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† The Electrification of Ships.

BY CAPTAIN WM. P. DURTNALL, R.A.F. (Member),

READ AT

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Saturday, October 18, 1919, *at* 7.15 *p.m.*

CHAIRMAN: MR. A. BOYLE (Vice-President).

The CHAIRMAN: We are about to hear a paper which appropriately follows those which have been read on the History of the Steamship and the Development of the Internal Combustion Engine. The author read a paper bearing on the subject he proposes to deal with about eleven years ago, and to-night he will indicate the progress made since then. There are many lantern slides, I understand, to be shown to us, and as we must close at nine, the discussion will follow at our own premises, the date will be announced in the usual Notices which are printed in the monthly issues of our Transactions.

IN these days when almost every technically trained mind is turning from the anxious progress of our arms at sea, on land, and in the air, from the practical application of destructive engineering to the transfer of these arts to commerce, well balanced minds are well aware that on the work of progressive engineers will the welfare of Empires rest.

Early in the days of the late tremendous war between scientifically trained and practised nations it rapidly became evident that the days of physical prowess of hardy seamen and soldiers was over and had really become a glorious past history in the

† The absence of Capt. Durtnall has prevented the publication earlier; awaiting details and illustrations.

annals of the World, and that they had been replaced by mechanical science much more conspicuously.

Indeed, if one reads right down through the known history of the civilised world, the work of the engineer is always pre-eminent; even from the pre-Christian days of "Hero" and "Archimedes," whose work is even to-day to be seen in many directions of engineering science in some of the very greatest industries, in the form of the steam turbine, the force pump, the air compresser, and a large number of mechanical apparatus, they indeed represented the blessings of the future generations and the rock bottom foundations of the great engineering industries of to-day.

Great as was the significance of these early engineering inventions, comparatively speaking, very little was accomplished, chiefly owing to the want of tools for the proper manufacture of the apparatus, and passing through the centuries we come to the period of 1543, when the Spanish sea captain, Blasco de Garay, succeeded in giving motion to paddle-wheels by means of steam. Various attempts have been made to use the propulsive force of a jet of water, and in 1661 a patent was granted to Thomas Toogood and James Hayes for a method of propelling ships by forcing out water through the bottom of the vessel, probably one of the very earliest attempts at jet propulsion, of which we have heard so much recently, owing to the fact that both prime-movers and pumps are to-day very much more efficient than at the early period.

Feathering paddle-wheels were the subject of a patent in 1681 by Robert Hook, and much has been done in that line to increase the propulsive efficiency of this type of propeller, until it was put out of date by the application of the screw propeller with deeper immersion.

Screw propulsion was, however, practically introduced in the 19th century, about 1835, by a farmer, Francis P. Smith, of Hendon, Middlesex. In May, 1836, a model boat fitted with a wooden screw propeller was exhibited in operation on what is now known as the Welsh Harp Pond at Hendon, and was inspected by Sir John Barrow, Secretary to the Admiralty. The results were deemed so satisfactory that in the autumn of the same year a boat was built of six tons burden and fitted with engines of six horse-power, driving a wooden screw propeller consisting of two turns. On November 1st, 1836 she was exhibited in operation on the Paddington Canal and continued to ply there until September, 1837, without a great deal of notice, as of course often happens with all really great inventions.

In February of that year, however, she became conspicuous by reason of an accident which occurred, about half the length of the propeller being broken away, and to the surprise of all, the boat immediately quickened her speed, a higher thrust was produced for the same horse-power, at the same time indicating that the continued thread was really unnecessary, and as is to-day seen in practice the part thread screw is the more efficient of the two. The sea-going qualities of the vessel were then demonstrated with great success, but before the Admiralty would give a decision they insisted that the screw propeller should be tried on a vessel of at least 200 tons, as it was stated that although it apparently operated with satisfaction on a small boat, it would perhaps not be suitable for a large vessel.

Considerable losses took place between the engine and the propeller owing to the installation of mechanical gearing being used to gear the propeller up, as the steam engine in those days was not far enough advanced in speed for direct-coupling in the most efficient manner possible. Mr. Smith, however, formed a Company and built a further vessel named the *Archimedes*, of 237 tons, at a cost of £10,000, and this was fitted with a 80 horse-power engine, and designed for 4 to 5 knots, which speed was about doubled on the trials; the vessel was thoroughly tried at sea and around the coast, resulting in the Admiralty deciding to adopt the screw propeller in the Navy. Mr. Smith was afterwards joined by that famous engineer and inventor, Captain John Ericsson, who cleared out the inefficient gearing and directly coupled the engine to the propeller shaft, and increased the revolution speed of the engine suitable for the propeller, but who after a most heroic attempt to interest people in this country, failed to do so, and crossed to America, ultimately to become the engineering hero of the American Civil War, when it will be remembered his famous steam driven *Monitor* successfully contested the rights of the *Merrimac*, a fighting vessel which he built in 100 days in spite of all sorts of official expert opposition. A story of this great fight, and the tremendous engineering victory, and its effect on the navies of the world after it was over, is of great interest.

It should not be forgotten that every possible credit should be given to those early workers in mechanical marine transport who experienced great opposition from many quarters, they had not the advantages of our modern manufacturing machinery, they had to educate both shipbuilders and owners, who were not engineers but sailors, most of whom were opposed to new methods of propulsion, and demonstrated very little desire or ability to master the higher branches of either navigation or mechanical sea transport, they being quite satisfied with sails, and the tactics which had sufficed for Blake and Nelson, for

Van Tromp and De Ruyter were good enough for their then successors.

Captain Ericsson whilst in America carried out much interesting work in the development of sea transport, and one of the greatest wonders of marine engineering was found in 1853 in the form of his famous ship *Ericsson*; indeed this vessel formed the boldest attempt which was made at sea for many years, she was operated by means of what was then known as the calorific principle, in substitution of steam. She was 250 feet long, 40 feet beam and 31 feet deep, with a gross tonnage of 1,920, and a sea speed of 12 knots for a consumption of only six tons of coal per day.

This interesting vessel was practically propelled by a "hot air engine" and in my opinion Captain Ericsson was very near to the solution and discovery of the internal-combustion engine. I daresay there are people alive to-day who well remember the arrival of this strange but efficient vessel at Liverpool, being somewhat conspicuous by the absence of the usual funnels.

An interesting attempt to bring about improvements in the propulsion of ships was that which was carried out by the Admiralty many years ago on H.M.S. *Waterwitch*. She was an iron-plated gunboat, 162 feet long, 32 feet beam and nine feet nine inches draught, with a displacement of 1,062 tons. She was propelled by means of two water jets placed about mid-ships, either "ahead" or "astern," including "steering," these jets for some reason were placed near the surface, in which position it was hardly likely that the highest propulsive efficiency could possibly have been expected.*

The water supply was created by means of a large rotary pump 14 feet diameter, driven by means of a horizontal three cylinder vertical shaft engine, the cylinders being placed at 120 degrees angle, the suction being taken from an aperture let into the bottom of the vessel, no attempt apparently being made to utilise the bow pressure for suction head for the pump.

With an indicated horse-power of 750 she made a speed about nine knots. She was however considered inefficient and the experiments were dropped. In my opinion it would add considerably to the interest of the marine engineering profession if a further trial of hydraulic propulsion were made to-day. My views are that the efficiency development of both prime-movers, pumps, and hull design have gone further ahead than the developments of the screw propeller since the *Waterwitch* experiments were made, and possibly some rather startling results may await

* See Paper by Mr. J. R. Ruthven, No. XXI., Vol. II., September, 1890.

those who continue the work, especially bearing in mind the facilities which are available in the form of electrically operated high-speed rotary pumps, and the splendid control which can so easily be given to same. There is no question whatsover as to the military advantages which a successful experiment would bring about for such vessels as warships or submarines, the propelling machinery is not only well down below water line, but is also inside the vessel, and they are not so easily damaged by projectiles or torpedo under-water explosion.

The next great advance in the engineering development of marine transport was the creation of the *Great Eastern*, which was propelled by means of both screw and paddle-wheel propellers, with direct-coupled steam engines, and had five funnels. was 680 feet long, 82 feet beam and a loaded draught of 30 feet, the displacement was 27,000 tons, she had four decks and six masts, and being an auxiliary vessel she carried a sail area of 6,200 square feet.

Ample attention was given to safety by the provision of twelve transverse and two longitudinal bulk-heads the spaces being utilised as coal bunkers, the paddle-wheels were 56 feet diameter with float boards 13 feet long, and three feet wide, the screw propeller placed aft, had four blades, was 24 feet diameter, and with a pitch of 37 feet. There were in all five boiler rooms supplying steam at a pressure of 25 lbs. per square inch, the total indicated horse-power being about 8,000. She was, however, a vessel of dimensions much before her time, the thermal efficiency of the steam engine had not advanced quite far enough to warrant the displacement and commercial speed, and indeed signs are not wanting now that the size of steam propelled ships has again reached the limit of commercial application, unless a further increase of the thermo-dynamic propulsive efficiency accompanies the proposition of still larger and speedier ships.

The next big development was undoubtedly the building of the *Lusitania* and the *Mauretania*, and this was possible by the adoption of the steam turbine as prime-mover, and although the highest possible thermo-dynamic efficient was far from reached in those vessels, they undoubtedly went far to open up the problem of the big ship, together (at the time) with the most suitable method of propulsion for same. It is highly questionable concerning the wisdom of putting in the heavy cumbersome cylindrical hand fired boiler as the best that could have been accomplished, but these vessels have done good work in that field where operating expense evidently is not of the highest possible significance, especially under Government subsidies.

It is obvious, however, that had water tube boilers been used, the displacement would have been decreased, and for a given vessel speed a reduced effective horse-power would have been required, which again is reflected in a reduction in the machinery weight, condenser plant, and bunker capacity for given radius at given vessel speed, and also what is to-day most serious, a considerable reduction in the amount of firing and trimming labour and cost.

The successful running of the *Saxonia*, which had this type of boiler, probably carried weight in the final decision, as she was undoubtedly a very efficient reciprocating engine propelled ship. Her boiler room equipment weighed about 1,000 tons, and over a run of 13 hours during which period only six out of her 27 furnaces were cleaned, the evaporation was as much as 11·3 lbs. of water per lb. of coal burnt, and the steam consumption per I.H.P. hour was as low as 13·26 lbs., which is equal to 1·175 lbs. of coal per I.H.P. hour. The propellers were driven by slow speed engines indicating about 10,000 horse-power, the propulsive efficiency was approximately 60 per cent. compared with the I.H.P., so the effective horse-power would be say 6,000; this with coal of a calorific value of 13,000 B.T.U. per lb., gives a thermo-dynamic propulsive efficiency of 10 per cent., which is a highly creditable result obtained under almost ideal conditions over a short period of time, the actual ocean-going results were probably only about eight to nine per cent., and even this is splendid work compared with the average tramp steamer, which gives something about five to seven per cent.

There is not much doubt, however, that the *Saxonia* represents the limit in thermal efficiency which can be looked forward to by means of the twin screw quadruple-expansion reciprocating saturated steam engined passenger ship, and her engineers can be well proud of their results.

Heavy slow-speed reciprocating engines, although very greatly improved and brought up to a fine state of efficiency for such type of prime-mover, have, however, grave disadvantages, the greatest perhaps in the case of passenger and warships, the principal being the unavoidable vibration, as it is a natural law that a heavy revolving not exactly balanced body always runs unequally and transmits a tremor to anything with which it may come in contact. Large power engines of this type as is required for modern high-speed vessels of heavy displacement stand so high in the ship that their cylinders are well above water level, and this feature is of a special disadvantage in warships, and no doubt the principal reason why the steam turbine has replaced the otherwise comparatively speaking efficient reciprocating steam engine in most of the world's navies.

From a thermo-dynamic aspect, however, the steam turbine did not show up so good, and many ships are consequently retaining the reciprocating engine, there being no doubt about the fact that although the turbine did lie nice and low in the vessel, it did reduce the vibration, but it used so much steam and coal per effective horse-power, owing to its higher revolutions and consequent propeller inefficiency that it was too costly to use in ships which had to meet international competition on the seas.

Another feature in this matter was, in the case of a vessel having to slow down for any considerable length of time, the steam turbine, like its competitor, the Otto and Diesel internal-combustion engine, practically has only one efficient revolution speed at its rated load, and whereas the steam reciprocating engine could link up and take the fullest advantage of expansion at low revolutions and load, the turbine was unable to give such economical result, and this was particularly noticeable in the case of the trials of the *Lusitania*. It was found that at 25·4 knots the coal consumption per shaft horse-power hour was 1·43 lbs. (for 68,850 S.H.P.), whilst when the vessel was slowed down to 15·77 knots the consumption rose to 2·52 lbs., an increase of nearly 71 per cent. per shaft horse-power developed (13,400), at 20 knots the propulsive efficiency was about 52 per cent., but at 25·4 knots this fell to 48 per cent., while at the 15·77 knot speed this again fell to 40 per cent. The fuel used was a mixture of Welsh and Yorkshire coal, estimated at a calorific value of 13,000 B.T.U. per lb., the consumption per effective horse-power was at 25·4 knots, 2·98 lbs., and at 15·77 knots, 6·3 lbs., per E.H.P. hour, the heat unit consumption per effective horse-power minute being respectively 645 and 1,366, the thermo-dynamic propulsive efficiency for the two vessels being 6·58 per cent. and 3·1 per cent. relatively; which indicates at least that the *Saxonia* with her quadruple-expansion engines, and with her slow running propellers, an increase in the thermo-dynamic efficiency of no less than 52 per cent., compared with the slow running turbines, and the comparatively speaking high speed propellers of the *Lusitania*, the latter vessel suffering in the author's opinion by a combination of unfortunate events, as it is well known that if steam turbines are to give off their greatest power per unit fuel used in the process, that they must run at high revolution speed, whilst on the other hand, in order that the screw propeller shall give its highest thrust per horse-power supplied to it, that it must run at a comparatively speaking much lower revolution speed, and have the area to utilise the power without excessive slip.

Besides, large area slow speed propellers have many other material advantages, particularly referring to rapid manœuvring, for reversing, and are in better control of the vessel than small high speed, high slip turbine driven propellers against strong winds and currents at sea, and vessels fitted with these bigger propellers are not so likely to be blown ashore, and these features are quite apart from the "Commercial" one, namely, of requiring less fuel per 1,000 tons of displacement per mile at any given speed.

Shipowners would be studying their own interests if in the future they were to put much more stress in contracts for ships, regarding the fuel consumption per effective horse-power, as will be readily seen by the comparative results stated, reflecting on ship's operating costs, that it is not the fuel consumption per shaft horse-power which is the most significant, but the fuel consumption per "Effective" horse-power hour which is "Commercially" the most important thing of all, and by such attention the maximum efficiency, not only in connection with the propelling machinery, but also in hull and propeller efficiency must then play a most important part in the competition for shipping plant.

Knowing full well the limitations of both the steam turbine and the internal-combustion engine in regard to inefficiency at slow revolutions, and also both suffering from high fuel consumption at reduced revolution speeds, the complication and unreliability involved,—if they were to be made Reversible a higher propeller efficiency would be obtained if the turbine was direct-coupled and run at high revolutions (to obtain reasonable low steam consumption per shaft horse-power) and the cumbersome heavy weights and moving masses essential in slow speed direct-coupled reciprocating internal-combustion engines would be reduced.

The author in 1902 made some extensive experiments with a view of using mechanical reduction gears between the efficient steam turbine and internal-combustion engine when running at high revolutions and slow running large area screw propellers. The system was, however, not new, as it had been used on a boat on the Thames as long ago as 1785 in the 18th century, when on May 9th Mr. Joseph Bramah, a fire engine maker of Piccadilly, London, obtained a British patent for using high speed steam engine and slow speed propellers for ship propulsion. The chief reason why the author dropped the idea in 1902 was the fact that although he searched not only Great Britain, but also North and South Europe, he could not get manufacturers to guarantee the manufacture nor the upkeep of such high-powered mechanical gears for which he was asking. The "Geared" system when applied with steam turbines had the material disadvantage of requiring two separate sets of turbines, *i.e.*, one set for "Ahead" and another set for "Astern" operation, and in the case of installations such as would have been required for battleships, where the major part of their time is occupied at what is called "Cruising" speed, say about 14 knots, instead of 22 knots, their "full speed," it was found that it either meant the installation of extra expansion or what were called "Cruising" turbines, the complication of which was considered too much, and the cost and space occupied too great, and even with all the mentioned features the thermo-dynamic efficiency was very low, not much better than was actually obtained with direct-coupled turbines, in fact, commercially speaking it was not worth the candle. A bright idea was however afterwards put forward, and this consisted of the installation of a distinct and separate set of "Cruising" machinery, so that a ship fitted with four shafts would have no less than 8 sets of propelling steam plant, in one case as many as 32 turbines were embodied in the plant for a single battleship, which indeed was somewhat humorous, indeed it must be thought in certain quarters that the hard-working marine engineer had not enough on his hands already.

Further, in the "Geared" system of turbine propulsion, each shaft wanted a complete installation of turbines, speed reducing gear, bearings, thrust balancing devices, steam and exhaust piping, and lubricating gear, all mechanically locked together, and as a practical engineer experienced with high revolution speed machinery, I have no hesitation in saying that such a locked together set of machinery is subject to many kinds of trouble, with any of its parts, one of which may easily necessitate the immediate stoppage of the whole system on that particular shaft, besides. the whole of the driving machinery has to be lined up with the propelling shafts, and placed right aft, this necessitating long lengths of steam piping reducing the steam pressure and increasing the radiation losses, besides always being liable to accident, which in itself is a very serious feature, especially in warships.

In the case of partial stripping of the turbines (a not uncommon thing with "Reversing" turbines), it is obvious that to keep a high speed steam turbine running out of balance, or with say bearing trouble, is impossible, and the speed reduction gears with their numerous operating teeth would present almost equal difficulty. In the event of a smash up a ship would have to be stopped until the wreck could be cleared, and the work necessary to uncouple and disconnect any part of such machinery and heavy apparatus would be a very serious matter, involving much valuable time, including that required to stop the ship, and after the disconnection was made the idle propeller would act as a drag on very fast vessels.

In all steam turbine driven ships (mechanically geared, or otherwise) it is thus essential to provide and instal "Reversing" turbines, these extra turbines being connected to the same shaft, must consequently revolve round at high speed in their reverse direction when the ship is being propelled "Ahead" and the ahead turbines are at work, they involve considerable control complications which are objectionable, and even if these are reduced to a desirable minimum the actual "Reversing" power is greatly inferior compared with the "Ahead" power, consequently, no turbine-driven vessel is fitted with a "Full Power" reverse, and it is surprising to me that ships so incomplete in regard to safe handling are allowed, especially for passenger carrying work at high speed. I have heard it stated that a certain battleship carried on for about 2 miles before being brought up from full speed by the weak reversing turbines, but in the case of the trials of the *Lusitania* she entered the measured mile at 22·8 knots with the revolutions of the propellers running ahead at 166 r.p.m., the engine room telegraphs were rung down for "Full Speed Astern," and it took three minutes 55 seconds to pull her up, and over a distance of about three-quarters of a mile, what she would have carried on over had she entered the mile at her full speed of 26 knots, instead of the 22·8 knots as tested, can well be imagined; it, however, indicated a feature of high interest in future marine engineering.

Elaborate experiments which have been made, show that a steam turbine forced to turn in an opposite direction to which it goes when supplied with steam, involves about seven times as much friction loss as when it is driven in its normal proper direction. This loss is very appreciable in the reversing turbines of ships and causes considerable "heating," which has to be dissipated by circulating steam, which causes further loss and waste.

There are also serious difficulties and dangers in high-speed turbine prime-movers incidental to the abrupt and wide changes of temperature, as say, when steam is suddenly admitted to a relatively speaking " cold " reversing turbine, this being the prime cause of many accidents by stripping the blades, etc. There are other serious effects possible in connection with very large steam turbine driven ships as the following will show.

Steam which expands without doing work has a high temperature, and if steam is turned on a reversing turbine which is being driven in the " Ahead " direction (or its reverse direction) the local heat is very considerably increased, and if superheated steam is used (as it ought to be used on all ships) these local temperatures may be extreme, as they affect the " Ahead " turbines, as well as the " Reverse " turbines, since the two turbines are often mounted in the same casing and on the same shaft. The mechanical effect of such abrupt change of temperature upon fragile structures such as turbine blades, representing as they do very extended exposed surfaces, is a matter which has been up to now very little considered, but, which has in the past, on turbine driven vessels given much serious trouble at sea.

Various statements have been made in the past few years concerning the efficiency and losses in high-speed mechanical reduction gearing by various people, much in advance of the accurate tests which have been made in a well-known large works in America. The losses shown by the most accurate tests carried out by the motor-generator method, which is generally acknowledged to be the most complete for large powers, and by which the actual transmission losses can be most correctly measured, these tests have shown that the losses are greater than those claimed by various manufacturers of high power reduction gearing, and to check these measurements, the same power was transmitted, " with " and " without " the gearing.

A further disadvantage of the set ratio mechanical reduction gear method of turbine propulsion, is the fact that unless a separate set of " Cruising " machinery is installed, that for " Cruising " speeds it is essential to slow the turbines, and this causes a rise in the steam and fuel consumption, and a fall in the thermal efficiency, and in the case of a warship this is serious, as about 90 per cent. or more of the life of the ship is spent when travelling at the " Cruising " speed, considerably affecting the fuel bunker capacity per 1,000 ton miles of displacement at those speeds.

Enough has been said to indicate that steam turbine driving for ships has really failed to improve matters commercially, and although when operated under its ideal conditions as regards high revolution speeds, and with high temperature steam, and always running in one direction, it is a useful and efficient high power " Steam " prime-mover, the operating conditions which are demanded at sea for propeller driving, are not at all suitable for its proper application, and its use has so far been only a wasteful compromise.

It was this knowledge which led the author to investigate the possibilities of the " Electrification of Ships " in 1903, experimenting with the continuous current system, which, although indicating an improvement in the thermo-dynamic propulsive efficiency, still offered many disadvantages, although eminent firms of high repute were in a position to quote for the electrical machinery, the matter did not proceed until 1905, when successful experiments resulted in the author bringing out what is now so well known as the " Paragon " Thermo-Electric Ship Propulsion System.

This system embodies the use of polyphase alternating current power transmission, and by its use the turbine or internal-combustion prime-mover could run at high revolution speed, always in one direction, independent of the direction in which the vessel was proceeding, it provided the ideal control from both bridge and engine-room, it facilitated the use of slow revolution large area efficient screw or other propellers, producing high thrust for the shaft horse-power; it brought into use the high speed non-reversing steam turbine, with all its simplicity and reliability, its low cost and maintenance, its light weight, its high thermal efficiency, and safe means of using the highest superheated steam, without danger or complications, it provided means by which the prime-mover could be made entirely (mechanically) independent of the propeller shafts, thus facilitating the installation of the power producing plant in any satisfactory part of the ship and in close proximity to the boilers, it thus reduced the pressure and the radiation losses and the size, weight, and cost of main, exhaust, and condenser piping, it provided a " Full Power " reverse for the propellers, making a safer ship, much more rapid handling, with the least trouble to the engineering staff, and owing to the smaller amount of steam required per effective horse-power hour, it materially affected the number and size of boilers required for given speed and displacement.

It was indeed because of the previously mentioned facts that I named the new system the " Paragon " System; it was the best, cheapest and most reliable system of ship propulsion that I had so far struck, and has since been so well tried at sea and has maintained its original name. In 1906 I applied for patents in 25 countries, and in 19 countries my patents were granted, at a cost of over £800, several applications being still in abeyance.

The system covered the use of exciter control for facilitating the change of connections which has been so successful in many ships of recent years, this brought about means by which the very largest powers could be controlled, with great rapidity and certainty, besides avoiding the usual difficulties of synchronising and other features in ordinary polyphase current plant operation, a very fine method being employed in the latest method for high powered liners and battle cruisers now being proposed.

The use of this system brought about means by which the heavy main current was generated in stationary parts, and not revolving parts, as in my continuous current system, patents for which were granted in 1905. The only revolving members in the system were the motor rotors and the generator exciting fields, and these were at very low voltage, and safe for attention and handling, and its use brought about means by which a whole multitude of schemes could be designed out for all classes of vessels, either with steam or internal-combustion prime-movers, and although in some cases the slip-ring type of motor has been used, the system provides the means by which the strong, efficient, light, low cost squirrel cage induction electric motor can be directly coupled to the propeller shafts, and thus forming the most simple and efficient driving force for main marine propulsion, in fact in the latest method of applying the " Paragon " System for large vessels there is no switch-gear at all with the exception of one for " Reversing," and this is only in use under no-voltage conditions, the whole speed control being carried out on the low voltage side of the system, representing a tremendous advance over my early schemes and what has been previously carried out at sea.

There is no doubt about it, the squirrel cage induction electric motor is the most efficient motor or driving machine in existence, and like the high speed steam turbine it has only one moving part. Its very simple construction, combined with its great mechanical strength has proved its high favour in the heaviest powered ships afloat, it has no slip-rings or brush-gear, to give possible trouble, the whole working current in the revolving portion being induced across one air gap, in which there is nothing touching, and consequently no wear can take place affecting the life and maintenance efficiency, which is a tremendous advantage especially when dealing with large powers. This motor has no sparking limit, as is the case in all conduction machines, consequently the output per unit weight is much higher than in any other type of electrical machine, and with gain in efficiency. A large section can be given to the windings of these machines, which combined with the fact that the windings are arranged so that copper losses are not localised, and that the iron is of a laminated character in construction of both the stator and the rotor, provides every means for effective ventilation. Burnt-out armatures and the turning of commutators are the bug-bears of all engineers operating electrical machinery, but these effects are practically unknown in the case of the squirrel cage induction motor. and now means are provided by which it may be satisfactorily started against load, it offers the ideal method of driving propeller shafts for all kinds of sea-going vessels, and I have had these motors running many months on end without stopping and under full load all the time, without skilled. and with very little un-skilled attention, without the least trouble.

The system was made public for the first time on July 18th, 1908, before this Institution, at the Congress Meeting held at the Franco-British Exhibition, London, in connection with a Paper I had the pleasure of reading on its application to Cross-Channel Ships, and the Institute honoured me by the award of the Denny Gold Medal.

Some years ago, Mr. Tachikawa, the well-known Japanese electrical power engineer, after having studied my system at my London office, went back and read a paper on Marine Electrical Propulsion before the Engineering Society at Tokio, Japan, and made extensive references to my work, and printed in English a full description of my original claims to be able to drive a battleship with a fuel saving of no less than 27 per cent., this as far back as April 12th, 1909.

Mr. Henry Mavor, in Glasgow, fitted a small vessel with the system, using a suction gas plant and polyphase alternating current transmission to the propeller; the boat was 50 feet long, 12 feet beam, and 4 ft. 6 in. draught, the engine ran at 800 r.p.m., and the propeller speed just under 400 r.p.m., she did $8\frac{1}{2}$ miles per hour over the measured mile, and could be brought to a standstill in 23 seconds, and it took 13 seconds to reverse from the full speed "Ahead" to two-third speed "Astern." Tests carried out on May 31st, 1911.

A further development by the late Mr. Mavor was made in connection with a Canadian barge, the *Tynemount*, the plant for this vessel consisting of two six-cylinder Diesel cycle engines. driving two polyphase alternators at 400 r.p.m., the combined energy being concentrated in a special squirrel cage induction motor which drove the propeller shaft at 78 r.p.m. at full speed. Tests made on this vessel showed that the propeller was reversed from full speed "Ahead" to full speed "Astern" in 15 seconds, which is an excellent demonstration of the capabilities of the squirrel cage induction motor to the work of starting and acceleration torque required for marine propeller driving.

For some reason this interesting vessel was afterwards equipped with reciprocating steam engines, it has not been made public as to why this was done, as there is no question that the engines were of first-class make, the alternators were of modern and reliable design, the only question which I raise was in the type of motor used, it was of a type with two windings in the stator, similar to that which I used in connection with my original petrol-electric motor omnibus a few years previously, in which I found that the two windings being placed in the one set of slots, made the slots extra long and thus increased the magnetic circuit and lowered the motor efficiency, otherwise the plant was well designed and made, and I have no doubt the present high cost of fuel has caused the owners to wish that the original plant had been retained, it was a pity that Mr. Mavor did not adopt the well tried and reliable squirrel cage single-winding motor which I have always advocated from the first introduction of the system in 1908.

In May, 1909, I contributed a Paper before a large company of naval engineers at Chatham, the chairman for the evening being Mr. F. Purser Fletcher, A.M.I.E.E., the then First Assistant Electrical Engineer of the Chatham Dockyard; in this Paper I referred to the possibilities of the utilisation of the "Paragon" System for the propulsion of battleships, and compared the steam consumption of well-known ships, and showed to the satisfaction of a technical meeting of sea-going naval engineers, that a saving in fuel could be made in battleships of no less than 27 per cent., as an estimate this was not far short of the facts which have since been proved at sea in the latest and heaviest battleships in the world in the United States Navy, but it was thought to be too good to be true in those days, and direct-coupled turbines were continued and installed.

On November 18th, 1909, Mr. W. L. R. Emmet, the chief engineer of the turbine department of the General Electric Company of Schenectady, U.S.A., presented America with its first enlightenment as to the great possibilities of the system, when he read a well thought out Paper before the Society of Naval Architects and Marine Engineers in New York, on Applications of Electricity to the Propulsion of Ships. Mr. Emmet confirmed all the claims which I had originally pointed out in my previous Papers, and, being such a well-known authority on the turbine, having designed and manufactured the direct-coupled turbines for a number of battleships, his words weighed greatly with the naval engineers in that enlightened and go-ahead country, in which most brilliant work has, and is being done with this English invention. Mr. Emmet has done more than anyone else in America to advocate and use this great advance in marine electrical engineering, and immense credit is due to him for such a display of intelligence and faith in his profession. Although especially interested in, and appreciative of this work, I do not agree with the well meant statement of Mr. J. Daniels, the excellent and progressive Secretary of the United States Navy, who, when reporting to Congress in December, 1918, referred to the most successful trials of the new electrically propelled battleship *New Mexico*, and gave details of her indeed wonderful performance, both from the engineering and military aspects, carried out by some of the cleverest engineers and officers of the U.S.A. Navy, expressed his high appreciation of their work, in face of the opposition.

"The *New Mexico*, report proceeds to state, has failed in none of the exhaustive trials recently carried out: the operation of her machinery has been highly satisfactory in every respect, and to-day in this unique vessel the United States Navy has a battleship which has no peer in the World's Navies, not only for economical propulsion and less liability to serious derangement, but for her military superiority in greater manœuvring power and increased under-water protection."

With splendid appreciation of great foresight and thoughtful consideration of a great departure from the orthodox methods of old fashioned "Steam Propulsion" he goes on to state:

"In this successful revolution in the propulsion of the biggest fighting ships, as too often before," he adds, "American ingenuity and inventive skill now lead the world in the propelling machinery of battleships."

Mr. Daniels, of course, was not aware of the origin or the development of the system in this country, and that the ingenuity and inventive skill originated in England, and was publicly described, and ably discussed by the members and friends of this Institution as far back as 1908.

We must, however, give the highest possible credit to the United States naval officers and Mr. Emmet for the fact that, although they did not introduce the system, they were the first to build the big power experimental plant, the trials at sea, and the magnificent appreciation of the merits of what can be well claimed as the most advanced development in marine engineering during the last century, in my opinion they have advanced this great art, by at least 25 years, the tremendous economies proved, the advance in the military aspect of such ships will compel others to follow, where they might well have led.

On March 17th, 1910, I read a Paper before the Institution of Naval Architects in London, the chair being taken by Sir William White, the title of the Paper was " The Substitution of the Electric Motor for Marine Propulsion." The discussion was opened by The Hon. Charles Parsons, who stated that in his views there was very great dangers of short circuits by the adoption of the system for ships.

I took the matter up with Dr. Kapp, of the Birmingham University, who was kind enough to investigate the matter, writing me to the effect that he could hardly coincide. It however had the effect that a contract which I had entered into on the 28th of October, 1909, with Mr. Arthur John Maginnis, Consulting Engineer of Liverpool, was very shortly afterwards cancelled, and what would have been the first ship in the world propelled on the " Paragon " System was stopped. The ship to be converted was the S.S. *Ivy*, a vessel of 1,241 tons, with a speed of about nine knots, and with about 500 I.H.P. The vessel, however, at a later date was lost at sea, but had the contract been carried out she would have been the first large vessel in the world propelled on my polyphase alternating current system.

The features which appealed to Marine Engineers and which must be complied with by any type of propelling machinery can be drawn up as follows:

(1) The driving power must be simply and quickly reversible.

(2) It must be capable of being started and stopped quickly.

(3) It must be capable of being promptly speeded up and down from dead slow to full speed, or even in case of emergency be capable of giving out power sufficient to produce vessel's speed above the normal for short periods of time.

(4) It must be capable of being kept running at any desired set speed, and of running at that speed economically for very long periods. The "dead slow" should, if possible, be slower than one-fourth of the normal "full speed" revolutions, and on very fast vessels one-eighth or less.

(5) It must be capable of working well and reliably in smooth or rough water, and with the power varying from zero, to sometimes more than the normal maximum for short periods, when the propeller changes in resistance to rotation.

(6) It must meet the previous conditions without racing or showing more than say five to eight per cent. deviation from the normal set speed, and in case of heavy rolling, means should be provided to vary the power automatically from "port" to "starboard" propellers when operating two or more propellers.

(7) All working parts must be readily accessible for overhauling and adjustment, and all wearing surfaces must be capable of being easily examined.

(8) The driving machinery must be economical in fuel at all speeds, especially at the normal full speed at which it is generally run, and the machinery should have the least number of working parts.

Fractures in the tunnel and tail shafts sometimes occur in spite of the most careful inspection, and such an accident is very serious, especially on single screw vessels, and may even lead to the loss of the ship and crew. A ship is practically a flexible girder, the longer the propeller shafts are the greater the strains set up in them, and this source of danger should be minimised by making the shafts as short as possible. This is done in certain vessels, such as cargo boats, in which it is prefered to have the machinery at the stern, to give by its weight sufficient propeller immersion when travelling light, but in passenger boats the boilers and machinery are generally placed forward, so that long tunnel shafts are unavoidable. Vessels driven on the "Paragon" system have the undoubted advantage that the steam or other power generating plant may be placed right forward, whilst the propeller driving electric motors may be placed as far aft as the lines of the vessel will allow.

In connection with the subject of the conversion of existing ships to "Paragon" propulsion, I, some years ago, had great difficulty in getting the diameter of the induction motor down to the proper centres on some small cargo boats which I was asked to design plant for. I found that in order to get good low steam consumption per kilo-watt generated, I was compelled to raise the revolution speed to 4,000 R.P.M., this with a two-pole generator produced a periodicity of 66·6 per second or 8,000 alternations per minute, the propeller speed was to be 80 R.P.M. (not counting slip), so this meant a motor with no less than 100 magnetic poles. Drawing this motor out, I found that the large diameter did not allow of installation in the vessel, and I was on the point of adopting mechanical gearing between the electric motor and the propeller shaft, when I found out a means by which I could generate only 4,000 alternations per minute at 4,000 R.P.M. in quite a novel manner; we can now provide at least double the reduction ratio than we could have done previously, and the reduction in the steam consumption or the heat units used by my higher speed turbines has solved the problem for the equipment of small cargo vessels, and one of the important departments of the "Paragon" Company will be the conversion of existing ships, and I may add that a considerable number of enquiries are now in hand for this work, as there are many vessels to-day with good servicable hulls and boilers which may be brought up to date with the installation of the more modern propelling machinery, and the change brought about in very short time.

This conversion business is full of interest; ships which have fairly good steam plant in the way of boilers may be converted and still use the steam cycle with the high speed light-weight turbine as prime mover. A few years hence, by simply taking out the boilers and turbine generators, these can be replaced by a "Paragon" internal combustion generating plant, these boats may be thus changed into internal combustion vessels with the minimum of cost, and the high thermal propulsive efficient of the new heat cycle embodied in the change,—a point which should be appreciated and given thought to by progressive shipowners and engineers.

Whilst on the subject of internal-combustion engines such as will be embodied in many of our new and converted vessels, I would draw attention to the excellent engine which has been the result of a number of years development by Commander Geoffrey T. Bowles, R.N., and myself. Com. Bowles in 1912 was a very progressive shipowner, and resulting from a lecture which he heard me give in this building in 1910 before this Institution, we became acquainted. He thoroughly appreciated all it meant to the shipowner if we could by some method make the internal-combustion engine more reliable and consequently more suitable for long-voyage vessels, such as on those his business was concerned in. In 1912 we brought out jointly what is now well-known as the "Paragon" silent cycle for internal-combustion engines, and which we thoroughly believe will be highly appreciated by sea-going engineers as well as shipowners who wish to reduce the operating costs of their vessels and provide reliable machinery for their ships.

The war, however, intervened, but just before the intervention the well-known firm of Messrs. R. & W. Hawthorne, Leslie and Co., Ltd., of Newcastle-on-Tyne, investigated the question of internal-combustion railway locomotives, and took up the manufacture of another of the "Paragon" inventions in that important sister field of transport. Tenders for locomotives, each of 1,000 horse-power and capable of hauling 800 ton trains, were sent with drawings at their request, to the Commonwealth Government of Australia. Unfortunately, during the last few years nothing has been developed, the firm has been otherwise engaged, while Commander Bowles has been on active service, and I have been engaged on engineering research in the Navy and Air Service.

The time has now arrived when further developments are to proceed in connection with the new internal-combustion engine, and during the last few weeks instructions have been placed for the building of the first 150 to 200 horse-power engine; this engine will run at high revolutions, and will be of the six-cylinder type; it will be non-reversing, as it is intended to use same in connection with the "Paragon" electrical transmission system, experimentally both on railway locomotives and boats. Compared with the I.H.P. we anticipate returning as much as 60 per cent. of the heat energy, and comparing this with the 44 per cent. which has been obtained with the "Diesel" cycle, the future has, I believe, in store, an advance in British engineering something of significance and especially in connection with the thermo-electrification of high powered ships. An application was made by the General Electric Co., of America, in which they were endeavouring to use my system jointly with a system of exhaust turbines which were proposed to be coupled on the propeller shafts with the electric motors, the high pressure turbine driving the polyphase alternating current generators to supply the current for the motors; these ran at high speed and the low pressure turbines at low speed, a most interesting combination, but I successfully pointed out that it was not possible without embodying my already patented system, with which the Comptroller-General agreed, and this application was amended to suit.

Electrical propulsion of ships had also become of interest in Sweden. In fact, in 1913 a vessel was already under construction, and proved very satisfactory, it saved as much as 35 to 40 per cent. in fuel by the combined use of my system and the very efficient "Ljungstrom" steam turbine as prime mover. This vessel was the *Mjolner*, a small coasting vessel, the motors of which I inspected with interest in the works of the General Electric Co., of Westeras, near Stockholm, Sweden, in February, 1914. The General Electric Company of Sweden had applied for a British patent for the polyphase alternating current system of ship propulsion, which had also been successfully contested by my original patents.

Another contested patent case which I had, was on an application by the firm of "Oerlikon" of Switzerland, in 1913. They had evidently seen the great possibilities of electric ships of high power, and naturally came to the conclusion that the polyphase alternating current system of transmission with its speed reduction characteristics was ideal for the purpose. The Comptroller-General's report was in my favour.

[Extract from the "*Electrical Review*" of August 1st, 1913.]

THE "PARAGON" SYSTEM OF ELECTRICAL POWER TRANSMISSION.—On July 18th an application by the Maschinenfabrik Oerlikon for Letters Patent No. 19,980/1912 came before the Comptroller-General, in respect of opposition to the sealing of the same by Mr. William P. Durtnall, inventor and patentee of the "Paragon" system of ship propulsion and petroleum-electric railway traction. Mr. F. Bosshardt appeared for the applicants, and Mr. Durtnall handled his own case in person.

The invention sought to be patented related to improvements in driving electric locomotives, motor-boats and the like, wherein the driving shafts were to be rotated by means of polyphase alternating-current motors, supplied with current from polyphase alternating-current generators, which were to be carried on the vehicle and driven by steam engines, turbines, oil or gas engines. The speed was to be regulated by varying the speed of the prime mover.

Mr. Durtnall asked that the patent should be refused, and argued that anything not specifically mentioned in his specifications was either there by inference or was common knowledge, so that there was no subject matter in the applicants' specification that would justify the grant of letters patent.

The Comptroller-General's judgment was in Mr. Durtnall's favour with costs, as follows:—

"The Comptroller-General having given the matter his consideration, has come to the conclusion that he ought not to allow a grant in this case. The combination suggested by the applicants clearly embodies the opponent's combination; and the additional features suggested are apparently for the most part well known in themselves, and cannot be said to supply any patentable matter. In other words, the main principle of the combination has already been suggested by the opponent, and the other features relied upon constitute no inventive step. The patent must, therefore, be refused, and I award the opponent, Mr. William P. Durtnall, the sum of £3 3s. in respect of his costs, and direct the said sum to be paid by the applicants, Maschinenfabrik Oerlikon."

The "Oerlikon" Co. then made application for a license to use my system. I will, at the right time, give them orders for some of the large plant which they are so capable of designing and constructing, as now that electric ship propulsion has proved all that was originally claimed for it and more, the shipowners in this country, and in several other countries, are beginning to wake up to the facts of international shipping competition; and as Lord Weir stated on his recent return from America that in his views it was not all the question of what number of hulls could be built in a given time and put in the water, it was more the question of providing the cheapest and most rapid handling of ships that really mattered. This is the right view, and in my opinion the rapid facilities and cheap operating costs of electric driving are to be the means by which British shipping will yet successfully compete against the world. It stands to reason that in the coming scramble for the shipping trade, if engineering efficiency is not allowed to be left out in the cold the old methods cannot possibly have a look in against the progress which has been made by other countries.

Too much has, in my opinion, been made of the hull building side of the shipping industry, and the competition of building the largest number of hulls, and the driving of rivets, etc.

What is really wanted is a thorough revolution in ships' operating machinery, by adopting the most efficient means, not only for propulsion, but, also for the auxiliary machinery in loading and discharging ships, thus allowing them to make quicker returns, reducing dock dues, and raising the ship as a valuable asset from the commercial point of view, not only will these new methods make a ship worth living in and give more living accommodation and comfort to their crews, but these new, clean, and what I call more respectable ships will do more: they will entice (what is so sorely needed in this country) to the sea trade, many thousands of highly educated youths and men. At present there is too much of the sailor about the mechanical shipping industry. What is wanted is a great deal more mechanical or engineering training for those that go to sea. The day of the sailing ship has gone, and the operating future of British sea transport is a matter for engineers and mechanically trained assistants. The day is about to dawn when the Engineer-in-Chief of a big ship will smoke his cigar in company with his friend the modern captain on the bridge, where he should be, and from that position he will control with rapidity the enormous power under his control at any time, thus bringing about far greater safety to both passengers and ships at sea. Had such a state of affairs been brought into play earlier the unfortunate *Titanic* and her host might have been with us to-day; for no engineer would have so driven such a great ship with a large number of passengers, after receiving signals of the danger of ice, also bearing in mind the full knowledge of what it meant to have only reversing power on two out of the three propeller shafts to bring the ship up rapidly in the case of grave necessity. More important than considerations of convenience, economy, speed of construction, or even revenue-earning capacity are those of the value and sanctity of human life, and it is up to us engineers to bring into service the solution.

The economic factors which are now rapidly developing, especially in the form of high fuel and labour costs, interest on capital, time in port, and maintenance, are all contributing to the survival of the fittest. No one can really blame the American people for putting so much energy into the sea carrying trade. In my opinion, and based on actual observation just before the war, there are other countries besides America that will be the most serious competitors to the British shipping industry. It is not a question of nationality, the whole solution of the competition is in the hands of the engineers of any nation; it is the improved Marine Engineering with its reduction in fuel and labour costs, together with its rapid freight-handling facilities which will be in the hands of those who will win. And if the fullest advantage is taken of British experience and national invention, there is nothing to fear from well-meaning and efficient competitors.

The spur of competition does "John Bull" good now and again, and it stands good to-day in many directions. There was a time, not so many years ago, when British ships were slow in loading in Chinese harbours at £3 10s. per ton of 50 cubic feet. American ships at the time received £6 to £6 10s. per ton of only 40 cubit feet with rapidly handled dispatch. Why? it was because the American ships at the time were the most efficient, they made very rapid passages, and Mincing Lane Tea Shippers could well afford to pay the extra price, and British ships well-manned and well-found have been known to have lain in "Foo-chow" harbour for weeks together, waiting for cargo, and seeing American ships coming in, loading, and sailing immediately with full cargoes at a higher freight than they could command, because of their slow sailing and operation. The arrival of these ships (the famous American Clippers) in the Thames caused great excitement, and aroused no small amount of criticism, even the attention of the Government became attracted to them, and draughtsmen were sent down to Green's dry-dock to take off their lines.

This fine spur in competition aroused the British shipowners to the danger of their position. There was not one vessel, but a whole fleet of American vessels bringing cargo from China, at high speed, and at double the rates that British ships could command, and unless some check were adopted no one could tell where the matter might end. Certain it is that British merchants did not pay so liberally to get their tea to the home market, because had they cherished any special affection for American ships or their owners, they would have been quite as willing to have paid British ships the same freights had there been any to have received them, or even Chinese junks, always provided that the service could have been performed as quickly and as well then, and not till then. British shipowners were forced to build the Aberdeen Clipper *Stornoway*, and others, and there ends the story.

The before-mentioned shows that competition certainly does do good, for in the end British shipping made great headway, improved ships were built, and what was done then can be equally well done to-day, only instead of the work of sailors being improved this time, it is going to be the Engineers who will use their skill to save British shipping from collapse.

There has been too much bickering as to the efficiency of the various systems of ship propulsion in the immediate past years, there has been an enormous loss of money in various directions in the vain endeavour to still use antiquated types of machinery for propulsion and otherwise in the shipping trades, with a result that vessels are now at work using new types of apparatus, and are cutting into the British shipping trades in many directions little dreamed of before the war.

So much has been said in connection with the subject of "turbine" against "reciprocating" engined ships, the trials which the United States Naval Officers carried out a few years ago are of the highest possible interest. There had been a cruise to Europe, and on the way back across the Atlantic two large battleships were trimmed for an experiment, one was the *Delaware*, fitted with superheated steam reciprocating engines, right up-to-date, the other vessel was the *North Dakota*, fitted with direct coupled steam turbines, both ships were bunkered from the same collier, to enable a proper calculation as to the calorific value of their fuel to be made, both proceeded at the cruising speed of 12 knots. The consumption for the 10 days voyage was for the *Delaware* 991 tons, and for the *North Dakota* 1,412 tons. This trial was carried out by most experienced engineers, and was very carefully made in every detail, and much explanation with excuses were offered by the turbine manufacturers for the failure of the direct coupled turbine to "commercially" compete, but the Engineers and Executive Officers demanded that "commercialism" was to be put aside, and recommended that the Government should allow them to select as to the future system and methods of propulsion for the Navy. To the credit of the Government, they listened to this appeal from their practical sea-going Engineers and Executive Officers, and as there was so much dispute between the various advocates of the three principles of propulsion involved, namely, the "reciprocating steam engine," the "geared turbine," and the "thermo-electric drive"; they gave permission for the three systems to be tested and tried right out at sea, under direct "Naval" and not "Commercial" supervision, in order to come to a conclusion as to which of the three systems should be adopted for the United States New Battle Fleet, then under consideration, and the ships about to be constructed, consisting of a number of high-powered battleships and battle cruisers, which I refer to later. It was thought that the best results would be obtained by the actual testing at sea of three ships "colliers," each of about 20,000 tons displacement, with a cargo capacity of 12,000 tons, at a sea speed of 14 knots; and for the purpose of this what may be called a thoroughly representative and satisfactory solution of the problem, the following vessels were selected and each fitted with one of the three systems of propulsion with twin screws:—

The *Cyclops* was fitted with "Triple-expansion reciprocating steam engines";

The *Neptune* with "Geared turbines," and

The *Jupiter* with "Thermo-electric drive."

They were practically of the same lines, and with the exception of the driving machinery they were sister ships in every possible aspect.

An extract from the data of the trials of these three vessels indicates at least the enormous success of the electric ship as compared with the sister vessels.

Type of Propelling Machinery, &c.	*Jupiter.*	*Cyclops.*	*Neptune.*
No. of Engines	1	2	2
No. of Propellers ...	2	2	2
Speed of Engines, R.P.M.	2000	88	1250
Speed of Propellers, R.P.M.	116·72	88	135
Ratio of Speed Reduction	18-1	1-1	9·3-1
Steam consumption per Shaft-horse-power hour	11·1	14·0	13·4
Weight of driving machinery (American tons)...	156	280	150
Vessel speed during 48 hours trials at sea ...	15·0	14·6	13·9

The above trials were carried out by naval officers who were not connected with trade firms, their only thought was to test the systems in order to be in a position to advise the Government as to the truth and to indicate the best system to utilise for the coming new American Navy, I think that you will agree they have done a very great thing; they have also indicated the direction in which the mercantile marine will have to throw its full weight and attention, for these ships were great cargo vessels acting as colliers to feed the American naval ships.

I have since learned that the *Jupiter* has been run on her most economical speed for fuel; this turns out to be 12 knots, and at this speed she only uses 55 American tons of coal per 24 hours (49·1 English tons), a record of about 36 per cent. better than any steamship of her size afloat to-day at the 12-knot speed.

As will be seen by the above table the "Electric" ship, even when run at full evaporation of her boilers, same as the other ships on the above trials, the economy in steam per shaft horse-power hour was 20·05 per cent. better than the *Neptune* and 26 per cent. better than the *Cyclops*

It is certain that the above trials show conclusively that there is not much doubt from actual sea-going conditions, regarding steam consumption per S.H.P., that the "Direct-coupled" turbine is not in the running with vessels of the speed named, that the "Geared-turbine" vessel as so fitted is economically better than the reciprocating steam engine, and that the "Electric" ship is by far better than either, and therefore the proper type to use.

Another feature which was very noticeable on the trials of the *Jupiter*, and she was specially tested in very rough weather, to witness the effect, it was found that the propellers were being continually lifted out of the water when pitching heavily, the only thing which took place was the ampere meters in the engine-room registered less current, and the absence of propeller "Racing" was most conspicuous and welcome by the officers on the bridge, and also in the engine-room, beside not straining the vessel to the degree which takes place in other types of propelling machinery, the whole thing is automatically brought into play, and independent of the operators, a feature which is only obtainable with the "Paragon" alternating current drive, as it is well-known that alternating current motors cannot fall back from or exceed say about two to three per cent. of synchronism with the electrical generators, the governing of the turbine being carried out with that accuracy from "Full load" to "No load" or visa versa, with that closeness which is so characteristic in high power units in power stations ashore, it consequently accounts for the views held by the United States naval officers, that they prefer the "Electric drive" owing to the fact that this is the only one by which they could if necessary fight a battle at sea in rough weather, and would allow them to push their boats at high speed even in the teeth of such weather, a military point of the highest possible significance.

The boilers on the ships were of the usual cylindrical double-ended type, each with a grate area of 150 square feet, and 6,460 square feet of heating surface, and generating saturated steam at 190 lbs. pressure. I have allowed that the evaporation was at least equal to those boilers on the *Saxonia*, namely, at the rate of 11·3 lbs. of water per lb. of coal burnt (coal with a calorific value of 13,000 B.T.U. per lb.). The " Reciprocating engine " driven ship with her 88 r.p.m. propellers, I estimate the propeller efficiency was 62 per cent. in the " Electric " ship, with her propellers running at 116·72 r.p.m. at 60 per cent., and the " Geared turbine " driven boat with her propellers running at 135 r.p.m., 58 per cent., the thermo-dynamic propulsive efficiency of each of the vessels would therefore be as follows :—

	Jupiter	*Cyclops*	*Neptu*
Steam used per shaft H.P. hour	11·1	14	13·4
Coal used per shaft H.P. hour (13,000 B.T.U.) ...	·98	1·36	1·29
B.T.U. used per shaft H.P. minute	212	295	279
Thermal efficiency per shaft H.P.	19·92	14·35	15·3
Propeller R.P.M.	116·72	88	135
Estimated propeller efficiency	60 p.c.	62 p.c.	58 p.c.
Thermo-dynamic propulsive efficiency compared with the calorific value of equal fuel	11·95 p.c.	8·9 p.c.	8·87 p.c.

The above figures, assuming them to be about in order with the facts, would indicate that the slow speed reciprocating engine driven ship is commercially speaking superior to the " Geared turbine " driven boat, and that the " Electric " boat is far in advance of either in extracting propulsion work from fuel.

Regarding machinery weight it will be seen that the weight of the *Jupiter's* plant was six tons heavier than that of the " Geared turbine " ship. I may add that the *Jupiter* was fitted for experimental work, and that the motors were of the " Slip-ring " type, instead of the " Squirrel-cage " type, the consequence was that two water-cooled resistances were required, and these weighed no less than 5·2 tons each; the squirrel-cage motors would also have been lighter slightly, and the nett weight can safely be assumed for an ordinary installation to be 145 tons or 5 (American) tons less than the "Geared-turbine" installation.

In connection with my experimental machines in London, it was found that the squirrel-cage motor met all the torque conditions that were really necessary for Marine Engineering, and I decided to use that motor on all the "Paragon" vessel installations, not only main propulsion, but also all the auxiliary machinery as well; in fact the *Jupiter* has proved that with resistance in the rotor circuits, a very powerful reversing torque is certainly obtained, but during the greater period of the time she is operated without them, and when reversing, the turbine is slowed down, the reverse connections made, and the turbine is then run up to speed, which also brings the motors up with it in the reverse direction. It must be borne in mind that although squirrel-cage motors do not develop a high starting torque, should the high full speed frequency current be suddenly thrown on; they do develop a very high starting torque when supplied with a lower frequency, as for instance when the turbine is slowed down, as is done on the *Jupiter* with every satisfaction. In the case of the driving of the auxiliary machinery, this is quite another matter, the operation of cranes, pumps, fans, etc., all require to be operated at variable revolution speeds, and in this case I provide one or more of my variable frequency generators, which deliver say from 3 to 7 frequencies, and the squirrel-cage motors driving the various individual machines do then run very economically at various speeds, according to the wishes of the operator, who controls the speeds at will by means of an ordinary finger contact drum controller, no resistances being required, for the reason that the lower frequences are generated at also lower voltages.

A feature which will be appreciated by all practical marine engineers, is the fact that when lowering loads, instead of wasting energy on the brakes, the squirrel-cage motors being then driven by the load, generate current which is automatically delivered to the general service conductors, and in the case of another winch at the moment lifting a load, this arrested and ordinarily wasted energy, contributes to the demand of the working motor or motors, and thus relieves the prime-mover in the main engine room, and also saves fuel in loading or discharging ships. A description of this important branch in the general "Electrification of Ships" may be given in an appendix, together with a description of the new polyphase alternating current, synchronous, follow-up-system of steering for ships, which does away with the ordinary "wheel-steering" and makes the work of helmsmen so simple that a battle cruiser or 1,000 feet ocean liner, can be accurately steered by the finger.

Electrical transmission of power on ships affords a very simple and highly practical means of speed reduction in almost any ratio which may be desired. It affords a very simple means of reversal by a change in the electrical connections, without mechanical devices, complication of piping, valves, etc. Any desired torque can be obtained without affecting the efficiency of the equipment in the forward direction. In the case of battle ships, and other vessels such as trawlers, which require at least two operating speeds, it brings in means by which the ratio of speed reduction is immediately changeable by simple and reliable methods from the bridge or any other practical position, thus making possible the economical use of the same machinery, both under the high-power speed, or for cruising or trawling conditions.

It also makes it possible to use a number of power generating plants so that damage to one or more parts will not disable the ship, thus raising the standard of safety at sea and in many ways. With electrical transmission, high steam pressure and super-heat can be safely used, and there is a great gain in economy by their use, for instance recent experiments made in this country have proved that with a total steam temperature of 700 degrees and 500 lbs. pressure, steam heat will bring about means so that as much as 36 per cent. of the fuel heat is available for work, whereas with ordinary conditions, say with 200 lb. steam and only 50 degrees super-heat, only about 29 per cent. is available, and this increase in gain will more than compensate at the right time for the cost of the electrical machinery desired to bring this desirable feature into play in the great marine engineering industry.

Turbine-generators are now built with an efficiency of over 80 per cent., which together with electric motors of 95 per cent. efficiency and a boiler efficiency of 80 per cent. will jointly produce a shaft-horse-power hour, for the expenditure of only ·825 lbs. of coal (with a calorific value of 14,000 British Thermal Units per lb.) or only ·61 lb. of fuel oil (with 19,000 British Thermal Units per lb.) and these figures are closely approaching the sea-going efficiency of many "Diesel" internal-combustion engines, especially when taking the high lubricating oil consumption of these prime-movers into account.

I am sure that there are thousands of vessels, the owners of which would be well repaid to have them examined and reported on, with a view of having them converted, many good hulls can be thus brought right up to date and commercially handled for many years to come.

The very satisfactory trials of the *Jupiter* were made in the Pacific Ocean on the east side of America, after which she was brought down the west side, through the new Panama Canal, where she was handled with splendid simplicity with the electrical machinery; she then came up the east side to Hampton Roads, where further trials were made, resulting in the immediate decision of the United States Naval Authorities in adopting the system for the new battleships and battle cruisers then under consideration and now building. The first of these big ships was the *New Mexico,* which has been completed and has visited France and is now the flagship of the United States Pacific Squadron on the west side, having quite recently satisfactorily passed through the Panama Canal without any hitch.

Orders for six more battleships were received by one firm, the plant, each of which will require an estimated energy of no less than 33,000 horse-power, whilst further orders have been placed for the power equipment of five new battle cruisers, each requiring 135,000 kilo watts, or 180,000 horse-power. The magnitude of such expenditure and power is highly significant of the confidence which learned and highly skilled Naval Officers have in this new series of Marine Engineering inventions, and speaks wonders for the progressive feeling which led them to the decision, after tests so thoroughly tried.

A very interesting report on this controversy was recently delivered by Lt.-Comdr. Wm. L. Cathcart, U.S. Navy, in which he refers to the crux of the opposition laid in " commercial " reasons—there were " Royalties " at stake. There were some eminent engineers in civil life who were wholly sincere in voicing their disapproval of what to their minds and inadequate knowledge of Naval affairs seemed to them a hazardous venture. However, the *Jupiter* had been tried and proved her superiority.

One prominent electrical expert wrote vigorously against the use of electricity in this way, and subsequently wrote again approving its use. The Naval Officers stood solid behind the Engineer-in-Chief, who, to his great credit, held unwaveringly to his decision. The plant for the battleships was ordered, and thanks are due to Admiral Griffin and to his predecessor, Admiral Cone (who ordered the *Jupiter* trials) from the Marine Electrical Engineering Profession the world over.

The controversy matters little now, as the recent trials of the *New Mexico* have proved even more than what was claimed for the system, and the decision that all the new vessels of the United States Navy are to be so equipped is the finest answer to those who endeavoured to stand in the way.

From the battleship aspect she has proved that the system at least provides the following significant advantages over all other systems of propulsion:—

(1) Greater flexibility and control in the use of power.

(2) Improved economy in every-day service and increased economy at high vessel speed.

(3) Less liability to serious derangement of propelling machinery.

(4) Less likelihood of the speed of the ship being seriously affected in the event of injury to any of the turbines.

(5) Military superiority due to the increased under-water protection which I stated many years ago could be given.

(6) Rapid and reliable reversing and other handling in battle-action.

(7) Capability of being propelled at high speed in rough weather, with absence of racing of propellers and its serious vibration, and effects on range-finding and other instruments.

(8) The first cost is cheaper. The contract for the machinery for the *New Mexico* was £89,791 13s. 4d., and the U.S. Navy Yard estimates show that a saving in cash is made of no less than £41,666 13s. 4d., by using the "electric" drive, instead of the "Parson's steam turbine" equipment as was originally contemplated.

(9) The machinery weight is considerably less. The guaranteed weight of the *New Mexico* machinery (without auxiliaries) was 530 (American) tons. The estimated weight of the Parson's turbine equipment for this vessel was 653 (American) tons, a consequent saving of 19 per cent. weight.

(10) Less boiler and condenser plant required, together with funnelage and auxiliary plant, smaller steam and exhaust pipes, valves, and radiation losses.

It may be of interest to observe the relative economy estimated by the operating engineers of various American battleships, and using the three principal types of propelling machinery. The figures are in relation to the steam used per "effective" horse-power hour. The *Florida* and the *Utah* are fitted with Parson's turbines, the *Delaware* with reciprocating steam engines, and the *New Mexico* with electric drive :—

Ship.	Steam Consumption per Effective horse-power hour. Full Power.	12 knots.	19 knots.	21 knots.
Florida	328	31·8	24·0	23·0
Utah	323	28·7	20·3	21·0
Delaware	175	22·0	18·7	21·0
New Mexico	122	17·3	15·0	16·4

The figures are of interest, insomuch that they certainly show that the electric ship has everything in its favour from all the operating conditions, desirable to meet Naval demands as regards economy in fuel consumption, and therefore should represent a tremendous reduction in the cost to the nation which uses electricity for the driving of its Naval and Mercantile ships.

The contract for the machinery for the *New Mexico* was placed on June 3rd, 1915.

The keel was laid four months later at the Navy Yard at Brooklyn, October 14th, 1915. She was launched on April 23rd, 1917. Commissioned on May 20th, 1918.

Length, 624ft.; beam, 97ft.; draught, 30ft.; displacement, 32,000 tons.

Her complement normally consists of :—

Commanding Officer	1
Wardroom Officers	26
Junior Officers	18
Warrant Officers	12
Crew, including Chief Petty Officers	1,011
Marines	72

She carries 12—14in. guns arranged on four three-gun turrets, 14—5in. rapid-fire guns, 4—3in. anti-aircraft guns, 4—6 pounders for saluting, 2—1 pounders for boats, 2—3in. field pieces, 2 machine guns, and 4—21in. submerged torpedo tubes.

Steering is done electrically with hydraulic transmission and in duplicate of 75 horse-power.

The main plant, which is about 215 tons less weight than the sister ship, the *Mississippi*, consists of nine (Babcock and Wilcox) boilers, working at a pressure of 280 lbs. per square inch, with total heating surface of 55,458 square feet (exclusive of super-heating surface). The single funnel is 14ft. 3in. internal diameter, and 92ft. 6½in. high from the bottom furnaces, all oil fired.

The generating plant consists of:—

Two alternating current turbo-generators, each of 10,500 kilo-watts with 78 per cent. power-factor, capable of carrying 25 per cent. over-load, with the same power-factor for four hours. They are two-pole machines, designed for 2,100 r.p.m., corresponding to a frequency of 35 cycles, and for 3,000/4,240 volts wound for 2-phase current.

All speeds of the ship are, however, obtained up to 17 knots with only one generator in operation.

The governors are adjusted to operate through a range from 700 to 2,200 r.p.m.

Two 300 kilo-watt direct-current turbo-generators for exciting and for electric motor driven auxiliaries.

Four double squirrel-cage induction motors, each designed for a full capacity of 8,375 horse-power at 175 r.p.m. (motors coupled one on each shaft).

The main turbines are of the ordinary "Curtis" type, and have ten controlling valves.

The average trial data obtained is given in the following table and shows very fine results.

	4-hour trials Full Power.	19 knots.	15 knots.	10 knots.
Steam at boiler's gauge pressure	278·6	274·8	273·8	—
At Turbines ...	272·1	274·2	274·6	277·5
Vacuum inches ...	29	29·5	29·8	30
Barometer ...	30·83	30·77	30·92	30·79
Boiler room air pressure inches of water ...	4·1	3·4	2·3	1·7
Feed water temperature, Fahr.	182·8	189·7	203·4	208·9
Main Generators—				
Volts	4257	3740	2915·6	1950
Amperes ...	2206·2	1873·5	1600	1565
Field Volts ...	171·7	152·15	143·8	118
Field Amperes ...	318·25	290	285·6	245
Main Motors—				
Amperes ...	994·5	860·3	417·5	272·5
R.P.M. ...	167·69	152·2	115·35	80·49
Slip of Propellers per cent. ...	16	14·97	13·24	14·83
Speed in Knots ...	21·08	19·37	14·98	10·26

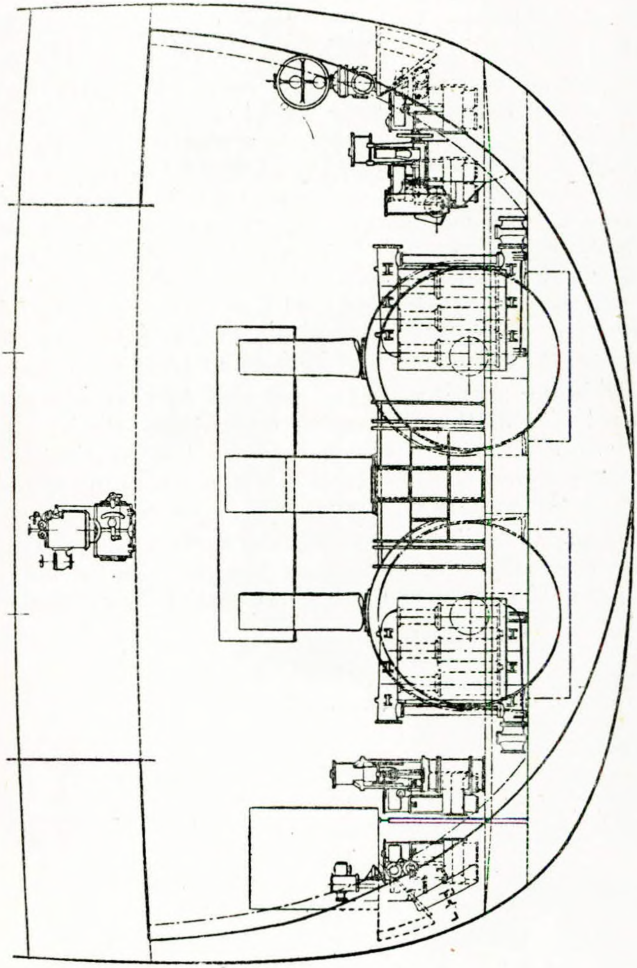
	4-hour trials Full Power.	19 knots.	15 knots	10 knots.
S.H.P. (from curve)	31197	23233	9648	3690
Steam consumption per shaft horse-power hour ...	12·01	12·33	12·475	13·96

The new battle cruisers will have installed in them the largest electric power equipment ever placed on board ship, it will consist of four steam turbine driven alternating current generators of 135,000 kilo-watts capacity, and 180,000 horse-power. There will be eight electric motors, each of 22,500 horse-power, running at a full speed of 250 r.p.m. (two on each of the four propeller shafts). They will have seven funnels and a sea speed of 35 knots, the displacement will be 34,800 (American tons); they will each be 874 feet long, 91 feet beam, carrying a battery of 10—14in. guns, 20—5in. and 4—3in., and 8—21in. torpedo-tubes, and the complement will consist of 1,274 officers and men.

Considering that it was only just over 11 years ago when the practical idea of the alternating current electrically propelled ship was first introduced, and before this Institution, it is marking progress in history, and the economies introduced, will reflect on the welfare of humanity.

The work indeed opens up a vista of vast Commercial and even Political significance, and being the maritime nation of the world, should now be of the highest possible importance to this country.

—o—



PARAGON. SUPER-DREADNOUGHT.
ELECTRICALLY DRIVEN.
BATTLESHIP.

UNITED-STATES SHIP
"CALIFORNIA" L.D. 1914.

DISPLACEMENT. 32000 TONS.

SHAFT HORSE-POWER. 32000.

CONTRACT MEAN SEA SPEED. 21 KNOTS.

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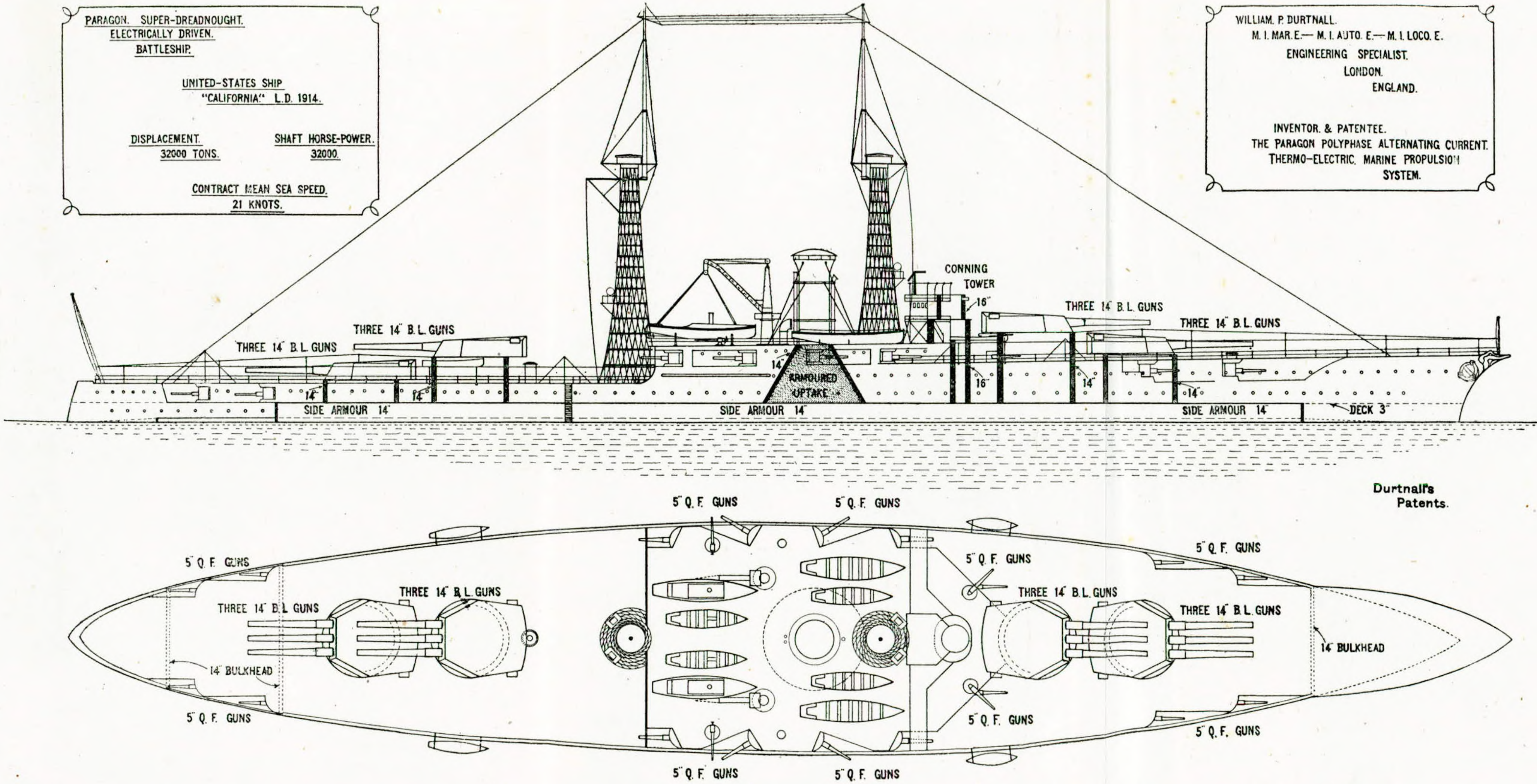
M. I. MAR. E.— M. I. AUTO. E.— M. I. LOCO. E.
ENGINEERING SPECIALIST.
LONDON.
ENGLAND.

INVENTOR. & PATENTEE.
THE PARAGON POLYPHASE ALTERNATING CURRENT.
THERMO-ELECTRIC. MARINE PROPULSION SYSTEM.



Durtnall's Patents.

LENGTH OVER ALL.	BEAM.	DRAUGHT.	MAIN ARMAMENT.	SECONDARY ARMAMENT.	SUBMERGED TORPEDO TUBES.	BELT ARMOUR.	GUN SHIELDS.	14 INCH ARMOURED.	16 INCH ARMOURED.	BELT ARMOUR DEPTH.	BELT ARMOUR ABOVE WATER.
625 FEET.	97 FEET. 3 INCHES.	29 FEET.	TWELVE 14" B.L. GUNS.	TWENTY TWO 5" Q.F. GUNS.	FOUR 21 INCH TORPEDOES.	14 INCH.	18–9 INCH.	FUNNEL BASE.	CONNING TOWER.	17 FEET 6 INCHES.	9 FEET.

50 PER CENT REDUCTION. IN BOILER ROOM SPACE.

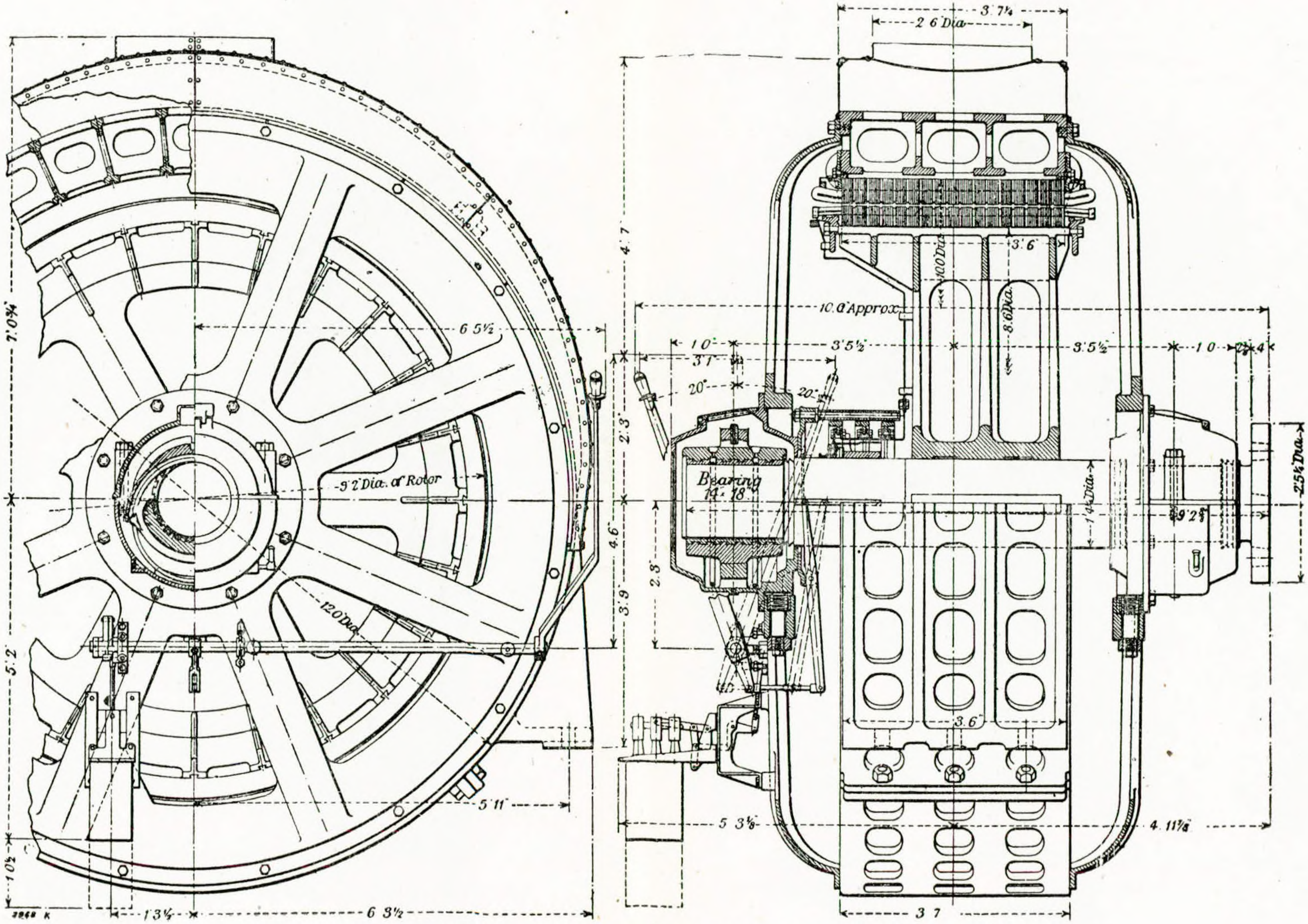
EXTRA ARMOUR PROVIDED AGAINST SUBMARINE EXPLOSION.

JAPANESE TYPE BOW GIVING IMPROVED SEA WORTHINESS.

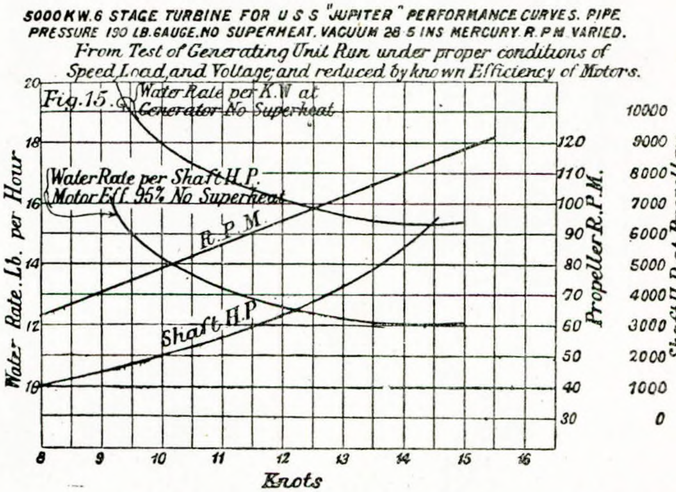
GREAT FUEL ECONOMY & EXTENDED TRAVELLING RADIUS.

ELECTRICAL CONTROL. WITH IDEAL MANOEUVRING POWER.

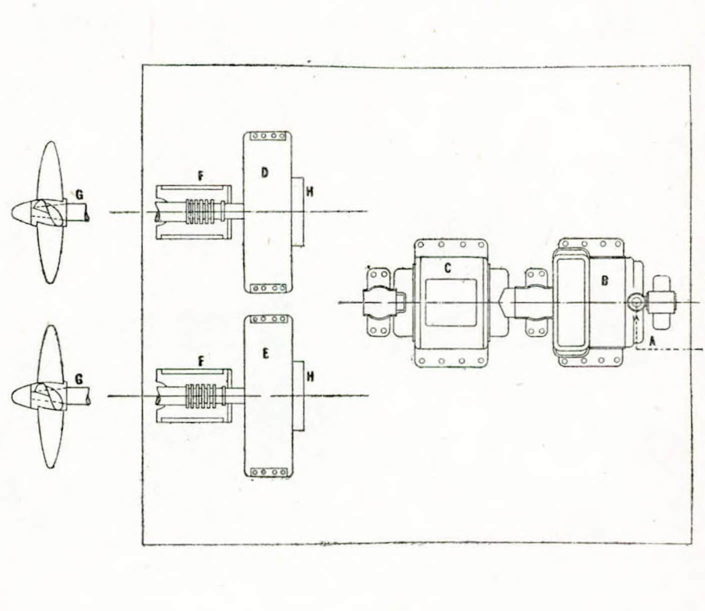
MAXIMUM THERMAL & FIGHTING EFFICIENCY.

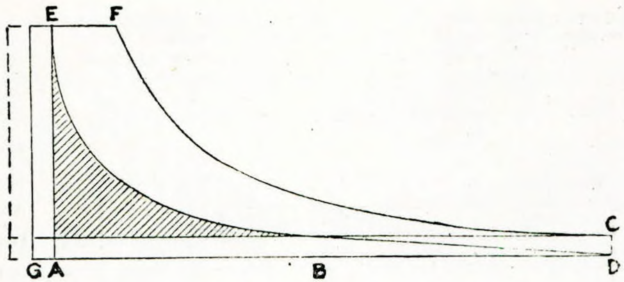


Details of Motor, Showing Switching Apparatus for Starting Resistance.



TEST PERFORMANCE CURVES OF PROPELLING MACHINERY.

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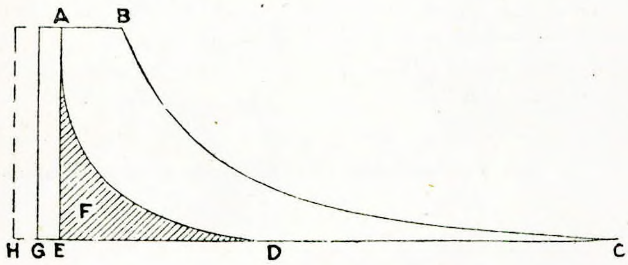
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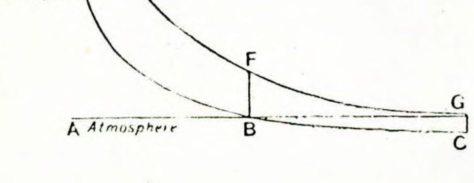
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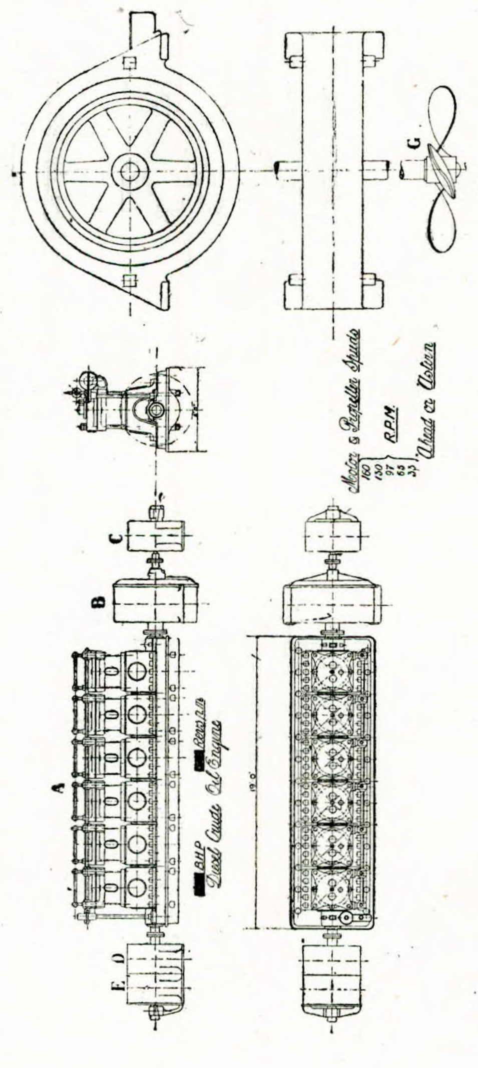
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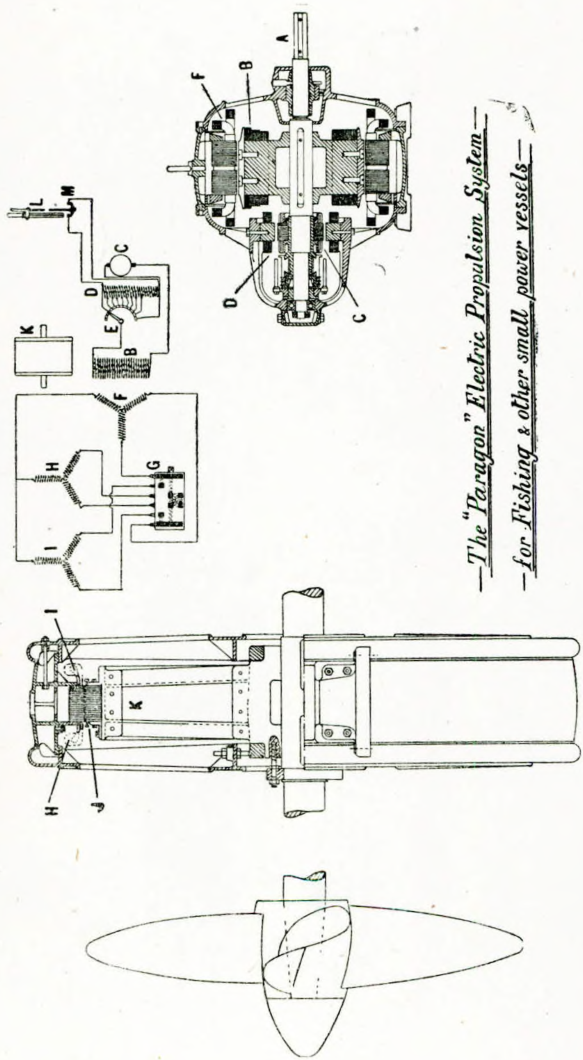

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