Discussion.

The PRESIDENT moved that the thanks of The Institution be The President accorded to the Author for a very suggestive and interesting Paper, which appeared to be a bold attempt to describe a change-speed gear for large steamers.

The AUTHOR thought it might appear from the diagrams that The Author. prominence was given to vessels of a smaller size than those with which a large part of the Paper was concerned. The reason for that was, that the design of an electrical equipment for a ship of 20,000 HP. must of necessity be preceded by some experience in driving smaller vessels. Taking that as a reasonable attitude towards the matter, attention had been devoted specially to the more immediate future. The smaller vessel did not lend itself to dealing with the problem in the same way as the larger vessel did; the economies were not realizable quite to the same extent; but notwithstanding that, it would be seen from the diagrams and descriptions that the project was possible and economical even on a comparatively small scale. Fig. 3, Plate 5, represented roughly the block outline of a turbo-electric equipment, as compared with the ordinary reciprocating-engine equipment in Fig. 4. Notwithstanding the disadvantage of the small size, that ship showed an economy in coal-consumption which just about warranted the extra expenditure involved. On the other hand, the use of the arrangement rendered feasible the use of internal-combustion engines, which lent themselves to the attainment of still higher economy, and therefore it seemed probable that the first experience would be gained with the internal-combustion engine. The problem of applying electric propulsion to large ships had been very seriously discussed both in England and in America, and very interesting suggestions had been made. But those who attempted to solve the problem were faced with the stern fact that the best full-power economy of the marine steam-turbine was alleged, on good authority, to be, under existing conditions, only 5 per cent. less than that of land turbines under the same conditions of steam and vacuum. If that was so, and it seemed that there was no escaping the fact, there was no room for the electrical engineer on such a ship at full power. But, as shown by the Paper, the claim of the electrician still remained, because he could effect economy by dealing more economically with the speeds at less than full power. It was evident that there was rather a

The Author. narrow case, and he quite realized that those who were engaged in the work would have to win their spurs on the smaller scale before they attempted to deal with ships of 20,000 HP. He desired to acknowledge his indebtedness to Mr. John Reid, of Glasgow and Montreal, for particulars and designs of the ships illustrated in *Figs. 5 and 6*, and to Mr. Henry Burrell, of Glasgow, for those illustrated in Plate 5.

Mr. Rich. Mr. T. RICH observed in the Paper the statement that it was difficult to have a multiple-speed motor without a good deal of complication, but in the locomotives which were running through the Simplon tunnel there were two squirrel-cage motors of 850 HP. with four speeds, and it seemed that the extra complication required by the use of the spinner motor shown by the Author was hardly compensated for by the difference in economy. There was another question: he believed that in the last few years it had been found possible to make three-phase commutator motors of much the same type as the single-phase motor that was giving such good results on electric railways. Not much had been done so far in that direction, but he thought it was quite probable that it would be possible to get any speed up to full speed with a three-phase commutator motor.

Mr. Swinton. Mr. A. A. CAMPBELL SWINTON, while much admiring the ingenuity of the Author's methods, could not help wondering whether the same results, and perhaps more efficient results, could not be obtained by ordinary mechanical gearing. The Author at present contemplated only comparatively small powers, and it was well known that with mechanical gearing very efficient results could be obtained for small powers. He had not been able to discover in the Paper exactly what efficiency of transmission the Author expected to obtain, but he thought it was something of the order of 85 per cent. or thereabouts; whereas he believed that with purely mechanical transmissions of 1,000 or 2,000 HP. it was possible to get 98 to 99 per cent. efficiency. Of course, the same amount of attention had not been devoted to mechanical gear-changes on a very large scale as had been devoted to arriving at the same results by means of electric generators and electric motors—due possibly to the reason that since mechanical methods had become so much improved there had been no particular object in devoting attention to that problem. He thought, however, there could be no doubt that with the modern appliances for the proper shaping of teeth and so on, mechanical transmission-gears could now be made with very much greater accuracy than had ever been previously thought possible, and it was likely that results could be obtained which in the past were not

possible. The Author stated that gearing had not been found necessary on board ship, but Mr. Swinton thought Sir William White would bear him out when he said that that statement was inaccurate. At present the problem was to reduce the speed of the engine to suit the screw-propeller: in older days the difficulty was, he believed, just the contrary, namely, to make the engine run fast enough for the propeller, and in order to meet this they had to gear up.

Mr. W. P. DURTNALL stated that he had gone somewhat closely into the important problem of marine propulsion by means of electric motors, as well as the propulsion of road-vehicles. He considered that the problem was not exactly as the Author had stated it. In road-vehicle work the torque-curves were diametrically opposite to those required for marine purposes. The investigation which he had made on road-vehicles had been directed to produce the maximum of torque at the lowest speed of revolution of the motor, and that had led to an investigation of the propeller-problem and of the design of electric equipment on the system to which he was most accustomed, in order that the highest torque might be produced at the highest speed of revolution. The Author had brought forward a very interesting and ingenious system, and great credit was due to him for the investigation he had made: evidently very few engineers in England had gone into the subject as deeply. Mr. Durntall would like to know the weight of the Author's generators and motors for the shaft-power developed in such large sizes as 10,000 and 20,000 HP., and the speeds of revolution which he recognized for that particular design. There was another interesting matter closely allied to the method described. Tests of various steamships had been made public quite recently, and some very low figures with regard to steam-consumption per shaft horse-power had been mentioned. It had been stated recently that the steam-consumption, per shaft horse-power, of a very large battleship or cruiser was as low as 12.03 lbs. per hour; but the most interesting point, to Mr. Durntall at least, was that the propulsive efficiency, or thrust produced for that power on the shaft, was omitted from the statement. The speed of revolution and the consequent propulsive efficiency had a good deal to do with the amount of power necessary to produce a given thrust. In a certain vessel using 41,000 shaft HP. the speed was, he believed, 300 revolutions per minute. The propulsive efficiency at that speed could not be much more than, if it were even so much as, 40 per cent. of the shaft horse-power. By reducing the revolutions to 200 per minute, by some such method as the Author suggested, or by one of the other electric systems that

Mr. Durnall. had been put forward, the propulsive efficiency might possibly be raised to 48 per cent., thus reducing the shaft horse-power to about 34,000 instead of 41,000 HP. for the same thrust. Then at least 7,000 HP. could be saved in boilers for that reason alone, quite apart from the interesting fact that the steam-turbine might be run at four or five times the speed of revolution of the propeller, and the fact that superheated steam might be used with safety in such turbines. He did not quite agree with the Author in his last statement about the weight and cost. In his own investigations during the last 12 months in regard to practical applications he had found that in vessels of up to 1,000 HP. the weight and cost were approximately the same with reciprocating engines at 80 revolutions per minute. When it came to larger powers—say, 5,000 up to 10,000 HP., which was the largest he had gone into—the weight in pounds per shaft horse-power developed and the consequent cost was less: the margin was not large, but it was a fact that the cost was less. When the Author actually began to build equipments on his system he would probably be able to show some improvements on his present methods. Mr. Durnall thought it would not be long before it would be realized that with superheated steam used in high-speed, light-weight, and consequently efficient turbines, electric power-transmission would be of value for propelling large ships. He believed that such low coal-consumption per ton of displacement per mile at various vessel-speeds would be recorded, that no shipping-firm would be able to exist without electric transmission on the lines indicated.

Sir William
White.

Sir WILLIAM WHITE, K.C.B., Past-President, asked whether the figures given by Mr. Durnall were only for designs and estimates.

Mr. Durnall.
Sir William
White.

Mr. DURNALL said they were.

Sir WILLIAM WHITE observed that the problem under discussion was by no means a new one; it was only a new phase of a very old chapter in engineering design. As Mr. Swinton had said, when the first screw-propelled ships were built, the problem was to gear up from the engine to the propeller. It was quite 25 years since he himself took up the converse problem, namely, to gear down, because experience was then being obtained with very fast-running reciprocating engines in torpedo-vessels. In the year 1877, in the discussion at The Institution of a Paper by Mr. Alfred Holt, he ventured to say that such data as were being obtained from torpedo-boats and torpedo-vessels must largely affect the future design of the machinery of much larger ships,¹ and in saying that of course he was only speaking of what he himself was then con-

¹ Minutes of Proceedings Inst. C.E., vol. li, p. 125.

templating as possible. In conjunction with the late Mr. Alexander Kirk, M. Inst. C.E., well known as one of the earliest introducers of triple-expansion engines in marine propulsion, the problem was worked out. In that case it naturally took the form of mechanical gearing—gearing down from quick-running engines to a slower-moving propeller-shaft. Mr. Kirk was at that time prepared to guarantee, and take the responsibility for, the application of that system to engines of considerable power, but the idea was not practically applied. An increase was made in the rate of revolution and in the piston-speed of reciprocating-engines of large size, which increase went to very considerable lengths; and so the space required for the propelling-apparatus was much reduced. In these latter days the problem was coming much to the front, because practically the limit of what could be done with the reciprocating engine had been reached, and large experience was being gained with the steam-turbine in marine propulsion. It was quite natural, looking at land practice with steam-turbines and at the arrangements which had so far been made in turbine-propelled steamships, that engineers should begin to ask whether it was not possible to have a very quick-running turbine of comparatively small size and high efficiency geared down to a propeller-shaft which moved at a reasonable rate in order to secure good propeller-efficiency. He wished at once to express his entire dissent from Mr. Durnall's statement with regard to the necessary inefficiency of a quick-running propeller. The problem really was, how to design a propeller so as to be efficient at a high rate of revolution. The assumption often made was that it was impossible to carry that programme into effect. Mr. Durnall had given figures which anyone acquainted with the facts would know must apply to trials of large turbine-propelled cruisers of recent design. It so happened that the Engineer-in-Chief of the Navy, Admiral Oram, a Member of The Institution—who he had hoped would have been present that evening to speak for himself—had dealt with the problem a few evenings ago in a Presidential Address to another Institution. Admiral Oram said:

“As regards increased propeller efficiency”—

that was, with the gearing down—

“it must be remembered that the efficiency now obtained with the slower-running propeller has been the result of many years' experience. The early turbine propellers had low efficiencies; experience has enabled these to be increased, but they do not yet reach the figures obtained with the slower-running reciprocating engines. There is no doubt that as more experience with small fast-running propellers for such large powers as have only been recently introduced is obtained, the efficiency of the latter will be still further improved. In particular cases”—

Sir William White.

Sir William White. and one of those cases was that which Mr. Durtnall had mentioned—

“such as in the large cruisers of the ‘Invincible’ class, there has been no falling off in propeller efficiency of the faster-running screws from efficiencies obtained in the slow revolution screws of older cruisers.”¹

Therefore, he must ask the meeting not to accept Mr. Durtnall's statement of 10 per cent. greater efficiency, which was an estimate and was contradicted by the direct statement of the Engineer-in-Chief of the Navy, who was in possession of all the information as to the effective horse-power, the shaft horse-power, and all the conditions necessary to form an accurate opinion. He was sure Mr. Durtnall would be prepared to admit that Admiral Oram was better placed than himself to form an opinion on the subject. But that was not all. He himself had ventured to say at least 4 or 5 years ago exactly what Admiral Oram was saying now. It was so obvious. Of course, very much had to be learned about the screw-propeller; screw-propellers had been at work for 50 or 60 years, but it was simply a fact that the problem had not yet been mastered. Discoveries were continually being made. The variables affecting the efficiency were so numerous that it was almost impossible to lay down a general law, and it was only by experiment and analysis that it had been possible to make the considerable advances already made. So in regard to the quick-running propeller; the propeller in association with the turbine must run quickly as compared with the propeller associated with the reciprocating engine and large powers. A little time had to be allowed to gain experience in order that efficiency might be advanced. The conclusion he had endeavoured to state, which Admiral Oram endorsed, was also endorsed by some of the most able investigators on the Continent. Only a few days ago he had been reading the result of investigations made by a German, Dr. Flamm, who absolutely accepted the same conclusion. The great series of experiments made on a model launch, electrically propelled, in connection with deciding upon the propeller-arrangements for the great Cunard steamships, had yielded an immense amount of information, and results had been obtained which contradicted the anticipations of most of the people concerned, with regard to the efficiency of propellers of various forms, in various positions, and running at various rates. The problem, therefore, in his judgment, must not be stated in the bald terms—which he thought the Author himself had rather accepted—that a

¹ Journal of the Junior Institution of Engineers, vol. xx, p. 127.

quick-running propeller must of necessity be an inefficient propeller. Sir William White. He granted that in many cases it had been so, but Admiral Oram gave his assurance that in a particular case it was not so. It need not be so always, and in that direction further investigation must proceed. Where the best solution could be found, no one could quite foresee; but he thought every engineer would admit that if it were possible to avoid the conversion of power and the introduction of intermediate drives, it would be a very good thing; and that also was worthy of investigation. He was sure it would be understood that in saying that he was not in the least intending to depreciate the excellent work the Author had done. He was all for inquiry, believing that the more rival systems were worked at, and the more openness of mind there was displayed in dealing with such recondite problems, the better it must be for engineering in general. Therefore, he welcomed the work done by the Author and by Mr. Durnall, and other work of that kind, which was going on in many quarters. Many of the members must have seen recently in the engineering papers what he himself had been cognizant of for many months past, namely, that in Germany Dr. Föttinger of the Vulcan Company in Stettin had devised a hydraulic arrangement for gearing down: and also a great deal had been said in the papers lately about the Melville-Macalpine system of gearing. Mr. Swinton could mention another system of gearing down with which Mr. Parsons had been busy for a long time past. It was an open secret that the Parsons Company owned a merchant vessel which had been worked with the old type of machinery with a view to investigate scientifically every detail of her steaming capability: into that boat there was now being put a turbine with gearing, and a similar record of facts would be obtained there. Each investigator was trying to discover, in his own way, how the best practical results could be obtained, and Sir William White trusted that when those results were obtained the engineering profession might have them placed at its disposal, so that shipowners, shipbuilders, and marine engineers might know in which direction it was best to work. He did not believe that any solution would be found which would be of universal application. The problem admitted of many solutions, and the best in one particular set of conditions might not fit other conditions. The wise designer was not an advocate of cast-iron methods or stereotyped processes.

Coming to the Paper a little more in detail, he thought the examples which the Author had worked out with the utmost care admitted of some criticism. Turning, for instance, to the bottom of p. 246, the Author gave an ordinary single-screw equipment with

Sir William
White.

reciprocating steam-engines in a vessel which, he believed, would give about 840 shaft HP., which roughly he supposed would be 900 I.HP. [The AUTHOR assented.] The weight given was 320 tons for 900 I.HP. Knowing a little about tramp steamers, he did not think there was any necessity to have 320 tons of weight to get 900 HP. Everything turned upon comparison. If that, which he presumed was taken from some actual ship, turned out to be, as he believed, rather an extreme case for a reciprocating engine as used in tramp steamers of good and recent type, then against any reduction that might be made in that weight of 320 tons had to be placed the possibility—which a somewhat extensive acquaintance with electrical appliances led him to look upon as a strong probability—that the 182 tons estimated weight in the alternative arrangement would be increased before the ship was put into actual service. Certainly his experience of electrical appliances was that they had an extraordinary habit of growing in weight. For many years he was in responsible charge of the electrical appliances of the Navy and he was a warm advocate of their extended use, but he was bound to say that on the question of weight and cost they generally went much beyond original estimates. If that should be the case in the present instance then that 182 tons would be increased; and he thought any marine engineer accustomed to build engines would be able to give a thoroughly dependable engine of 900 HP. for less than 320 tons, when the figures given in the Paper for possible economies in weight would hardly hold. Another factor was that oil-fuel was used in the first case, and he saw no reason why it should not be used in the second. He took it that the weight of fuel given for 15 days was coal. [The AUTHOR replied in the affirmative.] Everybody knew that by using oil-fuel an economy could be obtained of something like 30 per cent. as compared with coal, so that instead of 250 tons of fuel only 175 tons would be required. Those were a few general illustrations of the necessity for careful scrutiny of figures before acceptance. If a shipowner reading the Paper were to adopt the Author's method, Sir William White thought he would not realize nearly so large a saving, by the time he had got his ship at work, as was shown on p. 246. There were questions in connection with the electrical features of the motors to which he did not intend to refer, but there were other questions relating to the adoption of electrical apparatus on board ship which he thought were quite special to shipboard work; and he might say without any suggestion of unfairness that it would be unwise to adopt on board ship certain electrical apparatus which might be used quite safely on land. The Author, he thought, would agree with that. He was

glad to see that the Author took a more modest voltage in his apparatus than some electrical engineers had been disposed to take. There could be no doubt that, in applying to the main propelling-machinery of the vessel electrical apparatus, it would be necessary to provide a substantial margin of power, at least at the beginning. The Author made a great deal, and very justly, of the possibility of subdivision of the power between the motors, so that they could be thrown in and out according to the requirements of the service. That was a perfectly fair point. On the other hand, if that had to be done under a guarantee of steaming across the Atlantic he would be disposed to have some motors in reserve, and if that were so, then there would be a corresponding increase of weight and space required. He could not help thinking that what the Author said with regard to beginning at the smaller end was very wise. He hoped that the Author would have the opportunity of putting his theories into practice and of making experiments on some actual ship before long. When he did that, and if that ship went to sea, he thought the Author might be disposed to modify considerably his remarks about the extreme variations likely to occur in the load-factor for a ship when at sea. It was perfectly true, of course, that a ship had to slow down in very bad weather, but taking the ordinary conditions—and the larger the ship the more true the observation was—if indicator-diagrams were taken there would not be found to be ordinarily those very great variations which the Author assumed to exist; at all events, speaking of his own latest experience on board the “Mauretania,” when he came home in October from New York, the weather was bad—in fact wild weather—but the ship did $25\frac{1}{2}$ knots all the time, with a fairly constant rate of revolution. In the main, unless the weather was exceedingly bad, or the navigation had to be modified in consequence of other considerations, he did not think the load-factor did vary in a merchant ship in the way the Author suggested. But with warships the conditions were absolutely different. A warship capable of high speed had often to proceed for long periods at very low speeds, and economy in fuel-consumption at those low speeds was of very great importance. In cases of that nature the claims which the Author was disposed to make in favour of electrical apparatus were better founded than they were in some other respects. He hoped it would be understood that in raising those points he had no idea whatever of lessening the merit of the work which the Author had done.

The Author, in reply, remarked that he had endeavoured to emphasize the argument in favour of power-factor rather than of gearing simply because, as Sir William White had very properly

Sir William
White.

The Author.

The Author. said, it would be well to avoid in every case the introduction of unnecessary transformations of energy. One had only to deal with the matter really from the strictly mechanical point of view to find that claims for improved propeller-efficiency, or even improved turbine-efficiency, which had been made in the early stages of the suggestion for introducing electricity for the propulsion of ships could not be realized in practice. The size of the propeller was fixed by other conditions than the means of propulsion. The speed of the turbine was on the whole favourable in such cases as Sir William White had referred to, but the Author thought it was not quite fair to use the "Mauretania" as an example for the study of load-factor. The "Mauretania" was the ship about which he had personally expressed the opinion in the Paper—without naming the vessel—that there was no room for electrical propulsion on such a ship at all. He did not think there was any room for it on the torpedo-boat-destroyer or on many other high-speed vessels. But he thought Sir William White would be the first to admit that a cargo-boat doing general tramp service had to run at speeds varying from 9 to 13 knots for months at a time on one trade; at one time a 9-knot speed was most economical for her purpose, and at another time 13 knots.

Sir William
White.

Sir WILLIAM WHITE observed that he did not quite agree with being put in the position of admitting that as representing ordinary practice.

The Author.

The AUTHOR replied that he would put his example in a more concrete form. There was one firm in the north, Messrs. Burrell and Co., who had twenty-six tramp steamers, all alike, which were engaged in trading all over the world; and he was informed by that firm that the ships on some trades ran at as low as 9 knots, while in other trades they ran as fast as they could, which might be about 11 knots or slightly less, the speed attained by these vessels on trial trip or on very light draught being $12\frac{3}{4}$ knots. He argued that the speed-variation did not require to be so great as that to enable one to show economy by using electric transmission with the steam-turbine and the possibility of speed-change. That was the main point he wished to make in replying to the discussion. For adjustment of speed-ratio alone he was satisfied, after a careful study of the matter from a practical point of view, that probably there would be no case for electrical transmission. In the majority of instances the economy would be found in adapting the power to the load rather than in adapting the power to a lower speed of propeller. The use of the gas-engine without the intervention of electric motors, on the other hand, was not a proximate possibility. He thought one could not contemplate with serenity going to sea in a single-propeller ship driven by a single gas-engine; it would

not be wise to do it. On the other hand, to have three gas-engines and one propeller was a proposition of an altogether different kind. One gas-engine could be shut down and the other two used.

Sir WILLIAM WHITE pointed out that there were twelve cylinders in a submarine.

The Author.
Sir William White.

The AUTHOR said submarines were very interesting examples of electric propulsion and of internal-combustion-engine propulsion, but the limit of size was already within sight. In the example he had given there were three engines, each of about the same power, and he thought anybody would agree that that was a more flexible arrangement than could be conceivably applied to direct driving of the propeller. He had no doubt Sir William White's criticism of the first example in the Paper was perfectly just, and he admitted that one must pit oneself against the best that could be done in practice. In defence of the example, however, he might say that it referred to an actual ship in service, and the reason for the excessive weight of the machinery in that ship was that she had to run at a very low speed and carry a big cargo. He did not think that the reciprocating-engine equipment was unduly heavy for the conditions, but the conditions were favourable to a very low propeller-speed and he had chosen the example for that reason. The propeller-speed was only about 70 revolutions per minute, and the equipment was very heavy, both electrically and otherwise. With regard to the weight of the electric plant, there was room for a possibility of an increase in the weight in the fact that one who had given attention to electric propulsion for only 2 years did not know all about it. There were a great many little things in building a ship and putting machinery into her about which he knew nothing at all. The propositions in the diagrams were all actual propositions, and he had good hopes that in the course of another year he would be able to give The Institution the results of at least two of them. In going into the problem with the shipowner he had had his eyes opened in the direction Sir William White had indicated, since the Paper was written. At the same time it was perfectly clear that there was a large margin of additional carrying-capacity to be obtained on the ship shown in *Figs. 5* (p. 252) as compared with the one in *Figs. 6* (p. 253); the weight was materially less, and the fuel-consumption was much less. With regard to the comparison between the weights of fuel, certainly if oil-fuel were used on the steamship the fuel-weight would be decreased, but the cost would be enormously increased. Therefore he thought the comparison was a legitimate one as laying down what was found to be the best way to do the work on present lines, and the suggestion he had made of an alterna-

The Author.

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