospheric pressure is taken in from A to B, the inlet valve then closing and the pressure falling to C. The compression stroke then follows the line CBD, the pressure at the end of this stroke being sufficient to ignite and burn the fuel on injection from D to E, the expansion following the line EFG.

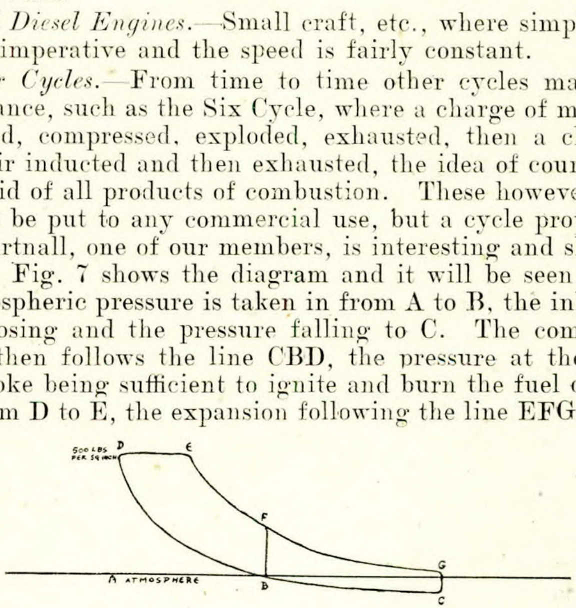


FIG 7

The vacuum at the end of the admission stroke gives a cushioning action and the expansion line falling to atmospheric pressure would apparently give a high theoretical thermal efficiency.

Compounding.—Attempts have been made at compounding internal combustion engines, but without much success, the power derived from the L.P. cylinder hardly balancing the extra frictional losses.

Double Acting Engines.—These are constructed by some makers in very large sizes for operating upon such fuels as blast furnace gas, the general lay-out greatly resembling steam practice, some types having their cylinders arranged in tandem.

Operation and Construction.—Cooling Pump.—Water jackets are fitted to cylinders in order to keep the temperature within practical lubrication limits, about 200° F., the circulation being promoted by means of a pump, often of the centrifugal type, or by means of a connection termed Thermo Syphon. In this case particular care has to be paid to pipe resistance, having the pipes of large diameter and all bends of easy radius. In large engines, valves, pistons, and rods are made hollow and water circulated through them.

Cooling Air.—Small automobile and other type engines are often air cooled, fins being cast on the cylinders to assist radiation.

Radiators.—Where only small quantities of water are available, radiators are provided to cool the water, often consisting of gilled tubes through which the water is circulated, a good air draught being produced by a suitable fan.

Cooling, Hopkinson Method.—Professor Hopkinson of Cambridge carried out some research work upon cooling and found that he could quite successfully cool engines by spurting jets of fresh water upon the parts inside the cylinder which were likely to get too hot, such as the exhaust valve, thus keeping them at a reasonable temperature and allowing the engine to continuously function normally. This system is interesting as it differs widely from any current practice, but so far as the author's knowledge goes it has not yet been adapted commercially.

Lubrication.—No startling innovations are noticeable in this respect with the exception of the small high speed type, which has forced feed through hollow crankshaft and connecting rods, the pressure used often being high, about 40lbs. per sq. inch. Very small two cycle crankcase compression engines are lubricated by mixing the oil with the petrol in the fuel tank, but the medium and larger sizes are fitted with a more positive system such as by gear or plunger pump.

Starting.—The starting difficulty is a great drawback, which applies to all types of internal combustion engines, and all manner of means have been tried to remedy the defect. One idea used on stationary engines is to put the engine upon the firing stroke, pump in a charge of mixture by hand and then ignite it. Many of them like the one just described are tedious and rather uncertain and a method extensively used is by means of compressed air, a diagram of the arrangement being shown in Fig. 8.

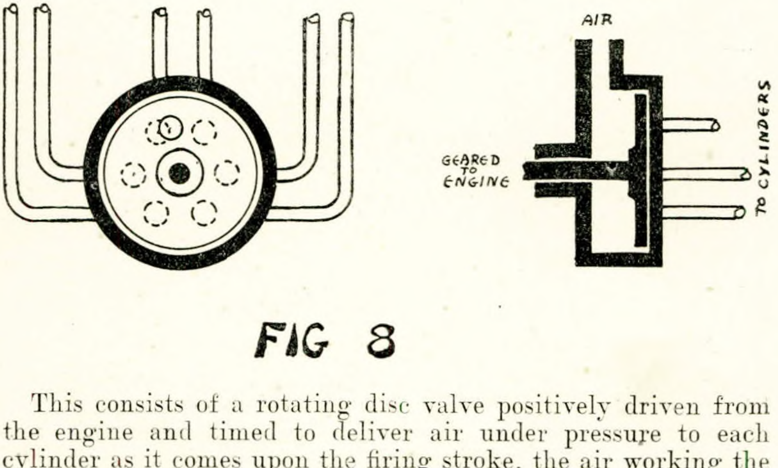


FIG 8

This consists of a rotating disc valve positively driven from the engine and timed to deliver air under pressure to each cylinder as it comes upon the firing stroke, the air working the cylinder as in steam practice. It should be noted that the air steams the cylinder on its firing stroke and is exhausted in the usual manner, the inlet and compression strokes not being interfered with. A non return valve is fitted to the air pipe at each cylinder so that when the engine takes up the firing the valve closes and prevents the explosion pressure entering the air pipe, the air then being shut off by hand.

Easy starting in large engines is obtained by sliding a differently profiled cam into position which reduces the compression pressure by delaying the closing of the inlet valve until the piston has traversed part of the compression stroke, thus returning to the induction pipe a proportion of the mixture taken in.

Small automobile type engines are very often started by means of an electric motor supplied by current from an accumulator, many makers fitting this system as standard.

Reversing.—This is often accomplished by sliding the camshaft endwise, bringing another set of cams into operation and restarting in the opposite direction by air.

Many types of two cycle engines reverse by slowing down and then causing preignition by injecting the fuel too early, so causing what is commonly termed a " back fire," which stops and restarts the engine in the opposite direction.

Governing.—Various methods of controlling the speed of engines are in vogue: in the case of:—

Diesel type engines for instance, this is done by varying the oil injection period although the minute variation of the exceedingly small quantity of oil injected per working stroke, entails considerable care in design and accuracy of workmanship, in constructing the pumping apparatus.

Hit and Miss.—Stationary gas engines fitted with heavy fly wheels were for years governed by cutting out an explosion now and again, known as " hit and miss," governing the governor causing the gas valve to miss opening altogether when the speed became too high.

Quality.—Modern times demand a smaller speed fluctuation and so quality governing by varying the gas valve lift is in vogue, which, however, is likely to result in weak and slow burning mixtures with resulting high loss to the cylinder walls thus unfavourably influencing the thermal efficiency, unless carefully arranged.

Quantity.—Governing by controlling the quantity of mixture inducted also has considerable vogue, especially upon engines used upon small craft, motor cars and aeroplanes; where it is universal, the quantity being varied by a throttle in the ordinary way.

Governing on the throttle is not good from a theoretical point of view, as it results in the cylinders being only partially filled with mixture, the engine thus running under inefficient conditions, but apart from this it is very satisfactory and often most convenient.

Pressure Fluctuation.—In gas engine work an elastic bag is fitted on the gas line to provide a reservoir of gas and prevent fluctuations in gas pressure, acting as a sort of air vessel.

Indicating.—All engines may of course be indicated, an optical type of indicator being used for the high speed variety, but generally speaking this is not done with the same ease and certainty as in steam practice, some type of dynamometer brake being a more reliable method of testing the condition of the high speed type.

The "Clerk" indicator has now been considerably improved and the writer is informed by Sir Dugald Clerk that a description will be published shortly; this will certainly be looked forward to with great interest, by engineers interested in the subject. The compression and explosion pressures may easily be obtained by means of the "Okill" indicator, Fig. 9, the thimble being screwed down until the movement of the valve can just be detected, the pressure then being read off on the scale.

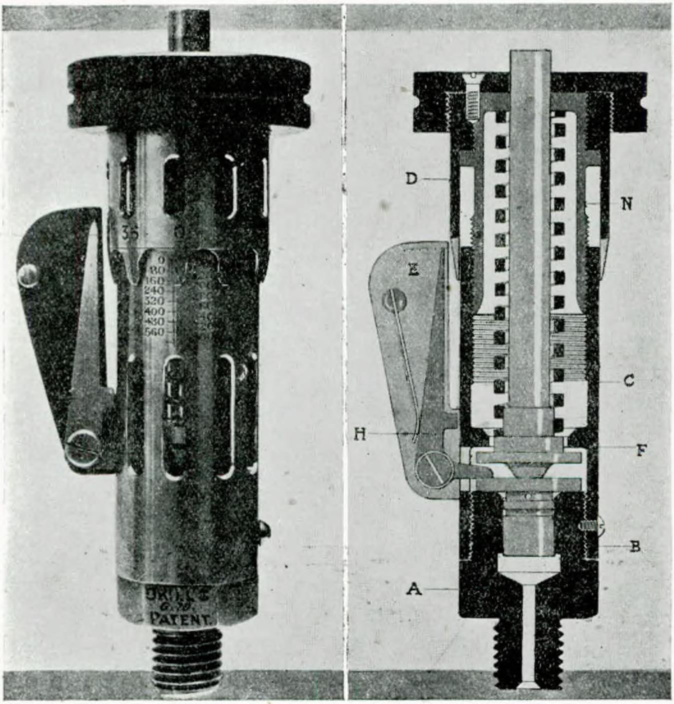


Fig 9.

Silencers.—A study of indicator diagrams will show that the exhaust valve opens some few degrees before dead centre and releases the gas at considerable pressure, which results in noise. An expansion chamber is therefore fitted on the exhaust line to minimise the sudden fluctuation in pressure, the art of designing this chamber consisting of arranging it so that the gasses are gradually expanded without putting back pressure upon the engine.

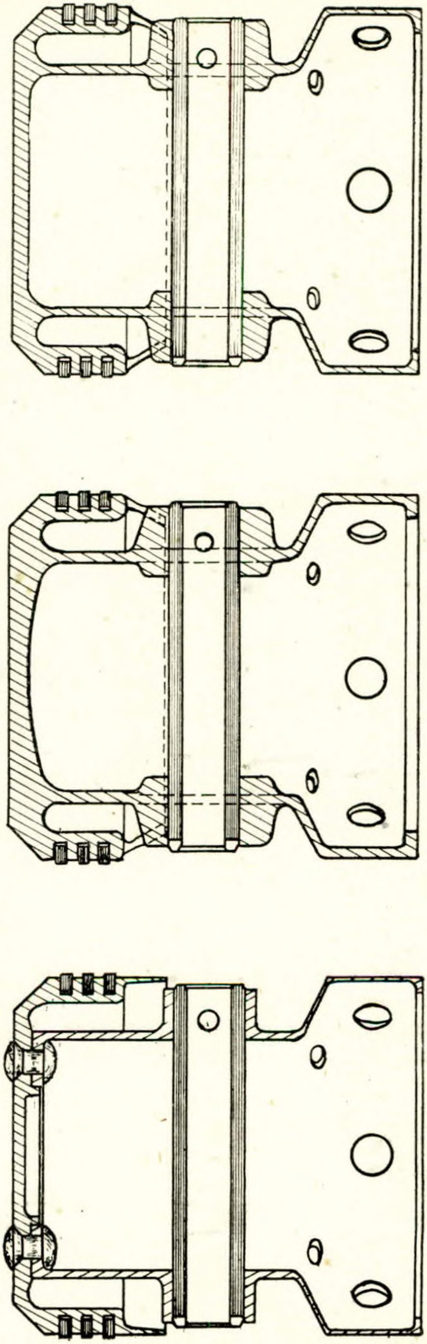
Cylinders.—The cylinders on small engines are cast solid, the larger types being fitted with detachable heads and separate liners. Many aero engines have their cylinders turned from solid billets, or cast in aluminium with steel liners fitted, a 5in. cylinder for instance having the aluminium block raised to 340° C. and the liner dropped in, the latter having a finished size 0·005in. larger than the block.

Pistons.—Large types are fitted with the usual junk rings, the small types being solid, an extra ring being provided near the bottom of the skirt to act as a scraper ring and prevent oil passing the piston and carbonising in the cylinder head. Many makers pin their rings in position to prevent the slots working into line.

In high speed type engines where the losses, due to inertia, become serious, special attention has been given to the construction of lighter pistons, it being found that a reduction of 10 per cent. in piston weight, for instance, influences the horse power developed considerably, being 12 per cent. on the higher reaches of the power curve, in an everyday example. The matter having been investigated separately by two engineers, E. Talbot and H. Ricardo, the two types shown in Fig. 10 and Fig. 11 have been evolved, the Talbot piston Fig. 10 known as the "Zephyr," being by far the earliest, enjoying an immense popularity, the steel one being very light indeed.

Aluminium pistons have been used with great success in many engines, the aluminium getting rid of the heat quickly, due to its higher conductivity, but greater clearance having to be given, due to the higher coefficient of expansion. The coefficient of expansion of iron being 556×10^{-8} and that of aluminium 1234×10^{-8} per degree Fahrenheit.

The majority of engines, being single acting, have their pistons functioning as a crosshead, this being quite satisfactory in practice, aero engines giving no trouble with a piston length over bore ratio as low as 0·6 with a maximum connecting rod angularity of 16°.



CAST IRON.

ALUMINIUM.

STEEL.

Fig 10,

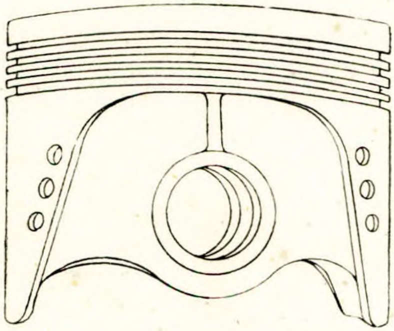


FIG 11.

Gudgeon Pins and other important parts are now made of high grade alloy steels, the H section connecting rod being very popular.

In stationary gas and oil engine practice the same rules apply to connecting rod bolts as to chains, insurance companies stipulating that they should be annealed periodically.

Gearing.—As the valves on a four cycle engine are operated every two revolutions a two to one gearing must be provided and this unfortunately often gives the engine a very complicated appearance, operating as it does a number of other mechanisms such as the ignition, fuel pumps and starting gear.

Neatness of design is now a telling point from a sales point of view and such matters are receiving more attention than hitherto.

Carburation.—It will have been noted that an engine of the internal combustion engine type can be run upon any substance which will form an explosive mixture, history telling us that some of the earliest were run upon gunpowder.

Modern engines function satisfactorily upon all kinds of fuel, from heavy oil to acetylene gas, the proportion of air of course depending upon the value of the fuel.

In gas engine practice a gas valve is provided in the air intake which lifts at the same time as the inlet valve thus mixing the gas with the air. In oil engine practice the oil is often injected directly by a small plunger pump into some part of the combustion head which is allowed to acquire considerable heat, the oil being thus vapourised upon the induction stroke, the part being heated for starting purposes by means of a lamp.

For light oil and spirit engines where simplicity is the main point the idea shown in Fig. 12 has been used the fuel being drawn in along with the air, upon the inlet valve lifting.

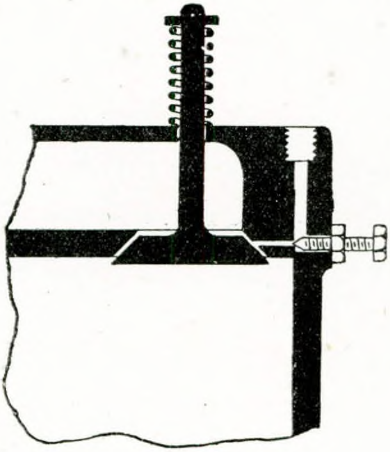


FIG 12

Small petrol and paraffin engines form their mixture in a carburetter, a diagram of which is shown in Fig. 13. A float chamber A keeps the level of the fuel just below the top of the jet B. Upon the induction stroke air is drawn in at C and fuel out of the jet B, the mixing taking place in the pipe.

In the case of paraffin the inlet pipe is heated externally by means of the exhaust, in order to assist vapourisation.

This type of carburetter is only satisfactory for constant speeds as it can be set to give a correct mixture for any given speed by altering the jet, but it is found that for a variable speed engine such as is used in automobile work some design is needed which will give an approximately constant mixture at all speeds. The reason why the mixture varies with the speed is because the laws of flow of air and fuel are not the same, the mixture getting richer as the speed increases.

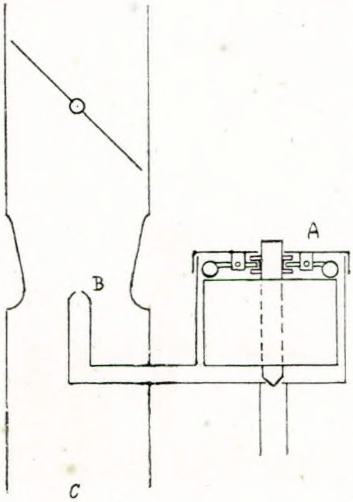


FIG 13

One very successful type of automatic carburetter designed to overcome this difficulty, is shown in Fig. 14 in its vertical and horizontal types.

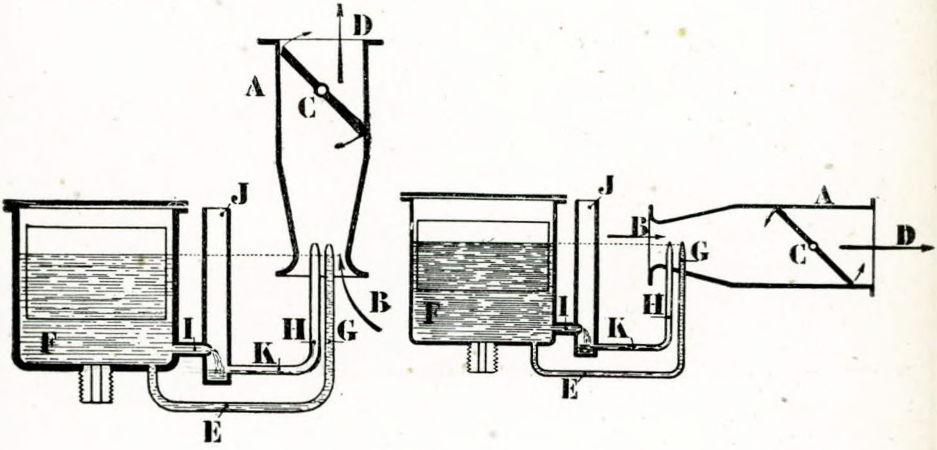


Fig. 14.

It will se seen that it is very similar to Fig. 13 with the exception that an extra jet H is provided, termed the auxiliary jet, the other one G being termed the main jet. These jets, the rates of flow of which are shown in Fig. 15 and Fig. 16, supply half the fuel each, the main jet Fig. 15 having a rising curve which has already been explained, and the auxiliary jet Fig. 16 a falling curve due to it being supplied through the restriction I, the flow of which is not influenced by the depression around the jet H.

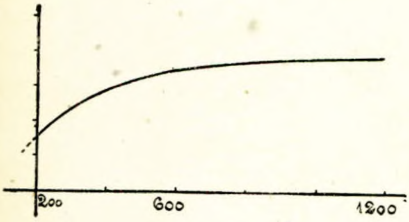


Fig 15. Main Jet.

Fig 16. Auxiliary Jet.

Together these jets correct each other, the mixture remaining practically constant in quality within reasonable limits over a wide range of speed.

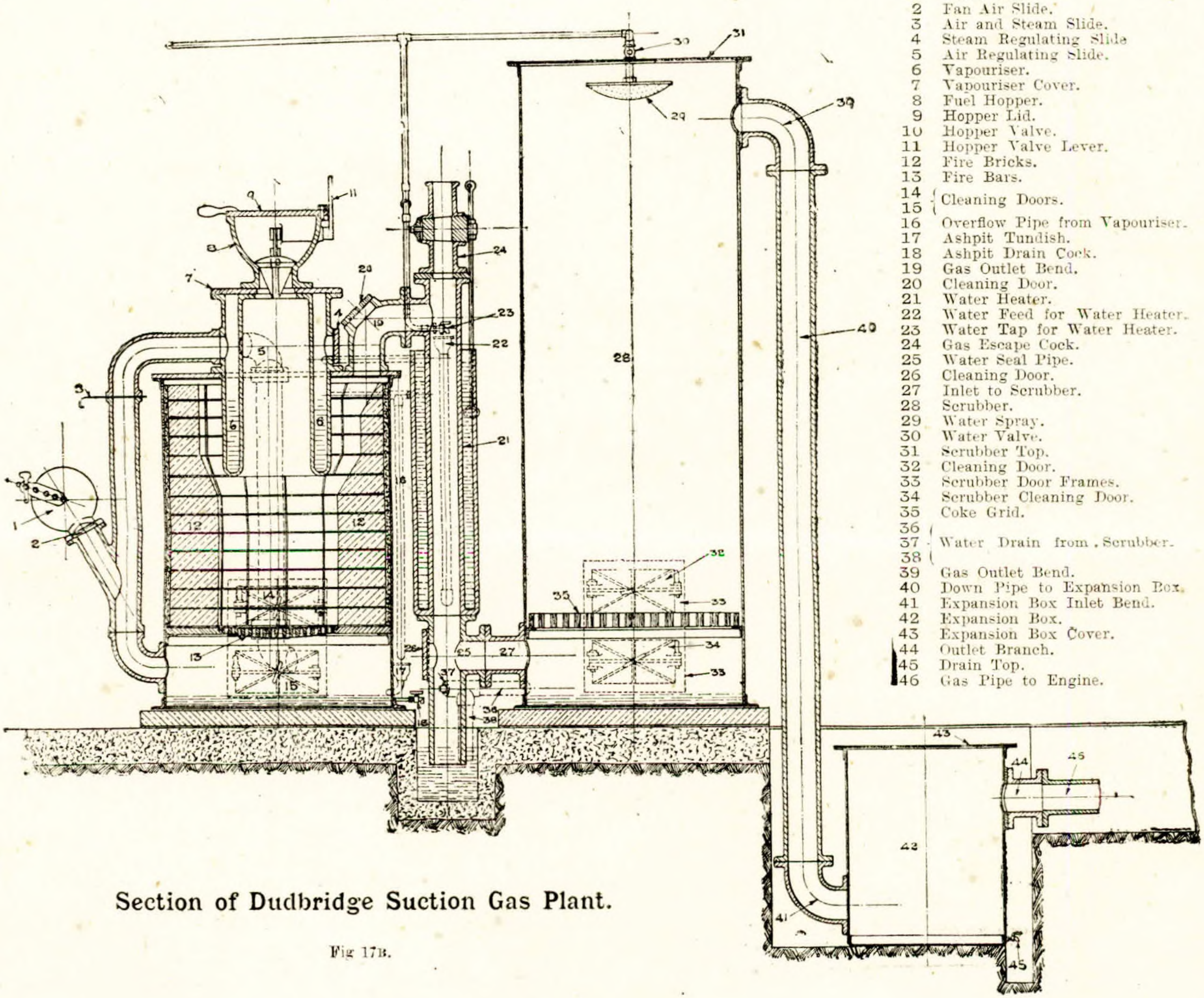
In Figs. 15 and 16 the abscissæ denote engine speeds and the ordinates the mixture strength.

Fig. 17 shows this carburetter in its commercial form with the addition of a slow running jet, a, which is practically a small carburetter in itself.

Gas Producers.—Many gas engines generate their own supply of gas by means of a gas producer Fig. 17B, the engine sucking its supply of air through red hot fuel contained in a generator and then through a scrubber where it is cleaned.

This method of generating gas is very satisfactory, especially from a financial point of view, the cost being very low.

Ignition Jet.—One of the earliest methods of igniting the charge was by means of a gas jet, admitted to the cylinder at the correct moment by a kind of slide valve. The explosion extinguished the jet, which was rekindled by a pilot jet.



No.	Description.
1	Hand Fan.
2	Fan Air Slide.
3	Air and Steam Slide.
4	Steam Regulating Slide
5	Air Regulating Slide.
6	Vapouriser.
7	Vapouriser Cover.
8	Fuel Hopper.
9	Hopper Lid.
10	Hopper Valve.
11	Hopper Valve Lever.
12	Fire Bricks.
13	Fire Bars.
14 15	Cleaning Doors.
16	Overflow Pipe from Vapouriser.
17	Ashpit Tundish.
18	Ashpit Drain Cock.
19	Gas Outlet Bend.
20	Cleaning Door.
21	Water Heater.
22	Water Feed for Water Heater.
23	Water Tap for Water Heater.
24	Gas Escape Cock.
25	Water Seal Pipe.
26	Cleaning Door.
27	Inlet to Scrubber.
28	Scrubber.
29	Water Spray.
30	Water Valve.
31	Scrubber Top.
32	Cleaning Door.
33	Scrubber Door Frames.
34	Scrubber Cleaning Door.
35	Coke Grid.
36 37 38	Water Drain from Scrubber.
39	Gas Outlet Bend.
40	Down Pipe to Expansion Box.
41	Expansion Box Inlet Bend.
42	Expansion Box.
43	Expansion Box Cover.
44	Outlet Branch.
45	Drain Top.
46	Gas Pipe to Engine.

Section of Dudbridge Suction Gas Plant.

Fig 17B.

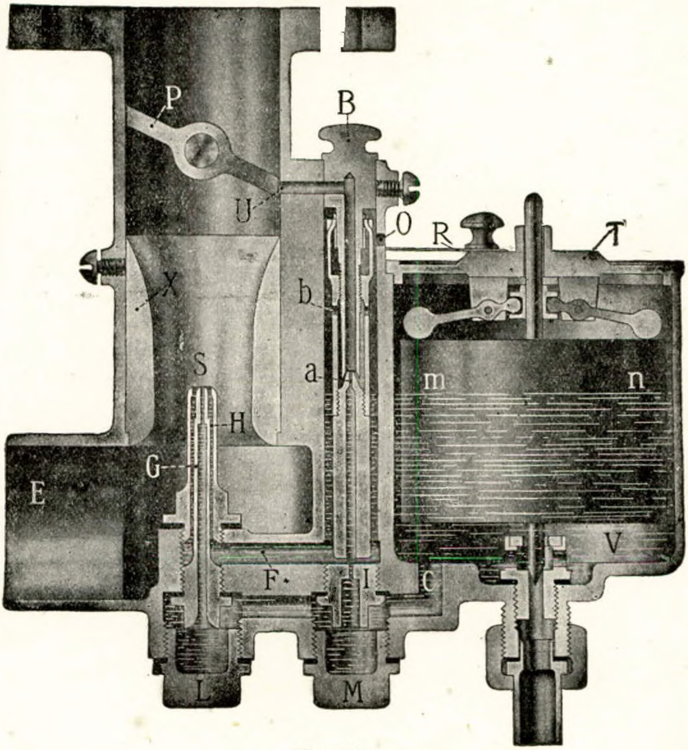


Fig. 17.

Hot Tube.—Jet ignition was soon replaced by the hot tube shown in Fig. 18, which consisted of a tube with a closed end screwed into the combustion chamber and heated by a bunsen, the mixture on compression being forced into the tube and ignited.

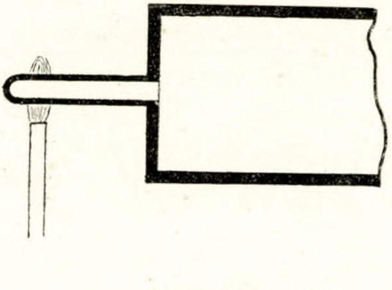


FIG 18

It worked better than at first may be imagined, some slight adjustment of the firing point being obtainable by moving the burner along the tube.

Firing Valve.—Larger engines were fitted with a firing valve which put the tube into communication with the cylinder at the required moment, thus somewhat controlling the firing point.

The early tubes were of platinum and then iron, but later porcelain proved very satisfactory.

Hot Spot.—The ignition of some types of oil engines is after this style, the bulb acting as a tube as well as a vapouriser, see Fig. 19.

Electric Ignition.—The modern ignition, however, is by means of the electric spark, the various forms being shown by Fig. 20.

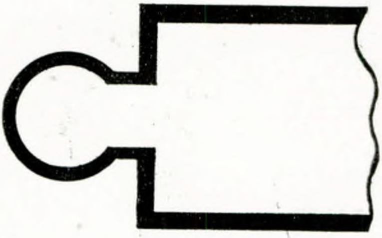


FIG 19

FIG 20

Low Tension.—Ignition by low tension magneto is extensively used for slow speed work, a diagrammatic sketch of the apparatus being shown in Fig. 21.

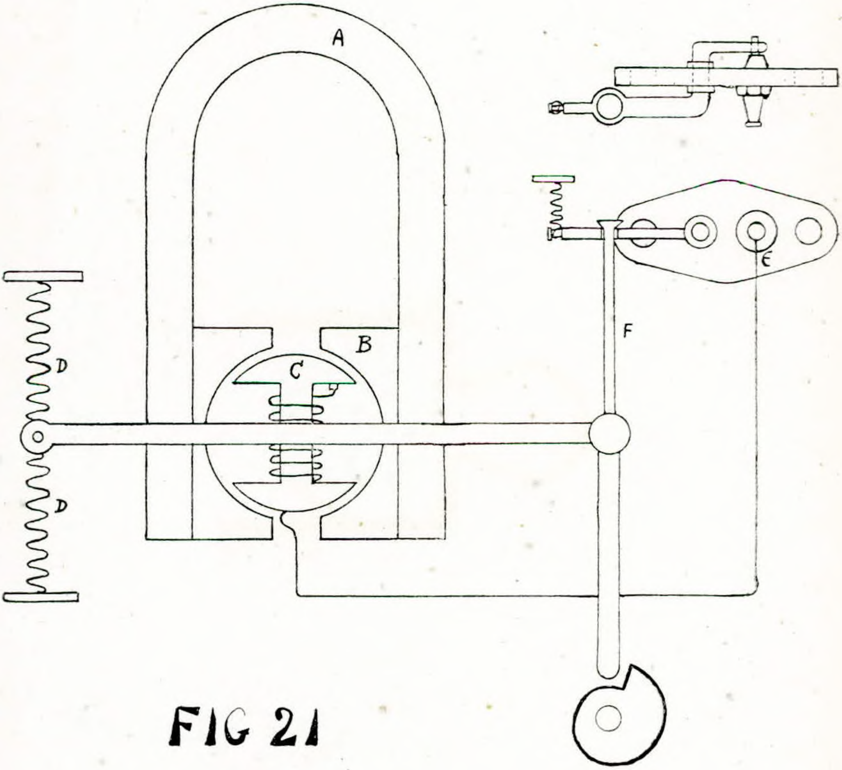


FIG 21

The magneto is of the oscillating type and consists of permanent magnets A, pole pieces B, a shuttle armature wound with fairly thick insulated wire C, and springs D for returning the armature to its position.

At the moment of ignition the cam releases the tappet, giving the armature a strong jerk, this causes a rise of EMF in the winding, one end of which is earthed and the other end led to an insulated button and by a wire to the insulated contact E of the igniter. Immediately after the armature has received its motion the tappet extension F pulls the rocking arm down, thus breaking contact with E and causing the spark.

High Tension Coil.—This type is termed high tension because the spark is not caused by breaking contact, but is given sufficient voltage to enable it to jump a gap at the sparking plug.

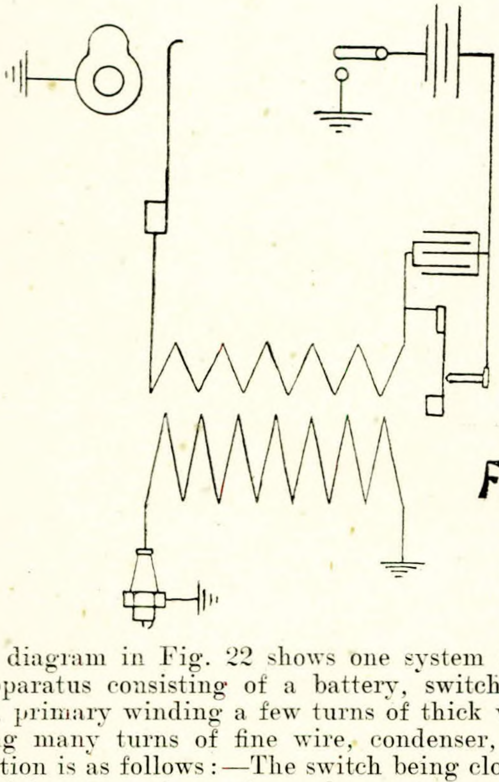


FIG 22

The diagram in Fig. 22 shows one system of connections, the apparatus consisting of a battery, switch, wipe contact maker, primary winding a few turns of thick wire, secondary winding many turns of fine wire, condenser, and trembler. The action is as follows:—The switch being closed the contact maker driven from the engine makes contact and completes the primary circuit at the required moment, causing the trembler to vibrate and thus rapidly interupt the circuit. This generates a high tension current of several thousand volts in the secondary circuit due to the proportion of the windings the current jumping the distance between the sparking plug points.

The practical function of the condenser is to reduce the spark at the trembler contacts which would rapidly destroy them, but incidently it increases the rapidity of demagnetisation of the coil core, thus causing a rapid collapse of the magnetic field which considerably augments the secondary EMF.

High Tension Magneto.—This is shown in Fig. 23 and is very similar to the high tension coil with the exception that a battery is not required, the magneto generating its own primary current.

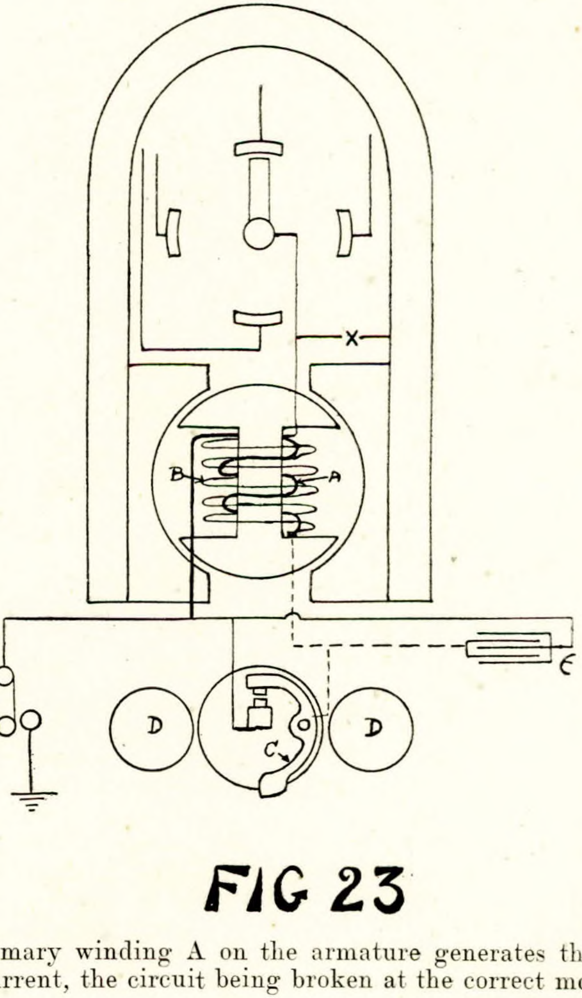


FIG 23

The primary winding A on the armature generates the low tension current, the circuit being broken at the correct moment by the contact breaker C, which is fixed to and revolves with the armature, striking a stationary cam D. This generates the high tension current in the secondary winding B, which is collected by a carbon brush and led to the sparking plugs.

It should be noted that the armature is nearly always arranged to revolve, instead of oscillate, upon this system, and incorporates the condenser E as well as the contact breaker.

A safety gap is provided at X which the spark takes should the plug wires be disconnected.

Lodge.—This ignition is of the coil high tension type and is shown in Fig. 24, the difference being that there are two sparks produced, the spark at A which takes place in the box and is not used and the spark B which is led to the plug.

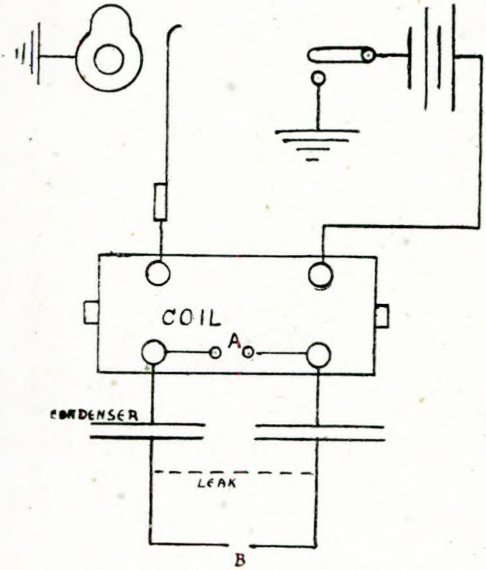


FIG 24

Review.—It has already been stated that the oscillating low tension magneto is used for low speed engines being very popular with this type.

The high tension coil shown in Fig. 22 has the advantage that it gives a shower of sparks at starting but carries with it the disadvantage of accumulator charging, and the fact that the sparking is not so accurate, due to the uncertain type of contact maker and the lag in the coil.

This system is not much used now, but is sometimes incorporated with the high tension magneto to facilitate starting, this then being termed dual ignition. In America where much attention has been given to this particular type of ignition it has been redesigned and now gives the same satisfaction as the high tension magneto, Fig. 25 illustrating the modern version.

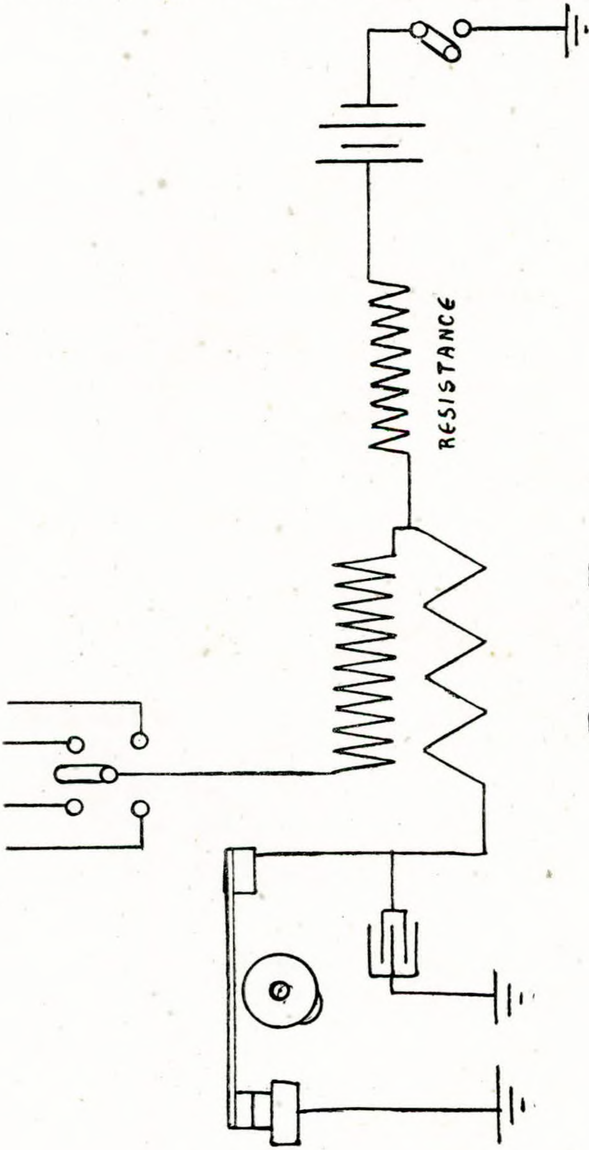


FIG 25

The high tension magneto is used extensively to-day for the ignition of high and moderate speed engines, the firing being accurately timed and it being easily possible to arrange for the ignition of more than one cylinder by the addition of a high tension distributor.

The claims made for the Lodge ignition are that the B spark, as it is called, is of a very detonating character and will prevent carbonisation of the plug, also sparking if the plug should become short circuited.

It has been used upon large stationary engines.

It should be observed that in all engines with any pretence to speed it is found necessary to make the spark occur earlier than dead centre as the charge takes a perceptable time to ignite, this is done by moving round the contact maker or breaker as the case may be.

In very large cylinders more than one plug is often arranged so as to ignite the charge simultaneously at different points.

The amperage of the current passing at the plug in the high tension type of ignition is very small due to the considerable step up in voltage, taking place in the transforming apparatus, this fact explaining why a considerable shock can be obtained from a plug lead without fatal results.

The sparking voltage between two brass spheres 0·5ins. in diameter is approximately as follows:—

Distance apart in inches.	Voltage.
0·1	5,000
0·5	15,000
1·0	25,000

The distance apart of the electrodes in the cylinder is about 0·020in., but it should be remembered that the compression influences the resistance of the gap and also that the facility for the passage of the spark depends upon the area of the electrodes, increasing greatly as one becomes more pointed. In practice they are made of heavy section so as not to cause preignition by becoming incandescent. A difference between coil and magneto ignition with regard to switching off may be mentioned inasmuch that in switching-off a coil the primary circuit is broken whereas with magneto ignition the primary winding is short circuited by earthing through a switch S, Fig. 23.

Fuels.—As previously stated in an earlier part of the paper the internal combustion engine will function satisfactorily upon many different fuels, the study of the characteristics of which becomes quite a complex matter.

Some of the principal points however which interest an engineer are the cost, the heating value, and the amount of deposit which they leave in the cylinder.

The cost of course is controlled by many factors and cannot be dealt with here, but an idea of the heating value of different fuels can be obtained from the following tables:—

Gases.	B.T.U's per cu. ft. Lower Value.
Natural Gas	900
Coal Gas	691
Water Gas	285
Producer Gas—Coke	135
—Anthracite	145
—Soft Coal	145
Coke Oven Gas	545
Blast Furnace Gas	100
*Acetylene Gas	1,480

Oils.	S.G. at 32° C.	B.T.U's per lb. Lower Value.
Crude average	0·870	19,100
Solar	0·870	
Petrol	0·680	19,300
,,	0·720	18,500
,,	0·760	18,300
Kerosene, American	0·800	18,500
†Alcohol	0·810	11,600
Benzol	0·880	18,200

Mixtures.	Air required for Combustion cu. ft. per cu. ft. of Gas.
Natural Gas	9·0
Coal Gas	5·25
Producer Gas—Coke	1·00
,, ,, Anthracite	1·15
,, ,, Soft Coal	1·25
Coke Oven Gas	5·00
Blast Furnace Gas	0·70
Petrol, maximum power	14·00
,, ,, efficiency	16·50
Alcohol	11·00
Benzol, maximum power	16·20
,, ,, efficiency	20·10
Acetylene	12·00

* 1 lb. Carbide = 5 cu. ft. of Gas.

† Can be made from Potatoes, Rye, Starch, etc., Dematurised by the addition of Wood Alcohol.

With regard to the deposit question it may be said that all fuels are offenders in this respect, the combustion chamber having to be cleaned out periodically, engines running upon poor fuels collecting a tar-like substance upon the valves, which unless cleaned off prevents their proper functioning. With the highest grade fuels such as petrol the intervals between cleaning are of course much longer, the deposit in this case being harder, the limit of time being reached when knocking takes place, due to the coating of carbon, reducing the size of the combustion chamber, or a piece of carbon upon one part assuming such proportions that it causes preignition, due to remaining incandescent.

An accurate idea of the conditions prevailing in the cylinder, besides those observed by the indicator, can be obtained by an exhaust gas analysis. This is easily done, the apparatus consisting of a frame holding pipettes containing solutions of—

Caustic Potash to absorb CO_2.
Alkaline Pyrogallol to absorb O.
Acid Cuprous Chloride to absorb CO.

The gas is brought into contact with the solutions, the amount of these constituents indicating the efficiency of the explosion, an excess of O for instance indicating weak, and an excess of CO rich, mixtures.

Engine Speeds.—Engines can of course be constructed to run at speeds suiting different purposes, but on an average speeds are higher than those used in steam practice, varying from 90 r.p.m. for marine engines to 3,500 r.p.m. for automobile racing engines, it being not by any means an easy proposition to control the position of the knee on the speed power curve.

Weights.—Under this heading information is rather difficult to collect, but it may be stated that the engine shown in Figs. 26 and 27, built by the firm which constructed the engines for the airship R34, weighs less than 3lbs. per horse power, and was used during the war in 55ft. boats for chasing submarines.

Aero engines of a similar type often fall below 2lb. per horse power, whilst at the other end of the scale we find two cycle Diesel engines at 160lbs. per horse power and four cycle Diesel engines at 260 lbs. per horse power. It should be noted that due to the heavy strains set up by the high temperatures and method of working, Diesel engines are of very robust construction.

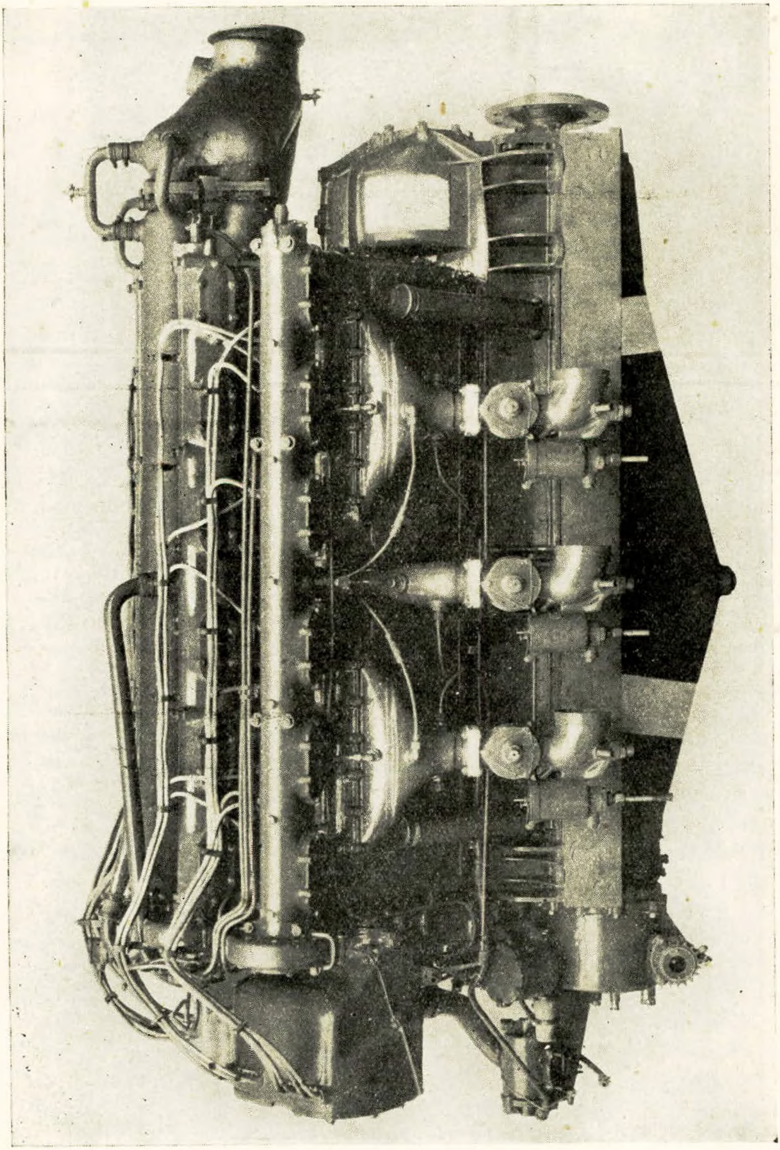


Fig. 26

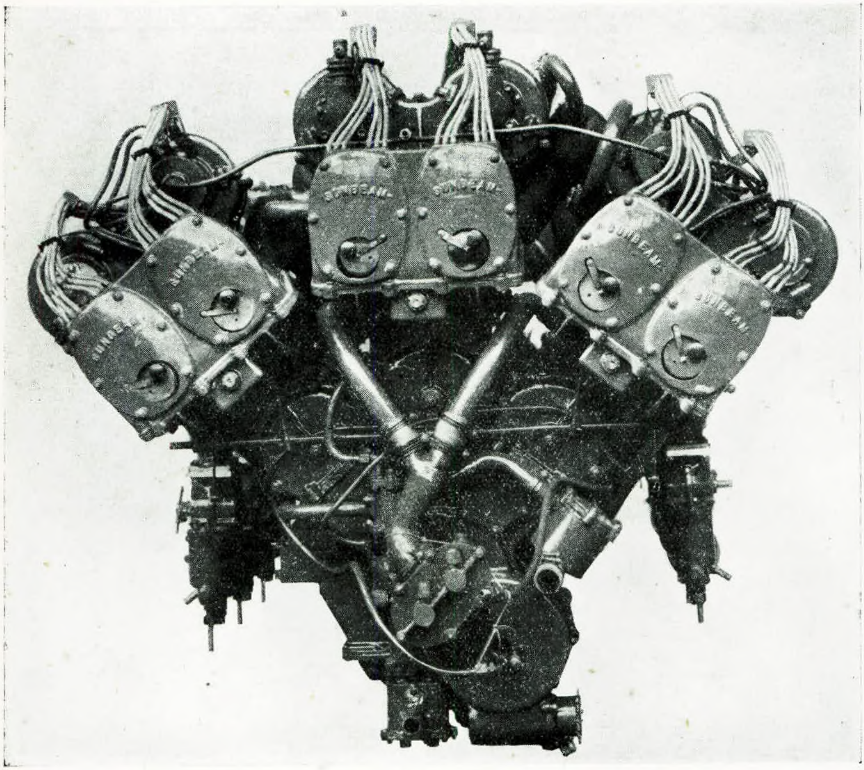


Fig. 27.

Valves.—The slide type of valve previously mentioned, was found to be unsatisfactory and the poppet valve soon came into universal use, being lifted by a cam operated by gearing and returned to its seating by means of a coiled spring. As cast iron was found to withstand the heat well they are often made by screwing a steel stem into a cast iron head, but with high speeds and compression pressures where valves often operate for long periods at a cherry red heat, it has been found necessary to construct them of special steels which resists the warping and burning action, a tungsten type of steel being often used.

For high speed work particular attention has to be paid to the shape of the gas passages in order to give the engines a good volumetric efficiency or free breathing capacity, the valve in head system Fig. 28 having important advantages over the T headed system shown in Fig. 29.

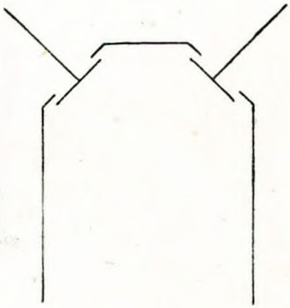


FIG 28

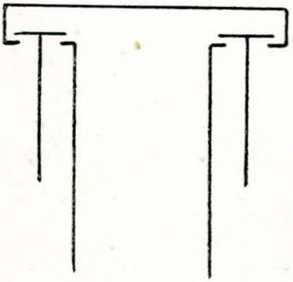


FIG 29

It must not be forgotten, however, that in a mixture, in which no eddying or whirling is taking place, a far longer period must elapse after ignition before the maximum explosion pressure is reached, than could be possibly allowed in any practicable engine. There is therefore a limit in every engine past which it is unwise to carry the free breathing question, if satisfactory running is to be obtained.

The arrangement and design of the valves and passages influences the valve setting, it being found necessary to take advantage of the gas inertia and thus not open and close the valves upon the dead centres.

Valve settings differ considerably, some makers attempting to get rid of the dead gas in the unswept portion of the cylinder by lapping the valves, i.e., allowing the inlet valve to open a few degrees before the exhaust valve closes, so taking advantage of the inertia of the exhaust gas to draw the new charge across the piston tap.

Other types of valves have been introduced from time to time such as the disc, plug and piston types, but the only one attaining any degree of popularity, and this only in one field, is the sleeve valve, Fig. 30.

The sleeves are reciprocated by small eccentrics, the ports registering at the desired points in the stroke.

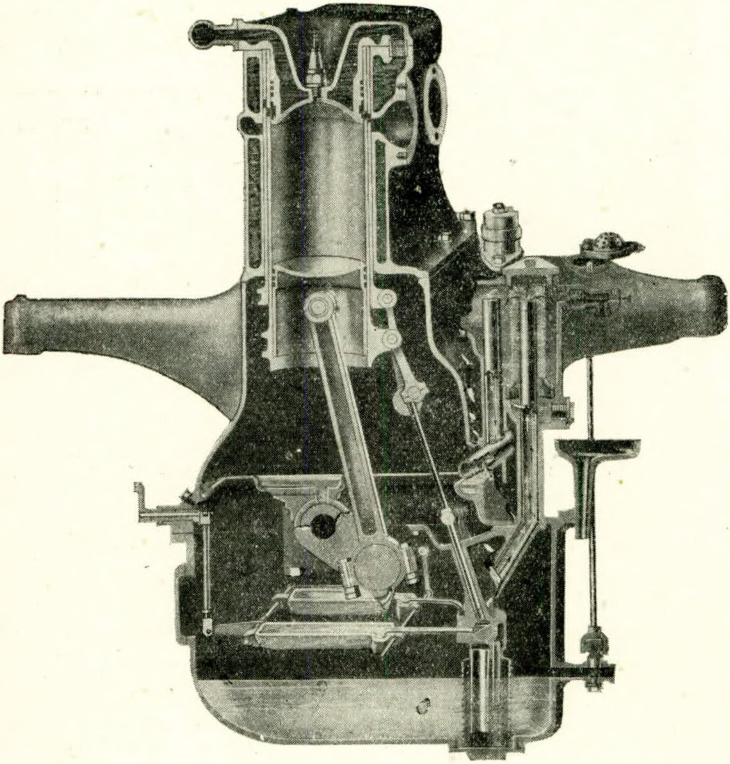


Fig 30

Compression Pressures. It is found an advantage upon theoretical grounds to use as high a compression pressure as possible, the limit being reached when spontaneous combustion takes place, upon the compression stroke, due to the heating up of the charge.

This critical pressure varies with different fuels, being low for fuels containing a large hydrogen content. The general design of an engine also influences the pressure permissible, as will be easily seen, engines with ample water jackets and no overheated local spots in the cylinder permitting the use of a higher compression ratio.

The volumetric efficiency of an engine, spoken of under the heading of Valves, is represented by the equation,—

$$\frac{X}{Vp}$$

Where—

X = Charge actually inducted.
Vp = Volume swept out by the piston.

The compression ratio which plays such a vital point in engine design is given by—

$$\frac{V + Vp}{V}$$

Where—

V = Volume of compression space.

In settling a suitable compression ratio there is not only the critical spontaneous compression pressure to contend with, but also the rate of flame propagation throughout the mixture, which varies with different fuels. For instance acetylene gas and also paraffin mixtures, explode with much violence and often cause severe knocking, which has led some makers to introduce water with the mixture, by means of a drip, in order to tone down the explosion, when the engine is under full load.

The compression of the charge is approximately adiabatic, the expression for which is

$$PV^n = \text{Constant.}$$

The compression pressure is given by the formula

$$P_c = P\left(\frac{V + V_p}{V}\right)^n$$

Where,—

Pc = Compression pressure absolute.
P = Pressure before compression.

As the expression $\frac{V + V_p}{V}$ is the compression ratio which can be represented by R, the compression in terms of it is given by,—

$$P_c = PR^n$$

The pressure P of the charge before compression is governed by the volumetric efficiency, it being in well designed engines about 14·2lbs. per square inch at low speeds and 11 to 13·75lbs. per square inch at normal speeds, the former figure being for a moderately well designed high speed automobile type engine and the latter for a well designed slow speed gas engine.

Other everyday examples fall somewhere between 12·7 and 13·5, 13·1 being a fair average.

The value of the exponent N is in the region of 1·3; a fairly accurate representation of its value being 1·27 for the compression and 1·32 for the expansion line.

The following table gives some of the successful pressures used:—

Fuel.	Engine.	Pressure lbs. per sq. inch gauge.
Paraffin	Four cycle boat	65
Petrol	Two cycle automobile ...	70
Petrol	Four cycle automobile ...	85
Illuminating gas	Four cycle gas	80
Natural gas ...	Four cycle gas	100
Producer gas ...	Four cycle gas	130
Blast furnace gas	Four and two cycle ...	160
Oil	Semi Diesel boat	150-210
Alcohol	Automobile type	200
Diesel	Two cycle marine	450 and upwards
Petrol	Aero engine and racing automobile	130

The following table is also interesting as it gives an idea of the maximum explosion and mean effective pressures prevailing:—

Engine.	Explosion pressure gauge.	M.E.P.
Gas Engine, four cycle ...	450	—
Diesel Engine, four cycle ...	685	151
Diesel Marine, two cycle ...	650	110
Automobile	300	84
Automobile	295	81
Aero Engine, air cooled ...	432	90
Aero Engine, water cooled ...	454	93

Efficiency.—A great point in favour of the adaption of internal combustion engines is the high thermal efficiency obtainable, the following table giving the approximate growth in efficiency of the various prime movers from early times to the present date.

Prime Mover.	Indicated Thermal Efficiency %
Boulton and Watt Condensing	3·8
Lenoir Gas Engine	4·0
Cornish Engine	9·0
Four Stroke Cycle, on inception, Gas ...	16·0
Triple Expansion Condensing	18·0
Oil Engine	22·0
Parson's Turbine	23·0
Petrol Engine, Automobile	25·0
Gas Engine	28·0
Diesel Two Cycle	33·0
Diesel Four Cycle	38·0
Still Engine (said to be)	44·0

The losses in the internal combustion engine are variously estimated by different authorities, but the following is a fair average:—

Loss.	%
In Exhaust	52·5
In Water Jacket	15·3
Mechanical Loss	4·7
Power at Crankshaft	27·5
	100·0

Design.—With regard to the design of this type of engine it may be said that the subject is now of a more settled nature compared with a few years ago when engines were built by rule of thumb methods.

Results are now foretold with considerable exactitude all stresses being fairly accurately computable, a great amount of research work having overcome numerous difficulties.

A small amount of trouble is still met with in connection with the heat gradient in cylinder walls and pistons, resulting in the occasional cracking of these parts from unequal expansion, this being confined principally to the larger sizes.

Many makers are now constructing engines with cylinders set desaxialy, *i.e.*, setting the cylinder not directly over the crankshaft, thus equalising the pressure upon the cylinder walls the amount of setting being reasonable, to avoid complications in other directions.

Balancing has also received considerable attention since it became such an important factor in high-speed engine design, many makers carrying this out with great care, installing apparatus for accurate static and dynamic balancing.

This has assumed such importance with certain makers of automobile engines that some of them fit a device for damping the oscillatory whip of crankshafts which is very liable to occur with six cylinder engines.

More attention is also being paid to the question of metallurgy, the heat treatment of steels being very much to the fore, all up-to-date firms considering this a very important subject the department being under the direct control of the works laboratory.

Some firms, however, as in all other branches of engineering, are still without even a microscope or testing machine, purchasing their materials in the ordinary way and trusting the vendor implicitly the whole sum total of the heat treatment given being the case—hardening of certain parts; this is not confined to the makers of one type of engine but applies to makers in practically every field.

It may be argued that failures due to bad material are few and far between, but this only indicates that the design is bad, the factor of safety being obviously too high. Makers who possess a laboratory, in nearly every case illustrate it in their catalogue, showing that the importance of the fact is realised.

Interchangability is also vastly better than it was, this, of course, being brought about by a free use of the limit system, but nevertheless some firms seem to be only just waking up at the present time, and studying the advantages derivable from its use. The drawing offices of many otherwise up-to-date firms do not seem to have moved with the times, the obviously correct method of designing upon an economical production basis being entirely unknown. This is brought about by the fact that the designers have had very little shop experience in the true sense of the word; so long as an engine can be built to run satisfactorily they seem to remain entirely oblivious of the fact that it is possible to cut off an immense slice of the manufacturing costs by suitably arranging the design with a view to ease of machining and fitting. This art can only be acquired by spending a number of years in the shops, one, two or three or even five years' experience is not enough, it must be considerably more to be of any consequence, as the members of this Institute will agree.

Engines and machines of all descriptions are being built in this country to-day by different firms, without apparently the slightest consideration being given to this question. This lack of workshop experience also reflects itself in such points as accessability, and an inspection of the blueprints issued by some firms will indicate that even in the method of numbering drawings unnecessarily complicated systems are in vogue which waste much valuable time even when a draughtsman gets to thoroughly understand them.

The previously mentioned limit gauge system also needs to be applied with considerable intelligence or it will be found to be expensive; some draughtsmen having no idea what effect a few thousandths of an inch play will have upon the correct functioning of certain parts, and therefore do not know whether to apply a wide or narrow limit thus hindering speed of production.

There is a very valuable table of limits broadly published, but this as its originators inform people, is not intended to be applied to all branches of engineering, and in spite of this it is applied almost universally without any attention to this point. The remedy is for each drawing office to modify the table to suit its own particular work, which is not a difficult matter. Volumes could be written upon the subject of design for economical production, but sufficient has been said to indicate that the present method of installing tool specialists in the works to cut down manufacturing costs, after the design is completed, is not enough as little can then be done compared with what can be accomplished if the subject be tackled in its proper place, *i.e.*, in the drawing office.

Present and Future Developments.—The prime mover with which the present paper has attempted to deal in a general way has now been extant for over a hundred years, during which time great strides have been made in its design.

The whole subject progressed very slowly at first, evidently due to the fact that few engineers were really interested in its welfare, but when the right line of construction was reached great steps were at once made in the development.

This rapid progress continued for some years, each new discovery opening up new fields, until, as in the case of all other prime movers, the design as we know it to-day seems very unlikely to be radically changed, the principals now being well understood.

Great speculation naturally arises in the minds of scientifically inclined people as to what form the next great advance will take, a lull apparently having fallen over the evolution of new prime movers. Supercharging, *i.e.*, forcing in an extra quantity of mixture or air at the end of the induction stroke has been accomplished with a little success, but nothing very revolutionary has transpired, the engine becoming complicated by the addition of such items as pump cylinders.

Suggestions have been made from time to time that a great advance in thermal efficiency might be obtained by combining the steam and the internal combustion engine. This idea occurred to the writer several years ago when a student, and a simple design was got out, but the simple design eventually assumed such a complicated form that the idea was given up for the time being.

The scheme was mentioned to Professor Spooner, which brought to light the information that one of Professor Perry's students had attempted the same thing some years previously. A successful engine of this form has now been evolved by Mr. Still, and judging by the result of tests upon the specimen constructed, is likely to justify much of the confidence reposed in it.

The chief problem, however, which has exercised the minds of designing engineers for a long time, the writer not being excepted, is the construction of a successful gas turbine, it being considered that this is the next and final step in the development of devices for internal combustion. Considering that this was the first engine known, being described in its steam form by Hero in the year 120 B.C., it is very strange that development has not proceeded more upon these lines.

The problems which have had to be surmounted in its steam prototype have shown that the question is by no means as simple as one would imagine considering its elementary form; and when it is considered from an internal combustion standpoint the difficulties are seen to be enormously magnified. The great heat generated is of course the principal obstacle, it being very difficult to construct a machine which will even run for any length of time, but now that refractories are being studied with greater vigour there should be more hope upon this point. Two suggested arrangements are shown in Figs. 31 and 32.

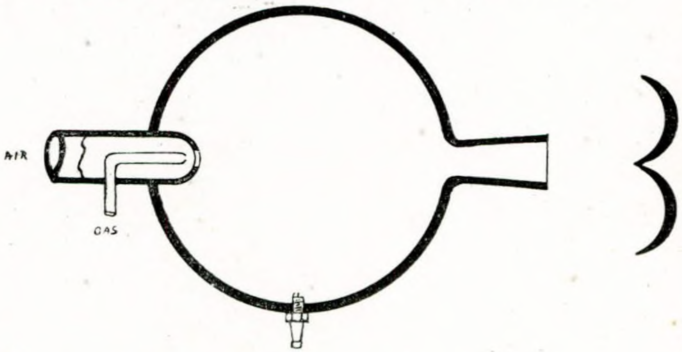


FIG 31

Fig. 31 consists of a chamber of refractory material in which the combustion of the fuel takes place, the gasses impinging upon buckets on a wheel, Pelton or De Laval style.

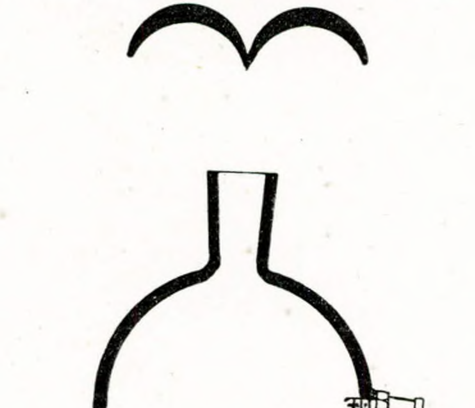


FIG 32

Fig. 32 is of a pulsating type, the action being obtained as follows:—

The chamber being charged and fired the gas rushes out of the jet, overrunning itself by inertia and drawing another charge of mixture after it through the flap valve, the action being rapidly repeated. It will be seen that this is very analagous to the action which takes place in a gas burner when turned very low.

The heat generated in these devices is of course very great, and the materials at present at our disposal do not inspire much confidence in development in this direction, the combustion being so continuous that no chance is given for cooling.

In the ordinary type of high-speed engine the explosions, although very rapid, are intermittent, which allows of the combustion chamber walls being kept at a reasonable temperature, the incoming cool gas being of great use in this direction. Working upon these lines the writer attempted some years ago to evolve a design, one of the results being shown in sectional elevation in Fig. 33, Fig. 34 being the inlet side, Fig. 35 a view on the exhaust side, and Fig. 36 a plan in part section.

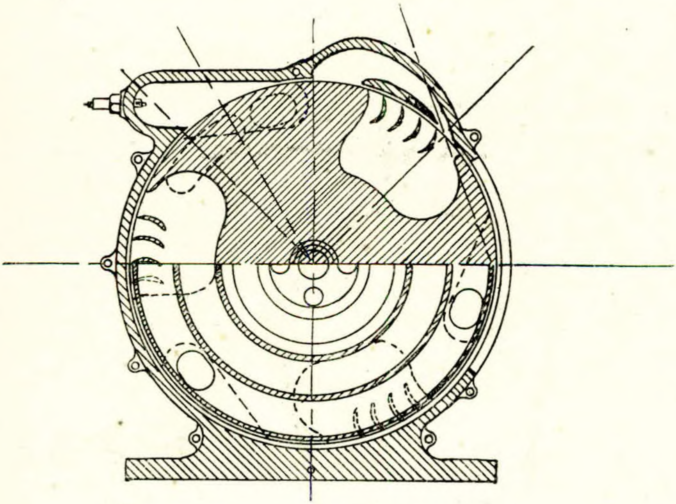


FIG 33

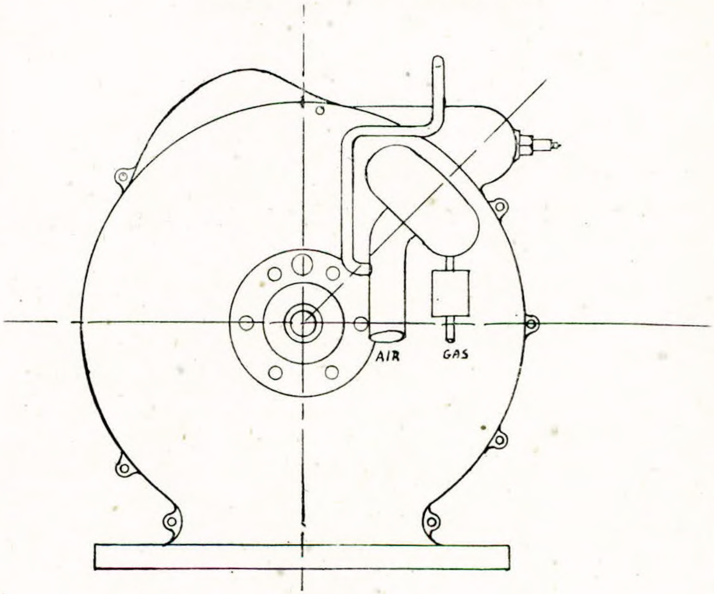


FIG 34

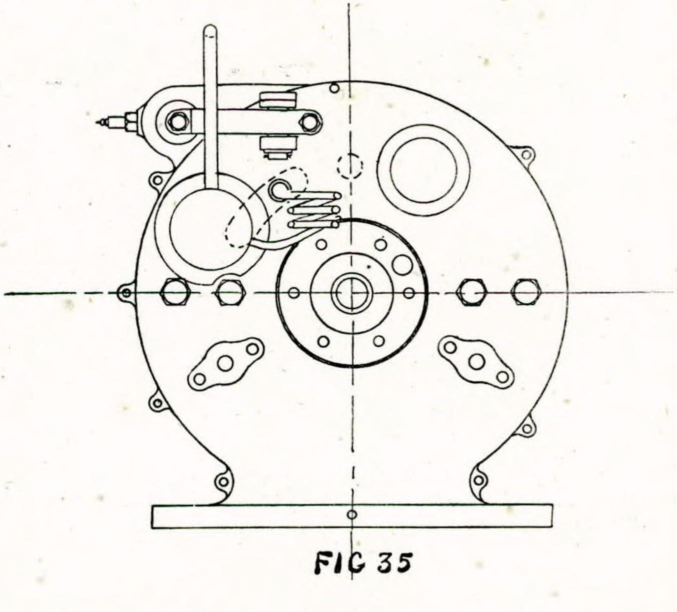


FIG 35

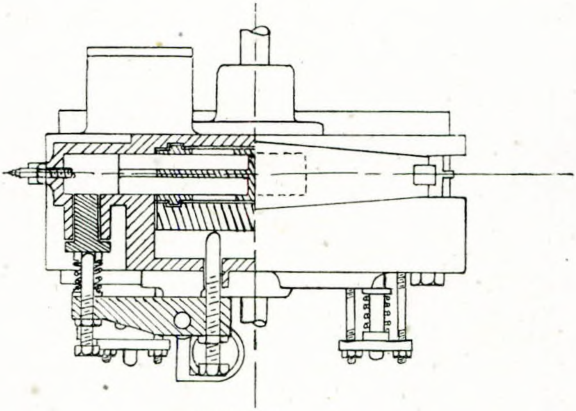


FIG 36

The gas was exploded in a chamber forming part of the casing the resulting explosion doing work by impinging upon the chamber in the rotor from which it escaped being returned again to the rotor vanes by means of a jet, the following charge under pressure scavenging the chamber and refilling it.

Such difficulties as holding the ported rings up to the rotor with just the correct pressure were surmounted by balancing the explosion pressure by means of a piston and fulcrum, Fig. 36, the proportions being such that the pressure tending to force the ring from the rotor face was exactly balanced by the pressure upon the piston.

It will be seen that the foregoing arrangements involve the use of turbo compressors, the efficiencies of which are at present low, and even if a compressor of reasonable efficiency was forthcoming there is no direct prospect of high combined efficiencies being obtainable. A combined steam and gas turbine, however, may do much towards solving the problem, and the writer already sees great prospects in this direction, the resulting machine even if its efficiency was not such as to render existing prime movers obsolete, being undoubtedly of some utility.

In conclusion the writer begs to tender his thanks to makers who have kindly loaned blocks of engines for the purpose of illustration.

TOLERANCES IN STANDARD HOLES.

(2 Grades).

Class	NOMINAL DIAMETERS.	Up to $\frac{1}{2}$"	$\frac{9}{16}$"-1"	$1\frac{1}{16}$"-2"	$2\frac{1}{16}$"-3"	$3\frac{1}{16}$"-4"	$4\frac{1}{16}$"-5"	$5\frac{1}{16}$"-6"
A	High Limit	+·00025	+ 00050	+·00075	+·00100	+·00100	+·00100	+·00150
	Low ,,	—·00025	—·00025	—·00025	—.00050	—·00050	—·00050	—·00050
	Tolerance	·00050	·00075	·00100	·00150	·00150	·00150	·00200
B	High Limit	+.00050	+·00075	+·00100	+·00125	+.00150	+·00175	+·00200
	Low ,,	—·00050	—·00050	—·00050	— 00075	—·00075	—·00075	—·00100
	Tolerance	·00100	·00125	·00150	·00200	·00225	·00250	·00300

ALLOWANCES FOR VARIOUS FITS.

FORCE FITS.

Class	NOMINAL DIAMETERS.	Up to $\frac{1}{2}$"	$\frac{9}{16}$"-1"	$1\frac{1}{16}$"-2"	$2\frac{1}{16}$"-3"	$3\frac{1}{16}$"-4"	$4\frac{1}{16}$"-5"	$5\frac{1}{16}$"-6"
F	High Limit	+·00100	+·00200	+·00400	+ 00600	+·00800	+·01000	+·01200
	Low ,,	+·00050	+·00150	+·00300	+ 00450	+·00600	+·00800	+·01000
	Tolerance	·00050	·00050	·00100	·00150	·00200	·00200	·00200

DRIVING FITS.

Class	NOMINAL DIAMETERS.	Up to $\frac{1}{2}$"	$\frac{9}{16}$"-1"	$1\frac{1}{16}$"-2"	$2\frac{1}{16}$"-3"	$3\frac{1}{16}$"-4"	$4\frac{1}{16}$"-5"	$5\frac{1}{16}$"-6"
D	High Limit	+·00050	+·00100	+·00150	+·00250	+·00300	+·00350	+·00400
	Low ,,	+·00025	+·00075	+·00100	+·00150	+·00200	+·00250	+·00300
	Tolerance	·00025	000·25	000·50	·00100	·00100	·00100	·00100

PUSH FITS.

Class	NOMINAL DIAMETERS.	Up to $\frac{1}{2}$"	$\frac{9}{16}$"-1"	$1\frac{1}{16}$"-2"	$2\frac{1}{16}$"-3"	$3\frac{1}{16}$"-4"	$4\frac{1}{16}$"-5"	$5\frac{1}{16}$"-6"
P	High Limit	—·00025	—·00025	—·00025	—·0005	—·0005	—·0005	—·0005
	Low ,,	—·00075	—·00075	—·00075	—·0010	—·0010	—·0010	—·0010
	Tolerance	·0005	·0005	·0005	·0005	·0005	·0005	·0005

RUNNING FITS (3 Grades).

Class	NOMINAL DIAMETERS.	Up to $\frac{1}{2}$"	$\frac{9}{16}$"-1"	$1\frac{1}{16}$"-2"	$2\frac{1}{16}$"-3"	$3\frac{1}{16}$"-4"	$4\frac{1}{16}$"-5"	$5\frac{1}{16}$"-6"
X	High Limit	—·00100	—·00125	—·00175	—·00200	—·00250	—·00300	—·00350
	Low ,,	—·00200	—·00275	—00·350	—·00425	—·00500	— 00575	—·00650
	Tolerance	·00100	·00150	·00175	·00225	·00250	·00275	·00300
Y	High Limit	—·00075	—·00100	—·00125	—·00150	—·00200	.00225	—·00250
	Low ,,	—·00125	—·00200	—.00250	—·00300	—·00350	—·00400	—·00450
	Tolerance	·00050	·00100	·00125	·00150	·00150	·00175	·00200
Z	High Limit	—·00050	—·00075	—·00075	—·00100	—·00100	—·00125	—·00125
	Low ,,	—·00075	—·00125	—·00150	—·00200	—·00225	— 00250	—·00275
	Tolerance	·00025	·00050	·00075	·00100	·00125	·00125	·00150

TOLERANCES IN STANDARD HOLES.

(2 Grades.)

	Nominal Diameters.	6$\frac{1}{16}$″-7″	7$\frac{1}{16}$″-8″	8$\frac{1}{16}$″-9″	9$\frac{1}{16}$″-10″	10$\frac{1}{16}$″11″	11$\frac{1}{16}$″-12″
Class **A**	High Limit	+·00150	+·00175	+·00175	+·00175	—·00200	+·00200
	Low ,,	—·00075	—·00075	—·00100	—·00100	—·00100	—·00100
	Tolerance	·00225	·00250	·00275	·00275	·00300	·00300
Class **B**	High Limit	+·00225	+·00225	+·00250	+·00250	+ 00275	+·00275
	Low ,,	—·00100	—·00125	—·00125	—·00125	—·00125	—·00150
	Tolerance	·00325	·00350	·00375	·00375	·00400	·00425

ALLOWANCES FOR VARIOUS FITS.

FORCE FITS.

	Nominal Diameters.	6$\frac{1}{16}$″-7″	7$\frac{1}{16}$″-8″	8$\frac{1}{16}$″-9″	9$\frac{1}{16}$″-10″	10$\frac{1}{16}$″-11″	11$\frac{1}{16}$″-12″
Class **F**	High Limit	+·014	+·016	+·018	+ 020	+·022	+·024
	Low ,,	+·012	+·014	+·016	+·018	+·020	+·022
	Tolerance	·002	·002	·002	·002	·002	·002

DRIVING FITS.

	Nominal Diameters.	6$\frac{1}{16}$″-7″	7$\frac{1}{16}$″-8″	8$\frac{1}{16}$″-9″	9$\frac{1}{16}$″-10″	10$\frac{1}{16}$″-11″	11$\frac{1}{16}$″-12″
Class **D**	High Limit	+·00450	+·00500	+·00550	+·00600	+·00650	+·00700
	Low ,,	+·00300	+·00350	+·00400	+ 00450	+·00450	+·00500
	Tolerance	·00150	·00150	·00150	·00150	·00200	·00200

PUSH FITS.

	Nominal Diameters.	6$\frac{1}{16}$″-7″	7$\frac{1}{16}$″-8″	8$\frac{1}{16}$″-9″	9$\frac{1}{16}$″-10″	10$\frac{1}{16}$″-11″	11$\frac{1}{16}$″-12″
Class **P**	High Limit	—·00050	—.00050	—·00050	—·00075	—·00075	—·00075
	Low ,,	—·00125	—.00150	—·00150	—·00200	—·00200	—·00200
	Tolerance	·00075	.00100	·00100	00·125	·00125	·00125

RUNNING FITS.

	Nominal Diameters.	6$\frac{1}{16}$″-7″	7$\frac{1}{16}$″-8′	8$\frac{1}{16}$″-9″	9$\frac{1}{16}$″-10″	10$\frac{1}{16}$″-11″	11$\frac{1}{16}$″-12″
Class **X**	High Limit	—·00350	·00350	—·00375	—·00400	—·00400	—·00425
	Low ,,	—·00675	—·00700	—·00750	—·00800	—·00825	—·00850
	Tolerance	·00325	·00350	·00375	·00400	·00425	·00425
Class **Y**	High Limit	—·00275	—.00275	—·00300	—·00325	—·00325	—·00350
	Low ,,	—·00475	— 00500	—·00550	—·00575	—·00600	—·00625
	Tolerance	·00200	·00225	·00250	·00250	00 275	·00275
Class **Z**	High Limit	—·00125	—·00150	—·00150	—·00150	—·00175	—·00175
	Low ,,	—·00275	—·00300	—·00300	—·00325	—·00350	—·00350
	Tolerance	·00150	.00150	·00150	·00175	·00175	·00175

Fig. 37. Newall Limit Table.

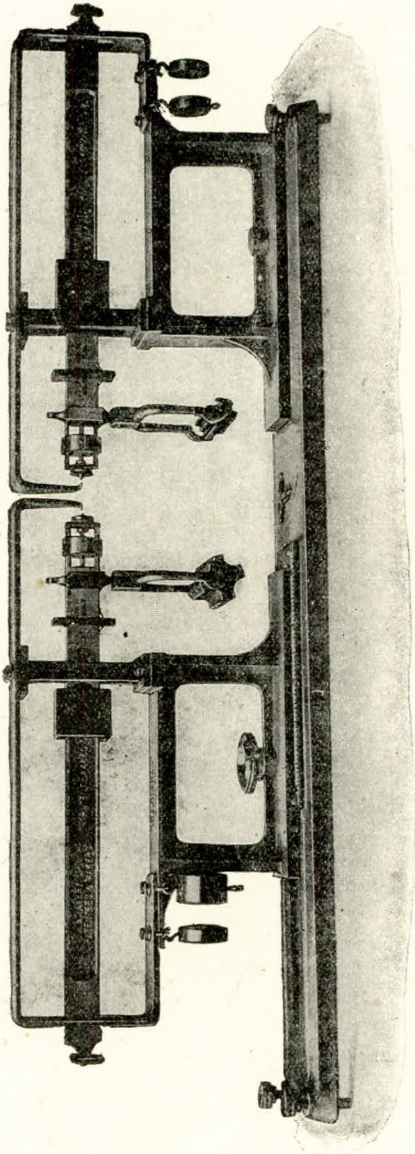


Fig. 38. Connecting Rod Balancing Machine.

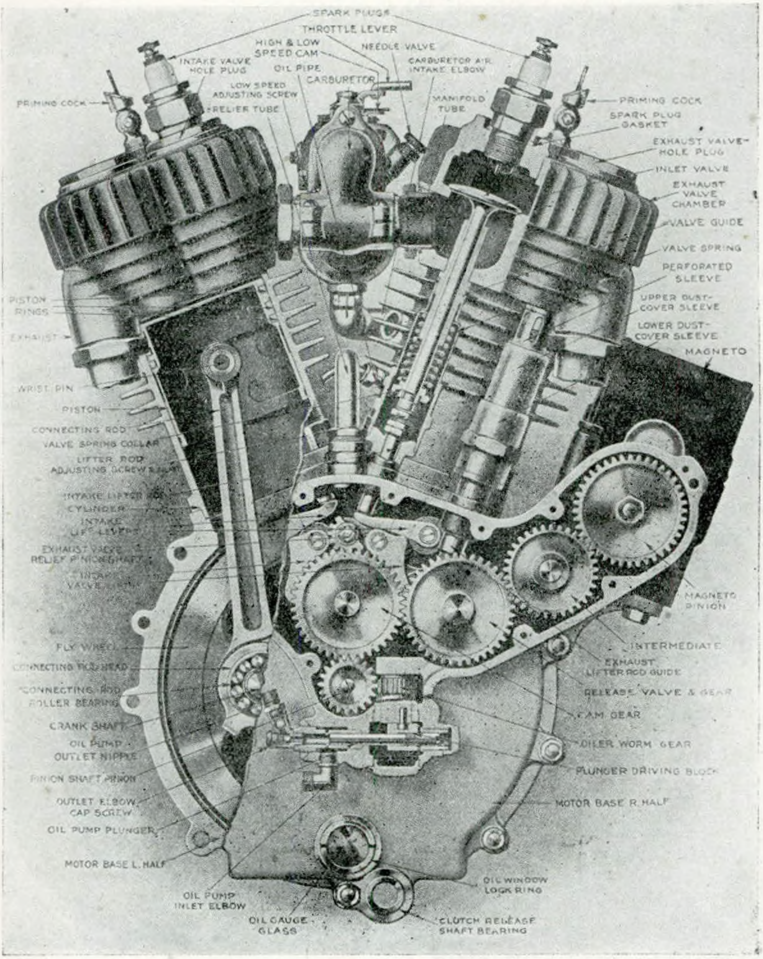


Fig. 39 Sectional view of the Indian Powerplus Motor.

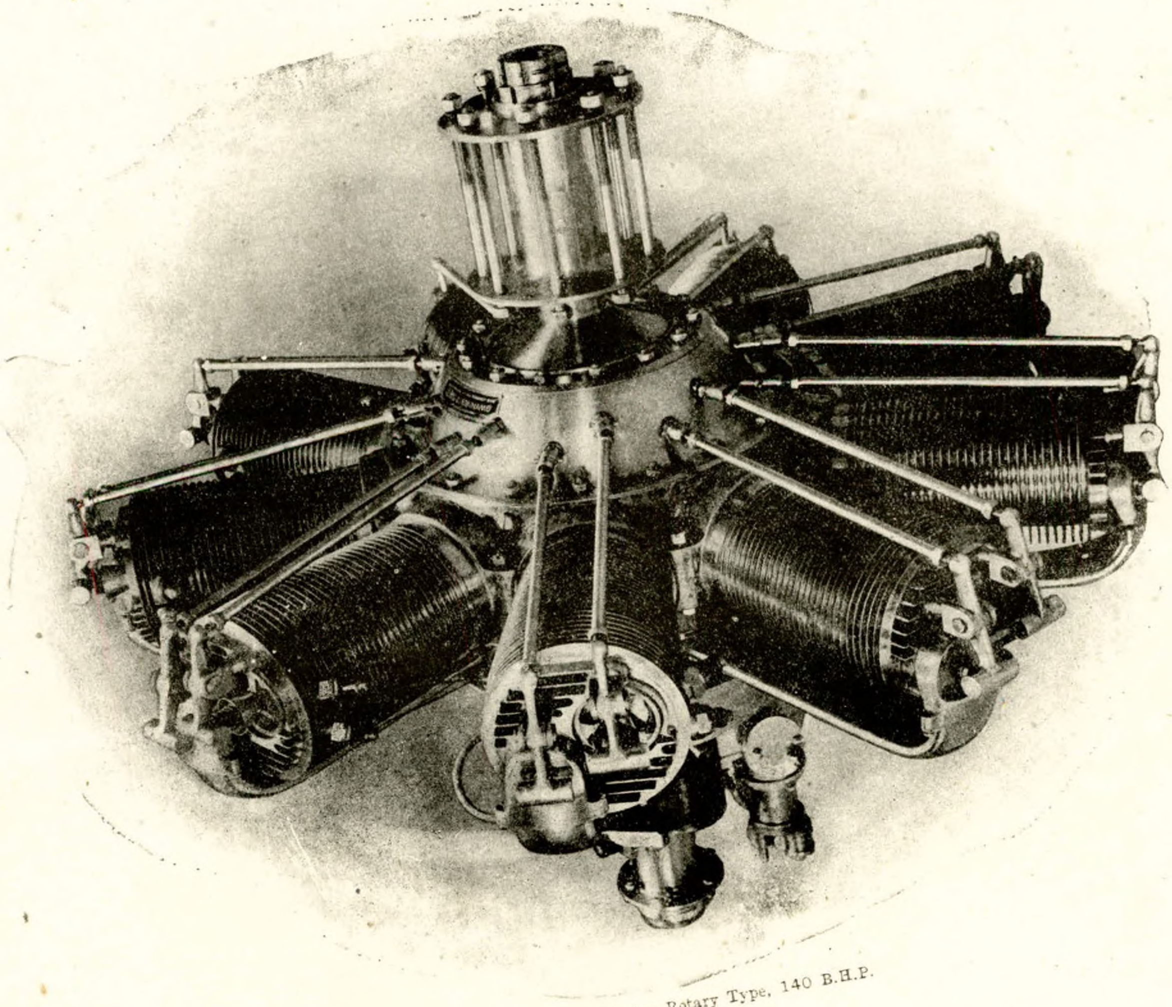


Fig. 40. Aero Engine Rotary Type, 140 B.H.P.

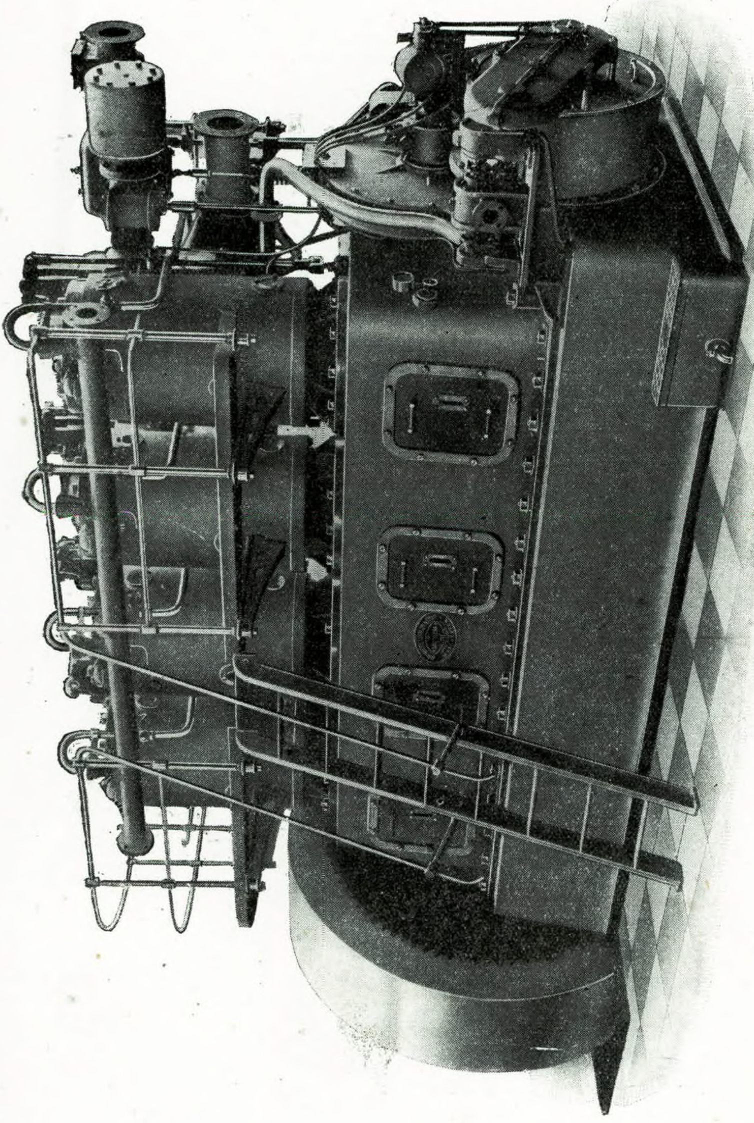


Fig 41. Four Cylinder Gas Engine.

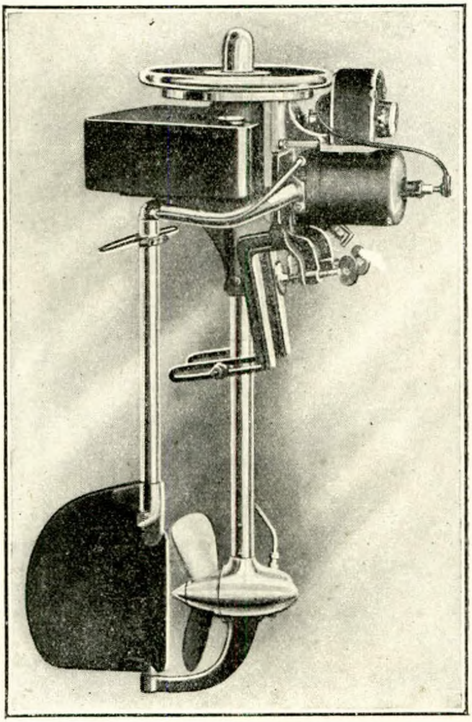


Fig. 42. Detachable Boat Motor.

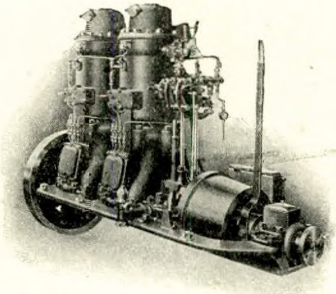


Fig. 43. Two Cylinder Hot Bulb Engine.

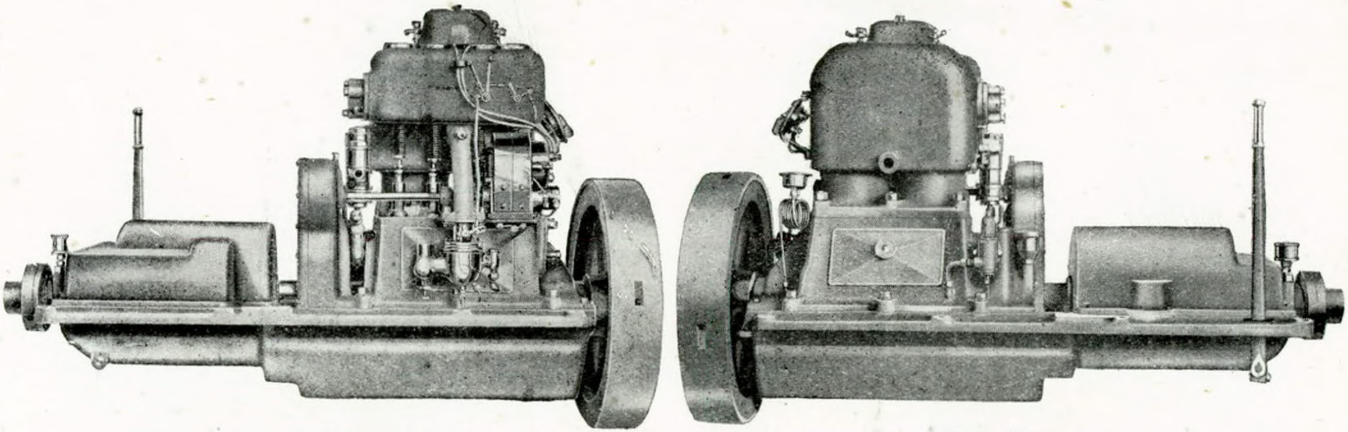


Fig. 44. Two Cylinder 15 H.P. Launch Engine. Bore, 5·5in.; Stroke, 7in.

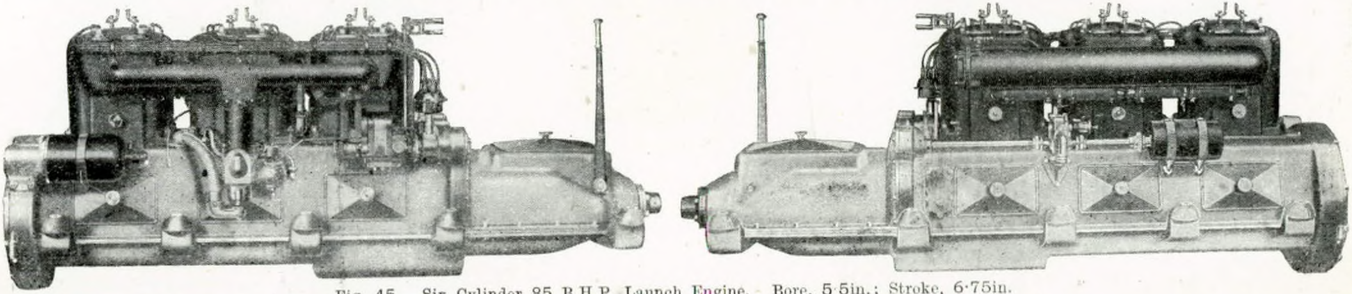


Fig. 45. Six Cylinder 85 B.H.P. Launch Engine. Bore, 5·5in.; Stroke, 6·75in.

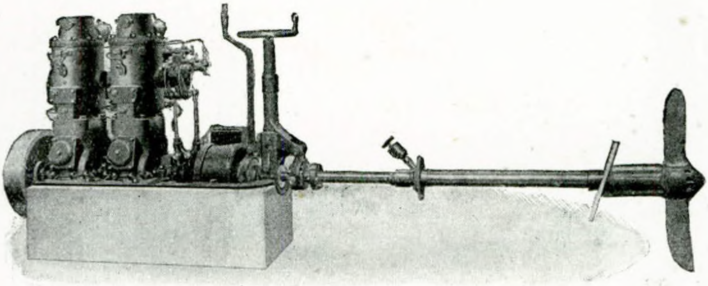


Fig. 46. Two Cylinder Hot Bulb Marine Oil Engine.

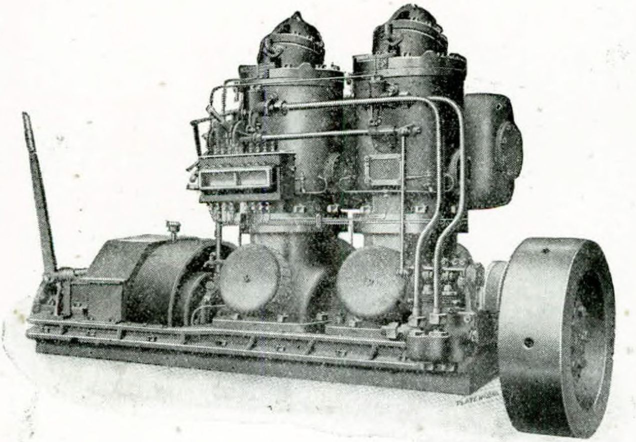


Fig. 47. Two Cylinder Direct Reversing Marine Oil Engine.

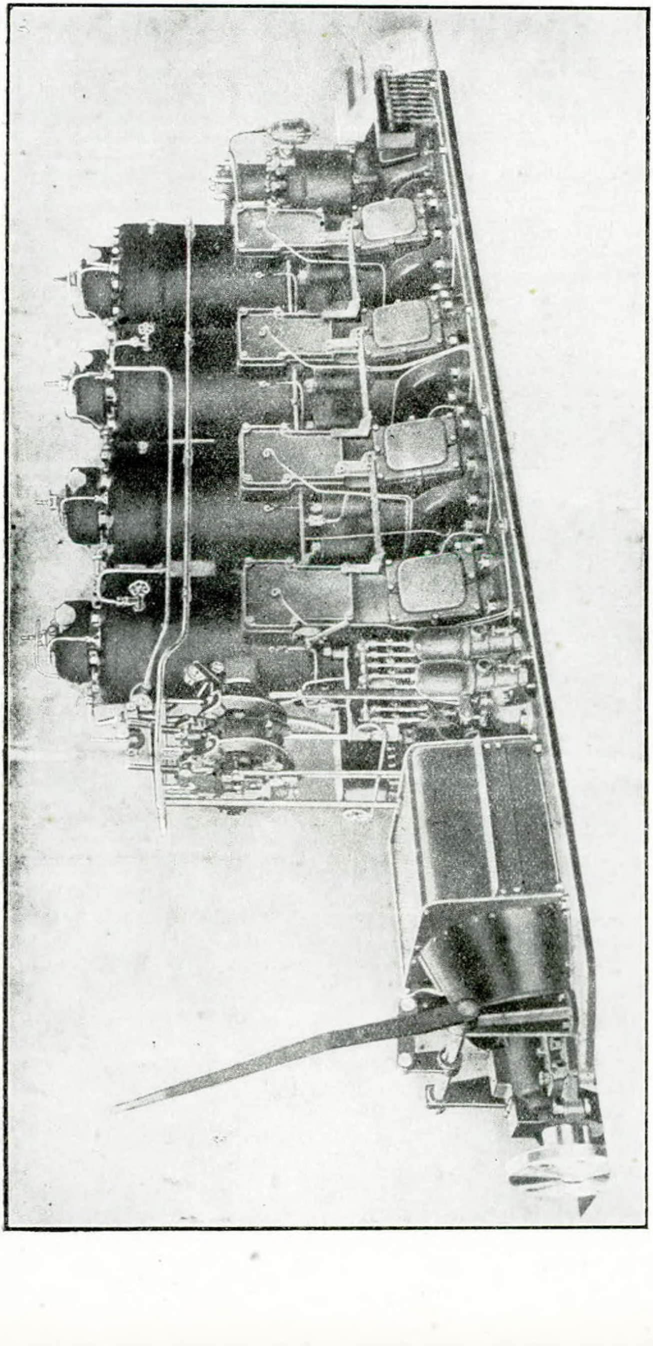


Fig. 48. Four Cylinder Marine Oil Engine.

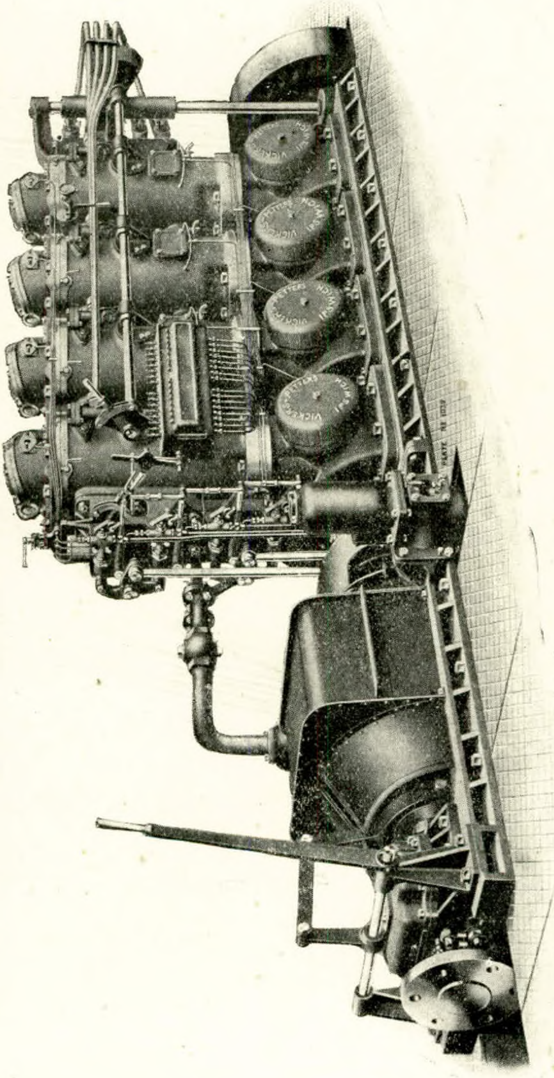


Fig. 49. 220 B.H.P. Direct Reversing Marine Crude Oil Engine.

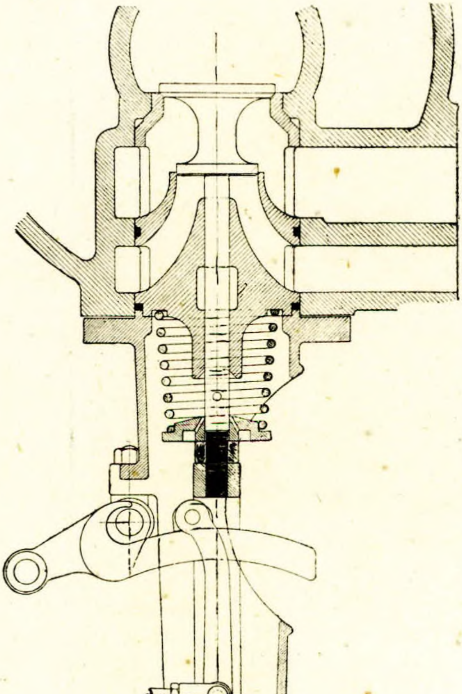


Fig. 50. Gas Engine Inlet Valve, Quantity Governing System.

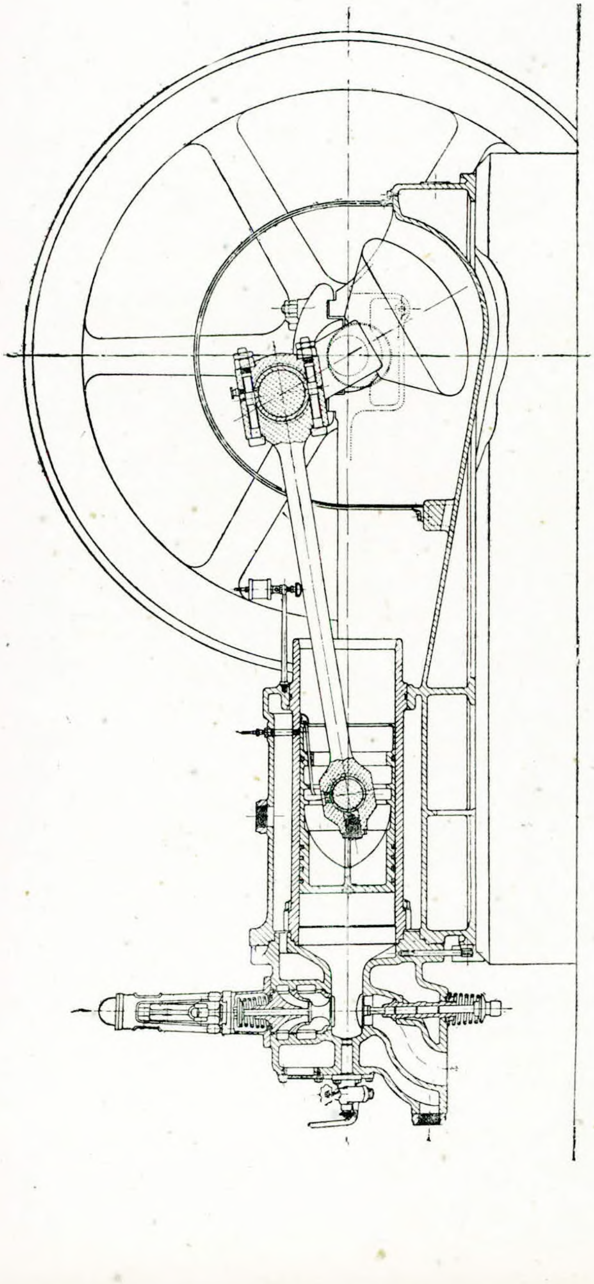


Fig. 51. **Section through Gas Engine.**

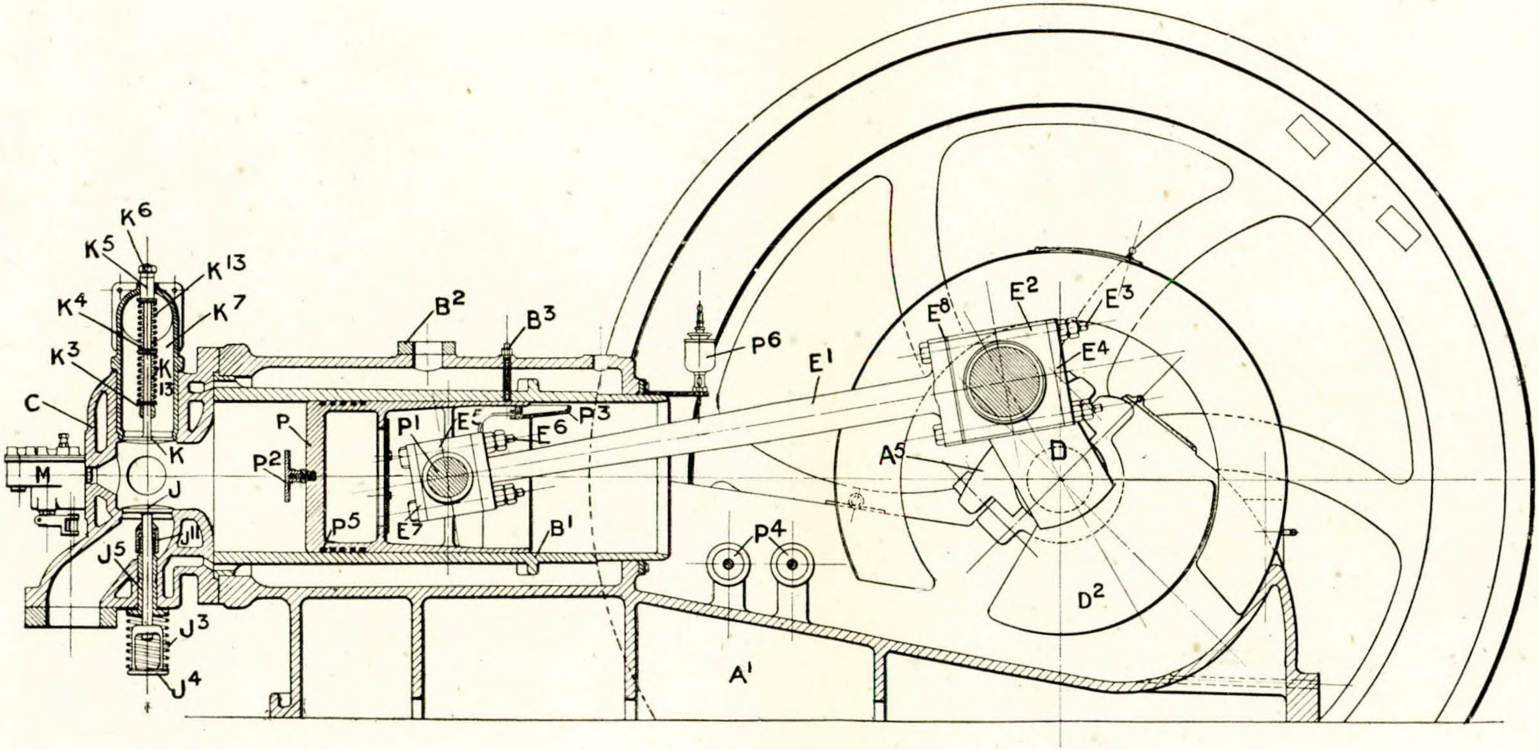


Fig 52. Section through Gas Engine.

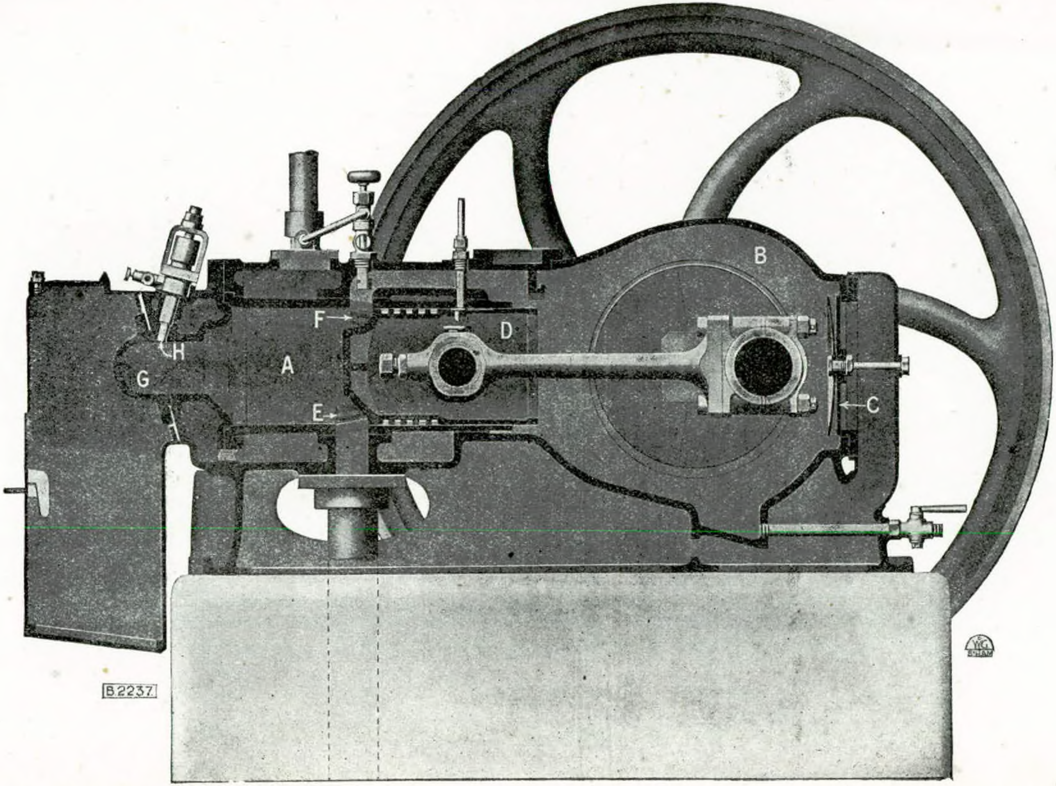


Fig. 53. Section through Two Cycle Oil Engine.

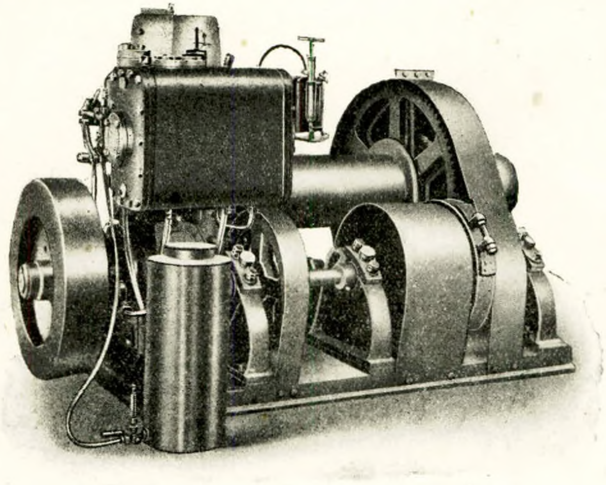


Fig. 55. Motor Winch.

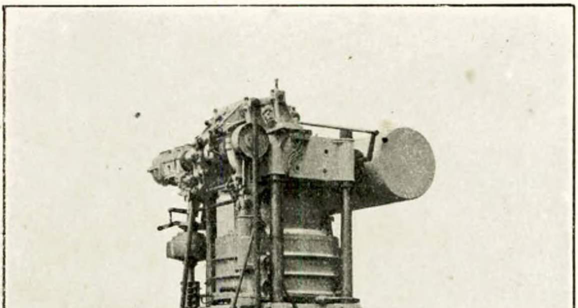


Fig. 56. Experimental Two Stroke Marine Oil Engine (Diesel).

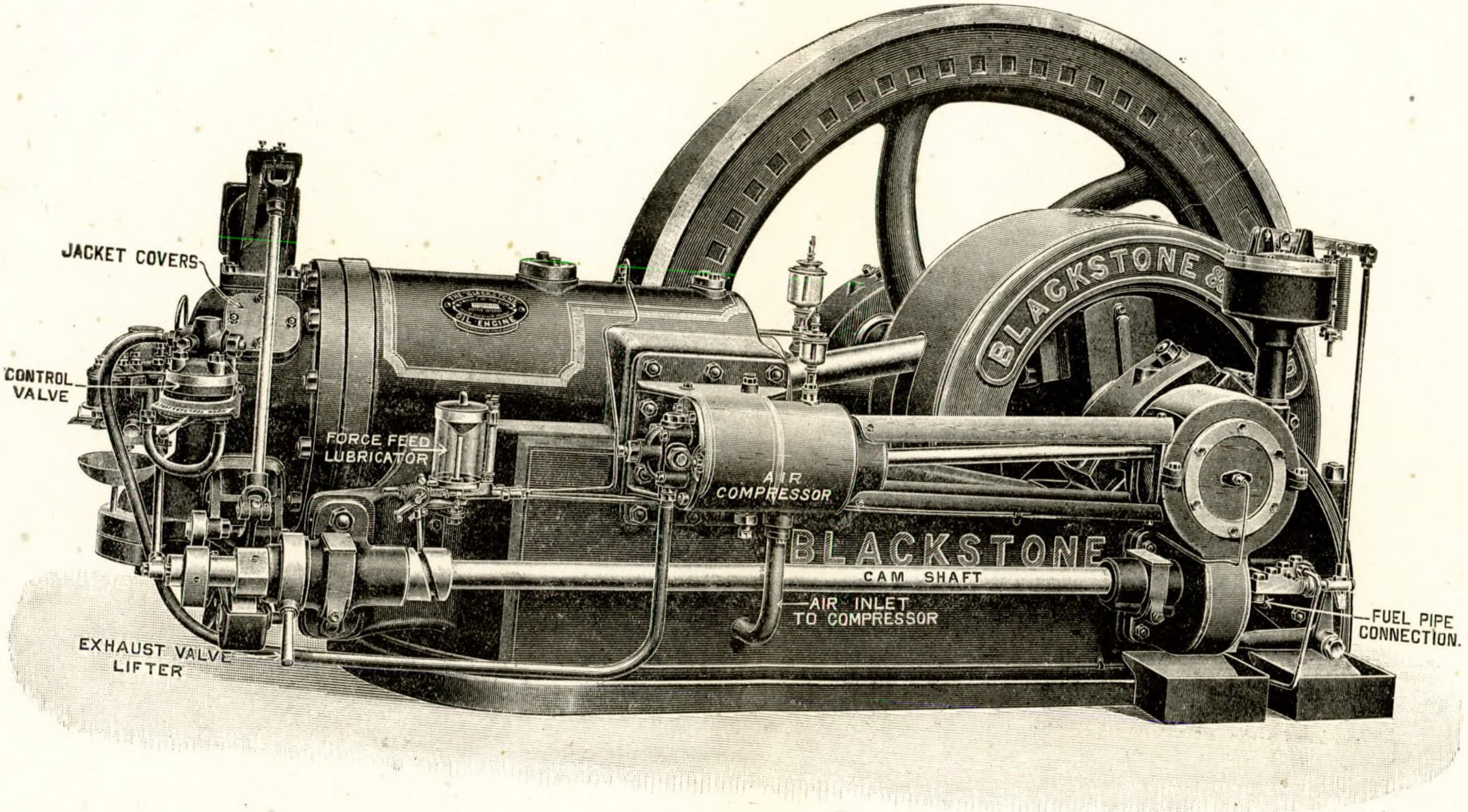


Fig. 54. Gas Engine.

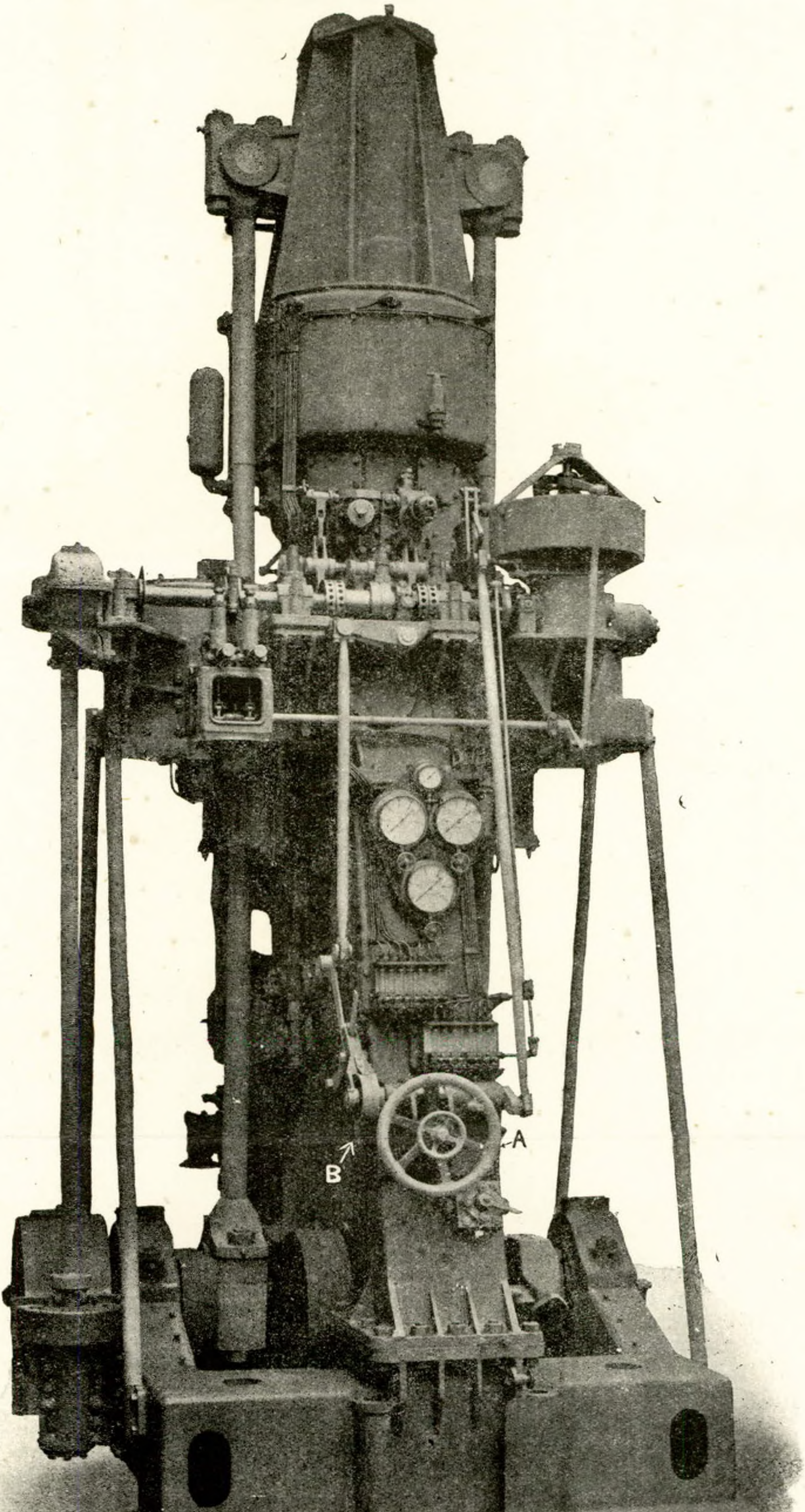


Fig. 57. Experimental Two Stroke Marine Oil Engine, Opposed Piston Type (Diesel).

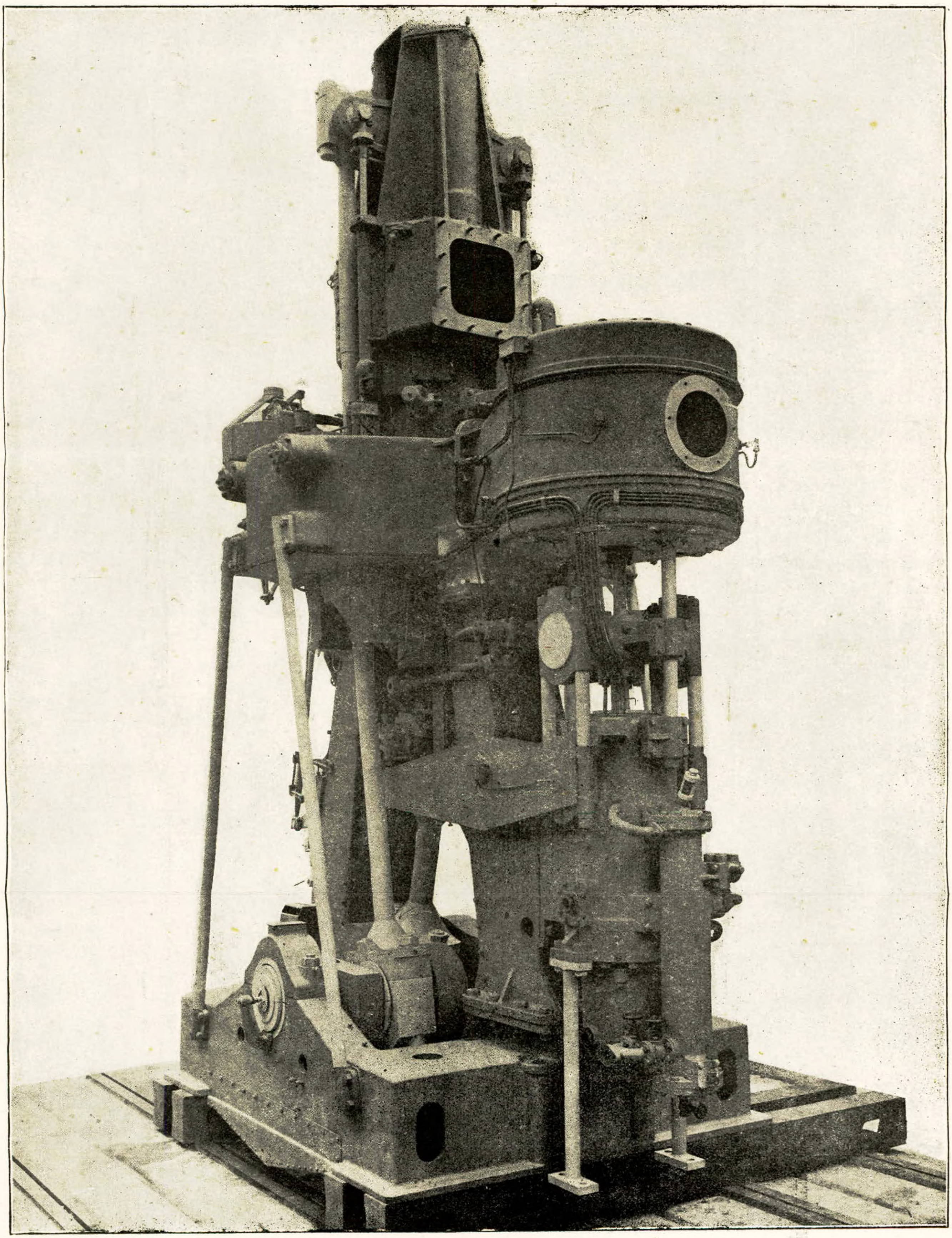


Fig. 58. Back View

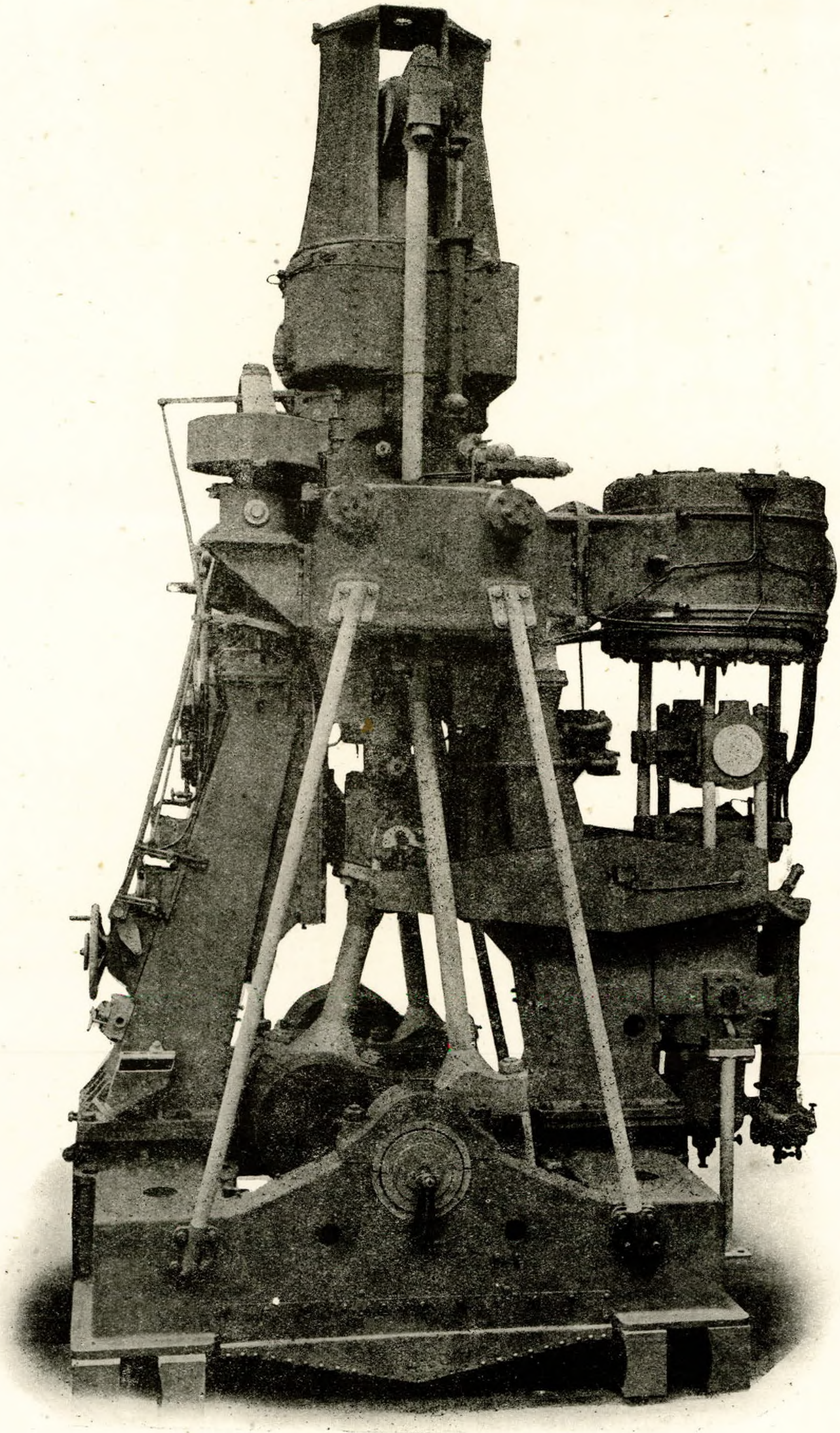


Fig. 59. Side View.

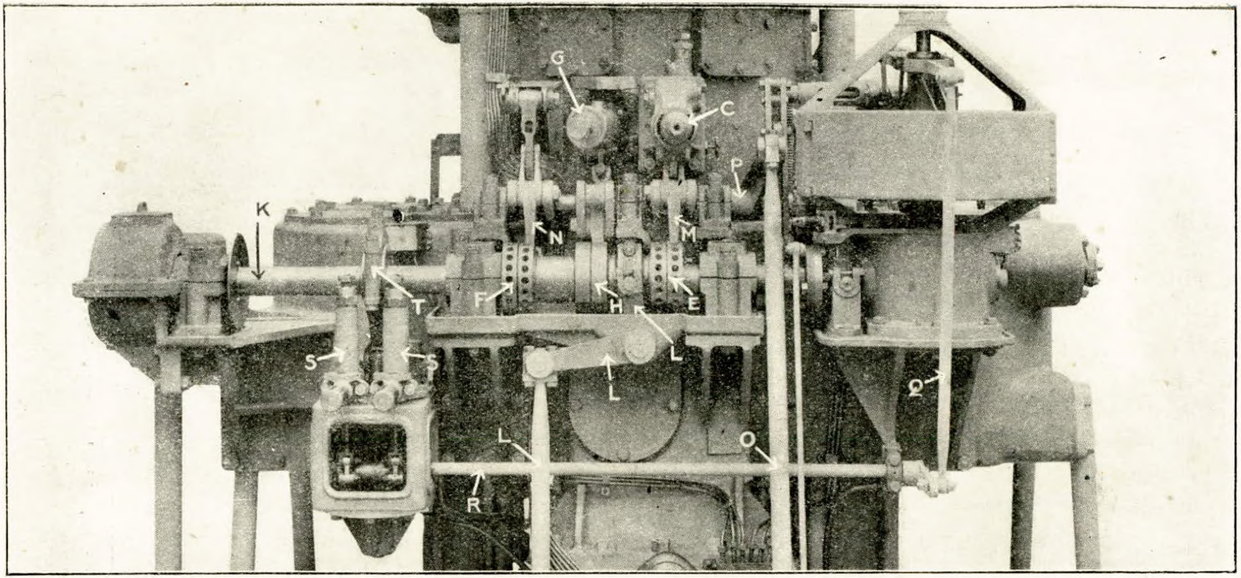


Fig. 60. Valve Gear.

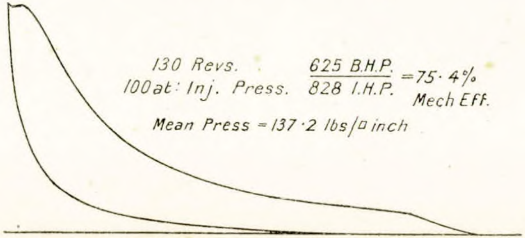


Fig. 61. Indicator Diagram.

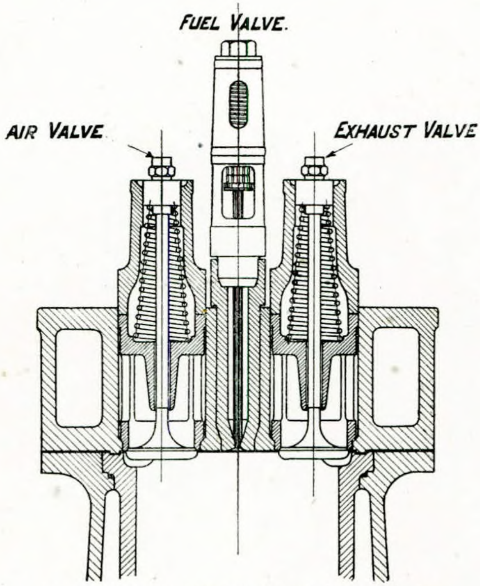


Fig. 63. Section through Valves, Diesel Engine.

Fig. 64. Diesel Full Load Diagram.

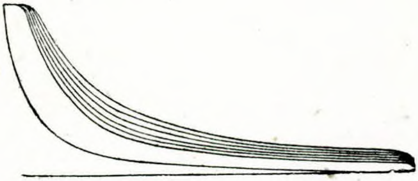


Fig. 65. Diesel Diagram showing Governing Action.

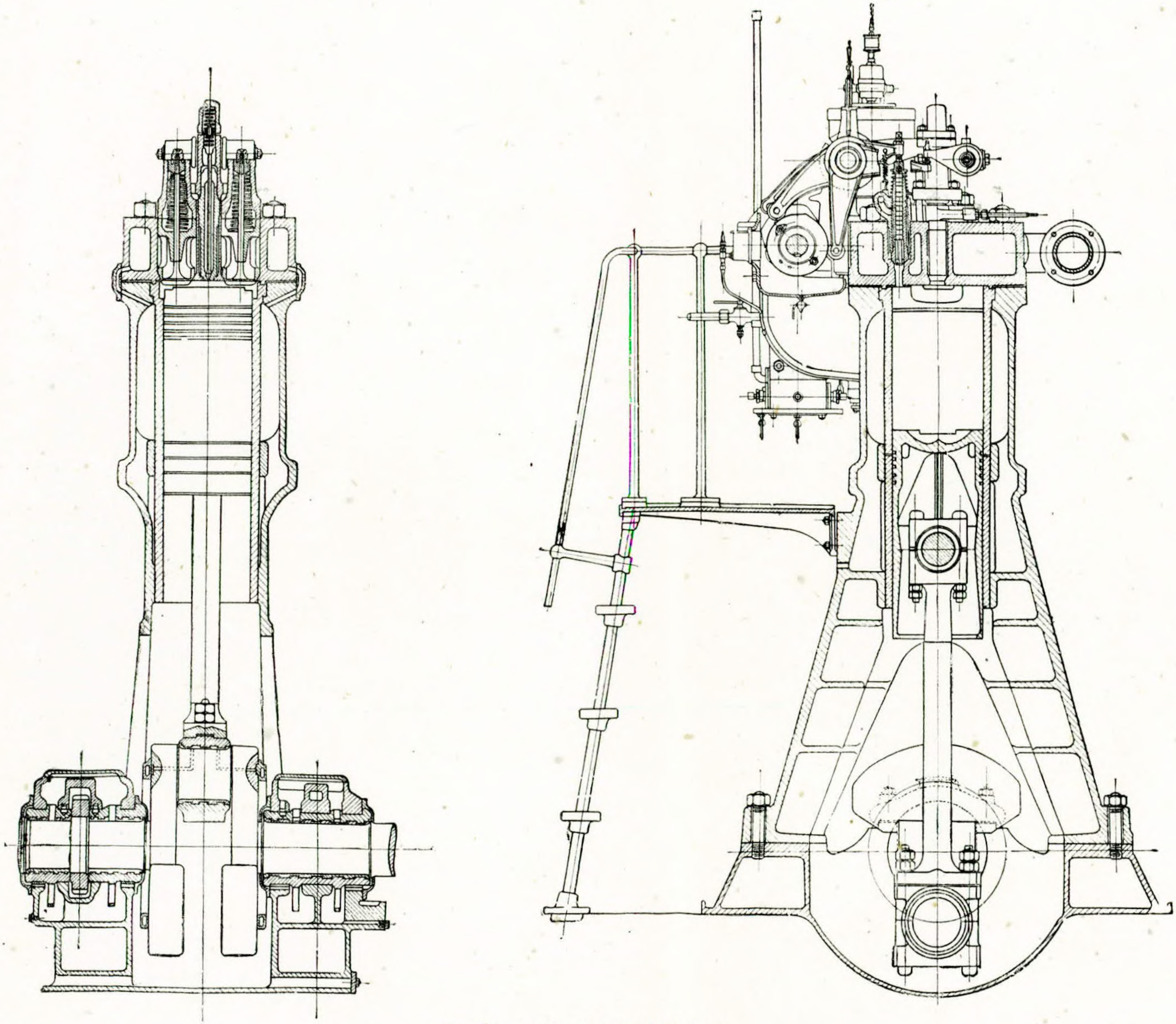


Fig. 62. Section through Diesel Engine.

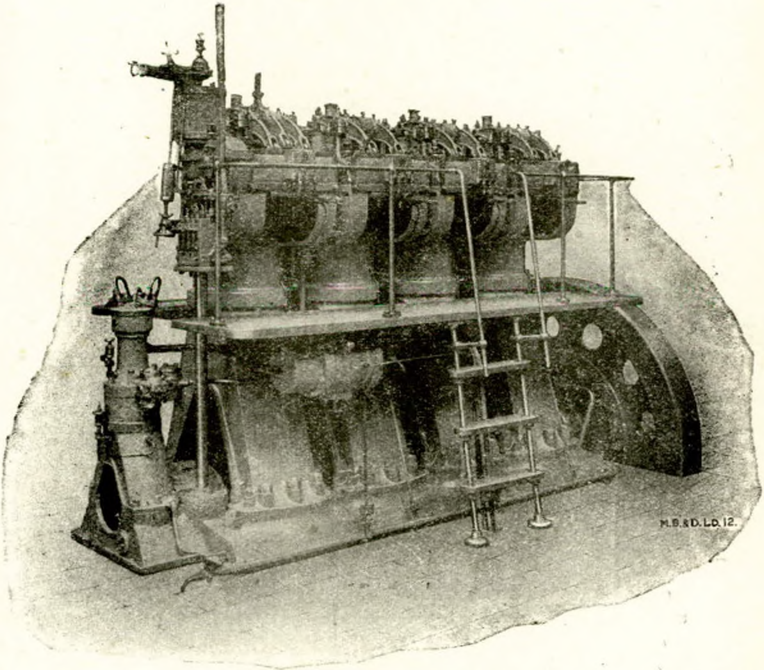


Fig. 66.—200 B.H.P. Diesel Engine.

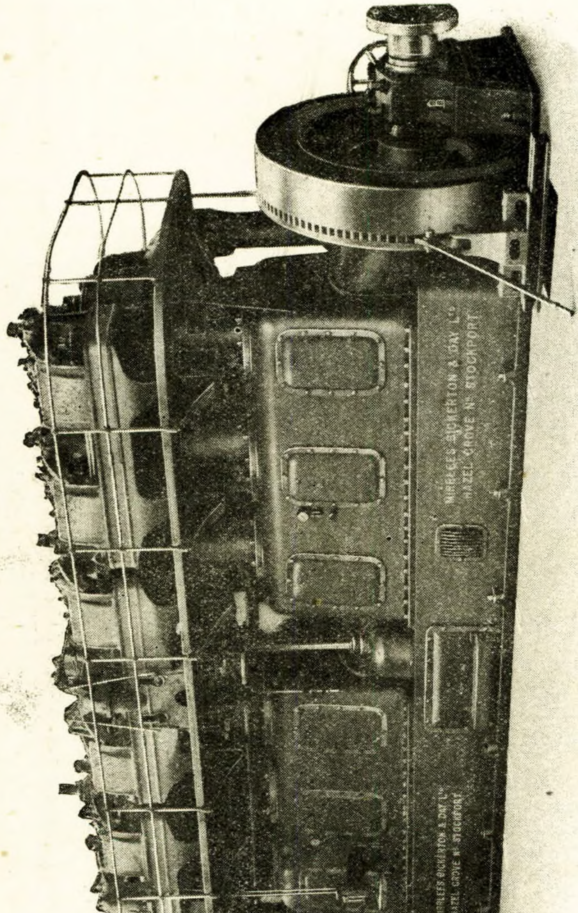


Fig. 67. 750 B.H.P. Diesel Engine.

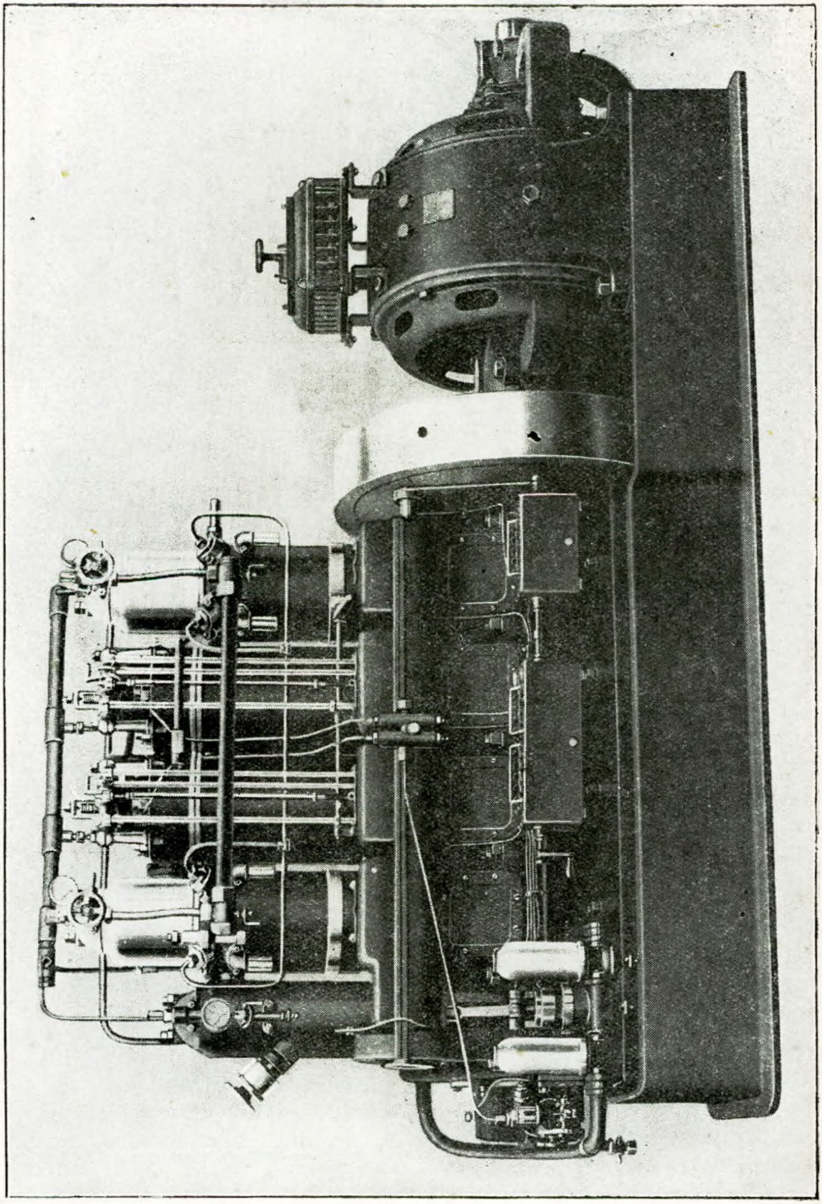


Fig. 68. Two Cylinder Auxiliary Diesel Engine.

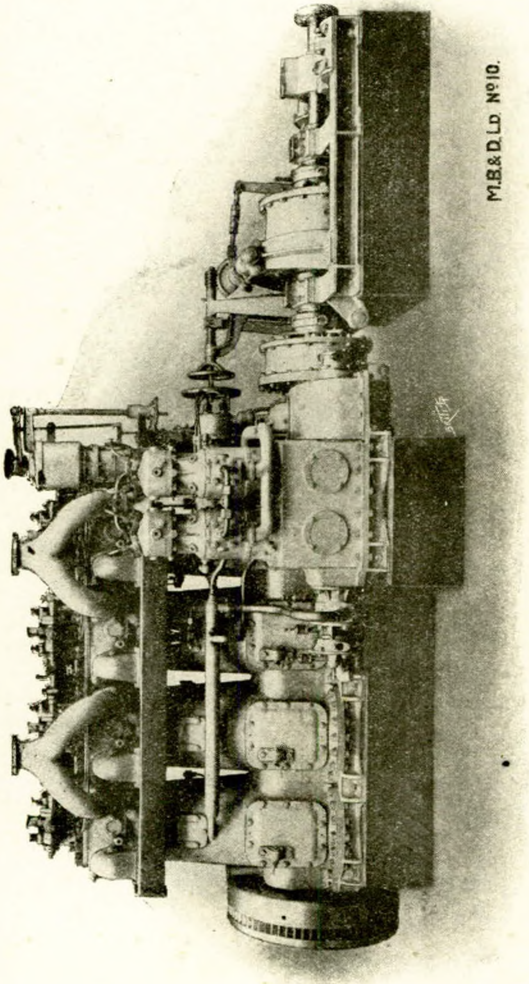


Fig. 70. 120 B.H.P. 50ft. Pinnace Diesel Engine.

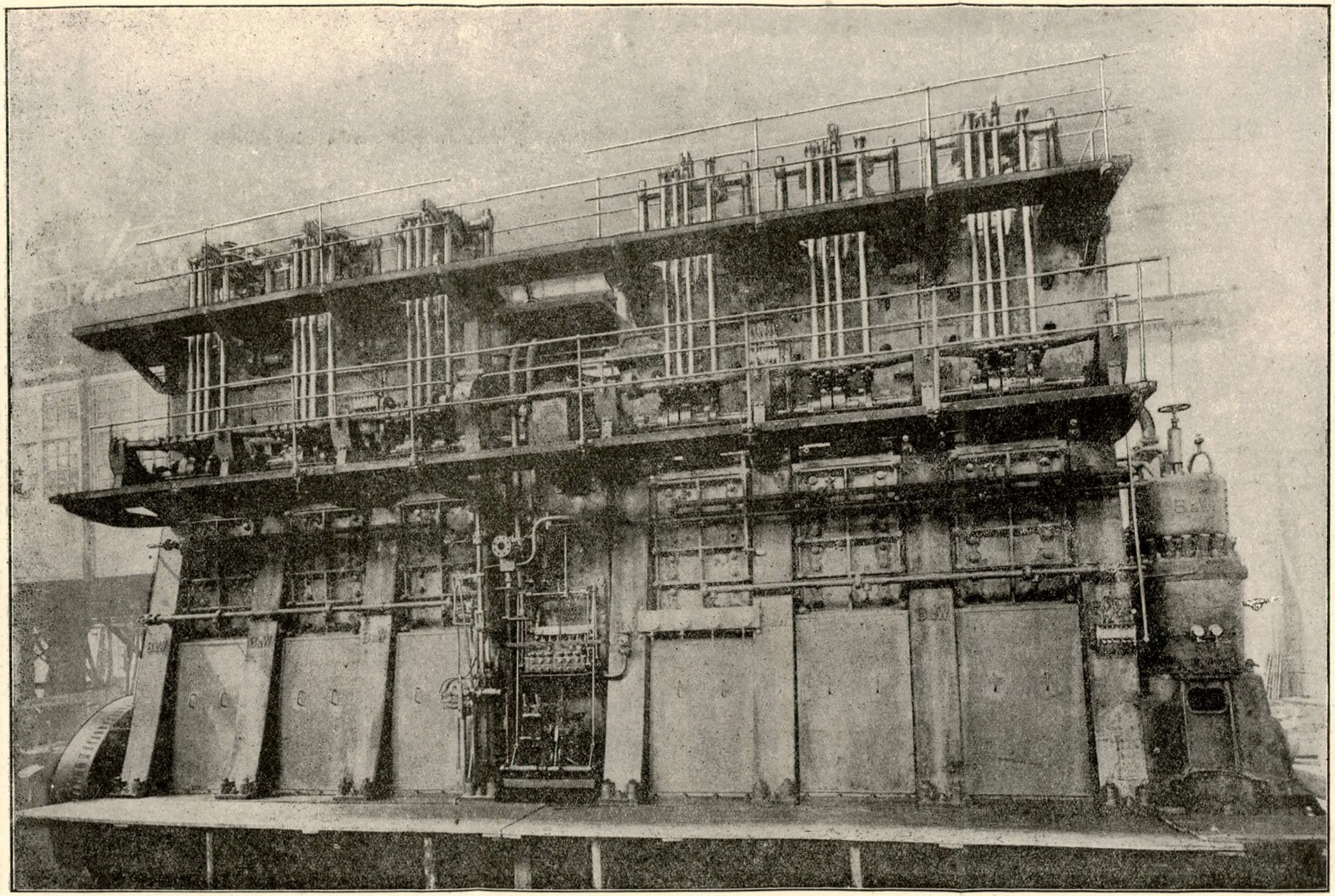


Fig. 69. 2,000 I.H.P. Diesel Engine (cargo ship) Cylinders, 740 M/M x 1,150 M/M; Speed, 115 R.P.M.

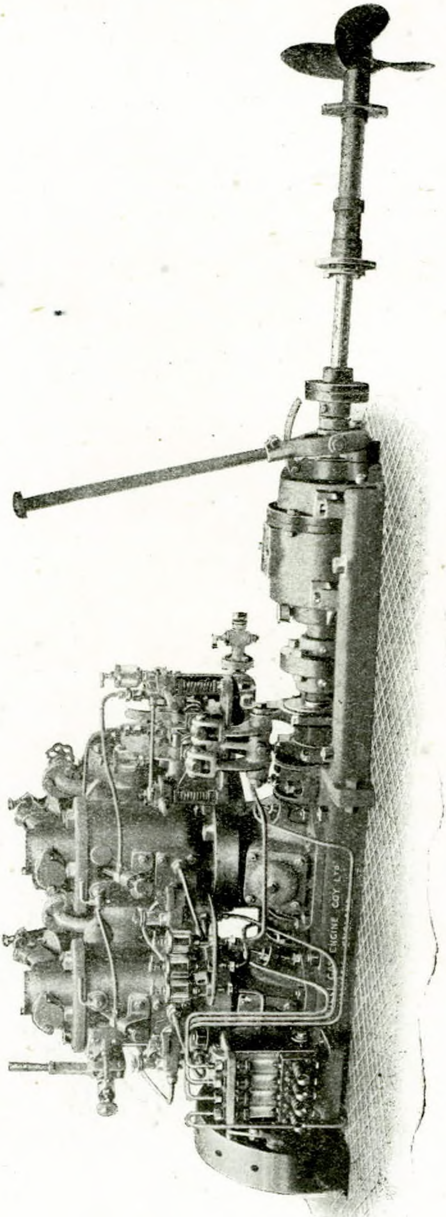


Fig. 71. 17·5 B.H.P. Two Cylinder Gear Reversing Engine.

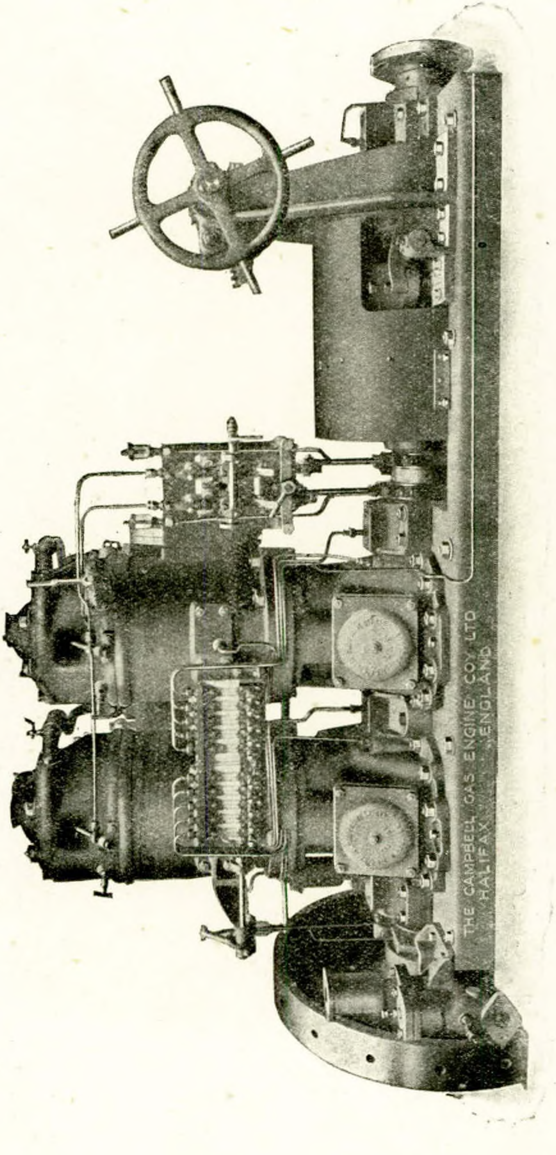


Fig. 72. 88 B.H.P. Two Cylinder Gear Reversing Engine.

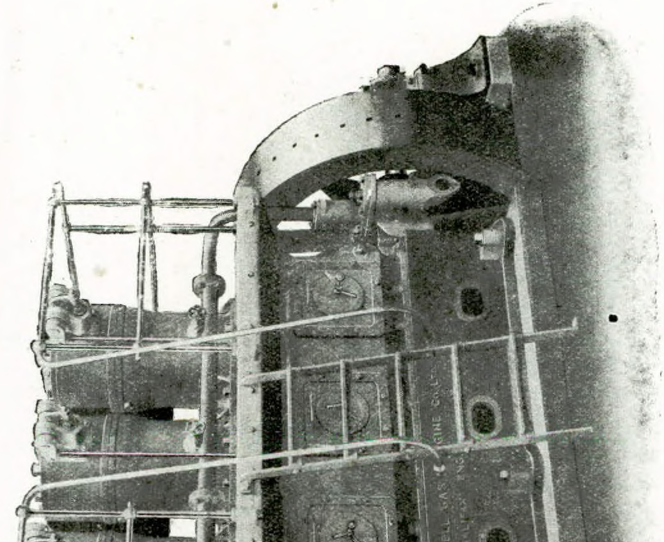


Fig. 73. 500 B.H.P. Four Cylinder Heavy Oil Engine.

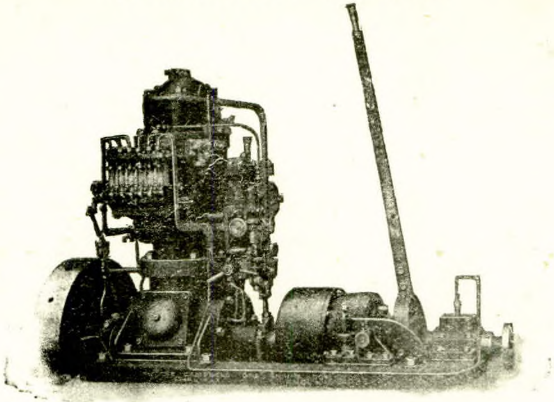


Fig. 74. Single Cylinder Hot Bulb Engine. 27·5 B.H.P.

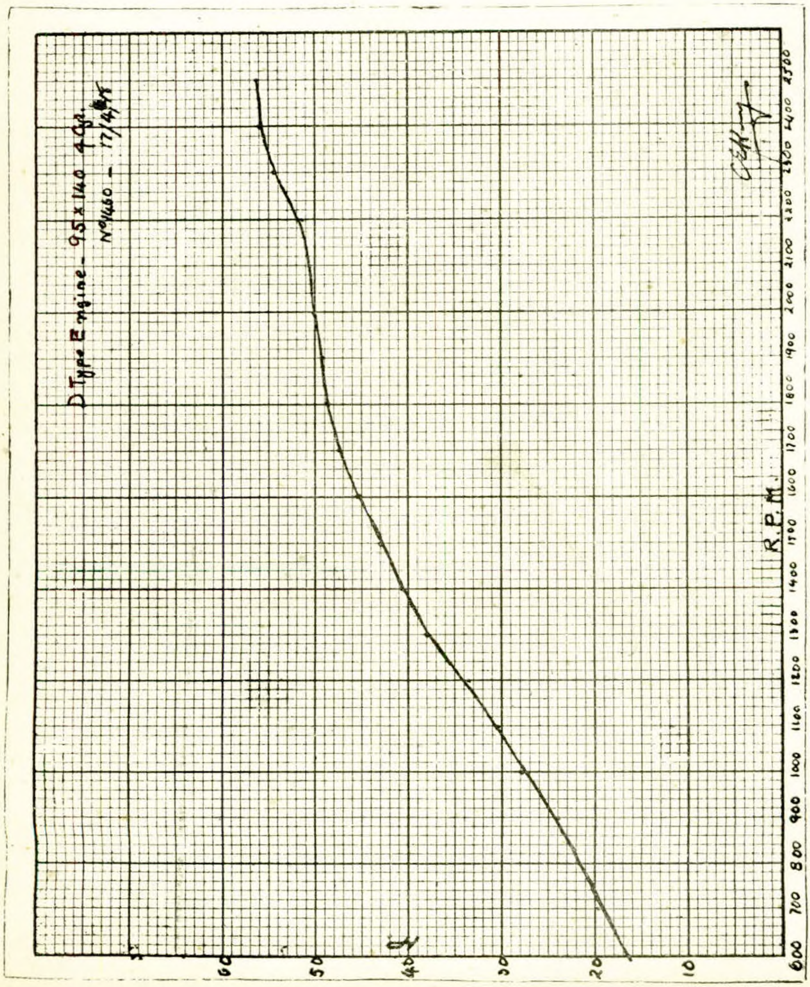


Fig. 75. Power Curve of Modern Automobile Engine.

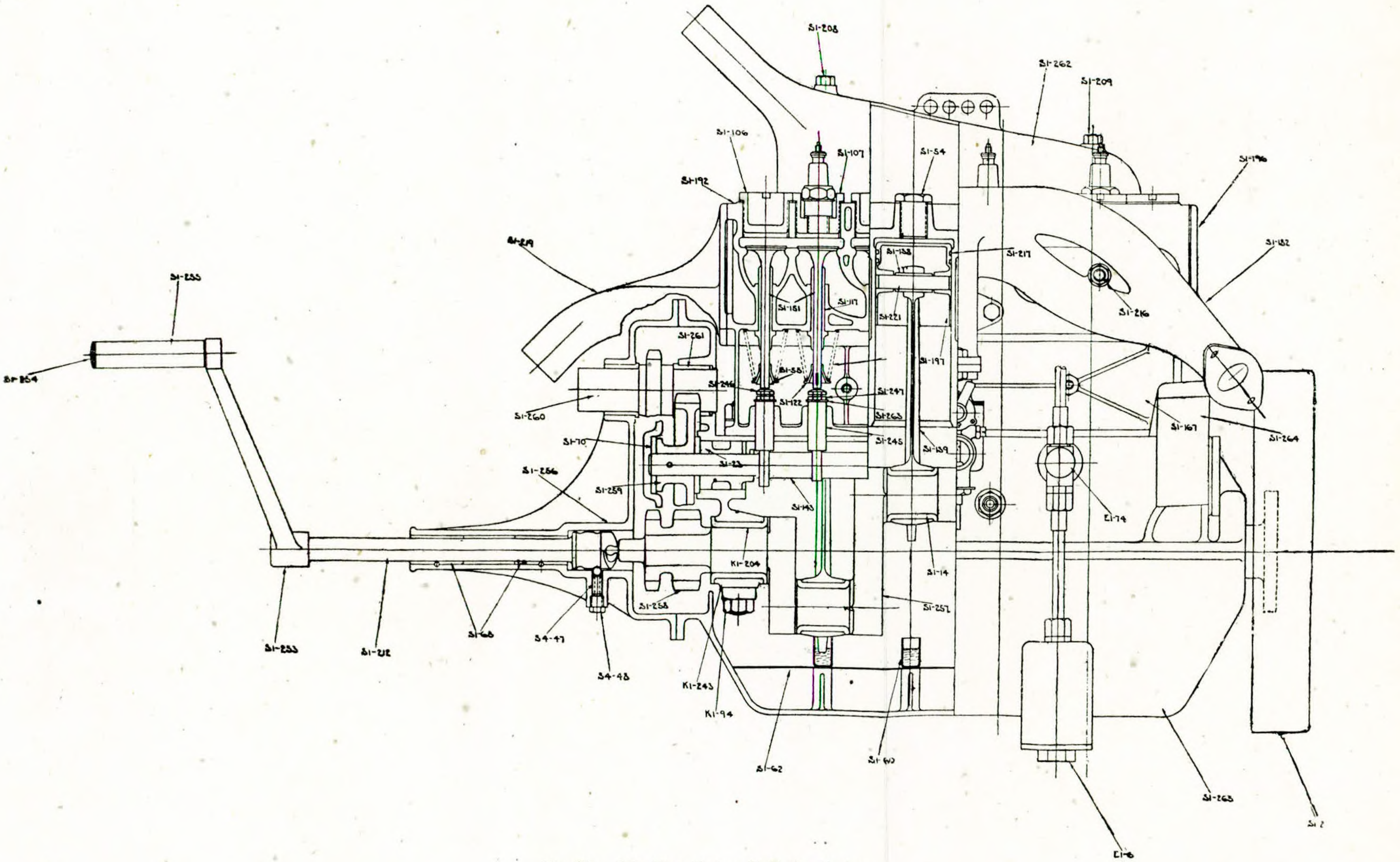


Fig. 76. Side View Modern Light Car Engine.

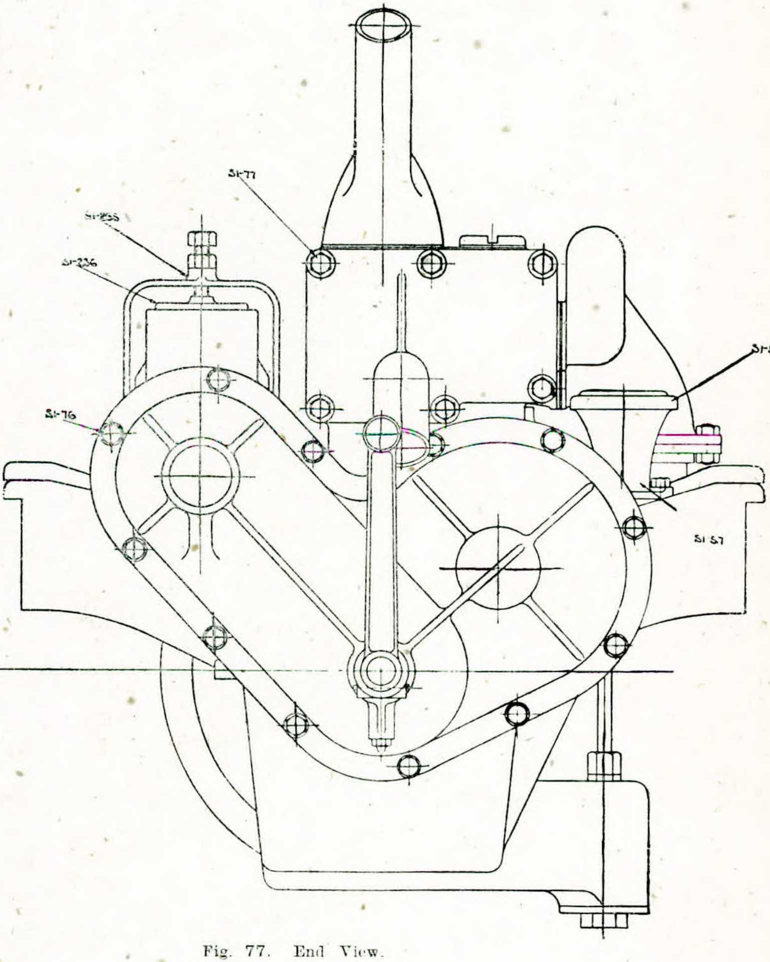


Fig. 77. End View.

Election of Members.

Members elected at a meeting of the Council held on October 13th, 1919:—

Members.

David Allan, Coronation Buildings, Eaglesham, Glasgow.
George Henry Ashby, 409, Romford Road, Forest Gate, E.7.
Frank Percy Bell, 57, Bishopsgate, E.C.2.
James H. Blight, 116, Wanstead Park Road, Ilford, E.
Arthur Jordan Boyd, 19, Hartington Road, Grove Park, Chiswick.
Chas. Henry Brookman, 70, Fenchurch Street, E.C.3.
Sidney Joliffe Butler, 17, Castlenau, Barnes, S.W.
John Cannell, 33, Warwick Gardens, Ilford, E.
William Coller, 4, Malwood Road, Balham Hill, S.W.12.
Walter Meredith Davies, 75, Navarino Road, Hackney, N.
William Duncan, *c/o* P. & O.S.N. Co., 122, Leadenhall Street, E.C.
Robt. Bruce Grier, 106, Kilmartin Avenue, Norbury, S.W.16.
John Kerr, 104, Aylmer Road, Shepherd's Bush, W.12.
John Lewis, Hamilton House, Carmathen, S. Wales.
James G. Lutes, 2981, Montana Street, Oakland, California.
Lionel Patrick McConville, 17, Dirleton Road, Portway, West Ham, E.15.
John Macfarlane Mitchell, 2, Wilton Mansions, Kelvinside, Glasgow.
Hubert George Morris, 8, Gresford Avenue, Liverpool.
Harold Percival Rhodes, 369, East India Road, E.14.
Courtenay Charles Speechley, "Oakwood," Crossways, Gidea Park, Essex.
Wm. Noel Tweedy, "Alltwen," Pontardawe, Glam., Wales.
Wm. Longman Watson, 47, Endsleigh Gardens, Ilford, E.
Henry John Barnett Webster, 54, Richmond Road, Ilford, E.

Companions.

Robert McIntyre, 51-56, Palmerston House, Bishopsgate, E.C.
Frank Whitworth, 37, Seagry Road, Wanstead, E.

Associate-Members.

John Snell, Marlow Villa, 13, Union Road, Exeter.
Patrick Victor O'Connor Jos. Twomey, 8, Park Terrace, Queenstown, Co. Cork.
John Herbert Williams, "Braeside," Watling Street, Church Stretton, Salop.

Graduates.

William Charles Grant, 74, Crownfield Road, Leyton, E.15.
Newton James King, 45, The Village, Old Charlton, S.E.7.

Transfers:—

From Associate-Member to Member.

James A. Grieg, 42, Wanstead Park Avenue, Manor Park, E.12.

From Associate to Member.

Walter Smith, Liverpool Engineering and Condenser Co., Ltd., Liverpool.
D. P. Lamb, *c/o* D.I.W.T., M.E.F., Basra, Mesopotamia.

From Graduate to Member.

John London, 5, Talbot House, Blackheath, S.E.

From Associate to Associate-Member.

R. St. A. Griffiths, Dept. of Overseas Trade (Board of Trade), Westminster, S.W.

From Graduate to Associate-Member.

Richard P. Jenkins, 123, Edridge Road, Croydon, S.E.

From Graduate to Associate.

John Dand Lawson, 479, St. Vincent Street, Glasgow.