

The Author. tive was very justly comparable with it. The addition of units on the ship was a problem which had rather baffled electrical engineers in the past. If one could imagine the three dynamos in Fig. 4, Plate 5, applied to drive the single motor on one propeller, it was obvious that if an order came from the bridge to add one, two, or three machines instantaneously, to bring up the speed of a ship in a current or in a river, the engineer would be in some difficulty if he had to synchronize alternating-current generators before he switched them in. It was for the purpose of simplifying that process that he had applied himself to making new arrangements, and he thought the spinner motor and the multiple motor he had described in the Paper attained that object. The windings in both these motors were absolutely independent and each separately associated with a generator, and he found experimentally that it was possible to throw all the generators together on the same work without paying any attention whatever to synchronizing, and the order could be carried out instantaneously, exactly as in an ordinary ship.

Correspondence.

Mr. Hart. Mr. GEORGE HART, of Paris, considered that it was entirely rational and logical to work the propelling-apparatus under the best possible conditions, whatever might be the variations of power demanded; and he quite agreed with the Author's view that consideration of the question of the "load-factor" of marine motors would lead to considerable advantages, and might result in important progress. In the present state of the matter, however, the application of electricity to marine motors would not proceed without giving rise to serious practical objections which, although they would become weaker and even perhaps vanish in time, must be taken into account seriously at present. First and foremost was the fundamental objection that the introduction of an additional transformation of the energy generated either by a steam-engine or by an internal-combustion motor, necessarily lowered the combined efficiency of propulsion. Without doubt, this reduction might be offset to some extent by advantages inherent in the suggested transformation, such as ease and rapidity of working, etc.; but even then the loss entailed by a transformation of energy could never, in practice, be fully retrieved. For example, in the system of triple or multiple electric motors advocated by

the Author, the variations in the speed of the propeller were Mr. Hart. obtained by combining the running, in the same or in opposite direction, of the various polyphase motors, which necessarily involved loss of energy, a portion of the developed force being employed in a negative and retarding form when graduating speeds and powers. The interference of the various motors in this graduation of speeds might be likened roughly to the introduction of a resistance into an electrical circuit. This interference was convenient, and might, in some cases, be useful and even indispensable; but it involved always a more or less considerable loss in the combined efficiency. The use of powerful electric motors on shipboard might prove a source of trouble, inasmuch as the insulation was always defective there, owing to the dampness of the air, and might, owing to the movements of the ship, at last break down completely, with the result that the compasses would be badly damaged. Though such cases were very rare, troubles on account of short-circuits were frequent. It was therefore not possible to follow the Author when he advocated the general use of electric motors on shipboard, inasmuch as the motive power must be derived for the present either from steam or from combustible gases. Undoubtedly, the reduction of weight and the greater compactness were attractive, because, for equal tonnages, both were conducive to better employment of the ship, while with the same power the tonnage could be reduced. But perhaps the gain would not be so considerable as was alleged in the Paper, because other considerations must be taken into account. It was upon these considerations that Mr. Hart would insist, inasmuch as they accounted mainly for his inability to follow the Author in his advocacy of the general employment of electric motors for propelling ships. The faculty of varying the efficiency, while at the same time working the motor under the conditions most favourable to its output, would be, unquestionably, very valuable, if it could be obtained without too many complications; but it could be really advantageous only in cases where, owing to special circumstances, the variations of speed, and consequently of power, must be considerable. And even then it must be considered whether the periods when the motors worked under unfavourable conditions were not precisely those in which improving the output would have but a relative advantage, and also whether their duration, compared with the whole time of navigation, was not relatively short. Moreover, it must be taken into account whether the improvement could be effected with simplicity—a requirement which in Mr. Hart's opinion was indispensable; and the best devices, giving excellent results on land, had frequently given but moderate results on shipboard, and had been a source of anxiety and trouble there.

Mr. Hart. This was explained by the fact that on shipboard the working-conditions—the marine contingencies and the state of motion—were dissimilar to those obtaining on land. Besides, the more highly the machines were improved, the greater were the chances of trouble and breakdown, and the more likelihood there was that these would occur at the worst moment, namely, when the safety of the ship called for the prompt use of all its resources of power. Simplicity was therefore compulsory, together with reduction in the number of links in the transmission of energy to the propeller. Hence, the application of electricity for propelling ships must be a special question, and before adopting it both its advantages and its drawbacks must, in every case, be weighed carefully. They depended, of course, both on the type of ship and on the choice of the most advantageous motor. In warships the adoption of electric motors, with the resulting reduction of weight and greater compactness, might certainly offer great advantages, such ships being fitted with motors calculated for the maximum speed, whereas in practice, on account of external considerations, the speed was rarely more than two-thirds or three-quarters of this maximum. It was even a question whether, for this class of ship—at least those of large size—it would not be advantageous for the sake of training the officers and crews, and also conducive to more economical working of such motors as turbines, to make the actual speed as nearly equal as possible to the maximum speed. The crew must be trained with a view to fighting, and this training must be commenced and continued in time of peace, as everyone familiar with marine practice knew how difficult it was to change suddenly habits of stoking or machine-driving, in order to realize a speed and efficiency greater than those to which a crew were accustomed. To bring the actual speed closer to the maximum would evidently diminish the advantages resulting from the employment of electricity, because then the existing motors worked generally under favourable conditions. The periods of working under unfavourable conditions would be reduced, and would occur only in circumstances where the question of output played only a subsidiary part. For warships fitted with reciprocating motors confined under an armour-clad deck, and whose proportions could not be as satisfactory as those of steamers and merchant vessels, the adoption of electric motors fed by multiple and small-sized generators might present valuable advantages. But the conditions were otherwise in steamers intended to run in regular service between two points within the shortest time, that was to say, working at their maximum speed and efficiency.

The sea conditions alone could make the working-conditions of the Mr. Hart. motors less favourable; and the measure of this influence depended on the dimensions of the ship and tended to decrease as these dimensions increased. Besides, for the sake of maintaining regularity of service, the running-speed of such vessels was slackened as little as possible, except in foggy weather. The periods during which a vessel ran at half speed, that was to say, at reduced power, represented, on the whole, only a relatively small portion of the aggregate navigation-time. When the motors had been proportioned for the speed to be realized in actual service—and not for that required under trial, in order to discharge the builder's guarantees, which allowed a margin not needed in service—they worked for the most part under very favourable conditions, as was shown by the coal-consumption. In cargo-boats whose highest speed was 11 knots per hour, which mostly ran at only 8 to 9 knots, the margin of speed was so narrow that it was a question whether, apart from the reduction of weight and greater compactness, there were serious advantages in the faculty of varying the power within wide limits by working the motors at their maximum output. It would seem, therefore, that as far as reciprocating engines were concerned, substituting electric motors for them would offer, except in warships, substantial advantages only in special cases. As to turbines, the margin of economical speeds and efficiencies was assuredly narrower than in the case of reciprocating engines: but the conditions were similar in regard to the eventual substitution of electric motors for turbines. Besides, steam-turbines of small dimensions would not have as good an efficiency as the present large turbines, for an equal load-factor. It would seem, therefore, that a considerable portion of the improvement made in the combined efficiency by the employment of electricity would be lost. The question of reversing alone seemed to offer much interest, so far as the employment of electricity was concerned. But it appeared that this question would be solved more advantageously by using the Del Proposto device than by the proposed system. By this device the turbine could be caused to drive the propeller directly for the forward motion, which was the more frequent, while backward motion could be effected through a dynamo. Thus the loss which would result, during the greater part of the working, from the interposition of the dynamo was avoided. Undoubtedly, it was not possible to vary the ahead motion within wide limits of power; but as turbines were adopted generally on fast-running steamers, it did not appear to be very necessary to provide for considerable reductions of speed and efficiency. When

Mr. Hart. the power was developed by internal-combustion motors, the employment of an electric motor as an intermediary was a question which called for close investigation. It was so simple a matter to disconnect one or several cylinders of such apparatus that it seemed generally useless to resort to the employment of electricity. The loss of output resulting from this disconnection of cylinders was assuredly less than that due to the supplementary transformation necessitated by the employment of electricity. Astern motion would be secured by the Del Proposto device. On the whole, the application of electric motors to marine propulsion, enabling the work developed to be better proportioned to the resistance, offered valuable theoretical advantages. But, in the present condition of the question, this application must be investigated carefully in accordance with the service to be performed, and it would not always lead to the results anticipated. Besides, electricity did not yet offer on shipboard the same safety as on land. The marine engineer of the present day, though electrically trained to a certain degree, would experience perhaps some difficulty in running very powerful dynamos. The engineers as a body would have to be further trained before the proposed system could come into general use. The solution of the problem would require some time, because the working-conditions of the apparatus and of the engine-room—dryness, etc.—were so different on shipboard from what they were on land. In his opinion, therefore, however interesting the question might be, it was necessary to proceed very cautiously in substituting electric motors for the present machinery. Nevertheless, the Author must be given credit for having directed attention to the matter, and, though the solution which he advocated had not at present all the advantages which he claimed, he had started a movement which promised to bear fruit in years to come.

Rear-Admiral
Sir H. Jackson.

Rear-Admiral Sir HENRY JACKSON considered that the system proposed in the Paper for the propulsion of ships was one that deserved careful consideration, in view of its attempt to reduce the consumption of fuel, and at the same time obtain a greater power on the engines when used for going astern than was at present practicable with the modern type of marine steam-turbine. Incidentally it was probable that in arrangements of propeller-shafting and engines some advantages in regard to space and weight might also be obtainable. It appeared to him that the advantages of the system would be more apparent when it was used in small vessels in combination with gas- or oil-engines than with steam-turbines, the economy of the latter with a direct drive in large installations having already reached such a stage as to make it improbable that any gain would

result from substituting an indirect for the present direct drive of the propeller. In the present stage of its development, as described in the Paper, there were, however, disadvantages which would prohibit its use in modern war-vessels. The most important disadvantage was the restriction of the propeller-shaft to three speeds of revolution, with apparently the possibility of only a slight adjustment of speed at each of these speeds. The demand of a war-vessel in this respect was the capability of readily altering and adjusting the revolution of the propellers to any desired extent at all speeds of revolution, and the Paper did not hold out any great hopes of this result being obtained without loss of economy and complication of switch-gear. Another disadvantage was the greater liability of damage to the electric generators, motors, and switchboard, by the accidental flooding of any of the compartments in which they were placed, than would occur to the propelling machinery in the case of steam-driven engines. To guard against the possibility of this it would be necessary to enclose them in watertight tanks, a course which would in its turn increase the difficulty of effectually ventilating the motors for the purpose of cooling them, and at the same time would increase the weight of the installation. On the other hand, the advantage claimed that the power available for astern propulsion was equal to that available for steaming ahead was a real one as far as large ships were concerned, and the abolition of the astern turbines would be of considerable benefit. In small, fast vessels, the necessity for equal power for astern and for-ahead running was not felt to such an extent, and in them the question was of secondary importance. If the most important disadvantages mentioned in the foregoing remarks could be eliminated without introducing other serious drawbacks, the system appeared to be one which might eventually compete with direct steam-driven propellers in small vessels, and a practical trial at sea would be of great interest to naval architects.

Rear-Admiral GEORGE W. MELVILLE, U.S. Navy, was in entire agreement with much that the Author said. Indeed, the Paper did good work in showing the necessity for a change in existing methods, if the application of the steam-turbine to marine propulsion was to make any real progress. As was well known, through the publicity given to the matter by *Engineering*, he was joint inventor of another means of securing the proper relation of speed between the turbine and the propeller, so that obviously he could not agree with the Author's remark that electricity offered the most convenient means, and indeed on a large scale the only means, for securing this proper speed-relation. In the same way he must take exception to the Author's remark on p. 241. Doubtless these remarks

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were made by the Author in ignorance of what was proposed as to the Melville-Macalpine reducing-gear, and certainly without any knowledge of the recent tests of that gear. Not being an electrician, he did not propose to discuss the electrical features of the Paper further than to say that it had always seemed to him an extraordinary thing to propose to use, for the simple purpose of securing a connection between two shafts which were close together, a method which was altogether foreign to the general nature of the machinery otherwise in use on board ship. He recognized the very important part which electricity played in long-distance transmission, but it certainly did not seem to him that it was the right means of transmitting power a few feet only. The Melville-Macalpine reducing-gear had been very fully described in *Engineering*¹ and he would not attempt to go into a detailed description here. It would suffice to say that the inventors used helical gearing with involute teeth, and provided for any lack of alignment or improperly-adjusted bearings by carrying the pinion-shaft in a frame which had a limited amount of flexibility and was named, for convenience, a "floating" frame. Except in the case of rolling-mills, he did not believe that any attempt had previously been made to transmit so large an amount of power by gearing as was actually done in the tests of this gear. It was designed for 6,000 B.H.P., and, through the co-operation and financial support, as well as the constant advice and encouragement, of Mr. George Westinghouse, the inventors had been enabled to test it to full power in the works of the Westinghouse Machine Company at East Pittsburg, Pennsylvania. The results of those tests were being written up, and would be published in pamphlet form, so that those who wished to go into them in great detail could do so, and could see the care which had been taken to measure the power actually developed. After preliminary tests of a few hours' duration at a time, in which the load transmitted was being constantly increased, and during all of which trials the gear proved admirable in every way, a full-power test of 6,500 HP. was carried out for a period of 40 hours, from 2.30 p.m. on the 16th October to 6.30 a.m. on the 18th October. At the close of this test the gear was found to be in excellent condition and without any signs of wear. This established without question the fact that gearing could be used to transmit such large powers continuously at high speed. The speed of the turbine was 1,500 revolutions per minute, and that of the gear-shaft 300 revolutions per minute. Continuous brake-readings were taken during this test, and other sets of brake-tests were made direct, on the turbine so that the turbine-conditions were

¹ Vol. lxxxviii (1909), p. 377.

identical in the two sets of cases, from which it was determined that the gear showed an efficiency of 98·5 per cent. This was checked in another way by measuring the increase in temperature of the oil used in lubricating the gear, and, in a very rough way indeed, by simply feeling the teeth at the end of the run, when they were found to be cold. In the Paper it was stated that the efficiency of the motor used in the Author's system was 93 per cent. Admiral Melville found that a very high value for the efficiency of the generators would be 96 per cent. This would make the combined efficiency 89·3 per cent. On the score of weight also the comparison showed very favourably to the reducing-gear. The weight of the gear used in the test, complete, including bed-plate, framing, casing, etc., was 61,000 lbs. For the 6,500 HP. of the test, this gave 9·4 lbs. per horse-power. There was every reason to believe, however, that with a slight increase of some parts of the transmission, the gear, as it stood, would be good for 10,000 HP., in which case the weight would be 6·2 lbs. per horse-power. Taking the Author's figures and making a reasonable allowance for the weight of the turbines, he calculated that the weight of the electric machinery in the Author's case would be about 322 tons. Allowing an efficiency of 96 per cent. for the generators, this would make their power in round numbers 17,000 HP. From this the weight per horse-power of the electric connection would be 42·2 lbs. Thus the reducing-gear had an efficiency of 98·5 per cent. as against the 89·3 per cent. of the electric drive, while the weight of the reducing-gear was only 6·2 to 9·4 lbs. per horse-power as against 42·2 lbs. for the electric drive. He did not think there could be any doubt whatever of the much greater simplicity of this purely mechanical method than of the electrical method, because the handling of the turbine would be exactly the same as if it were on the propeller-shaft. He recognized that the Author would naturally say at once that, while the comparison made thus far was fair enough, as between the electric drive and the reducing-gear, for the great bulk of the ship's work, which was going ahead, his method dispensed with astern turbines, which would be necessary in the case of a ship fitted with high-speed turbines and reducing-gear. This was perfectly true, but, inasmuch as the astern turbines were much simpler and weighed much less than those used for the ahead propulsion, because there was not the same necessity for economy, it was evident that the great difference of more than 30 lbs. per horse-power between the electric drive and the reducing-gear would not nearly be counterbalanced by the weight necessary for the astern turbines. Although these remarks might perhaps have the appearance of putting forward the gear with

Rear-Admiral
Melville.

Rear-Admiral Melville. which his name was associated, Admiral Melville believed that they gave information which the members of The Institution would certainly wish to have in connection with such an important problem as that of the economic application of the steam-turbine to marine propulsion.

Mr. H. Napier. Mr. HENRY M. NAPIER observed that electric propulsion was of great interest to shipbuilders, chiefly on account of the saving in weight, both of machinery and of fuel. Having seen electric driving successfully applied to a motor-car, he had felt justified in proposing this system in 1904 for the river-steamers for the London County Council, but it being thought too experimental, the better-known steam propulsion was adhered to instead. Then direct-current motors and generators were proposed, but the later alternating-current induction motors had added greatly to the chances of success. The Author's ingenious scheme of rotor, spinner, and stator, allowed ample variation of speed with the highest economy, but Mr. Napier thought too much stress was laid on economy at low speeds, and when reversing. Economy at one given speed, the ordinary sea speed, was the one thing wanted. It was also hardly correct to say that the motor would never have to start against a dead load, for while reversing the motor was so simply done by reversing the current, yet if the vessel's speed ahead had not stopped, she was practically a dead load on the propeller, and hence on the motor. No doubt, though, the Author could produce a motor and a starting-switch to get over this difficulty and give the man in charge no cause to be afraid of the fuse being burned out. Besides the great advantage of saving weight, much less electrical power would drive the vessel, as engine- and shaft-friction would be omitted—a gain of at least 20 per cent. over reciprocating engines and shafting. The addition of the spinner was very ingenious, but there might be trouble in lubricating the bearing between rotor and spinner, and he thought the simpler arrangement should be tried first, such as a twin-screw steamer with a fast-running steam-turbine, generator, and suitable motor for each shaft for use at half-speed and reversing, with a third steam-turbine and generator to supply extra current to the two motors for full speed. The boilers might be amidships, if trim conditions required it, with turbines and generators on deck, and a trunk down to the motor-room at the after end. Thus the tunnel would be omitted and more space would be left for cargo or passengers, and there would be no long shaft to get out of line. For large powers the motor must be of large diameter and placed correspondingly farther from the stern, as pointed out by the Author; but for a vessel of moderately fine lines and not excessive power there was room for a successful experiment, where the extra first cost would soon be repaid, and he hoped the Author would shortly have an opportunity of producing such a vessel.

MR. ROBERT T. NAPIER took up the matter of the Paper from the Mr. R. Napier. point of view of the marine engineer, the Author having naturally looked at it from his own point, the electrical. The proposal was the drastic one that the direct drive, at present universal on the sea, should give place to an arrangement of high-speed prime movers driving the propeller-shaft through an electrical equivalent to gearing. Only a proved financial gain could make such a proposal reasonable, and Mr. Napier proposed to go into some detail in connection with cost of running. Shaft horse-power was but seldom directly known afloat, but marine engineers knew that with well-made and well-kept reciprocating engines the shaft horse-power need not be less than 90 per cent. of the indicated horse-power. Following this it might be pointed out that if each of the alternators and electric motors proposed to be used had as high an efficiency as 95 per cent., then the collective efficiency of the combination would be 90·25 per cent. This meant that the shaft horse-power of the prime mover installed would require to be equal to the indicated horse-power of the steam-engine displaced. Starting with the Author's practical example No. 1, it had to be pointed out that he was not up to date in his knowledge of weights of marine engines. Mr. Napier had the designing of a cargo-steamer with engines well capable of giving the shaft horse-power named at 67 revolutions per minute, and the weight of the whole, with steam up, was 195 tons. Further, the power named could be maintained for 15 days with 230 tons of coal. As pointed out by the Author, an oil-engine required no firemen; but firemen afloat did more than fire. They did all the cleaning, they lent a hand to the engineer on watch when required by him, and they did the heavy work of the overhauls in port. Oil-engines required cleaning and overhauling: and the engineer, say on night duty, was little likely to be content with no one within hail; so three helpers were wanted—one for each watch—as against the steamer's six firemen. Firemen cost £6 10s. per month to pay and feed. The Author supposed that crude petroleum was sold at £2 per ton—the present price being about one-half more—and compared this with coal at 20s. per ton—the present f.o.b. price on the Clyde being barely one-half of this. If petroleum ever reached such a low price, then coal-merchants would have every cause for thankfulness if coal did not fall in price along with it. Mr. Napier proposed to take the Author's possible price of petroleum and the present actual price of coal, namely, 9s. 6d. per ton. The first result to be reached by the Author's proposal was the carrying of more cargo on the same size of ship, and the value of such result to the shipowner might be defined at the outset. Cargo-steamers paid

Mr. R. Napier. handsomely if the freight received covered all port-charges, and left them 2*d.* per day per ton of cargo carried throughout the year—the steamer being assumed to be fully loaded. Port-charges were the same, whatever the motive power might be, so, deducting, say, 10 per cent. for detention in port during the year, the running-time would require, say, 2½*d.* per day to balance. For 15 days this represented 2*s.* 10*d.* per ton. The case of the oil installation as against the steamer was shown by a glance at the following Table:—

	Steam.	Oil Installation.
Weight of machinery Tons	195	182
„ „ fuel for 15 days „	230	88
Total weight „	425	270
Excess cargo carried by oil installation . . . „	..	155
Freight earned in 15 days	say £22
Fuel per ton	9 <i>s.</i> 6 <i>d.</i>	40 <i>s.</i>
Cost of fuel for 15 days	£110	£176
„ „ firemen for steamer	£10	..
Total cost	£120	£176
Net result to shipowner Loss	..	£34

Clearly the oil-engine proposed could not pay at home-port prices. It might begin to pay with petroleum at about 25*s.* per ton more than coal. A promising field, however, suggested itself in the case of vessels carrying petroleum in bulk, as they could get their fuel-supply at the lowest price and, being non-dependent on coaling-ports, could go anywhere, and thus have the advantage over steamers. Turning to the Author's practical example No. 2, the economy of gas-engines was common knowledge, especially when using producer-gas, and such engines would have been fitted afloat some years ago but for the drawback that they would not reverse. The Author was not so far off the weights in this example, but the steam-engines, if placed as shown, need not weigh more than 180 tons, nor burn more than 210 tons in 15 days. Allowing the efficiencies above stated for alternators and motor, the collective brake horse-power for the three gas-engines would be $770 \div 0.9025 = 835$ B.H.P. The best published results of leading British makers¹ of gas-engines gave a fuel-consumption of 0.875 lb. for anthracite per brake horse-

¹ Messrs. Fielding and Platt.

power-hour and 1·125 lb. for slack coal. Thus, in 15 days the Mr. R. Napier. power mentioned would require 120 tons of anthracite, and 154 tons of slack coal. The case of the gas installation with each fuel was shown alongside that of the steamer in the following Table:—

	Steamer.	Gas Installation.	
		Anthracite.	Slack.
Weight of machinery Tons	180	129	129
„ „ fuel for 15 days „	210	120	154
Total „	390	249	283
Cargo carried in excess of steamer „	..	141	107
Freight earned in 15 days „	..	£20	£15
Cost of fuel per ton „	9s. 6d.	£1 5s.	8s. 6d.
„ „ „ for 15 days „	£100	£150	£65
„ „ firemen „	£10
Total cost „	£110	£150	£65
Net result to shipowner Gain	£60
„ „ „ „ Loss	..	£20	..

From the Author's figures the extra cost of the gas installation above steam was £3,639; and to cover what a shipowner would look for if he paid the higher price—5 per cent. on the extra money—as well as the usual allowance for insurance and depreciation, would, for the 15 days, come roughly to £30. The arrangement with slack coal would therefore pay. The disposition of machinery shown in *Figs. 5* would require to be reconsidered altogether. A cargo-steamer had often to shift port light, and her safety demanded that the centre of gravity of all weights be kept low. The engines would have to be placed on the top of the ship's floors, and the bunkers would have to be in the wings, as at present. There was nothing to prevent this from being done, as the coal could be supplied to the producer-hoppers by bucket-ladders.

In taking up example No. 3 certain facts must be kept in mind.

(a) In any steam-propelled ship the weight of boiler-equipment, auxiliaries, piping, condenser, and all gear apart from the steam-engine itself, was dependent on the weight of steam used in the period, whatever might be the type of steam-engine or the number of revolutions per minute.

(b) Provided it were properly designed for its service—a point which the patentees might be left to see to—a large steam-turbine driving

Mr R. Napier. direct was just as economical in using steam as was one with, say, a tenth of the diameter of drum, running at ten times the speed of revolution.

(c) The economy of turbines as steam-users, as compared with good reciprocating engines, was not so great at sea as to be any argument in favour of giving up the direct drive.

The foregoing being the case, the commercial practicability of the Author's proposal No. 3 limited itself to his being able to install—

(1) A high-revolution steam-turbine with shaft $HP. = \frac{1030}{0.9025}$
= (say) 1140 shaft HP.

(2) An alternator to suit the latter.

(3) An electric motor to give 1030 shaft HP. at 67 revolutions per minute (the Author's own figure in the first case).

And he would have to do this on a weight and at a cost not exceeding those of the reciprocating steam-engine displaced. The weight and cost were those of the engine up to the first coupling, under deduction of the portion due to the condenser, pumps, and pump-gear—which were wanted in any steam installation—and the weight, which Mr. Napier had worked out carefully, was between 52 and 53 tons. The cost the Author would be at no difficulty in learning. The fourth example the Author said was a “normal” modern equipment. As a fact it was far otherwise, as no marine engineer would dream of transmitting 6,000 shaft HP. through a propeller 8 feet in diameter, unless it were imperative to keep down weights, and so permit of speed being got on a very limited draught of water. Should an actual ship be wanted to meet such extreme conditions, then all those who would stand to gain by economy in running her would welcome the Author's arrangement, if it rendered possible the use of propellers of reasonable diameter, running at a less wasteful speed than the 380 revolutions per minute named. The Author seemed confident that he was able to meet the case, and he wished all success. On p. 255 occurred the words “The single electric equipment, while unable to drive the ship faster than 18 knots, can maintain this speed against a head wind, etc.” If these words meant that through keeping the number of revolutions per minute of the propeller uniform a steamer could be made to maintain uniform speed, whether in calm weather or against a head wind, then there was a mistake somewhere. Every marine engineer knew that the effect of a head wind was to increase the slip of the propeller, and that this told proportionately on the speed. There were cases in plenty in which a steamer, facing a heavy head wind, required all the revolutions that the engine was capable of, in order to make any headway whatever.

Mr. JOHN REID, of Montreal, was particularly interested in the Mr. Reid. development of electric propulsion in connection with investigations which he had carried on for the last 2 years as to the best method of reducing the machinery-weights and increasing the economy of propulsion in special vessels for the Canadian canal-traffic. In this service the dimensions of the vessel were restricted to 250 feet length, 43 feet beam, and 14 feet draft, by the dimensions of the numerous St. Lawrence and Welland Canal locks, through which the vessels had to pass. It followed that the only means of increasing the deadweight capacity of the vessel was by reduction in the weight of the hull or of the machinery. No sensible reduction in the weight of the hull being possible, owing to the rough usage which these vessels got, his attempts had been confined to reduction in the machinery-weight, and the best efforts had been in the direction of direct propulsion by gas-engines, which would simply take the place of the present marine engines, the producers occupying the place of the boilers. It had not taken long to discover that such an arrangement was quite impossible. In the first place, the certainty of being able to reverse the gas-engine was very questionable indeed, and as any failure to reverse meant almost certain disaster by the breaking of lock-gates, this idea had had to be dropped. An effort had then been made to find a clutch-mechanism which would allow of reversing by bevelled gearing. This also had had to be abandoned, because no clutch-maker could guarantee success with the large powers involved. Attention had then been directed to electric transmission, which at first sight appeared too expensive for the purpose. It was found that the electric method facilitated the introduction of other modifications, which were of the greatest possible value in this service, namely, the use of two or three units in making up the total power, thus enabling the reduced speed compulsory in the canals (about 4 miles per hour), to be obtained on a very economical arrangement by cutting out one or two units of a three-unit arrangement. It was also clear that while a single gas-engine would almost inevitably result in stoppage and breakdown from trivial causes, a three-unit arrangement provided an almost perfect safeguard against an entire breakdown of propelling-machinery. The arrangement illustrated on pp. 252 and 253 showed the stern of a Canadian lake-steamer from Messrs. John Reid and Company's designs, which illustrated his meaning very clearly. This method of propulsion had very much interested shipowners in both the United States and Canada, and it was confidently anticipated that the first vessel with this arrangement would be built shortly. Further, there was every possibility that, owing to the low price of

Mr. Reid. crude oil on the North American continent, a great development in propulsion by crude-oil engines of the Diesel or other type, with electrical means of transmission, might be looked for. An enormous barge-traffic might be carried on on the rivers and canals of America, and on such rivers as the Mississippi, by means of the very light and efficient machinery which this electric propulsion enabled to be brought into use. It seemed certain that, as far as inland navigation was concerned, a revolution was impending, towards which the Author's inventions would have been highly influential.

Mr. Russell. Mr. H. S. RUSSELL observed that the Author particularly applied a new system of propulsion by electric motors for use in connection with steam-turbines and internal-combustion engines. The problem was, however, not the same with the two types of engine, and Mr. Russell wished to deal with the subject more from the point of view of the internal-combustion engine, and particularly the Diesel oil-engine. He thought all authorities were agreed as to the great economy which could be effected by the use of internal-combustion engines for marine propulsion if a satisfactory arrangement could be produced on a sufficient scale. Not only would there be a large economy in fuel, but there would be also a great saving in labour, especially with Diesel engines. The Author seemed to have made out a very good case for his particular arrangement in association with steam-turbines, because their economical speed was greatly in excess of the most favourable speed for the propellers. This, however, was not the case with internal-combustion engines. At present all internal-combustion engines were of the reciprocating type and ran at speeds about the same as those of reciprocating marine engines. They could therefore be coupled direct to the propeller-shaft without loss of efficiency, and without the use of electric motors. The questions of reversing and speed-variation, however, entered largely into the problem of marine propulsion. Diesel and other types of oil- and gas-engines had been fitted in small vessels of moderate powers, and had either been made reversible or had been coupled to reversing propellers or reversing clutch-gears. Probably the relatively small size of internal-combustion engines as compared with steam-engines had prevented the application of such devices to larger vessels. As far as Diesel engines were concerned, larger sizes were now available, and engines giving about 150 HP. per cylinder had been made in England. With regard to speed-variation, a number of Diesel engines had been fitted in small vessels in which it had been found practicable to reduce the speed of the propeller-shaft to at least half the maximum speed, the engine remaining direct-coupled to the propeller—that was, without using the agency

of slipping clutches or equivalent devices. Thus it could be said Mr. Russell. that internal-combustion engines did lend themselves in a certain degree to speed-variation. In vessels propelled by steam-turbines, owing to the non-reversibility of the turbines, special turbines were provided for going astern. The power of the "astern" turbines provided rarely exceeded 40 per cent. of the full power of the "ahead" turbines, and this in association with propellers of comparatively small diameter. The behaviour of such turbine vessels had been under strict supervision and prominent notice, and in all cases the manœuvring of the ship had been considered satisfactory. If in turbine vessels astern power equivalent to 40 per cent. of the ahead power was considered adequate, there was no reason to supply more astern power to any vessel, and a system had been devised¹ which, whilst utilizing the advantages of electric propulsion within certain limits, offered special advantages worthy of consideration. The scheme was the following:—The engine-shaft was connected with the propeller-shaft by means of a combined friction and positive clutch. On the crank-shaft of the engine was fixed a dynamo capable of developing one-fifth of the power of the engine at half the maximum engine-speed. On the propeller-shaft was a reversible variable-speed motor capable of absorbing the full power of the dynamo at its speed. When running at full speed ahead, or at any speed ahead above half-speed, the engine and propeller-shafts remained connected. Losses in transmission were thus avoided, and by means of engine-control alone the necessary speed-variation could be obtained between these limits. When it was desired to propel the ship at less than half-speed, or to manœuvre the vessel ahead or astern, the clutch between the engine and propeller-shafts was disconnected, the engine drove the dynamo at one-half the maximum engine-speed, and supplied current to the reversible and variable speed-motor secured to the propeller-shaft. On emergency, such as to avoid collision, etc., it was possible while operating the propeller electrically, to increase the engine-speed to its maximum. The dynamo and motor were for the time overloaded, but were capable of withstanding this overload for a reasonable period. The advantages of this system were that the weight, space, and cost of the electric portion of the installation were reduced to a minimum, while losses in transmission which were inseparable from a purely electric transmission were avoided at all speeds above half-speed ahead. The astern power provided would, it was considered, meet all requirements. It should also be borne in mind, in regard

¹ British Patent No. 6126 of 1909.

Mr. Russell. to speed-control, that in ordinary circumstances there was no advantage in being able to reduce the speed of the propeller below the limit imposed by satisfactory working of the rudder, that was, below the amount required to keep steerage-way on the vessel. If the view expressed in the foregoing, namely, that it was not necessary to install in any vessel sufficient power to enable her to go full speed astern, were accepted, it reduced the electrical difficulties in installing motors of large power.

Mr. Sayers. Mr. W. BROOKS SAYERS remarked that the Author said very little about the brake which was required to stop the spinner and hold it at rest against the reaction torque of the rotor; as he did not mention the working of the brake when describing the various operations in controlling or altering speed, it must be presumed that he intended it to be automatically controlled. This brake would have to be a powerful one, capable of working equally well with either direction of rotation of the spinner, and its design would probably be a critical matter. Mr. Sayers thought it doubtful whether the spaces shown at G G (Fig. 1, Plate 5) as provision for the brake were sufficient. It occurred to him that the brake could be dispensed with in manœuvring operations, if not indeed altogether, by a simple expedient, which, however, he did not feel at liberty to describe here. By the same expedient the propeller of a ship driven by means of an induction motor could be held stationary or practically so against the torque produced by the ship's motion through the water, thus effectively "braking" the ship. This would probably be more effective in reducing speed or stopping the vessel than reversing the propeller, besides which no power would be required. No additional plant would be required by Mr. Sayers's proposal. Another point was that, as the Author said, the power required at half speed was perhaps only one-fifth of that required at full speed, yet the higher frequency was required at the higher power; and again, the frequency of the generator was the same as, or a multiple of, the speed of revolution of the generator, and the speed of revolution of the generator was again almost a fixture for highest efficiency, no matter what the driving-power might be; so that it would appear that the problem of accommodating the various factors to one another so as to secure the object aimed at, namely, facile control with high efficiency, was not too simple. How vastly superior a continuous-current system would be, if the commutation problem could after all be successfully solved!

Mr. Wingfield. Mr. C. HUMPHREY WINGFIELD remarked that the Author was on his own ground when he spoke about electrical matters. If Mr. Wingfield understood him correctly (pp. 240 and 241) the motor and generator followed each other as definitely as if they were geared together.

If so, this had both a bad and a good result: (1) if the propeller met with a suddenly increased resistance, the inertia of the generator's motor would carry it on and (the ratio of speed being such that it was more difficult for the propeller to affect the generator than for the generator to affect the propeller) a severe strain might result to the propeller-shaft unless it were abnormally large. (2) For the same reason a reduction in the resistance at the propeller would not greatly affect the generator, and racing would be less likely to occur. He did not quite understand the distinction between the Author's view of the two cases on pp. 242 and 244. In the first case he objected to independent windings because there must be idle material and consequent loss of efficiency. In the second instance he approved of two or more independent windings. Was Mr. Wingfield right in thinking that while all the windings and all the motors were to be at work in the second case at full power, only one would be in use in the first case? That would of course be unwise. Was there a misprint at the end of the second paragraph on p. 244? If 130, 99 and 66 revolutions were used they would be in a definite series (4, 3 and 2), which was not the case as printed here and on p. 250. The "bulky steam connections between the elements of the turbine" referred to on p. 245 were, he believed, peculiar to one type of turbine which had to be made so long that room could not be found for it when mounted on a single shaft on board ship. It was therefore cut into two or more lengths, each placed on a separate shaft, which had to be connected by the pipes to which the Author took exception. There were other types of turbine obtainable, however, which were so short that each shaft carried a complete turbine, not an "element" of a turbine.¹ Was it so certain (p. 249) that three propellers of small size were less liable to cavitation than a single large propeller? Of course, as the liability to cavitate might be measured by the thrust per square inch of blade-area, other things being equal, this would be correct if more blade-area could be secured in the case of the three propellers. It would be fairer to compare the three fast propellers with two slower ones, as single propellers were not in such favour as twin-screws. The reason for adopting three small propellers was not because at equal blade-tip speed they were less liable to cavitate, but in order to keep the blade-tip speed so low, even at high speeds of revolution, that cavitation was not serious. He was afraid the coal-bunkers,

¹ In such an arrangement each turbine is complete in itself and works independently—a condition which the Author rightly considers a desideratum (p. 254).
—C. H. W.

Mr. Wingfield. if placed so high as shown in *Figs. 5*, would necessitate much ballast when the ship was in light trim, in order to secure stability. He did not quite follow the calculation in the fourth paragraph on p. 253. How was the 10 per cent. increase of propeller-efficiency arrived at? There was no inherent property of a propeller which would indicate any better efficiency at 140 than at 380 revolutions, if both propellers were designed for the conditions. As the article in *Engineering* referred to in the footnote on p. 253 did not give the trial-trip results without superheat, perhaps the Author could give a reference to them. He presumed the figures given had been obtained from the same turbine. Referring to the statements at the top of p. 255, did the Author mean that if a turbine steamer could only just steam at 18 knots in calm weather, it would also do so against a head wind? If so, Mr. Wingfield was unable to agree. With these high-speed propellers there was great difficulty in keeping the thrust per square inch so low as not to cavitate, and any extra resistance induced serious cavitation. Mr. Wingfield believed with the Author that an electrical connection with the steam-turbine was a necessity of the future. Whether the ingenious arrangement in the Paper represented the ultimate method, time must show.

The Author. The AUTHOR, in reply to the Correspondence, observed that Mr. Hart likened the interference of the various motors, in the operation of the spinner motor for the graduation of speed, to the introduction of resistance into an electrical circuit. If Mr. Hart would look into the matter, he would find that this was not so; the very object of the arrangement was to provide that the motors when at work should be working without loss of energy due to the change of speed. It was only in retarding that the developed force was employed in a negative form, and when this retarding effect was occurring the analogy was not to an electrical circuit with a resistance in it but to a mechanical circuit in which power was absorbed by a brake and this power was returned into the working-circuit. Such an arrangement, of course, was entirely imaginary unless it were assumed that the heat from the brake was used for raising steam to drive the engine. The loss under the retarding conditions was slightly greater than it would be by the direct application of a motor, but very much less than if a resistance were introduced into the circuit. The Author did not advocate the general employment of electric motors for propelling ships. This might be possible, but the present position was that only in those cases where the variations in speed and power were considerable was it proposed to apply the system. Mr. Hart, in speaking of the comparison with direct steam-turbine driving, appeared to miss the point

that the coefficient of efficiency on small turbines as compared with The Author, large turbines was very much more favourable than the coefficient of efficiency of a large turbine at full load compared with the same turbine at a smaller load. The differences were such as to leave plenty of room for the electrical losses and still leave a very substantial advantage. Alternative methods suggested by Mr. Hart of carrying out the electrical transmission were associated with continuous current. The argument of the Author's proposal was that continuous current was admittedly inapplicable for very large powers.

With regard to the point of exact speed-adjustment raised by Rear-Admiral Sir Henry Jackson, it should be clearly understood that the three-speed arrangement proposed by the Author had nothing whatever to do with exact speed-adjustment; that this speed-adjustment was carried out precisely as at present by the handling of the prime mover; and that what was attained by the Author's proposals was economy approaching to the economy of full load at two speeds below the full-load speed. This being clearly understood, Sir Henry Jackson would doubtless see that no new complication, difficulty, or reduction of range of speed-adjustment was introduced by the new proposals, and that the ship might be manœuvred precisely as at present. At a critical time, for example, in a running fight where economy ceased to be of any importance whatever, the electrical speed-change would not be brought into operation at all, the machinery would operate under the full-speed connections, which would remain until attention could again be turned to saving the nation's money by reducing the consumption of coal. The difficulty suggested by Sir Henry in respect of the enclosing of the motors in watertight tanks was one which did not offer any material obstacle; in fact, the enclosing of the machine to the necessary extent rather facilitated the artificial ventilation which would in any case be desired.

Rear-Admiral Melville's communication was of special interest, but it had to do with the Author's argument only at one point. Admiral Melville's proposals could not deal with the problem of adding to or reducing the power-units in use according to the speed of the ship, and this in the opinion of the Author was the vital part of his proposals, which, as pointed out elsewhere, would probably not find any extended application if the purpose which had to be served was speed-reduction alone. The President had put the matter very succinctly by saying that it appeared that the Author's proposals were to put a change-speed gear into a ship, so that the economy could be regulated as in a motor-car.

The Author. Mr. Henry Napier used the expression "dead load" in a sense different from that intended by the Author. The Author's contention was that the propeller, being in a fluid in which it was free to move, was not acting under the same conditions as other mechanical arrangements in which there might be a dead block of the mechanism. The only case in which there was any material load at starting was when the propeller was reversed while the ship was still going ahead; even in this case the starting load against the motor was comparatively small.

The weight of the machinery in example No. 1, to which Mr. Robert Napier called attention, had been dealt with in the Discussion in the reply to Sir William White. The steamer referred to was an existing vessel. Mr. Napier's comparison of the costs of the steam and oil installations under conditions other than those assumed by the Author naturally changed the result. This meant that on the Clyde and at home-port prices the argument for the use of an oil installation would not stand. This was at once admitted. The oil installation would only be used in cases where the relative cost of oil and coal warranted its use. The same applied to the use of anthracite coal and slack. The use of either class of fuel was a question of relative price, and again, on the Clyde an anthracite installation showed but little advantage over a bituminous-coal arrangement with steam-power; but in other parts of the world, where the relative cost of fuel was different, the economical result was also different. The turbine-ship referred to in the example No. 3 was an existing ship.

Mr. John Reid's remarks were peculiarly interesting and encouraging and indicated that the Author's proposals put another facility into the hands of marine engineers for dealing with special problems.

With regard to Mr. Russell's communication, much useful work had been done by the Diesel Company, and in cases where the problem could be solved by the direct application of internal-combustion engines to the propeller there was no object in introducing an electric transmission. The use of clutches and alternative mechanical arrangements at large powers on board ship did not, however, appear to the Author to offer a satisfactory solution, and it was for that reason that these proposals had been brought forward.

The Author did not agree with Mr. Sayers that a continuous-current system would be superior to an alternating-current system, because the alternating-current apparatus was simpler, lighter, and more easily maintained in effective working-condition. It was not

necessary to provide the kind of electric control to which the continuous-current system lent itself advantageously as compared with the alternating-current. The fine gradations of change of speed could be accomplished with ease in the same way as they were accomplished at present on board ship, and the electric transmission was more easily accomplished by alternating current than by continuous current. The Author.

In reply to Mr. Wingfield, the speeds of motor and generator followed each other, but not as if the two were rigidly geared together. There was a slip in the electromagnetic system and no risk of undue strains from the cause suggested. The objection to ordinary multiple windings was not due to their independence, but because of the presence of unused windings at full power. In the Author's proposals the independent windings were all in use at full power. The numbers 130, 89, 66, were correct; they did not follow an exact series, nor need they do so in the multiple motor. The explanation of this would lead to a long dissertation, not of public interest. The discrepancy from regularity was due partly to slips and partly to making adjustments in the generator-speeds to suit convenience in winding-arrangements.