INSTITUTE OF MARINE ENGINEERS

INCORPORATED

SESSION 1910-1911

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

VOL. XXII.

Discussion on Mr. Lecoche's Paper, "Electro-Magnetic Transmission for Marine Propulsion."

Monday, November 7, 1910.

CHAIRMAN: MR. JOHN McLAREN, (MEMBER OF COUNCIL).

CHAIRMAN: The paper by Mr. Lecoche was read on the occasion of our visit to the Engineering Exhibition at Olympia. Unfortunately Mr. Lecoche is unable to be with us this evening as he has been called away to Paris. The paper treats of something new and is really worthy of a good discussion.

The HON. SECRETARY: I may say I saw the experimental machine in which this system was tried some time ago; it was a small machine of about 10 h.p. and it did its work exceedingly well. I questioned Mr. Lecoche at the time whether it would deal with bigger powers, but it seemed very suitable for small work, and from the paper he seems to think he would be able to build one to drive a propeller shaft. Mr. Lecoche's original idea was more for transmitting the power and reducing the speed, but in this case he seems to put forward the idea of transmitting the power from one engine to another and I am afraid there would be great difficulty in making the engines synchronize in the way he suggests.

Mr. G. W. Newall: I have made a few notes upon this paper because I think the subject is a very attractive one. It is practically a new departure in trying to save some of the waste power between the boiler and the propeller, that is, what vitality is left in the steam after passing through the engine, the author desires to make use of it. But as you go into a question of this kind it leads one into very many difficult paths. It is something quite new, and as marine engineers it is a matter to which we should give some attention. The suggested electro-magnetic gear, as I understand it, is very similar to the ordinary electro-magnet. I will make a sketch on the blackboard to illustrate two or three points in connexion with it.

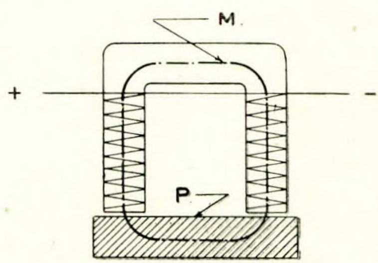

FIG. I.

Fig. 1 is the ordinary electro-magnet with an armature fixed or attracted to the field magnet as we know it; Fig. 2 represents an electro-magnet, the armature of which is driven

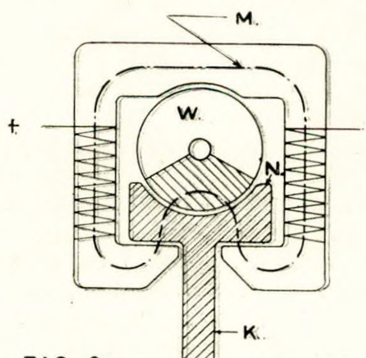

FIG. 2.

by a motive power whereby he proposes to utilize the exhaust steam. The limit of the magnetic forces are shown in each case by the thick lines M. The top portion of the worm-wheel N, and shaded portion of the worm W, Fig. 2, taking the place of the armature P, Fig. 1.

The worm W has a helix of, I think he says, 3°, and it is out of contact with the wheel. The object of this, as I understand the paper, is that when the system is fitted up on board ship and the engines are racing, no metallic resistance is offered to the movement of the worm-wheel K. He has a coil which incites this electro-magnet. Directly the wheel runs away past this worm, the whole magnetic field of the electro-magnet must get very hot or be thrown out of gear. Now we know that if a ship is in a heavy sea-way the engines sometimes race for a period of several minutes, and if this gear were running for some time past the synchronizing of the worm, it would soon make it so hot that it would become dangerous, in fact the insulation of the copper would be melted away. So that when the engines are racing the machine would have to be cut out of action altogether, and on that account I think the machine loses a point or two. There is another consideration I would like to raise about the paper, and that is that Mr. Lecoche does not say anything about the class of turbine he would propose to use. He gives neither the weight nor the space occupied, and owing to the disposition of such machinery it would have to be athwart ships, and, as we know, turbines require a good length of space on board ship. With the gear plus the turbine I do not think the arrangement would be quite so simple as is urged for it. Another question I would like to ask the author is, what must be the power of the main engine to give 300 h.p. at the exhaust? I should think the main engines would require to be of something like 6,000 h.p. if you wish to get 300 h.p. out of the exhaust to drive the electro-magnetic gear. Directly a turbine is interposed between the condenser and the low pressure cylinder, there must naturally be a back pressure. Taking the main engines at 6,000 h.p. and getting only 300 h.p. by the electro-magnetic gear, which is 5 per cent., I think the back pressure alone, brought about by the interposition of this turbine, would be more detrimental and wasteful than its use would be beneficial on board ship. But of course that is a point which has to be explained. If by putting a turbine between the low pressure cylinder and the condenser, the speed of the engine and the h.p. of the main engine is not interfered with, then it will be possible to put a second turbine of the same size between the first and the condenser, and so on. With the turbine between the low pressure cylinder and the condenser, acting as it does like a sieve or a screen, you either spoil the main engine to make use of it, or it is a case of perpetual motion, and you could have any number of them in a row along the shaft. On going into the author's drawings and taking the scale into consideration, I find the effective area contour of the worm covering the wheel is about 21 inches by 31 inches; that is to say the magnetic flux set up by the system has a tangential pulling force over the area of 21 inches by 31 inches by 22 lb. roughly, which gives a pull of about 14,300 lb. at 3 feet radius from the centre of the propeller shaft. If that is so, the work done by the steam robbed from the main engines does not appeal to me to be worth the trouble, because 14,300 lb. taken out of the main engine or even from the low pressure piston is very little; it would represent perhaps only a small amount of pressure per square inch on the pistons. Yet all this gear is proposed to be fitted on board ship with the idea of utilizing what would be taken as a waste product, or looked upon as being a force not now used, so that I think Mr. Lecoche might give us more particulars regarding what he considers is taking place between the low pressure cylinder and the tangential pull on the wheel. He speaks of the air-gaps being 1 centimetre; that appears to be very great, but whether it is or not in that class of machine I do not know. Please understand I am not condemning the system, and I am not taking an antagonistic view of it, but I think it is a device which should be fully gone into. In my own sea-going days I remember being shipmates with an engine called the "Marchant" engine, the object of which was to pump back the exhaust steam direct into the boilers. That was a good many years ago, but, as you know, it is an utter impossibility to pump back the exhaust from the low pressure cylinder into the boilers, yet there was a machine costing £20,000 on that ship by which an endeavour was made to do so. Engineers who have charge of the lives of passengers must feel the utmost confidence in all the plant and powers they have to deal with, and although these things were out of the usual line, they should certainly receive all the attention we are able to give them. Mr. Adamson has reminded me that this is a machine which is simply a reduction gear, but from the illustrations, and also the description in Mr. Lecoche's paper, it is plainly indicated that, although only a reduction gear from a speed of 3,000 to 75 revolutions, we are still told that a turbine must be used in the exhaust ; so that I do not think it can be called a reduction gear pure and simple.

The HON. SECRETARY : The original experimental machine I saw was purely a reduction gear for the reduction of revolutions, and the object of Mr. Lecoche at that time was to introduce the gear between the turbine of a turbine driven ship and the propeller shaft with a view to bringing down the number of revolutions of the turbine to give the best results in relation to the propeller. I understood that was the view he was going to bring before us and was surprised that he had altered and expanded it to that given in the paper.

CHAIRMAN : I must say I agree with Mr. Newall in his remarks with regard to racing. I do not see how racing of the engines can go on without causing overheating.

The HON. SECRETARY : Apart from that I do not see how one could get the synchronizing by means of this gear from the secondary to the reciprocating engine.

Mr. J. HOWIE : Probably there would be an automatic valve.

CHAIRMAN : That would not control the engine so as to prevent its racing.

Mr. A. P. WILLIAMS : I think that would be got over by having resistances in the series of field magnets. It seems to me this magnetic arrangement is simply acting as a brake on the turbine. If the turbine begins racing, this acts as a brake and reduces the speed, it simply means switching in the governor to break the circuit. I can quite see how it would be possible to synchronize by putting resistances in the field, but I do not see how the wheel is geared to the worm.

The HON. SECRETARY : In the experimental engine I saw there was a clearance of about $\frac{1}{16}$ inch. It should be noted that the teeth do not touch, the worm and wheel do not gear in the ordinary sense.

Mr. A. R. Newman : Would not this introduce a large number of new losses by heating ? I think they would be increased more by this method than by worm gearing and cut teeth. By revolving a large mass of iron such as this currents are formed and a good deal of power goes to waste. I should think more efficient results could be obtained from an ordinary well-cut worm.

Mr. Newall : I think Mr. Lecoche recognizes that he could not have a solid worm because the teeth would soon be stripped off. If you have a horse power of 6,000 and reduce the revolutions suddenly the teeth would simply be torn off, and that is why he no doubt has adopted the method of running it clear out of contact. Any effort of the engine to race, would mean heating the field magnets, and the arrangement would really become an electric brake on the engine shaft against it running away.

On the motion of Mr. Newall, seconded by Mr. J. R. M. Fitch, it was decided that the discussion should be adjourned till January 9, 1910.

ADJOURNED DISCUSSION

Monday, January 9, 1911

Chairman: Mr. Wm. McLAREN (Member).

Chairman : I am sorry Mr. Lecoche will not be with us tonight on account of illness. He has, however, sent a reply to the previous discussion on his paper, which the Hon. Secretary will now read.

Mr. Lecoche : Replying to the remarks of the Hon. Secretary, the gear was first intended for reducing the speed on ships driven by turbines only ; but I found that the great drawback of that scheme was just where lies the advantage of the present application, that is, as in the first case, there would be continuous danger of the gear being thrown out of step by a rough sea, in the present case, the fact of the gear coming out of step is an advantage, as the propeller, being on the shaft driven by the main engine, is never out of control. I will now demonstrate how both reciprocating engine and turbine always tend towards synchronism automatically. The gear is designed so that its magnetic torque is always greater than the torque of the turbine. Let us now consider the system at the moment when the gear has been thrown out of step by the racing of the main engine. The turbine, running light, has also a tendency to race, but not to the same extent as the main engine, which is obvious for several reasons; if the main engine is the first to slow down, there must be a moment when worm and wheel are in synchronism, and at that moment the magnetic torque is at its maximum, and, as I said before, this magnetic torque being superior to the torque of the turbine, the latter has to follow the motion of the main engine towards normal speed. On the other hand, if the turbine is the first to slow down by the action of its governor, the latter can always be adjusted so as to make the speed of the turbine running light say 2 per cent. higher than the normal speed under load, and again, the speed-curve of the main engine has to cross the speed-curve of the turbine and brings the latter to synchronism : so that, normally, both engines will always synchronize.

Mr. Newall fears that during the racing of the engine, the field magnet may get hot; I understand that Mr. Newall supposes that the field-fluctuations would produce extra current in the field-coil by induction; to this I must say that if such current is induced in the field coil, it will be an alternate current; consequently, the field being excited by means of direct current, the electro-motive force induced in the coils will have to be alternatively added to and deducted from the E.M.F. of the D.C. supply, so that the mean E.M.F. will be constant and equal to the E.M.F. of the current energizing the field; as to the heat from hysteresis, etc., it cannot be more than the heat generated in an alternator, which type of machine can run many hours without undue heating—besides, the variations of magnetic flux in this case are very small, especially as it is an unidirectional field; it even never decreases to zero. In my experience, I have often run a magnetic worm and wheel out of synchronism for as long as 15 minutes without the slightest increase of temperature.

Another question by Mr Newall is "what would be the power of the reciprocating engine?"—the reply to this question I should like to leave to the engineers who have made a special study of what is called the "combination system." Let it only be admitted that this system has advantages, as proved by its practical applications on board ship ; the advantages of a turbine between the low-pressure cylinder and the condenser as a steam-economizer are too obvious to be insisted upon.

After having worked out the pull at 14,300 lb. at 3 feet radius, Mr. Newall suggests that this is not worth saving ; of these 14,300 lb. I use only about 7,500 and this means 300 h.p. at a speed of 75 r.p.m. ; the main engine would not be more than 1,200 h.p., and I think that 300 h.p., as compared to 1,200 h.p., is worth saving. The 300 h.p. of the turbine are not, as Mr. Newall suggests, " robbed from the main engine " but saved, as, without the turbine, these 300 h.p. would reach the condenser under the name of " thermal units " or " calories."

An air-gap of one centimetre is not excessive for the sake of safety in a machine of that size ; it is sometimes more than that in large-size D.C. motors or generators. Besides, the small amount of electrical energy required for field excitation shows that it is not detrimental to efficiency. Mr. Newall does not think that the system can be called a reduction gear pure and simple, because I use it in connexion with the combination system ; it must be remembered that I do not claim anything in the combination system which was designed by engineers more expert than myself in steam-engineering. I only apply the gear, pure and simple, to an already existing system, after the capabilities of the said system have been recognized in practice.

The " automatic valve " suggested by Mr. J. Howie exists on any steam prime mover, and it is simply the valve actuated by the governor ; I have explained at the beginning of my discussion how it will insure perfect synchronism.

Replying to Mr. Chairman's objection, I do not attempt to prevent the engines from racing ; the gear does not act as a brake, as Mr. A. P. Williams thinks : as soon as both engines are out of synchronism, they are entirely independent of each other till they synchronize again. Field-resistances are unnecessary and would only bring a useless complication. The only braking effect (if any) would be due to hysteresis and Foucault currents, and these " magnetic frictions," as explained in the course of the paper, are negligible (about 4 per cent).

I do not agree with Mr. Newman, who thinks that the hysteresis losses would be more than the frictional losses of a cut worm and wheel. It is *impossible* to make a mechanical worm gear to reduce the speed from 3,000 to 75 rev., having a gear-efficiency OF MORE THAN 70 PER CENT., and nearly impossible to run satisfactorily a worm-gear of such power as 300 h.p. : the efficiency of the magnetic gear is well above 90 per cent. and it never wears.

CHAIRMAN : We shall now be pleased to continue the discussion on this subject.

Mr. W. P. DURTNALL : I regret I was not able to attend when the discussion was opened. Mr. Lecoche has brought out a very interesting gear embodying electro-magnetic and mechanical engineering principles, and I think great credit is due to him for what he has done. During the last few years he has practically re-designed the whole arrangement, and it is now much more practicable than when I first saw it about four years ago. Mr. Lecoche opens his paper with the remark, " It is now generally admitted that the combination of a reciprocating engine with an exhaust steam turbine provides the most satisfactory solution of the problem of marine propulsion." I do not think that is quite in accordance with recent developments. We all know that the combination of reciprocating engines and steam turbines has been successfully brought about by reason of the same principle that I propose in my paper on the gas engine, that is by using the tail end of the indicator diagram instead of the low pressure end of the steam diagram, and for that reason there is no question that the efficiency obtained as shown by the increased number of horse power hours per unit of fuel burnt is in excess of what could be obtained by using the ordinary reciprocating engine. But that is not the only, and in many instances not the most satisfactory, solution. In Italy a twin screw steamer of 680 h.p. has been built driven entirely by oil engines,—a practical evidence of a more satisfactory solution. Mr. Lecoche deals with his arrangement as a reduction gear. I believe I am correct in stating that it has been tested, and has given excellent results so far as they have been able to test it.

The HON. SECRETARY : Could you give an idea of what limit of power he has reached.

Mr. DURTNALL: I do not know exactly, but I believe the machine I referred to was of 8 to 10 h.p. Of course the efficiency of an 8 or 10 h.p. engine is not a criterion of what can be effected with the 1,000 or 2,000 h.p. required for marine engines generally. Further I do not see how it is possible with this gear, from electro-magnetic principles, to get the transmission of a large power at high revolution as given on the turbine. He states in his reply to the discussion that he is able to get 90 per cent. efficiency with this gear. I do not think it is possible to do that electro-magnetically, because of the fact that the whole action of the adhesion or "pull" forming the torque is delivered in one point round the wheel. In an induction motor for electrical driving there are twenty points round the circumference, each one contributing its portion towards the ultimate "pull," whereas he has only one point round the periphery of the wheel. Therefore, for a given diameter of wheel, I fail to see how he is going to get the same power for transmission. As a speed regulator I think it would work. At light loads, for instance, it would form itself into a speed reducing gear, but I do not think it would be correct to describe it as a power transmitter.

The HON. SECRETARY: You are, of course, aware that it is a worm gear.

Mr. DURTNALL: Yes, I appreciate that, but the whole action is on one point.

The HON. SECRETARY: Would it not form a series of points?

Mr. DURTNALL: As far as I can make out it would only act at one, whereas in a motor those points are all the way round. The author then gives us the weight per horse power developed. Of course we are aware that both in this scheme and for electrical driving, the final revolutions to effect a saving are decided by the propeller shaft. The lower the revolution speed, the higher will be the weight and brake horse power developed. There is no question that if this gear is to be made to work satisfactorily for marine propulsion it must be designed for constant running at full load, and the author does not give us any particulars as to the heating effect allowed for in relation to the weight of the gear. My own view on this method of concentrating the energy in one place, is that this machine will be heavier for a given number of revolutions than our modern three phase squirrel cage induction motor. The author goes on to say : " It must be remembered that, under certain conditions of the sea " (I take it he refers to heavy pitching conditions) " the reciprocating engine of a boat shows a marked tendency to race ; a tendency which is by no means equally shared by the turbine." I hardly think that expression quite illustrates the facts of the case. A reciprocating engine probably runs at about 100 revolutions per minute and for a given effective thrust it has a very large diameter of propeller. For a given depth of immersion or draught the tips of the propeller blades are sooner out of the water than is the case with the turbine driven boat. Owing to the high revolution speed the turbine must run at to give efficiency the diameters of the propellers are consequently smaller, and for a given depth there is less tendency for it to race owing to the increased depth of immersion. This racing will not be stopped in Mr. Lecoche's system. The reciprocating engine will race just as now unless means are taken to anticipate the racing, unless some quick governor is put on the turbine, or some means are taken of storing the energy in the way of steam between the turbine and the engine, as in land practice where reciprocating engines drive a generator and exhaust into a turbine driving another generator in parallel, thus getting increased efficiency. Mr. Lecoche deals with the question of mechanical gearing. About two years ago we discussed this question of gear reduction and as you know I advocated electrical gear. I quite agree with the author's remarks about the noise, vibration, wear and tear and low efficiency of mechanical gear at such high ratio—that is the point, the high gear ratio. In a turbine boat now running, fitted with gears, with the turbine at 1,500 r.p.m. and the propeller shaft at 75, there is a gear ratio of 20 per cent. One of the most efficient ways of transmitting power from one shaft to another is to have a mechanical gear of equal direction. If you attempt to gear a shaft up or down you immediately have trouble in the way of heat losses and, in the end, noise. That is one of the reasons why I took up the electrical proposition of driving, which I explained in my paper read before the Institute at the Franco-British Exhibition ; because of the inefficiency of the mechanical gears in dealing with the large powers necessary in marine propulsion. I thoroughly agree with Mr. Lecoche on that point. I do not wish to depreciate his system, because I know only too well how difficult it is to get a new thing adopted. I only hope it is true that he can get this efficiency and if he can, his is a far superior machine to any mechanical gear, whether worm or helical teeth gear, and for this purpose it is a most excellent machine. He goes on to say "Other means for transmitting power and simultaneously reducing the speed are the hydraulic and electrical transmissions, both of which have been tried in connexion with marine propulsion." At the present time there is a ship being built, in fact I am going next week to assist in connexion with the engines, fitted with hydraulic power transmission. It is a job of 400 revolutions per minute, 180 b.h.p. and the propeller at 120 r.p.m. top vessel speed, and they can regulate the revolutions for the propeller and reverse while still keeping the engines in one revolution direction. It is an engine built on the "off-set" principle, and there is no doubt that the engine will be a very economical one in regard to fuel consumed. Another hydraulic transmission engine that I know of is one in Germany which I saw at the Stettin works some time ago, and which was described in *Engineering*. It is an engine of 600 h.p. and is the invention of a German engineer of repute now at Danzic. It is a very interesting engine and a strong competitor to the electric drive. Mr. Lecoche also states "electrical transmission appears very attractive from the point of view of flexibility and ease of control." That is just where the advantage comes in and there is no question that any system to be adopted on board ship must approach the flexibility of reciprocating engine or turbine. The nearer we can approach that the more nearly will it meet the demands of marine engineers, especially if the speed variation can be done with the same, or possibly greater efficiency in fuel at the lower speeds. One of the vessels designed for electrical drive, was a twin screw 4,000 h.p. vessel fitted with electrical motors. There are four turbines with approximately 1,000 h.p. on each at full speed steam. They have a means of varying the frequency with squirrel cage motors, and if the engines are run at half the revolution speed for the propeller, the vessel will be not quite half speed. If a continuous half speed is required, one turbine does the duty and the other three turbines are closed down. For a vessel to run on a low speed there is no question about it that the electrical drive offers the best proposition to meet the case. Mr. Lecoche says "The illustration shows a magnetic frictionless gear of the screw type for an exhaust-steam turbine of 300 b.h.p. running at 3,000 revolutions per minute." I would like to inquire what powers he might go up to approximately, and whether the weight will increase in the larger powers in greater ratio to what it does in the smaller. In the concluding paragraph he says the weights of the electrical gear would be : "one 250 KW dynamo at 3,000 r.p.m., 3 tons (approximately) ; one 300 h.p. motor at 75 r.p.m., 27 tons (approximately) ; total 30 tons." It is soon reckoned up, but I think it is out of the question. That weight is for specially designed machinery, and the figure for the usual three phase electrical gear is very much lower than the figure Mr. Lecoche gives. Again he says, "the magnetic gear can run in both directions if the turbine is reversible." We have not a satisfactory reversing turbine up to the present ; we have to put in separate turbines for reversing. But I fail to see the necessity for a reversing turbine in this particular application, because of the fact, as he says, that it falls on the reciprocating engine to do the necessary driving and low speed manœuvring. It is a very interesting paper, and one we should welcome, as it opens up food for thought and gives us an opportunity of getting in touch with those who are working to provide us with something for the future.

Mr. E. W. Ross : I agree with Mr. Durtnall that our thanks are due to Mr. Lecoche for introducing this new subject. I had not the pleasure of hearing the paper read nor of being at the previous discussion, and I think it would be profitable if we could have a short resumé of the general principles of the apparatus.

Mr. Gerald L. Jones : With regard to the wheel shown on the diagram it is not obvious to me whether it is wired electrically, or whether they are simply stampings bolted together and the revolving magnet pulls on that wheel. Like many others I have spent money in patents from time to time, and I had a patent for a speed reducing gear on motor-car work. Mine was not exactly similar to this ; it consisted of a squirrel cage rotor and a stator, the stator being mounted as the flywheel of the engine, and the rotor connected to the gear shaft. I went to a lot of trouble, but found it was open to an objection which I think is found in this gear also. The maximum lock between the members occurs when they synchronise and the torque is very small when the difference in speeds is great. I do not see how the wheel is going to be moved unless rotation is started by external power.

Mr. Durtnall : Although I agree with the remark regarding the starting torque you will get on this machine, in this particular instance he suggests starting the wheel by means of the reciprocating engine, and when up to speed to turn on the exhaust turbine. When these two wheels are in synchronism, a slight slip takes place. There are parts going through the stampings, across into a ring at each side which forms practically a squirrel cage induction rotor. My point is that, taking the diameter of the wheel, owing to limitation of excitation, a point will be arrived at where saturation will take place, and it may be excited to any extent without effect. It will lower the heating effect.

Mr. Jones : The heating effect will be practically negligible.

Mr. Durtnall : It is a point to be considered because of the insulated wiring.

Mr. Jones : I do not think I have made myself quite clear. I am speaking of the worm wheel ; the worm wheel is built up of laminated plates bolted together. There is no wiring on the worm wheel.

Mr. Durtnall : The worm is in the magnetic circuit.

Mr. Jones : I understand, it is an induced field on the wheel.

Mr. Durtnall : Magnetically speaking, it is right enough, but diameter for diameter of wheel, you will not get the lb. ft. at the lower speed representing the true power transmission.

Mr. E. Shackleton : I must confess to a large amount of ignorance on this subject ; but the question occurred to me whether we got anything more than from a plain worm gear beyond flexibility, and if the cost of the apparatus would not outweigh other considerations. I do not think it should be called a transmission gear, it should be called a reducing gear as it fails to transmit power in the reverse direction. To say the least the cost would be enormous, and it is questionable whether any shipowner would adopt it. If we have to go to electrical driving let us adopt it out and out. I say "if we have ;" there are many doubts on the point.

MR. F. M. TIMPSON: It appears there is a good deal of complication in this system. There is an hydraulic reversing gear on the market, Dr. Fettinger's, I think, that offers many advantages. It is also used for controlling the speed of the main shaft. The cost of the gear is very high, sometimes almost as much as that of the engine itself. This will certainly have to be modified before it is generally adopted because the cost is out of proportion. The system suggested by Mr. Lecoche is certainly very interesting, but it is a pity he has not been able to be here as we might have had a more detailed description of it.

It was agreed, on the proposal of Mr. Timpson, seconded by Mr. A. Robertson, that the discussion be closed.

CHAIRMAN: The report of the discussion will be forwarded to Mr. Lecoche for him to reply to, and if he could give us a night at some later date I am sure we would all be pleased.

REPLY BY MR. LECOCHE: I have pleasure in replying to the very sensible remarks of Mr. Durtnall on this subject. Mr. Durtnall, in order to investigate the possibilities of the magnetic speed-reduction, avails himself of his experience in polyphase machines; yet I am afraid the magnetic gear cannot be compared to the usual type of electric machines. For instance, comparing the pull at the tangent of the wheel to the pull at the circumference of an induction-motor-rotor, I find that, although I produce the tangential pull at one point of the wheel, this pull is appreciably greater than the pull on an ordinary rotor, although the whole circumference is used for that purpose. The reason for this is that the working of an induction-motor is attended with the production of various phenomena such as inductance, self-induction, effects of capacity, etc. . . . and for the sake of efficiency it is advisable to work at a low magnetic induction. On the other hand, the field of the magnetic gear is excited by direct current; the only loss is due to ohmic resistance, and in large machines I can work at an induction of very nearly 20,000 lines of force per square centimetre without great loss or heating, provided the weight of copper is sufficient. What makes all the difference between the two machines is this: in an induction motor, the field rotates *electrically*: in the magnetic gear the field moves *mechanically* in the direction of the tangent. In consequence of this, there will not be any more difficulty in preventing overheating in continuous running than there is in cooling the field-coils of a D.C. motor or dynamo, the more so that the quantity of electric power used in the gear is infinitesimal as compared to the power actually transmitted. As to the weight compared to the weight of an ordinary electric motor, I should like to say that I have combined this magnetic gear to a D. C. armature, and this permits me to manufacture D.C. motors running at any speed from 120 to 1,000 rev. p.m., weighing less than one third the weight of ordinary motors of same power and speed.

Referring to the tendency to race respectively of a reciprocating engine and of a turbine, I am speaking at a general point of view, whether if the engine or turbine is driving a propeller or a prony-brake or any kind of load ; what I mean is that a turbine running light under full steam-pressure cannot race above twice its normal speed ; but a reciprocating engine under the same conditions will race as fast as the steam can expand in its cylinders, that means, till the piston velocity is nearly equal to the velocity of the steam expanding under full pressure ; of course, in practice this racing is partially checked by the automatic governor. Besides, there is the inertia of the rotating parts, and it takes longer to increase the velocity of a mass moving at high speed than of a mass moving slowly, as shown by the formula : $_2M. (V_2 - W_2)$ in which M is the mass of the moving parts, *V* the velocity when racing and *W* the normal velocity. The effect of the propellers, due to their different diameters, as pointed out by Mr. Durtnall, only accentuates the tendency to race.

The wheel of the magnetic gear is not wound and cannot be compared to an induction rotor ; the drive is positive, and there is no slip between the worm and the wheel ; the wheel starts under load in synchronism with the thread of the worm as soon as the latter begins to revolve ; it will keep in synchronism till very much overloaded.