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Internal Combustion Engines for Marine Use

By MR. W. R. CUMMINS (Member).

In the Garden Club, at the Japan-British Exhibition, Shepherd's Bush, W.

On Saturday, June 25, 1910, at 4 p.m.

Chairman: Sir Wm. HALL-JONES, K.C.M.G., High Commissioner for New Zealand.

Chairman: I am very pleased to be with you this afternoon because in New Zealand they did me the honour of making me an Associate of the Australian Institute of Marine Engineers. Some twelve months ago I had the pleasure of decorating your Honorary Secretary, Mr. Adamson, with a similar emblem to that which I possess, on behalf of that Institute. In New Zealand we have a special interest in marine engineers because of the distance we are from the heart of the Empire. I do not know whether any of you, in your wanderings over this extensive exhibition, have seen the New Zealand court with its specimens of that country's varied productions, coal, gold, cattle, wool, grain, timber, and minerals of every description. Backed up by a beautiful climate, a productive country and an enterprising people, you may imagine we believe ourselves to be in an enviable position. Our only trouble is that we are so far away from the heart of the Empire, and in this respect the marine engineer has been of immense service to us. I recollect the time when it took 100 days in a sailing ship—sometimes 120, 130 or even 140 days—to get to that country, but with the assistance of the marine engineer and the improvements in machinery we rely upon steamers doing the voyage from London or Plymouth in six weeks with the same regularity which we see shown at our railway stations in this country. When I glanced at this paper by Mr. Cummins and saw the reference to a subject which had certainly not occurred to me, I wondered if it would be of any assistance in shortening the distance. I am inclined to think it will. For a long time past there has been a good deal of talk about an " all red route." The route generally spoken of is a service from Great Britain to Canada, across Canada by rail, thence from Vancouver or some other port on the west coast to New Zealand and Australia, making the whole land journey across British territory. My friend Mr. Adamson would be able to form a better opinion than myself on this point, but I must confess that I would prefer to see these boats travel direct from this country to New Zealand, travelling at a higher speed. That is just the same to me as reducing the mileage. For instance, supposing the *Mauretania* to go from here to New Zealand. The ordinary vessel going at $12\frac{1}{2}$ knots takes six weeks ; if it were possible for the *Mauretania* to keep up her speed of 25 knots, it would take only three weeks to do the voyage. The question is whether by any such proposal as is mentioned in this paper we can bring about an increase in speed which will justify shipping companies in, at any rate, giving it a trial. At present the conditions are that the cost of coaling to get the higher speed would be such as to make it almost prohibitive. I myself at one time used to imagine that it might be possible to get a very suitable combination of coal and some of the oils which would give the heating power in a more economical way, but perhaps our friend Mr. Cummins offers a solution in his paper which will have the effect I wish to see, and which most of us wish to see, the speed of our ships increase so that the distant parts of the Empire may be brought closer in time if not in distance. I have travelled to and fro many times and in many directions on boardship, and the question has often occurred to me, Who is the most important man on the ship ? I think with a slight study of navigation and some assistance, I perhaps might manage to navigate a ship ; but I am very doubtful as to my ability to handle some of that intricate and huge machinery which is the propelling power of our ocean liners. Not only that, but all over the vessel one sees machinery doing the work which at one time was done by human hands, and it seems to be quite within reason, and I am not sure that it is not in some cases already required, that the man who commands should be a good practical engineer as well as a navigator. Again I thank you for the opportunity of meeting you this afternoon, and now have pleasure in calling upon Mr. Adamson, in the unavoidable absence of Mr. Cummins, to read the paper on "Internal Combustion Engines for Marine Use."

The object of this paper is to raise a discussion and to elicit the opinions of members, on the type and design of the standard marine internal combustion engine of the future. We are not yet in sight of the gas engined battleship or Atlantic liner, but steady progress is being made with engines of small power, and the problem of larger powers is now being tackled by several engineers.

The first question which arises is : Will the engine of the future be a gas turbine ? As there are, so far as the writer is aware, no practical examples of such a machine in use, the probability is that the reciprocating type of engine will be developed first, at any rate, until something practical is evolved in the way of a gas turbine.

The first consideration is that of fuel. The fuels at present used in connexion with internal combustion engines are coal, anthracite and bituminous, coke, crude petroleum, paraffin, petrol and alcohol. For mercantile marine use, cheapness of fuel is essential, and the choice would naturally fall on coal, except in certain parts of the world near oil fields, where it would pay to use crude petroleum. Petrol is quite out of the question owing to its prohibitive cost. Coke, unless sold as a bye product, would be too expensive. Alcohol may perhaps in the future be able to compete with petroleum.

The use of coal as a fuel involves, of course, the provision of a gas producer and its accessories, and in comparing a plant composed of engines and gas producers, with a plant using petroleum direct, either on the Diesel, or vaporiser system, due account must be taken of the additional space required for the former plant, its extra cost, and the value of the extra space occupied, compared with the dearer fuel of the latter plant.

The most successful gas producers, from the point of view of easy and reliable working are those using anthracite fuel. On account of the extra cost of this fuel, as compared with ordinary bituminous coal, it will be essential, if the best fuel economy is to be obtained to have producers capable of dealing with all qualities of bituminous coals, such as are now sold as steam coal. At the present time, owing to the trouble caused by the formation of tar, and other difficulties, producers dealing with bituminous fuel are not entirely satisfactory, but no doubt in the near future, the necessary improvements will be effected to enable ordinary bituminous steam coal to be used successfully.

The next question to be considered is, which type of internal combustion engine will best fulfil the somewhat difficult conditions imposed by marine necessities?

These conditions are—

(1) Absolute reliability.

(2) Capability of continuous non-stop running for long periods.

(3) Capability of running in either direction and of being started with absolute certainty from any position of the cranks, without the use of barring gear.

(4) Capability of working economically at various speeds.

(5) Complete accessibility of all working parts for examination, overhauling and repair.

With reference to the first two conditions, great advances have been made of late years, in this direction.

Greater attention has been paid to arrangements for lubricating the various working parts satisfactorily, ignition methods have been improved, and details generally brought to perfection.

There are, however, some difficulties to be overcome yet, mainly due to producer troubles and unclean gas, causing deposits of tar and other impurities on the valves and internal working parts.

Coming to the third condition, viz., capability of running the propeller in either direction, and of being started from any position without the use of barring gear, this brings us to one of the greatest difficulties experienced in adapting the internal combustion engine to marine use.

There are two ways of tackling the problem. First, by running the engine in one direction only and interposing some kind of coupling between the crank shaft and the propeller shaft, by which reversing of the rotation of the propeller shaft may be effected, or, second, by the direct coupling of crank and propeller shaft as in a steam engine and making the engine itself capable of reversing. Several methods of carrying out the first arrangement have been used, and proposed, a few of which may be mentioned here.

There is the ingenious "Paragon" system of our member, Mr. William P. Durtnall, in which an electric dynamo and motor are interposed between the crank shaft and the propeller, by which reversing, and also speed variation is effected. For smaller powers bevel gearing has been used to effect the necessary reversing motion.

Other systems which have been suggested are the interposition of an hydraulic pump and motor between the crank shaft and propeller shaft, and Mr. Dunlop's system in which the connecting medium is compressed air. Where reversing is effected by gearing some form of clutch is generally used, which also enables the engine to be started up with no load. For small powers, there is no vital objection, except that of complication, against clutches and spur gearing, but when larger powers have to be dealt with, there are serious mechanical difficulties to be overcome, and these difficulties have induced engineers to study electrical, and other methods of coupling.

In the writer's opinion all these coupling devices are more or less temporary measures rendered necessary in order to adapt the internal combustion engine as used for stationary work to the different conditions required for marine work.

Sooner or later, on the score of simplicity and cost, all gearing between the crank shaft and the propeller shaft will be abolished, the engine being coupled direct, as in a steam engine.

The present systems, actual and proposed, may be considered as a stage on the road towards direct coupling. In the early days of steam marine engineering, gearing was used between the crank and propeller shafts to keep down the speed of the engine, to what was, in those days, a standard.

It was only a question of time to make the necessary modifications to the engine to enable it to run at the same speed as the propeller. In the same manner marine engineers will now, no doubt, set themselves the problem of making the internal combustion engine into a satisfactory reversing machine with adequate provision for speed variation, thus dispensing with all gear and enabling the crank shaft to be coupled direct to the propeller shaft. Fortunately, in this case, the revolutions most suitable for the propeller are also suitable for the engine, and there is no need to make compromises as regards revolutions, or adopt reduction gearing, as in the case of coupling up a steam turbine and propeller.

As regards the fourth point, viz., capability of working economically at various speeds, the conditions to be fulfilled are certainly difficult, if the internal combustion engine is to be made as flexible as a steam engine.

The principal difficulty lies in the relation between the revolutions and power required for driving a ship at various speeds. The horse power falls at a much more rapid rate than the revolutions, as the speed of the ship is reduced. In a steam engine this reduction of horse power can be effected by cutting off earlier, and thus decreasing the mean pressure.

In an internal combustion engine any decrease in power, outside of that given by reduction of revolutions, must be effected by cutting out explosions, or varying the strength of the explosive mixture, or both. In mercantile marine work sufficient reduction of the power for the range of speeds required can be effected by either of the above methods separately, or combined.

We can now proceed to discuss the type of engine which will best lend itself to the stipulated conditions. The choice lies between double-acting or single-acting cylinders, two-stroke cycle, or four-stroke cycle engines.

The adoption of double acting cylinders, although used on gas engines of a certain type for land use, would in the writer's opinion be a risky proceeding. It entails arrangements for cooling the piston and piston rod by water circulation, and trouble might arise from the use of salt water for this purpose.

The two-stroke cycle has so many advantages over the four-stroke in fulfilling the conditions laid down that it would appear to be far and away the more suitable for marine work. In the first place it will run equally well in either direction, with adjustment of the ignition. This simplifies the reversing problem immensely. In a four-stroke engine reversing gear would be required for the inlet and exhaust valves. Also, as the two-stroke has an impulse every revolution, the cutting out of an explosion, will have just half the disturbing effect on the uniformity of turning, as that of a four-stroke. There are several other advantages of the two-stroke over the four-stroke, which may be enumerated here.

In the first place a cylinder of certain size, arranged as a two-stroke, will give twice the power of a cylinder arranged as a four-stroke, provided the number of revolutions is the same. This means a large reduction in the weight and cost of the two-stroke for a given power. Also an engine of certain size arranged as a two-stroke will develop the same power as an engine with same size cylinders arranged as a four-stroke, at half the number of revolutions. This is an important consideration in engines of small power, as a slow running and more efficient propeller can be adopted with engines of same weight and cost as the four-stroke type.

In the second place, as the two-stroke engine exhausts through ports in the cylinder wall, the hot gases do not pass through a valve. In the four-stroke engine the gases pass through a mechanically operated valve, and it has been found necessary, in engines of quite moderate power, to have this valve water cooled. This entails a lot of complication, including flexible water connexion to the valve spindle. Here, again, there would probably be trouble if salt water were used for cooling purposes.

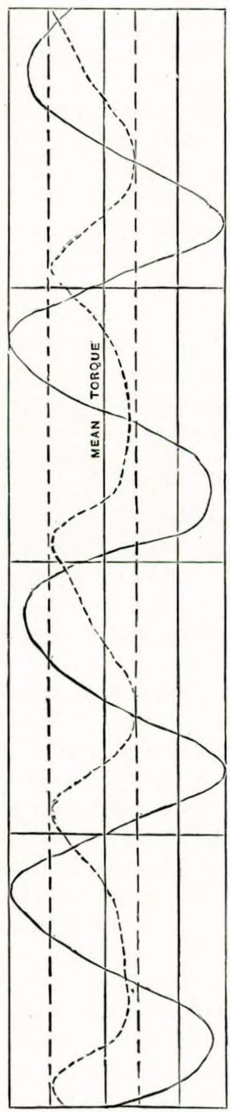
In the third place the impulse every revolution gives a vastly improved crank shaft torque over that of the four-stroke engine, permitting of a lighter fly wheel and crank shaft. It is difficult to get a large fly-wheel effect in a marine engine, owing to the very limited diameter of wheel possible, and the small number of revolutions.

The fly-wheel effect varies as the weight, and as the square of the speed of the rim, consequently a small diameter wheel entails a large weight to give the necessary effect. An irregular torque is said to be detrimental to propeller efficiency, but at the same time it is important that the fly-wheel effect be as small as possible, so that the engine may be stopped and started as quickly as possible. Here, again, the two-stroke has the advantage.

In order to show the excessive torque variation in a four-stroke engine, the diagram (Fig. 1) has been prepared, in which a comparison has been made between a four-crank, four-stroke engine and a two-crank, two-stroke engine. It will be seen

4 Cylinder Four-Stroke Engine Max Torque 80% Greater than Mean; Min. Torque 106% Less than Mean; Range 186%.

2 Cylinder Two-Stroke Engine Max. Torque 46% Greater than Mean; Min. Torque 28% Less than Mean; Range 74%.



Full Line Shews Turning Moment or Torque for 4 Cylinder Four-Stroke Engine with Uncushioned Reciprocating Parts, Dotted Line Shews Torque for 2 Cylinder Two-Stroke Engine with Reciprocating Parts Cushioned.

that the range of torque variation is 186 per cent. in the case of the four-stroke, and only 74 per cent. in the case of the two-stroke.

Since the advantages of the two-stroke engine compared with the four-stroke appear to be so obvious, one naturally asks the question why this type has not already displaced the four-stroke.

The four-stroke engine was first in the field, and thus had a good start in securing the market. The two-stroke engine, of course, requires a pump to force the charge into the power cylinder. In some of the earlier types of two-stroke engines this pump was separate and worked by a connecting rod from the crankshaft.

This system is used on the Ochelhauser engines as now made. The use of a separate pump has been urged as an objection against the two-stroke engine, the argument being that the four-stroke is so much simpler, as the power cylinder also performs the function of the pump of the two-stroke engine, A large number of makers of two-stroke engines of small-power now use the front end (i.e. the end nearest the crank shaft) of the power cylinder as a pump. This, of course, simplifies and cheapens the engine. The principal difficulty, however, experienced with most types of two stroke engines, is that of pre-ignition. It is a very usual practice to use the incoming charge to expel the hot gases through the exhaust ports, the result being that if a high compression pressure be used, the charge is liable to be fired by the hot gases remaining in the cylinder, after the piston has covered the exhaust ports. It is not practicable to expel the whole of the hot gases, as the volume of the charge admitted would require to be such that there would almost certainly be a loss of some of the charge through the exhaust ports. Pre-ignition may and does occur occasionally in four-stroke engines, as in ordinary designs there is always the volume of the combustion space left filled with hot gas, but there is more time for this gas to get cooled down before compression begins than in the case of two-stroke engines. The result is that two-stroke engines are generally run slower, and with less compression than four stroke, their advantages being thus to a large extent discounted. The remedy for these faults lies, of course, in providing for scavenging the power cylinder by cold air before the admission of the new charge.

Many methods have been proposed and used to effect the complete removal of the hot gases before the new charge is admitted. Two systems are in use, viz. the vacuum system and the pressure system. The first system aims at creating a partial vacuum in the cylinder at the end of the exhaust stroke by a pump or other means. Other systems create a partial vacuum in the exhaust pipe and allow cold air to pass through the cylinder and flush the combustion space. This latter system is adopted by Messrs. Crossley Bros., who use a long exhaust pipe, by which they obtain a partial vacuum by the intermittent action of the exhaust. When the air inlet valve is opened air flows into the combustion space and expels the hot gases through the exhaust valve. The pressure system by which cold air is supplied under a slight pressure appears to the writer to be the more effective system. It is this latter system which is carried out successfully in the Ochelhauser two-stroke engine. In other two-stroke engines, such as the Day, and a large number of similar type used in America, the crank chamber is used as a receiver for the explosive mixture, the front end of the power cylinder being used as a pump.

On the in-stroke the piston draws explosive mixture into the crank chamber through a valve, and compresses the mixture to a few pounds pressure on the out-stroke. The exhaust ports are arranged on one side of the power cylinder and the inlet ports on the opposite side. The exhaust ports open first and relieve the pressure in the cylinder. The inlet ports are then opened and the mixture flows into the cylinder, displacing the exhaust gases through the exhaust ports.

A rib is cast on the piston opposite the inlet port to deflect the incoming mixture away from the exhaust port in the hope of preventing the charge from escaping to the exhaust.

This system has several drawbacks, notably the use of the crank chamber as a receiver, owing to the difficulty of making it absolutely gas tight, the chief trouble being the leakage past the shaft when the bearings are worn.

Owing to the risk of pre-ignition, due to the large volume of exhaust gases which cannot be expelled without the risk of losing a good deal of the incoming mixture, the compression pressure and speed of these engines must be kept very low. They have, however, the merit of extreme simplicity, being practically valveless.

The next point the writer wishes to raise is that of cushioning the weight and inertia forces of the reciprocating parts. It is a point which should appeal to all marine engineers. In steam engines the compression is adjusted in such a way that the reversal of the load on the crank pin when turning the dead centre shall be as gradual as possible near the end of the stroke, the reciprocating parts requiring a certain definite force to bring them to rest. This force depends upon the weight and number of revolutions, and the same force is required to start them up again on the return stroke. This force is irrespective of, and additional to, any pressure on the piston. If the piston is not cushioned this force is expended on the crank pin and the main bearings, and to no purpose, as it cannot exert any turning force on the crank shaft. All it can do is to pound the bearings. If, however, the piston is cushioned, say, for example, the compression pressure is such as will just balance the inertia forces, then the crank pin will turn the centres without shock.

It is not usual in internal combustion engines to provide means for cushioning the reciprocating parts. It is true they are cushioned on the compression stroke, but in a four-stroke engine that is only one stroke cushioned in four, and in a two-stroke the in-strokes only are cushioned. The magnitude of these forces is not always realized, so an example may be given here.

Taking a cylinder 20 in. diameter and 24 in. stroke at 160 revolutions, the force required to stop and start the reciprocating parts, is on the top centre $7\frac{1}{2}$ tons and on the bottom centre 5 tons approximately, which is equivalent to 53 lb. per sq. in. on the piston at top centre, and 35 lb. per sq. in. on bottom centre.

These unbalanced forces acting on the crank pin and main bearings no doubt account for a great deal of the mechanical inefficiency of the gas engine as compared with a steam engine. The writer suggests that engines for marine work should be cushioned by means of an air cylinder.

If a two-stroke engine be adopted it will be only the down-strokes which will need to be cushioned, the up-strokes being cushioned by the compression of the charge in the power cylinder.

For a two-stroke engine a pump cylinder is necessary for dealing with the mixture, and this same cylinder can be utilized for cushioning on the down-stroke. If this pump cylinder is made as an extension of the power cylinder the objections as regards cost and space occupied by a separately driven pump are overcome, and the three operations of pumping the mixture into the power cylinder, supplying a scavenging charge, and cushioning the reciprocating parts on the down stroke, can all be performed by this one pump cylinder.

A further advantage gained by cushioning with an air cushion is that the reciprocating parts are started up again on the return stroke, and the engine is to a certain extent made double acting. With uncushioned reciprocating parts the crank pin has not only to stop the motion of the moving parts at the end of the stroke, but also to start them up again. When, however, cushioning is carried out, the crank pin is relieved of this duty.

In ordinary internal combustion engines every endeavour is made to cut down the weight of the moving parts in order to save the crank pin and bearings from these inertia stresses. Now the indicator diagram of this class of engine has a very high initial pressure due to the explosion, and a very rapid fall of pressure due to expansion and cooling of the gases. As the explosion takes place at the beginning of the stroke the crank pin has very little effective leverage to produce torque on the crankshaft, the result being heavy pressure on all the brasses, with very little effective work performed. If, however, the inertia forces are large—suppose, for instance, they are equivalent to a pressure on the piston one half of that produced by the explosion—then the load on the bearings would be reduced to one half of what it would have been if the moving parts had no inertia. This would give a much more effective distribution of the load on the crank pin, relieving it of the heavy initial stress due to the explosion, which would otherwise come on it, and retarding the effect of the initial pressure on the piston until the crank and connecting rod are at a more favourable angle for producing torque on the crank shaft. Another advantage of the cushioning is that a certain portion of the negative work of compression can be effected by the cylinder itself without any help from the crank shaft, as the work stored up in the cushioning air during the down power stroke is given back to the piston on the up compression strokes. If the air cushion pressure required to balance the inertia of the moving parts were equal to that of the compression then the whole of the work of compression could be effected in the cylinder, without the intervention of the crank shaft. This should tend to increase the mechanical efficiency of the engine, as the transfer of work by means of the alternate compression and expansion of air should be more efficient than the transfer by means of the crankshaft and connecting rod.

We have next to consider whether there is any loss of efficiency involved in this alternate compression and expansion in the cushioning cylinder. If the air is compressed and expands adiabatically and there is no leakage, the only loss of efficiency is that due to mechanical friction of the piston. There will be a certain loss of efficiency if the compression is not adiabatic; that is to say, if there is a continuous loss of the heat developed by compression. This, however, should be very small, as in the first place the alternations of temperature due to compression and expansion will be very rapid, and there will be very little time for the heat in the body of the cushion air to be transmitted to the walls of the cylinder and through them to the external atmosphere. In the second place the greatest temperature will be developed at the end of the stroke, when the surface exposed is at its minimum; and, thirdly, the average temperature of the surfaces, assuming them to follow the temperature of the air, will not exceed about 200° F. with a compression pressure of 50 lb.

The next question to be considered is that of starting and reversing. If there is no clutch between the crankshaft and the propeller shaft, a considerable amount of stored energy in some form will be required for the operations of starting and reversing, and when considering this question, the method of working the auxiliary machinery should also be considered with a view of adopting the same plant for both purposes.

The choice of the motive power for the auxiliary machinery, viz., water pumps, bilge pumps, ballast pumps, service pumps, winches, steering gear, windlass, refrigerating machinery and ventilating fans and electric lighting lies between steam, electricity, and compressed air. The use of steam would be a step backwards and would not be suitable for starting and reversing purposes. Electricity would be suitable for all pumping work, refrigerating machinery, fans, electric lighting and steering gear, but it has not yet been adopted to any extent for deck machinery, for which compressed air would, no doubt, be suitable. There are difficulties in using compressed air expansively, but these can be overcome by reheating the air before use. There is plenty of waste heat for this purpose.

The writer's suggestion is that the starting and reversing gear should consist of a high-speed internal combustion engine, coupled direct to an efficient air compresser, which would deliver into a receiver, from which air would be taken for manœuvring the engines and working the deck machinery, and any other auxiliaries suitable for compressed air. For the remainder of the auxiliary machinery, a high-speed internal combustion engine, coupled to a dynamo supplying current for lighting purposes, and for all the other auxiliaries. The air compressor would be running only when working the cargo and manœuvring in and out of port, the compressed air receiver containing sufficient air for emergency purposes.

The only other question remaining for discussion is the number of cylinders to be adopted and their disposition, having regard to limits of size and facility of handling. By adopting the two-stroke engine with its impulse every revolution, twice the power can be obtained from a cylinder of the maximum diameter allowable than from a four-stroke cylinder. Tandem cylinders are inadmissible as they would entail a piston rod exposed to the hot gases of the explosion, and double acting cylinders are unsuitable for the same reason, so that for large powers the number of cylinders will need to be increased to keep within the limits of the maximum possible diameter.

For ordinary mercantile work the stroke may be made relatively long and the revolutions should be made as high as possible consistent with propeller efficiency. For engines of small power the number of cylinders should, of course, be as few as possible, and the minimum number will be fixed to a great extent by the question of facility in starting and reversing.

The conditions are that the engines must be able to start in either direction, by simply turning on the compressed air. By utilizing the bottom end of the pump cylinder for cushioning, the advantage is gained that air can be admitted under the cushioning piston to give an upstroke, which is additional to the downstroke given by admitting air to the power cylinder. The minimum number of cylinders with this arrangement would be two; with a four-stroke engine uncushioned, the minimum number would be four. To get the best turning movement and balance with the two cranks they should be opposite one another, but this would not be the best position for certainty of starting up, as they might both be on the dead centre. Under normal conditions, however, when the ignition is cut off for stopping the engine, the action of the cushion air on the down-stroke and the compression on the up-stroke will make the engine stop with both pistons at half stroke. There is a remote contingency that they might stick on the dead centre, and for small engines a simple barring gear could be provided for this emergency. For engines of larger size three cylinders with cranks at 120° would make an ideal arrangement. The engine would start in either direction, irrespective of the position of the cranks, although under normal conditions, the engine would stop with one of the pistons at about half stroke.

In using compressed air in this way for starting and reversing it is important to have the starting valves on the cylinders controlled automatically for two reasons—viz., to ensure that the correct valves are opened to give the desired direction of rotation, and to prevent waste of the compressed air, such as would result, for instance, if air were admitted to a cylinder when the exhaust ports were uncovered, when there would be a straight blow through to the exhaust pipe. The reversing gear must also work the ignition timing apparatus which will make the necessary correction for ahead and astern running.

The writer has not attempted in the limits of this paper to go fully into details, but has merely outlined a few ideas for the criticism of the meeting. In conclusion, therefore, he ventures his opinion that—

1. The internal combustion plant of the future for marine work will consist of bituminous fuel gas producers, supplying gas to two-stroke cycle engines.

2. That crude petroleum will be used where it can compete in price with coal. It will operate in two-stroke cycle engines of the Diesel or vaporizer type.

3. That effective means will be taken to scavenge the power cylinder with cold air.

4. That some method of cushioning the reciprocating weights will be adopted.

5. That the crankshaft of the engine will be direct coupled to the propeller shafting without the intervention of gearing of any kind, except in the case of engines of very small power.

6. That manœuvring will be effected by compressed air, which will also be used for working the deck machinery.

Mr. O. Sumner, R.N.R. : I should appreciate the privilege of being allowed to say a few words on the subject of this paper. I had the honour of giving the first paper on this subject before the Institute some eight years ago, and that is harking back a considerable time in the history of the internal combustion engine. The impression given me by the paper is that the Institute of Marine Engineers is apparently asleep, as it would appear that we are not advancing, as an Institution, in keeping with the latest developments of the internal combustion engine. It is positively wonderful what has been done in the last decade in this branch of engineering. I am struck, first of all, with the omission of the cardinal point to which I believe marine engineers must necessarily give their first attention, i.e. facilities for manœuvring at varying speeds, to which I will refer later. Passing to one or two of the salient features of the paper, we find that items 3 and 4 do set forth the conditions imposed by marine necessities and with which we are all familiar, viz., "capability of running in either direction and of being started with absolute certainty from any position of the cranks without the use of barring gear," and "capability of working economically at various speeds" ; a demand for a flexible internal combustion engine. We have not got it, and its advent is no more in sight than when Dr. Otto took out his first patent. Some few years ago I was in consultation with Mr. Yarrow on this very subject. I had to see him with regard to some internal combustion engines he was then considering. He selected two ; one probably the best known oil engine in the world, and the other a petrol motor of high repute in its class—to be precise the oil engine was the Hornsby-Ackroyd and the petrol motor the Napier ; and while the latter is outside consideration for commercial vessels, the former is certainly not, but it was found that when fitting in a vedette boat it was necessary to keep the engine running at full speed. As the great gas engine makers have not been able to solve this difficulty, it would appear to be a waste of our time to offer them suggestions or impose conditions whereunder they should solve it. The question is, How can we allow or compensate for the inherent defect that the gas engine is a constant speed engine ? The author gives no suggestion other than a reference to various estimates of intermediaries between the driving power and the propeller. With regard to the point that the two-stroke engine gives twice the power of the four-stroke ; it would not nearly have this effect owing to the fact that it cannot effect equal scavenging ; and where a separate scavenging pump is used the power absorbed by this is considerably more than that necessary to operate the valve gear of the ordinary four-stroke type ; in short, I believe I am correct in stating the extra power gained averages 80 per cent. and not 100 per cent.

The suggestion with regard to cushioning is a very good one, and it has, I believe, been tried by certain of the big gas-engine makers, but was not a commercial success for the reason that it cannot be adopted without inducing resistance. The author cites an instance of a $12\frac{1}{2}$ tons shock per revolution with a cylinder of 20 in. diameter and 24 in. stroke at 160 revolutions ; but this has no bearing on the power and efficiency of the engine, because it only acts on the dead centres, whereas any cushioning must afford resistance to the movement of the piston at either end of the stroke. The author does not refer to the question of ignition of the fuel, which is probably the most important item in connexion with the marine gas engine itself. While the best engine would appear to be that with an internal vaporizing and automatic ignition device, this means a constant speed engine, and for any degree of flexibility we must have some form of externally operated vaporizing and ignition. In the author's opinion the internal combustion plant of the future for marine work will consist of bituminous fuel gas producers supplying gas to two-stroke cycle engines, with which I am in full agreement, provided that the bituminous coal is of a coking nature. With regard to the coupling direct of the gas engine to the propeller, of course that is the ideal form, but nothing has been done up to the present to inspire any confidence that this can ever be realized. The solution may come when a flexible gas turbine comes into being. The statement that "manœuvring will be effected by compressed air" is, I think, open to question. The difficulty is that as vessels must be capable of slowing down for even several days to half speed or less, we must provide that when running on the governor during engine racing in a heavy sea the intermittent abnormal immersions of the propeller will not stop the engine, as there can never be that automatic "pick up" in an internal combustion engine which is so valuable a feature of the steam engine when subjected to heavy racing. This is due to the fact that the gas must first be compressed in the cylinder itself before it is capable of developing any material expansion by explosion ; and as this means that at every fourth or second stroke (according to the cycle) each piston must first compress its gas to anything between say 3 and 40 atmospheres (according to the type of engine) before commencing its working stroke, the minimum speed of the gyrating mass necessary to accomplish this—and particularly at the psychological moment when the propeller is suddenly abnormally immersed—must always demand a higher crank-shaft speed than may be required when, say, hove to under " light ship with heavy head seas " conditions. I submit that compressed air reservoirs to ensure the pick up or restarting of the engine many times a minute for an indefinite period under the conditions referred to are quite prohibitive by reason of their weight and the great space they would occupy ; while the use of multiple cylinders to reduce the flywheel or similar mass would demand a prohibitive number of unit cylinders in an installation of anything over about 500 H.P. The ideal system for slowing down would be by a variable compression, which, however, affords no relief to the dangers of stopping during engine racing, and is quite impracticable for engines of the internal vaporizing type. We are applying our attention to the gas engine solely because the whole world knows that it can, if properly applied, drive our ships more economically than steam.

In my opinion the introduction of the much-needed marine gas engine is being seriously retarded by the marine engineer's hopeless attempts to tack on to, take from, or otherwise " adapt " the gas engine in order to make it a variable speed, direct coupled, prime mover ; whereas if we are to secure those very economies which are the *raison d'être* of the marine gas engine, we should be content to take the gas engine as it is, a fundamentally *constant speed engine*, perfected, well-tried, and ready to hand, and should devote our unceasing attention to the evolution of a flexible transmission apparatus between engine and propeller ; as I think we shall be obliged to recognize that whether its form be electrical, mechanical, or hydraulic, the transmission device is the only item which is keeping back the general adoption of gas-engine propulsion for sea-going vessels of medium powers. I hope the author will not think me antagonistic in any way. I am very interested in this subject. I have been studying it for several years with one or two companies who are more or less in the dark as to marine requirements. The progress that has been made with the internal combustion engine and producer gas plant is enormous, and I think we, as an Institute, are not getting the best results put forward. These are, no doubt, available, and I think it would be a good thing if we could get some of the most prominent men in the gas-engine world to give us their opinions.

Mr. W. P. Durtnall: We were all interested to hear our Chairman's remarks in reference to the relative time taken by sailing boats and steamships from London to New Zealand. As he says, it takes at present six weeks and there is no question, in my opinion, that with the better utilization of energy obtained by the use of internal combustion engines we can reduce it to five weeks and perhaps even to four weeks. But of course the question of cost in relation to speed would become very pressing, as the cost would go up considerably. In relation to the gas-turbine mentioned by the author as being the ideal form of internal combustion engine, of course I think it is a possibility, but it will be some years before it is a commercial success. Some great scientific men are working on the subject of the gas turbine in Germany. They have been very successful, I believe, in the experiments they have carried out, but as for applying it for marine purposes, that is another matter. After all, for the gas turbine to be successful it is a question of revolution speed; it is the same difficulty as that which presents itself with the steam turbine. The same problem will have to be solved with regard to the propeller. You will perhaps have a very efficient prime mover in the gas turbine, and not be able to use it with efficiency at the propeller. There is a limit according to the vessel speed and the depth of immersion. I quite agree that the matter of using petrol is a commercial question; although it would be quite possible to drive a ship by using it, the cost would be too great. Mr. Cummins mentions about producers, probably coal gas producers, being used in the future. I think the best system I have seen described is the system suggested by Mr. Stewart of Glasgow. He has a very interesting system for dealing with tar and other necessary evils in bituminous gas producers.

The author mentions as one of the necessary conditions of the gas engine for marine purposes "the capability of running in either direction, and of being started with absolute certainty from any position of the cranks without the use of barring gear." I have had occasion to study this question; as you know it was on these grounds that some two years ago I brought the question of electrical propulsion before this Institute, a question which has since been discussed throughout this country and in all parts of the world. With regard to reversing the propeller when the vessel is at full speed ahead, I do not think it possible having regard to the thermo-dynamic conditions involved in using the gas engine. In order to produce the torque and reverse under full-speed conditions, the alteration of the valve gear and the timing and other necessary apparatus in a direct-coupled reversing engine puts it out of the question from a practical point of view at present. During the last few years some very interesting experiments have been made by Messrs. Beardmore on the gunboat *Rattler*. They have made extensive trials with a 500 H.P. gas engine at sea for a 9-knot boat. They did not adopt direct reversing; they used a clutch, with epicyclic gear and hydraulic for reversing. I agree that the question of reversing is one of the most difficult problems we shall have to deal with in the future of the marine gas engine. I do not agree with him that the two-stroke engine would be preferable to the four-stroke; the efficiency is very low in a two-stroke engine. I got more horse power per ton of fuel with the four-stroke; it worked out at about ·45 lb. against ·52 lb. of oil per b. h. p. It is a most interesting paper and well deserves our very best thanks. I hope the Council will do more to bring papers of this description forward, so that they may be brought before the attention of shipowners and shipbuilders, and thus encourage the development of this style of machinery for the benefit of the shipping industry.

Mr. J. T. Milton: Before the discussion is adjourned I would like to say that the present is a very appropriate time for such a paper because we are just on the eve, not of experiments, but of fairly large installations of internal combustion engines to be used in marine work. One large twin-screw steamer is being built which will have Diesel engines of the two-stroke double-acting type, so that there will be no difficulty with regard to reversing, and each set of engines will indicate over 1,000 horse power. It is evident, therefore, that some of the builders are awake at the present moment. This is a foreign vessel, but there is also an internal combustion engine being made in this country for a smaller vessel with gas as a fuel made from anthracite coal. There can be no question that if internal combustion engines come into general use they will have to be suitable for use with bituminous coal, because bituminous coal can be obtained all over the world ; but I think the first of these engines that will be successful at sea will not be gas engines, they will be oil engines. With oil fuel we save the whole of the space occupied by the gas-making plant. If oil can be got fairly cheaply, and in many parts of the world it can be obtained cheaply, it will be found that oil fuel for internal combustion engines will have a great advantage over any coal whatever. When we come to long-distance ships the question of the cost of fuel is only one item. The question of space occupied by it is a very important matter. Every extra ton of fuel carried shuts out a ton of available cargo, and fuel economy therefore plays a very important part. There can be no doubt that oil fuel will have the advantage there, not only because it will give more heat per ton, but also because it does away with all gas-producing plant. I think, as there is another paper to be read, we will have to adjourn the discussion to one of our ordinary meeting nights, and I anticipate the paper will produce a useful discussion and one of very great service to our Institute.

Mr. Jas. Adamson (Hon. Secretary) : I quite agree with Mr. Milton that this paper has come before us at a very fitting time, for more reasons than one. No reference has been made to the use of compressed air for winches, but several of our members have spoken to me about it during the last twelve months, and I hope soon to hear of a paper being in preparation which we may have before us, as I think the subject is worthy of consideration. I was very glad to see that Mr. Cummins draws our thoughts in that direction. I was sorry to hear Mr. Sumner say he thought the Institute was asleep.

Mr. Sumner : I referred to our Institutes generally, not to this one in particular.

Mr. Adamson : Possibly the members of the Institute have the impression that Mr. Sumner has been asleep, as, if my recollection serves me rightly, he promised that we should have a paper from him on an internal combustion engine on the turbine principle ; this we are still waiting for.

Mr. Milton : I would like to propose a very hearty vote of thanks to the writer of the paper, and to Mr. Adamson for reading it on behalf of the author.

Chairman : Before putting this motion to the meeting I would like to add a word or two. I am only a layman with regard to engineering matters, but let me say—as, perhaps, the oldest man in the room—from what I have seen in life, if I were an engineer I would not recognize the word "impossible." All these things you have been referring to as difficulties are simply matters to be discussed and for which a solution has to be found, and I think the British race is sufficiently energetic to deal with any of these questions, the oil or gas turbines, or whatever it may be. It simply requires application for all these difficulties to be solved in the future.

The vote of thanks to Mr. Cummins was then put to the meeting, and carried with applause.

It has been decided to continue the discussion on this paper on Monday, Oct. 10th. Communications are invited from members on the subject prior to that date, when they will be read and responded to by Mr. Cummins in the course of his reply.

J.A.