ELECTRIC PROPULSION

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THE FIRST ELECTRICALLY PROPELLED DREADNAUGHT, U.S.S. NEW MEXICO

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VOL. XXII, No. 4

APRIL, 1919

CONTENTS

Commander S.M. Robinson U.S.N.

William Le Roy Emmet

U.S.S. NEW MEXICO

ELECTRIC MARINE PROPULSION

The adaptation of electricity to the propulsion of ships sets up another milestone along the path of progress of the engineering world in general and the electrical industry in particular. For many years the marine reciprocating engine has been in a state of virtually completed development, possible improvements being mere matters of detail. The first radical change in steamship propulsion was brought about by the introduction of the direct-connected turbine; but this drive is admittedly imperfect because the turbine is essentially a high-speed machine and a ship's propeller a low-speed load, so that the efficiency of each has to be sacrificed in compromising upon an intermediate speed for both. Furthermore, as the turbine is not reversible, both ahead turbines and astern turbines are necessary, or a machine containing ahead and astern bucket wheels. The reversing element when moving in the ahead direction introduces serious losses and, being of smaller capacity, gives a relatively less powerful reverse than that afforded in ships driven by reciprocating engines.

The introduction of speed reducing gears between the turbine and the propeller in many cases permits both turbine and propeller to be designed for their best inherent speeds, although in certain types of ships the simpler forms of gearing do not afford sufficient speed reduction. This type of drive, however, does not eliminate the necessity for reversing turbine elements. The limitations of the geared-turbine drive are least objectionable in low-speed cargo vessels and in these it has found a very large application.

The production of a radically improved method of propelling large, fast, and variable-speed ships, especially battleships and battle cruisers, presented a difficult problem, the solution of which lay in the adoption of electrical propelling machinery. Now that complete success has been attained, it is interesting to note that as long ago as 1909 Mr. W. L. R. Emmet, one of the consulting engineers of the General Electric Company, delivered a paper before the Society of Naval Architects and Marine Engineers advocating the use of electric motors for ship propulsion; and, furthermore, that it is due to his continued and indefatigable efforts that this type of drive has been developed and adopted.

The first electric propulsion other than that of small launches was applied by the General Electric Company in 1908, to two fireboats for the city of Chicago. These were equipped with generators driven by steam turbines, which also drove directly the [illegible] pumps, and with electric motors mounted directly on the propeller shafts. These installations were entirely successful and are still in operation. The next step was made a little over five years ago when the [illegible] twin-screw collier *Jupiter* was equipped with electrical propelling machinery. This equipment was adopted for a trial of the system. It was built by the General Electric Company at the same time that a geared-turbine equipment for the sister ship *Neptune* was built by the Westinghouse Company. Even though the requirements of this type of craft do not call forth the especially superior characteristics of electric drive, the success of this installation created such confidence that the Navy Department adopted electrical propulsion as the standard method for capital ships. The recent installation of electrical propelling machinery in the U. S. Battleship *New Mexico* represents the culmination of the campaign to improve heavy and variable-speed marine drive. Its performance on the trial runs has fully substantiated the claims of its advocates.

The particular feature of electric drive which resulted in its being adopted as the standard method for propelling the capital ships of the United States Navy is the flexibility it affords in the arrangement of the equipment. The full utilization of this property enables the building of capital ships far superior to any equipped with any other type of propelling machinery.

Another especially important feature of electric marine drive is its economy. As pointed out by Commander S. M. Robinson in this issue, the total fuel consumption of the electrically propelled Battleship *New Mexico* is materially less than that of the *Pennsylvania*, a turbine-driven battleship of comparable displacement and speed. This fuel saving, which varies with the conditions of navigation and at times amounts to some 30 per cent, is a matter of tremendous import for one of the most serious problems today is the conservation of our fuel resources.

It is satisfying to know that the United States Navy is in possession of the only electrically propelled dreadnought in the world and is soon to be augmented by similarly equipped battleships of the same class, the *California*, *Maryland*, and *West Virginia*. There are also under construction 35-knot electrically-driven battle cruisers each having a power plant six times more powerful than that of the *New Mexico*.

Electric Drive from a Military Point of View

By Commander S. M. Robinson

Bureau of Steam Engineering, Navy Department

When considering a new type of drive for battleships, it must be compared with the common types of drive on the basis of reliability, weight, and space occupied, economy and flexibility of installation. In this article the relative merits of electric drive and geared turbine drive are compared on this basis, from which it would seem that with respect to reliability and flexibility of installation the electric drive is greatly superior to geared turbine drive; in fact, the ease with which the electrical equipment can be arranged constitutes, in the words of Commander Robinson, the real and main reason for its adoption for our capital ships. As regards the weight and space occupied there is little to choose between the two methods of drive; while in economy the electric drive will show a considerable improvement over the geared turbine at intermediate and high speeds.—Editor.

Any type of propelling machinery, to be acceptable for a capital ship, must be entirely satisfactory in the following particulars:

(1) Reliability
(2) Weight and space occupied.
(3) Economy.
(4) Flexibility of installation.

Needless to say, the most important of these is reliability; and no machinery should be considered at all which has not proved itself satisfactory in this respect. The performance of the *Jupiter* during the past five years has thoroughly proved the reliability of electric machinery on board ship. For demonstrating this quality, the *Jupiter* was a good type of ship to select, as a collier ordinarily does a great deal more cruising than a capital ship. During the past five years the *Jupiter* has been held up only once on account of trouble with her electric equipment, and in this case the delay was for only two or three hours and the repairs were effected by the ship's force with the facilities available on board ship. The trials of the *New Mexico*, just completed, indicate that she should duplicate the performance of the *Jupiter* in this respect. In fact, there are inherent reasons why electric propelling equipment is more reliable than other types of machinery. As direct-connected or geared turbines are usually arranged, it is seldom the case that damage to one turbine does not affect more than one shaft; with electric machinery, each shaft can be absolutely isolated from the others by merely opening a disconnecting switch to the motor on that shaft. Furthermore, in case of damage to a turbine with the straight steam drive, the ship is left to drag one or more propellers while driving with the others; with electric drive, the failure of one turbine will still allow the ship to be propelled by all four screws in a perfectly normal manner. The latter will be seen to be no small advantage when it is considered that the effect of one dragging screw may be as high as 15 per cent of the total effective horsepower required to drive the ship, and to this may be added the fact that the maneuvering qualities of the ship are not nearly so good when it becomes necessary to drag one screw. It sometimes happens that the damage to a turbine is such that the shaft cannot be allowed to revolve; in this case, it becomes necessary to limit the speed of the ship, as the "jacking gear," or other locking device, is not sufficiently strong to hold the shaft at high speeds of the ship. There is still another advantage of electric propulsion that is brought out very strongly when the ship is maneuvering in shallow or muddy water, such as obtains in harbors and their entrances; the ordinary ship uses all of her main engines and therefore all of her main condensers and auxiliaries all the time, but an electrically driven ship need use only one turbine, condenser, and set of auxiliaries and the other can be kept as a standby. If the steam driven ship runs into mud, she will probably plug up all her condensers at the same time, or even if she only plugs one she will temporarily be deprived of the use of one or more shafts and this may be fatal for maneuvering in restricted waters. As an actual experience the *New Mexico* while entering New York harbor had to shift main generators twice owing to the plugging of her condensers with mud and these shifts were made so quickly that they did not affect the operation of the ship at all. There is one other point that adds to the reliability of electric drive, and that is that the direction of rotation of the steam turbine is never changed; reversal of direction of rotation is the most severe of all conditions imposed upon any form of steam machinery, and its entire elimination in electric drive adds very much to reliability.

When comparing different types of propulsion with regard to the other three points given at the beginning of this article, it is difficult to say that anyone of the three is of more importance than the others, inasmuch as the machinery must be satisfactory in all three respects; it is only where two types of machinery are nearly equally satisfactory in some of these respects that they can be directly compared in regard to the remaining points. For example, no type of machinery could be considered which was vastly heavier or occupied twice the space of other types of machinery, no matter how economical it might be, and vice versa, the economy must be reasonably good or any question of weight saving could not be considered. Therefore, the electric drive will first be compared with other types of machinery in these two respects before proceeding to a consideration of its relative advantage as to installation. It is difficult to arrive at exact comparisons with other types of machinery in regard to weight as, so far, we have built no capital ship with geared turbines arranged on four shafts and therefore are unable to get a direct comparison of the two types of machinery; but, from the data at hand, it is not believed that there is any very great or important difference between the electric drive and geared turbines in regard to weight, although it seems to be fairly certain that the geared turbine has a slight advantage in this respect. In regard to the question of floor space occupied, it is not believed there is any great difference, and what difference there is is probably in favor of the electric drive. It is at least safe to say that so far as weight and space occupied are concerned, the difference is not great enough to be of much importance.

As to the relative economy of electric and geared drives, we are able to make a little more definite statement than in the case of the weight comparisons. It seems fairly certain that in the case of large horsepower installations with large speed reductions, such as are found on battleships and battle cruisers, the geared turbine will have a slight advantage at full power, but at the lower speeds of the ship the electric drive will have a very material advantage over the geared installation. Just how great this advantage will be will depend to some extent upon the arrangement of the machinery. For example, on a battle cruiser developing enormous horsepower at full speed, and where it would be necessary to use all of this transmission gearing at the cruising speeds of the ship, the saving by the use of electric drive would be very much greater than in the case of a battleship where the percentage of reduction of power would not be so great. In connection with the subject of economy, it is interesting to compare the trial results of the *Pennsylvania* and the *New Mexico*. The *Pennsylvania* is fitted with direct-connected turbines and small geared cruising turbines which can be run up to speed [illegible]. The trial results of the two [illegible] at in total fuel consumption the *New Mexico* saves more than 20 per cent over the *Pennsylvania* at speeds from 19 knots to full power. At a speed of about 15 knots, which is about the limit of the geared cruising turbine and also of the low-speed connection of the electric drive, there is a very much greater saving, it being something in the neighborhood of 30 per cent. At ten knots, the fuel saving is apparently very small, although at both 10 and 15 knots the trial results were not directly comparable on account of the different conditions under which the trials of the two ships were run. Ships fitted with small geared cruising turbines, however, showed remarkably good economy at very low speeds of the ship, such as 10 knots.

It therefore appears that electric drive, generally speaking, is quite satisfactory in regard to points (1), (2), and (3), and compares very favorably with other types of propulsion in these respects. It may, therefore, be compared directly with other types of machinery in regard to point (4), the "Flexibility of installation." The tendency in building modern capital ships is to provide for more and more torpedo protection and it becomes necessary to crowd the machinery away from the sides of the ship as much as possible. This arrangement is also desirable from the point of protection against gunfire for a similar reason. In this respect, electric drive has an enormous advantage over any other type of machinery in which the prime mover is mechanically connected to the propelling shaft. The main turbine-generators may be placed in any part of the ship that is most desirable; they may be placed in compartments forward of each other and they may be raised up enough to place the main condenser underneath them—in fact, there is practically no limit, other than the head room, as to the position of the main turbine-generator in the ship. This gives an enormous advantage to electric drive over all other types of machinery and enables the Naval Constructor to give far more adequate protection to the ship and machinery against damage by torpedo and gunfire. Those parts of the machinery—the main motors—which it is necessary to connect mechanically to the shafts, are comparatively small and take up only a small space so that they can be placed in small isolated compartments which will not menace the ship in case of flooding; since no main auxiliaries are required for the motors, the flooding of a motor room will not entail any loss in that respect. Also, the motors may be placed very much farther aft than can steam driven turbines and therefore the length of the main shafting can be very materially reduced. This constitutes a big advantage; both on account of less liability to derangement of the shafting itself, due to injury to the ship, and also of less danger to the ship itself because of the shafting not having to pierce a number of water-tight bulkheads. These advantages of installation constitute the real and main reason for the adoption of electric drive for capital ships and any other advantages are minor compared with them. Utilizing these advantages to the fullest extent makes it possible to build capital ships which are far superior to any others fitted with any other form of machinery. In addition to advantages from the point of view of protection, there are also the advantages from an engineering standpoint. The shorter lengths of shafting make it easier to keep the shafts in line; the grouping of boilers around the machinery makes short and direct steam pipes with a consequent reduction in weight and complication and a smaller drop in steam pressure. The same may be said of practically all the other piping systems of the ship, such as feed lines, oil lines, exhaust lines, etc.

The Electric Propulsion of Ships

By W. L. R. Emmet

Mr. Emmet briefly reviews some of the advantages that result from the employment of electric drive for the propulsion of large warships. Electric drive affords a material economy in fuel, but this is secondary to the highly desirable factor of interchangeability of equipment in operation. Flexibility of arrangement, by which the vital parts of the propelling equipment may be crowded towards the center of the ship away from the side and if necessary placed in small water tight compartments, is another important advantage; as is also the ability to vary the ratio between propeller speed and turbine speed when changing from cruising speed to full speed, or visa versa.—Editor.

The possibility of propelling ships by electric motors has for a long time been considered, but it was only after the turbine-generator had attained a high state of development in the matters of efficiency and lightness that any justification for electric propulsion began to appear.

The first plans for electric propulsion contemplated by the writer were formed soon after these conditions had developed in turbine construction, and some time in advance of any serious proposal to apply mechanical gearing to the same purpose. The introduction of the turbine had by this time completely changed and greatly reduced the cost of power development from fuel on shore, and it was obvious that any method which could make these improvements applicable to ships would have a very high value. Fuel economy is relatively much more important on ships than it is in most power developments on shore. Ships must not only purchase their fuel but they must carry it; and they will often be compelled to purchase it at points where the cost is very high.

The first proposal made for electric ship propulsion related to large warships for the simple reason that in such ships this method affords its greatest advantages, and that in the introduction of a new method it is always wise to select the application which affords the largest gain and advantage.

The most important advantages afforded by electric propulsion in a large warship are that it introduces the feature of interchangeability by which the ship can be quickly put into operation after a portion of the apparatus has been damaged, and that it furnishes a means by which the ratio of speed reduction between the propellers and turbines can be changed; thus cruising speeds can be handled by a part of the apparatus without the sacrifice of efficiency which would be occasioned by a reduction of the turbine speed.

Other important advantages are that vital parts of the propelling machinery can be put into separate small compartments in those parts of the ship which are least subject to damage, and that no high-speed mechanisms or parts involving mechanical engagement are attached to the propeller shafts; thus the propeller shafts are free to revolve at all times whether they are being driven or not. No trouble which could occur in such electric motors would interfere with the freedom of their turning.

In electrically-driven ships the most advantageous speed of both turbine and propeller can be adopted, separate turbines for reversing can be dispensed with, and a high torque for reversing is readily obtainable.

The abandonment of the reversing turbine renders unnecessary the delivery of large flows of steam to turbine elements that are either standing still or moving in a reverse direction. Under certain conditions and in turbines of certain sizes, such reversing action may not be objectionable, but it involves the possibility of very high temperatures and it is probable that these temperature variations have constituted a fruitful source of trouble in ship turbines. The use of very high superheat, which with electric drive constitutes a perfectly safe method of obtaining a high degree of fuel economy, will unquestionably involve danger in reversing operations with geared turbines, and these dangers are likely to be most serious in large units designed for high efficiency.

In ship propulsion through turbines and gears, it is desirable in all cases involving large power to use a plurality of turbines for each propeller; whereas with electric drive each propeller is driven by but one turbine or by a part of the power received from one. A subdivision of turbine units involves considerable loss and complication due to the multiplication in the number of packings, and also it involves a loss of pressure and liability to steam and air leakage in the cross connections between different units.

While the simple operation of transmitting power through gearing is more efficient than its electrical transmission through generators and motors, the difference in large units is much less than has been generally supposed, and it is in a great measure compensated for by the friction load occasioned by the reversing turbines and by the disadvantage incident to the use of a plurality of turbines instead of one. If, in the interest of the gear proposition, anything is sacrificed in turbine speed or design or in the degree of superheat adopted, the electric drive will show an advantage even under the conditions for which the geared turbine is best adapted.

While much good service has been performed by geared-turbine equipments in ships, experience has shown that their success is dependent upon great accuracy of manufacture, that they are subject to injury through vibrations in the ship's structure or through wear in bearings or insecurity of mountings. Electric propulsion involves no motion other than simple rotation and this gives a maximum of mechanical simplicity.

The *New Mexico* at Full Speed

General Characteristics of Electric Ship Propulsion Equipments

E. F. W. ALEXANDERSON*

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An analysis of the power requirements for battleship propulsion shows that they are altogether special and are determined wholly by the speed-torque characteristics of the vessel's propellers. In a turbo-electric equipment for this service, where the motor and generator are so designed that the most advantageous working conditions of one correspond to that of the other, the torque developed by the induction motor is wholly dependent upon the field excitation of the turbine generator; the full speed of the ship being determined by the amount of excitation that can be applied continuously, and the performance under overload and in reversing upon the amount of excitation that may be applied momentarily. In this article Mr. Alexanderson gives a very interesting discussion of the theoretical considerations involved, and shows how the requirements were fulfilled in the design of the motors and generators.—EDITOR.

Introduction

The electric propulsion equipment for the U.S.S. *New Mexico* is an electric power plant of considerable size. On account of the special purpose for which this power plant is designed, its electrical characteristics differ fundamentally from those with which the electrical engineering practice has become familiar in connection with power distribution. In the early stages of electrical development, power plants were frequently designed to operate at constant current, but soon the constant-current system became displaced by the constant-potential system which is now so universally used that we have acquired the habit of thinking of the electrical characteristics of all machines in terms of constant potential. In an electric propulsion equipment we are, however, reverting in certain respects to earlier ideas, and inasmuch as this type of power plant resembles more nearly a constant-current system than a constant-potential system, it has become necessary to analyze the characteristics of the motors from this point of view. As a result of this analysis, the principle has been established that the peak load which the motors can carry is determined primarily by the generator and not, as we ordinarily are used to thinking, by the characteristics of the motor. In addition, there are special requirements for reversal which have been met by an analysis of the combined characteristics of motor and generator. Briefly, it can be stated that the key to the whole performance of an electric ship propulsion equipment is the field excitation of the turbine generator. The amount of field excitation that can be applied continuously determines the continuous performance at full speed, and the excitation that may be given momentarily determines the momentary overload and reversing performance. The control equipment which has been developed for the *New Mexico* is a departure from common motor practice in that the whole process of maneuvering has been planned around the idea of adapting the motors to the different functions which they are to perform by the manipulation of the generator field excitation.

The power that can be drawn from a turbine-generator of a given size is limited by its inherent drop in voltage; and, for reasons of economy, a turbine-generator is designed so that it is normally operated at or very close to its maximum output. It is therefore not possible even momentarily to draw an increased power from a turbine-generator unless the field strength is increased simultaneously. The maximum power that may be drawn from such a generator varies substantially as the square of the field current. The temperature of the hottest part varies also as the square of the field current. Therefore, heating is indirectly the limitation of the continuous output of a turbine-generator; whereas, the momentary output can be greatly increased by a momentary increase of field current. When the motor and the generator are designed so that the most advantageous working conditions of the motor correspond to the same conditions for the generator, the torque that may be developed by the motor is limited entirely by the power that the generator is able to feed to the motor; and, inasmuch as the power of the generator depends upon its field excitation, it may be said that the maximum power of the driving motor depends upon the field excitation of the generator.

The motors of the electrically propelled battleship *New Mexico* differ in several essential respects from the motors that have been heretofore used in the electrical industry. The new type of motor was arrived at through

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*In connection with the extensive theoretical analysis which has been made and which forms the basis of the electric drive adopted on the U.S.S. *New Mexico*, the author wishes to acknowledge the co-operation of Mr. A. H. Mittag.

careful study of the conditions to be met on an electrically propelled ship and the result is a motor specifically designed to meet those requirements. At the time when the motors for the *New Mexico* were designed, electric propulsion equipment had already been successfully operated on the U.S. Collier *Jupiter.* The *Jupiter* is equipped with induction motors of the slip-ring type designed for operation with a winding which permitted only one relative speed reduction between the turbine-generator and the motor. In applying electric propulsion to battleships, it became evident that the motor should have a pole-changing winding in order to permit efficient operation while cruising, as well as at full speeds. Inasmuch as the rheostats of the equipment for the *Jupiter* are used only for a few seconds at a time, it is apparently desirable to use for battleships a type of motor whereby the use of starting rheostats can be eliminated.

Starting and Reversing Characteristics

The requirements that a ship propulsion motor must fulfill in order to be adapted to the characteristics of the propeller during the various maneuvering operations of the ship were determined upon experimentally by the test of the electrically propelled collier *Jupiter* in actual operation, supplemented by tests of models of the *New Mexico* propellers furnished by the Navy Department.

Fig. 1 shows the propeller characteristics on which the design of the *New Mexico* motors was based. These propeller characteristics represent the relation between propeller torque and propeller speed when the ship is at full speed. The curve is drawn in such a way that full propeller speed is represented by 100 per cent on the X axis and the torque required to drive the ship at full speed is represented by 100 per cent on the Y axis. A further examination of the curve shows that if no driving power is applied to the propeller, it continues to rotate, driven by the water at a speed of 73 per cent. If the speed of the propeller is further reduced, by applying a braking torque, the propeller continues to be driven with considerable power by the water as a turbine and it cannot be stopped unless the braking torque is nearly equal to the full-load torque of the motor. This maximum torque of the propeller occurs at a speed of 35 per cent. After this point has been passed, the propeller can easily be stopped and can be held at standstill by a braking torque of only 40 per cent. If a quick stopping of the ship is to be effected, the motor not only has to stop the propeller, but it must be [illegible] in opposite direction. The propeller [illegible] shows that full-load motor torque in the reverse direction is required to [illegible] the propeller at 33 per cent speed backwards.

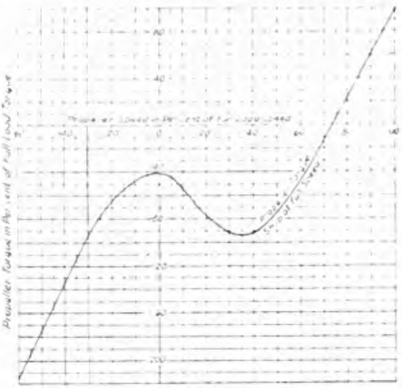


Fig. 1. U.S.S. *New Mexico* Propeller Characteristics

In order to design a motor to meet the requirements for quick maneuvering and reversal of the propellers, it is obviously necessary to have a motor which can not only develop a considerable driving torque to the propeller when it rotates in the reverse direction, but which also has a braking effect as high as full-load driving torque in order to stop the propeller before it can be reversed. To those familiar with induction motor design, it is evident that this is a particularly exacting requirement. In accordance with the practice of the past, such requirements could be met only with an induction motor of the type using special starting resistances. In the *New Mexico,* this problem has been solved by the use of a squirrel-cage type of motor of special design. The rotor contains two squirrel cages, one with a high resistance and one with a low resistance, these two squirrel cages being inductively related in such a way that the high-resistance cage produces a high reversing torque, whereas the other cage provides a low-resistance path for the current at full speed, thereby insuring high efficiency. The characteristics of the double-squirrel-cage motor, which will be treated more in detail later, is shown in Fig. 2. The two curves given in Fig. 2 represent the speed-torque characteristics of such a double-squirrel-cage motor, the upper curve when the motor is fed from constant potential and the lower curve when the motor is fed from a generator of corresponding size. Ordinarily, induction motors are designed for operation on a constant-potential system. The wide divergence between the two curves shows, however, that this conventional point of view must be abandoned in the design of an electric ship propulsion equipment, and the motor with its generator must be designed as one composite unit. This idea has been strictly adhered to in the design of the *New Mexico* equipment; and as the point of view differs from the conventional theory of induction motors some further explanation may be needed.

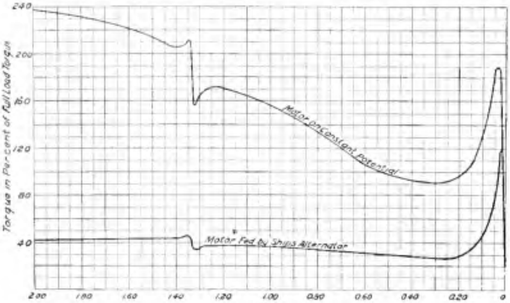


Fig. 2. Comparison of Characteristics of Double-squirrel-cage Induction Motor When Operated on Power Circuit of Constant Potential and the Same Motor Used for Ship Propulsion

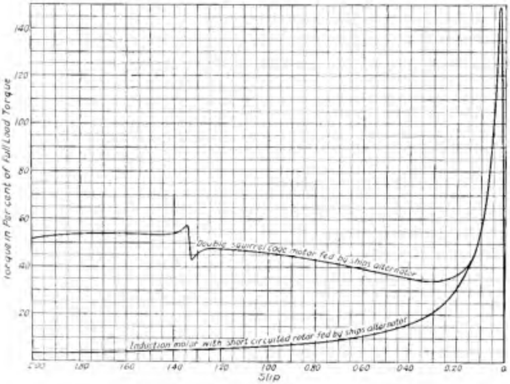


Fig. 4. Comparison of Double-squirrel-cage and Ordinary Induction Motor of Same Rating

Fig. 3 shows how the requirements of the speed-torque characteristics have been met in the U.S.S. *New Mexico* by the use of double-squirrel-cage induction motors. The combined speed-torque characteristics of the motor and generator are superimposed upon the propeller characteristics so that the diagram shows at a glance what torque is available to overcome this resistance of the water at different speeds of the ship and of the propeller. The two most interesting conditions are the normal full-speed forward operation and the reversal of the propellers while the ship is running full-speed forward.

The margin of motor torque over the propeller requirements during normal operation has been given careful consideration because it directly affects the cost and weight of the equipment. Off-hand, it might be thought that these conditions would be reflected in the size of the motor; that is, however, not the case because the momentary overload capacity is determined entirely by the size of the generator as has been explained in the foregoing. This is a matter that should be given careful consideration in the practice of operating electrically propelled ships, so that the economy of the propulsion equipments that may be designed in the future may be based upon practical experience. To illustrate this point of view, it may be assumed that the generator is designed so that it has no margin. In other words, it may be assumed that the ship is operated with a propeller torque which is, say, within one per cent of the maximum torque of the motor equipment. If this were the case, the least irregularity would cause the motors to fall out of step, with the consequent necessity of bringing them again into step by an increase of the field strength whenever this happens. If, on the other hand, the equipment were designed so as to give 50 per cent margin of torque to supply the momentary increase of torque which occurs in sharp turning operations, the equipment would be handicapped by the cost and weight of too large a generator.

In respect to normal operation and breakdown torque, the double-squirrel-cage motor has the same characteristics as the normal induction motor and whatever margin of torque is found necessary for one type will apply to the other. The necessity for developing a special kind of motor for ship propulsion is indicated by the speed-torque characteristics of the propeller at reversal, see Fig. 1. The propeller curve in combination with the comparative curves, Fig. 1, shows that an induction motor of the ordinary kind with short circuited secondary would give an entirely inadequate torque for reversal.

The curves in Fig. 3 show the propeller and motor characteristics of the U.S.S. *New Mexico*. A study of these curves will show the complete process of reversal and the reasons for the sequence of operation. The point *A* represents full-speed forward operation with full-motor torque. As soon as the motor power is interrupted, the propeller slows down to point *B*. In the process of reversal, the motor windings [illegible] the 24-pole to the 36-pole connection, [illegible] the speed-torque characteristic *C*. If this change is made without an increase in the generator field excitation, the propeller speed would be reduced by the braking [illegible] of the motor to the point *C*, but the propeller would not stop. In the process of reversing the generator excitation is therefore immediately increased 50 per cent so that the motor speed-torque characteristic *H* is obtained. Thus, the motor has sufficient power not only to stop the propeller, but to drive it backwards to a speed and a torque represented by the point *D*. While this condition in itself represents a powerful reversal, it is not all of which the equipment is capable. The adjustment of the steam governor is therefore changed simultaneously with the throwing of the reversing levers. Consequently, the generator slows down and the motor torque characteristic is modified accordingly. The result is that the operating point *E* is reached where the motor drives the propeller in the normal way with low slip

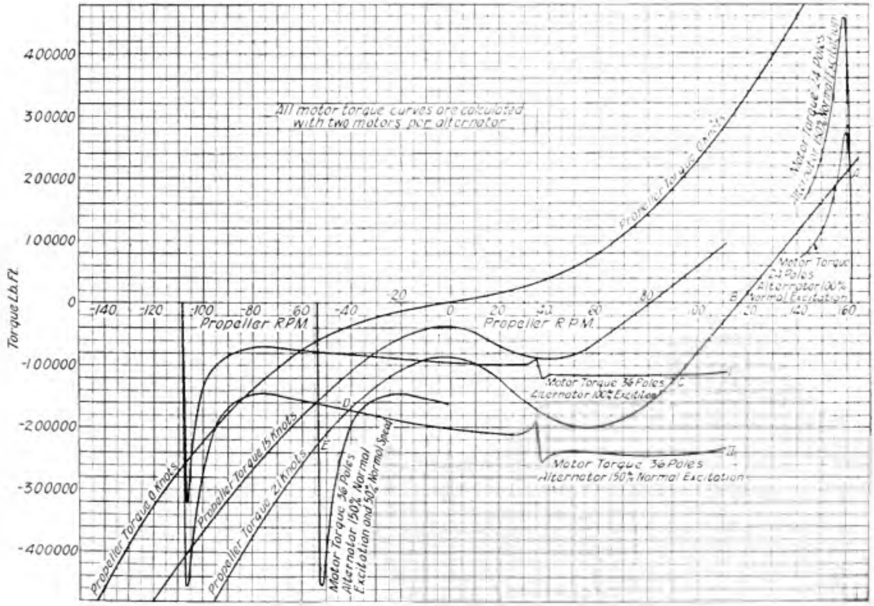


Fig. 3. *New Mexico* Motor and Propeller Characteristics

and ample overload capacity which permits the use of still higher backing power if desired.

For the benefit of those who may be interested in the design of double-squirrel-cage motors for other purposes, there are given in Fig. 5 design diagrams of the motor which are the basis of the sample calculations given in Table I (pages 230–231).

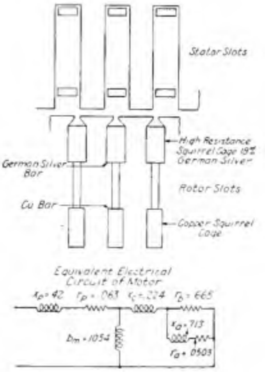


Fig. 5. Design Diagram and Equivalent Electrical Circuit of Motor for 24-Pole Connection at 35.5 Cycles

As a result of these calculations, the complete characteristics of the motor at a terminal potential of 4200 volts are given in Fig. 6.

Fig. 7 shows the characteristics of the turbine generator. In order to make it possible to transfer the ampere and kilowatt readings from the motor characteristics of Fig. 6 to the generator characteristics of Fig. 7, the scale of amperes and kilowatts on the generator curve are one half of the total; in other words, the amperes and kilowatts delivered to one motor.

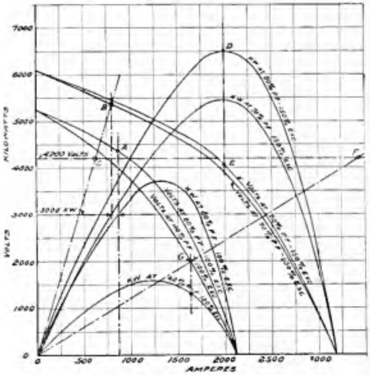


Fig. 7. U.S.S. *New Mexico* Turbo-generator Voltage and Kilowatt Curves with High Voltage Connection and at 35.5 Cycles. Amperes and kilowatts are one half of actual generator values, that is, they are values per motor

The combined motor and generator characteristics can be determined by transferring the readings from the motor characteristics to the generator characteristics as follows:

In Fig. 7, point *A* shows the volts and amperes of the motors when drawing 3000 kw. per phase at 100 per cent generator excitation.

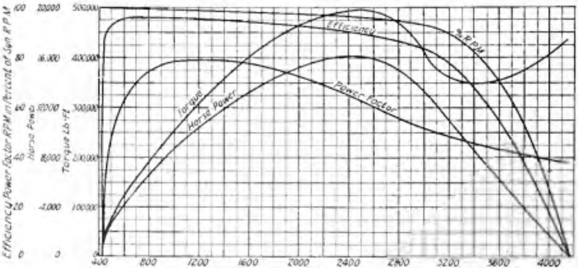


Fig. 6. U.S.S. *New Mexico* Double-squirrel-cage Induction Motor Characteristics on Constant Potential of 4200 Volts and at 35.5 Cycles

- Point *B* shows the volts and amperes of the motors when drawing 3000 kw. per phase at 150 per cent generator excitation.
- Point *C* gives the current (625 amperes) drawn by the motor when operated at 4200 volts at the same slip as point *B*. The efficiency and power-factor corresponding to point *B* may therefore be read from Fig. 6 at 625 amperes.
- Point *D* shows the maximum kilowatts (6500 per phase) at 150 per cent excitation. This is the load at which the motors break out of step.
- Point *E* shows the volts and amperes at maximum kilowatts.
- Point *F* shows the volts and amperes drawn by the motor at 4200 volts at 20 per cent slip according to Fig. 6.
- Point *G* shows the volts and amperes of the motor at 20 per cent slip when fed from the generator at 100 per cent excitation. This is the condition obtaining if the motors have broken out of step at full speed of the ship.

As a result of this analysis, it can be stated that an increase of 50 per cent generator field increases the overload margin from 23 to 116 per cent. At normal load, the generator with an increase of 50 per cent in the field will deliver power to the motor at 5300 volts instead of 4200, the efficiency remains practically constant at 95.5 per cent while the power-factor drops from 78 to 68 per cent. Thus it is obvious that with the generator operating at a less efficient point, at the lower power-factor, and with the excessive heating of the generator field, it would be uneconomical to operate continuously at this increased field strength; whereas it has proven necessary to increase the field momentarily to meet temporary requirements.

Pole Changing Motor Winding for Changing Speed Reduction

In motors of types used previously, it had been possible to change the speed at the rate of 2:1 by the use of a single winding, the connection of which had been changed from one number of poles to twice that number. In the propulsion of battleships, a speed ratio of 2:3 was desired. It had previously been the practice to accomplish speed changes of

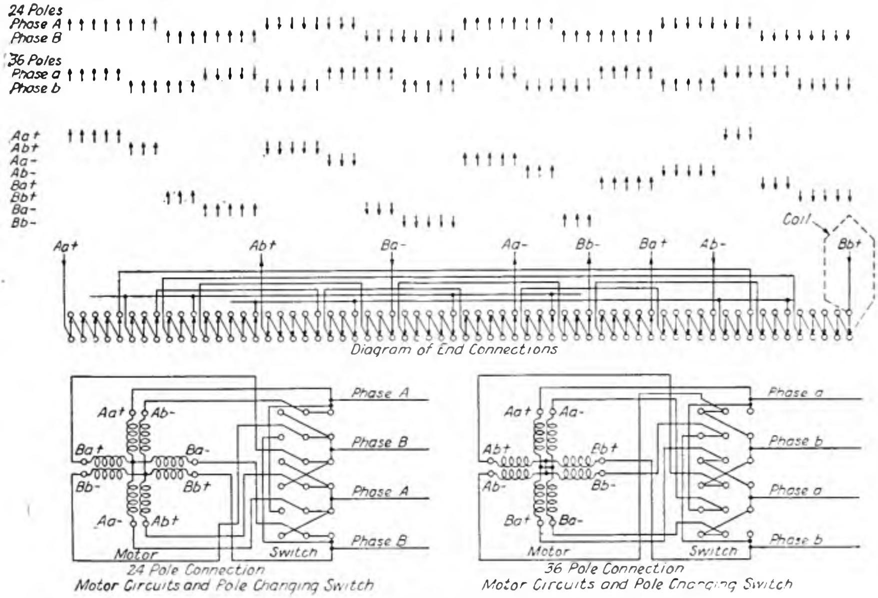


Fig. 8. Diagram of 24-36 Pole Motor Winding of U.S.S. *New Mexico* Showing Principle of Design, Winding Connections and Pole Changing Switch

TABLE I

THEORY AND CALCULATION OF CHARACTERISTICS OF THE DOUBLE-SQUIRREL-CAGE INDUCTION MOTOR

SYMBOL		SLIP OF MOTOR		EXPLANATION
	s	0.01	1.00	
r_a		0.0503	0.0503	Resistance of squirrel-cage winding in bottom of rotor slots. This winding will hereafter be called the lower squirrel cage and the squirrel cage in the top of the rotor slots will be called the upper squirrel cage.
r_{ap}	$=\frac{r_a}{s}$	5.03	0.0503	Equivalent resistance of lower squirrel cage at slip *s*.
x_a		0.713	0.713	The reactance of the lower squirrel cage which is not mutual with the upper squirrel cage.
Z_a^2	$=r_{ap}^2+x_a^2$	25.8	0.51	Equivalent impedance squared of lower squirrel cage at slip *s*.
g_a	$=\frac{r_{ap}}{Z_a^2}$	0.195	0.0986	Conductance of lower squirrel cage at slip *s*.
b_a	$=\frac{x_a}{Z_a^2}$	0.0276	1.40	Susceptance of lower squirrel cage.
r_b		0.665	0.665	Resistance of upper squirrel cage.
r_{bp}	$=\frac{r_b}{s}$	66.5	0.665	Equivalent resistance of upper squirrel cage at slip *s*.
g_b	$=\frac{1}{r_{bp}}$	0.01502	1.503	Conductance of upper squirrel cage at slip *s*.
g_{ab}	$=g_a^2+g_b$	0.21	1.602	Resultant conductance of both squirrel cages in parallel.
Y_{ab}^2	$=g_{ab}^2+b_a^2$	0.0449	4.53	Admittance squared of both squirrel cages in parallel but not including mutual reactance.
r_s	$=\frac{g_{ab}}{Y_{ab}^2}$	1.68	0.354	Resulstant rotor equivalent resistance at slip *s*, both squirrel cages in parallel.
x_{ab}	$=\frac{b_a}{Y_{ab}^2}$	0.615	0.309	Resultant reactance of both squirrel cages in parallel, but not including the mutual reactance.
x_c		0.224	0.224	Mutual reactance of both squirrel cages.
x_s	$=x_{ab}+x_c$	0.839	0.533	Total resultant rotor reactance of both squirrel cages in parallel.
Z_s^2	$=r_s^2+x_s^2$	22.5	0.41	Impedance squared of rotor.
g_s	$=\frac{r_s}{Z_s^2}$	0.208	0.864	Conductance of rotor.
b_s	$=\frac{x_s}{Z_s^2}$	0.0373	1.30	Susceptance of rotor.
b_m		0.1054	0.1054	Magnetizing susceptance.
b_{sm}	$=b_s+b_m$	0.1127	1.405	Resultant susceptance of rotor and magnetizing susceptances.
Y_{sm}^2	$=g_s^2+b_{sm}^2$	0.0636	2.71	Admittance squared of rotor and magnetizing circuits combined.
r_{sm}	$=\frac{g_s}{Y_{sm}^2}$	3.27	0.319	Resultant resistance of rotor and magnetizing circuits.

(Cont'd on next page)

TABLE I—Continued

THEORY AND CALCULATION OF CHARACTERISTICS OF THE DOUBLE SQUIRREL-CAGE INDUCTION MOTOR

SYMBOL		H.P. OF MOTOR		[illegible]
		[illegible]	[illegible]	
x_{sm}	$=\frac{b_{sm}}{Y^{2}_{sm}}$	2.21	0.518	Resultant reactance of rotor [illegible]
r_p	=	0.063	0.063	Resistance of primary winding.
x_p	=	0.42	0.42	Reactance of primary winding.
r	$=r_{sm}+r_p$	3.33	0.382	Total equivalent resistance of motor at slip s.
x	$=x_{sm}+x_p$	2.66	0.938	Total equivalent reactance of motor at slip s.
Z	$=\sqrt{r^2+x^2}$	4.26	1.012	Total equivalent impedance of motor at slip s.
$P.f.$	$=\frac{r}{Z}$	0.781	0.378	Motor power-factor.
I	$=\frac{E}{Z}$	985	4150	Motor current at 4200 volts (normal voltage) and at slip s.
$S.Kw.$	$=\frac{I^2r_{sm}}{1000}$	3170	5490	Torque per phase in synchronous kilowatts.
T	$=79.3\times S.Kw$	251,000	435,000	Total torque in pound-feet at slip s.
$Kw.$	$=\frac{2I^2r}{1000}$	6460	6580	Kilowatts input into motor not including core loss.

such character by using two motor windings, one for the one speed and one for the other, one winding thus being always idle, which necessarily results in reduced efficiency. In order to combine the highest motor efficiency with the requirements of the speed change, a new type of winding was worked out which is shown diagrammatically in Fig. 8. An examination of the diagram will show that this winding has a distribution of conductors which corresponds to a normal quarter-phase winding in the 24-pole as well as the 36-pole connection. By use of this type of winding the advantage is gained that all the conductors in the windings are active with the same efficiency as in an ordinary induction motor with a one-speed winding. The new type of pole-changing winding adapts itself better to quarter-phase than to three-phase connections and this is the reason why the whole propulsion equipment is designed for quarter-phase generator and motors.

Fig. 8 is a diagram of the 24 to 36-pole motor windings of the U.S.S. *New Mexico*, as well as the nearly completed battleships *California*, *Maryland*, and *West Virginia*. The diagram shows the principle of design, winding connections, and pole-changing switch. The arrows in the upper part of the diagram represent coils in the winding, the arrow heads directed upward indicating current flowing in a clockwise direction and the arrow heads directed down indicating current flowing in a counter-clockwise direction.

The upper group of arrows shows the distribution of coils and direction of current flowing in the two phases of the winding when the motor is in the 24-pole connection. The second group of arrows shows the corresponding 36-pole arrangement. The third group of arrows shows how the coils are permanently grouped together in eight winding sections. The diagram below shows how these winding sections are combined into a complete motor winding. The lower diagram shows how these winding sections are arranged with reference to the pole-changing switches. The diagram covers only one sixth of the complete winding, in other words, it is a diagram for a complete group of four to six poles, this winding arrangement being repeated to make the complete 24-to-36-pole motor.

It is to be noted that with the same system of winding design it is possible to work out a winding for any pole combination that may be desired, for instance, in the process of considering various propulsion problems, windings were worked out for motors such as 22 to 28 poles.

In the *New Mexico* equipment, the generator has a winding which may be connected either in a square quarter-phase diagram or in a diagram with two circuits in parallel in each phase. This arrangement is in accordance with the principle that the generator and motor must be designed as a composite unit. When the ship is operated at cruising speed, it is only necessary to use one generator to feed the four motors; whereas, at full speed, each generator carries two motors. Thus when the load circuit of one generator is changed from four motors in parallel to two motors in parallel, all resistances and impedances of the combined low circuit are doubled. The relative impedances of the motor and generator have, however, been carefully determined so as to give the best results. To maintain these favorable relations with two as well as with four motors per generator, the impedance of the generator should be changed correspondingly. Such a change of generator impedance could not be obatined by a series-parallel connection of the windings, because such a combination would change the impedance at the rate of 4:1. The square-parallel arrangement, however, gives exactly the desired change of 2:1. It is thus a fortunate coincidence that the quarter-phase system is at the same time particularly adapted to the new type of pole-changing winding which has been described and also makes possible the most efficient method of change from one to two alternators.

Summary

Simplicity and reliability have been aimed at in the design of the electrical equipment by the elimination of liquid rheostats, which have heretofore been required for motors of a similar duty, and a new type of squirrel-cage induction motor has been developed which has inherently the desired characteristics to meet reversing as well as operating requirements. All momentary power requirements are met by corresponding adjustments of the generator field excitation thereby insuring a maximum economy for all purposes. The motor has a pole-changing winding and the generator a voltage-changing winding which are adapted to each other in such a way as to give three working combinations corresponding to 32,000, 16,000, and 8,000 horse power. In each of these working connections, the motor as well as the generator operates at its maximum electrical efficiency and thus it has been possible to avoid the reduced efficiency which ordinarily accompanies the operation of electrical power apparatus at low output.

The Turbines of the U.S.S. New Mexico

By E. O. Hunt

Ship Propulsion Division, Turbine Engineering Department, General Electric Company

The birth of the kinetic power that propels the *New Mexico* takes place in two duplicate Curtis turbines direct connected to two alternating current generators. As emphasized in the following article, wh[illegible] their construction and operation, they are practically of the same design as those built for land operation by the same manufacturer. One of the distinctive features of these marine propulsion turbines is their ability to operate over a wide arrange of speed under the control of a novel governing arrangement especially designed for this application. At the conclusion of the article is described the exciter turbines and the reduction gears through which they drive the exciter generators.—Editor.

The impulse principle, as typified in the Curtis turbine, permits of a stronger mechanical construction than that of other types and one less subject to inherent difficulties in operation. This construction, as shown by Fig. 1, is particularly advantageous for turbines employed in the propulsion of vessels, an application where reliability is of prime importance. The general design of the turbines for the U.S.S. *New Mexico* is quite similar to the thousands of other Curtis turbines manufactured by the General Electric Company for various land purposes.

The adaptability of such land turbines for use in driving generators for the electric propulsion of vessels is clearly demonstrated by the turbines of the *New Mexico*, where the only modifications necessary were in the design and construction of those parts which are secured to the bed of the ship and in the novel arrangement of the governing mechanism to permit the desired wide range of speed control.

The turbines, as well as the other apparatus described in the accompanying articles, strictly conform to the general machinery specifications of the Bureau of Steam Engineering, United States Navy Department. A longitudinal section drawing of the turbine is shown in Fig. 1, and the principal overall dimensions of one of the complete propulsion units are given in Fig. 2.

Impulse Turbine Principle

The Curtis steam turbine is an impulse machine, i.e., the rotating element is actuated by the impact of steam passing through its buckets at relatively high velocity but without actual expansion in them. The steam is expanded in stationary nozzles, where it acquires relatively high velocity, and then passes through and impels the moving buckets of the stages.

The steam coming from the boilers enters the first-stage steam bowl through the combined throttle and trip valve with strainer, which is under the control of the emergency governor. The quantity of steam admitted is normally regulated by the operating governor which actuates a pilot valve of the hydraulic cylinder by an arrangement of floating levers that are connected to the governor lever; the pilot valve admitting oil under pressure to the hydraulic cylinder thereby moving a piston and rack up or down. The steam chest has ten controlling valves with ports leading from each valve to a group of first-stage nozzles. These control-

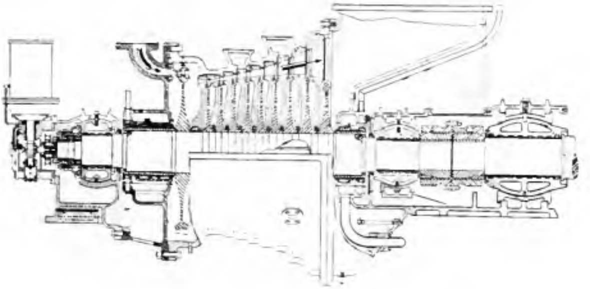


Fig. 1. Cross-section of one of the Turbines of the Two Turbine-generator Propulsion Sets of the U.S.S *New Mexico*

ling valves are operated by cams so arranged on a shaft that the valves are raised or lowered in a definite succession.

From the first-stage bowl the steam expands through the first-stage nozzles, entering the first row of revolving buckets of the first-stage wheel, thence passing through the stationary buckets, or intermediates, which reverse its direction and redirect it against the second row of revolving buckets of the same wheel.

This constitutes the performance of the steam in one stage, or pressure chamber. Having entered the first row of buckets with relatively high velocity, it leaves the last row of the first-stage with relatively low velocity; much of its energy between the limits of the inlet and discharge pressures having been abstracted in passing through the first-stage to the nozzles of the first diaphragm. It has, however, a large amount of unexpended energy, since the expansion has covered only a small part of the available pressure range. The expansion process is therefore repeated in subsequent stages.

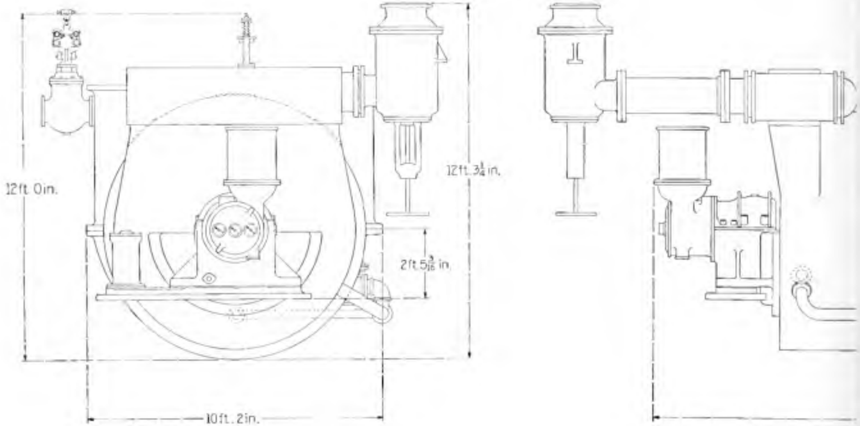


Fig. 2. Outline of Turbine-Generaror Un

The steam, having left the buckets of the first-stage wheel and having had its velocity greatly reduced, reaches a second series of bowls in the first diaphragm, opening upon a second series of nozzles for the second stage which are cast integral with the diaphragm. Through these nozzles the steam expands from the first-stage shell pressure to a lower pressure, again acquiring relatively high velocity in its expansion, and impinges upon and passes through the moving buckets of the second-stage wheel.

Again, the velocity acquired in the nozzle diaphragm of the third stage is expended in passing through the buckets of the third-stage wheel; this process being continued through the remaining seven stages of the turbine. After leaving the tenth-stage wheel, the steam passes through the exhaust hood into the main condenser.

Steam and Exhaust Pressure

The full-power operating conditions for the turbines according to the contract are 250 lb. gauge steam pressure, 50 deg. F. superheat at the throttle valve, and at the exhaust an absolute back pressure of 1.5 in. of mercury when referred to a 30-in. barometer.

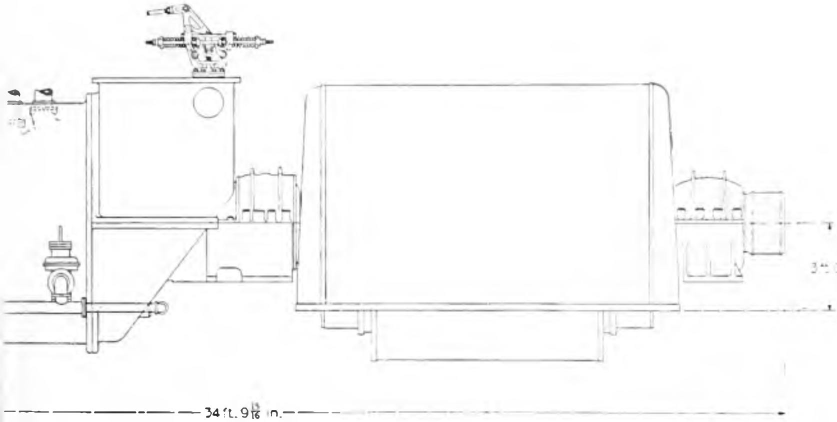
Direction of Rotation

The direction of rotation of the turbine wheels is always counter-clockwise, or left-hand, when viewed from the head end. With this system of ship propulsion the turbine-generators are run continuously in one direction; the propellers being reversed by the electric motors. This arrangement simplifies the maneuvering of the vessel and recent experience has proved it to be extremely simple and satisfactory. As the momentum of moving vessels is enormous, the full power available for astern operation in case of emergency affords a degree of protection not found in other methods of turbine propulsion.

Throttle Valve and Emergency Governor

The steam is admitted from the main steam pipe to the valve casing of the turbine through a combined throttle and trip valve with strainer. The strainer is provided to prevent the possibility of scale or other foreign matter from entering the first stage nozzles and doing damage to the rotating parts. The design of this valve is exactly the same as those used in connection with land turbines, and the valve seats are made of non-corrodable metal. This valve is automatically closed, in case of overspeeding of the turbine, by the emergency governor which is of the ring type and mounted on the main turbine shaft between the governor drive and the thrust-bearing mechanism.

The governor is slightly unbalanced, and the centrifugal force acting on this unbalanced weight is counter-acted by springs. The governor is so designed that when the turbine speed increases approximately 10 per cent above normal the centrifugal effort overcomes the springs and the rings move out and strike the trip finger of the emergency tripping device. When this occurs, the throttle valve and the stage valves which convey the steam from the exciters to the lower stages of the turbine are closed and the [illegible] from the exciter units is by-passed automatically through a spring loaded back [illegible] valve to the exhaust casing of the turbine, thence to the main condenser.



owing Principal Overall Dimensions

Valve Casing and Controlling Valves

The valve casing for receiving the controlling valves, one of which is shown in Fig. 3, is a steel casting with the upper surface machined for the valve stuffing boxes, the brackets for supporting the cam shaft being bolted directly aft of the controlling valve. The parts of the valves which are exposed to the action of the steam are made of non-corrodable metal, are easily renewable, and are so proportioned as to prevent injuries by high steam velocities.

The cams for the operation of the controlling valves are arranged on the cam shaft in such a manner that the valves are raised and lowered in proper sequence; this being determined by the angular spacing of the cams on the shaft. Provision is made so that the valves are automatically closed should they have a tendency to remain open when the load on the generator is reduced for any reason.

First-stage Nozzles

The first-stage expanding nozzle segments, which deliver the steam to the first-stage buckets, consist of several groups of nozzles.

each group being under the control of one of the controlling valves illustrated in Fig. 3. They are of such dimensions that the steam is expanded from the bowl pressure to the predetermined pressure necessary to give the steam the desired velocity. These groups of nozzles become active successively, and the regulation of the turbine speed is accomplished by lengthening or shortening this belt for admitting steam; at the maximum load the full nozzle segment is brought into action.

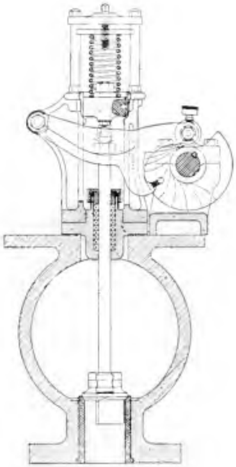


Fig. 3. Assembly of one of the Controlling Valves for First-stage Steam Nozzles

Bucket Wheels

The bucket wheels are steel forgings, machined over their entire surface and are proportioned to give good distribution of centrifugal load and to insure proper fit on the shaft to which they are keyed. In order to obtain a good fit between the wheels and the shaft, the bore of the hubs have varying diameters increasing from the first wheel and reaching the maximum at the tenth wheel. The rims are machined to receive a single row of buckets, with the exception of the first wheel which has a double row of blading. The dovetailed chamber is opened for the insertion of the buckets and is afterwards closed by a spacing block. The first-stage and tenth-stage wheels have tapped holes conveniently arranged for the reception of balancing weights; these holes being accessible through openings in the upper half of the head and the exhaust hood. All wheels have a number of holes for the purpose of equalizing the steam pressure on either side of the wheel.

Buckets

The buckets for the first eight wheels are formed with a dovetail shaped tenon as shown in the assembly drawing of the turbine, Fig. 1; the buckets for the remaining two wheels being of the standard inverted type. The intermediate or stationary buckets for the first stage are dovetailed into the intermediate segment which is secured to the upper half of the shell in an approved manner. The intermediate buckets are prevented from displacement by the use of a clearance block which is machined to exactly the same width as the intermediates; this block, as its name indicates, is also used when measuring the clearance between the stationary and revolving buckets.

All buckets, which are of rugged design, are carefully polished before being assembled. Surrounding their outer ends is a metal shrouding to which the end of each individual bucket is securely riveted. The shroud bands are made in segments, ample clearance being provided between joints for the purpose of preventing excessive strains being imposed upon the bucket tenons. The function of the shrouding is partly to stiffen the complete row and reduce vibration, and partly to assist in retaining the steam flow in the proper path.

Nozzle Diaphragms

The nozzle partitions are of nickel steel and cast integral with the diaphragms of the remaining stages; these diaphragms being in halves, split horizontally, and fitted at the joints with non-corrodable radial keys for the purpose of maintaining the alignment of the halves. As the steam expands from stage to stage, its volume rapidly increases and consequently a greater area of steam passage must be provided. This is accomplished by simply increasing the height of the buckets and the number and area of the nozzles for the various stages.

The nozzles of all diaphragms of the turbines are spaced on the complete circumference of the diaphragms. Ample arrangements are made for the handling of the diaphragms, and leakage of steam at the shaft is prevented by a type of semi-labyrinth packing. The diaphragms bear a relatively heavy pressure from the steam on their forward sides and steam tight joints are formed at the point of contact with the turbine shell without the use of bolts and nuts. Provision is also made for securing the upper halves of the diaphragms to the shell when these parts are being lifted for the examination of the interior parts of the turbine.

Head and Shell

The turbine head which supports the valve casing and the labyrinth type packing is a steel casting and is carefully annealed to eliminate casting strains. The steam which is fed from the controlling valves to the first stage nozzle passes through openings in the upper half of the head; one of these ports for a group of nozzles being shown in Fig. 1. The casting is strongly ribbed and the flange bolts are located so as to reduce to a minimum any possibility of distortion. Connections are provided for the steam seal pipes leading to the shaft packing.

The turbine shell is also in halves, split horizontally, and arranged for bolting together, to the head, and to the exhaust casing; this bolting being arranged to facilitate the inspection of the interior parts of the turbine. The shell has turned internal seats to receive the nozzle diaphragms. The upper half of the shell has two flanged connections for the admission of the exhaust steam from the 300-kw. exciter units: one of these connections leading into the fourth-stage shell, and the second connection leading into the seventh-stage shell, as indicated in Fig. 1.

The design of the lower half of the shell is quite similar to the upper half; the main exception being that flanged connections are provided on either side of the shell for the admission of the excess leakage steam which escapes from the head-end labyrinth type packing under abnormal conditions of operation.

The use of the impulse type of turbine makes it possible to reduce considerably the length of the turbine shell as well as the shaft in comparison with that which would be necessary were reaction blading used. The assembly drawing of the turbine, Fig. 1, clearly shows the simple and compact arrangement of the shell and enclosed parts. When it is required that the upper half of the shell be lifted for the inspection of the internal mechanism, this work is simplified and damage to the parts is prevented by guide pins which are used for preserving the alignment of the parts. Ample provision is made for draining the shell of water accumulations.

Exhaust Casing and Standard, Middle Bearings, and Exhaust Hood

The section through the exhaust casing and standard, and the turbine and generator middle bearings, is shown in Fig. 1. The casing is securely bolted to the ship's foundation and is fixed against longitudinal movement. By this method, the leverage between the seating and the center line of the turbine is greatly reduced. A novel feature in connection with the cast-in pipes for the sealing steam of the low-pressure labyrinth-type packing, which eliminates the troublesome features in connection with fittings, is shown by Fig. 1. Any accumulation or spill of water from the packing casing is carried away by a pipe which is connected to the chamber at the after side of the packing casing. The drain pipe for taking care of any water which accumulates in the low point of the casing is lead through suitably arranged piping to the turbine drain pump. The two middle bearings, as well as the flexible jaw coupling, are totally enclosed by the casing and bearing caps. The exhaust hood, which is arranged for an upward exhaust and conveys the steam to the main condenser, is of cast iron and rectangular in shape, and is supported against the pressure from without by suitable struts.

Flanged connections are provided for the bolting of the spring-loaded relief valve which is employed when the exhaust steam of the exciter units is being fed directly to the main condenser rather than to the lower stages of the turbine. The removal of the exhaust hood is expedited by the use of lifting straps.

Turbine Shaft

The turbine shaft is of forged nickel steel and is machined over its entire surface. The shaft is "stepped" for the reception of the bucket wheels; provision being made for preventing the axial displacement of the wheels on the shaft. Each wheel is balanced before being assembled on the shaft and the complete rotor is afterwards carefully balanced when assembled in the machine. The critical speed of the shaft is considerably higher than the operating speed, which is variable, and this prevents whipping of the shaft and injury to the bearings.

The forward end of the shaft is formed for receiving the driving mechanism of the operating governor; the thrust bearing being mounted directly forward of the head-end bearing, and the emergency governor being mounted between the thrust bearing and the governor driving mechanism. The sleeves of the shaft packings, the sleeve of the packing for the first diaphragm, and the male half of the flexible jaw coupling are mounted as shown in Fig. 1.

Main Bearings

The four main bearings of each unit are of the spherical-seat water-cooled self-aligning type, and are split horizontally to permit of their easy removal without displacing the shafts. The sleeves are heavily lined with the best quality babbit metal, and are bored and hand scraped to obtain the proper journal fit. Circumferential grooves are turned in the upper halves of the shells for the proper distribution and flow of the oil which is supplied by the forced lubrication system, under a pressure of about ten pounds gauge, by motor-driven rotary pumps.

By employing the forced system of lubrication, a perfect oil film is maintained between the revolving journal and the stationary bearing, and the heat generated in the bearing is properly dissipated. Reliability of operation is further insured by the oil being cooled as it passes through the bearings, by coils which are imbedded in the babbitt of the top and bottom halves. These coils are connected to the water circulating system of the ship; stop valves being supplied for controlling the flow of water to each bearing.

The outlet piping from each bearing is discharged into an open tank and arrangements are made so that the discharged oil may be observed and its temperature taken. The customary arrangement of oil deflectors, oil guards, and air shields is provided for the purpose of preventing the oil discharge from the ends of the bearings being thrown from the rotating shafts.

Bearing Standards

The standard and cap for supporting the head-end bearing and for enclosing the thrust bearing is strongly ribbed to furnish the required rigidity; ample surface being provided to form a proper seating for the turbine on the base which is bolted to the ship's foundation, and upon which the standard is free to slide in a fore-and-aft direction to compensate for the expansion which takes place. Axial alignment is maintained by a key which engages in a key-way machined in the bearing standard. The standard for the two middle bearings of the unit is formed with the exhaust casing of the turbine, and by this arrangement permanency of alignment is maintained. The generator-end standard is supported directly by the ship's foundation and is not in any way bolted to the generator frame, and for the purpose of preventing the flow of eddy currents in the frame of the generator, seating, and generator-end bearing standard, the latter is insulated from its seating.

Operating Governor

The operating governor is of the centrifugal type, which is standard for this type of apparatus, and is mounted on the upper end of the governor drive vertical shaft, which is driven through worm gearing from the main turbine shaft. The governor is designed for a normal turbine speed of 2130 r.p.m., although arrangements are provided so the speed may be controlled as low as 670 r.p.m. During operation, a balance is maintained between the main governor spring and the centrifugal force acting upon the governor weights; the motion being transmitted through the spindle to the transmission bearing which is mounted in the governor lever.

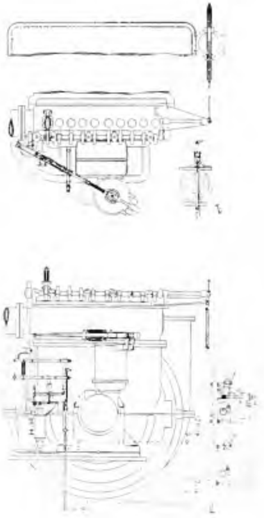


Fig. 4. Arrangement of Hydraulic Operating Mechanism showing connections to the main operating switchboard, and the 8-in. spring-loaded relief valve

From the governor lever the motion is further transmitted through a series of levers to the pilot valve of the hydraulic cylinder, the general arrangement of this mechanism being shown by Fig. 4.

Hydraulic Operating Mechanism

The hydraulic operating mechanism of the turbine consists essentially of a cylinder to which oil under pressure is fed through a pilot valve from the lubricating system of the turbine; this pilot valve being normally under the control of the operating governor just described. Fig. 4 shows the general arrangement of the hydraulic gear and the connection through the cam shaft to the spring-loaded relief valve, which is attached to the exhaust hood, and the diagrammatic arrangement of the connections, levers, etc., which are operated from the main switchboard.

The upper end of the piston rod of the hydraulic cylinder carries a rack which meshes with a pinion on the cam shaft and so actuates the shaft for the opening and closing of the controlling valves, Fig. 3, and the spring-loaded back-pressure valve.

By the system of control shown by Fig. 4, the amount of steam admitted to the turbine is varied and the speed altered to suit the changing conditions; the governor immediately responding to a variation in speed. Under certain conditions of operation, such as turning the ship, excessive load is thrown on the inboard motors due to the action of the operating governor which tends to maintain a constant speed by admitting more steam through the controlling valves to the first-stage nozzles. In order to prevent this condition, a steam-limiting device is provided so that when adjusted for a pre-determined speed only a definite number of controlling valves may be operated. This action is accomplished by a stop block which slides up or down on the connecting rod, and which limits the travel of the pilot valve of the hydraulic cylinder in one direction only.

A steam-limit indicating switch is mounted on the hook of the stop block. While maneuvering, this limit lever with collapsable indicating switch is normally out of range, but is adjusted as soon as under way. When adjusted, any increase in the load will cause a reduction in the turbine speed, but with a decrease in the load the governor immediately operates shutting off the steam and preventing the turbine from increasing its speed beyond its normal operating range.

Emergency Tripping Device

The turbine [illegible] over-speeding by the [illegible] governor previously described, which [illegible] in connection with the emergency [illegible] device and closes the valves [illegible]

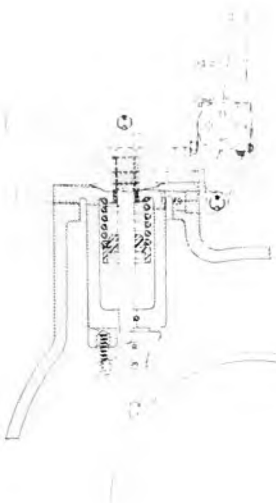


Fig. 5. Assembly of Emergency Tripping Device

steam to the turbine. When the emergency governor operates, the rings strike the trip finger of the tripping device, Fig. 5, and assume the running position shown by the dotted lines. The released rod of the emergency device, which is actuated by the stored-up energy in the main spring that is enclosed in the casing, slides on the inclined surface of the catch plate of the trip finger and carries the latter part beyond the striking radius of the governor rings.

When the trip rod is released, the hand lever is pulled downward which rotates the shaft an amount sufficient to release the catch plates that are attached to the trip lever and the trip connection leading to the valves. The upper connection, shown by Fig. 5, leads to the tripping mechanism of the combined throttle and trip valve; the lower connection being united to the two trip valves that are connected through check valves to the lower stages of the turbine. The throttle valve and the stage valves may also be tripped by simply pressing down on the hand lever, Fig. 5, sufficiently to disengage the catch plates.

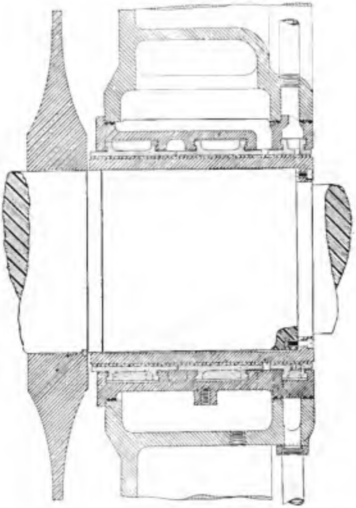


Fig. 6. Assembly of High-pressure Head-end Labyrinth-type Shaft Packing

Thrust Bearing

The axial position of the turbine rotor is determined by the setting of the thrust bearing which also absorbs the axial thrust of the rotor when the turbine is in operation. The bearing is mounted within the head-end bearing standard, and consists essentially of an outer shell which is in halves and supported by the main turbine bearing, an inner shell which is also in halves, and a thrust collar which rotates between two babbitt-faced thrust rings that are dowelled to prevent their turning. Arrangements are provided for making the necessary adjustments so as to obtain the proper end-play or oil clearance between the rotating collar and stationary rings.

The thrust bearing is so constructed that the axial position of the rotor, and therefore the effective bucket clearance, may be altered by adjusting a worm shaft which extends through the bearing standard. The thrust bearing is lubricated by oil which flows through holes drilled in the turbine shaft and which communicate with radial grooves in the bearing rings, and finally passes outward through the exit holes in the inner and outer shells, from whence it is returned to the main oiling system. The tendency of the turbine wheels, when under normal load, is to move the shaft axially toward the generator and if for any reason the thrust bearing rings wear abnormally, and decrease the bucket clearance beyond the predetermined amount, the wheels will rub and cause damage. For the purpose of warning the engineer in case of any such excessive wear or damage to the thrust bearing rings, emergency or "squealer" rings are fitted.

In order to indicate positively the position of the turbine rotor when the machine is in operation, a clearance indicator is fitted within the head-end bearing standard. This indicator is not normally in contact with the revolving shaft, but when desired to ascertain the operating clearance it is only necessary to press the arm of the indicator so that contact is made with the bushing of the indicator and the revolving member of the turbine.

Shaft Packings

For the purpose of preventing air being drawn inside the casing when the pressure is below atmosphere, and to prevent steam leakage when the pressure is greater than atmosphere, labyrinth-type shaft packings are fitted at the head and exhaust ends of the turbine in the manner shown by Figs. 1 and 6.

The revolving sleeves are arranged for bolting to the shaft and for the making of any necessary axial adjustments. The stationary rings are dovetailed and fitted to openings machined in the packing casings which in turn are fitted to the main casing. Under normal conditions of operation, the escaping steam from the high-pressure or head-end packing is discharged through the connection leading to the exhaust casing for sealing the low-pressure or exhaust-end packing. Under abnormal conditions, where the steam leakage from the high-pressure packing is in excess of the amount required for the sealing of the exhaust-end packing, the overplus steam is delivered through an automatic valve to one of the lower stages of the turbine. When first starting the turbine and when running at low speeds and light loads, arrangements are provided for admitting live steam to properly seal the packings and prevent air leakage.

Complications are avoided in the arrangement of steam seal connections so that at all times the full operating benefits are derived through maintaining a high vacuum.

The packings for the diaphragms, for preventing the leakage of steam between stages at the shafts, are of the semi-labyrinth type, with the exception of the one for the second stage diaphragm where a sleeve is mounted between the first and second wheels; the revolving sleeves for the remaining diaphragms being omitted as the flanges of the hubs are finished to the required outside diameter for maintaining the proper radial clearance.

Flexible Jaw Coupling

The mechanical connection between the turbine shaft and generator shaft is made by means of the flexible jaw coupling shown in Fig. 1. The coupling, which compensates for any slight inaccuracies of alignment of the shafts, consists of spiders which are shrunk and keyed on the ends of the shafts and of coupling claws which fit over and engage with the jaws of the spiders The coupling claws are bolted together by the usual type of flanges, and form a sleeve through which the power is delivered from the turbine to the generator. Bearing rings are provided for holding the coupling claws concentric with the spiders, and clearance is provided at the jaws for any axial movement due to expansion or wear of the thrust bearings.

Jaw bearing face plates are fitted in a manner so that their easy renewal may be made if required. The bearing surfaces of the coupling are lubricated by the oil discharged from the two middle bearings, it being delivered to circular grooves turned in the ends of the spiders. From these grooves the oil is carried by the action of centrifugal force through drilled holes to the bearing surfaces. By this means ample lubrication is provided, and as the coupling is completely enclosed by the bearing standard and caps no oil throwing or leakage can occur and cleanliness of operation is insured.

Lubrication

The main bearings of the turbines and generators, the thrust bearings, the flexible-jaw couplings, the operating governors, and the operating governor drives of the turbines are lubricated by the forced system of lubrication provided from the oil circulating system of the ship.

The system consists of the [illegible] number of oil pumps, oil coolers, pipes, tanks, strainers, relief valves and thermometers.

A complete system is arranged for the bearings of the port set, and a similar system in all respects for the bearings of the starboard unit; the two systems being cross connected in such a manner that in an emergency the system on either side will provide lubrication for all the bearings of both sets.

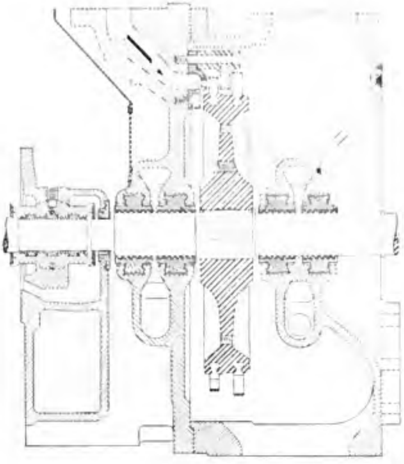


Fig. 7. Assembly of 300-kw., 5037-r p m , One-stage, Turbine for Connection Through Reduction Gears to 300-kw., 1000-r p.m., 120 240-volts Exciter Generator

The cooling water for the oil coolers is supplied by the oil-cooler circulating pumps, with emergency connections from the fire main and the main circulating pumps. The pumps draw the water from the sea, force it through the coolers and thence overboard. The discharged oil from the bearings is returned to the drain tanks which have filling pipes from the oil storage tanks.

300-KW. GEARED TURBINE EXCITER UNITS

The direct-current turbine-driven generating units which are used for excitation are designed to conform to the government requirements for this type of apparatus; the turbines being of the single-stage non-condensing type to operate at a speed of 5037 r.p m. with a steam pressure of 200 lb. gauge and atmospheric exhaust. The generators, which are rated 300-kw., 1000-r.p.m., 120 240 volts, are of the three-wire type of standard design and are driven by the turbine through a speed reducing gear.

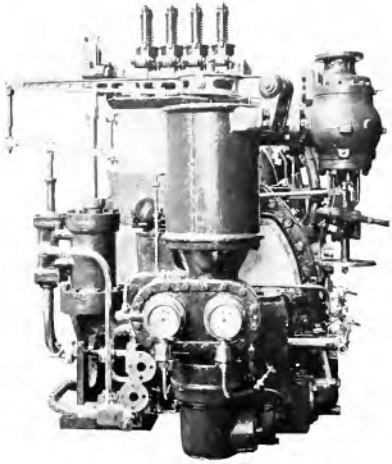


Fig. 8. View of 300-kw. Exciter Turbine

Turbine

A section through the turbine is shown in Fig. 7, the general design being in accordance with established practice. The lubricant for the various bearings of the unit is supplied by a geared oil pump which is driven through a worm and gear by the main shaft of the turbine; the upper end of the oil pump shaft receiving the operating governor.

Buckets

The single wheel carries a double row of buckets, the stationary buckets being fitted into the dovetail of the intermediate segment which is bolted to the first-stage nozzle and to the upper half of the turbine head as shown in Fig. 7.

Hydraulic Valve Gear

The general arrangement of the hydraulic operating mechanism of the turbines is shown by Fig. 8.

Pop Signal Valve

The exterior casing of each turbine is provided with a signal pop safety or sentinel valve which is adjusted to blow off at a predetermined pressure. When the signal valve discharges, it acts as a warning to the engineer that the turbine should be shut down. This valve also protects the turbine shell from excessive pressure due to a possible leaky throttle valve.

Speed Reducing Gear

The speed reducing gear, Fig. 9, is mounted between the turbine and the generator, as shown in Fig. 10, and is of the flexible-disk single-reduction type, provided with helically cut teeth and designed so as to equalize the driving pressure over the acting driving face and to limit the strain imposed at any one point.

Pinion

The teeth of the pinion are cut integral with its shaft, which is connected to the turbine by a solid flanged type of coupling.

Low-speed Gear

The disks of the low-speed gear are mounted on a hub against a central collar which sepa-

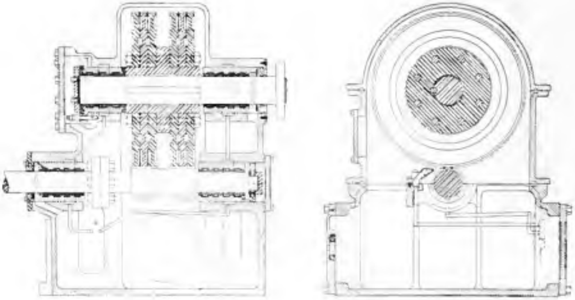


Fig. 9. Single-reduction Gear for connection of each Exciter Turbine to its Generator

rates the two members of the gear. Studs, pass through the disks and the collar to prevent axial movement of the disks at this point. The hub and the shaft have keys and keyways to prevent the displacement of the hub on the shaft. The half coupling of the low-speed gear shaft, for connection to the half coupling of the generator shaft, is forged solid with its shaft. The low-speed gear is mounted directly above its driving pinion.

Axial Adjustment

The end play of the main shaft is controlled by the thrust bearing which is fitted on the turbine end of the low-speed shaft, also by the dashpot on the generator end of the pinion shaft. The ends of the low-speed shaft thrust bearings are faced with babbitt metal. The inner face bears against the hub of the gear and the flange. The bearing is prevented from rotating by means of a stud. The adjustment of the clearance in the gears and turbine wheels is made by the stud and the two jack screws which are tapped through the flange of the bearing, and resting against the face of the gear casing.

Dash Pot

The dash pot for the pinion shaft is a plate larger in diameter than the shaft, babbitted on its wearing surface, and having a sliding fit in the bearing housing.

The plate is prevented from turning with the shaft by a stud. The discharged oil from the pinion shaft bearing fills the annular space on either side of the plate, thereby damping sudden axial movements or vibrations of the shaft and pinion at no load and light loads.

Lubrication

The bearings for the pinion and the low-speed gear, like the turbine bearings, are lubricated by oil supplied from the geared oil pump. The lubricant for the pinion and gears is fed through a nozzle in the lower half of the gear casing, as shown in Fig. 9.

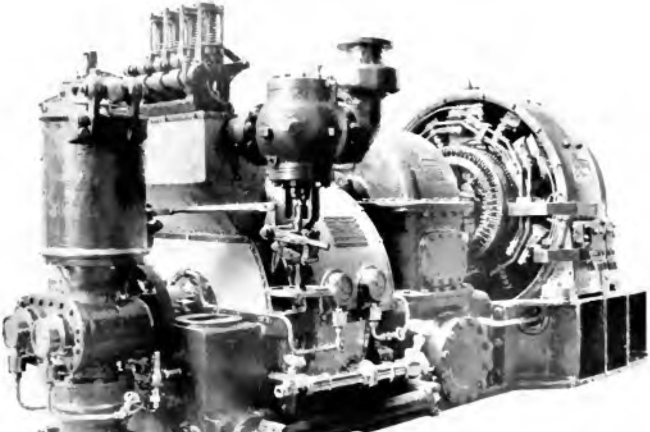


Fig. 10. General View of one of the two Exciter Turbines, Reducing Gears, and Generators

The New Mexico's Generators

By C. S. Raymond

Alternating Current Engineering Department, General Electric Company

The design and construction of the generators for the *New Mexico* involved no radical changes from established practice for land installations. Although relatively small machines when compared with the 45,000 kw. generators, the weight per kv-a. represents the lowest point on the curve. A special feature of these generators is the arrangement of the stator winding in two coils per phase, connected in parallel for low voltage and in "square" for high voltage operation. Another unusual feature is the provision for 50 per cent over-excitation, made necessary by the severe requirement of reversing the propellers while proceeding full speed ahead. The details of construction are fully illustrated and described in this article.—Editor.

Early History

It will be of interest to outline briefly the main features in turbine-generator development which have led up to its use in the propulsion of battleships by electricity.

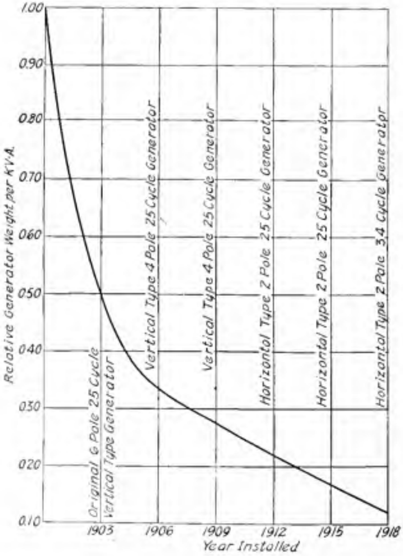


Fig. 1. Curve Showing the Decrease in Relative Weight per Kilovolt-ampere Capacity of Large Steam Turbine Generators Using Unity to Represent the Weight per Kv-a. of a Large Low-speed Flywheel Type Generator. The 1918 point applies to the *New Mexico* generators

The use of steam turbine-generators of considerable size began with the installation of the 5000-kw. 500-r.p.m. machine for the Commonwealth Edison Company of Chicago, Ill., in the year 1903.

During the period of 1903 to 1913, inclusive, vertical turbine-generators of capacities from 5000 to 20,000 kw. were made in vast quantities. The rotative speed was increased from 500 r.p.m. to 750 r.p.m. for 25-cycle machines having 4-pole generators; and to 720 r.p.m. for 60-cycle machines having 10-pole generators.

Fig. 2. An Early Salient-pole Type of Turbine-generator Rotor

Great progress was made in turbine efficiency. For example, the 12,000-kw. 25-cycle turbine-generators that replaced the original 6-pole 5000-kw. 500-r.p.m. machines installed at Chicago showed an increased turbine efficiency of 40 per cent. Generator design was radically changed, due to the increased rotative speeds. The salient pole type was rendered obsolete, it being necessary to design a smooth core type of rotor having a distributed winding.

Many improvements were made in ventilation. The air entering the generator was directed in definite paths to the parts to be cooled. The in going and out going air was entirely separated.

Important improvements were made in the design and support of stator coils to prevent distortion under short circuit strains. Stator punching material was developed which reduced the core losses by 20 to 30 per cent. Temperature coils were introduced by which hot-spot temperatures could be determined. These changes were accompanied by the adoption of improved insulating materials, methods of manufacture, and application.

During this 10-year period of unparalleled development of turbine-generator units, rapid advancement in the quality of materials obtainable, constant research work, and the ever-present demand for better efficiency led to another great advance in the rotative speed of steam turbines. The speed of 25-cycle units was increased from 750 r.p.m. to 1500 r.p.m. involving a change from 4-pole to 2-pole generators; 60-cycle machines from 720 r.p.m. to 1800 r.p.m., changing the 10-pole generators to 4-pole generators; while some of the smaller 60-cycle machines, up to and including the 5000-kw. size, were developed with a rotative speed of 3600 r.p.m. involving a 2-pole generator.

Referring to Fig. 2, a relative weight curve, assuming as unity the weight per kv-a. for a 7500-kv-a. flywheel generator running at 75 r.p.m., a marked decrease in weight is shown to have taken place in the period from 1903 to 1918, inclusive. The curve is based on 25-cycle turbine-generators with the exception of the point for the year 1918 which represent the relative [illegible] the 34-cycle, U.S.S. *New Mexico* [illegible]. A relative weight curve for 60-cycle 4-pole generators, due to the higher rotative speed and lighter stator cores, would show to an even greater degree the decrease in weight per kv-a.

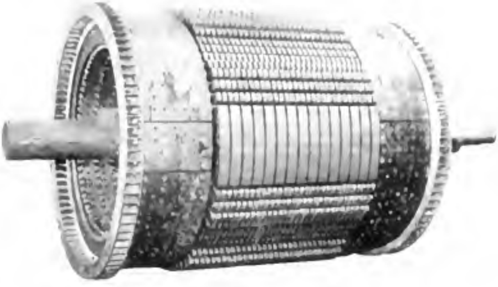


Fig. 3. A Development in Turbine-generator Rotor Construction Later than that Shown in Fig. 2

Prior to the year 1903, the maximum capacity of the low-speed reciprocating engine for driving electrical machinery was approximately 7500 kw. The development of the steam turbine has made possible a vast increase in generating capacity contained within a single frame. The following tabulation, giving the year of installation and the capacity of single units, is of interest:

Year Installed	Kw. Capacity
1903	5,000
1906	8,000
1908	14,000
1911	20,000
1915	35,000
1918	45,000

Fig. 4. The Highest Type of Rotor Development for High speed Turbine Generators. This type of construction is used in the propulsion generators of the U.S.S. *New Mexico*

Judging from the electrical and heating characteristics of the 45,000-kw. generator, the limit of capacity has not yet been reached.

The installation in 1903 of the 5000-kw. turbine-generator, referred to in the beginning of this article, marked a distinct epoch in steam-turbine units. Parallel with this is the application of the high-speed turbine-generator for propelling ships by electricity, made possible by improvements in the art by which fuel consumption and weights per kilowatt have been greatly reduced. Experience gained from a large number of machines in operation, including the electrically propelled U.S.S. Collier *Jupiter*, has resulted in the elimination of untried constructions and materials in the turbine-generators for the U.S.S. *New Mexico*. The purchaser and builder have every reason to expect successful operation by these units with respect to the three cardinal principles: reliability, economy, and maintenance.

Fig. 5. Cast Type of Generator Frame Construction

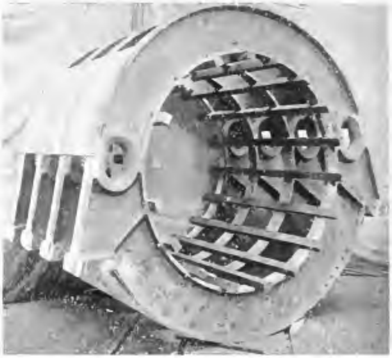


Fig. 6. The Sectionalized I-beam Type of Generator Frame. This construction, embodying light weight without sacrifice of strength and rigidity, is used in the *New Mexico* generators

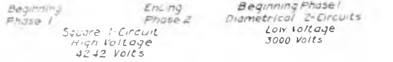


Fig. 7. The Square-circuit High voltage and the Diametrical-circuit Low-voltage Connections of Each *New Mexico* Turbine Generator, Obtained by Switching

Electrical Description

The U.S.S. *New Mexico* is equipped with two main turbine-generator units, each generator designed to develop 10,500 kw. at 78 per cent power-factor, and 13,500 kv-a. at full speed of the ship, and to carry a 25 per cent overload (16,850 kv-a. at 78 per cent power-factor) for four hours. The rotors have two poles and a maximum rotative speed of 2100 r.p.m. which corresponds to a frequency of 35 cycles. The stators are wound two-phase with leads brought out from the beginnings and endings of each phase to an 8-pole, double-throw, disconnecting switch placed in the main circuit between the generators and the motors. By manipulating this switch two generator connections, Fig. 7, are available: first, diametrical, two-circuit, low-voltage (3000 volts); and, second, square, one-circuit, high-voltage (4240 volts). With a constant flux, the voltage will vary directly or inversely as the $\sqrt{2}$ depending on the connection involved. Suitable interlocks have been installed, making it impossible to operate the two generators in parallel.

All speeds of the ship up to 17 knots inclusive are obtained by the use of one generator having the low-voltage connection, the generator furnishing power for driving the four motors. Above 17 knots, two generators having the high-voltage connection are used, each generator furnishing power for driving two motors. The generator efficiency curve, taken at loads and speeds corresponding to 10, 15, 19, and 21 knots, is shown in Fig. 8. This curve shows a uniformly good efficiency throughout a wide range of load. It is based on actual running conditions, and includes the windage loss of the rotor. The main turbine-generators are used only for propelling the ship, and are in no way connected to the lighting or other auxiliary power circuits. Therefore, it is possible under the varying conditions of load to adjust the voltage and current to obtain good efficiency.

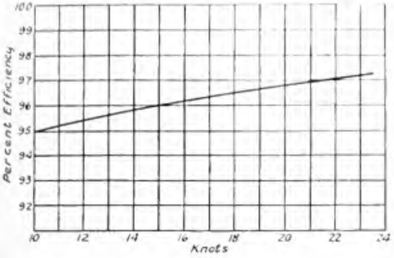


Fig. 8. Efficiency Curve of the *New Mexico* Propulsion Generators

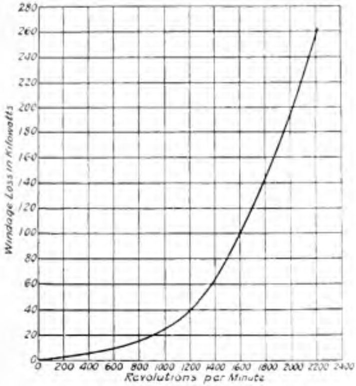


Fig. 9. Curve of Rotor Windage Loss

The induction motors, direct-connected to the ship's propeller shafts, are two-speed motors with connections for 24 and 36 poles. The speed reduction between the generator and the motors when using the 24-pole motor connection is 12 to 1, and with the 36-pole connection, 18 to 1. Hence, the extreme range of generator r.p.m. for the specified operating speeds of the ship, 10 to 21 knots, is approximately 1440 r.p.m. to 2100 r.p.m. In order to calculate the generator efficiency with accuracy, the windage loss must be carefully determined at various speeds, for this is the largest single loss. Tests were made at the factory to determine the windage of the rotor and the results are recorded in Fig. 9 (the friction of the bearings is not included). The windage loss varies approximately as the cube of the speed.

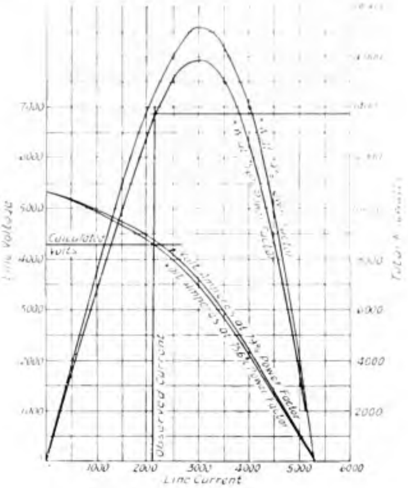


Fig. 10. Characteristic Curves of the Turbine Generators for Propelling the U.S.S. *New Mexico*

Generator Characteristics

The *New Mexico* generators are conservatively designed. Compared with the maximum rated machines for land practice, the relative armature reaction is considerably lower and the densities in the magnetic section are slightly higher. The characteristics of these generators are best shown by the curves in Fig. 10, which are based on data taken from a four-hour maximum-load endurance run. As indicated, sufficient excitation current is applied to the generator fields to insure keeping the motors and generators in step. In other words, the generators are not working at the peak of the kilowatt curve, but at a safe distance down where there is sufficient margin in power to take care of the rudder swings and heavy seas. Based on the maximum power-factor of the motors, 79 per cent, the generators have a margin in power of 24 per cent with the excitation given.

An interesting test was made with approximately maximum load and speed of the ship using one generator to drive four motors. With the kilowatt output and speed of the generator held constant, the excitation current was gradually reduced to a value at which the motors and generators dropped out of step. The sea was smooth and the rudder held amidship. In Fig. 12, two curves of this condition are given, one from observed readings and the other from calculated values. The point at which the motors and generators dropped out of step is clearly shown. This unstable condition corresponds to operation at the peak of a kilowatt-line-current curve. In other words, the generators with the excitation reduced to the breaking-out point, have no margin in power, and the excitation must be increased to insure stable operation on account of rudder swings and rough seas.

Over Excitation

Another very important feature in regard to

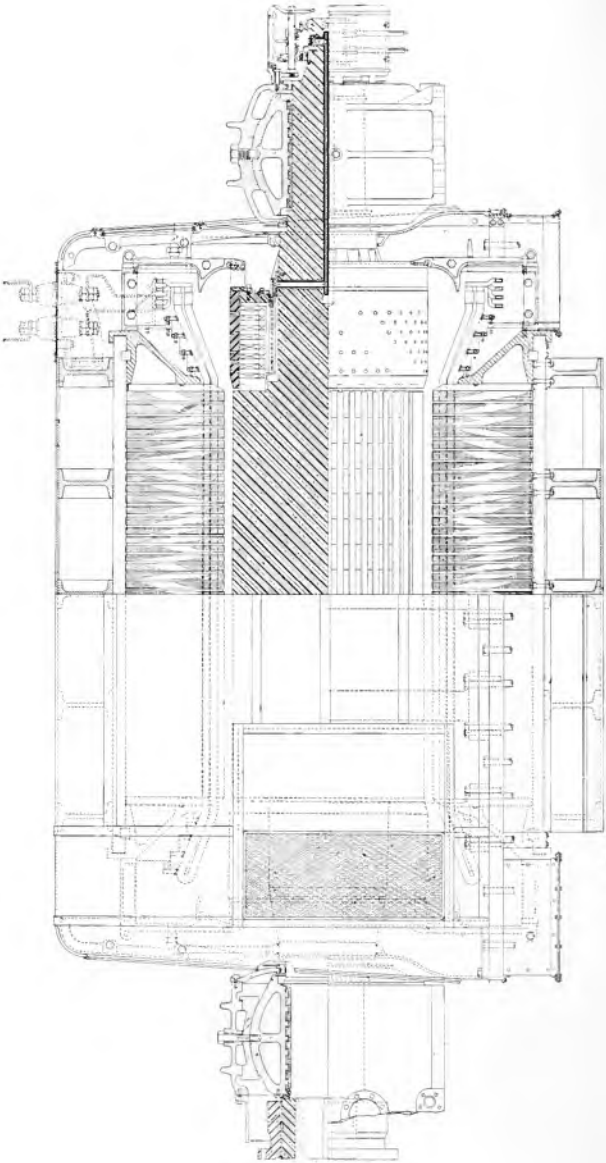


Fig. 11. Cross-section of One of the Two Turbine-generators for the U.S.S. *New Mexico*

the generator design, is the condition of over excitation required for starting and reversing the motors. The turbine-generators have a fixed mechanical rotation, but the motors may be run in a clockwise or counter-clockwise direction by changing the phase rotation by suitable switching. A very important feature inherent with electrical propulsion is that full power is always available for either direction of propeller rotation. From actual reversal tests, at maximum speed of the ship, the observed excess excitation current required for reversal was approximately 60 per cent above that for the steady running condition. The line current increased to approximately three times the steady running value. That these high values of current are not injurious to the generator is due to the extremely short time required for reversal and the large heat storage capacity of the generator. The observed time for reversal from maximum speed ahead to full reversing speed astern, with the motors in the 36-pole or low-speed connection, was approximately 20 seconds. To pull the motors into step in the reversed direction of rotation required holding the over excitation on the generator fields approximately eight seconds, the balance of reversal time being consumed in the release of the interlocks and in the switching operation.

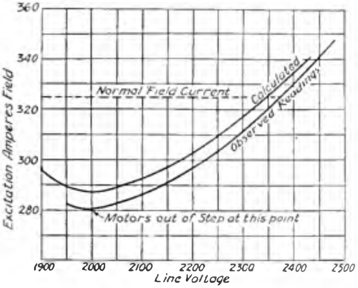


Fig. 12. Two Excitation Curves of the *New Mexico* Motors, made with the generator speed and kilowatt output constant, to show the dropping-out-of-step point of the motors with decreased excitation current

Temperatures

An evidence of the conservative design of the generators is the recorded temperature rise during the maximum-load endurance run, the power developed being 31,000 h.p. and the speed of the ship 21.3 knots. The maximum temperature [illegible] windings as measured by [illegible] was 29 deg. C. The temperature [illegible] located between the upper and lower [illegible] of the windings in the slot at the [illegible] the core and recorded the [illegible]

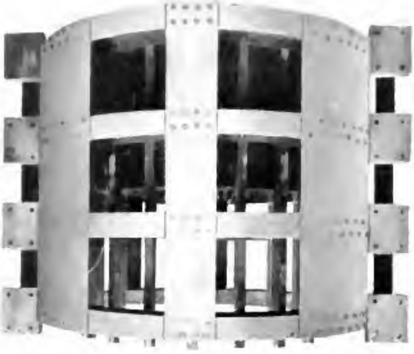


Fig. 13. The Sectionalized I beam Frame of One of *California* Generators on end for the purpose of assembling the core laminations

spot temperatures. The rotor or field temperatures as indicated by rise in resistance of the field winding indicate a safe working margin on the guaranteed actual temperature of 150 deg. C., allowing for the temperature of the air entering the generator to be as high as 45 deg. C.

Mechanical Design

The mechanical design of the generator is similar to that of other machines developed for central power stations. In fact, this type of machine has been manufactured in such numbers of varying frequencies and capacities that it is possible with slight changes to use standard designs. Fig. 11 shows a longitudinal cross-section of one of the two generators for the *New Mexico*.

One feature that differs from land practice is the omission of the turbine and generator base castings. The turbine casing, generator stator frame, and bearing standards are bolted directly to a stiff structural steel foundation which is securely tied in with the ship's structure.

Stator

The stator or armature is of a compact design. The stator frame is of the sectionalized I-beam type which consists of several

Fig. 14. Moulding the Turbine-generator Stator Coils in a steam mould before applying the external insulation

circular I-section castings, properly spaced and held together at their outer periphery by boiler plates, these plates being hot riveted to the I-section castings. The I-section castings after being properly spaced and supported are carefully bored out at their inner periphery for the attachment of rectangular steel bars, these bars forming the dovetail ribs for assembling the stator core punchings. The advantage of this frame over the solid cast type is the great saving in weight, being approximately one half as heavy. Other advantages are: the elimination of dangerous shrinkage strains always present in the solid cast frames, the simplified patterns and castings, and the general adaptability for shortening or lengthening and respacing of dovetail ribs to suit the various punching segments. The armature core or magnetic section is composed of thin laminations, each one being insulated with enamel. Special silicon steel is used to insure low losses. The punching segments and the dovetailing to the stator frame ribs are so designed that even with the great radial depth necessary for 2-pole turbine-generators, the laminations lie flat. The stator frame of one of the *California* generators, placed in a vertical position with its core partially assembled, is shown in Fig. 13. With the final pressure applied and the clamping flange assembled, a uniformly tight core is obtained, one that will stay so indefinitely.

Straight steel strips having an I-section were spot-welded to the punching segments and form the air ducts in the stator core. These strips or space blocks are so arranged that the air flows radially through the core. A liberal number of ducts are used to insure a plentiful supply of air and to expose the maximum amount of surface to the air.

The stator coils are of the conventional barrel type, two coils in each slot. The conductors consist of insulated rectangular wire which was formed into the proper shape in a bending form. Before the application of external insulation, the conductors were moulded in a steam mould as shown in

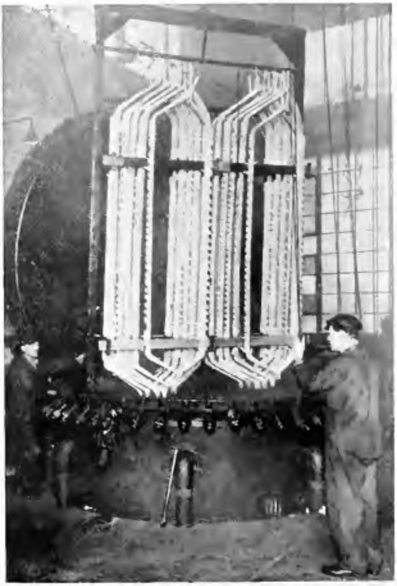


Fig. 15. After the Coils were Moulded as in Fig. 14, they were placed in this tank where all trace of moisture was removed from them and they were then impregnated with an insulating compound

Fig. 14. Following this treatment they were placed in a tank and subjected to vacuum to remove the moisture, and then as shown in Fig. 15 a compound was forced into the coil under pressure to entirely fill the spaces between the rectangular wires. External insulation was afterward applied, consisting of mica tape which extends uniformly over the whole coil. The moulding and filling operations were again repeated. Recognizing the severe conditions that would be imposed on the insulation by the salt-laden ventilating air, water proofing insulation treatments were applied to the coils, special attention being directed to the connections and to the portions of the coils beyond the stator core. By heat treatment, the insulation of the coils is prevented from loosening under the most severe operating conditions. Fig. 16 shows a completed coil. These coils after being heated by current were assembled in the stator core in the manner shown in Fig. 17.

Fig. 16. One of the Completed Turbine-generator Stator Coils

Fig. 18. The Completed Stator of one of the *Maryland* Propulsion Generators

To prevent distortion of the ends of the coils under short-circuit strains, they were securely laced to insulated binding bands. Blocks properly spaced were placed between the adjacent coils. The effectiveness of this structure has been demonstrated many times by actual short-circuit tests and also by short-circuits in such machines after commercial load. Careful inspection failed to reveal any movement of the coils. Fig. 18 is a view of the stator with its windings completely assembled.

Fig. 17. Assembling the Stator Coils in the Turbine-generator of the Electrically Propelled Battleship *Maryland*

Rotor or Field

The electrical and mechanical limits of turbine-generators are encountered in the design of the rotor or field. The electrical limits are confined to the heating of the field windings and the mechanical limits to the centrifugal strains and to the critical speed. The rotating elements of the turbine and the generator are supported by four bearings and are coupled together by a flexible jaw type coupling. This coupling is placed between the adjacent turbine and generator bearings and with them is contained within a common housing.

Radial slots for the rotor windings were machined in the solid forging in the manner shown in Fig. 19. The rotor coils are made of rectangular copper strip wound on edge by a machine, Fig. 21, which forms the corners of the coils and varies the span of each turn the correct amount. Before assembling the coils they were annealed and the turns insulated with mica tape. The coils were assembled in the slots one turn at a time.

The slot insulation consists of mica and asbestos sheets placed between horn fibre for mechanical protection in assembling the turns. This insulation is a continuous sheet and extends the entire length of the slots. After assembling, the coils were heated by electric current, cemented, and pressed into their proper position, Fig. 20, under a pressure exceeding that to which they are subjected in operation.

The portion of the coils outside the rotor body is insulated with mica tape. Over the mica tape is a layer of asbestos tape which serves as a mechanical support and protection to the mica. In the slots the insulation was lapped over the coils, cemented, the necessary filling strip inserted, and steel wedges driven in to retain the coils in the slots. The end coils are carefully supported by moisture-proof blocks to prevent any movement. To protect the ends of the coils from moisture, several layers of insulating varnish were applied and each layer baked until dry.

To support the ends of the coils against centrifugal force, forged-nickel-steel binding-rings were shrunk on over them. One end of the ring is supported on lugs integral with the rotor body, the other end on a centering spider whose inner circumference rests on the shaft. Thus the shrinkage stress is taken by steel members and not by the insulation. A completed rotor for the *Maryland* is illustrated in Fig. 22.

Collector Rings

The collector rings are placed outside the collector-end bearing and are encased in a neat ventilated cover. This cover may be opened, similar to the hood on an automobile, to expose the brushes and brush holders for any necessary adjustment. The collector rings are special heat-treated steel forgings and were shrunk on over hard mica bushings to the cylindrical collector shell, this shell being pressed on and keyed to the end of the main shaft forging. Soft graphite brushes are used and spaced so that the entire width of collector ring has brush contact. A helical spring is placed directly over the center of the

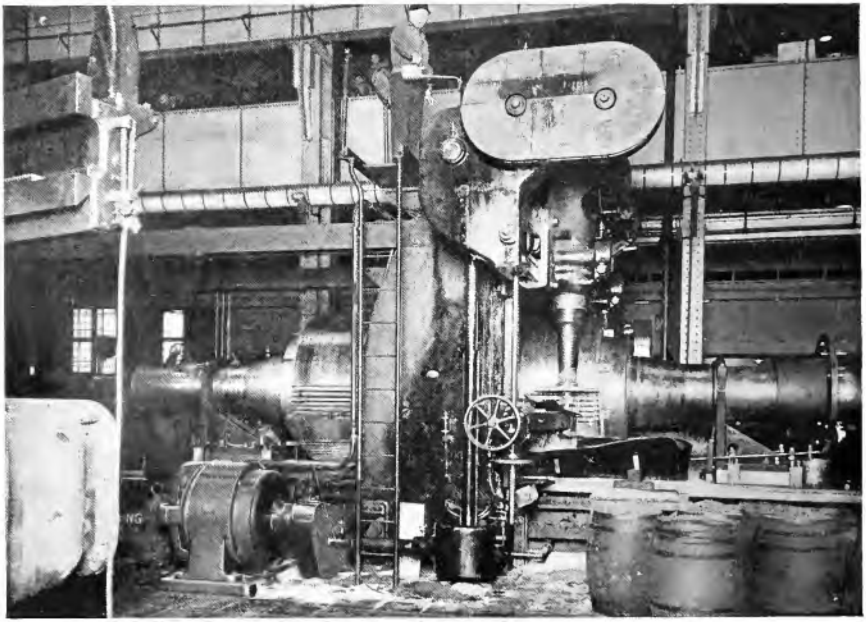


Fig. 19. Machining the Field Winding Slots in the Solid Forged Rotor of a Turbine Generator

brush and by adjusting this spring any desired brush pressure may be obtained. The parts pertaining to the support and control of the brush pressure are light and extremely quick in action, and when the brush pressure is properly adjusted all sparking between the collector rings and the brushes is eliminated.

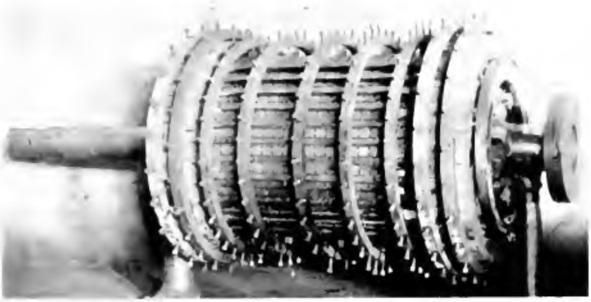


Fig. 20. Assembling the Field Coils in the Turbine-generator Rotor Slots Under Heavy Pressure

Ventilation

In the early turbine-generators, forced ventilation was not required, as the cooling of the machine was effected by the natural windage of the rotor. With the later high-speed turbine-generators, a system of forced ventilation is absolutely essential since the natural windage of the solid forged cylindrical rotor is negligible. The volume of air required is variable with different design factors, but, in general, it depends on the losses in the machine. The proper volume of air per kilowatt lost has been carefully determined from experimental data and from experience gained from a large number of machines of various capacities in service. The proper ventilation of a turbine-generator is absolutely vital to its successful operation. Sufficient cool, clean air must be delivered to the machine in ducts of minimum restriction.

Fig. 21. Special Machine Winding Edgewise the Strip-copper Field Coils

Good ventilation can [illegible] provided it receive proper consideration in the general scheme of installation.

The New Mexico turbine-generators are ventilated by two duplicate and separate ventilating systems, one for the starboard generator and the other for the port. The air is taken from out-of-doors through ducts placed just back of the upper superstructure on the starboard and port sides. The openings in these ducts face aft and are approximately 10 feet above the main deck floor and are designed to prevent the entrance of rain. Auxiliary blowers of ample capacity draw in the air through these openings and force it down to the bottom of the ship into chambers directly under the generators. These chambers and the air connections to them are made water tight and the danger of bilge drainage entering with the air into the generator windings is practically eliminated. Fans mounted on each end of the generator rotor take the air from these chambers and force it axially through the air-gap. The air then passes radially through the several air ducts in the stator core, thence circulates around the outer periphery of the stator punchings in the spaces formed by the I-sections of the stator frame. An exit duct of liberal area is connected to the top of the stator frame and the heated air is taken away through this duct, which passes through the several decks and exhausts out-of-doors. The pressure-volume curve, Fig. 23, represents actual factory test values of the performance of the fans mounted at each end of the rotor, the air being taken directly under the stator frame and exhausted through a long circular pipe attached to the top of the stator frame. The volume of air varies directly with the speed, the pressure as the square of the speed. The volume of air under actual operating conditions is approximately 10 per cent higher than was obtained in the test, due to the throttling at the entrance of the measuring pipe.

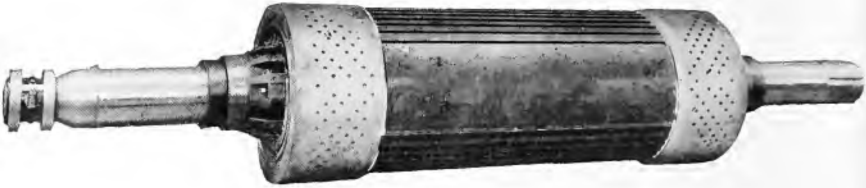


Fig. 22. The Completed Rotor of One of the *Maryland* Generators

Care of Generator

It is very important that the generator be kept clean. Oil should not be allowed to collect and enter the generator with the air and deposit on the windings. It is essential that the air ducts in the stator core and ventilating holes in the rotor retaining rings be kept free from dirt as any restriction in these passages will seriously interfere with the flow of air which is necessary to prevent excessive temperatures. Dirt, aside from restricting the flow of air, is a heat insulator. Compressed air will be found particularly convenient for removing dust from the various air passages. Some kind of swab may be used to advantage to clean out the air ducts, which should be done at regular convenient intervals. Every year or so it would be well to clean the end windings thoroughly and to supply a coat of insulating varnish. This varnish may be sprayed on by using compressed air in connection with an atomizer. When the generators are shut down for any length of time, the dampers at the air inlet and air outlet should be closed and live steam turned into the heating coils which are located within the inner shields at the collector and turbine ends of the stator. This will heat the internal parts of the generator several degrees higher than the room temperature and prevent the accumulation of moisture in the windings and interior parts.

Conclusion

Recognizing the importance of this installation from both the builder's and purchaser's view point, Secretary Daniels arranged for the presence of the interested designing engineers to witness the trial tests. All were deeply impressed with the intelligent and efficient manner in which the various tests were planned and conducted. Naval experts and visiting engineers were enthusiastic over the ease with which the maximum load and reversing tests were carried out, both in regard to the operation of the propelling equipment and its control by the operators.

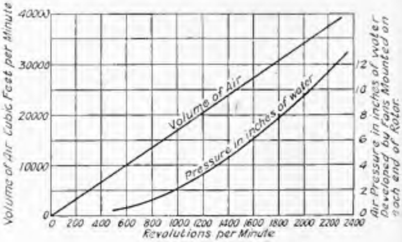


Fig. 23. Curves of Volume and Pressure of Ventilating Air Developed by the Fans on the Ends of the *New Mexico* Generator Rotors

The New Mexico's Motors

By A. D. Badgley

Induction Motor Engineering Department, General Electric Company

While the turbine generators of the *New Mexico* equipment are similar in most respects [illegible] for land installations, the propulsion motors are decidedly special and involve a number of [illegible] peculiar and original. They represent the first instance in which a single winding has been used [illegible] poles with a ratio other than 2:1; while the severe duty imposed upon the motor in reversing [illegible] for the adoption of a double squirrel-cage winding on the rotor: a high resistance winding [illegible] starting torque and a low resistance winding for carrying the rotor currents at normal speed. [illegible] cooled by forced draft and it was therefore possible to make them smaller than the average motor of [illegible] capacity. Another noticeable variation from usual practice is the reduced ratio of rotor diameter to length. These and other interesting features of the *New Mexico* motors are illustrated in this article.—Editor.

For a number of years the application of electric drive to large ships has been seriously considered by many electrical engineers. Boats of small power had been driven by direct-current motors; but for large power installations the induction motor, receiving its supply from a high-speed turbine-generator where a maximum efficiency with minimum weight and size could be obtained, seemed very attractive.

As a result of this study, the United States Navy Department became interested and decided to equip a collier with electric drive and give it a thorough trial. As the requirement was for a single speed, a simple induction motor of the familiar land type with polar-wound secondary and slip-rings was used so that a resistance could be inserted in the rotor circuit for starting and reversing.

Two of these motors were built during 1911–12 for direct connection to the propeller shafts of the collier *Jupiter*, a twin-screw boat of 20,000 tons displacement having a speed of 14.5 knots. This equipment gave greater efficiency than previous types and operated with entire satisfaction. After an exhaustive trial during which the ease of operation and improved maneuvering qualities of this boat became very apparent, the decision was made to obtain the advantages of electric drive for battleships in the United States Navy.

The *New Mexico*, a 32,000-ton ship now regarded as the most powerful battleship afloat, was selected to be the first of the electric-driven fighters. For this application the highest possible economy was desired at the two most important speeds, viz.; high speed with full power at 21 knots, and medium speed at 15 knots where the maximum cruising radius without re-fueling is of the greatest importance. With these requirements, it

Fig. 1. Marine propulsion Induction motor Stator Completely Wound. Its rotor is shown in Fig. 2

was evident that for the most economical operation a changeable-pole motor giving a speed ratio of 2:3 was desirable on each shaft, the four motors at full speed taking power from two generators, and when cruising from one generator. By changing the poles on the motor, the proper speeds of the screw are obtained with a maximum speed of the generator thus giving low steam consumption on the turbine in both cases

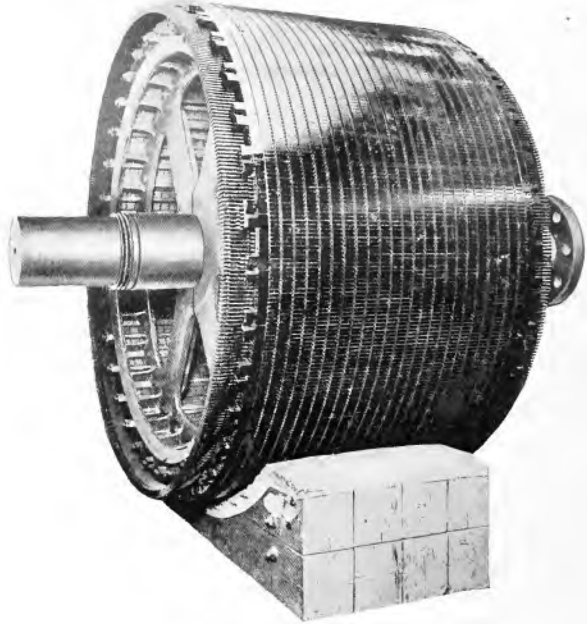


Fig. 2. Double-squirrel-cage Induction-motor Rotor. The ratio of diameter to length of this rotor is 2:1; whereas in the land type of machine it would be about 4½:1

Previous to the time of designing the motors for the *New Mexico*, a 2:1 speed ratio had been extensively used with single windings in stator and rotor. All other ratios of speed had been secured by using two windings in the stator, one for each speed, rather than a single winding with a large number of stator leads, which would cause too great a complication of the control. The double winding has the disadvantage of requiring a larger motor, as only half of the copper is in active use at either speed.

Since the motors and generators of the *New Mexico* were to be especially built to operate together, more liberty in design was allowed. A new type of winding was designed, the coils of which were so grouped that a change in the connection at the motor terminals would give a balanced quarter-phase distribution for either 24 or 36 poles. This gives a simpler control than if the motor were wound three-phase. In addition, since the four motors receive power from two generators at full speed, and one generator at cruising speed, the best combined operation is obtained with a decreased voltage on the 36-pole combination. This also works out best for a quarter-phase winding: by connecting the generators in square connection for high speed and parallel connection for low speed, the correct ratio of operating voltage is obtained. By this scheme of connection eight terminals were brought out of the motor, though only four-line leads were required.

The torque requirements derived from actual experiments on the *Jupiter*, supplemented by tank trials, showed that a resistance inserted in the rotor winding would be required only for a few seconds at a time, that is, during starting or upon reversal in order to obtain quick possession of the screw and bring it up to speed. With this in mind, a double-squirrel-cage type of motor was adopted thus eliminating the rheostat. The outer high-resistance, low-reactance winding takes the place of the rheostat when starting and reversing. The inner low-resistance, higher-reactance winding is the running winding when the motor is up to speed. The inductive action between these two cages is such that when the frequency in the rotor is high, as at starting or reversing, the current is choked back in the low-resistance winding thus forcing a large percentage of the current through the high-resistance and producing

Fig 3. **Laminations Assembled and Clamped in the Induction Motor Stator Frame ready for the insertion of the winding**

Fig. 4. **A Portion of the Stator, such as shown in Fig. 3, after the winding coils have been inserted and their ends laced to the insulated steel ring**

Fig. 5. **Induction Motor Rotor with two sets of winding slots ready for the insertion of the bars of the double-squirrel-cage winding**

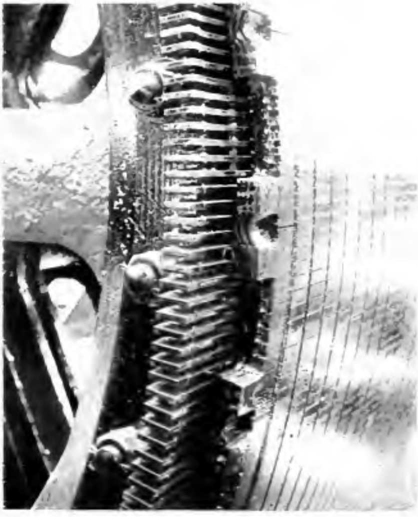


Fig. 6. **A Portion of the Rotor, such as shown in Fig. 5, after the double squirrel-cage winding has been inserted. Laminated copper expansion joints are shown in the outer cage end-ring**

adequate torque. As the motor speeds up, the rotor frequency drops off and the inductive effect on the inner winding decreases, allowing the current to increase with a corresponding decrease in the outer winding until at slip frequency practically all of the current passes through the low-resistance cage. By this construction, the torque advantage of a high-resistance rotor is obtained with the low slip and high efficiency of the low-resistance type of rotor when at full speed. The winding diagram and torque characteristics of these motors appear elsewhere in this magazine.*

The design of motors for use on shipboard differs very materially from that of ordinary commercial motors. For the latter, the question of size and weight is of minor consideration while for ships it is a vital one. On land, a motor is usually operated from a transmission system having a fixed source of supply and the power-factor of the motor is of great importance. A low-power factor load requires a larger percentage of the generator and line capacity than does a high one. The best design for the commercial motor of high power-factor usually requires a machine with as large a ratio of diameter to length as possible, without undue sacrifice in cost and efficiency.

For marine work this standard of design can be greatly modified. First: the power demanded from the motors can be very accurately determined and, except for a slight variation due to the depth of the propellors, roughness of the sea, and steering, it is constant for any given speed.

Second: the motors are supplied with external ventilation instead of being self ventilated and the amount of air forced through the motors for cooling can be varied with the load if so desired. These conditions taken together allow of a much smaller motor being used.

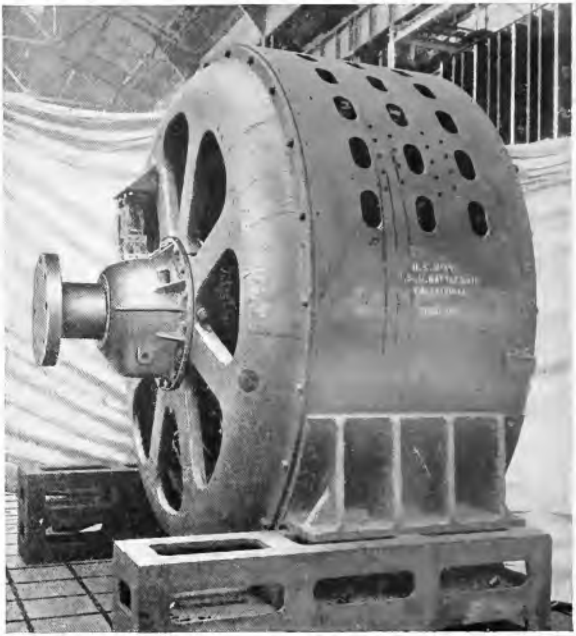


Fig. 7. A Factory View of one of the Propulsion Motors for the Battleship *California*. Similar motors are being built for the *Maryland* and *West Virginia*

As the motors and generators are close together, the effect of the motor characteristics on the transmission system can be ignored and they can be designed directly for each other with special attention to the combined characteristics of the units. To further reduce the size and weight of the equipment, the comparatively low-speed motor should be smaller in diameter and longer than is usual, and the resulting lower power-factor should be taken care of by increasing the size of the high-speed generator because of greater excitation necessary.

The motor with a smaller ratio of diameter to length also gives greater efficiency due to the decrease in the fixed rotation losses and a greater percentage of active copper in the slots compared to the inactive copper in the end connections. Figs. 1 and 2 show the small diameter and great length of those

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*General Characteristics of Electric Ship Propulsion Equipments," by E. F. W. Alexanderson, page 224, this issue.

motors. The ratio of diameter to length in this case is 2:1; whereas in the land type this ratio would be about 1½:1.

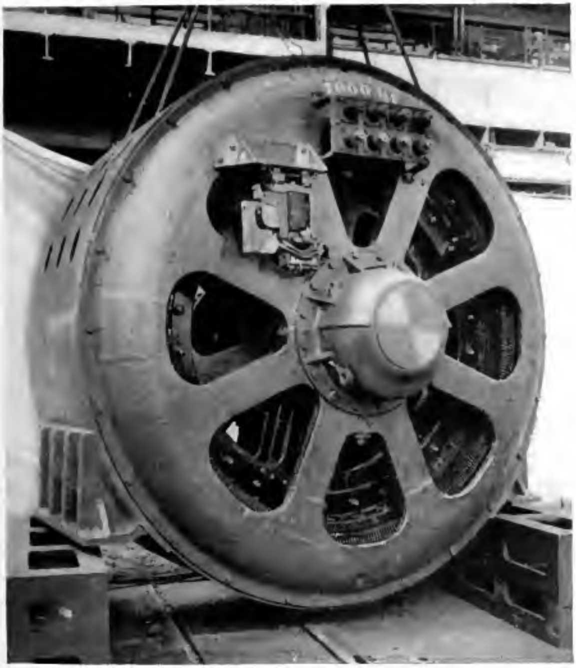

Fig. 8. Another View of one of the *California* Motors. This motor is similar in appearance to those of the *New Mexico*, except that the frame of the latter is somewhat longer and the contactor on the end shield is not used

In addition to reducing the size by designing a lower power-factor machine and using all the active material at both speeds, a minimum of weight with ample strength was obtained by the use of steel throughout for the mechanical structure. The stator frame was made up of a series of circular rings of I-beam section with dovetail ribs attached. Each ring is of sufficient strength to support its section of punchings, and is held in position by being riveted to rigid steel feet. Boiler plate extending the full length of the frame was rolled to fit the I-beams and was securely riveted to them, making a very rigid and compact structure. By increasing the number of circular sections any length of frame desired can be made up. Holes for ventilation purposes were cut in the upper half of the frame through the boiler plate. In this frame-work, the stator punchings were assembled on dovetail ribs and clamped with steel finger flanges held in place by bolts and studs. See Figs. 3 and 4. The rotor spider was made in two sections along the shaft to obtain a better flow of metal in casting than is possible with a single section. Dovetails were cut in the spider ribs on which the rotor core was assembled and further secured by steel pins driven through reamed holes in the punchings just over the dovetails, and clamped between rings held in place by studs passing through the rotor between the dovetail ribs and back of the rotor punchings.

The stator winding was made of form-wound coils of rectangular wire carefully moulded and insulated principally with mica and with a special varnish treatment to prevent damage due to moisture or salt accumulation on the windings. This insulation is capable of withstanding a higher temperature in the core than is usual for induction motors.

After insulation, the coils were assembled in open slots and held with wedges in the usual manner. The coil ends were laced tightly to an insulated steel ring, holding them rigidly in position as shown in Fig. 4.

The double-squirrel-cage secondary winding, Fig. 6, consists of two entirely separate cages, the bars in both cases being driven into close fitting slots without insulation to allow the heat generated in these windings to flow freely by conduction into the rotor iron.

The outer cage is of high-resistance metal short circuited by copper end-rings into which the bars are brazed. This ring also is in intimate contact with the rotor punchings. Thus, during reversal when the greatest amount of heat is generated in this winding, the heat storage of the rotor iron is taken advantage of and the temperature of the bars kept down to a very conservative value.

The end-ring is of special design made up of short sections connected together by expansion joints of laminated copper, thus allowing expansion due to heating to be taken up between sections around the periphery and limiting the possible bending effect on the bars to a few mils instead of the comparatively large value which would exist if the ring were made solid and the diameter allowed to change.

The inner cage is of copper electrically welded to a copper short-circuiting ring made of a single piece of bar copper rolled in circular form to accurate size and the two ends welded together. It was not necessary to break up this ring, as the inner winding was designed to remain cool under all conditions of running, the double-squirrel-cage design allowing full current in this winding only at normal speeds.

The bearings are of the ball-seated type supplied with oil from the ship's pressure system and are held in position by steel end-shields bolted to the stator frame. The bearing housings with the bearings are adjustable for centering the rotor in the stator frame so as to obtain a uniform air gap.

Over the top half of the motor frame is fastened a hood connected to the ventilating ducts. Two fans driven by direct-current motors and mounted in the hood draw air from the engine room up through the motor and force it through the ducts to the deck.

Figs. 7 and 8 show a completed motor such as is being built for the battleships *California*, *Maryland*, and *West Virginia*, ships of the same size as the *New Mexico*. These motors are of a slightly different type but are similar in appearance to those on the *New Mexico* except that the frame of the latter is slightly longer along the shaft and the contactor shown on the shields is not used.

The specified requirements for driving the *New Mexico* propellers called for 26,500 h.p. at 161 revolutions per min. corresponding to 21 knots ship speed, and 8350 h.p. at 112 revolutions per min. for cruising at 15 knots.

The motors were wound to operate with either 24 or 36 poles with an output of 6700 h.p. at 4000 volts on the 24-pole connection and 2050 h.p. at 2800 volts on the 36-pole connection, with an overload capacity of 8375 h.p. at 173 r.p.m.

At speeds from 8 to 15 knots, the four motors are operated on the 36-pole connection from one generator with its winding connected in parallel, the switching being so arranged that either generator can be used. The variation of speed is obtained by steam control on the turbine-generator.

From 15 to 17 knots, the motors are thrown over to the 24-pole connection, still using only one generator. Above 17 knots, two generators are used, connected in two squares. The two motors and generator on the starboard side and the two motors and generator on the port side are connected together and each set operated as separate units.

For reversing, the 36-pole connection only is used. When the motor is running on the 36-pole connection one phase is reversed. If operating on 24-poles, the connections are changed over to 36 poles and reversed.

During the trial run a test of this reversal was made with the boat running at a speed of 21.25 knots. The motors were reversed and the screw was brought up to full-speed astern on the 36-pole connection (two thirds of the forward speed) in 20 seconds; 12 seconds of this time being used in switching.

The official trials on the driving equipment of the *New Mexico* were made December 16-18, 1918. Runs were made at various speeds from 7.32 knots to 21.31 knots to establish points for the standardization curve.

It developed that due principally to overloading, which increased the displacement by over 1000 tons, the power required to drive was 29,100 h.p. at 161 r.p.m. instead of 26,500 h.p. at a screw speed of 166.5 r.p.m.

A four-hour endurance run under full power at 21.25 knots, requiring 31,000 h.p. at 170 revolutions of the propeller was made followed by runs at 19, 15 and 10 knots.

Two runs over the course were very interesting. The two inboard propellers were run from one generator with the motors connected 24 poles and with the outboard motors disconnected, allowing the propellers to run free. Another trial was made with the outboard motors driving and the inboard propellers free. In both cases a little over 15 knots speed was obtained. These two trials showed that to drive the boat at the same speed the inboard propellers required 11 per cent more power than the outboard.

During all the trials the motors were in charge of the ship's engineering force and the entire operation was highly satisfactory; especially so, since the power required to obtain full speed was considerably in excess of what was anticipated.

The Main Control Equipment of the New Mexico

By C. T. HENSCHEL

SWITCHBOARD ENGINEERING DEPARTMENT, GENERAL ELECTRIC COMPANY

One of the outstanding features of the battleship *New Mexico* is the unique control of its propelling machinery. The keynote of the control system is flexibility. This property, coupled with the ability of either or both generating units to drive all four propeller motors, produces a propulsion equipment of great reliability. The following article describes in detail the construction and inter-relationship of the elements of the control apparatus.—EDITOR.

The development of a new idea, such as the electric propulsion of vessels, naturally brings with it the necessity for designing suitable auxiliary apparatus; and this is in the fullest sense true of the electrical propulsion control equipment for the U.S.S. *New Mexico.*

At the beginning it was realized that, if speed of action and intelligent interpretation of commands were to be attained, the control of the main switching, the generator field adjustment, and the steam adjustment must be centralized at one point. This brought about the design of the propulsion control cell* which contains all the means of control and switching (with the exception of the generator disconnecting switches) for the two turbine-generators and the four propulsion motors.

The list of devices includes:

Two Generator Disconnecting Switches for isolating the generators and providing a means for changing the generator connections.
One Bus-tie Switch for connecting the opposite pairs of motors to either generator or for separating them when it is desired to use two generators.
Two Reversing Switches for changing the direction of rotation of the motors for the purpose of reversing the direction of travel of the ship.
Two Pole-changing Switches for changing the pole connections in the motors for different conditions of operation.
Two Operating Levers and mechanisms for reversing.
Two Operating Levers for pole changing.
Four Motor Disconnecting Switches for isolating the motors.
Two Bulkhead Panels (bulkhead piercing).
Two Field-control Levers.
Two Field Switches.
Two Booster-field Rheostats.
Two Speed-control Levers.
Two Steam-limit Levers.
Two Steam-limit Indicating Switches.
A complete set of Interlocks, both electrical and mechanical, to safeguard the operator and also to produce certain sequences of operation of the different devices necessary for the proper control of the ship.

Fig. 1 shows a diagram of the arrangement of cables and switches in their relative order.

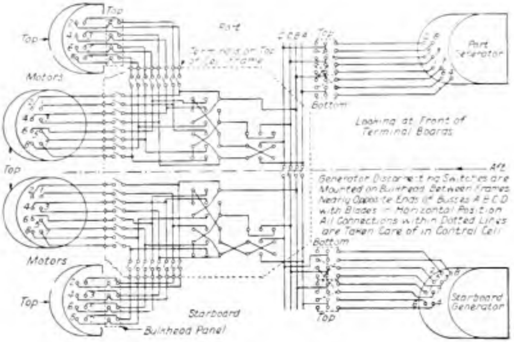

Fig. 1. Diagram of Wiring and Switches Between the Turbine-generators and the Propulsion Motors of the U.S.S. *New Mexico*

The Control Cell

The control cell, shown partially assembled in Fig. 2, is rectangular in shape 16 ft 8 in. wide, 9 ft. deep, and $11\frac{1}{2}$ ft. high. It is built of 4-in. channels, strongly riveted and bolted together to form a solid unit in order to withstand the vibrations due to machinery and propellers and also the shocks resulting from gunfire.

The cell is firmly anchored to the floor of the control room and machinery deck and it

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* See Fig. 5, "Controlling the Propulsion of the *New Mexico,*" by H. P. Harvey, p. 278, in this issue.

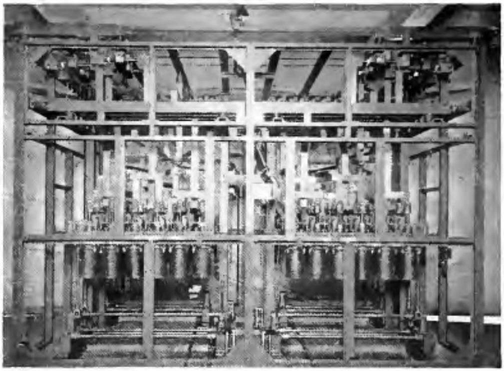


Fig. 2. View of the Control Cell, partially assembled, showing the fore-and-aft aisle

has no further supports. It is located in the center line of the ship and has ample passages around it. The outside surfaces are covered with steel basket-weave grille, except in the places occupied by the instrument, gauge, and control panels.

The cell is divided by a fore-and-aft aisle, shown in Fig. 2, into port and starboard sections, each section controlling a generator and two motors; and it is further divided by a thwartship aisle, Figs. 3 and 4, forming a natural division between the reversing and the pole-changing switches. This arrangement permits of ready access to all the devices. Grille doors, Fig. 5, are installed on the port and the starboard sides. The doors are provided with magnetic locks energized from the field circuits, so that the cell cannot be entered unless the field breakers are open. This protects the operators against contact with the high-tension circuits.

The cell is open at the top but a steel roof is installed about two feet above and extends about 12 inches on all sides. Without interfering with the ventilation, this roof protects the cell against the possibility of water dripping from above and the accidental dropping of tools into it. Inside the cell, and allowing sufficient headroom for operation, are mounted the four main bus bars which consist of two laminations of 5 by ¼-in. copper and which are located in the forward half of the cell. The other half of the cell contains the motor buses in the same plane. These consist of two laminations of 2 by ¼-in. bars.

Insulation

The problem of insulation was a serious one. On account of the vibration due to running machinery and to the more serious matter of gun shock, the service on a battleship is very severe. It was obvious that porcelain could not be used, and therefore it was decided to utilize a molded compound insulation. Two types of insulators were produced; one for use in insulating the studs of the switches, and the other shown in Fig. 6 for supporting the buses and connections.

Generator Disconnecting Switches

The generator disconnecting switches, Fig. 7, are eight-pole, double-throw and are rated 5000 volts, 1200 amperes. In addition to their serving the purpose of isolating the generator, they are used for changing the connections in the generator windings.

The switch blades are L-shaped which permits a complete throw-over with only 90 deg. of actual movement. There are two laminations per pole. The poles are

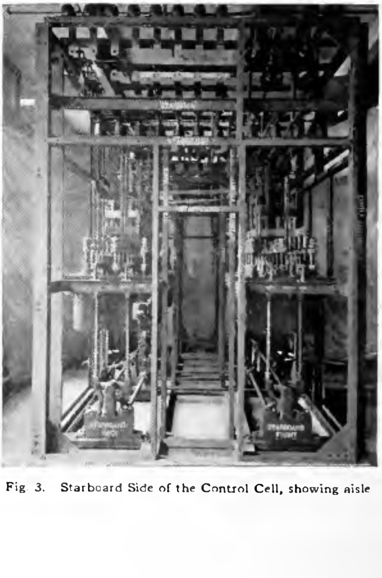


Fig. 3. Starboard Side of the Control Cell, showing aisle

connected in pairs by a cross-head which, by means of couplings and a wooden rod, is connected to a crank keyed to the operating shaft of the switch. The hinge blocks are connected in pairs by copper bars arranged for cable connections to the main busbars at the top of the cell. The studs extend through insulators securely locked to a cast-metal base, which is bolted to the fore-and-aft bulkheads forming the boundaries of the control room. In this manner, the switch in addition to its regular functions serves as a cable entrance panel through the water-tight bulkhead between the turbine and the control compartments.

The switches are mounted on end with the shafts vertical and are operated by means of a stout hand lever which is hinged at its fulcrum so that it can be let down into a vertical position when not in use, thus preventing its obstructing the passageway on either side of the control cell.

The shaft is provided with a notched quadrant and a roller pawl actuated by a heavy spring. This gives the operator an indication when he has reached the open or closed position of the switch.

Bus-tie Switch

The bus-tie switch, Fig. 8, is four-pole, single-throw and is rated 5000 volts, 2400 amperes. It is used to tie the port and starboard generator buses together when only one machine is used to drive all the motors. The blades of the switch consist of two laminations per pole, which operate between contact clips set into suitable blocks attached directly to the bus bars. They are in turn connected by means of couplings and wooden insulating rods to bell-cranks keyed to the operating shaft.

Fig. 4. Combination View of the Port Side and Back of the Control Cell

Fig 5. Starboard Side of the Control Cell, showing protective grille and magnetically locked door

A hand lever, directly attached to the shaft and operating in the thwartship aisle, provides a means for throwing the switch but, owing to the magnetic locks on the cell doors, it is not accessible until the field circuit has been opened.

Reversing and Pole-changing Switches

The operation of reversing and pole changing is accomplished by the use of double-throw, oil circuit breakers, Fig. 9, made up in single-pole units each having a capacity of 1500 amperes at 5000 volts. The reversing switch is triple-pole, each pole consisting of two units connected in multiple. They are mounted directly behind the front wall of the cell and are separated by the fore-and-aft aisle as shown in Fig. 2. Inter-connections between the switches, and from the switches to the main busbars directly above, are made with heavy copper bars. The studs are insulated from the frame by means of bakelite compound insulators.

The contacts are of the brush type and are provided with secondary arcing tips on the brush, and burning plates on the fixed blocks. All these parts are easily renewable. The contact arms are hinged to the center stud and the carrying capacity is maintained by flexible copper connectors fastened between the center stud and the brush.

Fig. 6. Special Insulator for Supporting the Buses and Connections

Each brush lever is connected by means of an impregnated wood rod and a coupling to the switch mechanism which is mounted on the cover frame and the mechanisms are connected six in tandem across the tops of the switches. These six mechanisms are operated in unison by means of a toggle arrangement which is connected to the bell-crank that communicates with the operating mechanism as shown in Fig. 9.

Each breaker unit has its individual oil tank for the handling of which an adjustable platform has been installed.

The pole-changing switches are identical with the reversing switches, but they are used in single capacity and are connected to the motor buses mounted above them and also to the reversing switches.

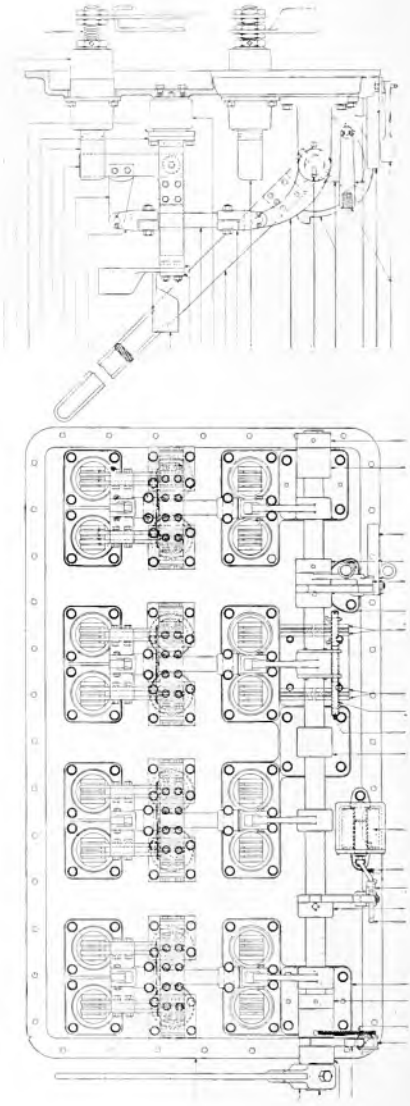


Fig. 7. Eight-pole, Double-throw, 5000-volt, 1200-amp. Generator Disconnecting Switch

Operating Mechanism

The switches are operated from the front of the board by means of the large levers shown in Fig. 9. The two inner levers are for reversing and the two outer ones for pole changing. They are pivoted on the pedestals and communicate with the oil circuit breakers through a pipe and crank mechanism to the operating shafts located under the breakers and thence through the vertical pipe to the switch mechanisms. The levers have three positions, the vertical one being "off."

Motor Disconnecting Switch

The four motor disconnecting switches, Fig. 10, are eight-pole, single-throw and are rated 5000 volts, 600 amperes. They are mounted at the top of the control [illegible], each side for the port and starboard [illegible] motors, and two at the back for the center motor which are located directly [illegible] cell. The switches are of multiple-blade construction, each blade being connected by means of couplings, insulating rods, and cranks to a common shaft for simultaneous operation. They are back connected through bakelite insulators and are operated by a handle on the outside which can be reached from the deck by a switch hook.

The lower studs are connected to the motor buses while the upper studs are led out at the top of the cell over insulators by means of

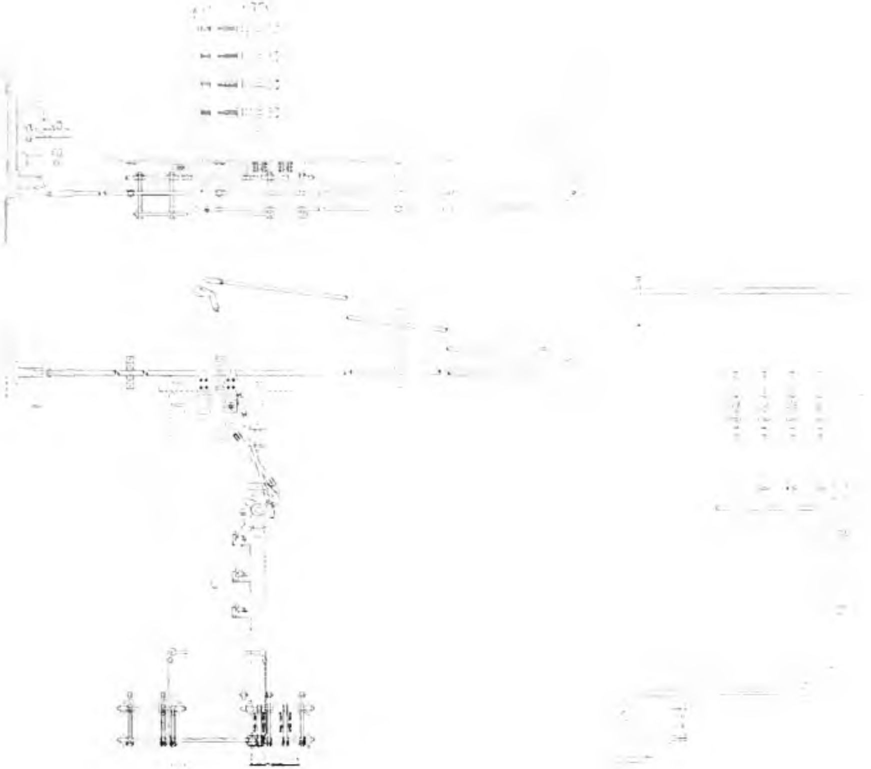


Fig. 8 Four-pole, Single-throw, 5000-volt, 2400-amp. Bus-tie Switch

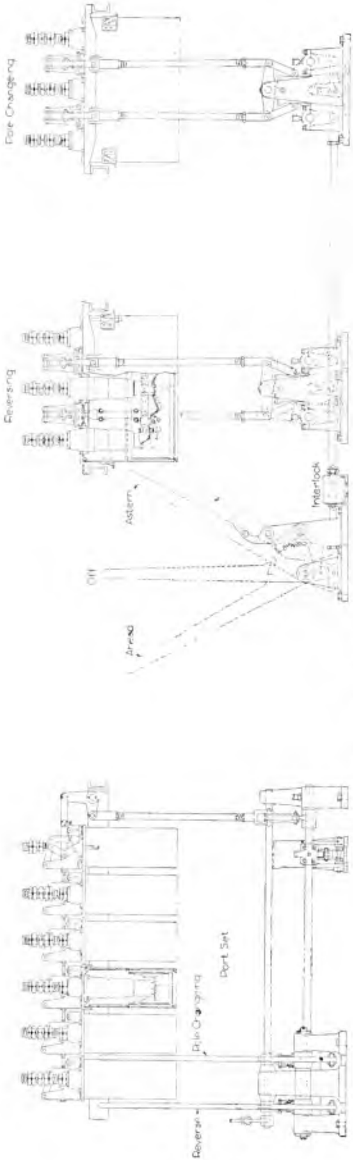


Fig. 9. Reversing and Pole-changing Oil Circuit Breakers with Operating Mechanism

connection bars and terminals to the motor cables.

A latching arrangement on the hand lever prevents opening the switch under vibration. This latch is automatically relieved by the normal use of the switch hook. The switch is provided with a sheet-iron cover so that accidental contact with live parts is impossible.

Bulkhead Panels

Two bulkhead panels are provided to carry the motor leads through the port and starboard bulkheads. These consist of a cast composition base mounting eight bakelite insulators, having a copper stud in each firmly locked by means of clamping nuts at each end. Terminals on each end provide means for attaching the motor cables and the connections to the motor disconnecting switches.

Field Control

The control of the generator is accomplished by the use of a booster set which is used either to buck or to boost the main field.

The booster set is regulated by means of the booster-field rheostat, Figs. 11 and 12, which is controlled by the field-control lever, Fig. 13.

Pulling the lever out from the board 30 degrees closes the circuit of the solenoid operating the field switch (which is mounted on the exciter board) and places the rheostat switch in the maximum-buck position. Continuing the movement of the lever another 30 degrees, which covers 28 steps of resistance, progressively relieves the "buck" and allows normal excitation to be impressed on the main generator. The following and last 30 degrees of motion produces a gradual boosting of the field over a range of 28 more steps of resistance to the maximum point. This excess field current is necessary for pulling the motors into step, but it must not be maintained longer than necessary. To insure this condition, the lever is provided with a spring-return action augmented by a stout spring and lever arrangement in the pipe mechanism, Fig. 14, near the rheostat, which returns the lever mechanism and rheostat switch automatically to the normal excitation position when the handle is released.

The hand lever is made of polished steel and straddles a notched quadrant. It is provided with a latching lever operating in the notches, thus giving a ready means for fixing the lever at any desired position. The notches in the quadrant cover only the range between

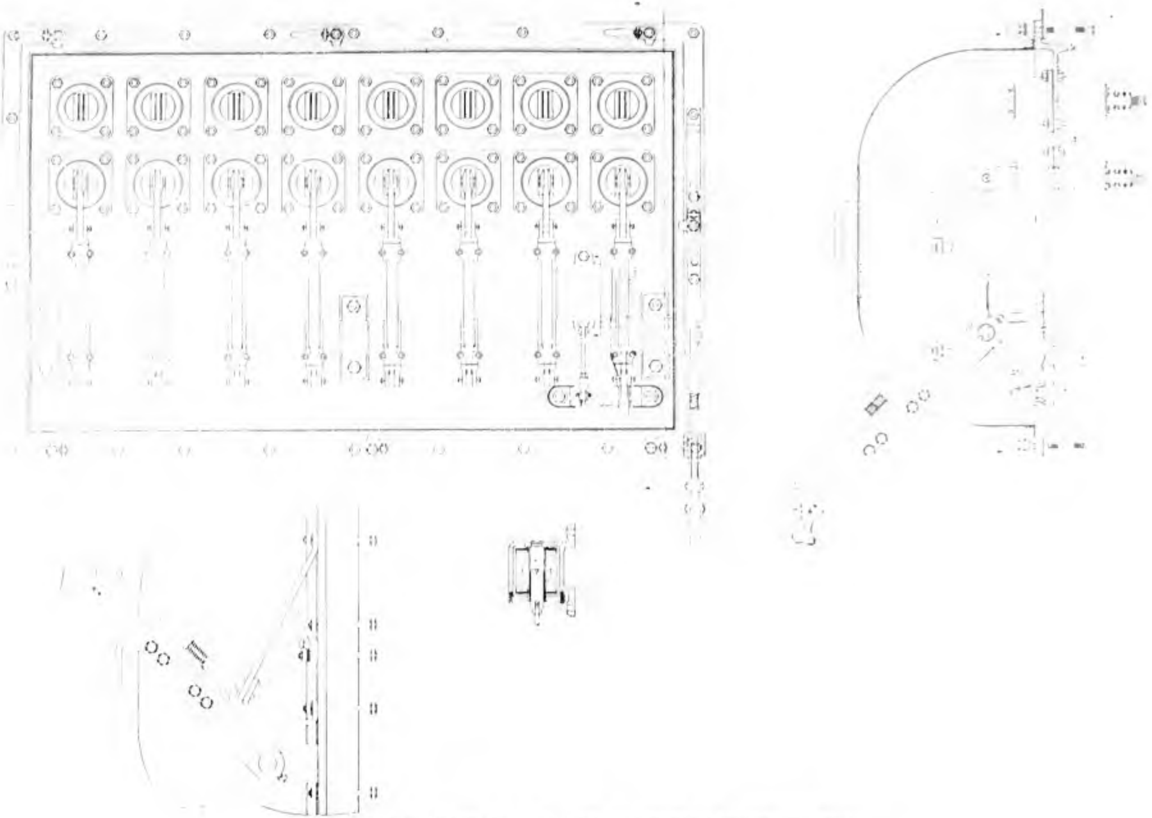
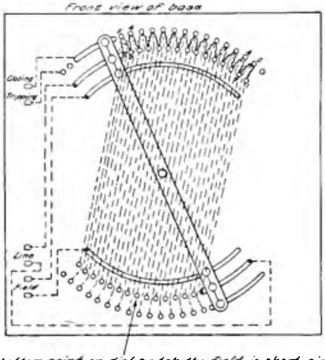


Fig. 10. Eight pole, Single throw, 5000 volt, 600 amp. Motor Disconnecting Switch

maximum buck and normal field, so that the lever cannot be locked in the over-excitation position. The booster field rheostat, Figs. 11 and 12, is mounted in the cell structure on either side of the fore-and-aft aisle near the rear wall.



At bottom point on dial switch the field is short circuited When switch passes this point the current is reversed.

Fig. 11. Booster-field Rheostat

The field switch is a double-pole, solenoid-operated circuit breaker rated 400 amperes 250 volts. It is equipped with magnetic blow-out coils at the secondary arcing tips and with a trip coil for connection to the contacts of the balance relay, Fig. 15.

Speed Control

Speed control is accomplished by adjusting the amount of steam flowing to the turbine, and it consists of two control levers for each turbine, one for speed control and the other for the purpose of limiting the number of open turbine valves.

The speed-control or steam lever, Fig. 13, is mounted at the side of the field-control lever and is similar in design. Its throw is limited to 45 degrees and it has notches corresponding approximately to $\frac{1}{4}$, $\frac{1}{2}$, $\frac{3}{4}$, and full speed. In addition to these, to provide a means for obtaining any intermediate adjustments by small increments, a hand wheel and screw arrangement is installed as shown. A four-spoked locking wheel is provided on the screw for holding the adjustment when made.

At the back of the board the lever ends in a crank and coupling which are attached to a shaft and a crank mechanism by means of which the motion of the speed lever is communicated to the operating levers at the turbine.

Steam Limiting Levers

The steam-limit lever, Fig. 16, is mounted below the speed lever and is similar in design, except that it is smaller. It has a throw of 90 degrees and is equipped with a spring arrangement at the hinge by which the lever is thrown into full-valve position when the speed lever is thrown into the off-steam position. This is accomplished by means of a connecting rod between the two which actuates the tripping mechanism at the proper time. The quadrant has 20 notches into which the heel of the latching lever fits when released. This gives 20 coarse steam adjustments which can be made independently of the speed lever and without interfering with the action of it.

This lever is connected by a shaft mechanism, similar to the one employed for the speed lever, to the valve control arm at the turbine.

Steam-limit Indicating Switch

Installed at the end of the steam limiting mechanism and on the valve-limit hook is the steam-limit indicating switch. It consists of a light switch arm installed in the hook and operated by the valve limiting arm in the hydraulic control mechanism. Here a roller operates upon the collapsible plate and link arrangement, which is connected to the switch arm, causing the arm to move its contact over a set of contact buttons suitably insulated. The contact buttons are connected to the 125-volt, direct-current circuit and to a set of indicating lamps on the control board.

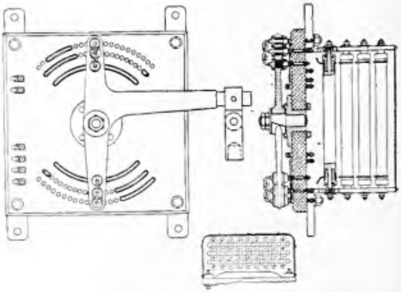


Fig. 12. Booster-field Rheostat

Interlocks

When a large number of devices, such as those described, are gathered together, it is readily discernible that means must be provided to prevent the making of mistakes and to confine operations to their proper sequence, therefore the very elaborate set of mechanical interlocks, described in the following, were designed and applied to the various devices:

The Generator Disconnecting Switches

(1) Must not be opened or closed when energized.

This operation is prevented by the magnetic lock, Fig. 7, which interferes with the rotation of the shaft and which is actuated by the field circuit when the field switch is closed. This means that the field-control lever must be placed in the vertical (field-off) position before a disconnecting switch can be moved.

(2) Must not be closed when the bus-tie switch and opposite generator disconnecting switch are both closed.

(3) Must not be closed in the high-voltage connection when the bus-tie switch is closed, Fig. 8.

(4) Must not be closed in the low-voltage position when the bus-tie switch is open, Fig. 8.

The Bus-tie Switch

(5) Must not be closed when both generator disconnecting switches are closed, Fig. 8.

(6) Must not be opened or closed when energized.

This protection is secured by the magnetic lock on the cell doors which prevents them from being opened unless the field circuit is "off."

The Reversing and Pole-changing Switches

(7) Are electrically locked by the locking magnet, Fig. 9, so that they cannot be opened until the line current has dropped to a predetermined value as governed by the undercurrent relay.

The coils of this relay are connected to the secondary circuits of the line-current transformer and its contacts operate the magnetic lock through the 125-volt excitation circuit.

The Reversing Switches

(8) Are interlocked with the pole-changing switches by means of the interlock box shown in Fig. 9, so that the former may not be thrown in the astern position while the pole-changing switches are in the 36-pole connection and vice versa. The pole-changing switches cannot be thrown in the 24-pole connection when the reversing switches are in the astern position.

Fig. 13. Steam (left) and Field Control (right) Levers

The Reversing and Pole Changing Switches

(9) Are also locked by the field-control lever, so that they cannot be operated unless the field lever is in the vertical (field-off) position, Fig. 14.

(10) Are further interlocked cross-ship with the field lever on the opposite side, so that they cannot be operated when the field switch is closed.

This interlock is shown in the lower part of Fig. 16 and consists of a shaft rotated by means of the pipe and bell-crank arrangement connected to the bus-tie switch operating a shaft as shown in Fig. 8.

The rotation of this shaft causes an extension of a set of springs attached to a second and a third shaft which are connected by links to the locking cams of the reversing and pole-changing switches on both sides.

The shafts, however, lock and cannot rotate until one of the field levers has been pulled

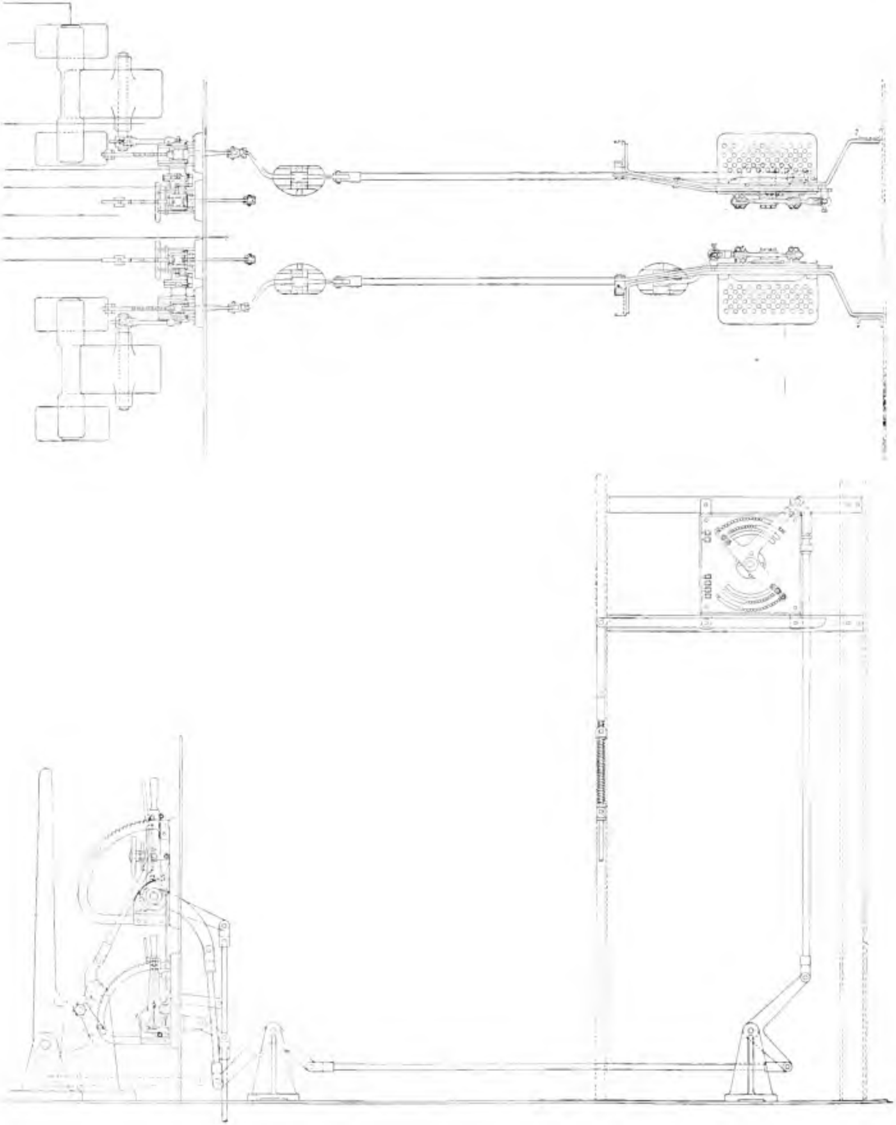


Fig. 14 Field Control Mechanism

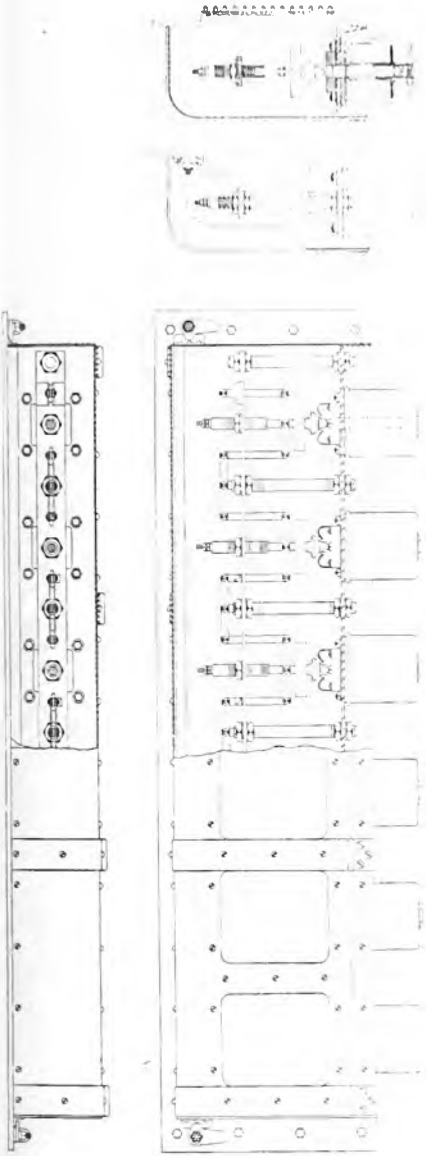


Fig. 15. Balance Relays and Operating Mechanism

Fig. 16. Steam-limit Speed, and Field-control Levers and Interlocks

out. The locking of the port switches is subject to the starboard field lever and vice versa; and the whole interlock is made inactive by the opening of the bus tie switch.

The Motor Disconnecting Switches

(11) Must not be operated when alive, and to prevent this they are equipped with a locking magnet, Fig. 10, connected to the field circuit.

Field-control and Steam-control Levers

(12) The field-control levers are interlocked with their respective reversing and pole-changing switches, so that these switches cannot be operated when the field lever is in the field-on position.

(13) The field-control levers are also interlocked with their respective speed-control lever, so that the field may not be taken off the generator without first pushing the speed-control lever to a low-steam position.

(14) The speed-control lever is interlocked with the field lever, so that only a limited amount of steam may be admitted to the turbine before the field circuit is closed.

(15) The speed-control lever is interlocked with the steam-limit lever, so that whenever the speed lever is moved to the off position the steam-limit lever is tripped to the full-valve position.

Controlling the Propulsion of the New Mexico*

By H. Franklin Harvey, Jr.

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In many respects the control apparatus of the *New Mexico* installation is the most intricate and important part of the equipment. As in all control apparatus, the question of convenience and smoothness of operation was a prime consideration. Another vital factor in battleship propulsion is to provide every means possible for keeping the equipment or a portion of it in operation. In an engagement every part of the equipment is liable to damage, and as far as possible provision must be made for every contingency. In this respect one of the striking features of the *New Mexico* control is the elaborate interconnection for obtaining a direct-current supply at the switchboard for turbine generator excitation. The control equipment is arranged on two boards, viz., a direct current board from which the exciters, boosters, blowers and other auxiliaries are controlled, and the main operating board on which are mounted the steam control levers, motor pole-changing switches, reversing switches, motor and generator disconnecting switches, meters, etc. The parts of the equipment, their arrangement, and the sequence of operations in starting and reversing are fully described in this article.—Editor.

Introduction

In describing the control of the propulsion equipment of the U.S.S. *New Mexico*, it is assumed that the articles on turbines, generators, motors, and control apparatus in the preceding pages have been read. The control equipment manipulates and ties together the machines for producing and utilizing the propulsive power in all its stages, and therefore frequent reference will be made to them without further explanation.

With the exception of the collier *Jupiter*, the *New Mexico* is the first electric driven ship in the United States Navy. About six years ago the *Jupiter* began its very successful career and has been running almost continuously ever since. The remarkable record of this collier was a big factor in causing the adoption of electric propulsion for the *New Mexico* and all larger subsequent ships of the United States Navy.

By reason of its purpose, the *Jupiter* is naturally a constant speed ship and consequently does not involve the extensive arrangement for speed control incident to the *New Mexico*, which must run efficiently at several speeds.

In designing the control apparatus for this battleship, particular attention was given to convenience in operation and smoothness of transfer from the type required for steam driven ships to that necessary for electric driven ones. This feature will greatly assist steam engineers to adapt themselves to electric control, and detailed evidence of the feature is clearly manifested in the article dealing with the description of control apparatus.*

The equipment for controlling the electric propulsion of this ship is shown in Fig. 1 and consists of:

(a) One direct-current switchboard for controlling two 300-kw. 120/240-volt, 3-wire turbine exciters, two 18-kw. 65-volt booster sets in conjunction with the main generator fields, ten engine room auxiliary motors, and a constant voltage control supply. Diagrams of this board and its connections are given in Figs. 2, 3, and 4.

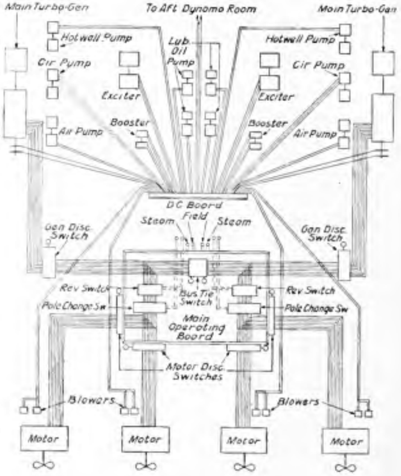

Fig. 1. Diagrammatic Arrangement of Apparatus and Main Cables for Propulsion Control Equipment

(b) One structural steel cell for controlling the two main 11,400-kw. 14,800-kv-a. 4200-volt 2-phase turbine-generators and the four 7250-h.p. 4200-volt, 2-phase induction motors

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* "The Main Control Equipment of the *New Mexico*," by C. T. Hentschel, page 261, this issue.

directly connected to the propellers. These generators are arranged with windings for obtaining 1212 volts on square connection and 3000 volts on parallel connection. The motors are provided with double-winding squirrel-cage rotors and the stators are arranged for 24 or 36-pole connections. Diagrams of this cell and its connections are shown in Figs. 5, 6, 7, and 8.

EXCITER AND AUXILIARY SWITCHBOARD

General Description

The panels are of ebony asbestos wood with marine finish. They are mounted on angle and tee bar supports with rubber backing to assist in absorbing shocks and to relieve any uneven surfaces between the back of the panels and the face of the supports. Name plates are provided for each piece of apparatus to indicate its service. Lamps in brackets with shades are mounted at the top of the panels to provide illumination for the board.

Due to the lack of space in the control room, it was necessary to mount this switchboard on a gallery in front of the main operating switchboard just above the two exciter generators and to brace it to the wiring passage from above. It therefore faces the main control board, making it possible for the operator to view both of them and giving him complete supervision over the entire control.

Exciter Generator Control

The turbines driving these machines are arranged to exhaust either into the fifth or eighth stage of the respective main turbine or direct to the main condenser. A special triple-pole, six-throw switch mounted on the subbase of the center panel transfers either exciter to either field circuit, to all auxiliary circuits, and to the aft distribution switchboard from which may be drawn the power from any of the four 300-kw. light and power sets as shown on the wiring diagram, Fig. 1. The connections from the aft distribution switchboard are also tied directly to a second set of buses feeding the lower throw of all auxiliary circuits. The arrangement of switch blades and connections prevent running the two exciters in multiple since no equalizing switches are included. Just above this switch are six red bull's eye lights to indicate which sources are available and to warn the operator against improperly throwing the center switch blade, since by so doing he may [illegible] multiple the supply from the aft di[illegible] switchboard with that from either exciter without properly equalizing, or he may [illegible] a dead exciter on the aft distribution supply

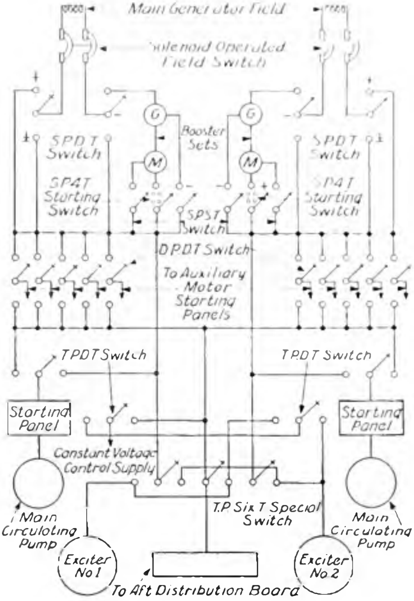


Fig. 2. One Line Diagram of Exciter and Auxiliary Circuits

and burn out its armature. These lamps are in multiple to assure an indication; it is highly improbable that the life of two lamps will be the same and, therefore, if at any time only one is burning, the other is evidently burned out and should be replaced. By use of a special socket device these bulbs can be easily removed from the front of the switchboard.

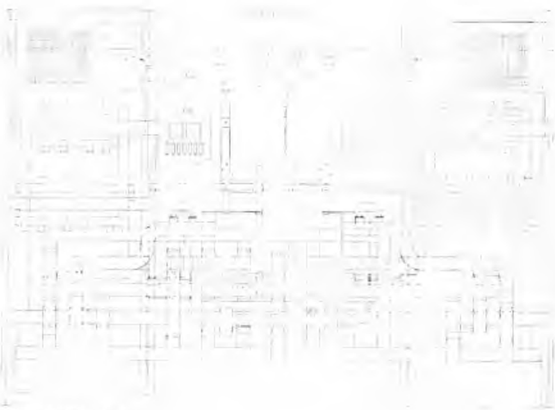
In addition to the lights, stops are provided for each set of blades in order to lock them in the open position, for preventing accidental closing and also causing the operator to think before throwing them.

On the upper section of the center panel, the field rheostat control hand wheels are mounted and directly connected by extended shafts to the rheostats which are supported on angle iron structure in the rear of the switchboard and suspended from the wiring

Fig. 3. Exciter and

EXCITER SWITCHBOARD EQUIPMENT

Part No.	Description of Apparatus
1	DH-3 ammeter, 150-0-150 amp. scale with shunt
2	DH-3 ammeter, 200 amp. scale with shunt
3	D-27 lever switch, d-p., d-t., 250 volt, 135 amp.
4	D-27 lever switch, d-p., d-t., 250 volt, 135 amp.
5	DH-3 ammeter, 1500 amp. scale with shunt
6	D-27 lever switch, t-p., d-t., 250 volt, 1200 amp.
7	D-27 lever switch, t-p., d-t., 250 volt, 1200 amp.
8	DH-3 ammeter, 100 amp. scale with shunt
9	D-27 lever switch, d-p., d-t., 250 volt, 65 amp.
10	D-27 lever switch, d-p., d-t., 250 volt, 65 amp.
11	D-27 lever switch, d-p., d-t., 250 volt, 65 amp.
12	D-27 lever switch, d-p., d-t., 250 volt, 65 amp.
13	D-27 lever switch, s-p., d-t., 250 volt, 350 amp.
14	D-27 lever switch, s-p., d-t., 250 volt, 350 amp.
15	D-27 lever switch, s-p., d-t., 250 volt, 350 amp.
16	D-27 lever switch, d-p., d-t., 250 volt, 135 amp.
17	D-27 lever switch, d-p., d-t., 250 volt, 135 amp.
18	D-27 lever switch, d-p., d-t., 250 volt, 135 amp.
19	D-27 lever switch, d-p., d-t., 250 volt, 135 amp.
20	Switch stop for 65 amp., d-t., lever switch
21	Switch stop for 350 amp., d-t., lever switch
22	Switch stop for 135 amp., d-t., lever switch



Auxiliary Switchboard

Name Plate Inscription
Booster Motor
Air Pump
Air Pump Bus No. 1
Air Pump Bus No. 2
Main Circulating Pump
Main Circulating Pump—Bus No. 1
Main Circulating Pump—Bus No. 2
Hotwell Pump
Hotwell Pump—Bus No. 1
Hotwell Pump—Bus No. 2
Lubricating Oil Pumps—Bus No. 1
Lubricating Oil Pumps—Bus No. 2
Booster
Generator Field
Bus
Ventilating Blower No. 1 (or 4) Bus No. 1
Ventilating Blower No. 1 (or 4) Bus No. 2
Ventilating Blower No. 2 (or 3) Bus No. 1
Ventilating Blower No. 2 (or 3) Bus No. 2

23	Name plate	Starboard
24	Name plate	Port
25	Clear bull's eye indicating lamp	Blower No. 41
26	Clear bull's eye indicating lamp	Blower No. 43
27	Clear bull's eye indicating lamp	Blower No. 42
28	Clear bull's eye indicating lamp	Blower No. 44
29	Clear bull's eye indicating lamp	Blower No. 17
30	Clear bull's eye indicating lamp	Blower No. 51
31	Clear bull's eye indicating lamp	Blower No. 49
32	Clear bull's eye indicating lamp	Blower No. 53
33	Clear bull's eye indicating lamp	Blower No. 54
34	Clear bull's eye indicating lamp	Blower No. 50
35	Clear bull's eye indicating lamp	Blower No. 52
36	Clear bull's eye indicating lamp	Blower No. 18
37	D-27 control bus transfer switch, t-p., d-t., 250 volt, 65 amp., with resistance	After Distribution Board
38	D-27 control bus transfer switch, t-p., d-t., 250 volt, 65 amp., with resistance	Three-wire, D-C. Control Bus
39	D-27 control bus transfer switch, t-p., d-t., 250 volt, 65 amp., with resistance	To Control Bus Selector Swt.
40	D-27 lever switch, t-p., d-t., 250 volt, 65 amp.	Exciter No. 2
41	D-27 lever switch, t-p., d-t., 250 volt, 65 amp.	Exciters
42	D-27 lever switch, t-p., d-t., 250 volt, 65 amp.	Exciter No. 1
43	Solenoid operated field switch, d-p., s-t., 250 volt, 350 amp.	Generator Field—Starboard
44	Solenoid operated field switch, d-p., s-t., 250 volt, 350 amp.	Generator Field—Port
45	D-27 lever switch, s-p., d-t., 250 volt, 350 amp.	Generator Field, 240-Volt
46	D-27 lever switch, s-p., d-t., 250 volt, 350 amp	Generator Field, 120-Volt
47	DH-3 ammeter, 2000 amp. scale with shunt	Positive Ammeter
48	DH-3 ammeter, 2000 amp. scale with shunt	Negative Ammeter
49	DH-3 voltmeter, 300 volt scale	Starboard (or Port) Voltmeter [illegible]
		Off
50	Voltmeter transfer switch, d-p., 6-t.	Pos. Neg. Pos. Neu. Pos. Grd. Neu. Grd. Neu. Neg. Grd. Neg.
51	Field rheostat mechanism	
52	D-27 lever switch, s-p., s-t., 250 volt, 350 amp.	Booster Generator, Neg.
53	D-27 lever switch, s-p., s-t., 250 volt, 350 amp.	Booster Motor, Neg.
54	H-16 starting switch, s-p., 1-t., 250 volt, 150 amp.	Booster Motor Starter
55	Mechanical interlock between booster motor starting switch and generator field switch	
56	D-27 lever switch, t-p., 6-t., 250 volt, 1800 amp.	Port Exciter
57	D-27 lever switch, t-p., 6-t., 250 volt, 1800 amp.	Bus No. 1 Starboard
58	D-27 lever switch, t-p., 6-t., 250 volt, 1800 amp.	Starboard Exciter
59	D-27 lever switch, t-p., 6-t., 250 volt, 1800 amp.	After Distribution Board
60	D-27 lever switch, t-p., 6-t., 250 volt, 1800 amp.	Bus No. 1 Port
61	Bureau name plate	
62	Name plate	New Mexico
63	Lamp bracket	
64	Solenoid control relay, s-p., 125 volt	
65	Generator field discharge resistance	
66	Fuse base	
67	Lamp bracket	

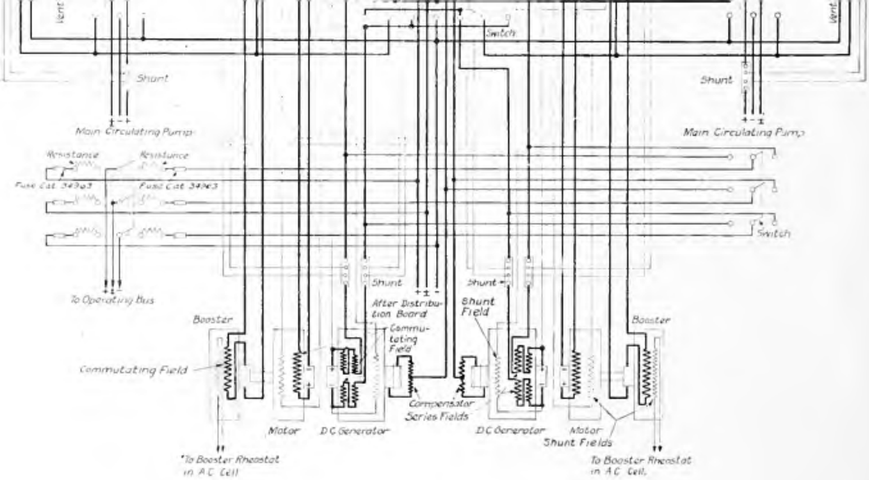
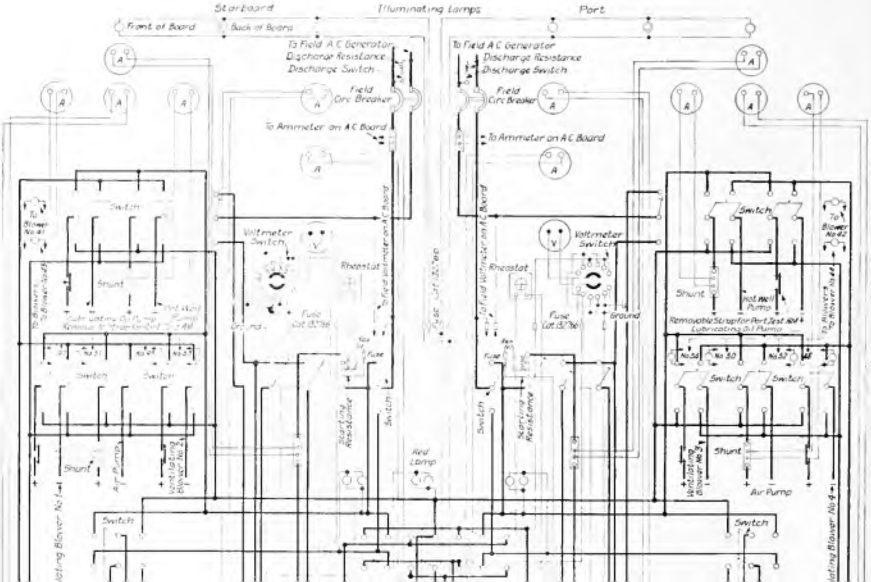


Fig 4 Wiring Diagram, Exciter and Auxiliary Switchboard


Starboard
Illuminating Lamps
Port
Front of Board
Back of Board
To Field A C Generator
Discharge Resistance
Discharge Switch
Field Circ Breaker
To Ammeter on A C Board
A
V
Voltmeter Switch
Rheostat
To Field Voltmeter on A C Board
Fuse Cat 82766
Ground
Fuse
Switch
Shunt
To Blower No 41
To Blower No 42
To Blowers To Blower No 43
To Blowers To Blower No 44
Hot Well Pump
Removable Strap for Port, Stat. RM Lubricating Oil Pump
No 51
No 49
No 53
No 54
No 50
No 52
Starting Resistance
Red Lamp
Air Pump
Ventilating Blower No 1
Ventilating Blower No 2
Ventilating Blower No 3
Ventilating Blower No 4
Fuse Cat 82766

passage. These hand wheels are provided with name plates and pointers to indicate proper rotation for raising or lowering the exciter generator voltage. For both the positive and negative legs of each exciter main circuit, ammeters are included, and shunts for operating them are mounted in connection bars at the rear of the switchboard. A voltmeter for each exciter is mounted on this panel, and by means of the six-point transfer switches the potential can be obtained between any of the exciter main leads or between the main leads and the ground. The voltmeter has a black target which is set on the scale at the normal voltage indication by a screw on the lower side of the case, for the purpose of aiding the operator readily to observe if the desired voltage is being maintained. The scales are white and are provided with special intermediate markings to facilitate reading. The white pointers with black background may be easily seen at a distance.

Booster Control

For each booster set, and on the upper section of the center panel, there are one single-throw lever switch to connect the motor armature to the local negative bus and one single-pole, four-throw pump-type switch for starting the motor from the local positive bus. The single-pole switch for the booster motor is provided with a red handle to indicate that it must not be opened until after the field switch or motor starting switch, as such operation would cause the motor to run away if the current were on the generator end. The first throw of the starting switch connects the motor shunt field, and the clip is so arranged that the blade remains in contact throughout the four throws to avoid opening the field when leaving the first throw or inserting the starting resistance in the field circuit through the other throws. A fuse is connected in the first throw to protect the motor in case of abnormal conditions. The particular design of switch necessitates an operation of the handle for each step, thereby introducing a time element in order to allow the motor to respond to the currents limited by the different sections of resistance, and to prevent instantaneously throwing the motor on the line. The starting switch is mechanically interlocked with the field switch so that the field switch cannot be opened unless the starting switch is open. This guards against running current through the booster generator without running the booster motor, and prevents the set from running away. On a separate base above each cell is mounted a zero-center ammeter. These are connected in the booster motor circuit and in addition to their regular services, indicate whether the machines are running as motors or generators.

Main Generator: Field Control

At the top of the center panel are mounted the two generator solenoid-operated field switches with red lights just above them to indicate when the switches are closed. These switches consist of two main poles, a discharge blade, an auxiliary switch, a closing coil, and an opening coil. Contacts for operating these field switches are included with the booster generator field rheostat, which is located in and controlled from the main cell. The off position of the lever controlling the booster rheostat energizes the opening coil of the field switch, and the next point energizes the closing coil through a solenoid control relay mounted on the rear of the exciter switchboard. When the field switch opens and just before its secondary contacts break circuit, the discharge switch makes contact and connects a resistance across the field to absorb the induced voltage and prevent rupturing the field winding insulation. When the field switch closes, it opens the discharge switch and makes it ready for the next operation.

In case the field switch fails to respond to electrical operation by the control lever on the control cell, a permanently arranged auxiliary handle is provided for closing the switch by hand, and it is easily opened by simply pushing up the tripping button attached to the core of the opening solenoid. The secondary contacts are encased by a magnetic blow-out coil to prevent excessive arcing when the switch opens under load.

The auxiliary switches mounted behind the panel, and mechanically operated by the movement of the switch brush, are of the magnetic blow-out type and control the current for energizing the coils of all apparatus which is locked when these switches are closed. The auxiliary switches also operate the indicating lights, both on this switchboard and on the main operating board.

For controlling the supply to these field switches, there are mounted on the upper section of the center panel one single-pole, single-throw and one single-pole, double-throw switch, and also on the feeder panels one single-pole, double-throw switch. All three of these switches are provided with red handles to indicate that they must not be

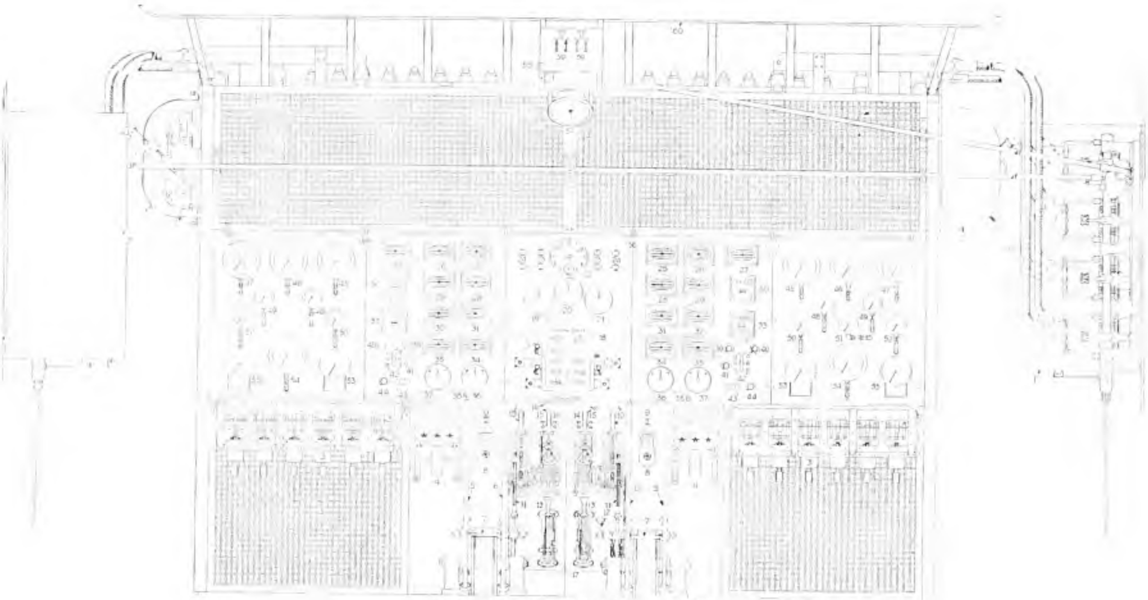


Fig. 5 Main Control Switchboard and Cell

TURBINE EQUIPMENT

Part No.	Description of Apparatus	Name Plate Inscription
13	Steam limit control lever	Steam Limit Control Lever
14	Red bull's eye lamp for steam limit indicating switch	
15	Clear bull's eye lamp for steam limit indicating switch	
16	Speed control mechanism	Speed Control Mechanism
45	Steam gauge	Main Steam
46	Steam gauge	Main Turbine, Steam Chest
47	Steam gauge	Main Turbine, 1st Stage
48	Steam gauge	Exciter Exhaust
49	Steam gauge	Auxiliary Exhaust
50	Pressure gauge	Oil to Turbines
51	Pressure gauge	Feed Water
52	Pressure gauge	Oil to Governor
54	Vacuum gauge	Main Condenser

GENERATOR EQUIPMENT

Part No.	Description of Apparatus	Name Plate Inscription
1	Generator disconnecting switch, 8-p., d-t.	Generator Disconnecting Switch
	(A) Auxiliary switch, d-p., c.o.	
	(B) Magnetic locking device	
5	Balance relay	Balance Relay
6	Reversing lever mechanism	Ahead—Astern
	* (A) K-31 oil circuit breaker, 3-p., d-t., 5000 volt, 3000 amp.	
	* (B) Magnetic locking device	

7 Interlock between reversing and pole changing levers
10 Field control mechanism
  * (A) Booster rheostat
  * (B) Pipe mechanism for (A)
11 Interlock between field control lever and reversing and pole changing levers
12 Interlock between bus section and field switches
  * (A) Bus section switch, 4-p., s-t., 2400-amp., 5000 volt, operating m auxiliary switch
17 Across-ship interlocking shaft for *12*
23 Red bull's eye lamp for field switch
24 Green bull's eye lamp for field switch
25 H-2 ammeter, 15 amp. with 10,000 amp. scale
26 H-2 voltmeter, 150 volt with 6000 volt scale
27 DH-3 temperature indicator $\left\{\begin{array}{l}\text{70-250 deg. F.}\\ \text{20-120 deg. C.}\end{array}\right\}$ scale
28 DH-3 field ammeter, 600 amp. with shunt
29 DH-3 field voltmeter, 300 volt
31 H-2 indicating wattmeter, 110 volt, 4 amp., 20,000 kw. scale
  * (A) E-18 current transformer 3000/5 amp.
  * (B) AQ-1 potential transformer, 4400/110 volt, 200 w
  * (C) Fuse support with fuse holder and fuse, 4400 volt
32 H-1 speed indicator, 110 volt, 1000-2500 r.p.m. scale**
39 Ammeter transfer switch
40 Voltmeter transfer switch
41 Balance relay cutout switch
42 Temperature indicator transfer switch
43 Temperature indicator test switch
44 Temperature indicator supply switch
58 Interlock between generator disconnecting switches and bus section switch
59 Booster generator field switch

MOTOR EQUIPMENT

2 Motor disconnecting switch, 8-p., s-t., 600 amp., 5000 volt
  (A) Magnetic locking device
5 Pole changing lever mechanism
  * (A) K-31 oil circuit breakers 6-p., d-t., 5000 volt, 1500 amp.
  * (B) Magnetic locking device
8 Under current relay
9 Blue bull's eye indicating lamp for 8
18 Revolution counter
19 Stop clock Average starboard shaft
20 Stop clock Average all shafts
21 Stop clock Average port shafts
30 IS-4 watthour meter ,110 volt, 5 amp.
33 IS-4 watthour meter, 110 volt, 5 amp.
  * (A) W-2 current transformer, 800/5 amp.
  * (B) AQ-1 potential transformer, 4400/110 volt, 200 w
  * (C) Fuse support with fuse holder and fuse, 4400 volt
34 H-2 ammeter, 5 amp. with 1600 amp. scale
35 H-2 ammeter, 5 amp. with 1600 amp. scale
36 Direction indicator motor No. 2 for 31
37 Direction indicator motor No. 1 for 1
53 Electrical speed indicator motor No. 2 for 31
55 Electrical speed indicator motor No. 1 for 1

MISCELLANEOUS EQUIPMENT

4 Speed indicator for engine room telegraph
22 Clock
38A Name plate
38B Name plate
56 Lamp bracket
57 Rudder position indicator
60 Sheet iron protecting shield

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* Located inside cell.

** Also has scales for indicating motor speed on 24 and 36 pole connection

Field Control Mechanism

echanism and

Generator Field closed
Generator Field open
Generator Ammeter
Generator Voltmeter
Generator Temperature Indicator

Generator Field Ammeter

Generator Field Voltmeter
Generator Wattmeter

Generator and Motor Speed Indicator
Generator Ammeter Transfer Switch
Generator Voltmeter Transfer Switch
Balance Relay Cutout Switch
Temperature Coils
Test
Indicator Supply

Booster Generator Field

24 Pole — 36 Pole

Under Current Relay

Motor No. 1 (or 3)
Motor No. 2 (or 4)

Motor No. 2 (or 3) A.C. Ammeter
Motor No. 1 (or 4) A.C. Ammeter

Starboard
Port

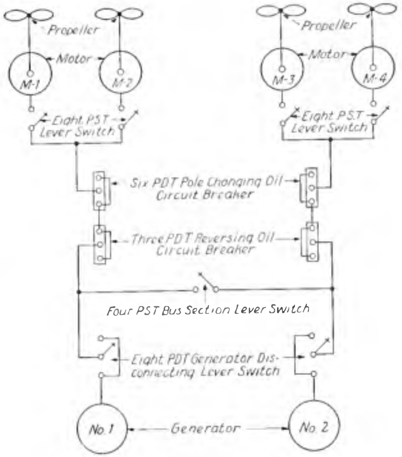

Fig. 6. One Line Diagram of Propulsion Control Equipment

opened when the field switch is closed, in order to prevent opening the field circuit and drawing a dangerous arc. The single-pole, single-throw switch connects the booster generator armature to the local negative bus and the single-pole, double-throw switch on the feeder panel connects the field circuit to either the local negative bus or to the booster generator. The single-pole, double-throw switch on the center panel connects the field to either the positive or neutral bus, thereby providing a 120 or 240-volt supply. With this arrangement of switching, the main generator field can be supplied directly from either of the exciters and without the booster, in which case the exciter supplying the field will have its voltage varied as required for excitation and, therefore, cannot supply any of the other circuits. Consequently, it will be necessary either for the aft distribution board or the other exciter to supply all the auxiliaries. Ordinarily, the booster will be used to vary the field voltage, but this provision of switching is made in case one or even both boosters fail and must be taken out of circuit.

The fields of the exciter generators are self-excited through a variable resistance. The booster motor fields are excited from the same source as their armatures. The booster generator fields are controlled by rheostats in the main cell and they are operated simultaneously with the generator field switches.

Constant Control Supply

On the lower part of the right-hand panel is mounted a special triple-pole, double-throw transfer switch for supplying, without interruption, the operating bus from either of the two exciters or from the aft distribution switchboard. This switch is provided with fuses and intermediate clips for connecting to the resistances. The clips of the switch are so arranged that the operating circuit is never broken (except voluntarily by removing the fuses) in transferring from one source to the other. This is accomplished by the insertion of a limiting resistance in the gaps between the outer and inner clips of each pole on both throws. The innermost clips of the two throws are close enough to be spanned by the blades, and during the act of transfer current is taken from both sources through the resistance to the control bus. The resistances are designed to carry the full control current as well as any short-circuit current which might be caused by a difference of voltage between the two sources, providing this current is not excessive.

On the lower part of the left-hand panel is a triple-pole, double-throw switch for connecting either exciter to the inner throw of the special triple-pole switch on the lower part of the right-hand panel. The other throw of the special switch is connected to the aft distribution switchboard supply.

This special arrangement for supplying the control bus is necessary, since it is desired to always have constant voltage available for the locking coils and for controlling the solenoid operated apparatus. When either exciter is being used directly for generator field excitation, its voltage is varied so widely that this supply cannot be used for the control, and in this case it is necessary to switch over to the other exciter or possibly to the aft distribution switchboard supply.

In case the control bus were being supplied from an exciter which was supplying a field in connection with a booster, and the booster failed, it would be necessary to throw the special triple-pole switch to the aft distribution supply, then the ordinary triple-pole switch to the other exciter, and then the special triple-pole switch back to the exciter supply contacts. It is assumed that such an emergency would occur when the ship was underway, and therefore the aft distribution supply would be available at this switchboard.

There are other times, however, when this aft switchboard supply would not be available and, therefore, it cannot be depended upon at all times for this control supply, a condition which makes it necessary to use the exciters also for this purpose.

In the manipulation of these switches, the operator should always be absolutely sure that his control bus is being supplied from a constant source, and this should be among the first operations performed on the exciter switchboard when getting underway. By using only one operating bus, the possible multiplying of different control sources is avoided, and also the operator has simply to remember that he has only one control bus to keep supplied at all times.

When manipulating these control bus supply switches, the practice of operating the special throw-over switch first should always be followed, since opening the exciter double-throw switch would interrupt the control bus unless at that time it happened to be on the aft distribution supply.

Auxiliary Propulsion Apparatus Control

Double-pole, double-throw switches for controlling the 240-volt motor-driven engine room auxiliaries are mounted on the upper sections of the two end panels. The upper throws are connected to the bus fed by either of the two exciters and the lower throws to the bus fed by the aft distribution switchboard. The air-pump and hot-well pump motors are provided with ammeters operated by shunts in the connection bars at the rear of the switchboard. The other three circuits have removable links in their connection bars for the insertion of a portable ammeter.

All these vertically-operated double-throw switches are provided with lever type switch stops for pulling up into the lower clips to prevent accidental closing of the switch by gravity or vibration when the switch is in the open position. When it is desired to throw the switch into the lower position, these stops will be pulled out of the clips and hang down below them. Near the switch for each main motor ventilating blower is a red light connected across the motor armature to indicate when it is running. There are also similar lights for the motors of the main generator blower fans even though their supply switches are not on this board. These lights are very valuable to the operator in the engine room since the motors are not in sight and he, of course, should be watchfully attentive to ventilation, especially at the higher speeds.

The triple-pole, double-throw switches for the main circulating pumps are also mounted on the sub-bases of the end panels. The middle throw connects to the exciter supply, and the outside throw to the aft distribution supply. An ammeter is provided for this circuit and is operated by a shunt in the positive leg. At reduced speeds these main circulating pump motors will run on 120 volts as selected at their starting control panel, which is the reason for the triple-pole switches on the exciter switchboard. The 120-volt supply is taken from the positive and neutral, since when the field is operating on 120 volts it takes its supply from the negative and neutral, and these two 120-volt loads tend to balance each other on the three-wire system.

Rear of Switchboard

On framework in back of the panels are mounted the field switch solenoid control relays, field discharge resistances, receptacles for indicating lights, auxiliary switch for field switches, and shunts for ammeters. Starting resistances for the booster motors are mounted above the exciter field rheostats.

The instrument and control fuses and fuses for protecting the field voltmeter on the main control board are also mounted on ebony asbestos wood bases in the rear of this switchboard. In order to avoid a mass of cables close to the back of the switchboard, thereby blocking access to it, the outgoing connections to the cables are brought to ebony asbestos wood supports.

Operation

When getting underway the operation at the direct-current switchboard should be as follows:

1. Obtain the voltage supply from the aft distribution switchboard.
2. Throw the required main-air, main circulating, oil, and hot-well pump switches into the lower clips (aft switchboard supply). These feed the respective starting panels from which the operator now starts the motors.
3. Make sure that every switch, except those in operation 2, is in the open position. After the desired turbine exciter generators are up to normal speed, read the voltage on the outside legs of the generator involved. This will probably be very low, since the field will be weak due to the fact that all resistance will be cut in.

4. Cut out the exciter field resistance until the voltage rises to 240 volts.

5. If the ship is to run above 17 knots, both exciters are to be operated and, therefore, the two outside sets of blades of the special triple-pole, six-throw switch should be thrown on the inner clips and the center switch blade should remain in the open position. If only one exciter is used, throw the outer blades to the outer clips. This ties the exciters to their respective buses.

6. Throw the switches already closed in operation *2* to the upper clips (exciter supply). If thrown over quickly, the hot-well pump motors can be "caught" to avoid restarting them; but the operator stands ready at the panel for re-starting the main circulating and air pumps after the switch is thrown over.

7. Throw the remaining feeder switches in the upper throw for supplying power to their respective panels. At this time start all the pumps, but leave the ventilating motors until the main motors have started for continuous running.

8. Throw the triple-pole, double-throw switch, on the bottom of the left-hand panel, to the exciter connections which are to be favored for the control supply on the particular trip. Then throw the special triple-pole, double-throw switch, on the lower part of the right-hand panel to the inner throw. This energizes the control buses with constant potential.

9. Throw in the booster motor negative switch and then the motor starting switch. This operation will bring the booster set up to speed, since its field will have previously been adjusted.

Note.—If the ship is going to run below 17 knots, only one turbine generator will be used and therefore but one booster set, in which case only its respective switches will be closed, the others remaining open. Otherwise the same operations as for full-speed conditions will be performed.

10. Close the field supply negative switch and also the single-pole, double-throw switch, on the center panel, to the upper position if 240-volt field supply is desired, or to the lower position for 120-volt supply; then close the single-pole, double-throw switch, on the feeder panel, to the upper position for connecting the field to the booster generator. This operation supplies current to the lower studs of the field switch through the booster generator, thus making ready for connection to the main generator field circuit. From this point on, the generator field will be controlled by the operator in front of the main control board.

11. If at any time either booster set fails, the field switch involved should immediately be opened and the single-pole, double-throw switch on the feeder panel thrown in the lower position, thereby connecting the field direct to the bus. Also, the two single-pole, single-throw switches connecting the booster motor and generator to the negative bus are to be opened, but the starting switch is to remain closed in order to have the field switch in since they are mechanically interlocked. These operations will connect the exciter direct to the field, in which case all auxiliaries previously connected to this exciter circuit will have to be transferred to the aft distribution switchboard supply by throwing their switches in the lower or outer throws as the case may be. If desired to disconnect the booster generator field, open the double-pole switch on the panel above the main control board.

If while running on one exciter it should fail, the following will be the procedure:

1. Throw the feeder switches to the aft switchboard supply in the following order:

Oil pumps, operating bus, main circulating, main air, hot-well, and blowers.

Note.—The operator can "catch" the hot-well pumps and blower motors, provided he is at the board when the supply fails or when simply changing over from one source to another.

2. Disconnect the booster.

3. Start the second exciter and throw it on the bus feeding the field switch to be used.
4. Throw the operating bus switch on the second exciter (just started).
5. Start up the booster set as usual (now ready for operation).
6. Throw over all the auxiliary feeder switches on the second exciter at convenience.

With this particular arrangement of switching, it is possible to obtain any combination of exciters, boosters, and aft distribution switchboard supply. That is, if either one or both of the boosters are disabled, either exciter or both may be used direct for the generator field excitation (thereby making it necessary to supply the auxiliary circuits from the aft distribution switchboard) or any combination involving one or both boosters, or neither of them. In case of both exciters failing, the aft distribution supply may be used for one field circuit and all auxiliaries by disconnecting the leads from one exciter and throwing the center set of blades of the six-pole switch to the exciter clips from which the leads were disconnected, and the opposite main switch to the outer throw.

The central blades of the special triple-pole, six-throw transfer switch must never be thrown in either set of clips until the lights connected to them are out, indicating that the line between this switch and the aft distribution switchboard is dead; otherwise the exciter may be thrown directly on 240 volts from the aft distribution board, thereby short circuiting its armature.

MOTOR DRIVEN AUXILIARIES

Not only is the propulsive power obtained by electrical means, but also most of the auxiliary apparatus necessary for the complete operation of the turbine generators and motors is electric driven. The hazard of failure in electrical machinery is no longer feared; and even though the initial cost may be slightly more than for steam driven auxiliaries, still the economy after installation is sufficiently marked to warrant the electric driven ones. The particular auxiliaries involved in this installation are listed in the table on this page, and a brief description is given of their control.

Quantity	Service	RATING OF MOTOR	
		H.P.	Volts
2	Main circulating pump	250	120 or 240
2	Main air pump.........	40	240
4	Forced lubrication pump.	10	240
2	Hot-well pump........	20	240
8	Main motor ventilation fans.................	8½	240

The motor of each auxiliary is controlled by a separate starting panel for which there is a lever switch on the exciter switchboard. These panels are located near the motors and are enclosed in sheet-steel cabinets provided with convenient doors and locks.

For the main circulating pumps, series relays and shunt contactors are employed. After the operator closes the starting switch, the motor comes up to speed automatically by the closing of contactors in proper sequence. Overload protection is afforded by a series overload relay in conjunction with the shunt contactor in the line. By means of a single-pole, double-throw switch on the starting panel, 120 or 240 volts may be delivered to the motor for obtaining different speeds. Fig. 9 is a photograph of this panel and Fig. 10 a diagram of its connections.

The starters for the main air, forced lubrication, and hot-well motor pumps employ series accelerating contactors; and after the starting button is closed, the contactors operate consecutively for cutting out resistance, the last one closed sufficing also for main line connection. It has a shunt-wound coil to release at low potential in order to provide under-voltage protection and open on failure of supply. In either case, the main contactor will drop out, making it necessary to start the motors again. Overload protection is obtained by means of a series relay with its contacts engaging the shunt coil of the line contactor.

The panels for controlling the ventilating motors for the main motors are equipped with a hand starter and a line contactor, the shunt coil of which causes it to drop out on low voltage as well as a failure of the supply. When starting, the operator holds down the latch in the handle until, at the end of travel, it rides up and into a notch and locks the arm against opening under shock. If the line contactor goes out, it is therefore necessary to bring the arm to the open position for starting again. Overload protection is obtained by the use of fuses on the main line switch, and speed regulation by varying the shunt field through a rheostat combined with the starter.

CABLES

The cable problem incident to electric drive is by no means a small one, but in this article only its most important features will be touched upon.

All cables carrying direct current are insulated with pure Para rubber, lead covered, and protected by an armor of woven galvanized steel wire. This armor is further protected against corrosion by a coat of red lead.

The main generator and motor cables, which carry alternating current, have a fiber core, pure Para rubber insulation, and a covering of asbestos braid filled with fire-resisting paint.

Where it is necessary to carry cables through a bulkhead, as is the case from the control cell to the outboard motors, a bulkhead plate is employed. It consists of studs leading through bakelite insulators mounted on an alloy base with a water-tight joint between it and the bulkhead. An alloy base is necessary to avoid heating due to eddy currents. Terminals are provided on each end of the studs for cable connections. This construction is also used for generator leads, except that it is combined with the generator disconnecting switch itself since the turbine generators are located in compartments separate from the control cell. Cables from the terminal studs on the generators run along the bulkheads on special racks, using bakelite cleats to eliminate trouble due to shock. To protect these cables, as well as the connection studs and insulators from the harm due to the condensation of steam which may escape from the turbine, sheet iron covers have been provided. Warm air generated in the cables is led through a pipe in the top of the cover to the ventilating system of the generator. On account of the abnormal strain and whip of the bulkheads, due to gun fire, special attention has been given to the supporting of all cables, especially the larger ones.

CONTROL CELL

Construction

The cell is constructed mostly of channel and angle-iron, forming supporting members within for oil circuit breakers, booster rheostats, instrument transformers, buses, and connections with the necessary insulators. It is enclosed with grillework for the protection of the operator. Without, on each side, and in the rear of the cell are mounted the motor disconnecting switches. Part of the cell front is formed by ebony asbestos panels on which are mounted instruments, meters, lights, transfer switches, gauges, indicators, and revolution counters. On the steel panels, which also form a part of the cell front, are mounted under-current relays and the field, steam, and speed levers with their interlocks. Just below the gauge panels are the balance relays and in the front of the cell, supported on the floor, are the operating levers for the oil circuit breakers. At each side of the cell, and mounted in the bulkheads, are the generator disconnecting switches.

Fig. 5 is a diagram of this control switchboard and certain photographs in another article in this issue show details of the construction.*

Turbine Control

The turbines at maximum efficiency run with 28.5-in. vacuum and at about 1950 r.p.m.

After the proper steam conditions have been reached the boiler room reports to the control room. The necessary auxiliary apparatus is then started and the control operator requests that the desired turbine be started by the main throttle valve. The turbine will then attain a speed equivalent to the setting of the steam and speed levers at the control board. The control operator will then adjust these levers for speeding up and operating the emergency trip, which when operated also closes the throttle valve. He will at this time apply current to the main generator field to obtain voltage for operating the potential transformers which control the speed indicators and afford the operator a means of knowing the turbine speeds. The control operator will then throw off the speed and field levers and will telephone the turbine attendant to reset the emergency trip and open the throttle valve.

The speed lever simply adjusts the governor for regulating the speed of the turbine, but this speed in turn is dependent upon a steam-limit lever which governs the number of valve openings. If the speed lever were set for a higher speed than the valve openings would permit, the governor arm would come up against a stop on the limit links and cause the turbine to eventually settle at that speed, or with increased load would slow down. The limit stop, however, does not prevent the governor from closing all the valves at any time. To provide the control operator with a constant knowledge of the proximity of the governor arm connection link to the steam-

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*Figs. 2, 3, 4 and 5, "The Main Control Equipment of the *New Mexico*," by C. T. Hentschel, page 261.

limit stop, a special auxiliary switch has been combined with the stop and operates a red and a white light just above the speed levers on the control board. When the link is about half an inch away from the stop the white light burns, when one eighth inch away both lights burn, and when against it the red light alone burns. The purpose of the steam-limit lever is to prevent the motors from falling out of step and to protect the boilers and turbines from sudden, abnormal, and harmful demands when the ship is turning or when there is a heavy sea

When running steadily the steam-limit lever is set to give ample margin for the usual small variations and this margin is such that the white light burns. The operator therefore endeavors to keep this condition, but if occasionally both lights or even the red light alone burns there need be no alarm since this would happen in a heavy sea. If, however, the red light continues to burn and the ship is not turning or any other such conditions exist, the operator should reset the steam-limit lever to have only the white light burn, since the desired speed of the ship is evidently being restricted by the steam-limit lever. If very little or no margin at all is desired, the red light will be kept burning, but at the present time this does not seem to be desirable.

The speed lever is provided with a vernier for obtaining small increments of speed, and in its minimum position the turbine runs at about 700 r.p.m. Also, the minimum position of the steam-limit lever permits two valves to be open. This means, therefore, that the turbine cannot be shut down by means of these levers at the control board; and in order to accomplish a shut-down, an emergency trip handle has been installed and is operated from the front of the control board. The usual gauges for turbines are mounted on the front of the control board and are listed in the tabulation accompanying Fig. 5.

Generator Control

Before starting a run the generators are tried out by connecting the motor load to them and just turning over the propellers as out-lined in the method of operation given later in this article.

The field lever controls the operation of the generator field switch on the exciter board as well as the rheostats inside the cell for the field of the booster generators. On the panel section, above the field levers, are pairs of red lights to indicate when the field switch is closed and green lights when it is open. When the lever is in a vertical position, buttons on the booster rheostat are engaged for energizing the trip coil of the field switch; and, when partly moved out, other buttons are engaged for energizing the closing coil. From this point, resistance is cut in to reduce the voltage from maximum buck to zero (or no field on the booster generator). Here, the field is reversed and resistance cut out to proceed to maximum boost. This produces over excitation for the main generator field and is used only when pulling the motors into step. The last few degrees of the lever operation are opposed by a spring to guarantee the return of the lever to a safe continuous value for the generator field. It is possible to select at the exciter board either 120 or 240 volts for field supply, but ordinarily 240 volts is used in order to be ready for reversing when called upon at higher speeds.

If it is known, however, that the ship will continue at a comparatively low speed for some time, the 120-volt source may be used since sufficient excitation may be obtained by means of the booster to reverse under these conditions.

Proper excitation of the main generator is very important in order to prevent the motors from falling out of step and also to produce maximum efficiency. In order to obtain the best power-factor and least possibility of overheating the generator under ordinary running conditions, only enough margin in the field currents should be used to prevent the motors from dropping out. Of course, when maneuvering considerable margin will be held. The power-factor of the outfit is ordinarily around 75 per cent at the best speeds. It, however, is considerably lower under certain conditions when the generators are somewhat over-excited for the corresponding speed. To assist the operator in determining the proper field current, a chart has been prepared which gives the proper values at the different speeds and under the different conditions.

The field ammeter has a red mark at 330 amperes indicating the maximum continuous field for the main generator. When over-exciting, however, the current momentarily goes considerably above 500 amperes.

The necessary indicating instruments, listed in the tabulation accompanying Fig. 2, have been provided for the generators, and no detail mention is required except to state that they are subject to unusually strenuous variations in voltage, current, frequency, and power-factor incident to the several speeds of the ship. The generator ammeters have extensive scales to indicate the amount of current taken when pulling the motors into step. The speed indicators have three scales, one for the generator, one for the motor on 24-pole connection, and the third for the motors on 36-pole connection. All instruments have specially marked scales to assist in speedy reading.

An eight-pole, double-throw enclosed disconnecting switch is provided for each generator. To this switch are attached the eight leads from the four windings in the main generator, and the studs are so inter-connected that the aft throw ties the windings in a parallel arrangement for 3000 volts and the forward throw in a square arrangement for 4242 volts. These switches are mounted on bulkheads at either side of the control cell

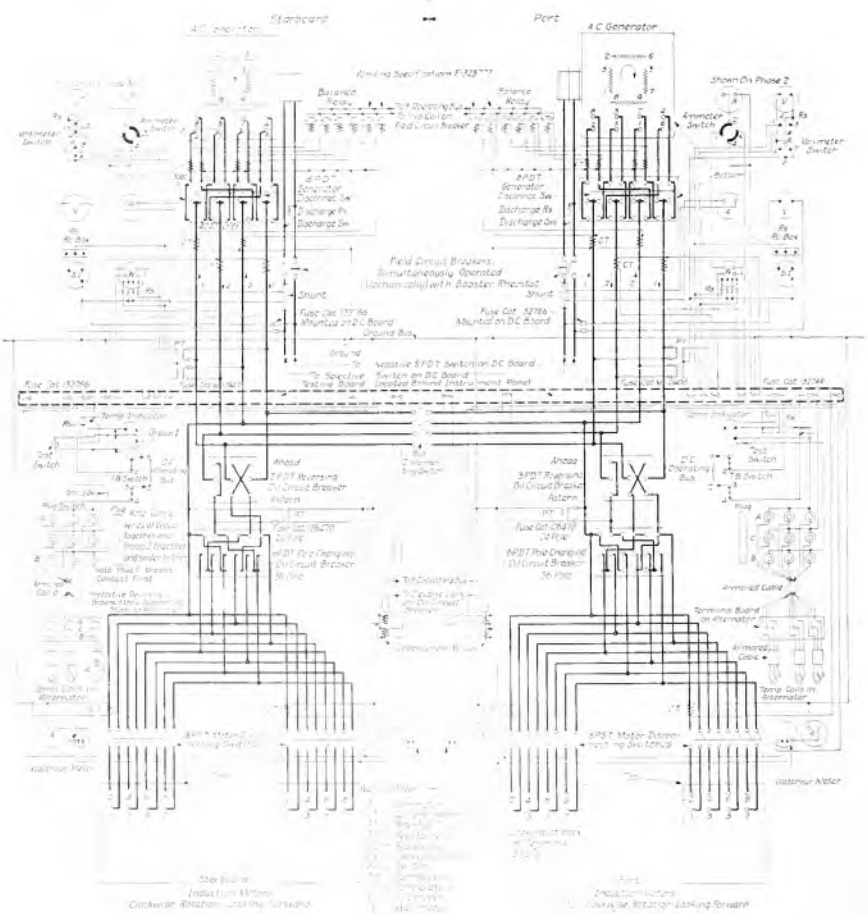

Fig. 7. Wiring Diagram, Alternating-current Switchboard

and leads from them are attached to the main generator buses at the top of the cell. They are interlocked with each other and the bus tie switch, so that only two of these three switches can be closed at the same time; and, when the bus section switch is in, the closed generator switch must be in the low-voltage position.

When both generators are running and the bus section switch is out, the generator switches should be in the high-voltage position, although this is not absolutely necessary and is not so interlocked. It is evident from these interlocks, however, that the generators can never be run in multiple.

When running one generator and four motors at maximum conditions, the high current required naturally demands the low-voltage connection, since with the high-voltage connection the generator would be over heated if called upon to deliver the same amount of current. Also, when both generators are running and each is supplying two motors, the generators should be in the high-voltage connection for best efficiency and least slip of the motors at high speeds, since the variation in the speed of an induction motor should be accompanied by a corresponding variation in voltage.

For protection against short circuits and grounds in the windings and trouble in the line, a balance relay is provided for each generator circuit. It consists of six units with four coils operated by current transformers in the winding connections before reaching the generator disconnecting switch, and the other two coils operated by current transformers in the phases beyond the disconnecting switch. The six units are tied together by a system of links and if the currents in all the coils are balanced or nearly so the relay will not operate, but as soon as sufficient unbalance occurs, as caused by the flow of current across a short circuit or to the ground in any part of the system, the plungers of one or more units will be pulled down and close the contacts to the 120-volt direct-current circuit through the main generator field switch trip coil. When the generator is connected for high voltage, the ampere-turns on each of the four coils are sufficient to produce the same pull as each of the other two coils, which have the $\sqrt{2}$ times as many ampere-turns and are operated by current transformers of double size. When connected for low voltage, however, even though the current in the two-phase coils is the same as that in the winding coils, still the pull is considerably more due to the larger number of ampere-turns and consequently an unbalance between the phase and winding units would occur were it not prevented by a stop in the link mechanism.

It is necessary to have the two-phase units, in addition to the four winding units in order to give protection in case of a neutralizing unbalance in the generator itself. If such occurred, there would be a resultant unbalance in the line coils even though the winding coils may be balanced with reference to each other.

When reversing the ship at full speed, high currents are required at low frequency. Were it not for the dashpots on the ends of the cores of each unit of the balance relays, and also the special springs in their balancing barrels, the units being in different phases would respond to the alternations of current, and operate the contacts. Consequently the field switch would be opened, thereby cutting off the generator supply to the motors and stopping the ship.

Main Motor Control

A slip of one to two per cent is possible between the motors and the generators, and when the motors are out of step their speed is about 70 per cent of normal. To put the motors back in step, over excite as when starting and slow down the generator until the motors pull into step, after which increase the generator speed to normal and increase the running field slightly to hold the motors in step. If they are left out of step, they will soon be damaged due to over-heating, since appreciable slip is accompanied by large idle currents and reduced voltage. When reversing the motors at high speed, as soon as they show evidence of falling into step the steam to the turbine should be increased to carry the load imposed and to prevent the motors from falling out of step.

Each of the four motors has an eight-pole, single-throw switch mounted at the top of the cell and used to disconnect the motors when they are not in use. The switches are enclosed in a sheet steel cover for protection and are operated by a lever. This lever is provided with a stop to prevent falling out under jar and is manipulated by means of a hook. The arrangement of buses and connections in the cell is such that the motors are operated in pairs, each pair being provided with a special six-pole double-throw pole changing oil circuit breaker and a three-pole, double-throw, reversing oil circuit breaker.

The rotors of the motors are of the double-squirrel cage construction with a high-resistance winding in the top of the slot for producing high torque when starting and a low-resistance winding in the bottom of the slot for normal and efficient running when the motor is up to speed.

Also, the motors have their stator windings arranged for obtaining a 24-pole connection for higher speeds and a 36-pole for lower speeds. The main generator has two poles and therefore the speed reduction is 12 to one for the 24-pole connection and 18 to one for the 36-pole.

The 36-pole connection is usually employed when starting and always when reversing, since the greatest torque is produced with the largest speed reduction. This matter is so important that an interlock is included between the pole changing and reversing levers to prevent a 24-pole connection being employed when reversing. These levers are also interlocked with the field lever so that they cannot be operated when their respective

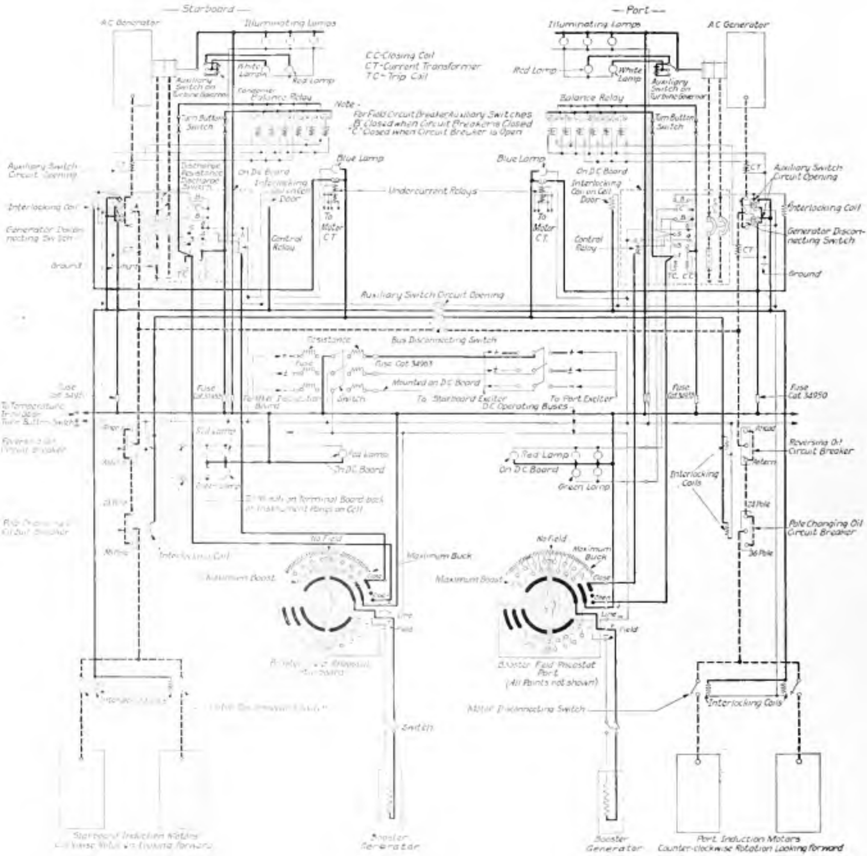

Fig. 8. Wiring Diagram of Control Circuits for Alternating-current and Direct-current Switchboards

field switch is closed. Furthermore, none of the oil circuit breakers can be operated when either field switch is closed, unless the circuits in which they are connected are dead, which would be true when the bus section switch is open. In addition to these interlocks, a magnetic lock is provided for each oil circuit breaker and is controlled by one under-current relay for each pair of motors. These two interlocks prevent operating the oil circuit breakers under heavy currents at high voltage and relieve possible abuse to the main generators.

The under-current relay has two coils connected in multiple and to the secondary of the two motor current transformers. Since the coils are located differently in the magnetic field, their torque is not the same and it is necessary to connect them in multiple. Although the relays are operated by the same current transformer as the motor instruments, the cross current in them is not objectionable since the error introduced is negligible. This arrangement would not be required if both motors of either pair were always in circuit since the required current would be in each coil and the combined torque sufficient to operate the relay at the set value of 0.75 of an ampere, permitting the oil circuit breakers to open a corresponding primary current. If, however, only one of the pair of motors was in and the coils of the relay were not in multiple, the current required to operate the relay by use of one of its coils would either be more or less than twice that required by the two coils, depending on the motor used; whereas if the coils were in multiple it would be just twice, and therefore the oil circuit breakers would always open the same amount of current regardless of the generator and motor arrangements.

Fig. 9. Starting Panel for Main Circulating Pump Motor

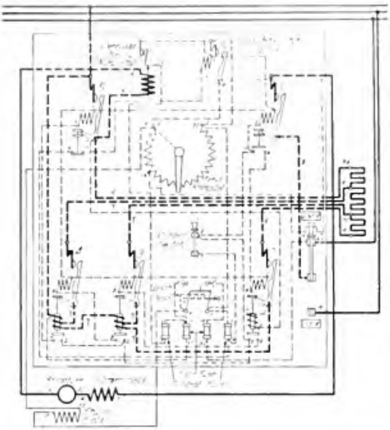

Fig. 10. Wiring Diagram of Starting Panel for Main Circulating Pump Motor

When the field has been taken off the main generator, the speed has also been reduced, since the minimum setting of the speed lever is required because of the interlock with the field lever. The voltage of the generator therefore drops rapidly and consequently the current in the line. This allows the under-current relay to operate its contacts and relieve the magnetic lock on the oil circuit breakers. A blue light is located just above each relay and is connected in multiple with the magnetic lock. When the relay functions the light goes out, indicating to the operator that the oil circuit breakers may then be opened. This relay opens its contacts when 0.75 ampere is flowing in the secondary of the current transformers. When pulling the motors into step, considerable current is required and the relay always picks up so that these relays are usually closed unless the current in the secondary is below 0.75 ampere, which happens at the very low speeds and thus allows the oil circuit breakers to be opened immediately after the field circuit breaker is opened.

An emergency pull button is mounted on the frame of the under-current relay to open the contacts in case these contacts fail to operate, but this is not to be used except when absolutely necessary.

Each motor is provided with an ammeter and a watthour meter. A current transformer for each motor and a potential transformer for each pair of motors are mounted inside the cell. Since the current transformer is located in only one half of one phase, it is necessary to provide a scale on the ammeter to indicate twice the current actually flowing in order to obtain full current in each phase. In the case of the watthour meter, this matter has been taken care of in the gear ratio.

For each propeller there is supplied a direction indicator and also a speed indicator. The former is pneumatically operated, while the latter is electrically operated and involves the use of a quarter-phase generator geared to the propeller shaft.

The main relaying counter is probably the most valuable instrument in connection with the propeller speeds since it records the speed of each propeller, averages the speeds of the port or starboard propellers and also averages the speed of all four propellers. There is also a means provided for transmitting this information to the bridge. By the use of a stop watch it is possible to obtain the actual speed of each propeller shaft. This is ordinarily the method followed by the operator.

Manipulation

In all cases assume that the turbines are running at the pulling-in* speed of the motors which is about 700 r.p.m. (the steam limit and speed levers are back against the stops) and that 240-volt current is available at the studs of the field switch. The "hands off" signal and stop will be put over the idle levers in case only one generator is running.

The most popular speeds are listed in Table I and the manipulation of the apparatus for obtaining them is given in detail.

Condition No. 1

(*a*) All the switches open except the motor disconnecting switches.
(*b*) Close the bus section switch.
(*c*) Close the proper generator disconnecting switch in the low-voltage position.
(*d*) Throw the pole changing levers to the 36-pole position.
(*e*) Throw the reversing levers to the "ahead" position.
(*f*) Pull down the proper field lever, thereby closing the main generator field switch and producing over excitation for pulling in the motors.
(*g*) When the motors are in step, their currents will drop from a high to a steady normal running value at which time the field lever should be brought back to the notched operating section of the quadrant for obtaining and holding normal running field current.
(*h*) Adjust the speed lever for the proper generator speed corresponding to the desired revolutions per minute of the propellers.
(*j*) Along with operation (*h*), adjust the steam limit lever to light the white indicating lamp near the speed lever.

Condition No. 2

Proceed as in Condition 1, except the pole changing levers should be thrown in the 24-pole position.

Condition No. 3

(*a*) All the switches open, except the motor disconnecting switches.
(*b*) Open the bus section switch.
(*c*) Close the generator disconnecting switches in the high-voltage position.

TABLE I

SPEED CONDITIONS

Condition	Speed in Knots	Number of Generators	Connection of Generators	Number of Motors Used	Pole Connection of Motors	Position of Bus Section Switch	Approximate Efficiency
I	0-15	1	Low Voltage	4	36	Closed	93.5
II	15-17	1	Low Voltage	4	24	Closed	93.0
III	17-Full	2	High Voltage	4	24	Open	95
IV	Backing about 10	1	Low Voltage	4	36	Closed	....
V	Backing about 10	2	High Voltage	4	36	Open	....

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* Pulling-in speed is that speed of the generators which permits the motors to pull into step when reversing at full speed of the ship without waiting for the ship to decelerate.

(*d*) Throw the pole changing levers to the 24-pole position.

(*e*) Throw the reversing levers in the "ahead" position.

(*f*) Proceed as in (*g*), (*h*), and (*j*) of Condition 1, except with both generators instead of one.

Condition No. 4

Proceed as in Condition 1, except the reversing levers should be thrown in the "back" position.

Condition No. 5

Proceed as in Condition 3, except throw the pole changing lever in the 36-pole position and the reversing lever in the "back" position (this arrangement is not used unless both generators are in use immediately preceding the signal to back).

The information given in Table II was calculated from results on second trial trip.

TABLE II

SPEED DATA

Approximate

Knots	R.P.M. of Propellers	Shaft Horse Power
7.5	60	1350
8	63.5	1800
9	71.0	2450
10	78.5	3200
11	85.8	4050
12	93	5000
13	100	6100
14	107.4	7450
15	115.5	9200
16	124	11300
17	133	13900
18	141	17050
19	150.5	20750
20	157	24400
21	166.5	29100
21.5	172.5	33000

Getting Under Way

When getting under way from lying at anchor, the time for starting is usually given to the chief engineer sufficiently early for him to make sure that the boiler room force has the opportunity to get up the 250-pound pressure 50-degree superheated steam in the required number of oil burning boilers. This number is determined by the speed which the ship expects to attain since all the boilers are not required except for full speed. They are arranged in three rooms each with seven burners and usually one or two of the seven are retained as spare. One boiler room, of course, is always operated to take care of the ship's miscellaneous requirements. Ordinarily, about one hour is required to start with a cold boiler and bring the steam to the proper condition, but this time may be reduced somewhat, if necessary. The draft in the boiler room is obtained by a slight air pressure which must be closely watched because of the danger of back draft from the burners. After the required steam is available, the engine room force must see that the necessary auxiliaries are running as set forth in the method of operation under the description of the exciter switchboard and also that the turbines are running at low speed. At this point the engineer tries out his outfit by closing the bus section and motor disconnecting switches, one generator switch on low voltage and both pole changing switches in the 36-pole positions with the reversing switch either "ahead" or "back." He will then pull down the field lever thereby throwing in the field switch and obtaining the necessary over excitation for turning the motors over. The motors when starting from rest will build up speed along with the generators.

The engineer in charge is now ready to respond to any signal from the bridge and probably the first one will be on the revolution telegraph indicator giving the number of revolutions of the propeller which the officer in charge has decided upon for beginning the trip. After receiving the signal the operator replies by turning the digit wheels on the telegraph indicator to the same number of revolutions per minute. The port and starboard speed telegraphs are mounted on pedestals in front of the control cell; they are electrically operated and provide the signals "stop," "1/3," "2/3" and "standard speed ahead" or "back." A duplicate mechanically operated signal outfit is provided for each in case of failure. Ordinarily, when starting from a stand-still, the first signal on this indicator is "1/3 speed ahead" or "back," then possibly "2/3" or "standard." (Standard meaning number of revolutions set by the revolution telegraph at the beginning of the run.) When under headway it is not absolutely necessary to follow this practice since the signal from the bridge may be for any of the speeds.

When the operator receives the signal, he proceeds as outlined in one of the conditions listed in Table I.

These are by no means all the conditions of running which might exist, since one motor on either or both sides may be disabled, in which case its disconnecting switch would be opened and then the procedure under any of the five conditions could be followed However, in Condition III or V, if, with one motor on each side disabled, continued running was anticipated only one generator would be used, which would result in the same arrangement as that for Condition II or IV. With both motors on one side disabled and continued running expected, only one generator would be used. The unused generator and motor disconnecting switches, as well as the pole changing and reversing oil circuit breakers, would be open and possibly the bus tie switch, providing the running motors were being supplied by the generator on the same side of the ship. Furthermore, if both generators were running and the bus section switch were open, one or both motors on one side might be running ahead at any speed and one or both motors on the other side might be backing on the 36-pole connection. This procedure assists in turning the ship. If only one generator is in use, of course the bus section will be closed, and all four motors should be running at the same speed, whether ahead or back, if they are all connected for the same number of poles. If the ship were moving ahead at a considerable speed, with one generator and the 24-pole connection of the motors and a signal to reverse one side were given, the generator field would be taken off, the pole changing lever thrown to the 36-pole position, and the desired reversing lever placed in the "back" position. In this case the ahead motors on the 24-pole connection would possibly pull in first, since they would already be turning over from the movement of the ship through the water.

When running ahead at about 10 knots or more with two motors, the force of the water against the propellers is sufficient to turn over the idle motors. Since the power to turn over these motors is comparatively slight, the efficiency of operation is scarcely affected by the idle propellers. The highest speed attainable with either the two inboard or outboard propellers is approximately 15 knots and is obtained by the use of only one generator since no higher speed could be acquired with both generators due to the fact that one is able to supply all the power required by two motors. In an emergency case, however, with both generators running before a condition involving the use of either the two inboard or outboard motors only exists, it would probably be more advisable to keep both generators running rather than to enter the cell and operate the bus section switch, thereby losing time.

Reversing the ship under full speed conditions requires approximately 20 seconds from the time the field lever is thrown off until the motors start to turn in the opposite direction. Part of this time is consumed in the operation of under-current relays which require from six to eight seconds. This time is short compared with the time required by other means of propulsion and it is not highly desirable to reduce it further.

It is believed that electric propulsion has a bright future, especially as applied to the larger variable speed ships. Wide interest is being manifested in this country and many problems in the design of the control apparatus are in store. Each installation will reveal added points to consider and continual progress will accompany the development of this important and advanced method of ship propulsion.

A Review of the Propelling Equipment and Operation of the New Mexico

By Eskil Berg

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In addition to briefly reviewing the main units of the propulsion equipment of the *New Mexico*, the following article describes the various auxiliaries, the description of which is omitted in the foregoing article. Among these minor units are the circulating, air, hot-well, and lubricating pumps, the ventilating fan, etc. Of particular interest are the statements of the contract weight, steam consumption, penalties, and price of the equipment, and its performance on the trial runs of the *New Mexico*.—Editor.

The contract for the electric propelling equipment of the U.S.S. *New Mexico* included the following machinery:

- Two main turbine-generator units, complete with throttle and governing valves.
- Four main propelling motors.
- Switches, panels, instruments, controllers, cables, insulators, etc., complete.
- Two main motor-driven circulating pumps.
- Two main motor-driven air pumps.
- Two main motor-driven hot-well pumps.
- Four motor-driven lubricating oil pumps.
- Two motor-driven oil coolers and tanks.
- Motor-driven blowers for ventilating the main motors.
- Spare parts for the above apparatus.

Requirements

The total weight of the apparatus and material above mentioned, complete in all respects with spare parts, was guaranteed not to exceed 700 tons. In case this weight were exceeded, a penalty of $500 per ton was to be imposed; and if it were exceeded by 5 per cent or more, an additional penalty of $10,000 was to be deducted from the contract price. The actual weight of all the apparatus furnished, with spare parts, was 590 tons.

The steam consumption guarantees were all based upon 250-lb. gauge steam pressure at the throttle and dry saturated steam, with the following corrections: Should superheat be used, the guaranteed steam consumption will be reduced at the rate of one per cent for each 13 deg. F. of superheat observed at the turbine. Should the steam contain moisture, the guaranteed steam consumption will be increased at the rate of $2\frac{1}{4}$ per cent for each per cent of moisture present in the steam at the turbine. The steam consumption guarantees as made to the Government cover the total amount of steam used both by the main generating units and the auxiliaries mentioned above, and were as follows:

Steam pressure 250 lb. at throttle, dry steam.

10 knots, 15.38 lb. per shaft h.p.-hr.
15 knots, 11.57 lb. per shaft h.p.-hr.
19 knots, 11.32 lb. per shaft h.p.-hr.
21 knots, 11.53 lb. per shaft h.p.-hr.

Very heavy penalties were attached to these guarantees in case they were not met; namely, $25,000 per lb. for 10 and 15 knots, and $20,000 per lb. for 19 and 21 knots.

The contract price for the *New Mexico* equipment, including all auxiliaries and apparatus mentioned in the beginning of this article, was $431,000.

Circulating Pumps

Two electrically driven circulating pumps were furnished, one for each main condenser. These pumps were made by the Alberger Pump and Condenser Co. and have a maximum capacity of 21,600 g.p.m. against a head of 36 ft. They are driven by a variable-speed, direct-current motor, having a rating of 125 and 250 h.p. at 400 and 500 r.p.m. respectively.

Air Pumps

Two motor-driven air pumps were installed, one for each main condenser. The pumps were furnished by the Wheeler Condenser and Engineering Co. They are 30 by 18 in. double-acting with a maximum speed of 100 r.p.m., and are each driven by a variable-speed direct-current motor having a rating of 28 and 40 h.p. at 70 and 100 r.p.m. respectively.

Hot-well Pumps

There are two electrically driven hot-well pumps, one for each condenser. These pumps were built by the Alberger Pump and Condenser Co. and have a capacity of 500 g.p.m. against a head of 70 ft. They are each driven by a 20-h.p. 1800-r.p.m. direct-current motor.

Lubricating Pumps

Four electrically driven lubricating pumps were furnished. These pumps were made by the Kinney Mfg. Co. and each pump is geared to a 10-h.p. direct-current motor running at 1800 r.p.m.

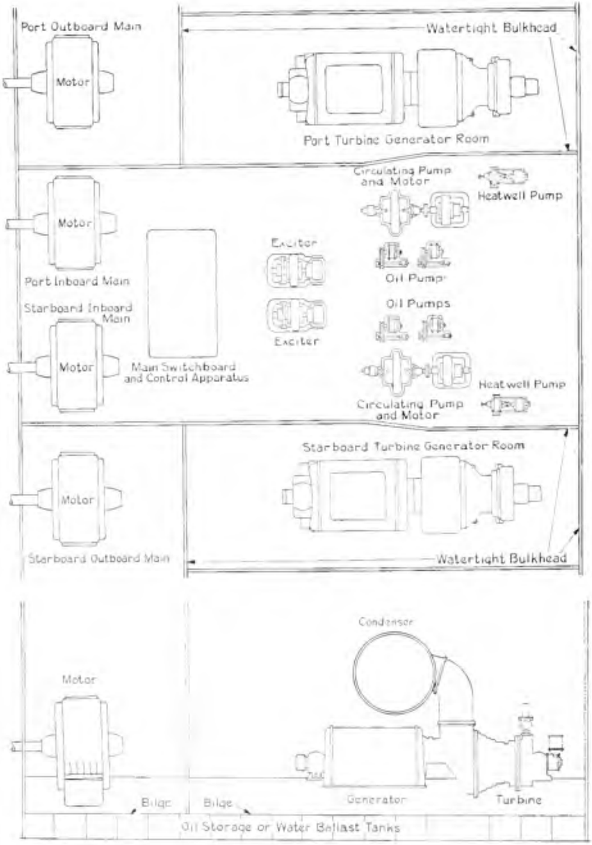

Fig. 1. Plan and Elevation of the Engine Room Arrangement

Method of Operation

The arrangement of the engine room is in accordance with the diagrammatic sketch, Fig. 1. Each of the two main turbines are connected to a quarter-phase generator having two poles. The four propelling motors are wound in such a manner that by suitable changes of connections, effected through groups of oil switches on the control board, the windings can be arranged either for 24 or 36 poles. The ratio of speed reduction, therefore, between the turbine and propeller is approximately 12:1 to 18:1.

The 36-pole connection is used for all low-speed running up to a maximum speed of about 15 knots. Above that speed the 24-pole connection is used. All reversing is done with the motors connected for 36 poles.

Each turbine is equipped with a special governor so designed that, by movement of a fulcrum connected to it, the speed can be held at any desired point within the range. The movement of this fulcrum is accomplished by a mechanical connection from a control lever on the operating board.

For all conditions of steady running up to about 15 knots only one turbine-generator is used with its required auxiliaries, and all of the motors are connected for 36 poles, giving a speed ratio of 18:1. If a higher speed is required, the pole connections are changed from 36 to 24, giving a speed ratio of 12:1, and a speed of about 17 knots can thus be obtained when only one generating unit is used to drive the ship. The windings of the generator are then connected in multiple by means of a switch, so as to reduce the voltage which increases the current capacity of the generator and also gives increased torque and better efficiency. Above that speed and up to the maximum speed of the ship, the second generating unit is in service. With this arrangement each generator operates a pair of motors, and the two circuits are entirely separate from each other. When both generating units are used, the windings of each generator are connected in series by a switch so as to give the desired higher voltage for maximum speed.

Starting the Ship

The ship can be started with either one or both generating units, and with the motors connected for either 36 or 24 poles. When both generating units are used for steady running, the motors are always connected for 24 poles for economical reasons.

Reversing

All reversing, whether the ship is operating with one or both generating units, is done with the motors connected for 36 poles.

Interlocks

All switching, pole-changing, etc., is done on a dead circuit. The switches are, however, designed so that they can be operated under full-load conditions, should an emergency require such operation. Interlocks are provided by which it is impossible to move any of the switches without having first interrupted the field circuit of the generator and allowing the line current to die down to a predetermined low value. This reduction of current enables the switching to be done smoothly and with minimum electrical and mechanical stress in the electrical circuits and switches. The door which gives access to the back of the switchboard is also safeguarded so that no one can enter when any of the circuits are alive.

Safety Devices

In order to safeguard the main propelling apparatus from short circuits or grounds, which may be produced by military or other causes, each generator is provided with a system of balanced relays, which under normal conditions, remain in a balanced position. If trouble should occur, even of a slight nature, there will be an unequal distribution of current in the solenoids operating these relays, the system becomes unbalanced, and in so doing opens the field circuit of the main generating unit. By this arrangement, any defect in insulation, ground, etc., will be detected before any serious trouble occurs, and repairs can be made by the regular engine-room force.

Excitation

Two 300-kw. turbine-gear-driven, direct-current generating sets, arranged for either 120 or 240 volts, supply the excitation and power for the auxiliaries mentioned in the beginning of this article. There are also two motor-driven boosters applied, one for each generator field. These boosters can either raise or lower the voltage 60 volts; in other words, if the field is connected to the 240-volt circuit the excitation voltage can be varied from 180 to 300 volts, and if on the 120-volt circuit from 60 to 180 volts.

In order to obtain quick reversal, increased field excitation is always used and can be obtained only by pulling the field lever by hand against a heavy spring which brings the excitation back the instant the lever is released. By this arrangement, injurious heating of the field is prevented.

Ventilation

When operating at full load and approximately 2000 r.p.m. each generator requires 38,000 cu. ft. of ventilating air per minute. The fans at each end of the rotor will provide this quantity, but on account of the resistance of the air ducts between the deck and the generator, it was desirable that these fans be supplemented by separately driven blowers. Therefore each generator is provided with two fans, each of which is capable of delivering 20,000 cu. ft. of air per min. when operating at a speed of 380 r.p.m. Under these conditions, each blower requires an input of about 17 h.p. These blowers are installed in a room directly above the generators. They receive the air from the deck and force it through ducts into large enclosed compartments directly under the generators. After passing through the generator, the air is discharged from the top and carried upward to the deck. In addition to the four 20,000 cu. ft. per min. air blowers, there are two similiar blowers used to supply air to the center engine room in which is located the two motors driving the inboard propellers as well as all of the engine room auxiliaries and propulsion control apparatus.

Under the most severe conditions of operation, each motor requires 20,000 cu. ft. of air per min. and the blower action of the rotating element must be supplemented by separately driven blowers. In the case of the motors, the blowers are placed in the outgoing ducts of the motors. Each motor has two blowers, each passing 10,000 cu. ft. of air per min. at a static pressure of about 1.9 in. of water. These blowers are driven by 8.5-h.p. direct-current motors at a speed of 510 r.p.m.

One of the advantages of using separately driven blowers as part of the ventilating equipment is that the quantity of air is not so seriously impaired when the motors or generators are operating at low speeds but at relatively high loads.

Steam Economies

The official report of the Board that ran the *New Mexico* trials, as shown in the following, gives water rates higher than those guaranteed, but the uncertainties of these trial results will be obvious to anyone who understands the conditions under which such trials are run and the circumstances of the particular runs which were made. The water rates of a ship are judged not from the readings of electrical instruments, but are calculated from the revolutions of the propeller as previously compared with the readings of torsion meters in shafts during standardization runs on the measured mile. The uncertainties of the horse power indicated by this method are illustrated by the fact that in the standardization runs on the first trial, at maximum speed, the torsion meter showed 1¼ per cent less power than was indicated by the electrical instruments; while in the high-speed standardization run on the second trial, the torsion meter showed 7 per cent less power than was indicated by the electrical instruments. This relation is naturally affected by conditions of wind and sea and by the retardation of the ship caused by the effort of the rudder to hold her upon a given course.

The guarantees made on the *New Mexico* apparatus included the operation of all the engine-room auxiliaries, and contemplated the use of exhaust steam from the auxiliary generating unit in the lower stages of the main turbine. As the trials were run, the ship was more heavily loaded than was contemplated, the power to drive was greater, and the conditions were such that the auxiliary steam could not be used as intended. One of the *New Mexico* generating units was tested in the Schenectady Works of the General Electric Company under load conditions corresponding to the trials up to and including that at 19 knots. The results of these tests, with reasonable assumptions as to motor efficiencies obtained from the tests of the motors themselves, indicate that the apparatus in service should meet the guarantees with an appreciable margin, even under the unfavorable load conditions which existed. The figures in Table I show a comparison between the trial conditions and those contemplated in the design.

TABLE I

Speed Knots	Estimated Horse Power	Actual Horse Power from Electrical Instruments	Estimated R.p.m.	Actual R.p.m.
10	2550	3200	75.0	78.4
15	8350	10350	112.0	115.6
19	18650	24350	144.5	149.2
21	26300	32480	161.0	166.7

In the first trials that were run, the conditions of sea were favorable, but there were indications of heavy priming and delivery of water to the turbines with the steam. In the second trial, the priming was apparently absent, but the conditions of sea during the high-speed runs were very unfavorable, probably causing the error in the assumption as to the power used as derived from the torsion meter readings in the standardization runs. There was also evidence of incorrect measurement of condensate, since the measured flow did not agree with observations as to the pressure and number of nozzles in use during the runs. The system of piping and valves in connection with these turbines is very complicated, and, since leakage will defeat any test, the results must be considered uncertain. Table II compares the results of the trial reports with other figures.

The reason for making a second trial of the *New Mexico* was that her bottom was foul during her first trial and that the priming conditions in the boilers were recognized to be very bad. While this excessive priming of the boilers during the first trial did not do any damage to the turbines, its continuation no doubt would. It was therefore thought best to make slight changes in the boilers to improve this condition.

The fuel economy shown by the *New Mexico* trials, as reported by Commander S. M. Robinson,* are 20 per cent better than the turbine driven *Pennsylvania* at high speeds, and about 30 per cent better at 15 knots.

The efficiency of such apparatus as is used in the propulsion of the *New Mexico* is well understood and there is nothing in the conditions of operation which can cause losses, in generation and transmission of power, any greater than those accomplished with similar apparatus on shore. Fig. 2 gives the performance curves of the *New Mexico* as

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* "Electric Drive from a Military Point of View," by S. M. Robinson, p. 220, this issue.

originally planned and upon which the design was based.

Auxiliary Steam

While the contract for the *New Mexico* calls for the exhaust of only the 300-kw. direct-current set to be admitted to the main turbine, it is the intention under normal conditions running to admit all the auxiliary exhaust except that required for heating feed water.

When such steam is admitted to the fourth stage shell of the turbine, a horse-power-hour will be delivered at the rate of approximately 22 lb. of steam at 10 knots, 16 lb. at 15 knots, and 15.5 at 19 knots. Above 19 knots, the steam will be led to the seventh stage shell, and will, at 21 knots, produce a horse power-hour with approximately 26 lb. of steam.

The propelling machinery of the *New Mexico*, although entirely new and different from the types of machinery which the officers and men were previously accustomed to handle, has functioned perfectly from the first day the vessel was put into commission. During all the breaking in periods of the various shifts of engine room crews, there was never a mishap to any of the electrical propelling machinery; and the men handled all the apparatus with perfect confidence after only a few hours of training.

Interchangeability

One of the many advantages claimed for electric drive is interchangeability, and this feature was demonstrated on two occasions during the preliminary runs. Once while running at about 17 knots with both main generating units in use, a small pipe supplying water to one of the packing glands on the circulating pump broke, which necessitated shutting down the pump while a new pipe was put in. In less than 10 seconds, all the propelling motors were being run from one unit and exactly the same speed was maintained as before. With ordinary drive this would have meant the shutting down of two propeller shafts and a reduction of speed to probably not more than 10 knots.

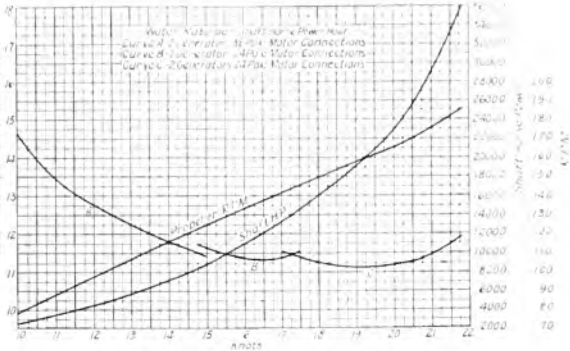

Fig. 2. Theoretical Performance Curves of New Mexico

TABLE II

	WATER RATE, LB. PER SHAFT H.P.-HR.			
	Full Speed	19 Knots	15 Knots	10 Knots
No. 1 Trial Report	12.29	11.926	11.667	14.223
Results indicated by readings of electrical instruments	12.30	11.55	11.35	14.35
Guarantees reduced to trial conditions	11.67	11.03	11.495	15.28
No. 2 Trial Report*	12.01	12.196	12.482	14.22
Results indicated by readings of electrical instruments	11.58	11.50	11.60	14.35
Schenectady test reduced to trial conditions	11.00	11.08	11.16	14.25
Guarantees reduced to trial conditions	11.31	11.184	11.45	15.28

* Given unofficially before the preparation of the report.

On another occasion, when running with only one main generating unit, the circulating pump became air bound and lost its suction. In a few seconds the other turbine-generating unit was brought into service and the same speed of the ship was maintained.

Gunfire Shocks

After all the official runs were completed, the *New Mexico* installation was subjected to the usual gunfire tests in order to observe the effects of shock upon the electrical installation, and also on the governing mechanism of the turbine. Great apprehension had been expressed concerning what would happen to the installation, especially the insulators, cable supports, and instruments. The maximum shock was naturally when all of the twelve 14-in. guns were fired broadside at the same instant. After all the firing tests were completed, a most careful inspection was made and it was found that not a single failure occurred in connection with the electrical system or the turbines.

The following is an abstract from a statement made by Secretary Daniels when testifying before the Committee on Naval Affairs of the House of Representatives, concerning the *New Mexico* installation:

> "I recently paid a visit to the battleship *New Mexico* which is the latest dreadnought to join the fleet and the first and only one of any nation to have electrically operated propelling machinery. On this account she has been an object of surpassing interest to the officers of our own navy and to those of foreign navies as well, and to electrical engineers in general.
>
> "The result was satisfactory from every point of view and confirmed the judgment of all who were in any way concerned in its design and adoption. There was not the slightest mishap with any part of it, everything worked to perfection, and the crew was as enthusiastic over the performance of the machinery as is the department proud in the possession of such an efficient dreadnought.
>
> "The machinery was designed to develop 26,500 h.p. at full speed, which it was expected would give the ship a speed of 21 knots. She actually developed more than 31,000 h.p. and maintained for four hours a speed of 21¼ knots, and this when running at a displacement 1000 tons greater than her design called for. If she had been tried at her designed displacement, as is customary with all new ships, she would have made 21.5 knots without any trouble whatever, and what is still better, she could have kept up this speed as long as her fuel lasted, for, like all our later dreadnoughts, she is an oil-burner and there would be no reduction in speed due to the necessity of cleaning fires, which must be done in coal burning ships after a run of four hours at top speed.
>
> "When we entered into contract for the machinery of the *New Mexico*, we stipulated that, in addition to being capable of developing the maximum power, she should also give an economy at cruising speed very much superior to that obtainable with the turbine installations that we had previously used, and I am happy to say, that this stringent requirement was also met. As a matter of fact, the *New Mexico* will steam at 10 knots on about 25 per cent less fuel than the best turbine-driven ship that preceded her.
>
> "The shipbuilders who have contracts for electric drive ships were as interested in the trials of the *New Mexico* as we were, and I arranged that they should have representatives present to witness the operation of the machinery. All took advantage of the opportunity and were as much impressed with the ease and efficiency of operation as were the naval representatives.
>
> "On the whole, I think the country has cause to be proud of this achievement in engineering, not alone because of the pronounced success in this particular instance, but because of the assurance it gives us of the superiority of our capital ships to those of foreign nations."

Biographies of Captain Bostwick, Captain Willard, and Commander Evans of the New Mexico

CAPT. LUCIUS ALLYN BOSTWICK

Lucius Allyn Bostwick was born in Providence, R. I., February 21, 1869, and first entered the Naval Service under an appointment as a Naval Cadet from the Tenth Congressional District of Massachusetts (Honorable W. W. Rice), on September 7, 1886; detached from the Academy June 6, 1890, and ordered to the U.S.S. *Kearsage*, on which date he completed a four-years course of instruction at the Naval Academy; graduated June 30, 1892; commissioned Ensign July 1, 1892; served on the U.S.S. *Philadelphia* from August 2, 1892, until March 26, 1894, when ordered to the U.S.S. *Alert*, reporting April 3, 1894; transferred to the U.S.S. *Monterey* July 5, 1895; reported at the War College November 30, 1895; on duty on the *Ericsson* from February 18, 1897, until May 27, 1898, when ordered to the U.S.S. *Oregon;* promoted to Lieutenant (junior grade) March 3, 1889; promoted to Lieutenant July 1, 1899; served on temporary duty on board the U.S.S. *Solace* from January 19, 1900, until the arrival of that vessel in the United States, when he reported to duty at Mare Island, California, being detached from this duty on March 12, 1900; served on the U.S.S. *Indiana* from September 6, 1901, until December 29, 1903, when ordered to the *Iowa*, serving on this latter vessel until November 7, 1904; ordered to the Naval War College November 24, 1904; promoted to Lieutenant Commander July 1, 1905; ordered to the U.S.S. *Brooklyn* as navigation officer September 26, 1906; assigned to duty on the U.S.S. *Tacoma* as executive officer on November 25, 1906; detached from the *Tacoma* April 25, 1910, and ordered to duty at the Navy Department, where he was assigned on April 28, 1910, as Judge Advocate of the Board of Inquiry convened at the Navy Department; ordered to the Navy Yard, Norfolk, Va., September 14, 1910; promoted to Commander March 4, 1911; detached as Aide to Commandant of the Navy Yard, Norfolk, Va., and assigned to duty as Inspection Officer, Navy Yard, Norfolk; assigned to the U.S.S. *South Carolina* as executive officer April 10, 1912; assigned to temporary duty in command of the U.S.S. *Montana* January 2, 1913, and upon falling in with the U.S.S. *Nashville*, assumed command of that vessel, reporting January 11, 1913, assigned to duty with the General Board, April 21, 1914, promoted to Captain October 9, 1916; commanding the U.S.S. *South Dakota* from April 5, 1917, until September 17, 1918, when ordered to duty in command of the U.S.S. *New Mexico* on September 27, 1918. April 9, 1919, assigned senior member Naval Overseas Transportation Service, Demobilization Board.

During Captain Bostwick's service in connection with the General Board at the Navy Department, Washington, D. C., and subsequently as Commanding Officer of the U.S.S. *South Dakota* and U.S.S. *New Mexico*, this officer's reporting seniors considered the performance of duty of Captain Bostwick exceedingly capable and efficient.

CAPT. ARTHUR LEE WILLARD

Arthur Lee Willard was born in Kirksville, Missouri, on February 21, 1870, and first entered the Naval Service under an appointment as a Naval Cadet from the First Congressional District of Missouri (Honorable W. M. Hatch) on September 7, 1887, and completed the course of instruction at the Naval Academy in June, 1891, finally graduating in June, 1893; promoted to Ensign July 1, 1893; assigned to duty on the U.S.S. *Boston* August 25, 1893; detached October 25, 1893, and ordered to the U.S.S. *Philadelphia;* detached and to the *Alert* as Watch and Deck Officer on November 18, 1894; transferred to the U.S.S. *Monterey* July 5, 1895; to the *Albatross* February 27, 1896; to to the *Philadelphia* May 19, 1896; to the Naval War College November 22, 1897; to the U.S.S. *Machias* April 4, 1898; promoted to Lieutenant (junior grade) March 3, 1899; promoted to Lieutenant July 8, 1899; assigned to duty on the *Bancroft* August 14, 1900, and detached June 7, 1901; ordered to Navy Yard, Washington, D. C., June 15, 1901; ordered to the U.S.S. *Maine* December 29, 1902; promoted to Lieutenant Commander September 9, 1905; to the Navy Yard, Washington, D. C., for duty in the Naval Gun Factory January 15, 1906; to the U.S.S. *Idaho* March 25, 1908, for duty as Ordnance Officer, reporting April 1, 1908; assigned to duty as Navigator on the *Idaho* on October 5, 1908; detached from the *Idaho* upon

A Close-up View of the *New Mexico*, showing her "clipper bow," an innovation in battleship design. The main battery consists of twelve 14-inch guns, arranged three guns to each turret. She is an oil burner, and is the first battleship to be propelled by electric motors. Her trial trips have fully demonstrated the superiority of electric drive over all other methods arrival in the United States and to the Navy Yard, Washington, D. C., reporting May 2, 1910; promoted to Commander March 4, 1911; detached from Navy Yard, Washington, D. C., and to command the U.S.S. *Hancock*, reporting August 6, 1913; detached and to the Navy Yard, Washington, D. C., as Captain of the Yard, June 3, 1915; promoted to Captain January 1, 1917; appointed Commandant of the Navy Yard, Washington, D. C., and Superintendent of the Naval Gun Factory at that place on September 12, 1917. This officer has been ordered to take command of the U.S.S. *New Mexico* and he is expected to report for this duty May 1, 1919.

During Captain Willard's service as Captain of the Navy Yard and subsequent as Commandant of the Navy Yard at Washington, and Superintendent of the Naval Gun Factory, his reporting Seniors have commended this officer very highly for his exceedingly capable, loyal and efficient service in connection with his duties, particularly his untiring energy in connection with the expansion of the Naval Gun Factory, by reason of which the fighting efficiency of the Fleet was maintained at the desired standard during the War.

COMMANDER JOSEPH SIMPSON EVANS

Joseph Simpson Evans was born at Park Place, Pennsylvania, December 9, 1885; he was appointed a midshipman from the State of Pennsylvania June 13, 1903; was detached from the Academy on September 12, 1906, and ordered to wait orders at home; assigned to the U.S.S. *Maine* September 26, 1906; assigned to the *Decatur* July 2, 1908; appointed an Ensign September 13, 1908; detached from the *Decatur* upon date of arrival at Cavite under orders of December 19, 1908, and to duty on board the *Mohican*; served on that vessel until January 7, 1909, when ordered to the *Charleston;* assigned to duty as aid on staff of Commander, Third Squadron Pacific Fleet January 17, 1910; Flag of Commander, Third Squadron, Pacific Fleet transferred to U.S.S. *New York* August 20, 1910; detached and ordered home May 15, 1911; arrived home June 15; granted leave of absence for 12 days, upon the [illegible] which he was ordered to duty in [illegible] with the fitting out of the *Florida* and to duty on board when placed in commission (September 15, 1911); promoted to Lieutenant (junior grade) September [illegible], 1911; detached from the *Florida* September 28, 1912, and ordered to the Naval Academy School of Instruction in Marine Engineering, reporting September 30, 1912; ordered to the Works of the General Electric Company, Schenectady, N. Y., for duty under instruction June 7, 1913, and transferred to the Columbia University, New York, N. Y., September 1, 1913, for duty under instruction; promoted to Lieutenant March 5, 1914; assigned to duty on the *Marietta* as Engineer Officer April 25, 1914, and transferred to the *Vestal* January 4, 1915, in the same capacity; on January 4, 1915, assigned to the Works of the General Electric Company, Schenectady, N. Y., in connection with the manufacture of machinery for the *New Mexico* preliminary to assignment to that vessel; detached July 24, 1916, and ordered to the Navy Yard, New York, N. Y., in connection with the fitting out of the *New Mexico* and to duty on board as Engineer Officer when placed in commission; ordered to the General Electric Company August 8, 1916, in connection with equipment for the *New Mexico;* reassigned to duty in connection with the fitting out of the *New Mexico* June 14, 1917, and on board when commissioned (May 30, 1918); temporarily appointed Lieutenant Commander to rank from August 31, 1917, on October 3, 1917; promoted to Lieutenant Commander August 15, 1918; temporarily appointed a Commander on October 14, 1918, to rank from September 21, 1918; detached from the *New Mexico* and assigned to the Bureau of Steam Engineering March 19, 1919.

Captain L. A. Bostwick, in reporting upon the efficiency of Commander Evans from September, 1918, to March, 1919, states that "this officer has excellent professional ability, very thorough, excellent judgment and initiative, good executive ability combined with tact and firmness; handles men and officers well. I consider him a valuable officer."

IN MEMORIAM

Stuart Thomson, of the General Electric Company, known by a wide circle of friends in Schenectady, passed away on Sunday, March 23rd, at his home in Brookline, Mass. He was stricken with bronchitis followed by double penumonia, shortly after his return from Washington, where he had been active in the military service since October, 1917.

Mr. Thomson was born in Lynn, Mass., August 13, 1886. He received his early education in the Lynn schools, followed by a course in the Volkmann school of Boston, and also in the Classes of 1908, Harvard University, and 1909, Massachusetts Institute of Technology. His special studies were chemistry, physics and mathematics, in which he received highest honors.

After leaving college Mr. Thomson was employed in research work at the Lynn and Schenectady Works, and later in the Consulting Engineering Department at Schenectady.

Responding to the call of war, Mr. Thomson at the request of the Government, went to Washington and entered the Chemical Warfare Service with the rank of First Lieutenant. His ability was soon recognized by his superiors and he was transferred to the Aircraft Section of the Ordnance Department and charged with the design, production, testing and shipping details of aircraft armament. His conscientious and painstaking efforts to accelerate production soon won for him a Captain's commission, but the arduous duties made great inroads upon his vitality, and as a result of his strenuous devotion to duty he became an easy victim of pneumonia.

Captain Thomson is survived by his wife, Dorothy Faunce, of Lynn, an infant son Elihu Craig, his father Prof. Elihu Thomson of Swampscott, Mass., and three brothers, Roland, Malcolm and Donald. Upon these the sense of heavy loss has fallen, which will be shared by many others.