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The Internal Combustion Engine

PART I

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Chairman: The PRESIDENT.

Looking backward, it is evident that the engineer, chemist and metallurgist have, during the last few centuries, brought out ideas and inventions so to advance engineering science that to-day our very existence is dependent upon. Had we been present at the battle of Creçy a new sound would have reached our ears—a loud, deep report, beyond that of charging cavalry or the clash of steel—the thunder of cannon, heard for the first time in warfare. Gunpowder, or the internal combustion of gaseous materials, was being used for the first time in the production of power, and was largely instrumental in bringing about that great English victory.

Another victory is now at hand, the practical application of the internal combustion engine for the production of mechanical power. A hundred years ago steam was in its infancy, but its use revolutionized the commercial world, brought the distant near, made travel to the multitude possible, added comfort all round, cheapened all kinds of goods, made, in fact, the world a better place to live in. Is not the whole matter of the production and application of steam for power or other purposes a great and interesting chemical and physical experiment, utilized so successfully by the engineer for the benefit of the community ? And although to-day the steam engine is a fine piece of mechanism and does good work in many directions, its efficiency as regards the amount of actual work per unit of fuel compared with what is possible by obtaining gas from the fuel and burnt in the cylinders direct, is very low.

It will be evident to the investigator that the dynamic principles involved in the internal combustion engine are, after all, very similar to those in the gun, as shown in Fig. 1.

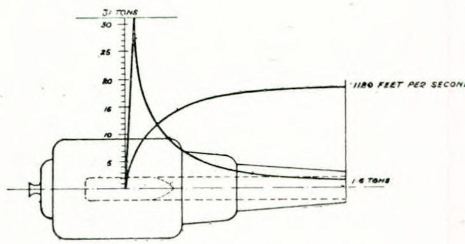


FIG. 1.

The pressure generated by the burning of explosive mixture rises enormously per square inch soon after the point of ignition, to, in fact, 31 tons in this particular gun, as soon as the projectile begins to move ; it will also be observed how the velocity of the projectile has risen to 1,180 feet per second, by taking advantage of the mechanical energy so generated and during expansion from the above pressure to 1·6 tons at the muzzle. It will be noticed that, owing to enormous pressure produced by the burning of the powder, the combustion chamber is constructed of great thickness and of consequent heavy weight, and represents a 12-inch 25-ton gun as constructed in 1869. Since then great improvements have taken place in the design and detail of guns with a view to reduce weight and increase the velocity at which projectiles are made to leave the gun muzzles. Fig. 2 shows a similar 10-inch 25-ton gun, constructed in 1884. The charge is so arranged that, instead of a rapid rise in pressure as given

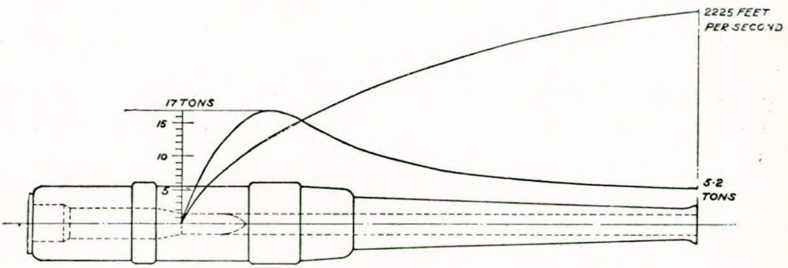


FIG. 2.

in the earlier 12-inch gun, the principle of constant prėssure combustion is adopted, insomuch that the pressure only rises to 17 tons per square inch during the burning of the charge, which enables a lighter gun to be produced ; also that by increasing the length of the gun, the pressure follows the projectile up to such degree that it issues from the muzzle at a velocity of 2,225 feet per second, and that owing to the smaller bore, the pressure falls to only 5·2 tons, which no doubt increased the noise that such a gun made in action. Of course the amount of velocity impressed on projectiles is the important thing aimed at, as every student of mechanics will easily understand, but, in the above, we have the analogy to the early and modern internal combustion engines, where coal or oil gas is selected and used in the place of gunpowder to generate the pressure necessary for power.

Many ingenious and futile attempts were made to produce a satisfactory engine using gunpowder as the medium of pressure, owing to the difficulty of safely arranging the supply in sufficient and regular quantities. However, a French engineer, named Lenoir, in 1860, took out patents for an engine that gave a great impetus to the design and actual construction of the internal combustion engine for industrial purposes. Lenoir made use of inflammable gas, mixed with a proper proportion of atmospheric air, ignited inside a working cylinder by electricity ; the rise of pressure and the expansion imparting motion to a piston, which was coupled to a crank-shaft in the usual manner, as applied at that time with steam engines. It is interesting to note that at that date electricity was recognized as being very suitable for ignition purposes, insomuch that the timing of the ignition of the gases could be brought about at the right instant at either end of the stroke, and at the right time to enable the maximum of expansion to take place in the production of work for a given fuel consumption, and at the same time to reduce the pressure as low as possible before opening the exhaust port to the atmosphere. Figure 3 shows this engine. The gas was

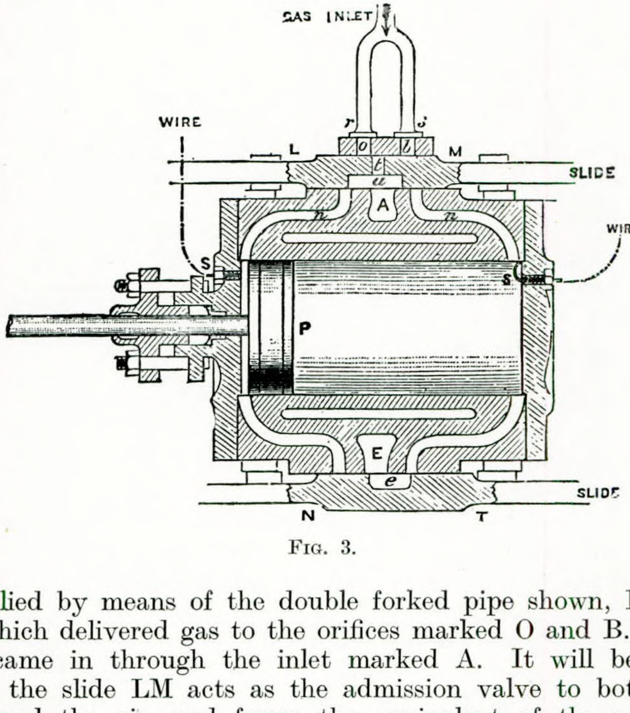


FIG. 3.

supplied by means of the double forked pipe shown, R and S, which delivered gas to the orifices marked O and B. The air came in through the inlet marked A. It will be seen that the slide LM acts as the admission valve to both the gas and the air, and forms the equivalent of the modern carburetter or mixer. The exhaust is taken charge of by a separate valve shown at NT, delivering the products of combustion to the atmosphere by way of passage E. There is no question that, had Lenoir so constructed his engine that both air and gas were externally put under pressure, the engine would have been a self-starting one, and reversible with link motion as with steam engines. Many of these engines, ranging from ·5 to 4, h.p. were sold, and in Vol. LI of the 3rd series of the *Franklin Institute Journal* there are some interesting diagrams taken from these pioneer engines. A curve which is set out in the diagram is interesting and instructive, but

Fig. 4 is not, strictly speaking, perfect, inasmuch as no scale of pressures is given. The atmospheric line is A to B, and shows the stroke of the engine. The charge is drawn in at atmospheric pressure, and it will be seen that the pressure,

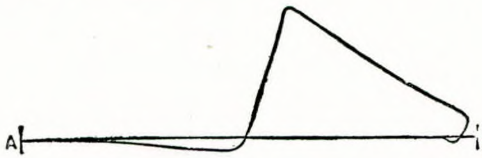


FIG. 4.

no doubt owing to small valve ways and passages, falls to about 11 lb. above vacuum, just before ignition; it then rises rapidly (as in the gun) to 48 lb. per square inch. The expansion, as shown by the diagram, tells its own story. The cylinder was $8\frac{2}{3}$ in. in diameter, with a stroke of $16\frac{1}{4}$ in., with revolutions 50 per min. The principles involved in this, the father of internal combustion engines, are to be found in the engines of to-day; these will, no doubt, be improved on as the demand for large-powered internal combustion engines increases. Engineers, always on the look-out for improvement in efficiency, realize that the last word has not been said in the matter of internal combustion engines, and both in Germany and England interesting experiments have been made in the production of power by internal combustion principles; hence came what is called an atmospheric engine, which certainly had merits, and probably much research work will result in further extensions.

The diagram of the Lenoir engine shows that the expansion is cut short by the opening of the exhaust valve to atmosphere, and that the energy represented in the remaining part of the possible expansion is consequently lost, with the result that the gas consumption per B.H.P. developed on the crank shaft was about 90 feet per hour, or more than four times the amount of gas used by the modern gas engine. This was no doubt due to the fact that, as will be observed, the great advantage of compression was, in those engines, not utilized.

In 1866 Messrs. Otto & Langen brought out their atmospheric engine, shown in Fig. 5. In this engine the gas consumption per B.H.P. hour was reduced so considerably that the Lenoir engine went out immediately. Although about 400 of these engines were sold and put to work in France, and about 150 in England, immediately the atmospheric engine was brought out the sale stopped, as it was found that the gas consumption of the latter was only 40 cubic feet per B.H.P. hour. Fig. 5 shows the engine to be a vertical one, and formed, practically speaking, a gun. The piston acted as a projectile, and was not connected to the crank shaft of the engine on the working stroke. There were many good points about it as an atmospheric engine, that is, an engine with an open cylinder in which the piston is driven up by means of the explosion (as in the gun). Full advantage of the completion of expansion of the pressure was taken, and also the momentum of the weight of the moving piston, with the result that the gases became cooled. The pressure inside the cylinder was also below atmospheric pressure, the piston being constructed in the form of a large weight, and at the same time having the atmospheric pressure behind it, as soon as expansion had gone as far as practicable, the piston immediately began to descend. It was then geared through a rack and pinion to the fly-wheel shaft. This engine worked very economically, and was a great advance, but it relied, as in the old steam engines, on atmospheric pressure for mechanical energy, and was thus limited in its application, at the same time being, like the previous engine, very heavy per B.H.P. developed. The constructional details of the engine were as follows :—A is the working barrel or cylinder ; B is the water-cooling jacket ; C is the combustion chamber in which the explosive mixture of gas and air is drawn ; P is the weight which also forms the piston ; and R is the rack which is disengaged with the wheel during the out or working stroke. The working was as follows :—The piston was raised to about one-eleventh of the working stroke, and sucked in the explosive mixture ; the charge was then fired, the engine being really a gun, standing vertically, with open mouth pointing upwards.

FIG. 5.

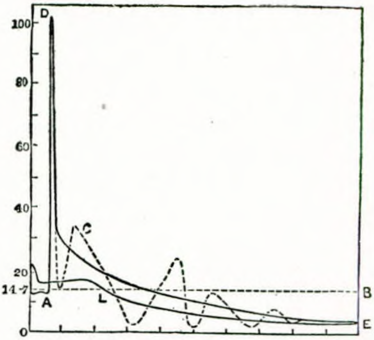
The charge, however, was not sufficient to force the piston out of the end, but only to send it to, approximately, the end of the cylinder. It should be understood that S is the main shaft attached to fly-wheel, and although P and R are always in gear with the spur-wheel T, riding on shaft S, yet inside the wheel (not shown) is a friction clutch, whereby T runs loose on the shaft S on the up-stroke, but is immediately in gear on the down-stroke. In the sketch shown the piston has been raised through about one-eleventh of the stroke, and has sucked in the amount of charge, and is on the point of being ignited by the flame at the side of slide L. The piston being raised through this space by the lever DHN, operated by an eccentric EH, on the shaft E; the end of the lever DN, whose fulcrum is at D, works on a tappet at N, attached to the rack R, and thus leaves the piston and rack free to ascend after the explosion and during the expansion. It is stated that the mean effective pressure obtained during the downward stroke for use on power is about 7 lb. per square inch, and that they were made up to 3 B.H.P.

They, however, showed a great economy in fuel, as compared with anything that was at work in those days, and in the author's opinion much more will be done in the immediate future by adopting a means by which the lower end of the expansion diagram may be utilized for the production of power, thus increasing the actual efficiency of all internal combustion engines. Whether this will be accomplished by means of compounding, as in steam engines, or by the lengthening of stroke, etc., remains to be seen, but the matter is worth the consideration of engineers and designers, as greater commercial results may yet be got from the gasification of fuel, whether it be coal or oil. I would here like to point out what appears to be very misleading to the average engineer. Internal combustion engines are described as either oil or gas engines. Both are gas engines, the only difference being that gas is made in the usually-termed gas engine externally, while the so-called oil engine makes its gas, generally, internally. It would be much better if all were termed gas engines, stating whether coal gas, or oil gas, or otherwise.

As might be expected, the scientific French were soon endeavouring to produce an engine that would be more efficient as compared with those using fuel consumption, and the above type of internal combustion engine was soon to be outdone, like that of Lenoir, by engines arranged so that the explosive mixture was compressed before ignition, a still further advance. It was in 1862 that the French scientist, Beau de Rochas, patented an internal combustion engine, the principles of which have formed the basis for designers of this class of engine ever since. The conditions laid down in the patent, upon which it was stated that the success of the engine relied, were as follows :—

(1) Maximum cylinder capacity, with a minimum of circumferential surface ;
(2) High piston speed ;
(3) Greatest possible compression ;
(4) Maximum pressure at the commencement of the power stroke.

He first pointed out the advantages of compressing the explosive mixture before ignition, to get a higher temperature



The above shows an indicator card taken from an atmospheric internal combustion engine.

and consequent greater expansion, also he proposed to have four operations, and during two revolutions of the engine, to have four strokes, as shown in Fig. 6.

During the first out-stroke from A to B, a charge of air and gas is drawn into the cylinder through inlet valve I, from B to C, the first in-stroke. The charge is compressed ; at about point C the compressed charge is ignited, causing a rapid rise in pressure (as in the gun, Fig. 1), which causes the piston to make its second out-stroke (power-stroke) from C to D. During the second in-stroke from D to E, the exhaust

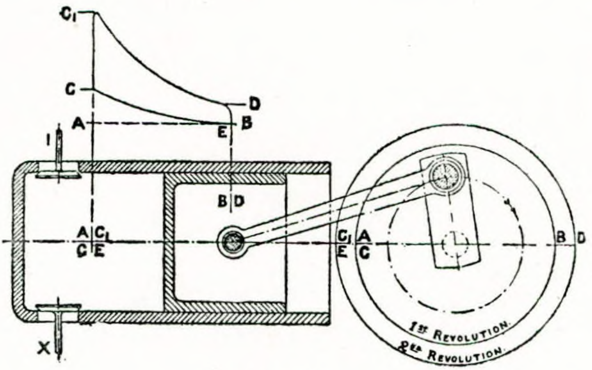


Fig. 6.

valve X is held up, so that the products of combustion are then expelled to atmosphere, thus completing the cycle. Fig. 7 shows the operation of this cycle, which is often mis-

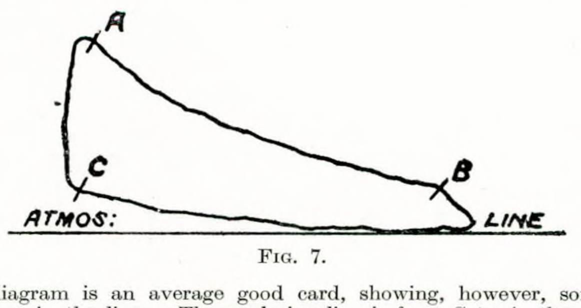


Fig. 7.

This diagram is an average good card, showing, however, some slight fluctuations in the lines. The explosion line is from C to A, the expansion from A to B, the exhaust at B. The suction stroke generally approximates the atmospheric line, from which the curve of compression rises to C.

called the Otto cycle, chiefly because an ingenious German engineer, Dr. N. A. Otto, was the first to make practical use of it in an engine so constructed. The whole credit of this epoch-making invention, however, is certainly due to the Frenchman's ingenuity.

To avoid infringing the patent rights which covered this cycle, many attempts were made to construct internal combustion engines working on a different cycle, and that patented in this country by Mr. Dugald Clerk in 1880 was one of the most successful. A separate pump was employed to force the charge of air and gas into the cylinder at the termination of the expansion of the power stroke. This charge was compressed by the in-stroke and ignited in the usual manner, and thus a power stroke was obtained once in every revolution of the crank shaft.

The majority of internal combustion engines to-day work on the four-cycle principle, but there is yet another cycle that has made advances, especially in small powers such as are required for launches and small cargo-boats, and a very large number of these engines are at work, doing good service in many directions, although their heat efficiency is not near that obtained by means of the four-cycle engine. Yet they are very interesting machines, insomuch that they embody simplicity of construction, in fact it would be indeed a very difficult matter to design a prime mover with less working parts, and consequently requiring the minimum of attention. The cycle referred to is what is known as the two-cycle principle, in which the four essential operations, namely, charging, compression, firing and exhaust, are performed in one revolution of the fly-wheel instead of two, as required in the previous cycle. Fig. 8 shows this engine in diagram, showing the

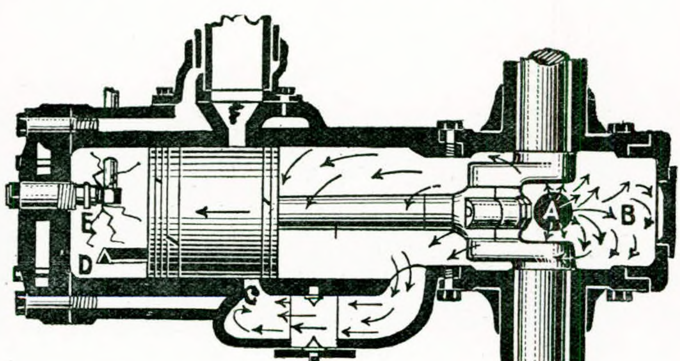


FIG. 8.

in-stroke of the piston. It will be seen that a mixture of gas and air is drawn in at A, from the carburettor or mixer, to the crank case B. A previous charge is being compressed in the combustion chamber D. Just as the crank is turning the top centre it will be observed that the electric spark is igniting the charge. The pressure so raised will push the piston forward, and expansion thus takes place, until the exhaust port F is uncovered by the piston (which forms its own valve), the exhaust gases then escaping under the remaining pressure into the exhaust pipe or box, the pressure in the cylinder being also at the same time reduced. It will also be understood that the charge drawn into the crank chamber is also being compressed by the downward movement of the piston, ready for the inlet port C to be uncovered by the piston. The mixture, being under slight pressure by means of the descending piston, immediately escapes into the combustion chamber, and by means of deflecting plate is guided up to the top of the chamber behind the still escaping low-pressure exhaust gases, but before the new gases have

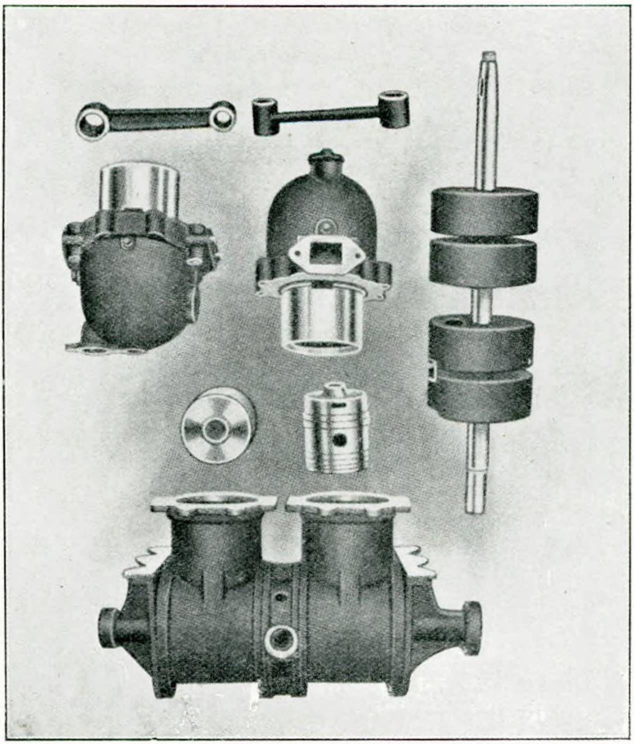


FIG. 9.

time to escape after the exhaust gases, the piston is on the return and the inlet port closed, and immediately after the exhaust port is closed likewise, so that the thus imprisoned live gases are compressed and the cycle reperformed. There is no doubt that a reduction in the weight of a given engine can be brought about by this cycle, but it is, in my opinion, only suitable for small powers, for such there is no question, however, as to its reliable working. Giving an impulse at every revolution it certainly is the ideal engine for the propulsion of small powered boats, and especially where simplicity is required. As is well known this engine has no valves, so to speak, or tappet rods, cam-shafts, springs, etc. Figs. 9 and 10 show a 20-B.H.P. two-cylinder engine of this

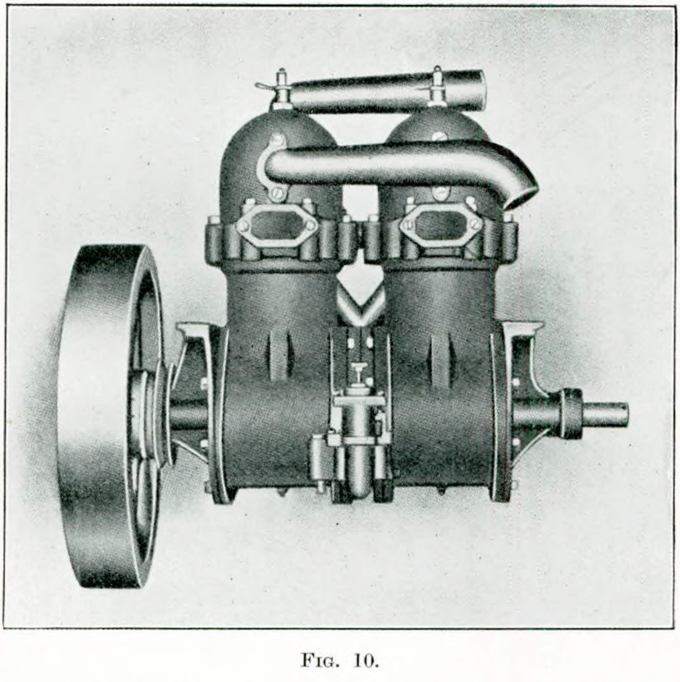


Fig. 10.

cycle in detail. It will readily be seen that for this engine there are only five working parts, namely, crank-shaft, two connecting rods, and two pistons. It would be difficult to construct an engine with fewer working parts, and there is no doubt that its simplicity is the reason why it is largely used, although its fuel economy does not approach that of the four-cycle engine, as previously mentioned. They are reasonably quiet as compared with equal four-cycle engines, owing to the absence of valve gear, etc., and also to the fact that there is a practically constant downward pressure on the heads of the pistons, instead of the alternating pressure and suction on the piston heads of the four-cycle engine, which no doubt tells on the bearings, etc. The two-cycle engine has thus found admirers, especially where the cylinders are off-set from the centre line of the crank-shaft, the consequent wear being then very slight, and they have a good life. In the engine shown, of which I have had good experience, a novel feature is that the cool incoming mixture through the channels of the piston keeps the piston from overheating, reducing the carbonizing of lubricating oil to a minimum. The arrangement of the distribution is such that the heat is not localized, so that the cylinder and the pistons are of more equal temperature; expansion and contraction are thus at a minimum, with little distortion of either. There are, however, some important points to be guarded against in the application of the two-stroke engine for marine and other work where the engines have to work in confined and possibly inaccessible places, especially when petrol is used as fuel. Some engines give quite a lot of trouble through crank chamber fires, caused by the charge in the crank chamber being ignited by the still burning charge in the combustion chamber. The remedy is to reduce the speed of the engine, or to increase the speed of combustion, by means of a weaker mixture. The faults may generally be traced to the design of the engine; the most successful and reliable are those engines that have a large area exhaust port, or several, so that the speed of the incoming charge can never catch up the exhaust. The engine shown in Figs. 11 and 12 is specially designed from great practical experience, in order to avoid these defects, a matter of vital importance, especially in sea-going boats. However, there are many engines of such design that give no such trouble, and in fact the *Britannia*, the small boat shown later, is fitted with one of this type of engine, and has never given the least trouble. At the same time it is as well to have means on any two-stroke engine to provide that the revolution speed cannot be excessive.

With the exception of perhaps the Lenoir engine all the above engines were constructed on the principles of explosion similar to that in the case of the gun shown in Fig. 1. Although very efficient as compared with what can be done with other methods of power production, as with the application of steam, they have drawbacks that even to-day have not been eliminated, although many designers are at work to this end. The ordinary four-cycle explosion engine is in many ways difficult to apply, for instance, to marine propulsion, or other applications in which certain essential requirements have to be considered. These faults are, for instance, inflexibility, as to run these engines really efficiently the revolutions must be kept about constant or otherwise, owing to atmospheric conditions being dominant, indifferent mixture may result in possible heat and other losses. These engines are not self-starting (as compared with steam engines), and means must be employed to overcome this objection, such as the use of compressed air, or by forming an explosive mixture in the combustion chamber when set on the out-stroke, which methods are not the most reliable. Such engines are, consequently, not reversing in the true sense of the word, and other means, such as reverse gear or a complicated system of cam alteration and timing, is necessary, which raises the cost and increases the wear and tear and also takes away the very object of the cycle in the way of simplicity, which is essential.

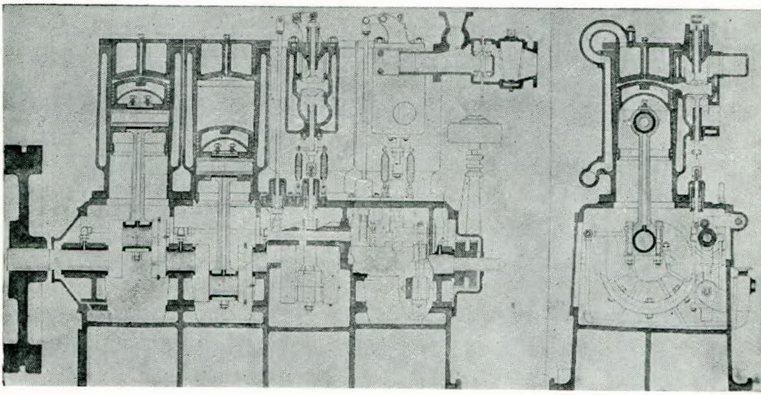
As will be seen by reference to the diagram in Fig. 7, such engines are noisy, owing to the pressure at exhaust above atmosphere, which is a loss of power. This should if possible be avoided, and must be if the engine is to have the maximum of efficiency. Further, these engines are liable to produce a certain amount of objectionable smoke, and smell, faults which must be considered when attempting to apply them to such vessels as ocean-going passenger boats, while also, unless complete combustion is obtained, the highest thermal efficiency will not be obtained, which is desired commercially. All the above faults are due to the thermo-dynamic principles involved in the engine itself, and it is impossible to avoid them without the use of starting handles, or other means of starting or giving the first necessary movement to the piston, etc. If a change of speed is required on the driven work, it is essential to put in some sort of change speed gear, and if silence is required it must embody a suitable exhaust or further expansion box, and all the time that such types of engines are used the above parts are absolutely necessary. Further, the admission of gas being constant it is not possible with economy to vary the torque on the crank-shaft to any great extent, and even then by such methods as gas variation or alteration of the ignition points which will be shown later are wasteful, and not ideal methods. Owing to the explosion principles being used in such engines, the compression before ignition is limited, and for that reason the clearance between the piston head and the cylinder head must be large, in proportion to the total volume of the sweep of the piston in cylinder. This clearance is in some engines as much as 20 per cent. of the total volume, and for that reason alone brings about enormous losses in the possible thermo-efficiency in the engine itself, and is a question that should receive the very closest attention by all designers of engines, especially those who are working on a possible marine engine, where the weight must be considered. As already expressed at the meetings of this Institute, the marine engine must be designed on the principles that are involved in the gun as shown in Fig. 2, that is on the lines of constant pressure combustion, thus reducing the initial pressure, and increasing the length of expansion.

The idea of securing combustion in an internal combustion engine at constant pressure instead of constant volume (as in the previous engines) during the period of combustion is not a new idea, for as far back as 1873 Brayton, in Philadelphia, U.S.A., brought out his well-remembered cycle and engine, in which the gas and air were compressed in a separate cylinder and burnt in the working cylinder. In 1878 Messrs. Simon, of Nottingham, acquired the Brayton patents and brought out this type of engine with a miniature steam boiler over the combustion chamber. The steam thus generated was blown into the combustion chamber, and although some very interesting experiments were made, this engine was stated to have not been successful. Messrs. Hennig & Co., in Germany, about this time, brought out the Brayton or Simon engine with many mechanical improvements. Foulis, of Glasgow, in 1878, patented an engine similar to that of Simon, and in 1881 brought it out in improved form, and what is also interesting is the fact that he utilized the heat from the exhaust gasses for raising the temperature of the incoming gases, as well as the separate compression principles and constant pressure combustion.

In theory all these engines proved very attractive, but as the mechanical difficulties multiplied for the small sizes that were required in those earlier days, the simple Rochas, or Otto, type of engine was pushed with such success that designers were not encouraged, so that no doubt the constant pressure combustion type of engine was neglected, in favour of the engines which have compression, ignition and expansion in a single cylinder. In the small type that were then in the majority of cases required, this gave a simplicity with which the small type constant pressure combustion engine could not compete, and therefore were abandoned.

They have been revived from time to time by various experimenters, but in spite of the great possibilities shown by theory they have until the last few years found little demand of importance, with exception of the Diesel type, which is based on the principles laid down by both Rochas and Brayton. I believe that now the question of large power is suggested for the propulsion of vessels of large tonnage, designers and manufacturers will be driven to take the matter up with a seriousness never before thought of, and that the obstacles that lie in the way of successful construction will, with modern engineering practice and materials, be overcome, also that the constant pressure combustion engine will soon be in general use, not only with gas made from oil, but also from coal or other fuel.

It will be observed from Fig. 2, that the designers of guns have seen the advantages of the constant pressure method of combustion. Here the advantage of the burning time of powder has been made use of, and it will be seen that the projectile has travelled some distance before the maximum pressure or the completion of the burning period has taken place. The pressure has not risen above 17 tons per square inch, and as the charge is larger and longer, the expansion is extended, resulting in an increased velocity being given to the projectile, and no doubt less recoil, as compared with the gun shown in Fig. 1. Here, again, is an analogy and a matter which go to show that with the constant pressure combustion engine less strains are set up and more equal turning moment obtained. This matter has received, as



In reference to the off-setting of cylinders in the direction of rotation, the above marine engine by Messrs. E. S. Hindley & Sons, London, shows interesting detail of these engines. They are of the 4-cycle principle and have a very quiet movement with a minimum of vibration.

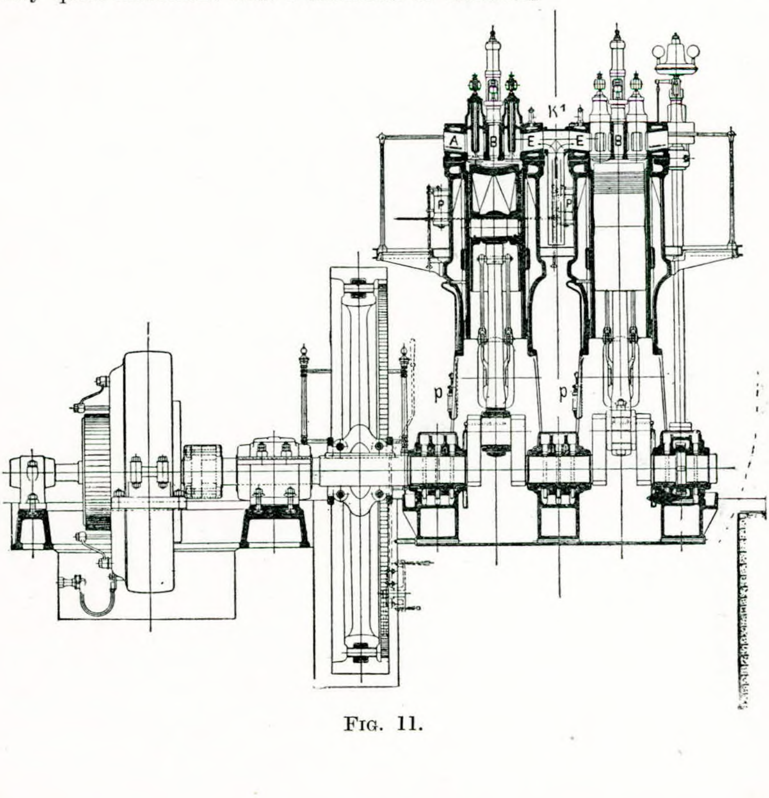


FIG. 11.

far as the author is aware, very little attention by those advocating internal combustion engines for main propulsion; it is, however, one of very great moment, and no doubt will receive close attention from designers. The multi-cylinder engine would appear to somewhat reduce the strains, a matter that will have to be taken into account when coming up to very large powers. The author's opinion is that as the efficiency of engines of modern power and those of larger power do not alter materially as the power goes up, to overcome the difficulty the most suitable way is to split the total power of the prime-movers up in various units, and by some connecting medium such as electrical power transmission bring

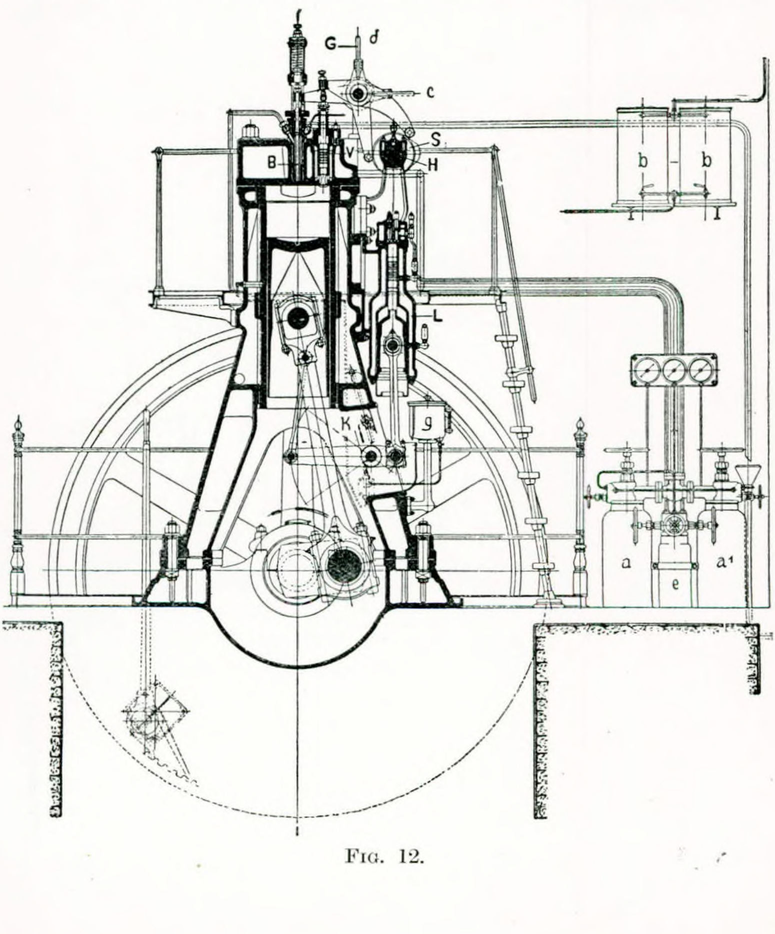


Fig. 12.

several engines to concentrate their power into one powerful electric motor driving the propeller shaft; a view that is also held by our highest authority in naval engineering, and many others that have given this application of the internal combustion engine technical consideration. It will be shown later how such arrangement will facilitate economy all round.

Figs. 11 and 12 show side and end sections of the Diesel engine, and it should not be forgotten that nearly every writer on the thermo-dynamic principles of heat engines has drawn attention to the Brayton type of engine, and its greater scope for higher thermo-dynamic efficiency, and have lamented the neglect of this cycle by our leading designers and builders of internal combustion engines. Credit is due to Dr. Rudolph Diesel, who brought out the cycle engines under his name, which are now meeting with such a large and successful demand in all parts of the world. There is no question that in large or small sizes it is the finest prime-mover that we have, and by a study it will be seen that the laws that Rochas and Brayton laid down have been carefully considered by him, as regards high compression and constant temperature, pressure and combustion. Fig. 13 shows a normal curve

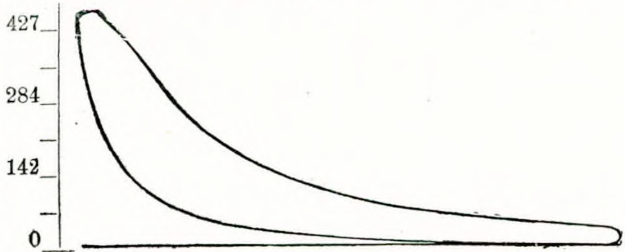


FIG. 13.

taken from one of his engines, and Fig. 14 shows the action

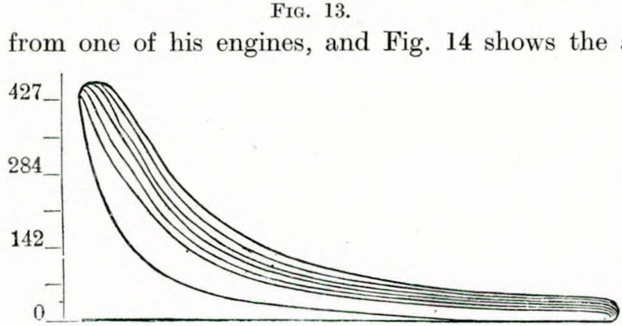


FIG. 14.

of the governor fitted to the engine, which varies the point of cut-off very similarly to that of a steam engine. Dr. Diesel has been good enough to forward especially for this paper also a very interesting sectional drawing, shown in Fig. 15,

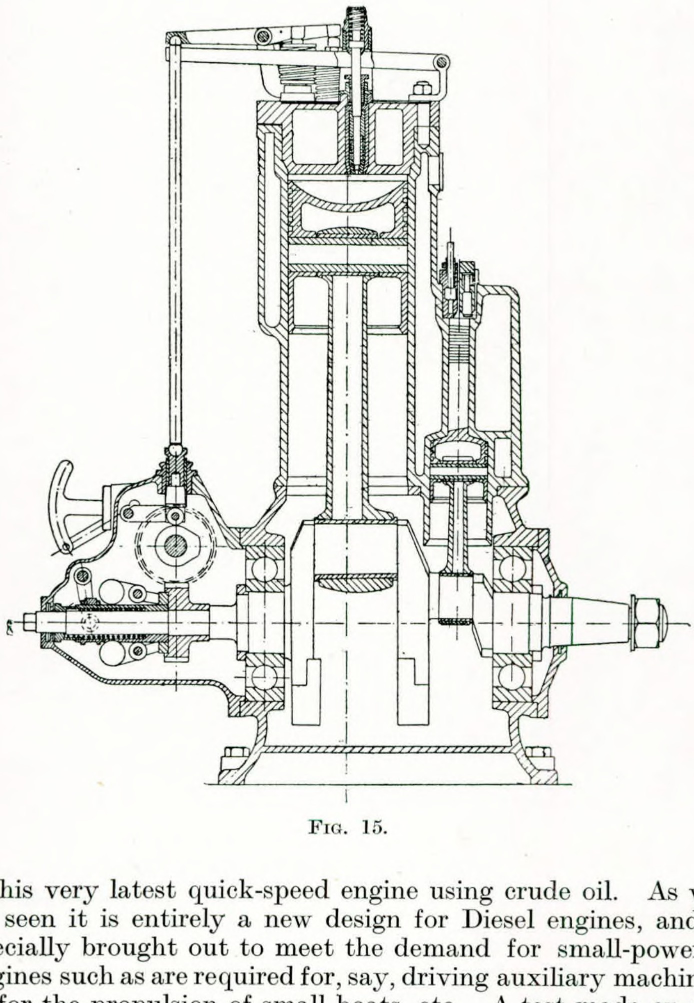


FIG. 15.

of his very latest quick-speed engine using crude oil. As will be seen it is entirely a new design for Diesel engines, and is specially brought out to meet the demand for small-powered engines such as are required for, say, driving auxiliary machines, or for the propulsion of small boats, etc. A test made on one of these engines is interesting and is as follows :—

Loading Trial for small latest type "Diesel" engine.

Rating Delivered.	½ Load.	¾ Load.	Normal Load.	Over-load. Normal Speed.	Over-load at higher Speed.
Duration of Test, Mins.	28·5	35·2	49·49	31	8·29
Average Speed . .	620·3	610·4	609	603·8	828
Indicated H.P. . .	6·20	7·24	8·17	9·66	13·26
Brake H.P. . . .	2·61	3·83	4·76	5·58	7·65
Fuel required per H.P. hour in Kilograms .	0·315	0·262	0·248	0·273	0·284
Cooling water per hour in Kilograms . .	24·2	19·3	18·0	36·0	21·5

The above shows remarkably good results for so small an engine, and the test was carried out by Professor Romberg at the King's Technical High School at Berlin quite recently. The engine can be made at the present time up to 30 B.H.P., in which case there are six cylinders, and the weight is not more than 80 lb. per B.H.P., which includes a bedplate (not shown), air-vessel, oil-vessel, and exhaust pipe, etc., which is about one-tenth of the weight of the original stationary Diesel engines of the same rating, but the sketch shows how the engine would appear for fitting into small passenger and cargo boats. The exhaust is colourless, and without fumes, and the revolution speed can be arranged from 600 to 200 r.p.m., or can be accelerated in such cases as in racing boats for short periods up to 1,000 r.p.m. The machine is somewhat different from the usual design of Diesel engine, and I understand that Dr. Diesel in the near future intends to develop an engine that will be suitable for larger powers. He states also that it will be very suitable for use in connexion with the Paragon electrical propulsion scheme, in which he has taken an interest, both in its application to marine engineering, and also in another sphere of transport, i.e., that of main line railway traction, to which, in conjunction with such efficient internal combustion engines, the author intends to shortly apply it.

In connexion with the above and other high-speed engines, an interesting advance in propeller design has been recently brought out and patented in this and other countries. Fig. 16 shows this propeller ; it is constructed on the feathering paddle

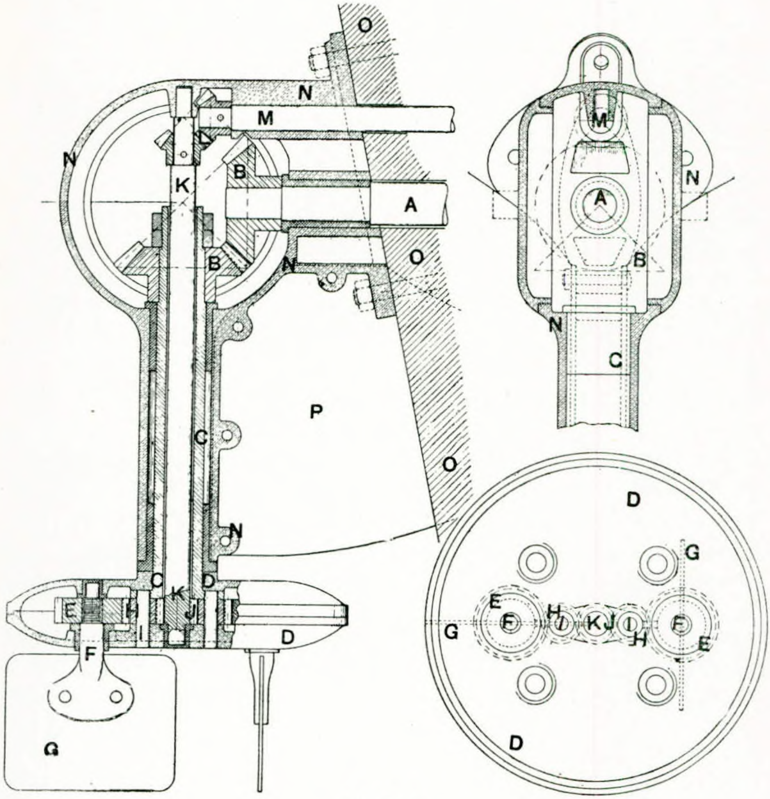
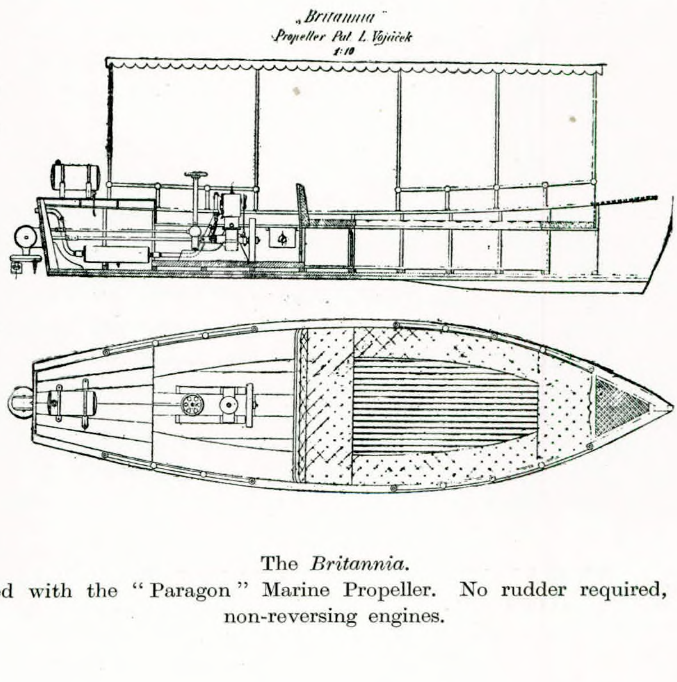


FIG. 16.

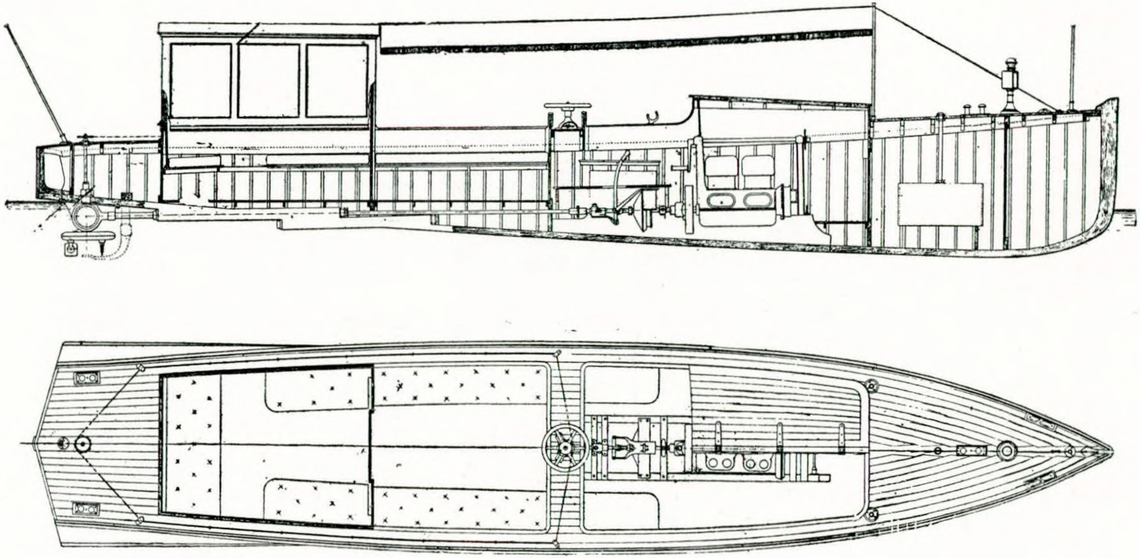
design and has some novel details about it. For instance, the full power reverse can be given under control from the steering wheel, with the least exertion, and the ahead speed, or the steering of the vessel can be carried out by the direct power of the prime-mover, and without the necessity of altering the torque or direction of speed of the engine. It seems to me a great advance in the most troublesome matter of propeller design for propulsion. Referring to Fig. 16 a description will be of interest :—A is the power shaft from the engine or turbine, as may be desired ; B, equal drive bevel wheels driving vertical revolving power sleeve ; C, the above power sleeve coupled to the revolving small case ; D, revolving power case, containing feathering small gear wheels ; E, two small gears, only carrying the small power for feathering the blades ; F, short shaft taking the power from the revolving case D ; G, propeller blades, generally two, renewal a very easy matter ; H, two intermediate connecting wheels ; all these small gears are running below water line and in grease, absolutely quiet and lasting ; I, fixed spindle on which run the loose intermediate wheels H ; J is a centre pinion that is usually in a stationary condition ; by its means, however, the degree of feathering is adjusted, which decides if the re-action from the propeller shall be ahead or astern, or partly so ; this position is controlled by means of the steering wheel ; K is the small vertical shaft that is attached to the angle bevels above, leading to the steering wheel shaft ; L are the above bevels ; M is the horizontal shaft leading to the steering wheel, by which means full control is brought about ; N is the stationary case taking the whole propeller, which from the present design will be seen, and the importance of requiring no usual thrust block, this case is bolted direct on to the stern-post shown ; O is the stern-post, and it will be seen that only two small holes are necessary for the application of the propeller to existing boats, etc. ; P is a steel plate that takes a part of the direct thrust of the propeller, and also forms a steadying piece. This propeller has been tried on various types of vessels with greatly improved results, as compared with what is possible with the ordinary screw type of propeller, and in some cases as much as 30 per cent. more effective thrust per shaft horse-power at given revolutions has been demonstrated and accepted by some of the highest authorities on the Continent. I will, however, not dwell here on its effect on the application of the internal combustion engine for marine propulsion, and all the difficulties that can be got over by its use, these are obvious ; rather will I rely on advantage being taken of inspecting and testing the small vessel now running on the Thames with easy and quick steering, stopping and turning on its own centre and other essential points. The maximum of manœuvring power, applying with equal effect, not only to vessels on the surface, but also to those called submarines, in which the ideal of automatic stability can be brought about, may be claimed for this propeller.

I have endeavoured to place the subject before you in as lucid a manner as I am able, but it involves an immense number of points. It has been felt that the details are of such a complex character that it will be better to divide this paper into two sections, the second of which I propose to read to you at the meeting arranged for by our Secretary, on November 28 next. Whether my paper is altogether equal to the subject and whether my contentions appeal to you as convincing or not, I sincerely hope that the facts I am placing before you will lead to the further development of this important subject, possibly on the lines indicated, and that some further real progress will be made in the evolution of the internal combustion engine.

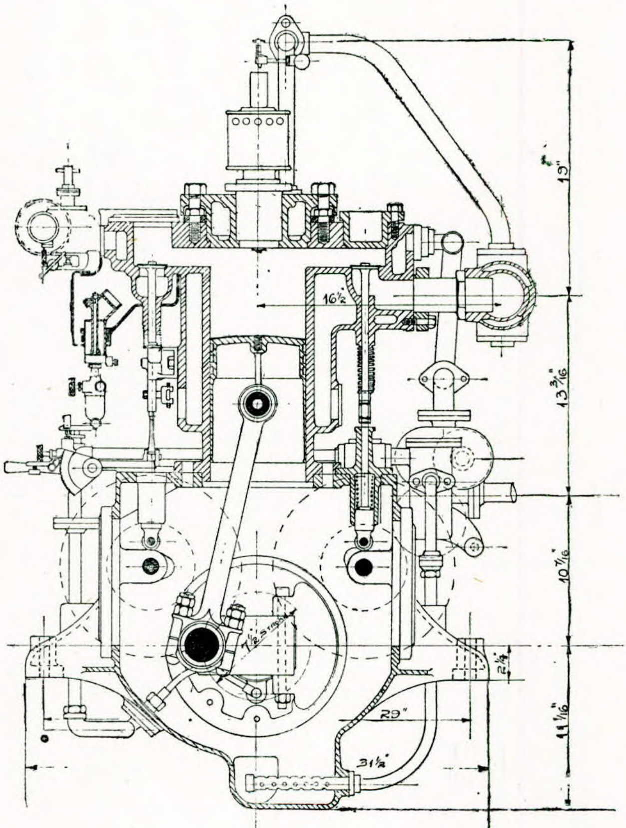
I must express my indebtedness for some of the data given above to the following excellent works, Goodeve's *Text Book of the Steam Engine*, I. Hyler White's *Petrol Motors and Motor-cars*, and Homan's *Self-Propelled Vehicles*.



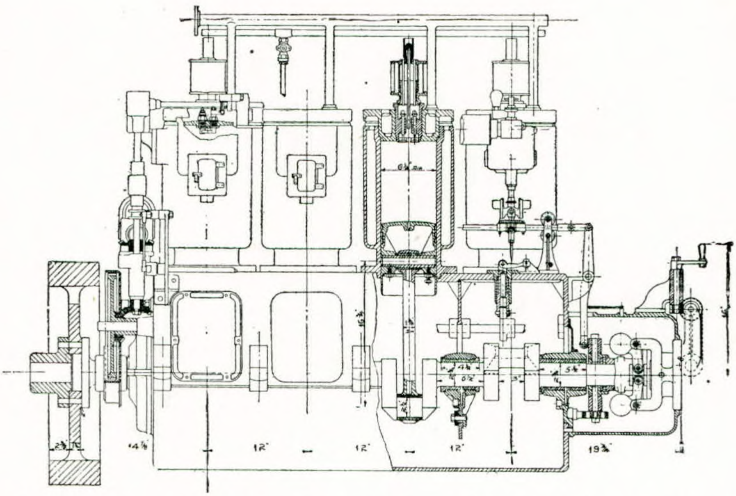
The *Britannia*.
Fitted with the "Paragon" Marine Propeller. No rudder required, and non-reversing engines.



A powerful high-speed motor boat fitted with the "Paragon" Marine Propeller, now under trials in the Mediterranean.



End section of drawing of Messrs. Norris & Henty's Marine Internal Combustion Engine.



Side view and section of Messrs. Norris & Henty's Marine Internal Combustion Engine.

CHAIRMAN : I am sure, after the interesting evening we have had, you will all agree with me that we ought to return a most hearty vote of thanks to the authors of the papers. The first is Mr. Lecoche's paper, which was not read, but which I have no doubt you will study with advantage at home and which, I understand, will be discussed at a future meeting. Then we had Mr. Gibbons' most excellent and practical paper, which, as I said, is best illustrated by inspection of the model itself in the Exhibition, and last of all we have Mr. Durtnall's most charming and most beautifully illustrated paper, of which we have had only the first part, and we look forward with great pleasure and interest to the second part. His historical statement seemed to me to be extremely well put and his conclusions to rest on sound reasoning based on practical as well as theoretical grounds. To myself, who am somewhat of an outsider, it was most interesting and most useful to my comprehension of the general principles necessary to the construction of that important instrument of the future, the gas engine. I am sure you will all applaud very heartily the vote of thanks I now propose.

The meeting concluded with a vote of thanks to the Chairman, proposed by Mr. Durtnall and seconded by Mr. Gibbons.

The Internal Combustion Engine

PART II

BY MR. WILLIAM P. DURTNALL (MEMBER).

Read on Monday, November 28, 1910.

CHAIRMAN: MR. WM. McLAREN (MEMBER).

CHAIRMAN: The Hon. Secretary has a communication to read from Mr. W. R. Cummins in reference to Part I of Mr. Durtnall's paper.

The HON. SECRETARY: Mr. Cummins writes as follows:—

Mr. Durtnall is to be congratulated on his excellent paper on internal combustion engines.

The relative advantages and disadvantages of the various types of engine illustrated and reviewed in the paper are treated in a very impartial manner.

There is one type, however, which is not described in much detail, viz., the oil engine of the vaporizer type. It is quite true, as Mr. Durtnall points out, that the oil engine is an internal combustion engine, as is the Diesel; but a clear distinction should be made between engines which use fixed gases, forming, when intimately mixed with air, an explosive mixture, which can be ignited by a purely local application of heat (such as that given by an electric spark), and engines of the Diesel type, in which the fuel, in a very finely divided state, but still in liquid, and not gaseous form, is distributed throughout the body of air necessary for combustion, such air being heated throughout its mass to a temperature sufficiently high to burn the hydrocarbon. This process of combustion is certainly not of the nature of an explosion, whereas the ignition of fixed gases by electric spark or hot tube approximates to a true explosion.

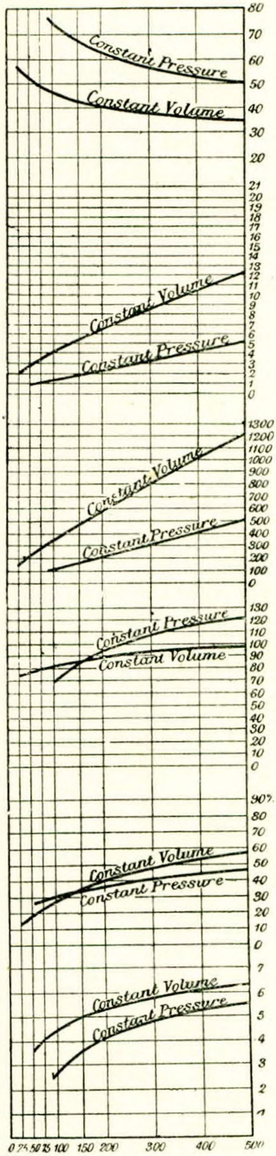
The oil engine of the vaporizer type is a cross between the two above mentioned types. The more volatile constituents of the oil when admitted to the vaporizer will be gasified by the heat, and form an explosive mixture with the air ; but the less volatile part of the oil will be burnt in a similar manner to that occurring in the Diesel engine. This vaporizer type of oil engine has been greatly developed lately for marine use, and practically the whole of the engines shown at the recent Exhibition at Yarmouth were of this type, which included such well known makes as the Blackstone, Bolinders, Beardmore, Peck, Gardner, Griffin, Kromhout and Thorneycroft. At this comparatively early stage of the development of the marine internal combustion engine, it is very important and essential that due consideration be given to the type of engine to be adopted.

For marine work the first essential is fuel economy. We cannot afford, for instance, to use an inefficient thermal cycle, simply because there is one ready to hand which has been successfully developed for land use. To compete with and displace the well tried and reliable steam engine, it is not sufficient that the fuel economy be only better. It must be a long way ahead. The importance of fuel economy, and the lavish expenditure of capital to secure this economy, can be seen in the engine and boiler rooms of the modern steamer. Starting with the boiler, there is Howden's forced draught with its fan, and closed ashpits, and air-heating tubes to extract the maximum possible from the heat of combustion. In many cases superheaters are fitted. Then coming to the engines, there are the three or four cylinders for triple or quadruple expansion, with their valves and valve gear, or the turbine with its thousands of blades, and in many cases the combination of the turbine with the reciprocating engines. Then comes the condenser, often of special design, and the circulating pump capable of dealing economically with large volumes of water.

Then the highly efficient air pump to get the best vacuum possible, and finally the feed pumps putting the water back into the boilers through feed heaters.

In fact, every endeavour is made, almost regardless of cost, to get the last ounce of available energy out of the steam.

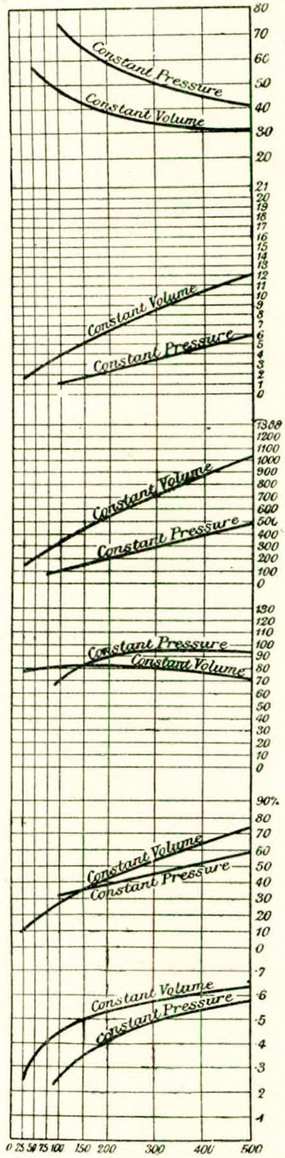
The second consideration for marine work is that of weight economy, which is of secondary importance in the case of merchant work, and of great but not vital importance in naval work.



Lbs. per sq. in. compression

FIG. I.

Constant Volume. Compression temperature increased by 2,000° F.
Constant Pressure. Compression temperature increased by 2,000° F



Lbs. per sq. in. compression

FIG. II.

Constant Volume. Compression temperature increased to 2,960° F. abs.

Constant Pressure. Compression temperature increased to 2,960° F. abs.

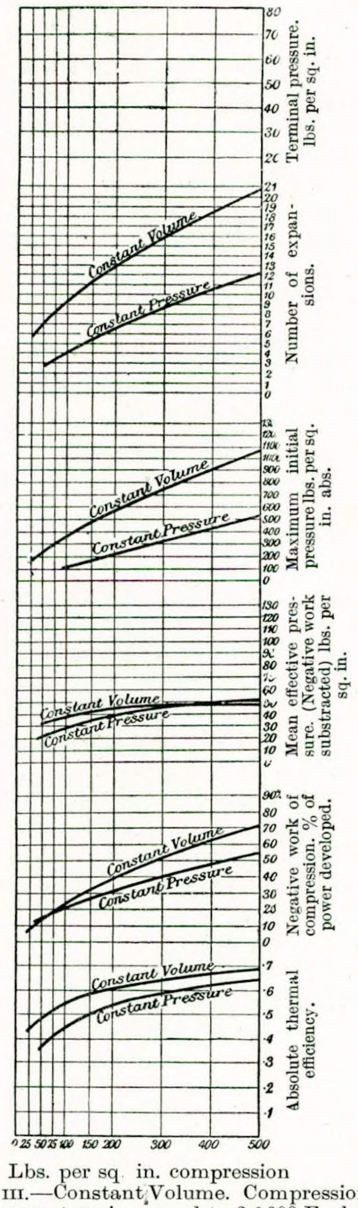


FIG. III.—Constant Volume. Compression temperature increased to 2,960° F. abs. Constant Pressure. Compression temperature increased to 2,960° F. abs.

Mr. Durtnall's simile of the gun illustrates in a graphic manner the relative value of fuel and weight economy in the case of these huge weapons. The time during which a gun is burning fuel amounts to about fifteen minutes of its life-time, whereas the ship has got to carry the weight of the gun and its mountings for several years, so that it is good policy to sacrifice fuel economy to weight economy, which latter is secured by diminishing the maximum initial pressure, and at the same time prolonging this reduced initial pressure by using slow burning powder.

If the two diagrams, Figs. I and II are set out to the same scale, and compared, the increased mean pressure in the case of the constant pressure combustion is very marked in spite of the reduced initial pressure. This increase, however, is obtained at the expense of fuel economy.

In order to show graphically the characteristics of the two cycles, which use compression previous to combustion, the diagrams on the board have been prepared. There is no need to trouble with non-compression cycles as their low thermal efficiency puts them out of court.

The two cycles are—

I. Those in which the heat is added to the working medium at constant volume.

II. Those in which the heat is added at constant pressure.

The first class is exemplified by the ordinary gas engine, and the latter by engines of the Diesel type. The oil engine is intermediate, but the more nearly approaches the constant volume type.

In the calculations it has been assumed that the whole of the heat is given to the working medium at constant volume or at constant pressure.

It is doubtful whether this addition of heat does or can take place thus in actual practice. In the case of the gas engine, dissociation, no doubt, takes place, and part of the heat will be added after the piston has left its dead centre; and in the case of the Diesel engine it is probable that the combustion is not completed until the pressure has fallen by expansion. This, however, will not materially affect the comparison of the two types, as the variation is in the same direction.

The other assumption made is that the compression and expansion are adiabatic. This process also is not possible in actual practice, owing to the loss of heat to the water jacket and the gain of heat from the delayed combustion; but this also will not affect the comparison. The temperature of combustion must also be assumed, as, on account of dissociation, it cannot be estimated from the heat value of the fuel. A usual temperature of combustion in the gas engine, with about 100 lb. compression pressure, is 2,500° F., and in the calculations this temperature has been used as a basis to calculate the increase of pressure and of volume in each particular case.

The diagrams have been prepared for two conditions, the first being that in which the charge is compressed in one end of the working cylinder, in which case the expansion is limited by the volume of the cylinder at the beginning of compression; and the second condition is that the expansion is carried to such a degree that the pressure is reduced to that of the atmosphere.

All the present-day engines fulfil the first condition, and there are no examples now at work fulfilling the second condition. The diagrams show for the two conditions and for each type—

(1) The absolute thermal efficiency.

(2) The negative work of compression.

(3) The mean effective pressure.

(4) The maximum initial pressure.

(5) The number of expansions.

(6) The terminal pressure at the end of expansion. In Fig. II. the compression temperature has been increased by the addition of such an amount of heat as will raise the maximum temperature of explosion or combustion to 2,960° F.

In Figs. I. and III the compression temperature is raised by 2,000° F. Figs. I and II represent Condition I. Fig. III Condition II.

Taking (1), the absolute thermal efficiency, it will be seen that for both conditions the efficiency of the constant volume type is much superior, the rapid rise of the curve at 25 lb. compression for Condition I being most marked. After 200 lb. compression the curve gets flatter, so there is not much gain in increasing the compression pressure over this, which suits the constant volume type, as an increase of compression might cause pre-ignition of the mixture. For Condition II also the efficiency of the constant volume type is superior. Coming to (2), the negative work of compression, there is not much to choose between the two types, the negative work at 150 lb. compression being about the same ; and although the curve for the constant volume type rises above the constant pressure curve after this pressure, it does not signify, as it will not pay to use pressures over 200 lb. There is little or no loss in the compression process, as the work of compression is given back on the power stroke. It affects the crank-shaft torque, and the starting up, which will be gone into further on.

Passing on to (3), the mean effective pressure, the constant pressure type has the advantage at the higher pressures. At about 150 lb. compression, which is suitable for the constant volume cycle, the mean pressure is about the same.

The mean pressure, of course, determines the volume of the cylinder for a given power, and to a certain extent the weight ; this latter, however, being also influenced by the initial load.

We come next to (4), the maximum initial load, which to a large extent governs the weight for a certain power.

When making the comparison between the types in this case, the difference in the indicator diagrams must be taken into account. In the constant volume type diagram the maximum initial load occurs on the dead centre when the inertia of the reciprocating parts is at a maximum, thus preventing a great part of the load on the piston from reaching the crank-shaft. The fall of pressure is also very rapid. In the case of the constant pressure, however, the maximum initial pressure is carried on for a considerable period of the stroke, during which the inertia effect, which protects the crank-shaft on the first half of the stroke, is rapidly decreasing, and the "leverage" of the crank is rapidly increasing, thus producing a much larger crank shaft torque, for the same initial pressure, than the constant volume type.

Finally coming to (5) and (6), the number of expansions and terminal pressure, the constant volume has a distinct advantage in the number of expansions, which conduces to fuel economy, and in the lower terminal pressures and temperatures, which is of material advantage in the practical working of the engine, especially when the exhaust has to pass through a valve.

The above considerations treat the comparison of the types on more or less abstract lines ; but it is very necessary to keep the special needs of the marine engine well in view, and the most special need is that of ease in starting and reversing.

Comparing the two extremes of the two types, viz., the gas engine using fixed gases, and the Diesel type using crude oil, we see that the former can practically dispense with compression when starting up, as impulse strokes can be obtained from the explosive mixture with say 5 lb. compression pressure. This means that when compressed air is used for starting, only low pressures of say 80 to 100 lb. are needed, making the work of compressing, storing, and using this starting air a very simple process.

With the Diesel engine, on the other hand, a compression pressure of 500 lb. in the working cylinder and a pressure of 750 lb. for injecting the oil is required before an impulse stroke can be obtained. This means the compressing, storing, and using of starting air at 1,000 lb. pressure, entailing stage compressors and special means to prevent leakage.

Mr. Durtnall's description and illustrations of two-stroke cycle engines is confined to the simple but inefficient type, developed largely in America.

He does not describe the large two-stroke engines of the Oechelhauser and Koerting type—engines capable of developing 2,000 B.H.P. in a single cylinder at revolutions not exceeding 140 per minute.

By the courtesy of Mr. J. W. B. Stokes, of Messrs. W. Beardmore & Co., I am enabled to illustrate by lantern slides kindly lent for the purpose the leading features of the Oechelhauser engine.

Mr. Stokes has made several important improvements to the original design of Dr. Oechelhauser, and the table of tests, the reliability diagram, and the fact that some of these engines are engaged on rolling mill work speak for themselves. There is no doubt that this two-stroke engine is quite as economical and reliable as any four-stroke engine on the market.

Of course the design of the Oechelhauser engine as made for land use would not be suitable for marine work, but the essential principles of the engine, viz., the valvelessness, the ideal combustion space, and the scavenging arrangements, are what should be aimed at for a marine engine.

Description of Slides.

No. 1. Diagram of engine illustrating scavenging and charging processes.

No. 2. View of earliest gas engine operated by blast furnace gas at Hoerde Ironworks, 600 B.H.P.

No. 3. Interior of Dalmuir power station, 7 sets, total 5,300 B.H.P.

No. 4. View of 1,000 B.H.P. engine, single cylinder, at Parkhead.

No. 5. View of 1,000 B.H.P. engine, single cylinder, at Mossend.

No. 6. View of 1,500 B.H.P. engine, single cylinder, at Mossend, driving rolling miles.

No. 7. View of 3,400 B.H.P. engines driving cement mills.

No. 8. Improved design of engine

No. 9. Comparative designs, Nurnberg *v.* Oechelhauser tandem type.

No. 10. Typical diagrams from Oechelhauser engines.

The Koerting engine, another German invention, now being manufactured by Messrs. Mather & Platt, is also of the two-stroke type, and is moreover double acting. The principle of scavenging by air is also adopted in this engine, which is made in large units.

As these remarks are getting rather lengthy, the comparison of the actual fuel consumption of the two types of constant pressure and constant volume engines, and the intermediate oil vaporizer type, must be left over for a future occasion, and I would suggest the discussion of this interesting paper be adjourned to the next meeting.

It is very evident, however, that there is plenty of scope for improvement in the thermal economy of the vaporizer type of engines. There is, moreover, no physical or chemical reason why they should not equal or exceed the fuel economy of the gas engine or the Diesel engine, but the discussion of this point must be left for a future occasion ; yet it might be stated in the meantime that the chief reason of their comparative inefficiency is their low compression pressure.

CHAIRMAN : Mr. Durtnall will now read Part II of his paper. We are fortunate this session in having a flood of matter in connexion with the internal combustion which it will take us a few evenings to digest ; but we can quite sympathize with the advocates of this new form of motive power in forcing its claims upon us as they seem to be very confident that the steam engine is going to have a bad time of it in the future.

PART II.

Mr. Durtnall:

In selecting the title of this paper the author was well aware that the subject could cover a great volume of technical matter, in fact much more than would be in order with the objects at issue. Thousands of different designs and types of prime-movers have been investigated by engineers all over the world, during the history of this important power, and with ever-increased efficiency both in design and operation. A tremendous impetus has been given to the building of small power boats and other means of utilization of power by the great improvements in the internal combustion engine. This engine may employ either petrol or similar volatile spirit, petroleum, alcohol or producer gas. Steam has had a good long innings, and has been developed through years of practical experience, so that though it cannot be said to have reached finality, yet no startling developments are to be anticipated. The internal combustion engine is of recent growth, and its rapid advance gives promise of still greater possibilities.

The steam engine claims the attention of shipowners on account of its freedom from breakdowns, due to the knowledge obtained from many years of experience; the flexibility of the engine, from the maximum number of revolutions down to zero, giving easy control in reversing, its economy in fuel, quietness in running, and simplicity of construction. On the other hand, the machinery takes up a considerable portion of valuable space, and coal is dirty to handle, either in getting on board or in stoking, for which many men have to be carried; further, valuable time has to be spent in getting up steam before proceeding on the voyage. This is considerable in large ships, although in small pleasure craft as little as ten minutes can accomplish this latter duty, especially where liquid fuel is used for raising steam. Liquid fuel is cleaner to use and does not require so much attention, but its cost is much higher for steam raising than coal; petrol is dangerous and expensive to run, but easy to start; petroleum is cheaper and comparatively safe, but unless used in certain types of engine causes delay in starting, whilst producer gas is safer and cheaper still, but in some designs is heavy and cumbrous and takes time to start. Taking the whole line of types into consideration, it can be safely put down that on the matter of ready starting the petrol engine is an easy first, and in a certain type of speed boats its application is desirable from many aspects, its light weight per horse-power developed, which must be of great advantage in those cases where boats have to be hoisted in davits ; it also permits of less displacement and should consequently give greater speed per horse-power, and the small amount of space taken up, allowing a power installation in a small boat, and bringing the possibility of a power-driven boat within the reach of those who, although desiring power, perhaps could not afford the larger size and cost of steam. Its comparative cleanliness and small amount of attention required whilst running, cheapness for small sizes, and other advantages have made this class of internal-combustion engine popular. On the other hand, it is liable to a number of derangements, to many of a puzzling nature, is rather noisy unless a proper installation is carried out, only

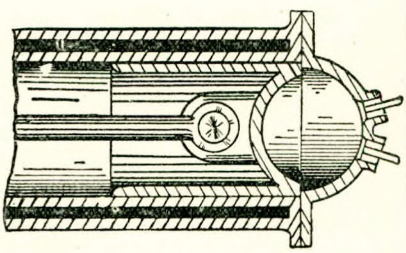


FIG. 1.

met by experience, and petrol is so dangerous on account of its inflammability, as to make its application prohibitive in, say, cabin boats.

A few points in connexion with this class of simple prime-mover of the four-cycle type will not be out of place in this paper, especially to those who have not been fortunate to have had experience with them. By far the greater proportion of internal-combustion petrol engines are constructed on what is known as the water-cooled cylinder type, and Fig. 1 shows a section of such a cylinder, having a spherical clearance head, and a depression on the piston head ; the shaded portion at top and bottom indicate the water jacket space, in which the cooling or circulating water passes, to carry away the excess heat from the cylinder walls. The circulating water used is assisted by means of a pump, driven from the engine crank shaft, and coupled to a supply tank and radiator, to dispose of the heat units to the atmosphere. Fig. 2 shows the method of coupling

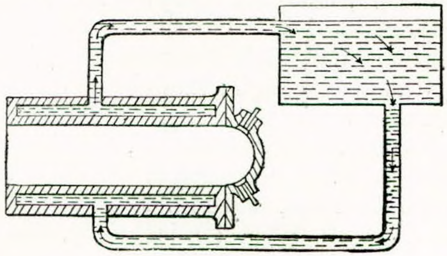


FIG. 2.

up same, and the path of the water circulation and working on the thermo-syphon system. As before stated, the reason why the petrol engine is such an easy starter is the fact that petrol vapour is given off at a much lower temperature than the heavier oils, and it is obvious that by bringing a quantity of air at a high velocity past a small jet in which the petrol is present that the vapour will be given off and mix with the air, and thus form by proper adjustment an explosive mixture. Fig. 3 shows the action of a so-called carburettor, or mixer.

FIG. 3.

It will be observed that A is the hollow float carrying a small needle valve at the top, which does the duty of closing the supply of petrol from the supply pipe, should for some reason the fuel consumption be reduced either by slowing the engine or on being stopped, etc.; its duty is, therefore, that of keeping the level of the petrol in line with the top of the jet in the air-way on its passage to the cylinder, drawn in under the suction of the outgoing piston. B is the connexion between the float chamber and the jet, C is the spraying nozzle or jet as it is more usually called, and it will be seen at this point noticed that the air comes in through the small way under the jet chamber, as will be seen by the arrow mark; the inlet valve is shown at D, which opens inward against the spring E, which closes the valve on the pressure in the cylinder F, again getting back to that of the atmosphere. On the return stroke of the piston the inlet valve, as shown closes, and Fig. 4 shows how the compression is raised, and the petrol further atomized by the rise in temperature that also takes place under this compression. The pressure half-way through the stroke increases above that of the vacuum line to approximately 30 lb. per square inch, and at three-quarter stroke it is about 60 lb., and at seven-eight stroke is 120 lb.; the energy to carry this into effect is given off by the action of the flywheel. The next, or third stroke, is that known as the working stroke, in which the compressed explosive mixture is fired by means of, say, an electric high-tension spark, termed electrical ignition; the mixture immediately burns and the temperature also rises to a high degree; the crank being now in the outward stroke again the piston is driven forward under the influence of this superior pressure; the fuel is burnt, the pressure raised, and the expansion stroke has commenced as in a steam engine. Fig. 7 in Part I of this paper shows a diagram taken of an engine during this stroke; on this diagram, at B, the piston has arrived at approximately the end of the stroke, but the expansion is not complete. The exhaust is positively opened, whilst a good portion of the pressure formed by the explosive mixture is still available; such is sheer waste, and this will be investigated and utilized by the author in the early future, by means of a suitable gas or exhaust turbine. As it is to-day this good pressure is simply turned into the atmosphere, which is the cause of the noise previously referred to, or it is taken into what is termed an exhaust or

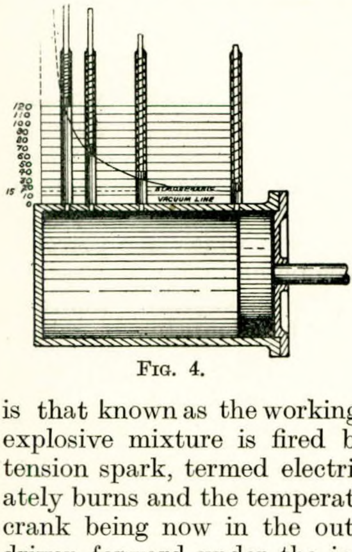


FIG. 4.

expansion box, and so arranged that the gases are expanded to no purpose before being allowed to reach the atmosphere, it being obvious that if they were to arrive at the same pressure as that of the atmosphere there would be no noise.

Fig. 5 shows such an exhaust box, and it will be observed that the exhaust gases still under pressure are delivered to the

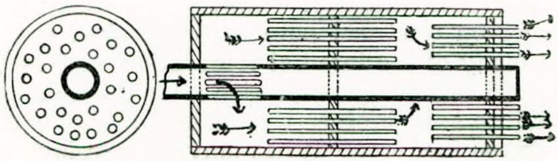


FIG. 5.

inlet as shown by the arrows; they are expanded by coming out of the pipe by means of the slots shown into the space in the front of the box, they then find their way at lower velocity through the small tubes fixed in the centre division, and thus they arrive at the second chamber for still further expansion, then through the small tubes that lead them to the atmosphere, where they arrive usually with a loud report, especially when the engine is under full duty. During this period, and whilst the contents of the cylinder are thus being disposed of, the piston has returned to the end of the cylinder again, which formed the fourth stroke of the cycle and is usually termed the four-stroke engine. The cycle is again repeated and continues, and Fig. 6 shows two diagrams taken from a normal engine, under service conditions; the bottom one shows the engine under approximately half load, and the top one shows the engine under full load; both exhibit the variations in the pressure and expansion curves, usually noticed in consecutive explosions, and they show three successive strokes each.

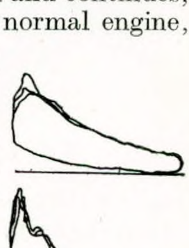


FIG. 6.

As regards carburettors, there are many different types on the market, the best are those which provide a means whereby a rich mixture can be obtained when the engine is running at a low revolution speed. In the ordinary way the velocity of the air will, of course, be lower, and the petrol is, therefore, not drawn off quickly enough to form a proper explosive mixture, consequently the same is not in right proportion and is not fired by the spark and the engine usually stops from that cause. But there are what are termed automatic carburettors that reduce the area of the air inlet and thus increase the velocity of the air on its way to the cylinder, so that more petrol is drawn off and the right mixture is formed, and thus the engine will under these certain conditions run at a variable speed, but not with the same fuel efficiency, which, as previously pointed out in my paper on electrical power transmission, is one of the defects of many of the internal combustion engines that have been proposed for marine propulsion ; the internal combustion engine, like its twin brother the steam turbine, is a machine that as regards fuel economy has only one revolution speed at which the maximum of work can be performed with the least amount of fuel.

Engineers who have had experience with American two-cycle engines have come across the mixing valve shown in Fig. 7. The inlet to the engine is shown at the side, and the main air inlet H to the valve is at the bottom, on which is fixed a non-return valve B under the influence of a spring C, the cap K. carries the lift regulating screw I, so that the stroke of the inlet valve can be regulated to suit the best running conditions of the engine. The petrol inlet is shown at G, and it will be observed that on the valve B lifting, the petrol as well as the air inlet is opened. These mixing valves work very well with engines that are always running at full load and speed, but are unsatisfactory, both as regards fuel and general efficiency, when engines have to work at varying speeds, such as are used on marine work for propulsion ; it is just as well to mention this valve, as there are thousands of this type in work, and they need a certain amount of understanding, otherwise they are, as will be seen, quite simple and effective ; of course, the before-mentioned carburettor is not required when the above type of mixing valve is used. As regards lubrication, one usually

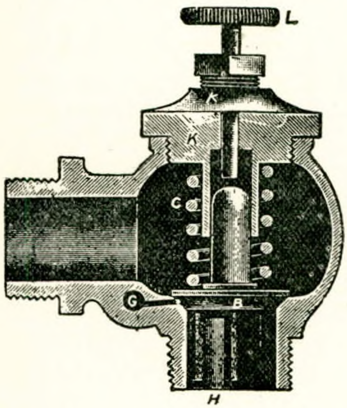


FIG. 7.

sees a box of tricks called a pressure lubricator, and unless one has had experience with this type of lubricator it appears strange. Fig. 8 will explain one of these very simple and gener-

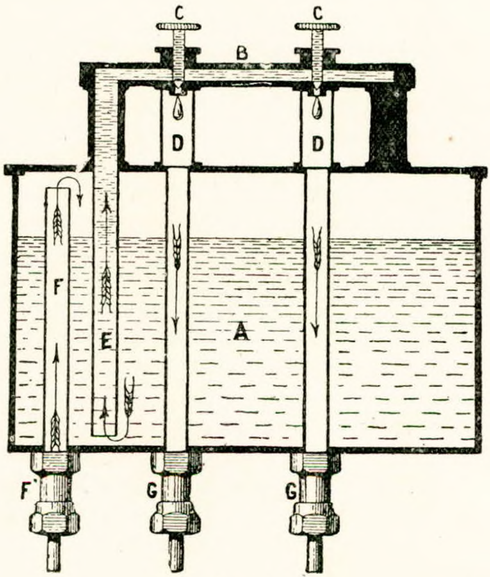


FIG. 8.

ally effective lubricators ; the oil is filled in through some suitable cap in the top of tank A, a connexion through suitable gauze is taken from the exhaust pipe from the engine and taken to the pipe F ; this leads to the top of the chamber A, and consequently the pressure is on the top of the oil, which forces the oil up the pipe E, and after passing through the regulating screws or valves shown at B, the drops find their way through the pipes D, and through the connexions G to the engine bearings or cylinders as may be. The real advantage of this type of lubricator will be seen and is that as soon as the engine is stopped, or is reduced in speed, the pressure is automatically reduced in the pipe and the chamber A, and the drops are consequently either reduced or stopped as may be, and generally speaking, once set, this type of lubricator is very reliable and rarely gets out of order. As before noted, the economy is reduced if the engine is to run at below the critical speed for which it is designed to give the maximum speed and power, and various methods are to be found for bringing about a variation in the revolution speed of such petrol engines ; one way is to put in a small wing valve in the pipe between the carburettor and the engine inlet, but it will be observed that this only cuts off the fuel supply, and does not alter the point of ignition of the fuel in the cylinder, so that as the speed of the engine decreases a time comes when the spark arrives too early and the engines usually give a kick and stop. The reason for this is very evident to those who study the question, and is this, that an explosive mixture takes a certain time to ignite and burn the fuel, and thus to raise the pressure in the combustion chamber, so that if an engine is designed to run and do its work at, say, 800 r.p.m., the ignition of the compressed mixture will be really arranged for before the end of the second or compression stroke, so that as the time for burning the fuel is different from that of the speed of the piston, owing to the high revolutions of the engine, by the time the piston has arrived at the full compression or end of such stroke, the full pressure will be available for expansion during the next outward or expansion stroke. If the engine is reduced, say, to half speed, the engine will stop for the above reasons, or a great knocking sound called pre-ignition will be evident, which means a great loss of power and is in many cases dangerous, unless the engines are very strongly built to withstand these abnormal pressures, as it will be observed the time taken to ignite and burn the fuel remains constant, but the piston speed has reduced to half.

In the author's opinion no engine should be put to work that does not provide automatic methods by means of some suitable sensitive governor that the advance or retardation of the point of ignition is automatic with that of the speed variation, and this, especially so, in very powerful engines, such as will in the near future be used in marine engineering work, whether for propulsion or auxiliary driving. Fig. 9 is a diagram showing the shape of the pressure and expansion curves for an engine with the point of ignition varied, while indicating the engine with a constant mixture ; if the ignition is too early there is likely to be a jar on the engine, and a great part of the power stroke effect is wasted ; it is also desirable that the point of maximum pressure should not occur at the dead centre, otherwise the friction losses will go up considerably, especially at the crank-pin and bearings, and thus cause loss of power by excessive friction. Under the best conditions the point of

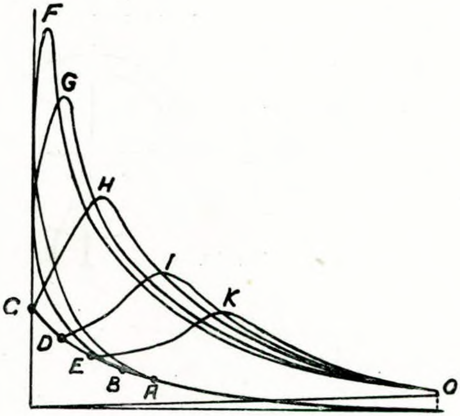


Fig. 9.

maximum pressure should be arranged for at the beginning of the out, expansion or third stroke. On reference to Fig. 9, points A, B, C, D, E, are taken at the moment of ignition, and the points F, G, H, I, K. are those of the maximum pressure. The point A is about one-third stroke ahead of the dead centre, B is about one-fourth ahead, C is on the dead centre, D one-sixteenth after, E is one-seventh after. The curves A F, B G, C H, D I and E K show graphically the relative power effect to be obtained by varying the point of ignition from positive to negative lead or ahead or after the dead centre, and it will be obvious to many that the economy when the spark is E K is very low. It, however, goes to point out the importance of having some means to automatically arrange for the alteration of the point of ignition with the variation of speed, if economy is required, etc., and this would also provide that the engines would be safe on starting up, and at the same time run at the maximum of fuel efficiency when under work. Further, if the ignition is arranged for the highest pressure to come on just after the turning over dead centre, the expansion will be more complete, and a lower pressure and temperature will have to be dealt with by the exhaust valve when opening, and the maintenance of the engine will be less.

Fig. 10 shows proper points to arrange for the ignition of small power engines at various speeds and loads. A is the point for starting by hand with safety—it will be impossible to get a kick back if so arranged. B is the point that gives

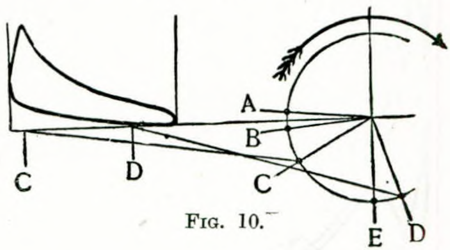


FIG. 10.

best results for running dead slow, say, about 200 r.p.m., and it will be observed that the point of ignition is just before the piston reaches the end of the compression stroke. C. is the point that will give the most economy when the engine is running with the maximum load at 400 r.p.m. D is the point of ignition when the engine is run at 1,200 r.p.m., with the full load; and E is the point that gives the best results when the engine is running with a weak mixture, and consequently light load at about 450 r.p.m., to meet the above conditions automatically by means of a speed governor. It will be appreciated that it would involve difficulties that could not be overcome by an ordinary centrifugal governor, and many ingenious attempts have been suggested to bring about automatic spark timing, with the consequent economy to be gained, but up to the present none of these have proved satisfactory, and hand-sparking has been relied on, but this is only guesswork and not scientific or accurate; much will shortly be done in this important line of investigation.

To thoroughly appreciate the difficulties involved, it is necessary to consider all the causes that render the spark variation necessary. As the engine runs faster, the point of ignition has to be advanced to make it earlier, and when the engine is running very fast the theoretical point of ignition must be even as early as 110° of the crank travel before the dead-centre is reached, before the actual working stroke as is seen in Fig. 10 by diagram. The principal reason for this is the interval of "time" between the first ignition of the gas, and the instant that maximum pressure is reached, as this interval is practically constant with certain mixtures, it is absolutely necessary to advance the point of ignition as the engine increases in revolution speed, if it is desired to keep the point of maximum pressure as shown in the diagram, at the beginning of the working stroke. Two other causes add to this effect—the time-lag of the trembler on the induction spark coil, and also the lessened compression attained at the high speeds of the engine, due to the loss of volumetric efficiency caused by the wire-drawing effect of both induction and exhaust valves ; these are, however, slightly compensated for by the quicker burning of the richer mixture taken in at the higher engine speeds, caused by the increased suction from extra vacuum in the jet chamber. The coil lag is a time-element and that the interval between the completion of the electric circuit and the " break " due to the downward movement of the trembler blade, will be constant for the same coil, and quite independent of the engine speed. This factor is of less importance recently owing to the later design of high-speed tremblers, and is entirely absent in certain designs of magneto ignition systems. The loss of volumetric efficiency results in more burnt gas being left in the cylinder from the previous charge, and the taking in of a smaller new charge, causing a drop in the compression and consequent slower burning of the gas. The degree of compression has a considerable influence on the burning speed of any mixture of given quality. The enrichment of the gas at high engine speeds compensates for this to a certain extent, depending on the efficiency of the valve gear and carburettor, but, of course, this compensation is at the expense of fuel efficiency. If the mixture is throttled, thus lowering the compression, the spark must be advanced to obtain a correct diagram at the same engine speed, and this effect will be intensified, as throttling usually is accompanied by the weakening of mixture ; therefore any automatic device must not only be able to vary the contact of ignition to compensate for the variation in engine speed, but means must also be provided to vary the throttle to get the suitable quality mixture. The speed of an internal combustion engine may be varied by the ignition point of contact, but is a very wasteful method, as sometimes exhausting takes place before complete ignition, to the detriment of the exhaust valves.

Important points in connexion with valves and their setting have to be studied before the engine running at high revolution speed is economical. The setting of valves is one for the engineer to note, as on their satisfactory working rests efficiency. It is evident that the valves, especially in the multi-cylinder type, must open and close precisely at the proper moment, otherwise uneven working and waste of power will be the result. Fig. 11 shows one setting of the

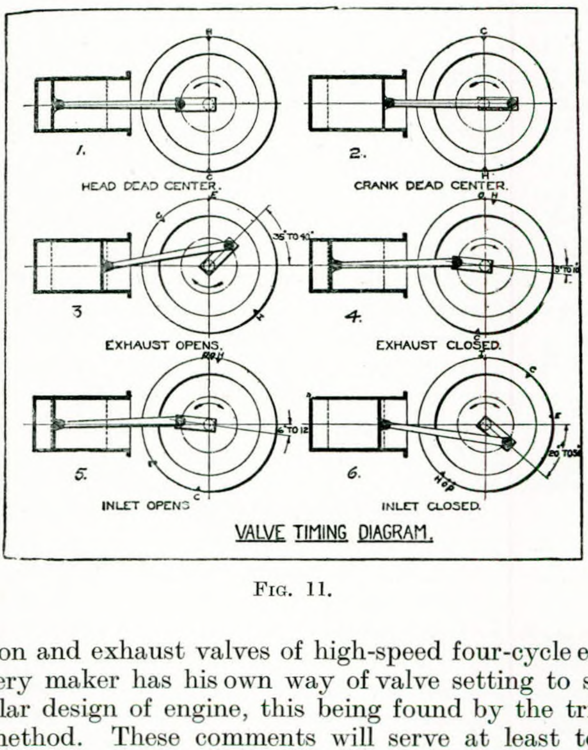


FIG. 11.

induction and exhaust valves of high-speed four-cycle engines, but every maker has his own way of valve setting to suit his particular design of engine, this being found by the trial and error method. These comments will serve at least to draw attention to a vital point in high-speed internal combustion engines working with atmospheric pressure on carburettors, etc.

Referring to Fig. 7 in Part I. of this paper, 1 and 2 show the dead centres at either end of the stroke. It will be seen that the exhaust valve lifts as marked at B, cutting short the expansion at this point ; 3 shows the position of the crank on the working stroke when this occurs. The valves lift when the crank has arrived at 35° to 40° from the end of the working stroke; an early opening of position 4 shows when the exhaust valve closes. It will be seen that the valve closes about 5° to 10° after the crank has passed the dead centre and is already on the induction stroke, remaining open, say, during 220° of the crank-shaft revolution. Position 5 shows the point where the induction valve opens about one degree after the exhaust valve is closed; 6 shows that the induction valve has remained open during the remaining part of the induction stroke and also that it does not close until the crank has arrived at, say, 20° of the compression stroke. To those who are used to the setting of valves on the ordinary slow revolution gas engine this timing for the valves will possibly be new and is brought about entirely by the elements of time and speed. The valve opens early (see 3 and 4) to allow the pressure to be high enough for the burnt gases to escape quickly to the expansion box at first part of the exhaust stroke; and for the valve to remain open past the dead centre to part of the induction stroke—the reason of this is that in all elements, such as air or gas, at high velocity there is a certain amount of momentum, and it has been proved that by leaving the exhaust valve open past the top end of the stroke more of the burnt gases are allowed to escape from the cylinder, as they are still above the pressure due to the back pressure in the exhaust or expansion box, also the atmosphere. The amount of valve opening depends to a great extent on the cylinder diameter and stroke, valve area, etc. at various engine speeds.

Positions 5 and 6 refer to the induction stroke, and the valve does not open until the crank is 6° past the top centre, the reason being that the exhaust is open till then; the induction valve now draws in its charge by means of the mixer. The velocity of the piston soon raises that of the incoming charge until a good vacuum arises owing to the limitation of the area of the induction pipes, etc., the high speed brings the piston at the end of this stroke, with pressure below that of the atmosphere, and the charge is wire-drawn; the valve is thus left open for a longer period, that the incoming gases may have time to get as good a mixture in the cylinder as possible. In Fig. 4 the compression pressure is very low at this end of the compression stroke. It will thus be evident that it is most important to have a thorough knowledge of valve setting, and these few remarks may lead to further investigation. In the designs now in hand of large internal combustion engines combining those with electrical power transmission for marine propulsion, the points indicated will be attended to by means of electrical apparatus, the valves being arranged to lift and remain open, the period also will be electrically controlled automatically, and probably such is the only method that will prove suitable.

Where the engines are not required to reverse, as when using electrical, hydraulic or mechanical gear, or in the application of the "Paragon" propeller, an internal combustion engine embodying good points as regards efficient working is the design known as the off-setting of the cylinders in the direction of the revolution of the engine, where the cylinder is placed, say, one-third of the diameter out of the centre of the shaft. On automobiles and other machines it has been found that engines so constructed work with greater smoothness, and higher mechanical efficiency than those in which the centre of the cylinder is exactly in line with the crank centre. This design of engine is to be employed in a vessel now being built, fitted with suction gas plant and will, no doubt, prove efficient for quiet working and cause less strains on the hull. By reference to Fig. 7, Part I., the point of highest pressure is when the piston is just over the top dead-centre; the side pressure is then between the piston trunk and the cylinder walls, but, as the crank goes round, the angle is increased and although the pressure per square inch on the piston head is reducing, by reason of the expansion, it has been proved that a great amount of energy is lost in the pressure causing extra friction between the piston and the cylinder walls. Many attempts have been made to reduce this, employing extra crank levers and other means, but the design stated appears to be the best, because of its simplicity, easy arrangement and reduction of working parts, and there is no question that in the designs of engines of large power, this will be embodied for efficiency. If, however, such engines are to be made direct-coupled and reversible, this method of getting high mechanical efficiency will have to be sacrificed, and it must be remembered that this high side pressure will cause the cylinder to wear oval, consequently engines constructed on the off-setting principles will have longer life as regards liners, etc.

In designing marine internal combustion main or auxiliary engines dealing with large power, the question of balance is of vital importance, especially as such engines do not have a concrete base to work on. I do not refer to the workshop balancing of the pistons and crank-shafts by weights, etc., but there is an out-of-balance due to the effect of the explosion or high pressure during the working stroke, and although an engine may be found to be perfectly under ideal condition as regards balance, when being turned round by some external means, when it is working on its own power it may run greatly out of true balance ; thus great vibration may be set up, and in order that the balance shall be as nearly as possible equal, and also that the maximum amount of actual work shall be got from the engine per unit of fuel burnt, it is essential in multi-cylinder engines that the points of ignition shall be identical in each of the cylinders in relation to the position of the crank. The timing of the valve gear should also be accurately set equal in each cylinder, otherwise the amount and quality of the mixture will vary in each cylinder, and the indicator cards taken from the cylinders will have different shapes ; the engine will then be working under wasteful, noisy, vibratory conditions. Attempts have been made to make the synchronous working of such engines reliable, but it is a difficult matter, and in some designs of marine engines separate ignition devices have been tried on each of the cylinders, but in the writer's opinion the only way in which this may be secured is by means of an accurately divided and reliable distributor directing the current for ignition to each cylinder at the proper and right moment, when also the control of advancing and retarding the point of ignition can be carried out with greater precision than is possible by other methods and at the same time quicker than is the case where the ignition is separate for each cylinder, as in the case where a hot tube or hot cylinder end is relied on, where the difference in the temperature of either tube or cylinder end will cause an unequal time of ignition for mixtures of equal quality.

The question of equal turning moment is also important, and as regards four-cycle engines there is no question that the six-cylinder engine gives a very satisfactory job ; it gives absolutely smooth running owing to its continuous turning moment, which at the same time reduces the cost of upkeep, and this is applicable to propulsion as regards

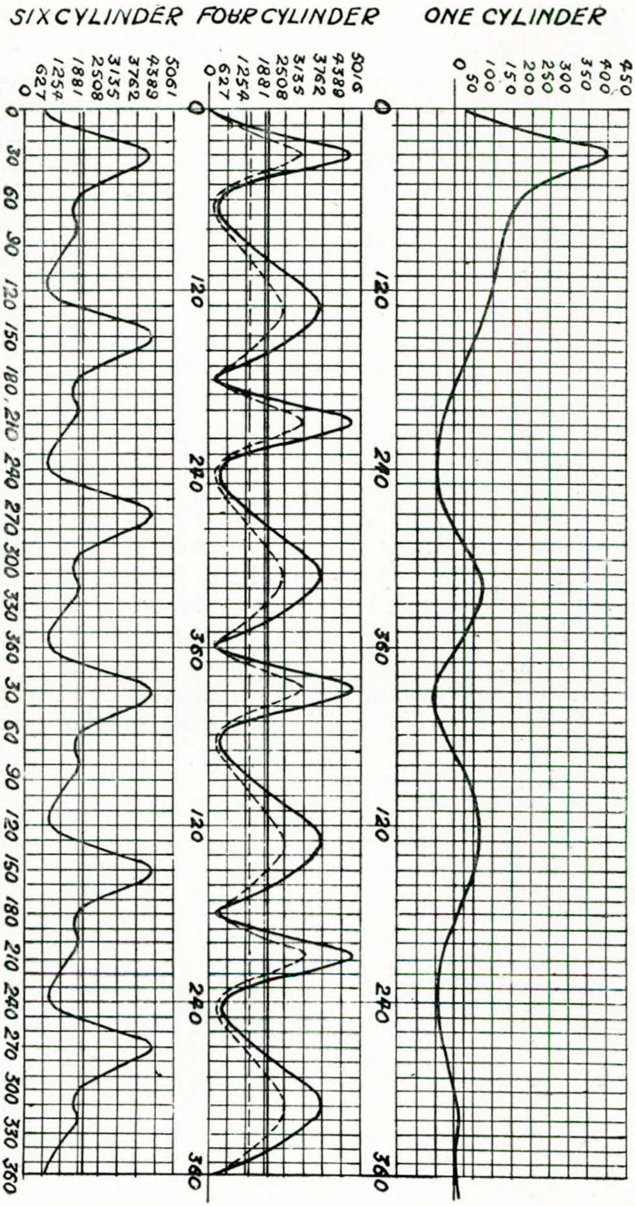


FIG. 12.

propeller shafts, etc. Fig. 12 shows the torque diagrams and pressure curves for single, four and six-cylinder engines, and emphasizes this point. The variation of pressure in the cylinder is a matter for first consideration, and for the purpose of discovering what actually takes place a standard six-cylinder Napier engine was used under the tests from which this curve is drawn, and by way of monograph indicator diagrams and pressure recorders.

As a means of all these readings the indicator diagram shown at Fig. 13 was constructed. The vertical line is graduated

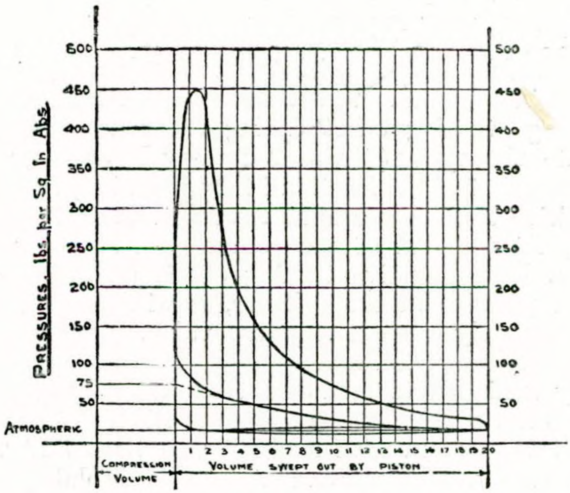


Fig. 13.

to give the pounds per square inch, and shows in the diagram that the compression was carried up to 75 lb. per square in., the ignition taking place considerably before the end of this compression stroke, the pressure rising very rapidly to about 450 lb. per square inch when just over the top centre, as it should be. The enormity of this pressure can be better appreciated, perhaps, when given as a total weight on the piston, the bore of the cylinder was 4 in. and the area equalled 12·56 square inches, and therefore the total pressure on each piston is roughly 2 tons. The diagram also shows the fall of pressure during the working stroke, and the slight rise and fall above the atmospheric pressure during the exhaust and suction strokes. At the beginning of the suction stroke, for instance, the piston is being pulled along at an ever-increasing rate, whilst the crank travels through approximately 90°. Then until the end of the stroke the piston tends to keep on moving, and has to be retarded and brought to rest by the crankshaft; in other words, the inertia of the piston and parts moving with it is retarding the crank during the first half of each stroke, and urging it on during the latter half. The pressure in the cylinder and the force necessary to accelerate the piston have both been taken into account in the torque diagram for the single-cylinder engine. The turning effort in Fig. 12 is shown in inch-pounds. For example, at point A, 400 inch-pounds represents a pressure of 200 lb. on the crank pin, tangential to the crank arm, and acting at a two-inch radius. The thick horizontal line represents the average turning effort during the four strokes, which constitute the cycle (it was a four-cycle engine); it also shows the effort of the inertia of the piston in giving negative and positive turning efforts at the beginning and end of the strokes. At the end of the compression stroke instead of getting a large negative turning effort, on account of the increased pressure in the cylinder, it will be seen that the torque has only a small negative value. This shows that the inertia of the piston coming to rest at the top of the stroke is nearly sufficient to compress the charge, also, when the crank is on the dead centres, there is no turning effort. It is from this diagram with its large variations that we must start and endeavour to obtain that which is absolutely essential, i.e., a constant torque with the internal combustion engine, so as to avoid those disadvantages previously dealt with as vibration, etc. The dotted line in the four-cylinder engine figure is found by superimposing four of these diagrams, corresponding to four cylinders with cranks at 180°. It is not fair to compare the diagrams for four and six cylinders as the cylinders being all of the same size, the six-cylinder engine will be giving one-and-half times the power of the four-cylinder engine, therefore each vertical height of the dotted line has been increased one-and-half times to the full line, corresponding to the larger pistons to equalize the powers of the two engines. The interesting point to be noticed is that with the six-cylinder engine there is always a positive effort of at least 700 inch-pounds, on the crank-shaft, and that at no point of the cycle does it approach zero. With four cylinders and cranks at 180°, there must be four points in the cycle of operations (when the cranks are on dead-centres) at which there is no turning effort.

The four-cylinder diagram shows also four other points, at which the torque has only a very small positive value, namely, less than 200 inch-pounds, which is accounted for by the retarding force of the pistons when being accelerated, after the effort of the explosion has passed. Had this diagram been constructed for any other pistons than the extremely light ones such as are used on petrol engines of the Napier type, it is extremely probable that at this point the torque would have had a considerable negative value. The next rise in the torque is due to the forward pressure of the pistons when nearing the end of the stroke. A comparison of the two diagrams will be far more convincing than anything that can be written about them, and the total inch-pounds is given for convenience. The foregoing is an illustration of what has to be studied and taken into consideration by those engineers who may be considering the application of the internal combustion engine for marine propulsion of large powers, and in the writer's opinion, these will have to run at high revolution speed in order to get the power into the space, also electrical power transmission will have to be used, in order to get the best commercial results. The lack of efficiency has been previously noted and one way of correcting this will be to design the engines on other lines, such as, for example—assuming that the compression chamber of engines is at present, say, equal to 25 per cent. of the space or sweep of the piston and clearance, and assume that it is equal bore and stroke ratio, that is to say, 6 in. by 6 in.; design the new engines with a bore of 6 in. and 12 in. stroke, let the compression chamber remain the same, and design the induction valve gear so that the incoming gas will be cut off at half stroke, then when the piston returns and compresses this charge, it will have the same maximum compression as the first-mentioned engine. We will assume that the ignition takes place in the usual form as explained above; the pressure will at half the out stroke be the same as that of the former engine; now as both engines have received the same amount of gas, they have thus far delivered the same amount of work. The first engine exhausts at this point, but the second has still a charge of perhaps 60 lb. per square inch, multiplied by four times the compression space. Owing to this fact the pressure will fall very slowly during the remaining part of stroke of the new engine, which is 12 in. instead of 6 in., as in the first engine, and there being no compression pressure to subtract from it, for the simple reason that the compression did not begin before the piston reached half through the compression stroke, as explained. Hence the last part of this stroke is very efficient and the work got for nothing, so to speak, as compared with some of the existing types of engines. This is well worth the attention of designers of internal-combustion engines, as it is certain that we have no losses to allow for due to compression, for this added power, nor the loss due to pressure leakage and heat losses under the high pressure and temperature at the beginning of the working stroke. Taking these facts into account the design of this engine would have at least 25 per cent. more efficiency for a given amount of fuel than the engines that have equal stroke and bore and the valves arranged in the ordinary manner. The output of this engine would be perhaps less than that obtained by the other method, but the efficiency and power may be further increased by raising the compression, for the higher point of compression is reached so much later in the stroke, that the point

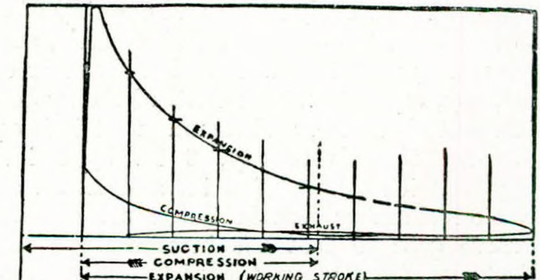


FIG. 14.

of self-ignition will be nearer the dead centre. The average temperature is lower and better suited for marine work, owing to the consequent reduction in the amount of circulating water required. The dimensions given are only for convenient illustration, they will, however, serve to point out a method that is being investigated, and so far shows that the idea is not far wrong ; views have been expressed as that the internal combustion engine will in the early future be greatly improved both as to thermal and mechanical points. Fig. 14 gives some idea of the diagram that may be found on such an engine.

In the early part of this paper reference was made to the type of engine most suitable for large powers, such as will be required for the propulsion of large war and other ships. An interesting example of one is from an inventor in America who has been working on the subject of the Brayton cycle and has constructed an engine shown in Fig. 15. The side

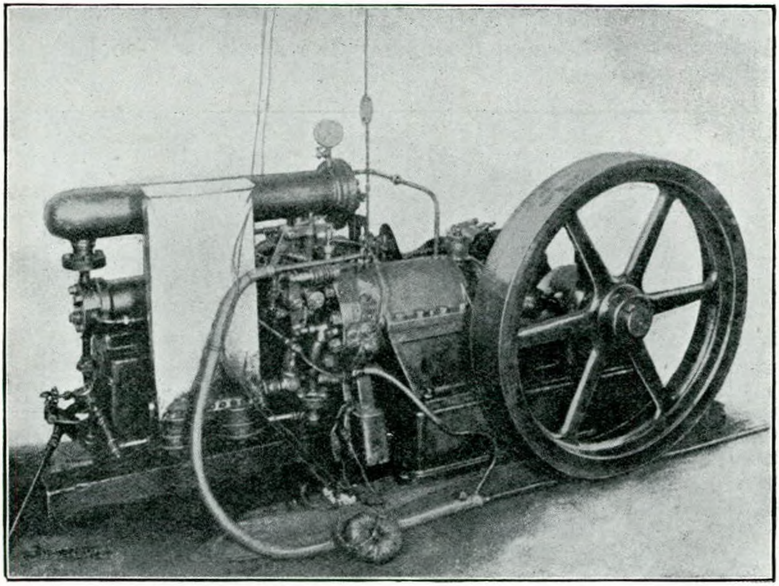
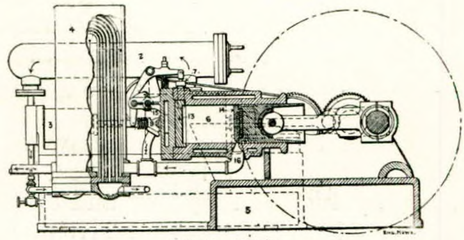


FIG. 15.

view gives the separate compression pumps and inter-cooler as seen.

Fig. 16 shows a side section of this interesting engine, which in the writer's opinion has a great future before it. Fig. 17 shows the engine head-on ; it will be seen the method adopted for the driving of the pumps from the crank shaft. Fig. 18



Sectional Elevation
FIG. 6. PLAN AND ELEVATION OF CONSTANT-PRESSURE
COMBUSTION ENGINE.
(Designed by H. B. Stilz)

FIG. 16.

is a plan of the engine showing the small inter-cooler and

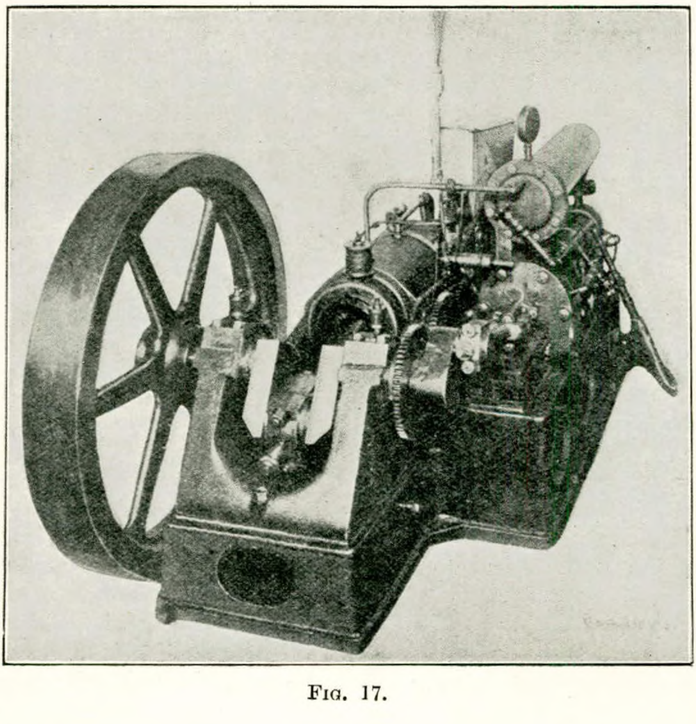


FIG. 17.

general layout. Fig. 19 shows the cycle and apparatus in diagram; it will be noticed that this engine is fitted with

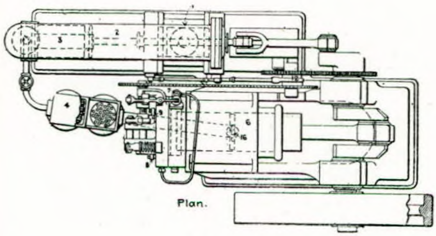


Fig. 18.

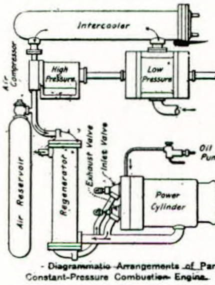


Fig. 19.

air compression reservoir enabling the engine to be started by means of a valve similar to the method adopted in steam engines. Fig. 20 shows the type of low voltage ignition that

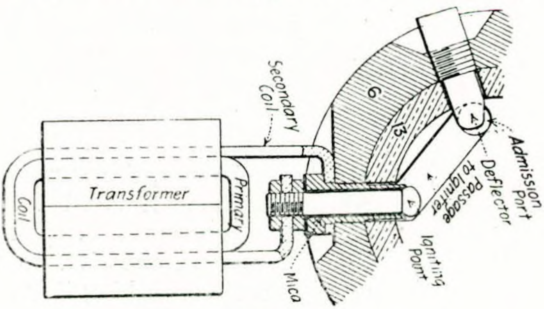
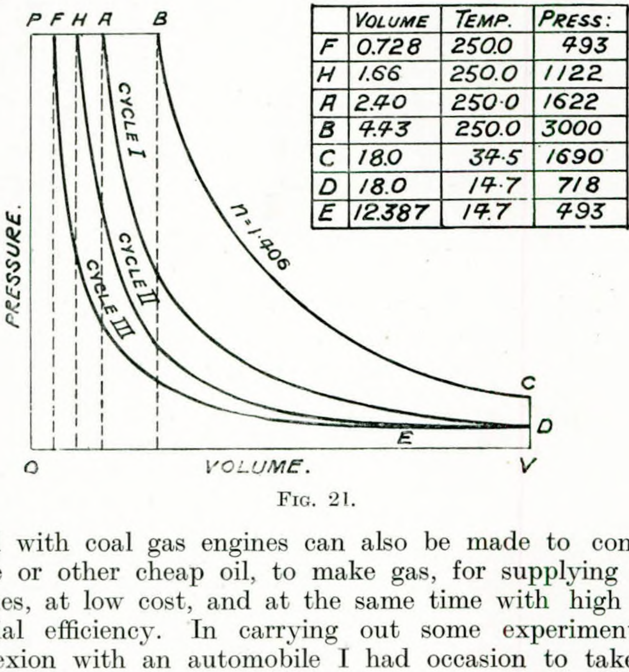


Fig. 20.

has been adopted in this engine, which is more than likely to have a future use in engines of large power in this country. Fig. 21 shows the constant pressure combustion diagram of cycles for this engine, which it will be observed is very similar to that of the Diesel. The engine operates on the two-stroke cycle and much more will be heard of it in the early future. The valves are similar to those used in superheated steam practice, and the engine has stood some remarkable tests very satisfactorily.

With reference to the suction gas engine, and its application for main propulsion, statements have been made by various

Members that this engine is limited in its application, as coal can only be had in certain countries, while crude oil can be secured cheaper in many countries abroad than in England, I wish to say that means can now be provided so that ships



	VOLUME	TEMP.	PRESS:
F	0.728	250.0	493
H	1.66	250.0	1122
A	2.40	250·0	1622
B	4.43	250.0	3000
C	18.0	34·5	1690
D	18.0	14·7	718
E	12.387	14.7	493

FIG. 21.

fitted with coal gas engines can also be made to consume crude or other cheap oil, to make gas, for supplying these engines, at low cost, and at the same time with high commercial efficiency. In carrying out some experiments in connexion with an automobile I had occasion to take out the float from the carburettor, and on shaking it I was rather surprised to hear a rattling sound in same, such as would have been heard if a small piece of metal was loose inside the float. This really was so, as after being in use about six months, the float always being submerged in the petrol, a certain portion found its way through the thin metal composing the case of the float, no doubt as vapour, and condensed into fluid again when inside. The quantity was perhaps only equal to one drop, but in order that you may realize what an enormous power can be stored up in that one drop of energy in the form of petrol, I had a weight tied to that float, and placed it in a pail of boiling water. In the course of a few seconds an explosion took place, sending the water in all directions; on examination, after the turmoil was over, the float had its ends blown out, and the sides were flattened out straight almost equal, as if it had been done by a workman, a right good job. I could not let such an interesting thing pass without investigation, and the theory is really quite simple, the heat of the water transferred the fluid petrol again into vapour, and being in a limited space, confined in the float chamber, the drop of petrol, when brought back again to vapour in the float, pressure was so formed and the explosion was the result. This was sufficient experience to lead one to believe that if properly designed, a gas producer could be made that would generate a suitable gas from, say, crude oil, under pressure and utilized in coal gas engines, so that ships could be constructed to burn either or both types of fuel for the purpose of gas-making, to supply the engines. It further struck me that possibly the pressure so generated could be also utilized in the engine, for work, if the engines were constructed on say the Brayton cycle, with the air supply also under pressure, and so get back some of the work of compression, etc. I am pleased to say a system of this nature has been invented and in which I am interested; it has been well tried, using crude oil and can now be made and supplied in sizes varying from 50 to 5,000 horse-power, under the strictest guarantees as to the working results. The inventor of this gas-producing system is a clever engineer and chemist, and in my opinion it is one of the greatest advances in the design of gas-making apparatus that I have come across, and is especially suitable for marine work. A few extracts from letters that I have received are not without practical interest, especially to the Members of the Institute from the inventor :—

"I have considered the application of the system to marine uses, which is one of its most promising fields, as there are many arguments in favour of petroleum as a marine fuel, and gas engines have proven practicable for marine purposes. Combined with your interesting system of electrical power, transmission and speed regulation, together with suitable gas engines driving your generators, should be far superior to any other method of ship propulsion, and would rapidly become standard through the world. I should think that it would be of special interest for the Admiralty, for petroleum in some form is available throughout the world, and the fields are being rapidly extended. This patent covers the basic idea of process and apparatus, and may be made up in any desirable form. My process uses any form of carbonaceous matter, fluid enough to be carried through pipes. The lighter hydrocarbons, if any are contained, are made into 'fixed' gases, while the essential element, carbon, is combined with oxygen into carbon monoxide, the most economical, tractable and safest power gas known. It seems perfectly feasible to wash the gas and cool the engine with the sea-water only, and as I do not need steam, this would do away altogether with the use of fresh water about the plant. A small quantity of practically pure carbon, free from tar or oil, is a bye-product, and is valuable for many purposes, such as a marine and weather-proof paint, fuel, etc., or it may be allowed to go to waste, as may be. The above gas is also valuable fuel; for any purpose such as metallurgical heating, etc., it could be piped about the ship as fuel, and if converted into electrical energy would serve all purposes. The actual record of a plant recently erected will interest you, I designed and installed a 375 kilo-watt electric generating plant consisting of—

One double tandem, double-acting 500 B.H.P. gas engine with alternator on shaft direct-coupled.

One 90 B.H.P. single-acting single cylinder gas engine belted to an alternator.

One of my oil gas producers with auxiliaries.

Complete duplicate set of water pumps, as plant takes its water from its own wells and circulates engine water through cooling tower. All auxiliaries and pumps are electric motor driven.

Three men have been found more than is necessary to run this plant 12 hours' daily, and it is proposed to operate with two next season. On a run of ten days and nights without a stop, practically carrying full load continuously the fuel consumption proved to be for each net B.H.P. hour, delivered, by the main engines, a little less than one pound of crude oil from which the petrol and kerosene had been taken off by the refinery, leaving it about 23° Baume and weighing about 7½ lb. to the gallon, giving off over 315 B.H.P. hours per each 42-gallon barrel of such fuel, the power for driving the producer auxiliary machinery having been charged to the main engine. I get the same economy from every kind of petroleum or any portion of it. For instance, Californian oil is very heavy and viscous, with a heavy asphalt base, the most difficult of all petroleums to decompose into gas, I have two plants running on this oil. The gas can be made to run down, to any desired leanness, or up to a high degree of thermal efficiency, using AIR only. Steam increases the hydrogen, enriches the gas somewhat and improves the fuel economy though, personally I prefer to do without it and the undesirable hydrogen it produces. Simple automatic devices care for the uniform quality and quantity of the gas under varying loads, etc. A 500 B.H.P. plant installed has a vertical generator 6 ft. diameter and 11 ft. high, connected to a static tower scrubber 4 ft. diameter and 18 ft. high, the outlet delivering to one of my centrifugal scrubbers about 3 ft. in diameter and 6 ft. long altogether occupying a floor space of about 6 ft. by 21 ft. including connexions, and in this case there was no attempt to save space, as would be in the case of a sea-going design. A small storage of gas is advisable but not necessary, say, for a five-minute run, either a gasometer or closed tank will answer.

A test carried out by one of the most learned internal combustion engine experts about two years ago, on a 100 B.H.P. set showed the following results (with oil with a specific gravity of 19° Beaume).

The object of the test was the determination of the overall economy of the producer and engine combined, as expressed by the relation between the oil fed to producer and the B.H.P. given off by the main engines.

Time.	Elapsed Time.	R.P.M.	B.H.P.	Lb. Oil per Hour.	B.H.P. Hours.	Actual Oil Consumed
	Minutes.					Lb.
1.15						
2.00	45	197·33	111·3	105·3	83·48	79
3.00	60	192·70	108·7	108·0	108·70	108
4.00	60	195·00	110·0	109·0	110·00	109
4.30						
5.00	30	195·50	110·3	106·0	55·15	53
6.00	60	193·60	109·2	109·0	109·20	109
7.00	60	198·70	112·1	109·0	112·10	109
7.35						
8.35	60	196·40	110·8	107·5	110·80	107·5
9.35	60	*183·10	103·3	112·5	103·30	112·5
10.20	45	*182·80	105·2	100·7	78·90	75·5

* One sparking plug was occasionally missing fire.

	B.H.P. Hours.	Actual Amount of Oil.
Totals	871·63 . .	862·5 lb.
Average for eight hours	108·95 . .	107·81 ,,
Oil per B.H.P. Hour	— . .	·99 ,,

Omitting the last two hours the results are as follows :—

Totals	662·43 . .	646·5 lb.
Average for six hours	110·41 . .	707·75 ,,
Oil per H.P. Hour	— . .	·976 ,,

In the interests of this Institute, coupled with the great British shipping industry, it is hoped that the preceding notes may be of value and that those who have neither the opportunity nor the time to study this problem of the future of sea transport, will find something that will further their knowledge on the subject. Should this be so the pleasure the writer has had in going into many details in order to lay these scant notes before the members will be greatly enhanced."

Chairman : Mr. Durtnall has given us a very large amount of information in his paper, and I do not know whether it is suitable at this late hour to commence a discussion upon it. However, the meeting is open for any one to express their views upon the subject.

Mr. E. Kilburn Scott : I think this Institute is to be congratulated on having such a member as Mr. Durtnall. He not only proposes revolutionary methods of propelling vessels, but he is absolutely irrepressible, whatever the opponents of such methods say against them. Not only that, but he is a prophet also ; for he has shown us this evening what war vessels are to be like in a few years' time. Right through his paper there are suggestions as to how the internal combustion engine may be improved, and I think Mr. Durtnall has made out a very strong case for the combination of the three new methods he has brought before the Institute. First of all is his system of electrical propulsion ; then his proposals in regard to the internal combustion engine ; and again his bringing forward this combined propeller and rudder. The three schemes, although they seem to be quite apart, are really intimately associated. For example, the propeller-rudder is clearly one which must be driven by means of a vertical shaft, and I cannot conceive of any steam turbine or reciprocating engine driving such a rudder direct. If the device is to be used at all, in a large way, it will have to be driven by an electrical motor. Then again, the internal combustion engine has very great advantages in thermal efficiency; but at the same time it has the great disadvantage, as compared with the steam engine, of being a "single revolution" engine; it will run best at one speed only. Therefore if the internal combustion engine is to be applied to marine propulsion, it can only be done by some means of transmission between the engine and the propellers, and the most convenient method of linking them up is by electric power.

The key-stone of the whole question of the gas engine seems to me to lie in the producer. In the Johannesburg fiasco the engineers made a mistake in forgetting that Johannesburg was several thousand of feet above the sea level, and therefore the engines could not give the same power as at sea level. But the greatest trouble was with the producer plant. If that had been satisfactory I believe those engines would have been working to-day. The engines were of the Oechelhauser type, a "spread eagle" kind, with two crank-shafts, and faulty in that respect from a marine engineering point of view, for I do not see how such engines could be put on board ship, unless fore and aft. But for land purposes the engine is a good two-cycle type, and it was made by a good Glasgow firm, so I do not think the engineers were at fault in recommending it. The failure was entirely due to the gas producers made by a German firm, who had built up a reputation beyond their merits, by advertising. It does not follow because of the failure at Johannesburg, however, that the idea of using the internal combustion engine was wrong. We learn most from mistakes, and we have learned a tremendous lot from that particular mistake.

I think the solution of the problem lies in the producer plant, and the large boiler-making firms are the likeliest to solve it. When they find that not so many boilers are being purchased, they will have to make something else instead, and it is to be hoped that it may be gas producer plant. In the writer's opinion boiler-makers are best qualified for the work. So far, those who have been making them are somewhat of amateurs.

Some seven years ago I was deputed to go over to the Continent to visit all the big iron and steel works, and see what was being done in large gas engines. I found there most of the works were equipped with Cockerell, Koerting or Oechelhauser engines driving dynamos and alternators. One of the points I had to satisfy myself about was the question as to whether they could drive alternators in parallel. I found that it was being done quite easily, and it was surprising to see how few men were required in the power houses and how little trouble the engines gave. They were engines of 500 to 600 H.P.—that is to say, small compared with the 2,000 H.P. engines of to-day. They were nearly all working with blast furnace gas or coke oven gas—that is to say, a poor low-grade gas with very little of the explosive hydrogen in it that so frequently gives trouble.

One great difference between steam prime movers and those working with gas is that there is only two varieties of steam, namely saturated and superheated, but with gas the varieties are infinite. It is much more trouble to produce a suitable gas than it is to produce suitable steam, and that is why I emphasize the fact that the key-stone of the gas engine prime mover lies in the development of really satisfactory gas producer plants.

Mr. Binyon : This is a subject interesting not only to land engineers, but particularly so to marine engineers. Mr. Durtnall has shown us to-night a way to utilize the gases after they have done their work in the cylinders, and in some of the diagrams this is shown added to indicate the total energy obtained from the gases in the same way as in the combined diagram of multiple expansion steam engines. But in place of the loss in the steam engines between the cylinder and the condenser, he practically utilizes the heat right to the end. Although not a marine engineer, I take a keen interest in marine engineering, and from that point of view I was very much interested in the application of the propeller referred to by Mr. Durtnall. I spent some months trying to understand propeller design, but confess I know very little about it. I gave the names of two experts on propeller design to a friend who has a motor boat, for which he wanted the best type of propeller. The diameters given by them varied by 5 in. to 6 in. ; so that the design of the propeller is not so simple as it appears at first sight. What appeals to me in this propeller is that the vanes can be readily altered; one can be taken off and another larger or smaller one can be put on as required, till the best results are obtained. It can be driven by mechanical means, but I should think the best way of driving it would be by an electrical motor. In this propeller there is feathering gear, but as there is a pressure of water on both sides of the vanes there is no strain on the gear, just as in the case of a balanced rudder; it is simply a matter of altering the pitch. I have had the privilege of studying this propeller with Mr. Durtnall. At first I was not very sympathetic, but I have seen it tested in a small vessel, and it did exceedingly well.

It was decided, on the proposal of Mr. W. McLaren, seconded by Mr. W. J. N. Brett, that the discussion be adjourned till Monday, January 9, 1911.

A vote of thanks was accorded to the Chairman on the proposal of Mr. Durtnall.

ADJOURNED DISCUSSION

ON

"THE INTERNAL COMBUSTION ENGINE."

CHAIRMAN: MR. WM. McLAREN (MEMBER).

Monday, January 9, 1911.

CHAIRMAN: We have come to a state of things when we must consider the question of the internal combustion and its utility for marine propulsion. What we want, as marine engineers, is to have the same confidence in its flexibility as we have had in the steam engine. The steam engine has been tried and has proved itself, I think, a very faithful servant. It has grown, and has been enormously improved since its first introduction, and I think there is a great deal to be obtained from it economically. The point to be considered is the economical aspect of the present engine as compared with the internal combustion engine, either driven by oil or gas, or as the author of this paper puts it, coal gas or oil gas. It is open to you to say which you prefer. This is like a "pressure" paper, it is being forced upon us, and it is for us to criticise the internal combustion engine, just as we did the Scotch boiler and the water-tube boiler when they were introduced. They are still going "hand in hand," and no doubt these engines will also go "hand in hand" for some time yet. The objection of the high speed is put forward. Well, we seem to be treating the propeller too kindly. We have been attempting to bring the speed down to suit the normal propeller of the day, but we should try to alter the propeller to see if we cannot obtain a combination of lightness and high revolution speed. To do this it may be necessary to ask the makers of internal combustion engines to lower the high revolution speed to meet the size of propeller, and to reduce the propeller in diameter so that the engine revolution speed may not be reduced too much. I have taken a great amount of interest in this new class of drive and am inclined to advocate its adoption, whether it is by gas producer, or by pressure or suction, or whether it is by oil. I now have pleasure in declaring the meeting open for the discussion and will ask Mr. Shackleton if he would begin it.

Mr. E. SHACKLETON : I am sure we are much indebted to Mr. Durtnall for his very extensive paper. Certainly he must have devoted a great deal of time to the subject of the petrol engine ; but while he has investigated and put before us the claims of that engine, such a type of engine could not be considered except for small power marine work. Much of the subject matter which forms the body of Mr. Durtnall's paper of course refers to high speed petrol engine practice. The diagrams are very interesting, but I must say that as far as the matter goes I can find nothing very important from my point of view that would afford any great amount of interesting criticism to the members of this Institute. Mr. Durtnall raises the point of the "Paragon" propeller, which I believe in time will be adopted, particularly for large powers. Although I myself was very much impressed by the electrical drive I must confess that for the tramp steamer of over 2,000 h.p., there would not be the slightest hope of getting a shipbuilder to adopt it. The oil engine is reversible. It was simply a case of a gun being held at the engine-builder's head ;—he has had to make his engine reversible, although I think every engine-builder would have preferred to have an intermediate electrical drive for facility of reversing and speed variation. Mr. Durtnall gives some description of the Brayton Engine. The old Brayton

Engine was in advance of its time as a constant pressure engine, but it had the unfortunate tendency in developing say 10 h.p., to absorb about 5 h.p., in turning itself round, which meant, of course, a very low mechanical efficiency. I am now thinking about a number of other things in connexion with the internal combustion engine, but will reserve them for my paper to be given in March. The proposition of the internal combustion engine *versus* the steam engine, is roughly this. The thermal efficiency of the Diesel engine is 38 per cent., the gas engine 20 to 25 per cent. as compared with the steam engine 12 to 14 per cent.

Mr. W. Arnold : I think it was stated in the preceding discussion on this paper a short time ago that the two-stroke engine was as economical now as the four-stroke. I should like to know whether that is in accordance with the facts.

Mr. Shackleton : Mr. Timpson is, I think, responsible for upholding the case of the two-stroke engine. It is certainly economical. There is a loss even in the very latest types, I have been investigating a loss in the admission of compressed air, but the economies are now exceedingly close, there is a very small percentage.

Mr. F. M. Timpson : The position I stated was that there are makers of two-stroke engines working with ordinary paraffin oil, whose guarantee is lower than that of the marine type four-stroke engine. The guarantee is ·6 of a pint, while that of the four-stroke is ·75 of a pint. These are the actual specification figures, and it is borne out in service with the engines. These figures are, of course, for small engines, and for a vessel of over 100 h.p. crude oil would be necessary as regards economy.

Chairman : I think Mr. Durtnall mentions in his paper some system which has been tried where they use either crude oil or coal, or a combination of both.

Mr. Durtnall : I do not think I made it quite as clear as I might have. A firm of engineers in America have utilized the lower pressure engine under the ordinary form of a gas engine, with the gas supplied under a very slight head, or a suction head from the piston. They make the gas in a crude oil power producer in the American way. They make it from the raw crude oil, and they have sent me most interesting matter and details, which I described in the *Liverpool Journal of Commerce* recently, of a 500 h.p. four-cylinder engine running on the gas producer from this crude oil. The fuel consumption in that case, after allowing for driving the auxiliaries necessary in that type of engine, the amount of crude oil fed to the producer and delivered to the engine came out at ·9 lb. per b.h.p. per hour. I believe that in some cases we shall have to make provision for burning coal as well as oil. In some countries we can get coal for making gas in the producer, anthracite and bituminous coal in a bituminous gas producer as suggested by Mr. Shackleton some months ago ; or we have the means of producing gas from crude oil which is found in some parts of the world, and means of burning both coal and oil if desired. These producers seem to be in the form of a large retort, and they are very light as compared with the ordinary coal gas producer. The combined weight, taking the boilers into account, is not so large as that of a steam installation for a given power. I suggested it as an interesting point for discussion, in view of ships going abroad where either coal or oil may be procured.

Mr. SHACKLETON : Mr. Durtnall raised a point that I might touch upon. The gas managers in some instances bring down the calorific value of the fuel by the addition of cold water, and the extent to which this is done can generally be denoted by the amount of black section in the gas flame—in some instances there is more of the black section than of the flame. Producer gas can always be " enriched " in this way, and managers take care to water the coal gas, thus letting it down. Certainly the idea of enriching the gas might be carried on in connexion with the gas producer.

Mr. DURTNALL : This engine I referred to is certainly a great advance, and as soon as my drawings arrive I will reproduce it for this paper. But if not I will probably illustrate in one of the latter issues of the Transactions with the Hon. Secretary's permission.

Mr. TIMPSON : I remember an engine on this principle, producing gas from crude oil and retaining the solid parts in the producer, the gas formed being used in the engine, and the solid deposit in the form of coke was drawn out from time to time from the producer case which is attached to the back of the engine. There are certain merits attached to this system. I saw it at the Yarmouth Exhibition a short time ago.

Mr. Arnold : I presume you refer to the Griffin engine ?

Mr. Timpson : Yes. It aims at producing gas as referred to. It might interest Mr. Shackleton to know that in China, a huge coal bed of anthracite has been discovered, enough to supply the world's demands for many years. A portion of this is now being worked. The fuels required are being found in different parts of the world, and as the demand occurs the supply will be ready to meet it.

Mr. Durtnall : Of course in my paper I gave the various points of value in connexion with each engine. As Mr. Timpson rightly remarked, the so-called paraffin engine, or vaporizer type of engine, is of value as a prime mover up to a certain horse power. Mr. Timpson mentioned 100 h.p., but I would go a little higher than that.

Mr. Timpson : I only spoke of the commercial value of an engine using refined oil.

Mr. Durtnall : Going back to the historical matter, it has been my intention, as nearly as I am able, to explain the operation of the internal combustion engine to those of our members who have not had opportunities of studying the matter. Of course the internal combustion engine will be enormously improved as time goes on. The steam engine has taken many years to develop up to its present state. At the present time we have some of the finest steam engines that will ever be made, giving great economy in fuel to an extent absolutely unknown twenty years ago. At one time 40 lb. of steam per b.h.p. would be considered to be very good for a steam engine. A short while ago I saw some engines tested at Berlin running at 250 to 300 r.p.m. with superheated steam, and the fuel consumption was down to ·8 lb. per b.h.p. developed. It shows the advance which has taken place, and I believe that the internal combustion engine before many years will be even more greatly advanced. It will have to be specially designed to use the cheapest kind of fuel, such as crude oil.

Mr. Timpson : Mr. Durtnall deserves our thanks for this paper ; it will be explanatory not only to our sea-going members but to the members of the Institute at large. Everybody is not privileged to be in close touch with the oil engine, and if the paper gives an idea of it, it may be productive of further ideas. The whole question is narrowed down to the commercial aspect. The question is, will it meet ocean-going conditions with certainty ? Such will have to be demonstrated. The oil or gas engine will have to grow gradually and as shipowners gain confidence in it.

Mr. SHACKLETON : I think that, whatever form of internal combustion engine is adopted, either oil or gas, you as marine engineers will appreciate the fact that the internal combustion engine is not going to enter into the field as a motive power with anything like the ease that the old steam engine entered it. In the days of Watt, it would be a wide question to ask what would be the actual consumption per horse-power per hour, probably 40 to 50 lb. But you ask the internal combustion engine to fight the steam engine when the latter is at its highest state of development, yet within a period of about twenty years it has practically ousted the steam engine in regard to fuel consumption. The steam engine can never hope to approach the most modern types of internal combustion engine. But the engine builder, either gas or oil, will have a hard task in substituting the internal combustion engine for steam at the present day.

Mr. TIMPSON : There is a vessel of some 800 to 1,000 tons at present under trial on the Continent, with a two-cycle engine. The consumption of crude oil is $2\frac{1}{2}$ tons, against 8 tons of coal used for a similar vessel. There were some difficulties on the trial trip, but I believe on the whole it was successful.

Mr. DURTNALL : It is not only the extra thermal efficiency of the engine per brake horse power developed, but so much less fuel will be used, that for a given cargo capacity the draught will be much less. For the same speed less shaft horse power will be required and the consequence is that the commercial efficiency is very much higher than steam.

Mr. G. L. JONES : One point that occurred to me in connexion with the use of the system is the comparative capital cost. I do not know whether it has been previously dealt with. Of course it is an important consideration with people who are interested in central station work. Comparing internal combustion engines with turbines, the ratio is very largely in favour of the turbine, and for the generation of electricity the internal combustion engine is very little used in consequence except in sub-stations where it is used to replace storage batteries. The troubles with the Diesel engine are innumerable, the item for repairs is heavy, the difficulties of lubricating are great, and the cost of lubricating oil is nearly the same as the fuel oil.

Mr. Durtnall : It might be necessary to add a little further explanation in reference to the application of the steam turbine to marine propulsion. The turbine working in a power station on land will probably run at from 2,000 to 3,000 revolutions per minute. In a 5,000 h.p. plant you will probably run at 1,500 to 2,000 r.p.m., running in parallel and probably with the temperature of the steam up to 600 deg. F. You can therefore understand that the fuel consumption per b.h.p. developed by a land turbine in a central station is much lower than turbines in marine work. Not only that, the weight of the turbine is very much less than in the marine turbine, and the racing is practically nil. It all rests with the propeller. If you run the propeller at 2,000 r.p.m. and have the propeller produce the same effective thrust per h.p. at that speed the capital cost would be the same as on land.

Mr. Jones : What is the speed of the average marine turbine ?

Mr. Durtnall : 300 to 700 revolutions per minute, that is the one I know of. These high revolutions per minute are only commercially valuable on special boats, such as torpedo boats, where vessel speed is above all commercial considerations. But what I wished to point out was that the turbine as used commercially on passenger and freight boats, is more costly per unit per h.p. delivered to the propeller than the land turbine, and therefore the internal combustion engine is on a more favourable basis in competing with it.

Mr. Jones : Not sufficient to make a difference of 20 to 1, which I believe is the ratio.

Mr. Shackleton : May I ask what is the first cost of the land turbine the last speaker has in view ?

Mr. Jones : £1 per h.p.

Mr. Shackleton : Does that include the boiler ?

Mr. Jones : No, I admit another £1 per h.p. would have to be added on that account.

Chairman : We as marine engineers want to know what we are to face in the future. We want to be prepared to accept this engine with confidence. Mr. Durtnall and Mr. Shackleton are both confident as to its value, but it is for us to assure ourselves as to its flexibility and reversibility, and to present it with confidence to the shipowner. At one time we had a proposal in the technical press by Mr. McGlashan with his constant running machine, reversing by means of some other gear, with the intention of lightening the engine. This competitor has certainly its work cut out, but I believe it has done it, and it certainly has done it satisfactorily in connexion with a small job I had the privilege of doing. It was an experimental boat, steam installed. She happened to have a slight mishap, and instead of driving her as a steamer, we took the engine and boiler out and put in a 60 h.p. Daimler 6 cylinder engine. She is running to-day and has been running for a year. The place for the driver is rather confined, but where the boiler used to be is now cargo space, and instead of the boat taking 7 tons she is now taking 13 to 14 tons of cargo and sometimes as much as 15 tons out to the warships, through the extra space and the extra draught obtained by using the motor. The engine was not built for the boat, it was a cheaply set job and the boat was merely arranged slightly to take the engine. We have, I believe four of these boats now running under petrol. I cannot say anything in favour of the petrol, I think it is rather dangerous for craft. In this particular case it is a mechanic who drives it although in the other craft it is looked after by a " handy " man.

Mr. Timpson : I suppose you find the extra efficiency pays you to have the services of a mechanic ?

Chairman : That is so.

Mr. Adamson : One point at which I was surprised was in relation to the oil consumption for lubricating purposes as mentioned by Mr. Jones. If it is so enormous as he said I should think it was a serious point against the engine.

Mr. TIMPSON : I think it was very much overstated. There are several cases in which it has gone to a high figure, where the driver has been very careless, but it is not by any means so much in general practice.

Mr. SHACKLETON : It is usually $2\frac{3}{4}$ per cent. Whatever the fuel consumption is in tons $2\frac{1}{2}$ per cent. of that would be the consumption in lubricating oil.

It was agreed, on the proposal of Mr. A. Robertson, seconded by Mr. Timpson, that the discussion be adjourned till Monday, February 13th.

The meeting closed with a vote of thanks to the Chairman.

The following were elected at the meeting of Council held Thursday, January 12, 1911 :—

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David Hay Aitken, Fife.
Archibald Campbell, Brisbane.
Wm. Jas. Esplin, London.
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John Macleod, Stornoway.
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Robt. McGregor, New York.
J. J. McKimm, Belfast.
John Murray, London.
Stewart Ollar, Calcutta.
Robert J. Pritchard, Menai Bridge.
W. G. Rutherford, Perth.
John Frederick Shale, Brisbane.
James Strain, Trieste.
B. A. Vakeel, Bombay.
A. J. Walker, Calcutta.
Kennedy Walker, London.

AS ASSOCIATE MEMBER.

T. C. Armstrong, London.

AS GRADUATES.

J. Ross Baker, Cardiff.
William Minto, Yoker

INSTITUTE OF MARINE ENGINEERS

INCORPORATED

SESSION 1910-1911

President: SIR DAVID GILL, K.C.B., F.R.S., etc.

VOL. XXII.

PAPER OF TRANSACTIONS NO. CLXXIII.

THE STEAM ENGINE INDICATOR AND ITS DIAGRAM

By MR. W. G. WINTERBURN (MEMBER).

Read November 21st, 1910.

CHAIRMAN: MR. JOHN LANG, R.N.R. (MEMBER OF COUNCIL).

LECTURE ON THE USES OF THE STEAM ENGINE INDICATOR DIAGRAM

By MR. J. G. HAWTHORN (HON. MINUTE SECRETARY).

On Monday, December 12th, 1910.

CHAIRMAN: MR. WILLIAM McLAREN (MEMBER).

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SESSION 1910–1911

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