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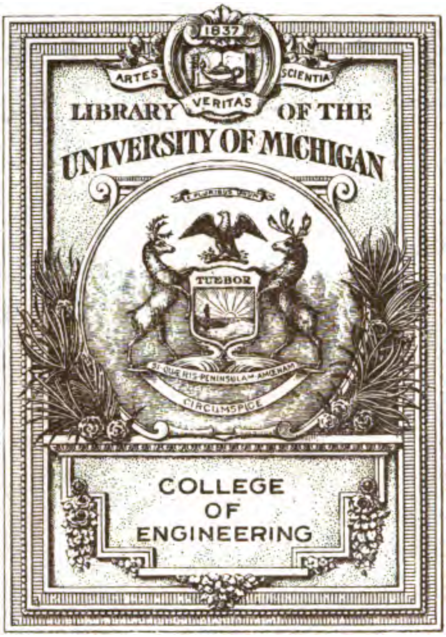
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Electric Ship Propulsion

By

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FOREWORD

IT is assumed that the readers of this volume will have an elementary knowledge of the theory of steam turbines, electric generators, induction motors, etc.; it would not be possible to treat all these subjects adequately in a book of this kind. An attempt has been made to cover as thoroughly as possible the special points that arise in connection with the propulsion of ships by electricity and to compare this method with others that are already in use or projected. Where use is made of apparatus that has not previously been thoroughly described in existing text-books, a full description of it is given.

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Table of Contents

CHAPTER I

CHAPTER II

CHAPTER III

CHAPTER IV

CHAPTER V

CHAPTER VI

CHAPTER VII

CHAPTER VIII

CHAPTER IX

CHAPTER X

CHAPTER XI

CHAPTER XII

CHAPTER XIII

CHAPTER XIV

CHAPTER XV

CHAPTER XVI

CHAPTER XVII

Electric Ship Propulsion

CHAPTER I

History of Electric Propulsion and Types of Ships for Which It Is Best Adapted

THE propulsion of ships by electricity had been proposed for many years and in many forms, but until the use of turbines became general there was no real reason for its adoption and consequently no serious efforts were made in that direction. But the rapid development of the turbine brought this question up again, and in an entirely new light. The unsatisfactory performance of backing turbines, the poor efficiency of high speed propellers and the great disparity between the weight and economy of high speed turbines for driving alternators and low speed turbines for driving propellers made it highly desirable that some method be found of reconciling the inherently opposite characteristics of the turbine and propeller. At that time the mechanical reduction gear had not been brought up to its present state of perfection, so that any method which offered an immediate solution of the problem was very attractive to marine engineers.

More recently a new type of prime mover, the Diesel engine, has come into the marine field. This engine is also unsuitable for direct connection to the propeller on account of the difficulty of starting it under load and reversing it, and also because its best speed is somewhat greater than the best propeller speed. Here, again, electric propulsion offers a solution of all these difficulties.

Mr. W. L. R. Emmet, of the General Electric Company, was the first engineer to make a successful attempt to introduce electric propulsion for ships. His efforts were at first directed toward its application to battleships, which seemed to be the class of vessel most suited for the purpose. But it was decided by the United States Navy Department that the suitability of electric propulsion for marine purposes should first be tried in an experimental installation, and the collier *Jupiter* was selected for this purpose. This vessel was commissioned in April, 1913. Her trials, and also her performance in service, were so satisfactory that, in 1915, it was decided to install electric machinery in the battleship *New Mexico;* since that time, all capital ships of the United States Navy have been designed for electric propulsion.

Outside of the United States, the development of electric propulsion has been very limited. This is doubtless due to the situation caused by the World War. The Swedish Ljungstrom Steam Turbine Company, of Sweden, has equipped two small cargo vessels, the *Mjolner* and the *Wulsty Castle,* with electric machinery. This equipment has shown a remarkable improvement in economy, amounting to about 40 percent, over a reciprocating engine installation in a sister vessel.

Practically coincident with the development of electric propulsion has come the remarkably rapid improvement in the mechanical reduction gear. At the present time both systems have been developed to a point where they can be used on practically any type of ship. But as each class of ship is a complete problem, it will be necessary to consider each one separately in arriving at a conclusion as to what is the most satisfactory propelling machinery.

It must be understood that the following subdivision of ships into classes can only be considered as a rough guide and not as an absolute one; also, the developments in the art are very rapid, and in a short time we may see a very large extension of the Diesel engine in the marine field over that laid down in the following subdivision of classes of ships.

In any comparison of various types of propulsion it is necessary that all efficiencies involved should be considered in order to make the comparison complete. The propeller efficiency plays a large part in determining the overall efficiency of propulsion, and it may be assumed that for vessels using a single screw, or twin screws, the most efficient propeller speed will be very low because, in these cases, it will be possible to use a propeller of large diameter; the exception to this rule is in the case of destroyers, and other light, high-speed vessels, and these are treated as a separate class. Where it is necessary to use four screws, the propeller speed will be fairly high. In the case of the turbine, the conditions are just the reverse of that of the propeller—that is, the smaller the horsepower of the turbine the higher the speed at which it must be run in order to preserve maximum efficiency. Therefore, it will be seen that all the parts of the machinery installation, from the turbine to the propeller and including the shafting, must be taken into consideration when making comparisons of efficiency.

In drawing conclusions as to the suitability of various types of prime movers, the following assumptions will be made:

(*a*) The loss in backing turbines will be about 1½ percent.

(*b*) The loss in a turbine due to the use of two casings and inter-connecting pipes, instead of a single casing, will be about 1½ percent.

(*c*) The shafting losses with gear drive will be about 1 percent greater than for electric drive, except for vessels of Class 3.

(*d*) The loss in a double reduction gear will be about 5 percent.

(*e*) The loss in a single reduction gear will be about 2½ percent.

(*f*) Alternating current generator loss (including excitation and ventilation) will be about 3 percent.

(*g*) The alternating current motor loss (including ventilation, and also excitation for synchronous motors) will be about 5½ percent for induction motors and 4½ percent for synchronous motors.

(*h*) Transmission loss, including excitation, when using direct current will be about 13 percent.

The *first* class of ship to be considered will be the low powered cargo vessel requiring not more than about 3,000 shaft horsepower. For this class of vessel, the Diesel engine in its present state of development is quite suitable. That there are not more ships of this type equipped with Diesel engines is probably due to the difficulty of starting this engine under load and reversing it; neither of these difficulties are met with where electric drive is used in connection with it.

The use of electricity with Diesel engines involves a transmission loss of about 13 percent (direct current will be used) but there is no loss at all in over-all efficiency and in some cases there is an appreciable gain due to its use, as will be seen.

Direct connected, Diesel-engined ships use twin screws operating at a speed considerably higher than is suitable for the best propeller efficiency. By the substitution of Diesel-electric propulsion a low speed, single screw can be used. The use of the twin screws will increase the effective horsepower necessary to propel the ship on account of the appendage resistance of the propeller struts; the thrust deduction will be greater when using twin screws than when using a single screw; and the low speed, single screw will be more efficient than the high speed twin screws.

The net result of these various differences in efficiency is that the electric transmission losses are made up by the gain in propulsive efficiency; in some cases the electric driven ship will actually show a higher over-all efficiency than the direct connected ship.

In addition to the above advantages, the electric driven ship will also be more reliable; this is partly on account of the greatly reduced liability of derangement due to the fact that it is not necessary to start the engine under load, nor reverse it; it is partly due to the fact that with electric drive a greater subdivision of power can be made, thus using smaller engines; and it is also partly due to the fact that the engine can be designed especially for reliability and economy since it is entirely free of the propeller. The cost of upkeep will also be reduced since there will be fewer derangements of machinery.

This type of propelling machinery should be very attractive for this type of ship since it should give about double the efficiency of any other form of propulsion. It will be heavier than either a turbo electric or turbine with mechanical reduction gear installation, but this disadvantage is far outweighed by the great increase in efficiency.

The *second* class of ship to be considered will be cargo vessels and passenger vessels requiring more than 3,000 shaft horsepower, but less than enough to require the use of four screws; the maximum speed will vary considerably, depending on the character of the ship, but it will probably not be greater than about 20 knots and for most ships of this class it will be less than this. The slower speed ships of this class will use a single screw, and the higher speed ships twin screws; in either case the most efficient propeller speed will be very low, so that in order to use the most efficient possible turbine, as well as propeller, it will be necessary to use a double reduction.

That this is true is shown by the fact that European shipbuilders, who originally were using single reduction gears, are now changing over to the double reduction gear. The increased loss due to the use of the double reduction gear is more than made up by the increased turbine and propeller efficiencies, especially the turbine efficiency, which is the one most affected. Using the table of losses previously given, and taking losses (*a*), (*b*), (*c*) and (*d*) for the double reduction gear, and losses (*f*) and (*g*) for the electric drive, it will be seen that turbo electric propulsion is more efficient than the mechanical double reduction gear by ½ percent or 1½ percent, depending on whether induction motors or synchronous motors are used; in other words, there is practically no difference in efficiency.

However, it is believed that electric machinery is more suitable since it has other advantages. The cost of upkeep should be very much less with the electric than with the mechanical installation. This point has been thoroughly demonstrated by the *Jupiter,* which has had practically no expense for the electrical part of her machinery during the six years she has been in commission. When her upkeep expense is compared with that of a similar ship equipped with gears, the difference is very apparent. Also, the efficiency of the electric machinery will remain constant, while that of the mechanical gear will depreciate unless renewals are made. The electric machinery can be arranged to give a better disposition of cargo space than is possible with machinery which is connected to the propeller shaft; it will be possible to do away entirely with shaft tunnels of single screw vessels by placing the propelling motor well aft in the stern of the boat; this latter is quite an important point, not only from the standpoint of additional cargo space, but on account of the better arrangement of the space. In certain cargo vessels which discharge their own cargo, it will be possible to utilize the main machinery for running deck winches, thus giving more efficient and more reliable deck machinery.

The statement is sometimes made that electrical machinery is more complicated and requires greater care and attention than geared turbines. This may be true with some electric installations, but it certainly is not true for this type of ship. Nothing could be simpler than the operation of the electric machinery for a ship of this class, if it is properly designed. The difference in weight between the two types of machinery will be very small and will be negligible.

The *third* class of ship to be considered will be the high speed passenger vessel with sufficient horsepower to make the use of four screws necessary. In this case the most suitable turbine and propeller speeds will be such that a single reduction can be used between turbine and propeller. However, with the mechanical reduction gear it will be necessary to use an independent turbine for each of the four shafts and each of these turbines will be contained in two casings, while the electrically propelled ship will use only two turbines, each contained in a single casing, so that the turbine losses previously assumed, given in (*b*) of the table of losses, will be doubled. In this case the losses of the reduction gear will consist of (*a*), 2(*b*) and (*e*), and the losses of the electric drive will consist of (*f*) and (*g*). This shows the reduction gear to be 1½ percent more efficient, assuming that induction motors would be used with the electric drive.

As in the case of Class 2 ships, there is practically no difference in efficiency. But the advantages enumerated under Class 2 ships for electric machinery hold equally well here, so that electric propulsion is also the most suitable for this class of ship. In fact, it can be broadly stated that, unless there is a considerable advantage in efficiency due to the use of mechanical gears, electric propulsion should be used owing to its other advantages.

The difference in the weight of the two types of machinery for this class of vessel will be very small and is negligible.

The *fourth* class of ship to be considered will be the light draft, high speed, high powered naval vessel, such as the destroyer, scout cruiser or light cruiser. These vessels may be fitted with twin screws, three screws or four screws. The screws are always high speed, so that only a small reduction between turbine speed and propeller speed is required; in no case will it be more than

8 to 1 and it may be as low as 4 to 1, so that a single reduction can always be used.

With this type of ship, the mechanical gear has a very decided advantage over the electric machinery. A small change in the displacement of these vessels means a very large increase in horsepower required to make the speed. Consequently the saving of weight becomes of the greatest importance. Owing to the small reduction used, there will be a saving in weight per horsepower by the use of the mechanical gear. This will mean a reduction of the displacement and, therefore, also of the total turbine horsepower required as compared with the electric machinery, and, consequently, a further reduction in weight.

In regard to comparative efficiencies, the losses of the gear will consist of (*a*), (*b*) and (*e*), from the table, and the losses of the electric drive will consist of (*f*) and (*g*). The mechanical gear, therefore, will be about 3 percent more efficient at full power than the electric machinery. This will mean a reduction in the turbine horsepower required and a corresponding reduction in weight.

It will be seen that, if we use the weight and horsepower required by the electric machinery as a basis of comparison, all saving in weight by the use of mechanical gears becomes accumulative, so that the final saving in weight and total reduction in horsepower are very large.

There is another important point in connection with the use of gears for this class of vessel. These ships seldom steam at their maximum power, so that the actual tooth pressure of the gears is very low. This gives the gears a very much longer life than in the case of ships steaming at full speed all the time, as is the case with a merchant vessel.

The *fifth* class of ship to be considered will be the capital ships of the Navy—that is, the battleship and battle cruiser. These vessels will always be fitted with four shafts. Here the reduction is considerably more than in the case of light naval vessels, being as much as 12 to 1 in some instances, but still within the range of a single reduction, although at the expense of a slight loss in propeller efficiency in some cases.

At full power the difference in over-all efficiency of transmission, assuming equal propeller efficiency in the two cases, would be about the same as for Class 4 ships. At the cruising speeds of the ship, the electric machinery would have an advantage of from 15 to 25 percent. This advantage comes from the following causes: first, the electric machinery can use two reduction ratios, thus keeping up the turbine speed at the lower speeds of the ship; second, with the electric machinery, only one turbine is used at the lower speeds, thus doubling or quadrupling the load on the turbine and generator according to whether the ship has two or four turbo generators; and, third, the number of auxiliaries for serving the turbines in use in the electric engine room will be only one-half or one-fourth of what will be necessary for the geared engine room. Cruising speed economy is of great importance in these ships; of course the most important economy is that at full power, but in such a case as this, where the difference at full-power is small, the great improvement at cruising speeds is of the greatest importance.

As regards the weights of the two installations, there will be no very great difference. For battleships, the geared installation will probably be somewhat lighter; for battle cruisers, the condition will be reversed. In neither case, however, will the difference be great enough to be of any consequence.

From the above it will be seen that from a comparison of economies the electric machinery has considerable advantage for this type of ship. However, there are other considerations that give it a more decided advantage.

The most important of these is the flexibility of the electric machinery as regards installation. The steam part of this equipment, being entirely independent of the propeller shafts, can be arranged so as to get the maximum protection against torpedoes and gunfire. This is an advantage that can hardly be overestimated for this type of ship, as it makes it possible to protect the ship itself, as well as the machinery, in a way that is entirely impossible with any type of machinery where the prime mover must be connected to the propeller shafting. With the electric machinery, the motors are attached to the shafting but they can be placed in much smaller compartments than can steam turbines, thus reducing the danger to the ship in case the compartment is flooded, and, at the same time, allowing greater protection to the compartment. The motors can be placed so as greatly to reduce the length of shafting required for the turbine drive, thus cutting down the number of bulkheads pierced by the shafting and adding to the reliability of the shafting, as well as adding to the protection of the ship.

The installation arrangement also adds considerably to the reliability of the steam machinery; all of the main auxiliaries can be grouped in the engine rooms, allowing greater duplication, both of the units themselves and also of the piping systems, and at the same time giving them better protection. The leads of steam, exhaust and other piping are simplified, the length shortened and the pipes are given better protection. The maximum pipe diameter required will also be less—a point which is very important in the case of the main steam pipe of a battle cruiser.

There are other minor advantages of electric machinery which are of more importance to a military ship than to a merchant ship. With a gear drive, damage to a turbine means that one propeller must be dragged; with electric machinery, turbine damage only operates to reduce the speed of the ship and not the method of propulsion, as all screws will still be used. A dragging screw may add as much as 20 percent to the horsepower required to drive the ship at some speeds; it will reduce the maneuvering qualities of the ship; and in most instances it will be necessary to prevent the shaft of the damaged turbine from revolving, in which case, the horsepower will be still further increased and the speed of the ship limited to that at which it is possible to keep the shaft locked (usually with the "jacking gear")—generally a very low speed. The ability to run all screws from one generator, virtually gives duplicate or quadruplicate main engines, condensers and auxiliaries so far as maneuvering at slow speeds or in harbors is concerned. As an example of this advantage, the *New Mexico* has found it useful to keep both main turbo generators running when entering certain ports. When one condenser becomes plugged with mud, a shift is made to the other, an operation which requires only a few seconds of time. With a turbine drive, this would usually mean a burned-out condenser. When cruising at low speeds, only one generator will be used and consequently only one set of engine room auxiliaries, thus reducing the necessary attendance and supervision.

In the above discussion of the relative merits of gears and electric propulsion for the various classes of ships the question of superheat has been entirely neglected. The present tendency is toward the use of more superheat for marine purposes. With backing turbines, very high temperatures are produced during the short interval of time in which steam is flowing through the backing turbine and the ahead turbine is still turning over in the ahead direction. Considerable experimental work has been carried out in regard to this point with the result that most engineers recommend that the superheat be limited to 80 or 100 degrees F. with geared turbines. This excessive temperature lasts for only a very short time, but it may cause local distortions which will eventually cause the turbine to strip. From experiments made, some engineers have placed this temperature as high as 1,100 degrees F. With electric machinery, the turbine always revolves in the same direction and it does not start up under load, so that the limitations caused by a reversing turbine do not exist, and we may shortly be using superheat of 250 to 300 degrees F., which will mean a very great increase in the economy.

To recapitulate, the following table shows the type of machinery best adapted to each class of ship:

(1) Low speed cargo vessels of less than 3,000 shaft horsepower—Diesel electric propulsion.

(2) Cargo and passenger vessels requiring more than 3,000 shaft horsepower, but not enough to require the use of four screws—turbo electric propulsion.

(3) Passenger vessels of high speed and sufficient horsepower to require four screws—turbo electric propulsion.

(4) Destroyers, scout cruisers and light cruisers—geared turbines.

(5) Battleships and battle cruisers—turbo electric propulsion.

CHAPTER II

Systems of Propulsion

THE first question to be decided in regard to electric propulsion is what system shall be used. Some of the points to be considered in deciding this question are reliability, efficiency, simplicity, flexibility and weight.

It will be necessary first to decide whether alternating or direct current shall be used. In nearly all land applications of electricity it has been found most satisfactory and economical to transmit power in the form of alternating current to the point of application, where it is in many cases converted into direct current before it is used. In order to transmit power over long distances without great loss it is necessary to use high voltage, while it is usually desirable to use low voltage at the point of application. Alternating current has a great advantage over direct current in respect to the method of transforming high voltage to low, or vice versa. In a transformation of voltage with direct current, power is supplied to a motor which drives a generator which delivers current at the desired voltage. The apparatus is expensive, requires constant attention and its efficiency is never greater than 90 percent. The transformation of voltage with alternating current is accomplished by means of a transformer, which is cheap, has an efficiency of over 97 percent and requires no attention. For ship propulsion, however, none of these advantages holds, as the distance of transmission is short and no voltage transformation is required.

But there are other advantages that make it proper to use alternating current for turbo electric propulsion. The direct current generator is essentially a slow speed machine, mainly on account of the difficulties of commutation at high speeds. This makes it necessary to use a gear reduction between turbine and generator in order to get the best steam economy and this adds one more link in the chain between the turbine and propeller and, at the same time, reduces the efficiency of the turbine by the amount of the gear loss.

The weight of the direct current turbo generator will also be much greater than that of the alternator, it being assumed that voltages as high as 5,000 may be used with alternating current.

The efficiency of transmission of the alternating current system will be greater than that of the direct current system; the maximum efficiency for the first being about 92 percent and for the second about 87 percent.

The alternating current system, having no commutator and no sliding contacts with high voltage, is much more reliable than the direct. This difference between the two systems is greater on board ship than ashore, owing to the fact that the air for ventilation is always charged with salt moisture.

The direct current system would be somewhat simpler and more flexible than its rival, but the latter is quite satisfactory in this respect, so that the advantage is of little importance.

Having decided on alternating current as being the most suitable for turbo electric ship propulsion, the next point to decide is which is the best of the various alternating current systems that have been proposed. Many patents have been taken out covering special arrangements of motors and generators to get several speeds, but none of them has been put to any practical use by an actual installation in a ship. Most of these are schemes for getting a great number of speeds by changing electrical connections while keeping the speed of the generator constant. While these schemes might work in a merchant vessel, none of them would be suitable for a war vessel because it is necessary for these ships to have any desired speed within the limit of the full power of the vessel—in other words, an infinite number of speeds. Also, in most of these arrangements it has been proposed to use a multiplicity of generators and motors, some of which would not be in use at full speed; this is not economical of either space, weight or money. Before describing the arrangements that have actually been used, and indicating probable future developments, a brief description will be given of some of the proposed schemes.

Mr. Henry Mavor has patented, in England, a system of ship propulsion which consists of several squirrel cage induction motors on a shaft and an equal number of generators, the latter having different frequencies. By various combinations of generators and motors a number of propeller speeds can be obtained. For example, suppose we have the following arrangement:

Generator	*Speed*	*Number of Poles*
A	1800 revolutions per minute	2
B	1800 revolutions per minute	4
C	1800 revolutions per minute	8
Motor		
E		16
F		32
G		64

Then, at full power, if generator *A* drives motor *E* and generator *B* drives motor *F* and generator *C* drives motor *G*, each motor will be running at $\frac{1800}{8} = 225$ revolutions per minute. If it is desired to run at a lower speed, we may use generator *A* to drive motor *F* and generator *B* to drive motor *G*, the propeller shaft will then run at $\frac{1800}{16} = 112.5$ revolutions per minute, or we may use generator *A* to drive motor *G*, when we shall get a propeller speed of $\frac{1800}{32} = 56.25$ revolutions per minute. The disadvantages of such a system are very apparent. It is not desirable to subdivide the power of the ship to any such extent; if the ship had two shafts, there would be required six generators and six motors, and only three speeds would be available even then. Also, no scheme is feasible that involves running several generators to drive motors on one shaft, as the difficulty of maintaining synchronism is too great.

Mr. Mavor has also patented a "spinner" motor which has two rotating elements and one stationary one. The stationary element is similar to the stator of other induction motors and the inner rotating member is similar to other rotors. The intermediate rotating member is supplied with a squirrel cage winding on its outer periphery and with a primary winding on its inner periphery. The object of this arrangement is to provide variable speed with one supply of frequency, and also to provide a means of starting the low resistance squirrel cage motor which has very little torque for starting. This is accomplished by first starting up the intermediate rotating member, which will require practically no torque for starting. When this member has reached its speed, a brake is applied and, while it is gradually brought to a stop, the other rotating member will gradually be brought up to speed without taking an excessive current owing to the low frequency that is imposed on it. This motor has three speeds when supplied with only one frequency. This is accomplished as follows:

(*a*) Slow speed by running the intermediate member in the opposite direction to that of the rotor on the propeller shaft.

(*b*) Intermediate speed by holding the intermediate member stopped.

(*c*) Full speed by running the intermediate member in the same direction as the rotor on the propeller shaft.

This motor could not, of course, be built in large sizes on account of the arrangement necessary to give the intermediate member proper bearings, nor could a large brake be provided. The power factor of such a motor will also be very poor.

Mr. Hobart has described a system which he calls the alterphase system of ship propulsion. It is based on the fact that a motor stator winding which has been arranged to correspond to, say, P poles for a three-phase system, will be suitable for a quarter-phase system when arranged with $\frac{3}{4}$ P poles. This change in polar arrangement may be made by taking the terminals to a switch which will be double-throw, giving the quarter-phase connection in one throw and the three-phase in the other. A motor arranged in this manner must be supplied by two different phase systems, which may be obtained from two generators, one wound for quarter-phase, and the other for three-phase, or from a single generator wound to supply both phases. The objections to such a system are that it involves the use of generators which are dissimilar and not interchangeable, or else the use of a complicated generator; it is not necessary to do either of these, as the same result can be obtained by arranging the motors for pole-changing; this can be very readily and simply effected on motors without in any way changing the generator. This method will be described in Chapter IV.

Many other schemes have been proposed for electric propulsion, but space forbids their enumeration; the foregoing examples, however, illustrate how difficult it is for one entirely to change his methods of thinking when confronted with a problem involving entirely new conditions. The electrical engineer is used to dealing with problems where the frequency and voltage are constant and it is difficult for him to think in any other terms but these.

The method of ship propulsion in use in this country is that of variable frequency—that is, speed changes are made in the prime mover itself, just as with any other steam engine, and the generator and motor are considered simply as a reduction gear. This arrangement is very flexible and gives an infinite number of speeds; it is also very simple, as it keeps the number of necessary switches down to a minimum; it is efficient for all loads since the reduced frequency and voltage that go with reduced load maintain a very high efficiency for both the motors and generators; all motors are alike and all generators are alike, so that all spare parts are the same. For ships which have a high speed, but which generally cruise at a low speed, the system may be used in conjunction with an induction motor which has its stator and rotor wound for two different pole arrangements, thus giving two speed reductions; or, if the power to be transmitted is great enough to require two motors on each shaft, the two speed reductions may be obtained by running the two motors on one shaft in cascade, or in parallel. By properly dividing up the power plant and using only part of it at the lower speeds, a very efficient arrangement can be obtained at all speeds up to the maximum.

Having settled on the plan of using variable frequency, we can now proceed to a more detailed consideration of the requirements of the classes of vessels discussed in Chapter I. For the second class of vessel it will be possible to use turbo generators driving either synchronous motors or induction motors. A synchronous motor has some advantages over an induction motor; it is slightly more efficient; it would have a much larger air gap; it would have unity power factor, so that the generator would be lighter and more efficient; it would have no high voltage in its rotor, there being only the low voltage exciting current in the rotor fields; and, being more efficient, it would require less ventilation. To oppose these advantages, there is the disadvantage of this motor being less flexible than the induction motor. It is necessary to use a high resistance squirrel cage winding on the rotor field to produce the necessary torque for reversal and the operation of starting or reversing this motor is more complicated than in the case of an induction motor. It is not believed that this motor would be satisfactory for the high speed vessels of Class 2 on account of the difficulty of getting the necessary torque for reversal. When everything is taken into consideration, it is believed that the induction motor will really be the most satisfactory for all vessels of this class on account of the simplicity of the installation, and the ease of operation.

For vessels in Class 3, it would be necessary to use induction motors, as synchronous motors would not be satisfactory for the reasons given above. For these ships it would seem to be unnecessary to provide two-speed motors, as these ships do not use a greatly reduced speed often enough to make the additional complication worth while.

For vessels in Class 5, turbo alternators and induction motors would seem to be the most satisfactory, for the same reasons as have already been given. The motors would be arranged for pole-changing to give economy at cruising speed.

The exact arrangement of motors and generators will have to be decided in each individual case by the conditions governing. However, it should always be borne in mind that, for a marine installation, the simplest possible plant is the one to be most desired and unnecessary complications should not be introduced unless they add very considerably to the reliability or efficiency of the plant. Running alternating current generators in parallel should be avoided, if possible, and should not be attempted at all, if the speed of the generators in parallel must be changed. The power plant should not be divided more than is necessary for reliability and for giving the best economy under the desired operating conditions, as it should be remembered that the fewer the number of units the more efficient they will be and the less the total weight will be. For example, a single generator is quite satisfactory for a freighter and two are enough for a battleship; for a battle cruiser, it will be necessary to use four, as the size would be prohibitive if a less number were used.

In the case of a ship which only uses reduced speed for maneuvering, it is possible to use a constant frequency and an induction motor with a definite-wound rotor which is connected to external resistances through slip rings. Mr. Ljungstrom, in his latest electrically propelled ship, uses this method. Speed variations are accomplished by inserting a varying amount of resistance into the rotor circuit. The arrangement he has used is very simple in the way it is worked out and that is a great point in its favor. This scheme would, of course, be unsatisfactory for a war vessel, as the motor is very inefficient at all speeds except full speed; it is even questionable whether an arrangement that provides only one efficient speed is satisfactory even for a freight steamer, particularly since the lower speeds are so very inefficient. Also, this method could not be used for large power, as the rheostats would be too large.

The reasons given in the first part of this chapter for using alternating current apply only to the case of turbo electric propulsion. For Diesel electric propulsion direct current will be more suitable, as will be seen when that subject is discussed.

CHAPTER III

Propeller Characteristics

WHEN electric propulsion was first proposed, it was believed that a propeller load was an ideal one for electric machinery. This is true when a ship is steaming steadily but when a ship is maneuvering the propeller characteristics are such as to be very exacting on an induction motor.

When the design of the *New Mexico's* propelling machinery was begun it was found that, while the data on propellers were very complete for the normal condition of "ahead steaming," there was practically no information available regarding the characteristics of a propeller under maneuvering conditions. As these conditions are the most important in their bearing on induction motor design, it was decided to investigate propeller action thoroughly before designing the motors. It was fortunate that this decision was made, as the motors would not have been able to reverse the propellers, if the commonly accepted ideas regarding propeller torque had been used as a basis of design.

The first experiments were made in the model tank. Fig. 1 shows a complete set of contour curves of propeller torque obtained by running a model of the *Delaware's* propeller. These curves cover all conditions of speed of the ship ahead and astern, and revolutions per minute of the propeller ahead and astern.

The curves shown are curves of equal torque. If a vertical line is drawn through any speed, the revolutions per minute corresponding to each torque curve can be found; if these revolutions per minute are plotted against torque, the result will be as shown in Fig. 2.

In this figure the revolutions per minute and torque have been plotted as a percentage of the revolutions per minute and torque required to drive the ship at the given speed. This curve has been drawn for the full speed condition but it will have the same general shape for any speed; at the lower speeds the maximum torque

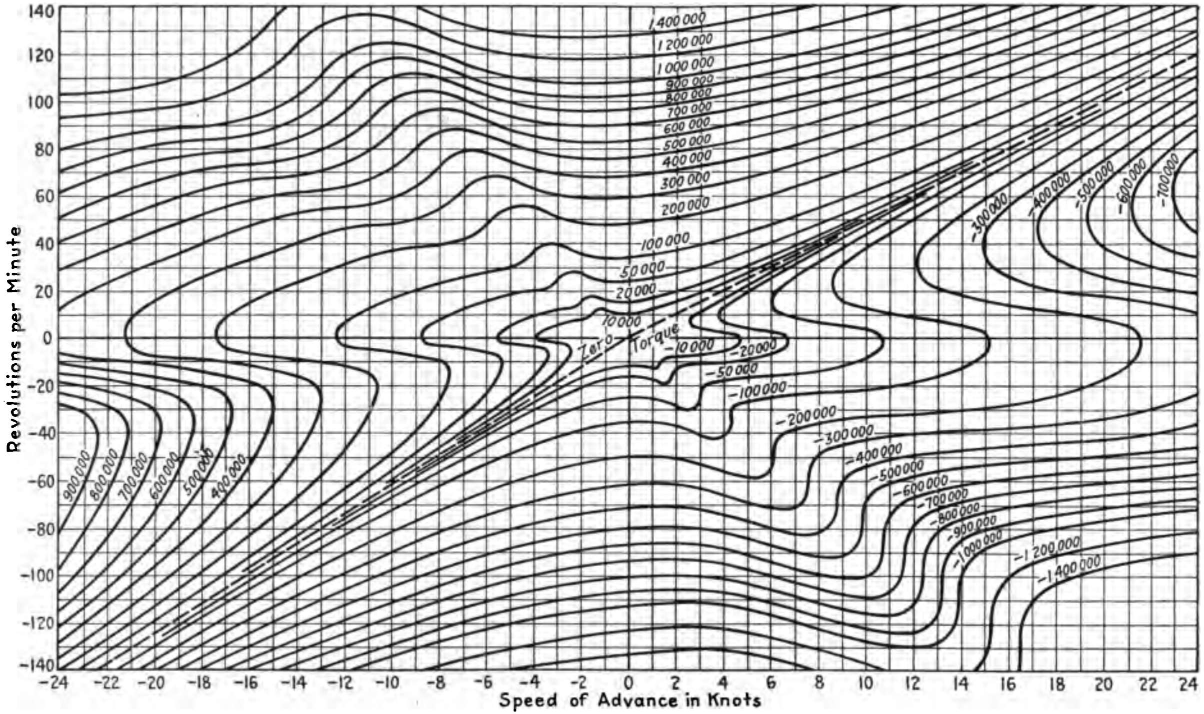


FIG. 1.—Contour Curves of Torque, Expressed in Pound-Feet, for one Propeller of the U. S. S. *Delaware*. Derived from Model Experiments and Based on the Assumption that the Law of Comparison Holds Fully and that there is No Cavitation. Diameter of Propeller 18 Feet 3 Inches, Pitch 19 Feet 9 Inches

point during reversal is a greater percentage of the driving torque, being about 120 percent at 10 knots as compared with 95 percent at 21 knots.

Fig. 3 shows a curve that was obtained from the *Jupiter*. It is similar in all respects to that obtained from the model tank but the maximum point is lower, being only about 77 percent of the "full-load driving torque." Two points are shown at the "stop" point, one being the point at which the propeller will start revolving ahead and the other the point at which it will start revolving astern; the difference between the two is twice the shaft friction.

The above experiments with the model of the *Delaware's* propeller and with the *Jupiter* established the following important facts:

> First—On reversal, the propeller speed drops suddenly to about 70 percent of its original speed, which is the speed corresponding to zero torque.
>
> Second—From zero the torque increases to a maximum, this maximum being substantially the same as the ahead torque.
>
> Third—Maximum torque occurs when the propeller speed has dropped to about 40 percent of the original speed.

For reasons that will be seen later on, these three facts have an important bearing on the design of the electric ship propulsion machinery.

On the *New Mexico* the maximum torque required during reversal was found to be about 106 percent at 18 knots; this agrees very closely with the model tank experiments on the *Delaware* and would indicate that, with high speed ships, the torque required for reversal is a greater percentage of the driving torque than is the case of low speed ships, although for each individual ship the lower speeds require a greater percentage of torque for reversal than the high speeds.

The other condition of maneuvering that most affects the design of machinery is "turning." Very few marine engines are fitted with speed governors, the control of speed being entirely dependent on the throttle. With constant throttle opening, a reciprocating engine will develop practically a constant torque, regardless of whether the ship is turning or going straight ahead, and the steam flow and the power will vary directly as the revo-

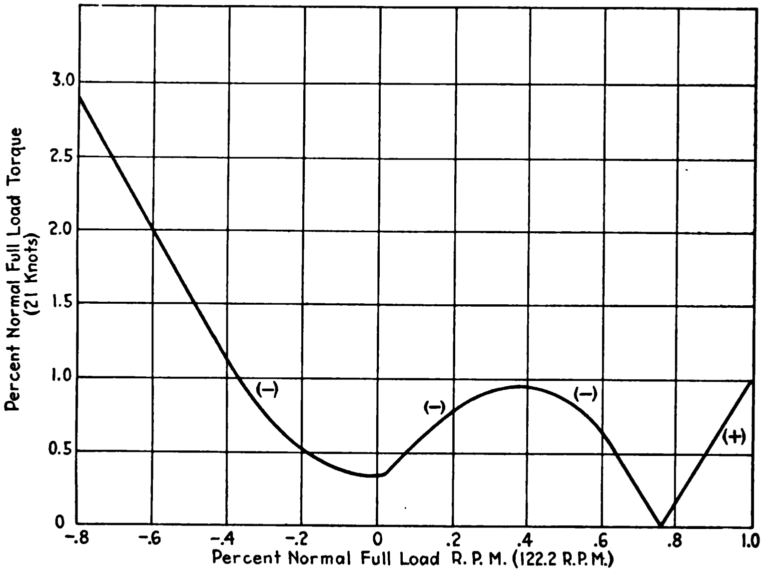


FIG. 2.—Propeller Torque Curves for U. S. S. *Delaware*, Ship Going Ahead at a Constant Speed of 21 Knots, Derived from Model Propeller Tests in Undisturbed Water

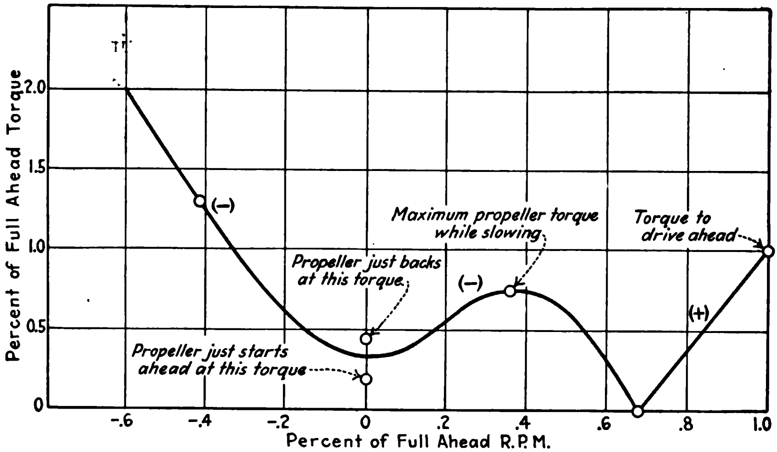


FIG. 3.—Propeller Torque Curves for U. S. S. *Jupiter*, Ship Going Ahead at Constant Speed of 10 Knots

lutions per minute of the engine. With the same conditions for a turbine the amount of steam flow will remain practically constant and the revolutions per minute of the turbine will decrease as the torque imposed on it increases; also, the power will vary approximately as the revolutions per minute of the turbine. With an engine or turbine fitted with a speed governor the revolutions per minute will be kept constant and the power will vary as the torque.

Figs. 4, 5 and 6 show horsepower curves taken on the *Delaware, Jupiter* and *New Mexico,* respectively, while these ships

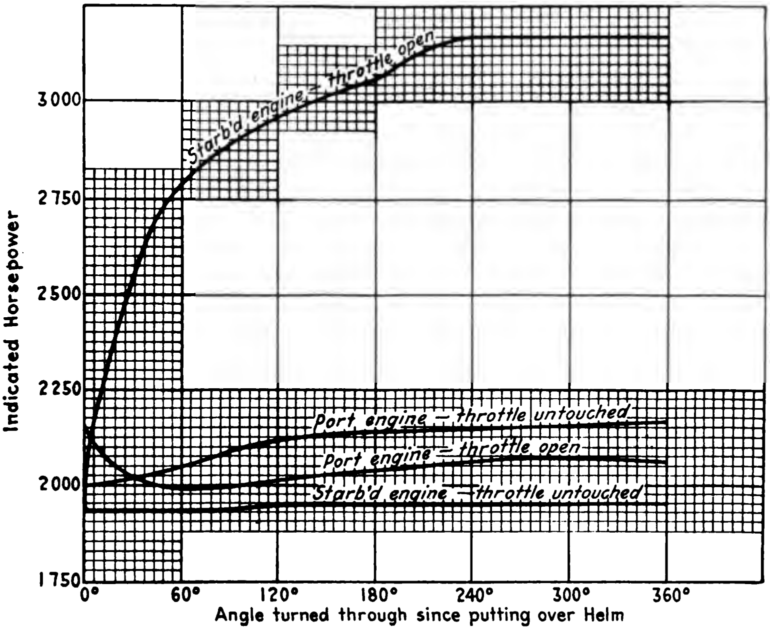


FIG. 4.—Horsepower Curves taken on U. S. S. *Delaware* while Ship was Turning with 16 Degrees Right Rudder

were turning. In Fig. 4 the curves marked "throttle untouched" show the changes in horsepower that take place when the ship turns with the throttle opening the same as before the turn was started; it will be noted that the change is comparatively small and is exactly the reverse of the changes shown in the curves marked "throttle open." The curves marked "throttle open" show the

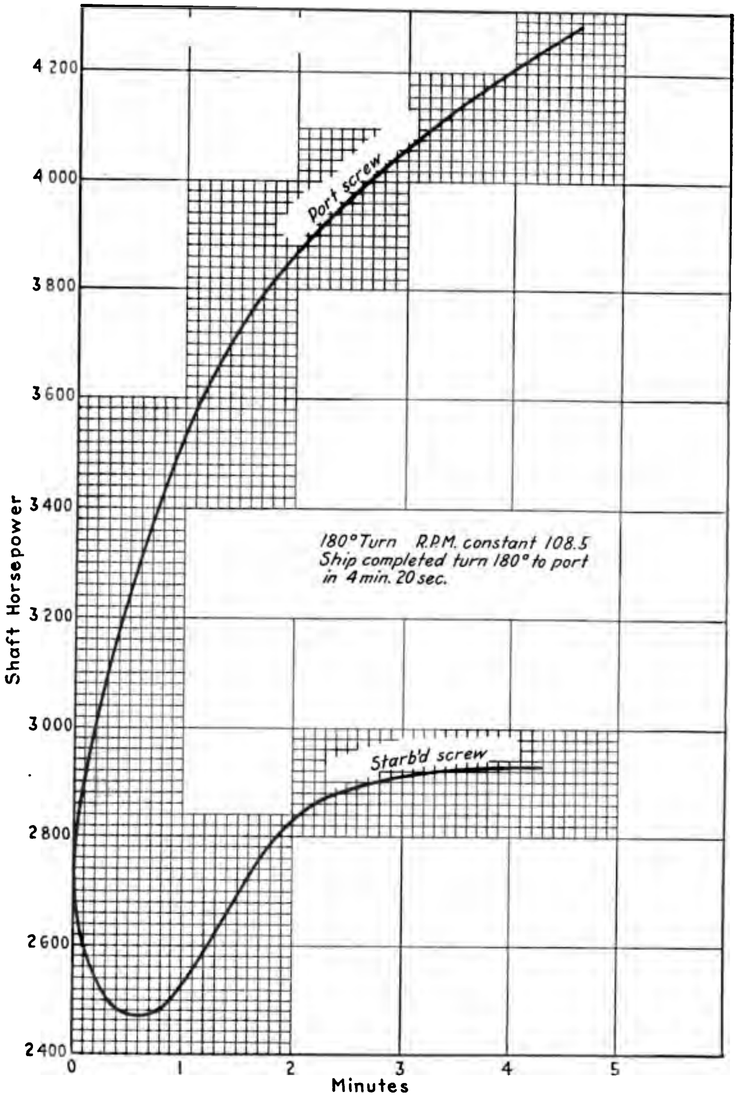


FIG. 5.—Horsepower Curves taken on U. S. S. *Jupiter* while Ship was Turning at a Speed of 14 Knots with Rudder at 25 Degrees

changes on the same ship when the throttle is changed to maintain "constant revolutions per minute." It will be noted that the power on the screw on the outboard side of the turning circle drops and that on the screw on the inboard side of the turning circle rises. After a short time the power on the outboard screw also rises.

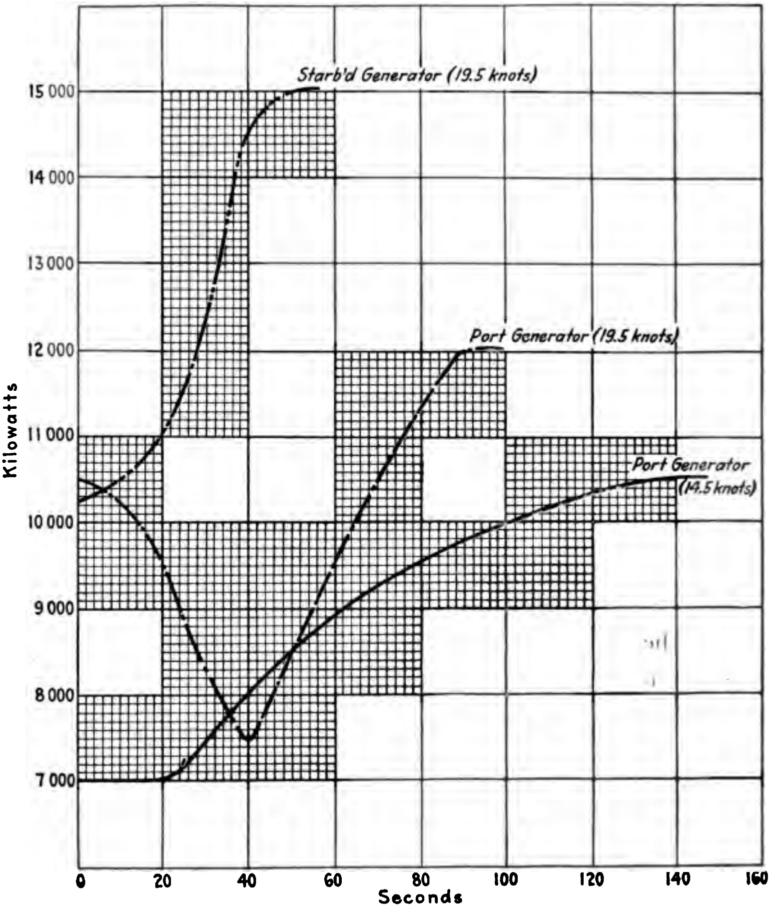


FIG. 6.—Power Curves taken on U. S. S. *New Mexico* while Ship was Turning with 35 Degrees Right Rudder

Figs. 5 and 6 show the same phenomenon. Here the engine is governed and the condition is the same as that on the *Delaware* when the turn was made with "throttle open." These curves are smoother than those of the *Delaware,* as power readings could be taken more frequently; they also show the changes in power more clearly.

In Fig. 5 (the *Jupiter*) the power first drops on the outboard screw, reaching a minimum when the ship has turned through about 20 degrees; it then begins to rise, reaching its original value when the ship has turned through about 40 degrees, and reaching a constant value when the ship has turned through about 140 degrees. The power rises on the inboard screw from the beginning to the end of the turn.

In Fig. 6 (the *New Mexico*) the power was measured on the generators instead of the motors and, therefore, one curve shows total power when only one generator is being used. This curve is marked "14.5 knots." The other two curves each represent power on only one side of the ship. When turning with one generator at 14.5 knots, the power rose steadily until the ship had turned for 2 minutes and 20 seconds, when it became constant. When turning with two generators at 19.5 knots, the power on the outboard screws reached a minimum at 40 seconds of turn, reached its original value at 1 minute and 10 seconds of turn and became constant at 1 minute and 30 seconds of turn. The power on the inboard screws rose steadily until it became a maximum at 50 seconds of turn; this latter was due to the fact that the input of the turbine at this speed was limited to 15,000 kilowatts.

From the three figures we see that on the *Delaware,* turning at 12 knots with the rudder at only 16 degrees, the increase of power on the inboard screw was 58.75 percent. On the *Jupiter,* turning at 14 knots with the rudder at 25 degrees, the increase of power on the outboard screw was 4.6 percent, on the inboard screw 53 percent and the total increase of power was 29 percent. On the *New Mexico,* turning at 14.5 knots with the rudder at 35 degrees, the total increase of power was 50 percent; turning at 19.5 knots with the rudder at 35 degrees, the increase of power on the outboard screws was 14 percent and the increase on the inboard screws was 42 percent, this latter being limited by the maximum allowed steam flow.

It will be seen from the above figures that when turning at high speeds with large rudder angles, the increase of power becomes greater than the maximum output of the generators and means must be provided for limiting the steam flow to the turbine so that it will slow down when a certain predetermined load has been reached.

CHAPTER IV

Characteristics of Alternating Current Motors and Generators for Ship Propulsion

IN Chapter III we have seen what the characteristics of a propeller are; in this chapter it will be shown how to meet these conditions in the design of alternating current generators and synchronous and induction motors. The characteristics of direct current machinery for ship propulsion will be given in the chapter on Diesel electric propulsion. The methods used for the induction motor will be described first since the induction motor must be used in connection with the reversal of the synchronous motor.

The design problem is different from any encountered in land practice, due to the fact that ordinarily any one motor is only a part of the load on the system from which it is being fed; any overload that one motor can pull will, therefore, have practically no effect on the voltage of the system, so that the motor is always operated with a constant voltage. With a ship installation, the conditions are entirely different; the motor constitutes the entire load of the generator, so that the voltage will be very materially affected by large changes of load and this entirely changes the characteristic curve of the motor. Fig. 7 shows the torque characteristics of a double squirrel cage induction motor when fed from constant voltage, and also when fed from a ship's alternator. At 200 percent slip (when reversal begins), when the motor is fed with constant voltage, the torque is nearly six times as great as it is when the motor is fed from a ship's alternator.

Since the maximum power that can be drawn from any generator is limited by its drop in voltage with increase of current, it follows that the maximum power that can be exerted, even momentarily, by the motor will always be limited by the generator, regardless of how large we may make the motor. The only way the maximum power of the generator can be increased is by increasing its voltage by giving it more exciting current. The maximum allowed exciting current will be limited by the heating of the generator field, so that the maximum torque of the motor will really be limited by the heating of the generator field.

It is desirable from the standpoint of weight and economy that the generator should be made as small as possible; the best economy will be obtained, if the generator works at about its normal capacity at the full power of the ship. But it is also necessary to provide the large torque for reversal that is shown to be necessary in Chapter III. Since this torque is required for only a short interval of time, it is possible to use a very large exciting current for this period without overheating the field; as soon as reversal has been accomplished, the current can be restored to its normal value. Thus we can use a generator which is of the proper size for full speed driving and which will also furnish the necessary torque for reversal.

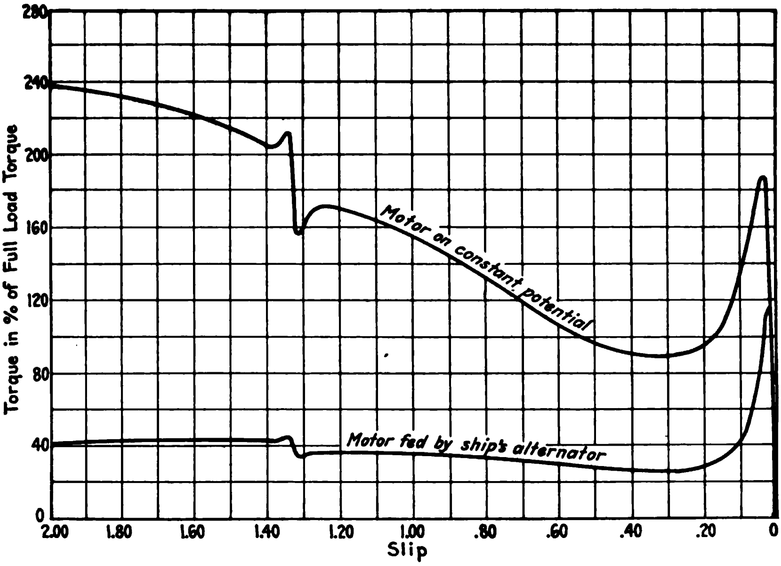


FIG. 7.—Comparison of Characteristics of a Double Squirrel Cage Induction Motor when Operated on a Power Circuit of Constant Potential and the Same Motor used for Ship Propulsion

This method takes care of the loss of voltage of the generator due to overload but there still remains the problem of getting large torque with an induction motor when it is out of synchronism with its generator. A reference to Fig. 2 of Chapter III shows that this torque must be about 100 percent of the torque required to drive the ship. This is indeed an exacting condition, for an induction motor that must have the highest economy when driving. This large torque may be provided, (1) by using a motor having a wound rotor with slip rings and inserting resistance in the rotor circuit; (2) by the use of a double squirrel cage motor; or (3) by the use of a combination of a high resistance squirrel cage with a wound rotor, the latter being open circuited when it is desired to reverse. In the case of (1)—resistance inserted in the rotor circuit—this resistance may be (*a*) in one solid block, or (*b*) in the form of a variable resistance which can be cut out gradually. Each of these methods will be illustrated by describing a typical installation. The *Jupiter* will illustrate (1) (*a*), the *Tennessee* (1) (*b*), the *New Mexico* (2), and the *California* (3).

The single block of resistance is the simplest of these methods and will be described first.

Fig. 8 shows torque curves of the *Jupiter's* motors under various conditions of excitation and with and without external resistance; the propeller torque curve is also shown. A comparison of curves *A, B* and *C* shows very clearly the effect of increasing the generator excitation and a comparison of curves *B* and *D* shows the effect of inserting external resistance in the rotor circuit. The curves are all made using constant frequency, the generator running at 1,990 revolutions per minute.

It is evident from curve *E* that the propeller could not be reversed by using curve *D,* as the motor torque is less than the propeller torque. By inserting external resistance, however, the motor torque is at once brought above the propeller torque, so that the propeller will be reversed and brought up to speed in the reverse direction. It will be brought up to 37.5 revolutions per minute (intersection of *B* and *E*), if curve *B* is used, and to 46.5 revolutions per minute, if curve *C* is used.

In order to develop sufficient power when backing it would be desirable to carry the maximum allowable excitation when reversing. With this arrangement it is simpler not to provide for

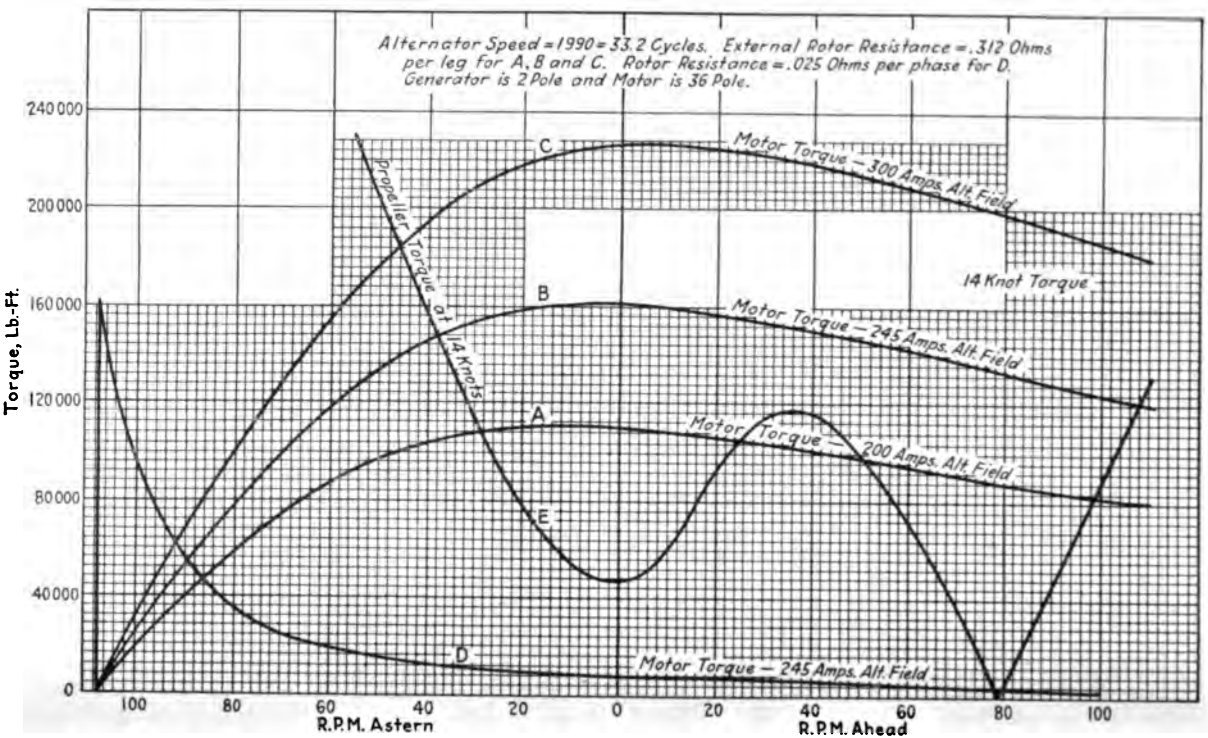


FIG. 8.—Torque Curves for Motors and Propeller of U. S. S. *Jupiter*

cutting out the external resistance when reversing; the resistance should, therefore, be capable of giving continuous operation.

The operation of inserting resistance takes care of the reversing condition satisfactorily and also the condition of starting up from rest. This operation can be carried out with the generator running at full speed, if desired. However, when it is desired to reverse this operation and cut out the resistance it will be necessary to change the frequency (speed of the generator).

Referring to Fig. 9, suppose that the ship is going ahead and the propeller has been brought up to 86 revolutions per minute (about 11 knots) with resistance inserted and excitation at 300 amperes (curve *C*); this is the maximum speed that can be obtained using curve *C* and is represented by the point *x*. If the resistance were now cut out, the motor would pass from curve *C* to curve *D* and the motor would fall "out of step," as the motor torque would be less than that required to drive the propeller at that speed. If, however, the turbine is slowed down before the resistance is cut out, curve *D* will move to another position, say that of curve *F*. This corresponds to a frequency of 29.1 cycles (1,746 revolutions per minute of the generator). Curve *F* inter-

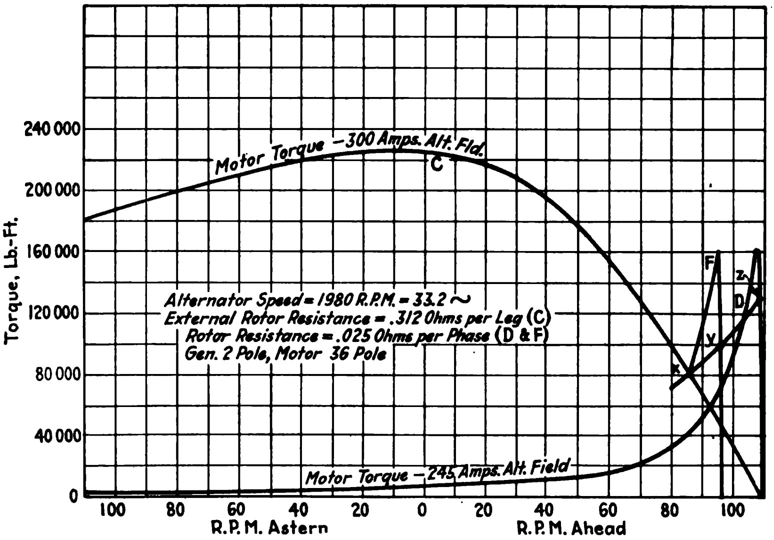


FIG. 9.—Motor Torque Curves of U. S. S. *Jupiter*

sects curve *C* at the point *x* and has an excess of torque above that required to drive the propeller at that speed, so it will accelerate the propeller till the point *y* has been reached. This corresponds to 96 revolutions per minute or about 12.3 knots. If the turbo

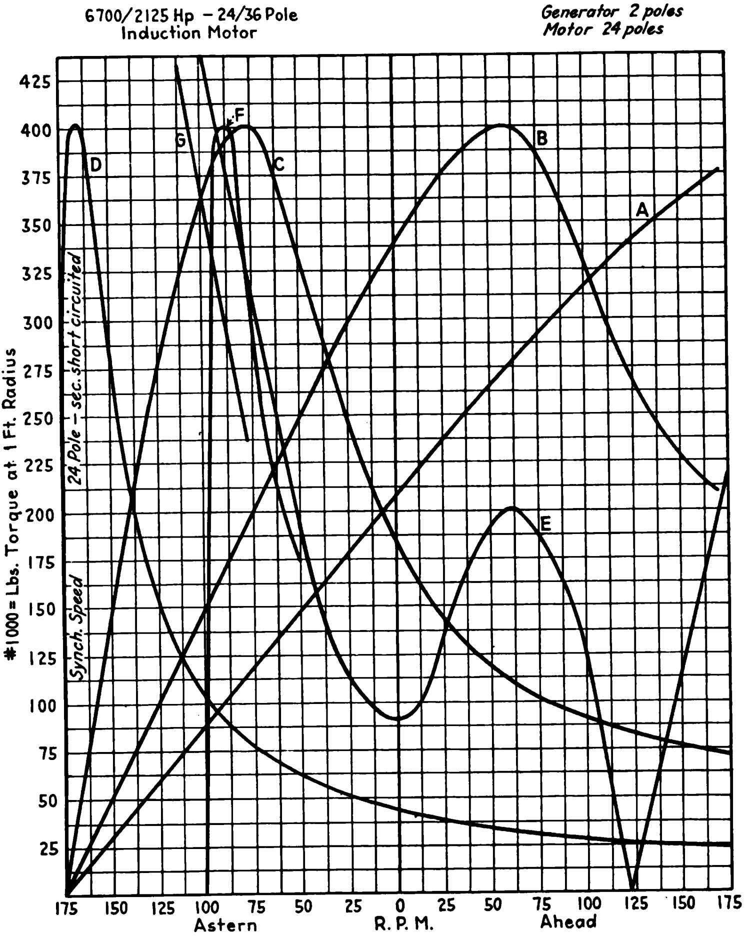


FIG. 10.—Approximate Torque Curves of U. S. S. *Tennessee*

generator is now speeded up, curve *F* will move to the right and the propeller revolutions per minute will be increased till the point *z* has been reached on curve *D*. This point corresponds to 14 knots or the designed speed of the ship.

When arranged as described above, the single block of resistance installation is the simplest possible method of operation, since reversal is accomplished merely by opening one switch and closing another—it being unnecessary to change either the speed of the turbine or the field of the generator. But when it is desired to utilize the full power of the installation during backing, the variable resistance method is more suitable; it is necessary to cut out the resistance to obtain full power and this can be accomplished more readily with a variable resistance than with a single resistance.

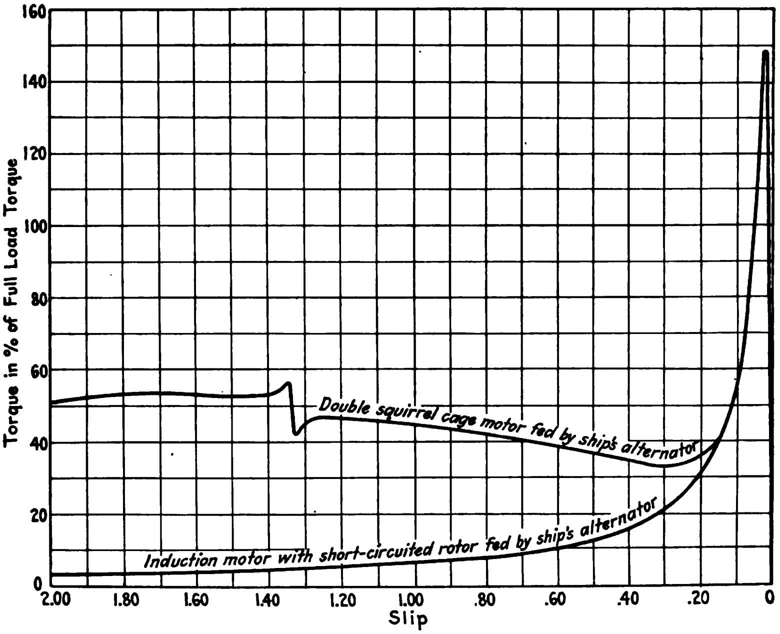


FIG. 11.—Torque Curves—Comparison of Double Squirrel Cage Motor and Ordinary Induction Motor of Same Rating

Fig. 10 shows the torque curves of the *Tennessee* motor, which is provided with a variable resistance. The operation of reversal is started with all resistance in the rotor circuit. In this condition the motor has the torque characteristic shown by curve *A*. As the resistance is gradually reduced, the characteristic changes from curve *A* to curve *D*, passing through an infinite number of curves, such as *B* and *C*. Curve *E* gives the propeller characteristic and it will be seen that this curve lies above curve *D*; in other words, the propeller torque is greater than that given by the "out of synchronism" part of curve *D*. In order to bring the motor into synchronism with the generator, it will be necessary to reduce the frequency (turbine speed) at the same time that resistance is cut out. This will have the effect of moving curve *D* over to the right and it must move at least as far as the position shown by curve *F*. Curve *E* intersects curve *F* on the stable side of curve *F* and this condition will therefore give stable running. As the ship loses headway due to the backing of the propellers, the propeller torque curve will fall lower and lower, passing through successive curves, such as *G*; as this occurs the speed of the generator can be increased to keep the point of intersection of the two curves near the maximum point of the motor torque curve, thus keeping the power delivered to the propeller up to the maximum.

The General Electric Company has perfected a type of motor which furnishes the necessary torque for reversal without the use of external resistance. It is called a double squirrel cage motor, since the rotor has two independent squirrel cage windings. Fig. 11 shows the torque characteristics of this type of motor as compared with an ordinary motor of the same rating. It will be seen that for a slip of 200 percent the double squirrel cage motor has seventeen times as much torque as the ordinary motor.

Fig. 12 shows the arrangement of the bars in the slots of a double squirrel cage motor. The rotor slots are double, with a narrow air gap connecting them; the outer slot contains a German silver bar of high resistance and the inner slot a copper bar of low resistance. At low frequencies of the rotor the reactance due to leakage of flux across the narrow air gap will be of little importance; this is the condition that obtains when the motor is running at practically the synchronous speed of the generator. When the motor stator connections are reversed while the propeller is revolving, the rotor frequency will be double that of the generator at the instant of reversal. Under this condition the reactance due to the leakage across the narrow air gap becomes the predominating factor, so that there will be very little current flowing in the inner squirrel cage and the motor will become practically a high resistance squirrel cage motor with large torque for reversal. Thus, in one motor, we have combined a high resistance squirrel cage for reversal and a low resistance squirrel cage for ordinary running conditions; the transition from one condition to the other is entirely automatic.

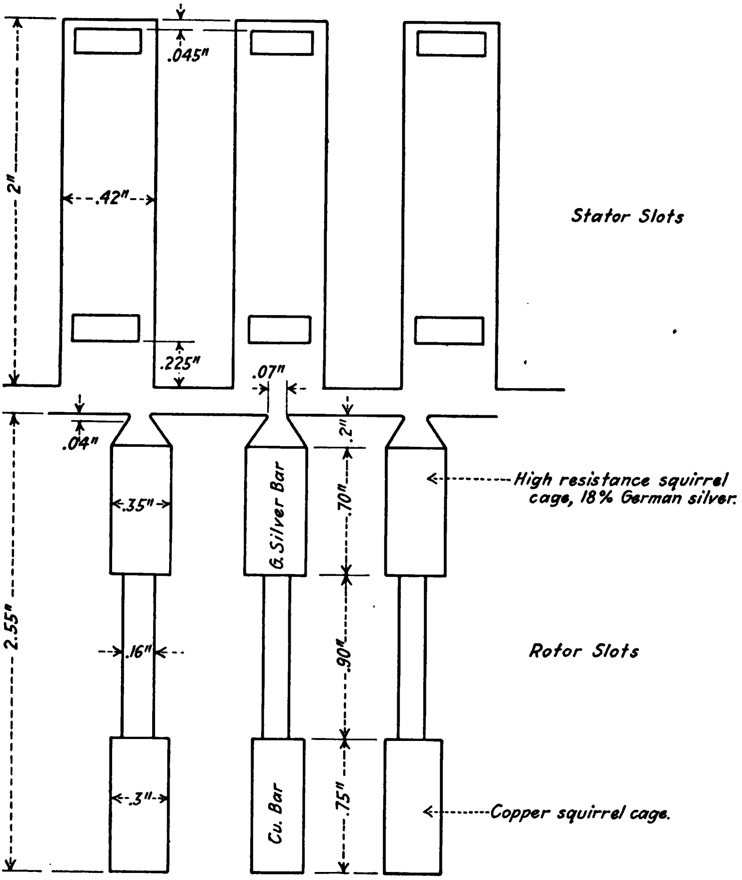


FIG. 12.—Arrangement of Bars in the Slots of a Double Squirrel Cage Motor as used Aboard U. S. S. *New Mexico*

The torque characteristic curve is really the resultant obtained by combining the torque curves of the two squirrel cages and that accounts for the dip in the torque curve which occurs at a slip of 0.3 in Fig. 11; this point is the intersection of the two torque curves. While the two circuits are not connected electrically in any way, the result is the same as if the two squirrel cages were in parallel.

By the use of such a motor, all external resistance can be omitted and the operation of reversal will also be simplified. This motor will, however, have a lower power factor than a motor with external resistance and it will, therefore, require a larger generator.

In order to make the action of this motor entirely clear, there is shown in Fig. 13 an equivalent circuit of the *New Mexico's* motors. This circuit differs from the ordinary equivalent circuit of an induction motor in having the additional circuit, x_a r_a, in its rotor circuit. In this circuit:

x_p represents the reactance of the primary or stator.
r_p represents the resistance of the primary or stator.
x_c represents the common reactance of the two squirrel cages.
r_b represents the resistance of the outer squirrel cage.
r_a represents the resistance of the inner squirrel cage.
x_a represents the reactance of the inner squirrel cage, which is not also common to the outer squirrel cage.
b_m represents the magnetizing susceptance.

The values of the different parts of the circuit given in Fig. 13 are for the *New Mexico's* motors. The following table of calculations shows the method of solving the problem of obtaining the torque for any condition of slip; the two conditions taken are for a slip of 0.01 (normal running) and for a slip of 1.00 (standstill):

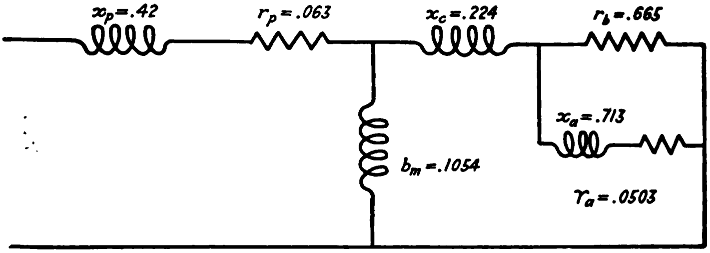


FIG. 13.—Equivalent Electrical Circuit of Double Squirrel Cage Motors as Installed on U. S. S. *New Mexico*

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

S	0.01	1.00	Slip of the Motor
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; 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	1.502	Conductance of upper squirrel cage at slip *s*.
$g_{ab} = g_a + g_b$	0.21	1.602	Resultant conductance of both squirrel cages in parallel.

S	0.01	1.00	Slip of the Motor
$Y_{ab}^2 = g_{ab}^2 + b_a^2$	0.0449	4.53	Admittance squared of both squirrel cages in parallel but not including mutual reactance.
$r_s = \frac{g_{ab}}{Y_{ab}^2}$	4.68	0.354	Resultant rotor equivalent reactance 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.
$Z_s^2 = r_s^2 + x_s^2$	22.6	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.
$b_{sm} = b_s + b_m$	0.1427	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.

S	0.01	1.00	Slip of the Motor
$x_{sm}=\frac{b_{sm}}{Y^2_{sm}}$	2.24	0.518	Resultant reactance of rotor and magnetizing circuits.
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 impedence of motor at slip *s*.
$P.F.=\frac{r}{Z}$	0.781	0.378	Motor power factor.
$I=\frac{E}{Z}$	985	4,150	Motor current at 4,200 volts (normal voltage) and at slip *s*.
$S.K.W.=\frac{I^2 r_{sm}}{1000}$	3,170	5,490	Torque per phase in synchronous kilowatts.
$T=79.3\times S.K.W.$	251,000	435,000	Total torque in pound-feet at slip *s*.
$K.W.=\frac{2I^2r}{1000}$	6,460	13,150	Kilowatt input into motor not including core loss.

By using the above method the torque, current, power factor, etc., can be found for any given slip and the complete characteristics of the motor can be obtained. These have been plotted in Fig. 14 for a voltage of 4,200 and a frequency of 35.5 cycles. The same method can be used to determine the characteristics at any other desired frequency and voltage.

The action of this motor during reversal is similar to that described for a motor with external resistance, but there is one point of difference. With external resistance the amount of resistance can be made so great that the motor will be on the stable part of its curve from the very beginning of the reversal; this is evident from a reference to curve *A* in Fig. 10. This is not true in the case of the double squirrel cage motor, which is on the unstable part of its curve till the propeller has been reversed and brought up to the synchronous speed.

This action will be better understood by a reference to Fig. 15, which shows the entire operation of reversal of this motor. The explanation is complicated somewhat by the fact that, at full speed, the motors are arranged for 24 poles and when reversal takes place they are changed to 36 poles. This is done, however, only because the torque is somewhat greater with the 36-pole arrangement than with the 24-pole and does not in any way affect the principle of the reversal.

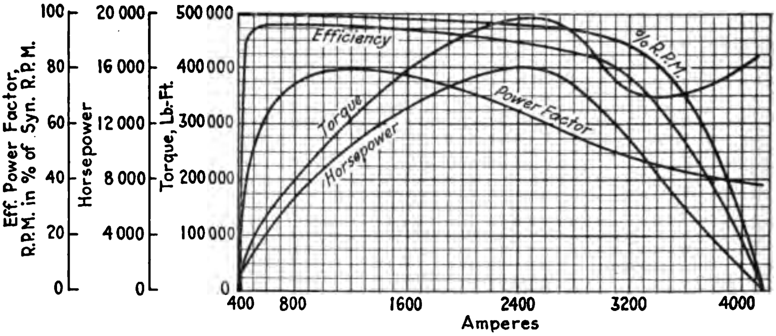


FIG. 14.—Characteristics of U. S. S. *New Mexico's* Double Squirrel Cage Induction Motor for Constant Potential of 4,200 Volts and a Frequency of 35.5 Cycles

In Fig. 15 the motor is running on curve *A* at 21 knots, the torque required being indicated by the point *x*, which is the intersection of the propeller torque curve *B* and the motor torque curve *A*. When it is desired to reverse, the motors are changed to 36 poles, the turbine speed is reduced, the motor connections are reversed and the excitation of the generator is increased to 150 percent normal excitation.

The reversed torque curve is shown as curve *C*. It will be seen that the torque of this curve exceeds the torque of curve *B* at all points, so that the propeller will be reversed and brought up to the speed indicated by the point *y* (intersection of *B* and *C*).

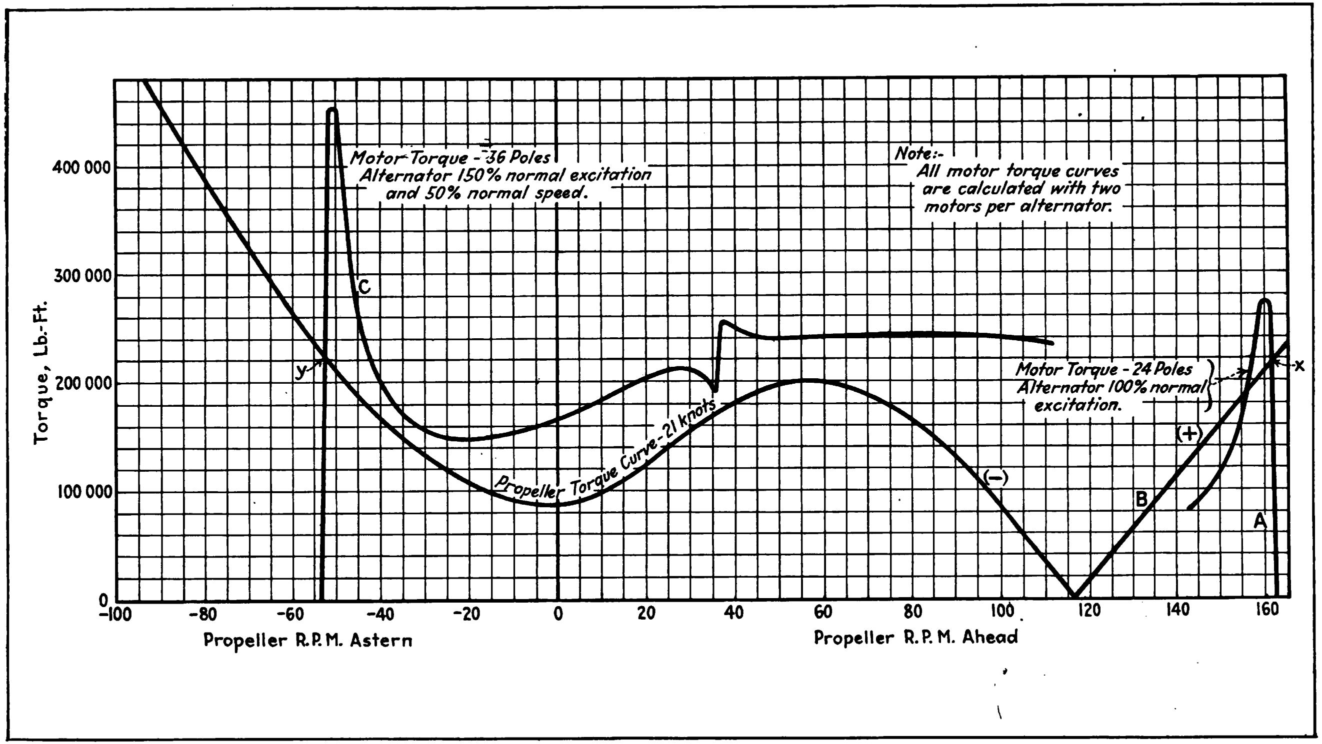


FIG. 15.—Motor and Propeller Characteristics for U. S. S. *New Mexico*

There are two points where curve *B* comes very close to curve *C*; the first occurs at about 55 revolutions per minute ahead and the second at about 35 revolutions per minute astern. If the speed of the turbine were not sufficiently reduced, it might very well happen that the propeller would be reversed; but, owing to curve *C* being too far over to the left (turbine speed being too high), the propeller would not come up to speed but would simply hang at the intersection of curves *B* and *C* in the unstable portion of curve *C*. It is therefore best, in this operation, to have a certain definite speed to which the turbine is always brought during reversal; after the motor and generator come into synchronism, the turbine can be speeded up till the point *y* is near the top of curve *C*.

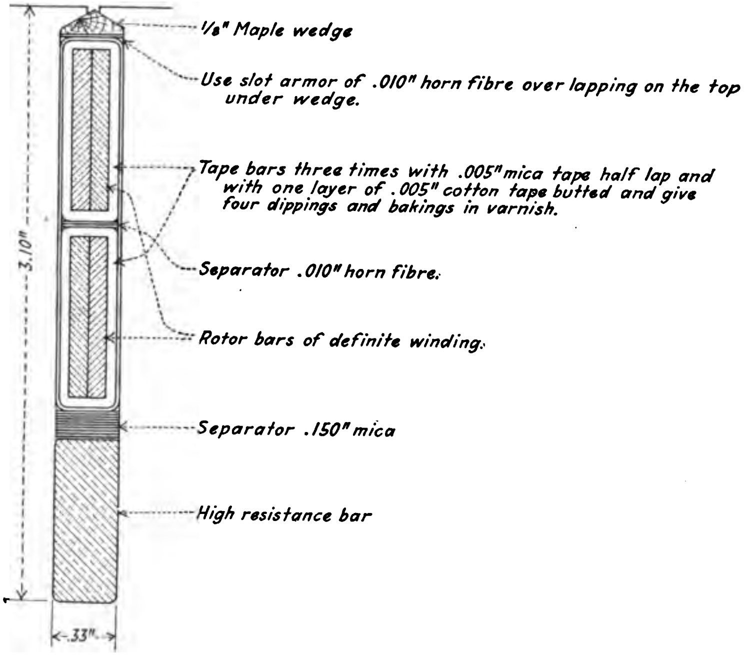


FIG. 16.—Rotor Winding Insulation of Motors on U. S. S. *California*

The desirability of knowing the exact time that the motors and generators come into "step" has brought out the necessity for an instrument that will indicate this condition; this instrument will also be useful in deciding on the amount of excitation that is necessary when the ship is making a turn, as will be seen when that point is discussed later on. Such an instrument has been devised by Mr. Alexanderson, of the General Electric Company, and installed on the *New Mexico;* it will be described under instruments and switchboards. With such an instrument there can never be any doubt as to whether or not the motor has "pulled into step"; as the motor approaches synchronism, the pointer of the instrument travels over from the unstable or unsafe part of its dial to the safe or stable part.

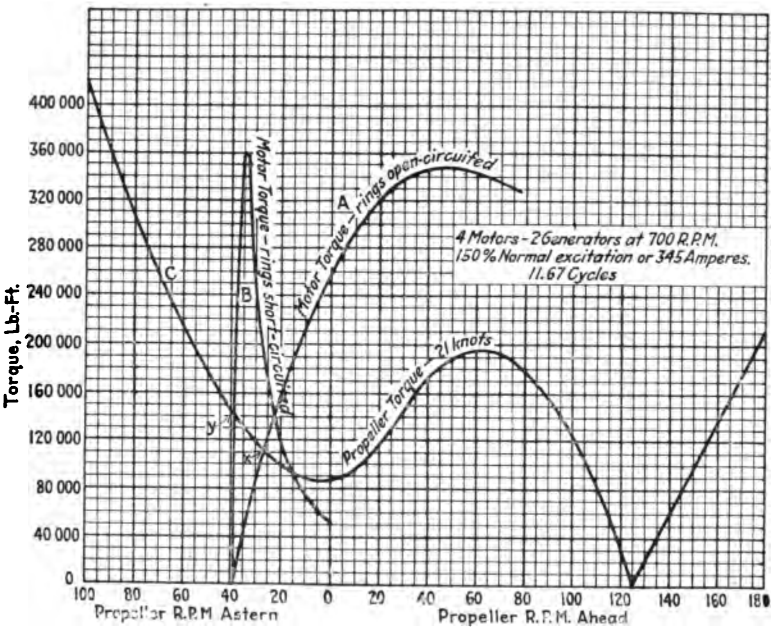


FIG. 17.—U. S. S. *California:* Motor and Propeller Torque Curves

The method of combining a high resistance squirrel cage with a definite winding to obtain large reversing torque without the use of external resistances has been used for the motors of the *California.* The rotor of the motor has a high resistance squirrel cage winding and also a definite winding, both being located in one slot. The arrangement of the windings is shown in Fig. 16. The squirrel cage bar is placed at the bottom of the slot and the definite winding is placed on top of it.

Fig. 17 shows the torque curves of such a motor, both when the definite winding is open circuited (or entirely inactive) and also when the definite winding is short circuited. Curve *A* is the open circuited condition and curve *B* the short circuited condition. Curve *A* is simply the torque curve of the high resistance squirrel cage and curve *B* is the resultant torque curve of the squirrel cage and the definite winding, although the squirrel cage has very little effect on this curve in its stable portion.

When it is desired to reverse the motor, the definite winding is opened by a switch and the motor will then operate on curve *A;* after the motor has been reversed, the definite winding is short circuited by closing the switch and the motor then shifts to curve *B;* before this change is made, however, it will be necessary to slow the turbine speed so that curve *B* will be in a position where its torque will be greater than the propeller torque.

In fact, this must always be done with any arrangement for reversal where it is desired to cut out the resistance after reversal has taken place. The two operations of reducing the frequency and increasing the excitation may be said to be a necessary part of any method of reversal, except for the single case of reversal with a single block of resistance, which is left permanently in the circuit during reversal.

In Fig. 17, for curves *A* and *B,* it has been assumed that the generator has been slowed to a frequency of 11.67 cycles. At this speed the intersection of curve *A* and curve *C* (propeller torque) is at the point *x*. The torque on curve *B* at these revolutions per minute is much greater than that on curve *A,* so that when the short circuiting switch is closed and the motor shifts to curve *B* there will be an excess of motor torque over propeller torque and the propeller will be accelerated until it reaches the point *y* (intersection of *B* and *C*); the turbine can then be speeded up.

Various other methods have been proposed for utilizing the effect of a high resistance squirrel cage in combination with a wound rotor to give the desired torque for reversal.

According to one of these, the primary is arranged so that a portion of it can be interrupted. The general scheme is shown diagrammatically in Fig. 18. The arrangement of the circuits is shown in the upper part of the figure; the dotted half of the primary winding is taken to a switch so that it can be opened independently of the other half of the winding. The effect of opening this switch can best be understood by remembering that the induction motor is a transformer. The lower half of the figure shows an equivalent transformer circuit for the circuit shown in the upper half of the figure. The stator winding is equivalent to two primary transformer windings in parallel; the wound portion of the rotor winding (being all in series) may be considered as two secondary transformer windings in series; the two parts of the squirrel cage winding located under the definite winding may be considered as two independent secondary transformer windings. When the dotted primary winding is opened, the other primary will still induce current in its secondary and, since the two secondaries are in series, current will flow in both of them. The secondary under the dotted primary will now act as a primary and induce current in the squirrel cage underneath it. This portion of the squirrel cage winding will become highly active for producing torque. This method has the objection that only half the coils are effective for producing torque.

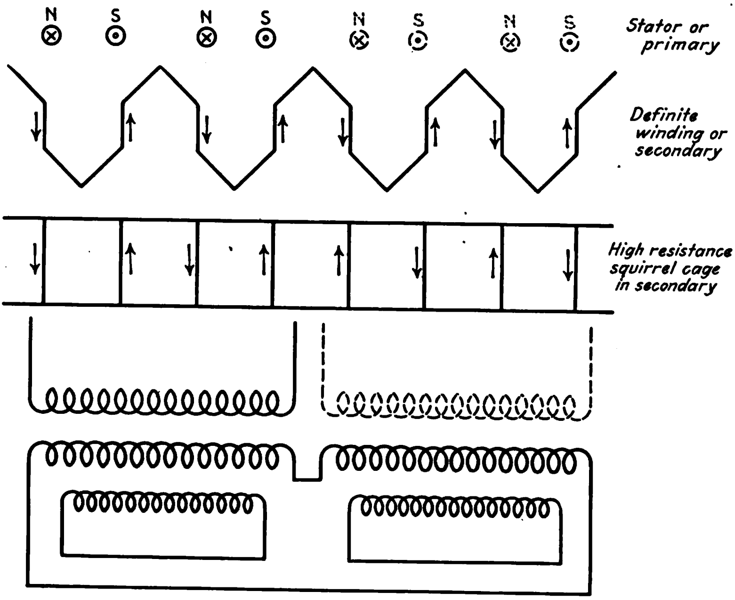


FIG. 18.—Diagram Showing General Scheme for Reversing by Interrupting a Portion of the Stator

Another method of utilizing the high resistance squirrel cage for obtaining large torque for reversal is to arrange the primary winding so that it can be changed by switching in such a way as to neutralize the wound portion of the secondary, thus making only the squirrel cage effective. The scheme is illustrated diagrammatically in Fig. 19. Each phase of the primary is divided into three circuits in parallel. With the switch in the "up" position, both the wound secondary and the squirrel cage will be active, if the rotor windings are arranged in series as shown in the lower part of the figure. Consider the portion of the secondary which is under the primary windings marked *"a"*; this portion of the secondary circuit is shown at the bottom of the figure marked *"a-a-a."* The three induced voltages will be in proper

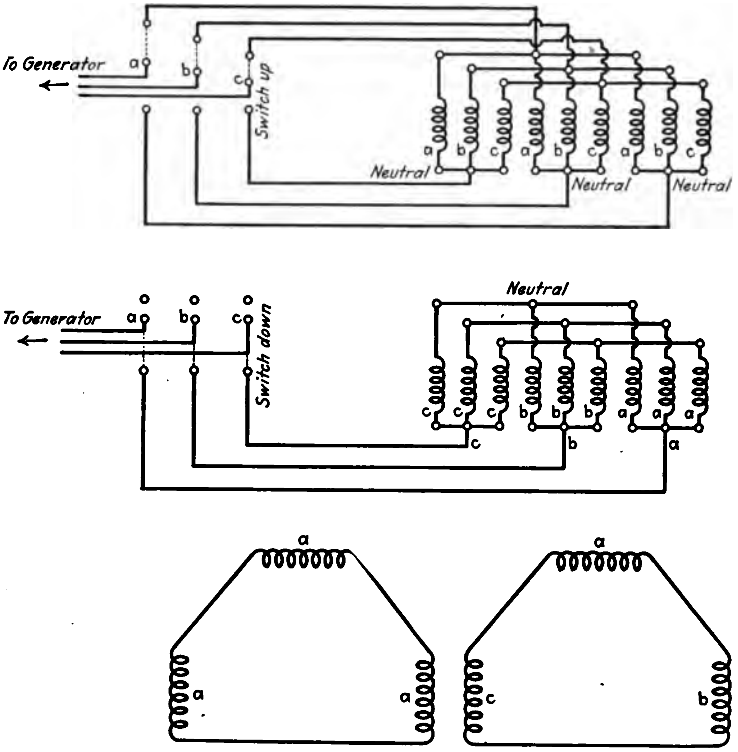


FIG. 19.—Diagram Showing Method for Obtaining large Torque for Reversal by Neutralizing Definite Wound Rotor by Changing Connections of Primary

phase and will, therefore, cause load current to flow. When the switch is thrown to the "down" position, the wound secondary is made ineffective. Consider the same portion of the wound secondary as before; one of each of the three legs will be acted on simultaneously by the three phases, so that the total induced voltage around the circuit will be zero (as the three induced voltages are equal) and 120 degrees apart in phase.

Both this method and the one previously described would be unsuitable for use with a motor wound for pole changing. They might, however, be useful in the case of a motor located a long distance from the point of control, as it would make it unnecessary to return the leads from the secondary to the control point.

We have just seen the various methods by which induction motors can be arranged to give the necessary torque for backing; it will now be shown how the same thing can be done with synchronous motors.

The synchronous motor will be provided with a squirrel cage winding on its rotor to assist in the operation of reversal. In reversing, the turbo generator will be set to run at a constant low speed (about one-fourth speed) and its field will be opened; at the same time the connections to the synchronous motor will be reversed and double excitation will be applied to its field. The synchronous motor will now become a generator driven by the propeller and will supply power to the main turbo generator, which will now be acting as a high resistance squirrel cage induction motor, the solid field of the generator acting as a high resistance squirrel cage. The power supplied to the turbo alternator from the synchronous motor will tend to reverse its direction of rotation; but, since it is driven by a governed turbine, it will continue to run in the original direction at a constant speed and the power supplied to it from the synchronous motor will be absorbed in heating the rotor. If the combined torque necessary to drive the turbo alternator and the synchronous motor is greater than the torque of the propeller, which is now driving the synchronous motor, then the speed of the latter will be reduced until the two torques are equal.

Before proceeding with the remainder of the operation of reversal, a further explanation will be made of the above sequence of events. Fig. 20 shows the combined torque curve of the synchronous motor and the turbo alternator when the latter is acting as a squirrel cage induction motor and the former as a generator. Curve *B* is the torque curve of the propeller and curve *A* shows the combined torque curve of the synchronous motor and turbo alternator. It will be noted that the shape of this curve is very similar to that of an induction motor when supplied with current of constant frequency. This is due to the fact that the torque curve is the resultant of the I^2R losses in the rotor of the alternator, the stator of the alternator and the stator of the synchronous motor. At the point *a*, when power is first applied to reverse, the losses in the alternator rotor predominate, but as the synchronous motor slows down, decreasing the frequency of the current, the skin effect of the alternator rotor will decrease and the effective resistance of the rotor will decrease, while the resistance of the stator windings of both alternator and motor will remain constant. Therefore, the rotor losses will become a smaller percentage of the total losses as the propeller slows down. As the synchronous motor approaches standstill, the alternator rotor resistance is reduced so much that the synchronous motor approaches the condition of being short circuited through an external resistance equal to the resistance of the generator stator winding.

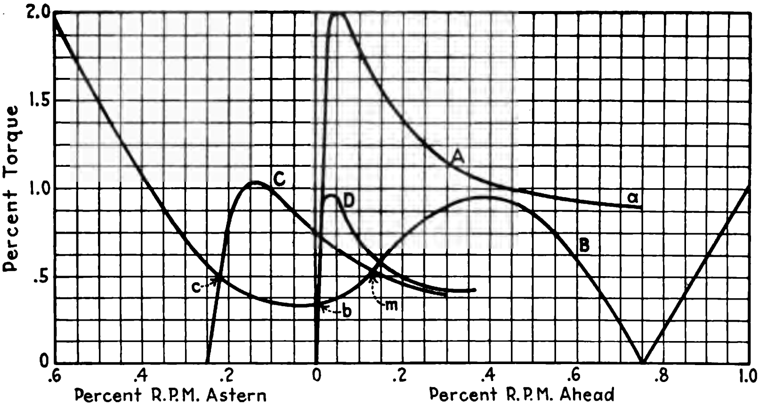


FIG. 20.—Combined Torque Curves of the Synchronous Motor and Turbo-Alternator

If it were not for the preponderating influence of the stator losses at the low speeds, curve *A* would fall very rapidly with reduction of speed, instead of having a peak like an induction motor torque curve. The effect of this peak in the curve has a very important bearing on the operation of reversal, as will be explained after the description of the entire process has been completed. It will not be possible to bring the propeller to absolute standstill by this action, as the torque of curve *A* is zero at standstill.

As soon as the propeller speed has been reduced to the point *b* (intersection of curves *A* and *B*), the excitation of the synchronous motor is reduced; this will have the effect of shifting curve *A* to curve *D*.

The next step is to apply excitation to the alternator and, as soon as this field has built up, remove excitation entirely from the synchronous motor. The squirrel cage winding of the latter now becomes effective, making it an induction motor, and the torque shifts from curve *D* to curve *C*. The propeller will now be reversed and brought up to speed in the opposite direction till the point *c* is reached. Curve *C* is the torque curve of the squirrel cage on the rotor of the synchronous motor. During the interval in which there is excitation on both motor and generator the torque will be slightly less than the sum of the torques due to the induction motor and the synchronous motor as there is a certain amount of interference between the two. As soon as the excitation has been entirely removed from the synchronous motor the torque on the propeller will be that represented by curve *C*.

The point *c* is the highest speed that can be attained by the squirrel cage, but this is less than synchronous speed, so the next step in the operation will be to bring the motor up to full synchronous speed, as represented by the point *e* in Fig. 21. To do this, normal excitation will be applied to the synchronous motor and double-excitation to the alternator. The propeller will then be accelerated, as explained below, until it reaches point *g* on curve *B*, which is full synchronous speed as represented by *e*. The turbo generator and motor can then be speeded up together to the desired speed.

Since the action of a synchronous motor in pulling into synchronous speed from a lower speed is not as generally understood as other electrical problems, it may be well to review this point here. During the process of pulling into synchronism, the torque of the synchronous motor will pass through cycles of positive and negative torque and the effect of this alternating torque will be to set up oscillations in the speed of the rotor, so that it will oscillate above and below the point *c*. If these oscillations are great enough, the point *g* will be reached in swinging past point *c;* at that instant the motor will be at synchronous speed and there will be a very large positive torque to hold it at that speed. Tendencies to oscillate out of synchronism will be checked, since increase of speed will result in a decrease of torque, and *vice versa;* also, all other torques, such as those due to induction motor action and hysteresis, will tend to check any fluctuations.

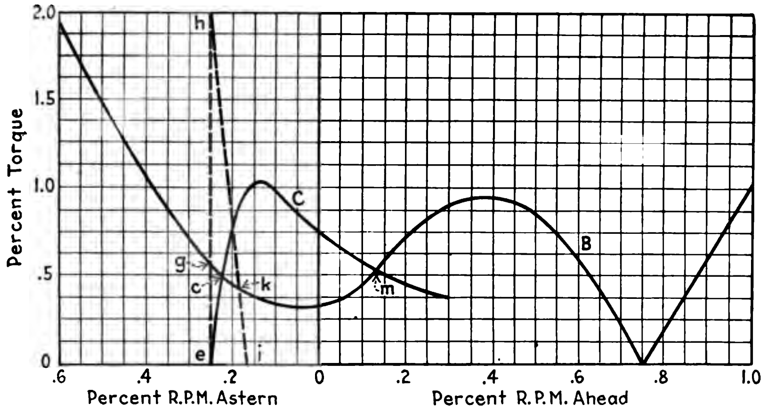


FIG. 21.—Torque Curves Showing Action of Synchronous Motor in Pulling Into Synchronism

Whether or not a synchronous motor can oscillate into synchronism from any given speed will depend on the amount of load on the motor. For example, in Fig. 21, at the speed *i*, there must be no load on the motor, if it is to be brought up to synchronism; at the speed represented by the point *k*, the load, or "resisting torque," can be that indicated by the point *k* (that of the propeller at that point); as higher speeds are chosen, greater loads can be thrown on the motor until, at the point *h*, the maximum torque of the motor and synchronous speed of the motor are reached simultaneously. The point *k* is the intersection of curves *hi* and *B* and it represents the lowest speed of the propeller from which the motor can be brought up to synchronism. It is essential that the point *c* must never be to the right of the point *k,* if the motor is to be brought into synchronism.

Having seen the complete cycle of reversal of a synchronous motor, we can return to an examination of the effect of the peak in curve *A,* Fig. 20. First, it makes it possible to reduce the synchronous motor excitation before applying generator excitation and this reduces the rush of current when this change is made. Second, it reduces very much the propeller speed at which curves *A* and *B* intersect from what it would be if it were not for the effect of the stator winding losses; in other words, the point *b* would be very much to the right of its present position, if it were not for the effect of the stator resistance. Point *m,* Fig. 20, shows the maximum propeller speed at which it would be possible for the induction motor to reverse the propeller. If the effect of the stator windings were removed from curve *A,* the point *b* would be to the right of point *m.* This would necessitate the use of a higher resistance in the induction motor to bring the point *m* farther to the right and this would incline curve *C* more to the right, bringing point *c* over to the right and making it more difficult to bring the motor into synchronism. There is a third possible advantage that results from the shape of curve *A;* by inserting resistance in the line between the motor and alternator, the position of the peak can be moved to the right as much as desired, so that it could be brought directly over the maximum point in curve *B,* if necessary.

The efficiency of the synchronous motor is slightly better than that of the induction motor; it has a power factor of about 100 percent and it also has a large air gap and no high voltages in its rotor. As a result of the high power factor and superior efficiency, a considerable saving of weight is effected by its use. On the other hand, the operation of reversal is more complicated and it is doubtful if the advantages outweigh this. In any case, it should not be used for high speed ships on account of the difficulty of obtaining sufficient reversing torque; the large air gap of the synchronous motor does not allow the construction of a very efficient squirrel cage, which must be used in the process of reversal. Another objection to the synchronous motor is that it gives only one speed reduction.

The next point to be explained in connection with the design of generators and motors for propulsion will be the method of obtaining combined motor and generator characteristic curves. As an example of this it will be shown how the characteristics of motor and generator can be combined to give the curve shown in Fig. 7.

In Fig. 22 are shown the characteristic curves of the *New Mexico's* generators under various conditions of power factor and excitation but at a constant frequency of 35.5 cycles. The motor characteristic curves shown in Fig. 14 were calculated for the same frequency, so the characteristics of motor and generator can be combined to give the lower curve shown in Fig. 7 by transferring the readings of the motor characteristic to the generator characteristic in the manner illustrated in the following:

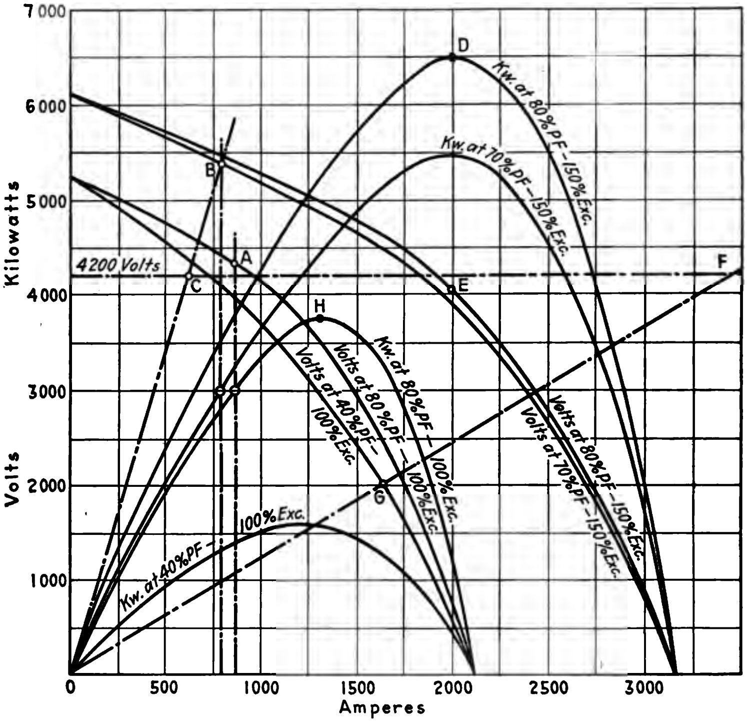


FIG. 22.—U. S. S. *New Mexico:* Turbo Generator Voltage and Kilowatt Curves with High Voltage Connection and at 35.5 Cycles. Amperes and Kilowatts are One-Half of Actual Generator Value, that is, they are Values per Motor

Point *A* shows the volts and amperes of the motors when drawing 3,000 kilowatts per phase at 100 percent generator excitation and 80 percent power factor. This point is obtained by finding the point on the curve marked "kilowatts at 80 percent power factor and 100 percent excitation," which gives 3,000 kilowatts; then a vertical line through this point to the point *A* will give the data desired. This method presupposes a knowledge that the power factor of the motor, under these conditions, will be 80 percent; if this were not known, it could shortly be determined by "trial and error" and an error of a few percent in the power factor would not appreciably displace the point *A*.

Point *B* shows the volts and amperes of the motors when drawing 3,000 kilowatts per phase at 150 percent generator excitation and 70 percent power factor. This point is obtained in a similar manner to point *A* for 100 percent excitation.

Point *C* gives the current drawn by the motor when operated at 4,200 volts and at the same slip as that of point *B*. The point *C* lies on a straight line connecting point *B* with the origin; therefore the ratio of volts to amperes will be a constant for all points on this line; also, if the load is increased with the voltage in such a way as to maintain the slip constant, the power factor and efficiency will remain constant. We can, therefore, pick off from Fig. 14, at the amperes corresponding to point *C*, the power factor and efficiency of the point *B*.

Point *D* shows the maximum kilowatts (6,500 per phase) at 150 percent excitation and 80 percent power factor. This is the load at which the motors will "fall out of step."

Point *E* shows the volts and amperes corresponding to point *D*.

Point *F* shows the amperes drawn by the motor at 20 percent slip and 4,200 volts, the amperes for this point being taken from Fig. 14 at 20 percent slip.

Point *G* shows the volts and amperes of the motors at same slip as point *F* and when fed from the generator with 100 percent excitation and at 40 percent power factor.

Point *H* shows the maximum kilowatts at 100 percent excitation and 80 percent power factor.

Two very important points of these curves are the points *D* and *H;* these have a very important bearing on the turning of the ship, since it is the maximum output of the generator that is the limiting feature and not the motors or turbine. If the generator capacity were greater than that of the turbine, the turbine would slow down, if its capacity were exceeded, but in actual practice the turbine is always designed with a margin over the generator.

We will now consider the condition that arises when a ship makes a turn. In Figs. 4, 5 and 6, Chapter III, we saw that when a ship turns a large overload is imposed on the propellers and a particularly heavy overload on the propellers on the inboard side of the turning circle. It is obvious from Figs. 4, 5 and 6 that on a high speed ship, which is turning, the screws on the inside of the turning circle must slow down during the turn; otherwise it would be necessary to have machinery of much greater capacity than would be necessary for the full speed desired. In other words, if the generator is to work normally somewhere near the point *H,* Fig. 22, and hence at its best efficiency, some means must be found to limit the load in turning.

The problem has been solved by limiting the power of the turbine for any given speed. This is accomplished simply by fixing a limit to the maximum amount of steam that the turbine can take; the method of doing this will be described in detail in another chapter. The result of this is that when the turbine reaches its capacity any further demand for power by the generator will simply cause the turbine to slow down until the demand is reduced to what the turbine can give. The steam limit can be set to give any desired margin over the amount of steam required for the speed, but the greater the margin allowed, the more excitation it will be necessary to carry on the generator field.

The excitation should always be kept to a minimum, as excess field current means excess heating in the field and will also reduce the efficiency of transmission, if the excess is too great. There is quite a wide range of excitation, however, for which the efficiency of transmission will be practically constant. It would not be desirable to carry just enough excitation to keep the motors in step under normal conditions when turning, since a slight variation from the normal would throw the motors out of step. Therefore, a certain margin of excitation should be allowed as a factor of safety. Just how much margin should be allowed should be determined by experiment for each ship.

On the *New Mexico,* experiments were made to determine the minimum allowable excitation when steaming straight ahead; then the steam limit was set and the minimum excitation determined for the ship when turning under this condition. It was found that the excitation required for turning (with steam limit set) was about 10 percent greater than that required for straight steaming. The excitation is actually carried about 10 percent higher than this, or 21 percent higher than that required for straight steaming. This is doubtless on the safe side, and further experience may show that a reduction can safely be made. For ships that are not cruising in formation, the amount could certainly be reduced.

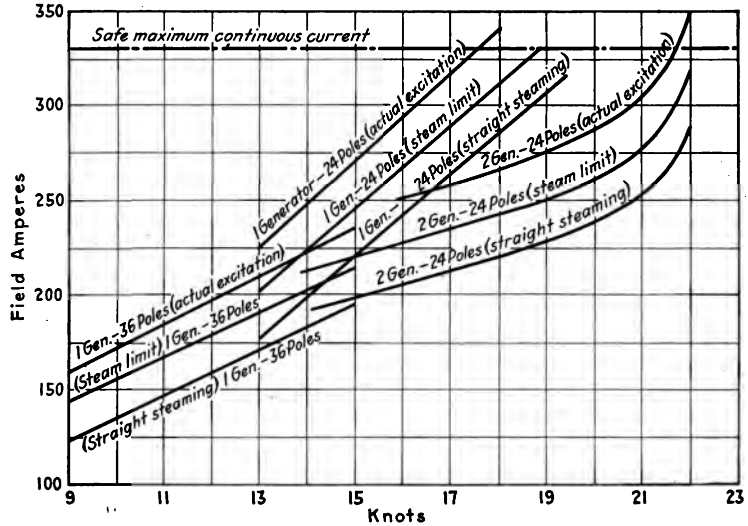


FIG. 23.—U. S. S. *New Mexico:* Excitation Curves

Fig. 23 shows the excitation used on the *New Mexico.* One set of curves shows the excitation at which the motors drop out of step when steaming on a straight course. The next set of curves shows the excitation at which the motors drop out of step when turning with the rudder at 35 degrees and with the steam limit set. The third set of curves shows the excitation that is actually carried.

In addition to the special requirements for providing torque for backing and turning, it is frequently desirable to arrange motors to give two different speed reductions. This will usually not be necessary for merchant ship work where the speed variation is small except when maneuvering, but, for a man-of-war, it will always be desirable to have the two speeds in order to obtain the best turbine efficiency at the cruising speed of the ship. For a battleship of 21 knots speed, the motors will usually be arranged to allow the turbine to run at full speed at about 15 knots as well as at the full speed of the ship.

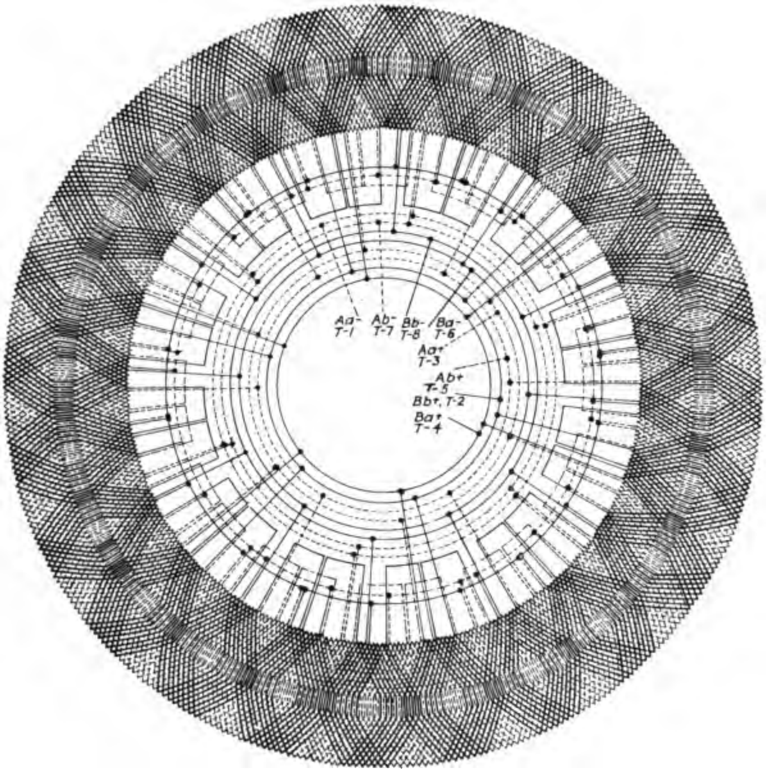
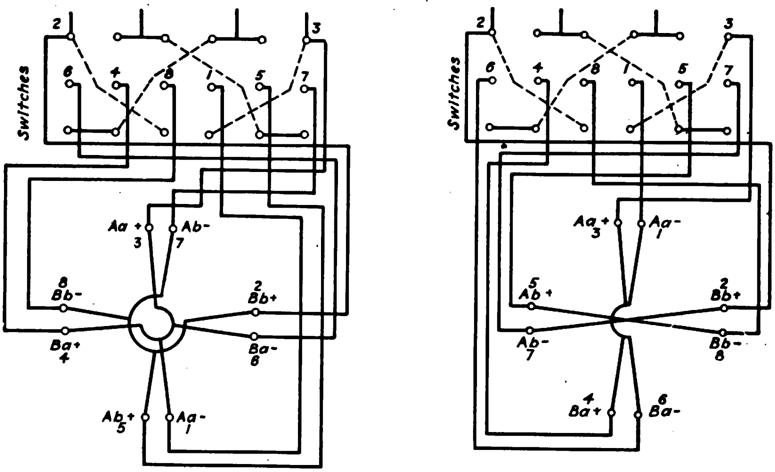


FIG. 24.—U. S. S. *New Mexico:* Stator Coil Diagram

This is accomplished by winding the stator of the motor with two polar arrangements and bringing the end connections to a double throw switch; in one throw this switch will give, say, 24 poles, and in the other 36 poles. If the generator has 2 poles, then there will be a speed reduction of 12 to 1 in the first case and 18 to 1 in the second case. This double polar arrangement of stator winding may be accomplished either by providing two independent stator windings—one for each polar arrangement—or by arranging one winding to give the two sets of poles. Previously this latter method of pole changing had been limited to the single case of a 2 to 1 change in the speed reduction; for example, a motor might be wound to give 24 poles and also 48 poles, but not an intermediate number of poles. This change does not fit the case of a battleship, so a new type of winding was developed which will give any desired change in the speed reduction. This type of winding is somewhat better adapted to a quarter-phase system than to a three-phase and, for that reason, the quarter-phase system was adopted for the *New Mexico*. The motors of the *Tennessee* have independent stator windings for the two polar arrangements and a three-phase system is used.



24 Pole Connection, Switches up. 36 Pole Connection, Switches Down

Note: Positive Direction of Rotation Clockwise Facing Coupling.
Front End of Motor.
Positive Direction of Rotation Counter Clockwise.

FIG. 25.—Winding used for Motor on U. S. S. *New Mexico*

The *New Mexico's* motor stator winding is shown in Figs. 24 and 25. The method used in working out this winding is shown in Fig. 26. In this figure the arrows represent complete coils and also indicate the direction of current flow in the coil. The first group shows the arrangement for 24 poles. Actually there are shown only 4 poles for each phase; this is one-sixth of the complete diagram, which is made up of six parts in parallel, as may be seen by a reference to Figs. 24 and 25. The second group shows the 36-pole arrangement; six poles are actually shown, the remainder being made up of six parallel circuits as before. It will be noted that in the 36-pole arrangement the two phases are not entirely symmetrical for each polar area. For example, the first polar area has five coils in phase *a* and six coils in phase *b*, but the total number of coils in each phase is, of course, the same. The third group of arrows shows how the coils are divided into sixteen groups for winding, eight of these groups consisting of 5 coils each and eight of 3 coils each. The fourth group of arrows shows how the groups are connected to form a complete section of the winding. Figs. 24 and 25 show six of these complete groups connected in parallel to form the complete motor winding. At the bottom of Fig. 26 the complete winding with its connections to the switch is shown diagrammatically. With this system of winding practically any desired ratio of speed reductions can be worked out.

When a motor has its stator arranged for two different numbers of poles the motor rotor will operate satisfactorily under both conditions, if the rotor has a squirrel cage winding, since this type of winding does not have definite fixed polar areas but will automatically accommodate itself to any number of poles on the stator. But if the rotor has a definite winding, then it must be specially arranged to meet the condition of pole-changing.

Fig. 27 shows how this has been accomplished in the case of the *Tennessee*. Here the rotor winding acts as a definite winding, when the 24-pole arrangement of the stator is in use, and as a squirrel cage winding when the 36-pole arrangement of the stator is in use. The definite winding is used with the 24-pole arrangement because the *Tennessee's* motors are arranged to reverse on the 24-pole combination and it is necessary to have the rotor winding connections come out to slip rings for this purpose so

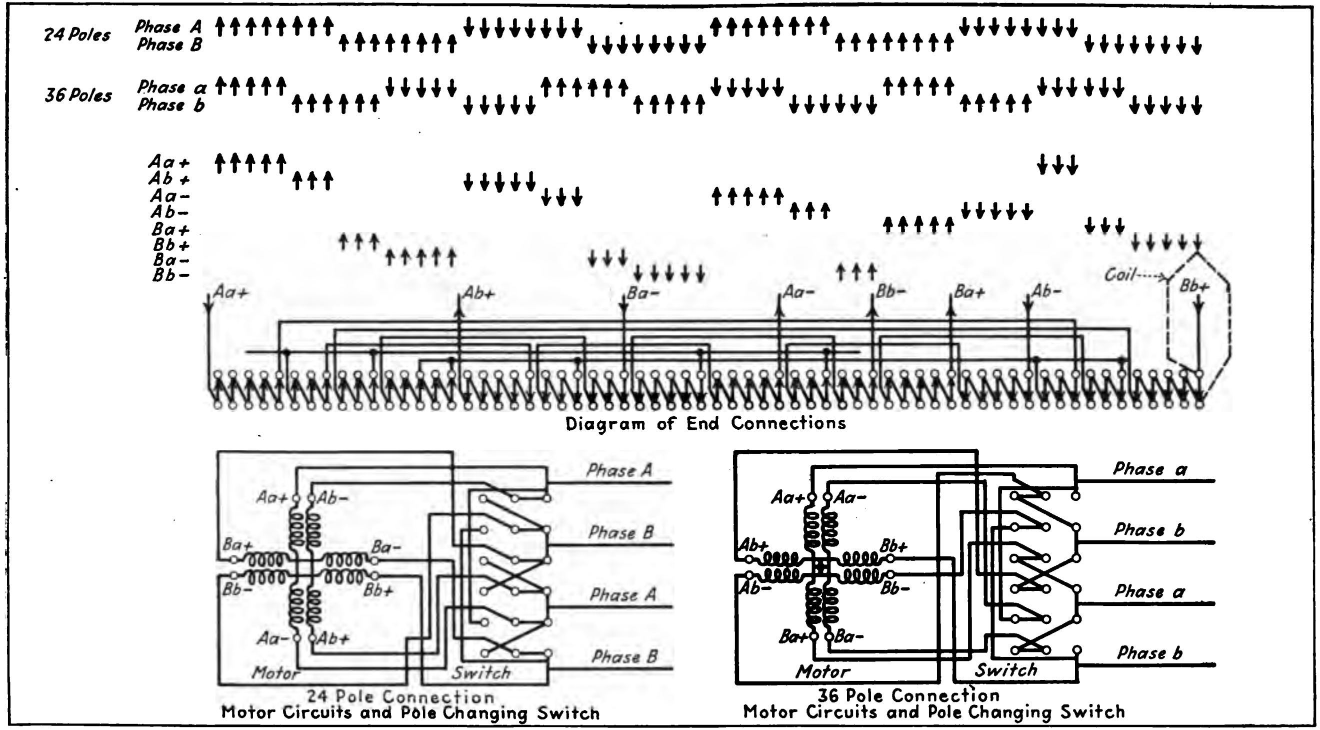


FIG. 26.—Diagram of 24-36 Pole Motor Winding of U. S. S. *New Mexico* and U. S. S. *California* Showing Principle of Design, Winding Connections and Pole Changing Switch

that external resistance can be inserted. If the motors had been arranged for reversal on the 36-pole combination, the arrangement of the rotor winding would have been reversed. The change that takes place in the rotor winding is automatic and is within the winding itself.

Fig. 27 represents one-sixth of one phase of the rotor winding.

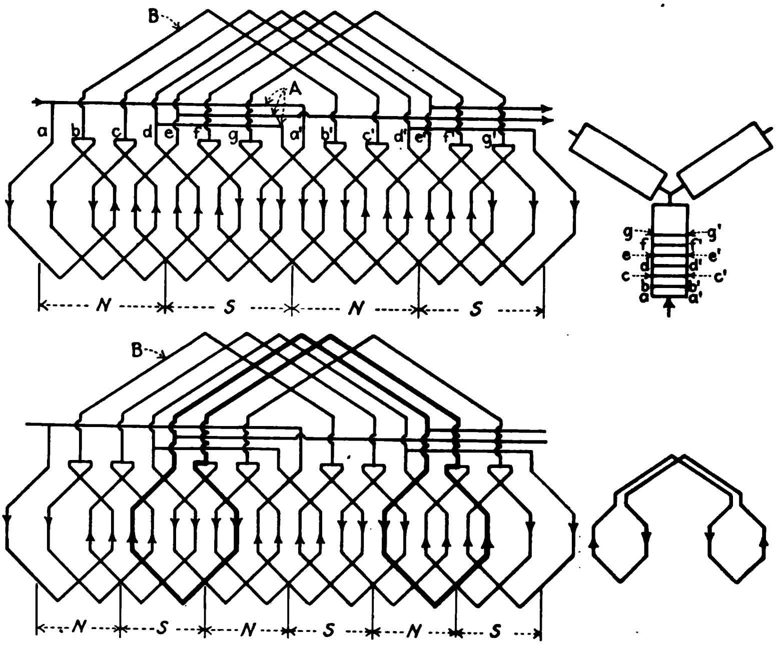
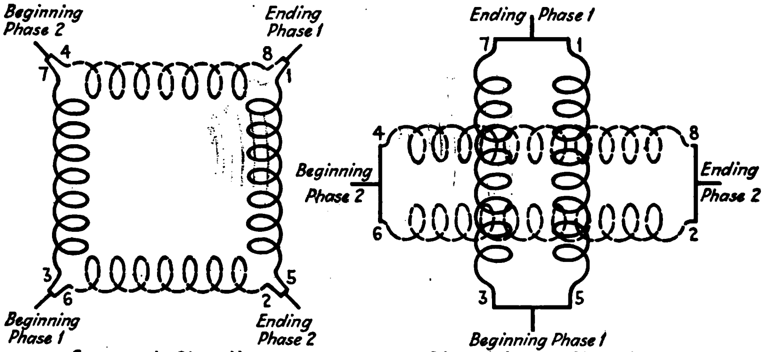


Fig. 27.—Special Arrangement of Rotor with a Definite Winding to meet Conditions of Pole Changing adopted on U. S. S. *Tennessee*

The upper group of conductors shows the direction of the E. M. F. in the coils when the stator is arranged for 24 poles and the lower group shows the direction when the stator is arranged for 36 poles.

The coils are arranged in groups and, by means of group connectors (*A*), are connected for 24 poles in two parallel circuits for each phase as shown by the diagram at the top of the figure; the phases are then connected in star as shown in the small diagram to the right of the conductors. Under this condition the machine will operate in the usual manner for induction motors with a definite winding.

Since each phase consists of two parallel circuits, it follows that corresponding points in the two circuits will have the same potential. In the arrangement shown, these points are located at *a* and a^1, *b* and b^1, *c* and c^1, etc. These points of equal potential are joined together by special connectors (*B*). When the motor is operated on 24 poles, these connectors will carry no current since they have equal potential. But when the motor is operated on 36 poles, the conditions change, as shown by the diagram at the bottom of the figure, so that in the space occupied by 4 poles in the upper diagram we now have six poles in the lower diagram. By tracing out the direction of the E. M. F. in the coils as indicated by the arrows, it will be seen that the special conductors (*B*) now serve as short circuits connecting pairs of coils in series. Such a pair of coils is indicated by heavy lines in the lower diagram and separately in the small diagram to the right at the bottom of the figure. The entire rotor winding now consists of a number of coils short circuited in pairs and will therefore have characteristics similar to those of an ordinary squirrel cage motor. Due to the distance between the two coils in a pair, a slight magnetic balancing action is obtained similar to that on a squirrel cage motor.



Square 1-Circuit
High Voltage
4242 Volts

Diametrical 2-Circuits
Low Voltage
3000 Volts

FIG. 28.—The Square Circuit High Voltage and the Diametrical Circuit Low Voltage Connections on Each Turbo Generator on the U. S. S. *New Mexico* which is Obtained by Switching

There is another special condition that arises in connection with electric propulsion. At the low speeds of the ship one generator will be used to drive four motors and at the high speeds each generator will drive only two motors. Therefore, the resistance and impedance of the motor circuit will be twice as great at high speed as at low speed. It is possible to arrange the generator windings to take advantage of the greater current path offered by the four-motor condition and this has been done on the *New Mexico*. When driving with four motors, the generator winding is arranged to give two parallel circuits for each phase; when driving with two motors, the generator windings are arranged in the form of a square.

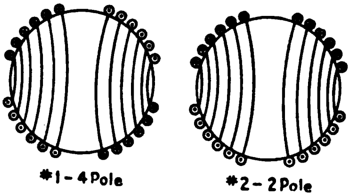


FIG. 29.—Method of Arranging the Generator Field Winding to Provide for Two Different Polar Arrangements

The arrangement of the generator windings is shown in Fig. 28. It will be noted that the impedance of the generator winding is changed in the ratio of two to one when changing from the high voltage to the low voltage condition, so that it is changed in the same proportion as the motor circuit when it changes from two motors to four motors. Each end connection of the parts of the generator winding, numbered 1, 2, 3, etc., is taken to an 8-pole, double-throw switch; one throw of the switch gives the parallel connection on the generator and the other throw gives the square connection. This switch is also used as a disconnecting switch by placing it in the neutral position with both "throws" open. If the turbine speed and flux density are the same for both arrangements of the generator winding, the voltages will be in the proportion of 1 to $\sqrt{2}$ for the parallel and square connections, so that if the low voltage is 3,000 the high voltage will be 4,242.

It is possible to arrange the generator for pole changing instead of the motor and thus get two speed reductions between generator and motor. The method of arranging a generator field winding so that it will be capable of giving two different polar arrangements is shown in Fig. 29. The winding is normally a 4-pole one; by means of switching, the direction of current flow is changed in the right half of the coil and the field becomes 2-pole as shown. This arrangement will not generally be used because the rotor end windings are complicated and increase the length of the rotor to such an extent that, in the case of a large turbo alternator, the critical speed will be below the maximum speed desired.

CHAPTER V

Special Characteristics of Turbines and Governors for Electric Propulsion

TURBINES and their governors for electric drive differ slightly both from land turbines and from high speed marine geared turbines. Land turbines run at a constant speed and are at all times under the control of a governor set for a constant speed; marine turbines are controlled entirely by a throttle, except that the maximum speed is usually limited either by a maximum speed governor or by an emergency governor.

A turbine for electric propulsion should at all times be under the control of a governor since the load is thrown off and on suddenly and it would not be possible to get satisfactory operation using a throttle; but, since an infinite number of speeds of the turbine are required, it is necessary that the governor should be capable of very rapid adjustment from one speed to another. Also, since the control gear will usually not be in the same compartment as the turbine, it will be necessary for the governor adjustments to be made by distant control.

Two methods of accomplishing this have been used on naval vessels. One method is entirely mechanical and direct. By means of rods and bell-cranks, the motion of a hand operated lever in the control room is transmitted to the fulcrum of the governor. Moving the governor fulcrum will change the speed at which the fly-ball weights balance the springs and thus change the speed of the turbine. The other method balances the centrifugal force of the weights by an oil pressure; the control of the oil pressure is in the control room and any variation will change the speed at which the balance is maintained. Both methods will be described in detail in succeeding chapters. Mr. Ljungstrom uses a constant speed governor in his installations, and varies the speed of the motors by an external resistance, but this is unsuitable for a war vessel and it is very doubtful if it is really satisfactory for a merchant vessel, as a great deal of fuel will be wasted if it becomes necessary to do much steaming at reduced speeds.

It is necessary that the governor should function properly at all speeds of the turbine from about one-fourth speed to full speed. This is a very stringent requirement and necessitates great care in details of design. The ordinary constant speed governor would not be at all satisfactory for low speeds as its directive force would be so small as to cause serious hunting of the turbine. The governing at one-quarter speed must be practically as good as at full speed since the ship may use that speed for considerable periods of time when maneuvering, and also because it is essential to have good control at that speed to get good results in backing. If the governor hunts badly, the probabilities are that the turbine will be stalled during backing, or else it will be difficult to get the motor "into step" with the generator. In order to get good governing at the low speeds, the change in the angle of successive cams must be very gradual, if the control is by cam-operated valves; if a throttling governor is used, the valve and seat must be designed to restrict the steam flow greatly without actually seating the valve. Too much emphasis cannot be laid on the design of the governor, as the operation of the plant will never be satisfactory without a good governor.

The governor does not appear to be affected in its action by the rolling and pitching of the ship, as perfectly satisfactory governing is obtained in the roughest weather. However, parts of the governor, such as weights, may be displaced by this motion unless they are positively secured. The ordinary method of holding the weights on their knife edges by spring tension alone is not satisfactory, as has been demonstrated by experience.

It has been found by experience that the periodic swing of a governor in a seaway tends to start up rapid vibrations in the hydraulic relay, operated by the governor, and it has been necessary to fit a dash pot on the transmission arm; this entirely does away with the trouble. The dash pot should be fitted with a needle valve so that it can readily be adjusted.

In addition to having perfect governor control it must also be possible to limit the maximum amount of steam flow. The reason for this is the effect on the generator produced by turning the ship, which has been described in the previous chapter. This practically amounts to a combination of governor and throttle control. Since the required position of this steam limit will vary for each speed of the ship, it must be adjustable, either automatically or by hand. In practice, it should be set to give the minimum flow consistent with good governing at the speed desired. If hand adjustment is used, it will have to be distant control, as the lever for controlling the limiting mechanism will be in the main control room.

The means for transmitting motion from the control room to the governor may be mechanical, electric, hydraulic, steam, etc., but the mechanism for actually limiting the motion of the governor or hydraulic relay must take the form of a positive stop. Means must also be provided, by springs or otherwise, for allowing the actual governor movements to continue, although without doing any work, after the stop has been reached.

Actual details of governors and steam limits will be discussed in later chapters.

On marine turbines it is customary to utilize the surplus auxiliary exhaust steam in the main turbines. For purposes of economy this is also desirable in the case of turbines for electric propulsion. If this is done, the auxiliary exhaust must automatically be shut off the turbine and directed into the main condenser when the load is thrown off the turbine. It thus becomes necessary to have a valve in the auxiliary exhaust line which is operated by the governor and which is really the first admission valve of the turbine.

In addition to the main governor it is necessary for safety to fit an emergency governor which will shut steam off the turbine in case it over-speeds. As it is necessary that all sources of steam supply be closed, this governor must operate an automatic valve in the auxiliary exhaust line to the turbine as well as the main throttle.

Details of steam and exhaust connections to turbines will be discussed in later chapters.

CHAPTER VI

Ventilation, Heaters, Fire Extinguishers

VENTILATION is very important and must be carefully worked out for any electrically propelled ship, if the maximum length of life is to be obtained for motor and generator insulation. For merchant ships this offers no difficulty whatever, as a simple arrangement of ventilating ducts to and from the compartment or machine to be ventilated can very readily be worked out. For a war vessel it is desirable that the size of the opening in the decks be reduced to a minimum. Large volumes of air are required for cooling electrical apparatus, and it is not feasible to supply this air at high velocity; therefore, it will require unusually large deck openings unless the air is utilized for other purposes after it has been used for cooling, so that the total air used is no greater than would be required if the electrical apparatus were not used.

The simplest method is to take the exhaust air from the generators and motors (or at least as much as possible of it) and use this for supplying the forced draft blowers in the firerooms. In this way the deck openings are not made any larger than they would have to be to supply the firerooms.

Another method of ventilating is to cool the air by means of circulating water and use the same air continuously. No installations of this type are in use on board ship at present, but this system will be used in the future in capital ships of the Navy.

Fig. 30 shows the plan of a type of cooler that has been proposed for the generators of battleships *49-54*. This is called the radiator type of cooler since the arrangement is somewhat similar to the radiators of automobiles. It consists of sixteen sections of tubes arranged as shown. Each tube has a spiral fin soldered to its outer periphery to increase the transfer of heat. Circulating water passes through the tubes; the air passes across the tubes. The various sections of the cooler are practically

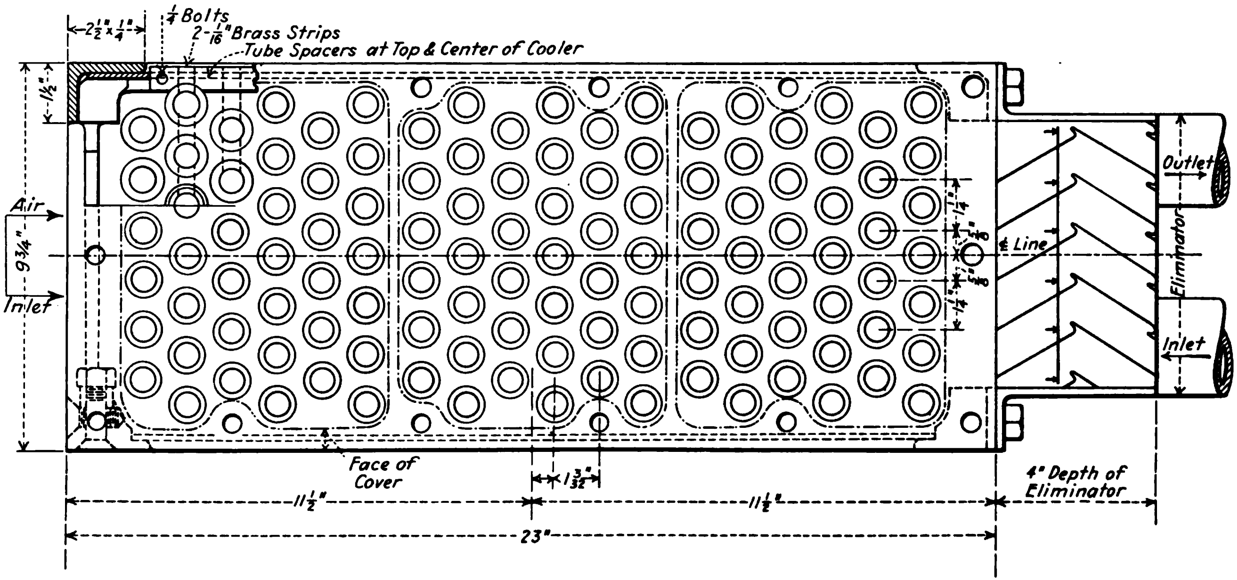


FIG. 30.—Type of Coolers Proposed for the Generators of New Battleships Nos. 49 to 54

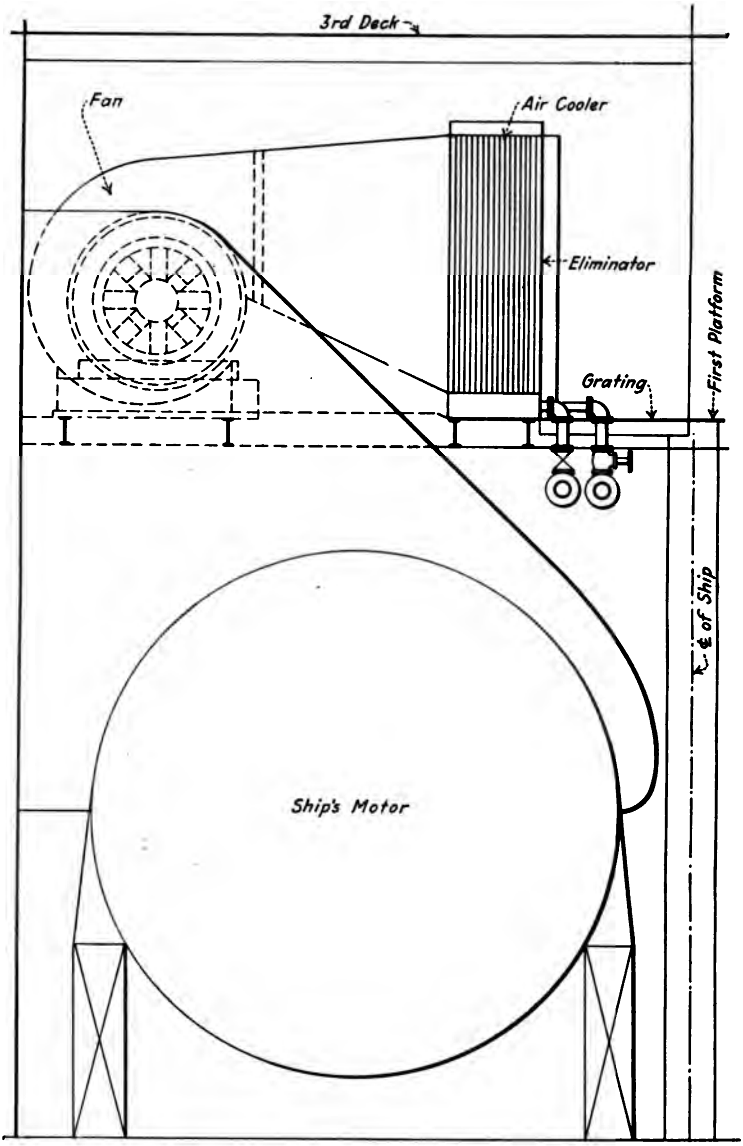


FIG. 31.—Type of Cooler Used for Main Motors

integral with the generator and are supported by the generator foundations. The whole is enclosed in a sheet iron lagging, so that the only change produced in the external appearance of the generator by the addition of the cooler is to give it a greater diameter. An eliminator, consisting of a set of baffle plates and drain, is provided so that the failure of a tube will not send salt water into the generator.

The same type of cooler sections is used for the main motors but the cooler is external to the motor. The general arrangement is shown in Fig. 31.

In arranging air ducts to or from a machine there should always be an offset in the duct, fitted with a coaming, so that spray or water coming down the duct will be trapped and can be drained off without getting into the machinery.

The various units of the propelling machinery should be as nearly self-contained as possible and, therefore, the generators should be provided with their own ventilating fans. This arrangement also makes for economy of weight and space. The motors will have to be provided with exhaust fans but the main motors themselves should be designed to give as much fan action as possible, as it is desirable not to have the motors dependent on auxiliaries, if it can be avoided.

When a generator or motor is not in use it should be closed up to keep dirt and moisture from entering it. As it is not possible to close the openings up absolutely airtight, there will always be a certain amount of moisture present and this will be condensed and deposited on the coils due to the fact that the temperature of the air inside the machine will usually be different from that of the compartment. The temperature of the compartment will undergo periodic changes, as will also the temperature of the air inside the motor or generator, but the two cycles will never coincide, since there will always be a certain amount of time lag between the two cycles. To prevent this, all generators and motors should be provided with heaters which should be kept turned on when the machine is not in operation.

Steam heating coils can be satisfactorily fitted in a generator. They should be located in the base of the generator. All joints should be external to the generator to prevent the possibility of leaks getting into the generator.

Electric heaters can be fitted into the base of a motor; it will usually not be feasible to fit steam coils, owing to the design of the motor and also to its distance from a supply of steam. The heaters should be located as far as possible from the motor windings to avoid damage to them in case of a short circuit in the heater.

Motor compartments should be provided with radiators for heating them, if they are separated from the remainder of the machinery.

Provision must be made for by-passing part of the air from the exhaust of both generators and motors back to the compartment from which they draw air unless the ventilating air is supplied by totally enclosed ducts. This will prevent these compartments from becoming unduly cold in cold weather. It will also prevent the motor or generator from becoming cooler than the compartment in which it is located; if this should happen, a rapid condensation of moisture would take place in the machine as soon as it was shut down.

As the most serious damage that can occur in a generator is from a fire caused by a short-circuit, each generator should be fitted with a steam fire extinguisher. To make this effective the supply of air to and the discharge of air from the generator must be arranged so that they can be shut off at the same time that steam is turned on. A fire extinguisher of this type will probably prevent serious damage to the insulation and ought surely to prevent any damage to the laminations.

The main factor in putting out the fire is the element of time; if the fire has been burning for any appreciable time, considerable damage will be done. As soon as the fire is discovered, excitation should be removed from the machine and steam shut off the turbine; next, the inlet and outlet dampers to the air ducts should be closed; then steam should be turned on the generator extinguisher.

In order that the steam supply may not damage the generator insulation by leakage, it should always be fitted with a valve and also a cock; the latter should be so arranged that any leakage past it, when it is shut off, will be directed into the engine room and not into the generator.

The volume of steam which will be required may be determined from the cubic feet of air space in the generator, allowing one pound of steam per minute for each 2.5 cubic feet of enclosed space, if the leakage past the air dampers does not exceed 10 percent. If the leakage is greater, the amount of steam should be approximately one pound of steam per minute for each 20 cubic feet of leakage air. The leakage air should in no case exceed 20 percent.

A fire should be extinguished practically instantaneously after the application of steam, but it will be found necessary to leave the steam on for about half a minute to prevent re-ignition.

The best location of steam inlets is on the inner shield, so that the jets will impinge directly on the end windings and be carried through the generator by the action of the fan.

CHAPTER VII

Switchboards, Interlocks and Controls

IN any control arrangement the following considerations should govern:

(1) No switches should be provided that are not really useful. The possibilities of providing different combinations with electrical apparatus are so great that there is always a temptation to overdo it.

(2) All instruments, levers, etc., used in the operation and control of the machinery should be grouped together where they can be handled (or at least supervised) by one man.

(3) Sufficient interlocks should be provided to prevent the possibility of damage due to a mistake in operation.

Switchboards and all parts mounted on them should be of rigid construction. This is particularly necessary for war vessels which are subject to severe shocks. There is always a tendency in this sort of construction to determine the size of a part by the stress it has to undergo in normal operation. This is not a safe rule; no part on a switchboard should be of flimsy construction but should be rugged enough to stand severe and repeated shocks and vibrations.

Switchboard structures should always be covered over on top with inclined sheet metal covers to deflect water from exposed connections inside the structure.

Unless switches are so large as to make it impracticable, they should always be arranged for hand operation as a normal condition. In cases where this is not practicable, electro pneumatic operation will probably be the most satisfactory. In any case, switches should always be so arranged that they can be operated by hand in an emergency. Where switches are held closed by power, they should always be so designed that they will not open automatically in case of failure of the supply of power.

In general, where either air or electricity is used in the normal process of operation, the source of supply should be duplicated at least once.

All switches should be so designed that they will not open under shock. Plain knife blade switches should be secured, when closed, by latches.

No porcelain or other fragile material should be used as insulators on switches. Some of the various forms of bakelite have been found to be best for this purpose.

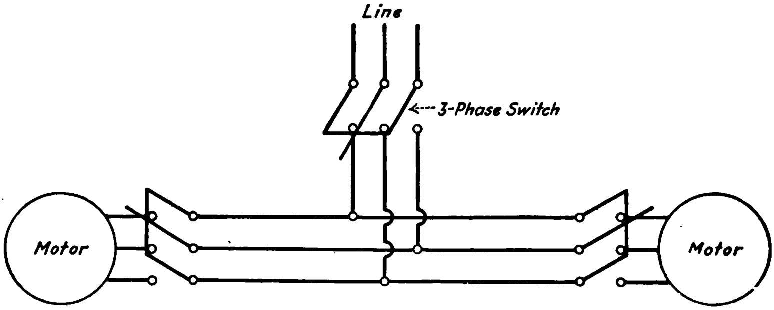


FIG. 32

All resistances or grids used in the circuits or on the switchboard should be shock proof. In general, these will be of very light sections; in that case, cast iron will not be a satisfactory material for this purpose.

The switches should be so arranged that normally they will not be operated when the circuit is alive—that is, the field of the generator should always be opened first. This will greatly reduce the strain on the insulation of both generators and motors and increase the life of it. The operating switches should, however, be of sufficient capacity to open full load current in an emergency. One reason for this is that the armature circuits of motors and generators are highly inductive and there is very considerable "electrical momentum" in these circuits; this can best be explained by a reference to Fig. 32. It was found by experiment that, after opening the switch marked "3 phase switch," a very high voltage persisted in the motor circuit for several seconds and in order to "kill" the circuit it was necessary to open one of the motor switches. It is, therefore, necessary that all switches be able to handle large current, even if the field is removed from the main generator before moving any switches.

The field switch should be of the air break type, designed to open double the normal full exciting current without excessive arcing or burning of contacts. The field switch and the rheostat for controlling the voltage of the exciting circuit should be operated by the same lever and the connections should be arranged so that the field switch will be opened when the exciting voltage is at its minimum value. Auxiliary contacts must be provided on the field switch so that it will short circuit the main field through a resistance before the switch is opened. It is very important that this resistance should be absolutely shock proof, as damage to the field would be sure to result, if this resistance should become open circuited by breakage; for this reason, cast iron grids should not be used for this purpose.

Where the size of the installation permits, the main operating switches, such as reversing and pole changing switches, should be of the oil break type in preference to the air break type, as the operation is much quieter.

No fuse or automatic circuit breakers should be provided in the power circuit on account of the unreliability of this class of apparatus and also because, in the short leads of circuits on board ship, these protective devices do not really give much protection. For example, a short circuit in the generator is more probable than at any other point in the circuit and against this a circuit breaker would give no protection.

A protective device, called a balanced relay, has been developed which really gives protection without having the objectionable features of circuit breakers. It consists of coils energized by current from the different phases of the circuit. As long as the conditions are normal these coils will be in balance but anything that disturbs the equality of current in the phases (such as a short circuit in generator, motors or transmission circuit) will upset the balance of the coils. The coils are so arranged that when unbalance takes place they automatically trip out the main field switch, thus taking power off the circuit. This protective device has given satisfactory operation.

As to the number of switches to be provided, these should be kept to the minimum consistent with the necessary operations to be performed. Simplicity should be the guide in this matter. There are certain switches that should be provided in all installations; for example, it should always be possible to cut out an individual motor without affecting the operation of the others; also, it should always be possible to propel the ship, using all shafts, with one generator and, therefore, the two sides of the ship should be provided with a switch tying them together and, also, with switches for cutting out any generator.

The number of interlocks should also be kept down as much as possible but enough should be provided to make it impossible to do harm to the machinery through errors of operation. Interlocks should be mechanical when this is feasible. In the case of power operated switches which have no positive mechanical connection to the control levers, the latter should be equipped with locks so that they can not be moved to full position until the switch has responded to the partial movement. All interlocks should be operated by the final movement of the lever—that is to say, the interlock should not be released till the full travel of the lever has been completed.

Switchboards should be equipped with signal lights which will show whether or not any important operation has been carried out in response to the movement of the proper lever. The most important of these lights should be fitted two in parallel so that, if one burns out, no mistake will be made in reading the signal. Signal lights should be fitted only for important things, as too many of them would tend to confuse the operator.

Instruments for use on board ship should be carefully balanced so as to be unaffected by the roll and pitch of the ship. They should also be rugged enough to be shock proof. As most electrical instruments are designed for operation on circuits having constant frequency and constant voltage, they will usually not be suitable for an electric propulsion circuit. For example, watthour meters of commercial design are correct for only one condition on board ship; so far it has been impossible to supply a satisfactory instrument of this type for ship propulsion work and it has been necessary to calibrate these instruments for one condition of voltage and frequency and provide curves giving the error at other frequencies and voltages. The following list of instruments will give a general idea as to the number required for an electric propulsion switchboard:

One alternating current voltmeter for each generator (arranged to read all phases).

One alternating current ammeter for each generator (arranged to read all phases).

One indicating wattmeter for each generator.

One watt-hour meter for each motor.

One power factor meter for each generator.

One frequency meter for each generator (this should be graduated in revolutions per minute and should have one scale for the generator revolutions and scales for motor revolutions—both high speed and low speed connections, if two are used).

One instrument for each generator for indicating when generator and motors are "in step." (Stability meter.)

One speed meter for each generator (this must be independent of the main propulsion circuit so that it will always give an "indication" when the generator is running).

One ammeter for each motor.

One direct current voltmeter for each generator field.

One direct current ammeter for each generator field.

Temperature indicators for motors and generators.

Necessary gages, clocks, counters, etc.

The ammeters provided for the generators should have scales with a very large range, so that they will not "go off the scale" when the motors are reversed; this will make the scales much greater than would be necessary for normal use but it is necessary for proper operating that the operator should know the instant that the current begins to fall in the circuit.

An instrument which will show when an induction motor is in step with its generator is a new one, as there has been no necessity for such an instrument in the past. Mr. Alexanderson, of the General Electric Company, has designed such an instrument. One of them is installed on the *New Mexico* and is giving good satisfaction. It is called a "stability meter" because it not only indicates when the motor and generator are in step but also indicates the factor of safety, or amount by which the voltage can be lowered before the motor will "fall out of step." It consists of an ammeter element and a voltmeter element working together on the same pointer and so arranged that their torques are opposed; the voltmeter element is equipped with a reactor instead of the usual resistor so that its indications will be inversely proportional to the frequency and directly proportional to the voltage. Therefore the reading of the meter will be volts divided by amperes and frequency or impedance per cycle. The characteristics of the generators and motors are such that the load impedance per cycle at which the generator gives its maximum output is always the same regardless of the speed or field excitation; the maximum output of the generator, which is the breakdown load of the electrical equipment, thus corresponds to an indication of the instrument which is always at the same point on the scale. The scale is divided into ten parts, one-half indicating when the motor and generator are "in step" and the other half indicating when they are "out of step." A glance at this instrument during reversal will show just when the motors have come "into step." During a turn, the instrument will show whether or not the motors are approaching too close to the "out of step" part of the scale and will enable the operator to increase the field excitation of the generator in time to prevent the motors from "falling out of step."

CHAPTER VIII

Wire, Cable, Insulators and Insulation

THE cable used and the method of installing it are of the greatest importance in connection with any electric drive installation. The cable installation should be practically permanent, like the main steam pipe of the ship.

If all the electric machinery is contained in the same compartment, then the cable "runs" become very simple and most of the problems in connection with it disappear entirely. In this case, a good rubber covered cable, mounted on non-fragile insulators (such as bakelite), will probably be entirely satisfactory and will certainly be the cheapest. The cable should always be given mechanical protection and also covered over to keep water from dripping on it.

It is seldom that such a simple case as that described above is met with in practice. Even in merchant ship installations it will usually be desirable to place the motors some distance from the generators and it will be necessary to pierce bulkheads and run through wiring passages. This condition will always obtain on naval vessels. This immediately brings up two conditions that must be met; the first condition is that the cable insulation, which normally is in a warm compartment (perhaps for several years), must remain absolutely watertight, if the compartment becomes flooded; the second condition which must be overcome is the inductive effect of alternating current cables when surrounded by closed magnetic circuits, such as a bulkhead through which cables must pass.

Many cable arrangements have been proposed to meet these conditions but it is believed that the recommendation submitted to the United States Navy Department by the "Standards Committee (subcommittee on wires and cables) of the American Institute of Electrical Engineers" is the most suitable in every way for an installation on board ship. The specifications for this cable and the method of installing it are as follows:

(*a*) Alternating current cable may be either single or multi-conductor.

(*b*) Large alternating current cables should be provided with rope core to reduce skin effect.

(*c*) The shape of cables should be round.

(*d*) The wires of cables should be tinned. (Tinning is required mainly because it facilitates making good brazed joints at cable terminals.)

(*e*) Impregnated jute should be used as a filler for multi-conductor cables.

(*f*) A separator of treated paper or cloth tape should be used between the cable and the insulation.

(*g*) The insulation should be black varnished cambric of the highest standard; this should be covered by a jacket of reinforced rubber. Between the layers of varnished cambric there should be a suitable mineral base compound which will not dry out, oxidize or combine with the film of varnish on the varnished cambric or the reinforced rubber.

(*h*) The insulation should be protected by a sheath of pure lead in the case of multi-conductor cables and by a non-magnetic armor in the case of single-conductor cables. The armor should consist of two bronze tapes laid up so that the outer layer overlaps the space between turns of the inner layer. The space between turns should be 10 percent of the width of the tape. The tapes should be protected against unfurling at the cable ends. There should be a covering over the armor of cotton tape impregnated with a flame proof compound.

(*i*) Single conductor cables should be mounted on insulators which will not break under the severest shock. The bronze armor should be solidly grounded at the middle point only and the remainder of the armor should be kept clear of grounds. Multi-conductor cables should be mounted on approved supports and the lead sheath should be grounded at several points.

(*j*) All varnished cambric cable terminals should be sealed against the admission of moisture.

(*k*) All alternating current cables should be given a test between conductors and ground of 20,000 volts applied for one minute.

(*l*) In all cases, cable supports must be arranged to prevent chafing the cables at the point of support.

(*m*) The supports of alternating current cables should be not more than 2 feet apart. These supports should be designed to give sufficient strength to take care of all short circuit conditions.

(*n*) When single-conductor cable is used for alternating current, the following precautions must be observed in installing it:

(1) Closed magnetic circuits around individual cables must be avoided.

(2) No magnetic material must be allowed between cables of a group.

(3) In passing through bulkheads, the cables must be so grouped that the inductive effects of a group are practically eliminated.

(4) Cables must be spaced as closely as is consistent with proper supports and good ventilation.

(5) The distance of the centers of cables from bulkhead stiffeners should generally be not less than 3 inches and from parallel bulkheads the distance should be not less than 4½ inches.

In selecting the insulation for the cable proposed, the fine insulating qualities and great length of life of varnished cambric have been recognized. In order entirely to preserve these qualities, however, it is necessary to protect this insulation from exposure to air or moisture and for this purpose the reinforced rubber jacket is put on. The specific insulating and dielectric constants of this jacket are not very high, so it is necessary to combine it with the varnished cambric to get the desired amount of insulation. By placing the reinforced rubber outside of a thickness of the varnished cambric, the potential gradient is reduced so that the lower dielectric strength of the reinforced rubber does not materially lower the total dielectric strength of the cable. The rubber jacket is impervious to moisture (even after long exposure to hot dry air) and has great mechanical strength, so that the combination of the two is ideal.

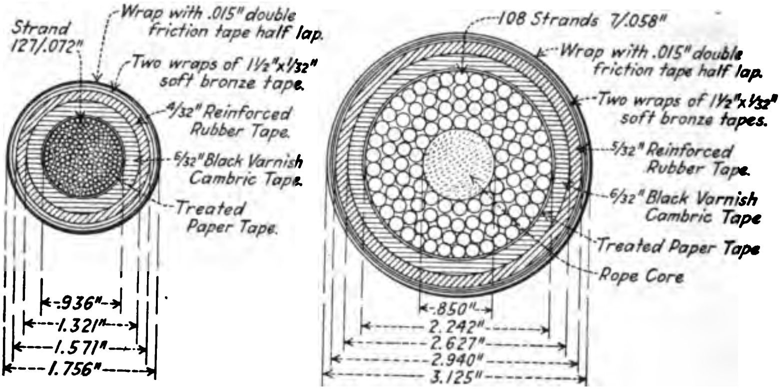


FIG. 33.—Cross Sections of Two Sizes of Single Conductor Cable used on U. S. S. *California*

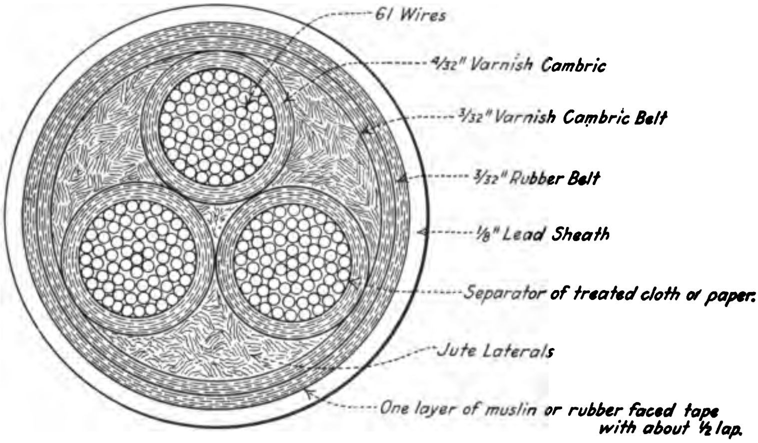


FIG. 34.—Cross Section of 3-Conductor Cable used on U. S. S. *Tennessee*

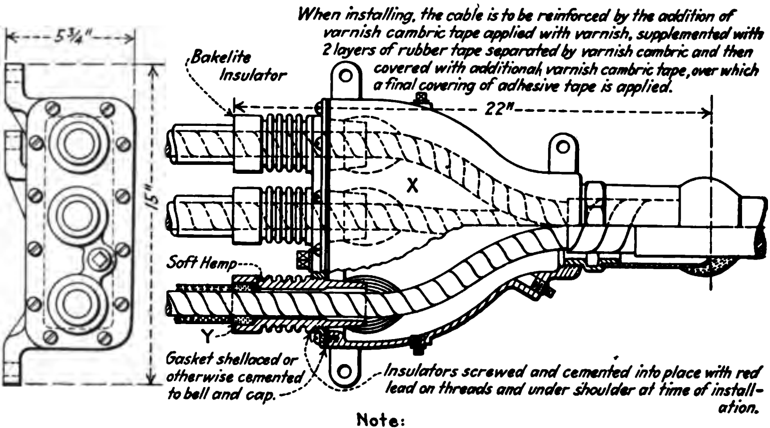
Reinforced rubber is made by calendering a rubber compound into one or both sides of a cotton fabric previously dried and waterproofed. Under this process the fabric obtains a thorough filling of rubber which, during calendering, becomes partially vulcanized. The prepared fabric is then cut into tapes and applied over the varnished cambric insulation in the usual manner, except that all contact surfaces and interstices are filled with rubber cement. The insulated cable is then dried under moderate heat and the rubber is further vulcanized. This last process reduces the rubber covering to a homogeneous structure, the various layers of rubber tape being united into a solid jacket by the vulcanizing process.

This gives a very elastic and tough covering for the cable—one that is also permanently waterproof and will stand continuous high temperatures and vibrations. The outer surface of this jacket may crack after exposure to heat but the crack will extend only through the first thin layer of rubber; as soon as the cotton reinforcing is reached, the crack stops and the rest of the jacket will be solid.

In Fig. 33 there are shown cross sections of the two sizes of single-conductor cable used on the *California.* The small cable is used for the connections to the motors and the large cable for the connections to the generators. In Fig. 34 is shown a cross section of the three-conductor cable used on the *Tennessee.*

The ends of the cables must be sealed by pot heads both to prevent moisture from entering at that point and also to prevent gradual "eating away" of the insulation at the point where it is cut away to make the terminal connection. This phenomenon always accompanies any abrupt change in thickness of insulation which produces sharp corners. In Fig. 35 is shown a pot head for a three-conductor cable of the *Tennessee;* in Fig. 36 is shown the same thing for a single-conductor cable of the *California.* An examination of these figures will show the extreme care that has been taken in the design of the details of these pot heads to guard against the possibility of having moisture get in.

In regard to the relative advantages of the use of single-conductor or multi-conductor cable, there are advantages for both. The single-conductor cable is much simpler to connect to the generator or switchboard. A comparison of Figs. 35 and 36 will show the three-conductor pot head to be much more complicated. The use of the three-conductor cable makes it imperative to use bus bars at both generator and switchboard for the terminals, as it will be necessary to have several multi-conductor cables in parallel for each phase. Again, the insulation between phases is not quite so good when three conductors are combined in one cable as when the cables are independent of each other. On the other hand, the multi-conductor cable is absolutely neutral and can be run through steel bulkheads, stiffeners, etc., without requiring any special arrangements; it can also use a continuous lead sheath, as there is no danger from circulating currents in the sheath. This gives better protection to the cable than does the bronze armor. Since there is no danger from circulating currents, the lead sheath may be grounded at numerous points and, therefore, the supports for this cable need have only mechanical strength and no insulating properties; since the single-conductor cable is grounded only at its middle point, there is greater danger of this one connection being broken, thus allowing static charges to accumulate on the cable.



When installing, the cable is to be reinforced by the addition of varnish cambric tape applied with varnish, supplemented with 2 layers of rubber tape separated by varnish cambric and then covered with additional varnish cambric tape, over which a final covering of adhesive tape is applied.

Gasket shellaced or otherwise cemented to bell and cap.

Insulators screwed and cemented into place with red lead on threads and under shoulder at time of installation.

Note:

These terminals may be used in upright, horizontal or inverted position. No additional tape needed at "X" when installed in upright position. When terminal is used in horizontal or inverted position, additional tape should be applied around and also between the insulated single conductor and the inner end of the insulator (as shown at "X") to act as a plug to prevent the egress of the filling compound through the bore of the insulator.

If cable insulation is paper, the insulation should be removed and varnish cambric or rubber tape applied or commercial braided leads joined to cable, joint to be made inside of terminal bell.

The recess in top of insulators, at "Y", is provided for hard compound to hold in place the insulated lead extending out of the insulator, and to prevent the ingress of dust, dirt, etc.

As the insulated lead may be smaller in diameter than the bore of the insulator, hemp or other soft packing should be wrapped around the conductor at the bottom of recess to prevent compound from filling space below recess.

FIG. 35.—Pot Head for 3-Conductor Cable used on U. S. S. *Tennessee*

In connection with the use of single-conductor cable, one of the specifications is a requirement that there must be no closed magnetic circuits around the individual cables. This necessitates cutting holes in bulkheads sufficiently large to allow the whole group of cables to pass through. The hole is closed by a bronze plate secured to the bulkhead and the individual cables passing through the plate are made watertight by means of stuffing boxes. Since the armor of the cable must not be grounded at this point, the stuffing box must be provided with packing which has some insulating properties. The insulation required is not very great, as its only purpose is to prevent the possibility of circulating currents in the armor. The same requirement applies to other insulators used for supporting this cable. In Fig. 37 are shown the bulkhead plate and the stuffing box used on the *California.*

The greatest care must be exercised in running cable and making connections at the switchboard to see that the principle of "no magnetic circuits around single wires or cables" is carried out. In the switchboard, in particular, these circuits may be established and they will give trouble, due to overheating the metal forming the circuit, until the trouble has been remedied.

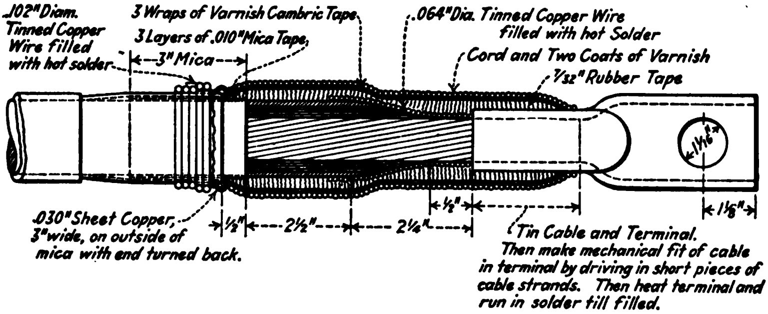


FIG. 36.—Pot Head for Single Conductor Cable used on U. S. S. *California*

Exposed bare copper used for making connections to generator, motor or switchboard should always be protected from water dripping on it. If these connections are made in a compartment which is normally filled with air containing a great deal of steam or moisture, these connections should be covered over and then supplied with dry warm air under pressure so as to make sure that the connections will always be free from moisture. This can best be accomplished by running a small pipe to supply air from the generator exhaust duct; this air will always be warm and dry and will be under sufficient pressure to insure a flow of air. In addition, all such connections should be made waterproof by successive applications of tape, each application being covered by several coats of varnish, each of which is dried before the next is applied.

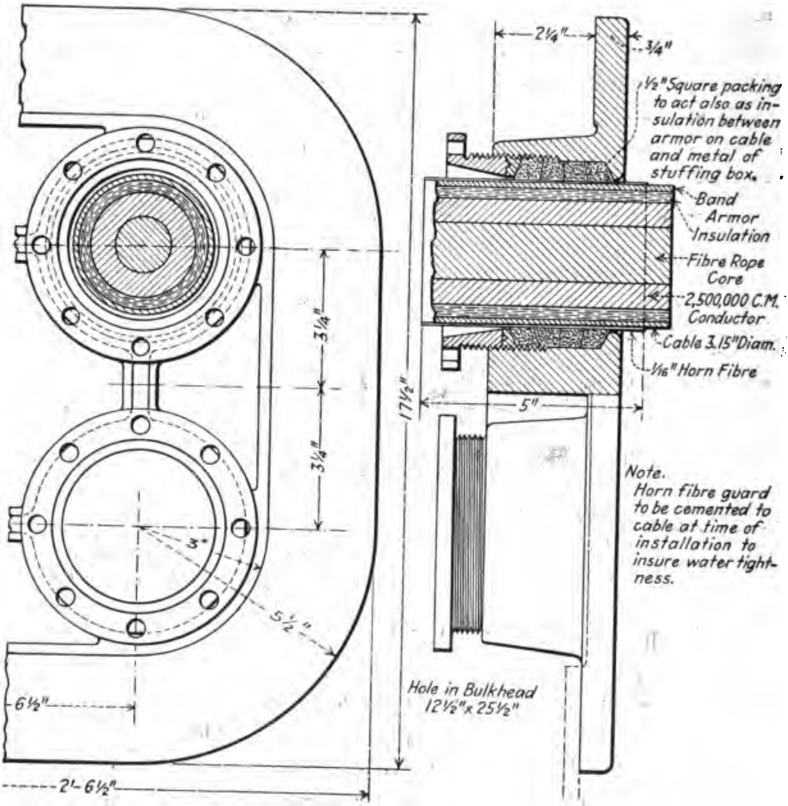


FIG. 37.—Type of Stuffing Box used on U. S. S. *California* where Main Generator Leads Pass Through Bulkheads.

After the cable installation is complete in the ship, it should be tested for one minute by 15,000 volts. During this test, all switch connections, etc., should be made in such a manner that all insulation between the circuits and ground will be tested. In selecting this test voltage, and also that for the cable itself, it is assumed that the maximum voltage used at any time will not exceed 5,000 volts.

Cable used for direct current which is used in connection with propulsion should conform to the same specifications in regard to insulation as alternating current cable. With this cable the lead sheath may be omitted and some form of fireproof braid substituted to give mechanical protection.

Insulators which are to be used on board ship should be made of non-fragile material; in the case of war vessels, it must be proof against the severest shock and also against continuous and severe vibrations. These conditions eliminate the use of any form of porcelain; even on merchant vessels, it will be found that this material is not satisfactory, as insulators made of it will crack or break off in the course of time. The material that has proved most satisfactory to date is bakelite; this is a compound which is made up in various proportions, depending on the degree of insulation required. It is very tough and elastic and can be relied on to withstand any shocks or vibrations.

The insulation used for the coils of the main generators and motors should consist mainly of mica, as it should be able to withstand continuously a temperature of 300 degrees F. If the machines are designed so that a temperature rise of 150 degrees F. will not be exceeded under the most severe conditions of service, then the life of the insulation should be as great as that of the remainder of the machinery. Thermo-couples should be provided for measuring the temperature of the coils in at least three places in the windings; the instruments for indicating the temperature should be located on the main switchboard.

The end windings of the stator coils of the generators are subject to a continuous blast of very moist salt air when the machine is running; this makes it imperative that special care should be taken to make these end windings moisture proof. This can best be accomplished by successive dippings and bakings of the ends of the coils until they are covered with a thick coating of varnish; this coat should be renewed by spraying varnish on about once a year after the vessel has been in commission about three years.

Owing to the presence of so much moisture in the air, no hygroscopic material should be used as insulation where this can be avoided. It is necessary to use a certain amount of asbestos on the generator rotor coils on account of the high temperatures encountered but wherever used it should always be treated so as to be as nearly moisture proof as possible.

CHAPTER IX

Exciters and Other Auxiliaries

IT will practically always be necessary to use an independent generator for furnishing excitation to the main generator field. Exciters which are direct connected to the main generators are not suitable on account of the wide variations that take place in the speed of the generators.

The source of exciting current should always be duplicated to insure reliability; this is usually best accomplished by making the exciter a duplicate of the generators which furnish light and power to the ship. These generators are usually larger than would be necessary for excitation alone but the excess power can be utilized to drive some of the main engine auxiliaries. In this case, it will be necessary to supply a booster in the main generator field circuit so the voltage supplied to the main field can be varied without affecting the voltage of the exciter which also supplies the auxiliaries. When a booster is used it should be arranged so that it can be cut out in case of emergency and excitation taken direct from the exciter, which must be designed to have the necessary wide range of voltage required for excitation. When exciting direct from the exciter, the auxiliaries will, of course, have to be supplied from the ship's power circuit.

No fuses or circuit breakers should be allowed in the circuit which supplies excitation to the generator field; any interruption of this circuit would probably damage the field itself and would certainly burn up the circuit breaker on account of the high voltage induced in the field by a quick break of its circuit.

All motor driven main engine auxiliaries, whether supplied by exciters or ship's generators, should always have at least two sources of supply in order to give sufficient reliability.

Auxiliaries which are necessary for proper functioning of the boilers are not suitable for motor drive; for example, boiler feed pumps and fuel oil service pumps should be driven directly by turbines or engines. If motor driven pumps are used for forced lubrication, some emergency arrangement should also be provided. One method of doing this is to provide a small gear pump driven from the main generator shaft; another method is to have half of the lubrication pumps motor driven and the other half steam driven and then use the motor driven pump to get the best economy but have the steam driven pump arranged to come in automatically in case of temporary failure of the motor driven pump. Still another method is to have the oil discharge line connected to the oil supply tanks through a check valve, so that in case of failure of pressure the tanks will supply oil; if the lubrication pumps are arranged to supply oil to overhead tanks which feed the bearings by gravity, then no emergency arrangement need be provided, as the oil in the gravity tank will be sufficient to save the turbine bearings in case of failure of the pump. This latter method is the favorite one in use in the merchant service for geared turbines and would also be ideal for the same ships fitted with electric propulsion. For naval vessels it is not feasible to get sufficient head for gravity tanks, as they must be located beneath the protective deck.

For naval vessels, which will be subject to the shock of gun fire, the same care should be taken to avoid the use of fragile material in the starting panels of auxiliaries as in the case of the main switchboard. All starting panels for auxiliaries should be rugged and all the switches, resistance grids, circuit breakers, etc., should be shock proof.

Starting panels should be arranged to start the motors automatically, as soon as power is supplied, after a temporary interruption of the service.

Generally it will be best to supply current to auxiliaries through switches, instead of circuit breakers. Each starting panel should be provided with a circuit breaker for its own motor; this will give a more reliable arrangement than providing the generator with a circuit breaker.

It is difficult to lay down a general principle as to when electric driven auxiliaries should be used; each ship is a separate problem in this respect; the character of service the ship has to perform, the size of the installation, etc., will be deciding factors. As a general rule, electric driven auxiliaries will be more economical than steam driven ones. This is so because the power can be generated in large turbo generators which have more efficient turbines than the small ones. This arrangement also makes it possible to keep the load factor on the turbines high, as a turbo generator can be cut out, if the auxiliaries are running at low capacity. A second reason for the high efficiency of electric driven auxiliaries is the fact that the speed of the electric motor can always be made to suit the auxiliary which it is to drive without sacrificing any motor efficiency. A third reason is the fact that the efficiency of electric motors does not fall off as rapidly with reduction of load as that of a small turbine. The final result is that the over-all efficiency is better where electric driven auxiliaries are used than where turbine driven auxiliaries are used.

CHAPTER X

Langley

The ~~Jupiter~~

THE *Jupiter* is a twin screw, single deck, cargo vessel designed for a speed of 14 knots when developing 5,500 shaft horsepower with a load displacement of 19,230 tons and a draft of 27 feet 6 inches. On her trials she developed 7,150 shaft horsepower and made a speed of 14.99 knots.

Completed in 1913, the *Jupiter* has been in continuous commission since that date and has a greater number of "miles steamed" to her credit than any other collier during the same period of time. There has been only one "Navy Yard repair job" to the machinery and that was to the main turbine a few months after commissioning. Her performance has demonstrated the highly reliable character of this type of machinery.

The propelling machinery consists of one 5,500 kilowatt turbo generator, two induction motors, two water cooled rheostats, one main switchboard and one auxiliary propelling turbo generator of 450 kilowatts. Excitation is furnished by one of the ship's 35 kilowatt generators of which there are three.

The weight of the propelling machinery is as follows:

Bedplate	16.3	tons
Main turbine	28.7	"
Main generator	35.7	"
Main motors (2)	76.8	"
Rheostats (2)	5.8	"
Switchboard and cable	3.7	"
Auxiliary generator	8.0	"
Total	175.0	tons

GENERAL ARRANGEMENT OF MACHINERY

The machinery is all contained in one engine room. The main turbo generator is mounted on its bedplate on the centerline of the ship; the auxiliary generator is mounted on a platform above the main generator and on the port side of the engine room. Both the main and the auxiliary turbines exhaust into the same condenser. The two motors are connected directly to two propeller shafts. The main switchboard is located at the forward end of the engine room on the centerline and on each side of it is one of the water cooled rheostats. The ship's three 35-kilowatt generators, any one of which may be used for excitation, are located on a platform in the after end of the engine room on the starboard side.

GENERAL DESCRIPTION

At 15 knots, the turbine runs at about 2,130 revolutions per minute and the motors at 117 revolutions per minute, the reduction being approximately 18 to 1. All changes in speed are made by varying the speed of the turbine. Reversal is accomplished by reversing the connections of two of the three phases and inserting resistance in the rotors of the motors. All control of speed, direction of rotation of motors, etc., is from the main switchboard. In case of breakdown of the main turbo generator, the ship can be propelled at a speed of about 6 knots by the auxiliary generator.

MAIN TURBINE

The main turbine, shown in Fig. 38, is a nine stage Curtis turbine. The turbine wheels are made of forged steel and are pressed onto the shaft, the diameter of which decreases slightly, in steps, from the low pressure end to the high pressure end; the turbine shaft is a solid steel forging.

The first stage has two rows of moving buckets and the other stages have only one row each. The blades of the first stage are made of monel metal which resists the erosive effect of the high velocity steam in the first stage. The fixed blades of the first stage are also made of monel metal and are secured in an intermediate segment which is bolted to the turbine casing. The blading of the second to sixth stages inclusive is made of bronze. The blading of the seventh and eighth stages is made of monel metal to resist the erosive and corrosive effects of water in the steam. The ninth stage blading is made of nickel steel; originally

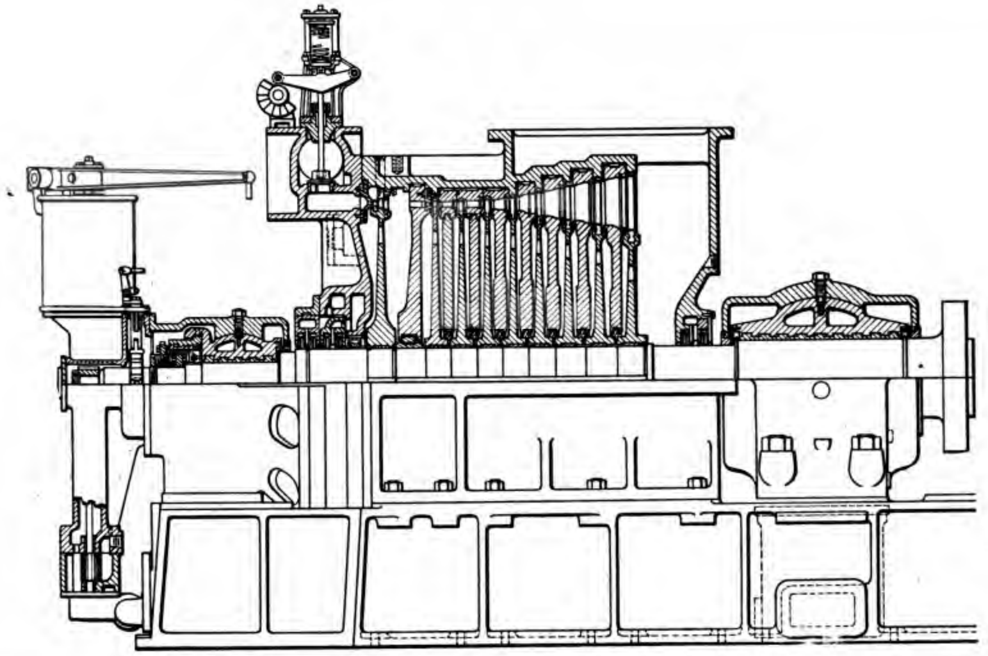


FIG. 38.—Main Turbine on U. S. S. *Jupiter*, 9-Stage Curtis

this blading was also made of monel metal but it was found that this long blading did not stand up well in service and blades would occasionally break off so it was changed to steel. All blades are secured to the wheels by being inserted into dovetail grooves.

The turbine casing is an iron casting, divided along its horizontal axis and arranged for upward exhaust. The head end of the turbine which contains the steam chest is a steel casting; the admission valves are contained in the steam chest.

The expanding nozzles for the first stage are of bronze and are bolted to the steam chest. The nozzles for the remaining stages are cast into the intermediate diaphragms which are of cast iron.

The packing rings for the intermediate diaphragms are made of soft brass and divided in halves to facilitate renewal; originally these rings were made of aluminum but it was found that this metal deteriorated rapidly due to the action of boiler compound. These rings are turned with a number of very fine ridges on their inner circumference and are adjusted so that they have practically no clearance from the shaft; if any ring rubs when the turbine becomes hot, the ridges wear away to give sufficient clearance.

The shaft packing at each end of the turbine consists of carbon rings in sections which are held together by garter springs resting in grooves in the outer circumference of the rings. The rings are prevented from turning with the shaft by a stop secured to the garter springs. The rings are supported by flat springs which keep them centered with the shaft. There are four of these rings on the low pressure end and two on the high pressure end of the turbine. Both high pressure and low pressure stuffing boxes are also sealed with steam.

The governor is mounted on a vertical shaft driven by a worm gear from the turbine shaft. It consists of weights resting on knife edges and acting by centrifugal force against a coiled spring. The motion of the weights operates a small pilot valve which admits oil pressure to the cylinder of a hydraulic relay. The piston of this relay operates a rack which, in turn, moves the cam shaft mounted on the steam chest; the position of this cam shaft determines the number of admission valves that are open and thus controls the speed of the turbine. At the end of the governor arm which operates the pilot valve is connected a diamond shaped frame or parallel motion transmitter which is connected, by a system of rods and bell crank levers, to the operating stand in front of the main switchboard.

The operating stand contains a small hand wheel which operates a worm which, in turn, is geared to a segment mounted on one of the bell cranks of the transmission system. Motion of the hand wheel is thus transmitted to the parallel motion transmitter at the turbine and gives the governor a different fulcrum for each position of the hand wheel.

The governor, hydraulic relay and parallel motion transmitter are shown in Fig. 39. The hand wheel drives a very fine pitch worm so that it requires considerable motion to change the speed of the turbine one revolution; it is possible to adjust the speed accurately to a tenth of a revolution.

There are eight admission valves, controlled by the hydraulic relay. These are globe valves and are kept on their seats by heavy coiled springs; they are opened by motion of the cam shaft. The stems of these valves must be kept free and the springs properly adjusted or the valves will stick open after they have been in that position for a long time. This difficulty has been overcome in later designs by making the cam shaft positively close as well as open the admission valves. Each valve is raised by a lever which has a roller on the end which rides on a cam on the cam shaft.

The bearings are of the spherical, self-alining type and both the upper and lower halves are water cooled, the water passing through copper coils imbedded in the "babbitt." Water is supplied from the main circulating pump or sanitary pump and passes through a twin strainer before going to the bearings; these strainers are of very fine mesh and must be cleaned frequently. Oil for the bearings, and also for the governor, is supplied by a gear pump driven from the lower end of the governor shaft. The oil reservoir is in the bedplate of the turbine and is fitted with vents, level indicator and strainer at the filling connection. Oil also passes through a strainer after leaving the pump and before it goes to the oil cooler; from the cooler the oil goes to the bearings and returns to the reservoir by gravity. A steam pump mounted on the bedplate is used to supply oil in starting up and shutting

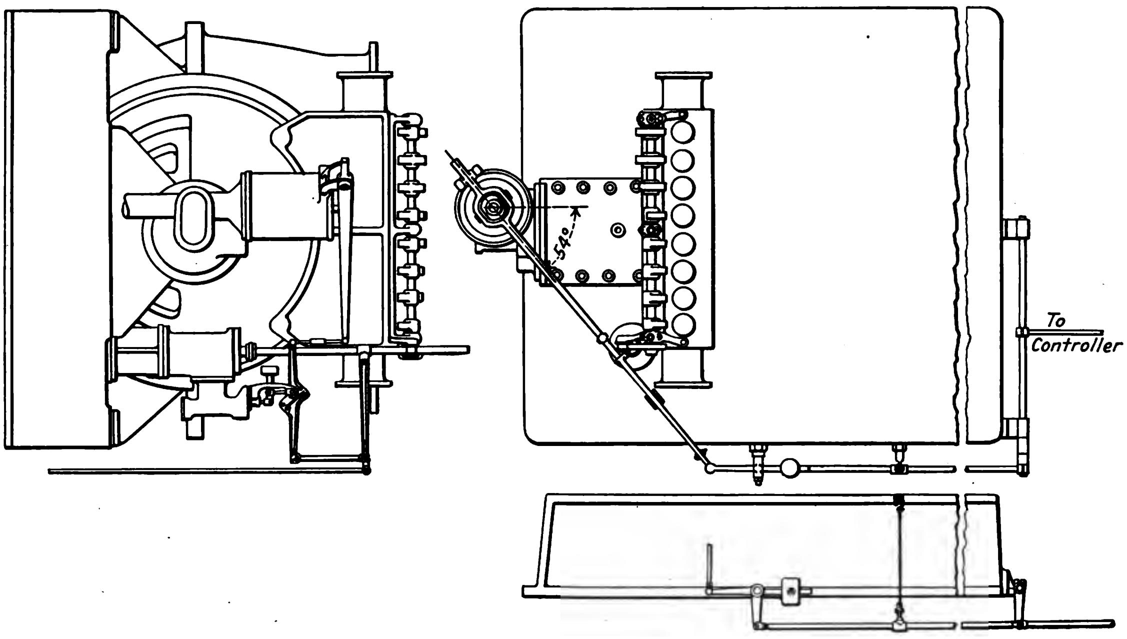


FIG. 39.—Governor, Hydraulic Relay and Parallel Motion Transmitter for Main Turbine on U. S. S. *Jupiter*

down. Oil is supplied to the bearings at a pressure of about 25 pounds per square inch.

The thrust bearing is of the Kingsbury type. The outer surface of the block is threaded and works in a nut which is secured to the turbine end bearing; this nut is fitted with a worm wheel which engages a worm mounted on a shaft projecting through the bearing and fitted with a hand wheel. By moving this hand wheel the whole thrust bearing will be moved forward or aft and carry the turbine rotor with it, thus giving it the desired position in the turbine casing. A sight hole is fitted in the turbine casing for measuring the blade clearances so that the rotor can be properly set. The float in the thrust is set at about 0.017 but is capable of being altered by changing the thickness of the shims used in adjusting the thrust bearing.

The turbine is solidly coupled to the generator as it is a three bearing set, there being two turbine bearings and one generator bearing.

The throttle valve is a Schutte-Koerting automatic valve fitted with quick closing attachment which can be tripped by hand or by the emergency governor.

The emergency governor consists of a weight, mounted in a recess in the shaft near the turbine end, which is restrained by a coiled spring from motion due to the centrifugal force of the revolving shaft until the turbine speed rises to about 2,300 revolutions per minute, at which point the weight flies out and trips a trigger and allows the throttle valve to close.

MAIN GENERATOR

The main generator, shown in Fig. 40, is a two pole, three phase alternator rated at 4,350 kilowatts but which develops 5,500 kilowatts with ease. The normal voltage at the rated speed is 2,300 volts.

In most respects the generator is of ordinary commercial design, but an attempt was made in this installation to produce a flame proof winding for the stator. The stator winding insulation is shown in Fig. 41. It will be seen that both the slot portion of the coil and the end connections are covered with asbestos; this was done to protect the coil against damage by flame in case of a

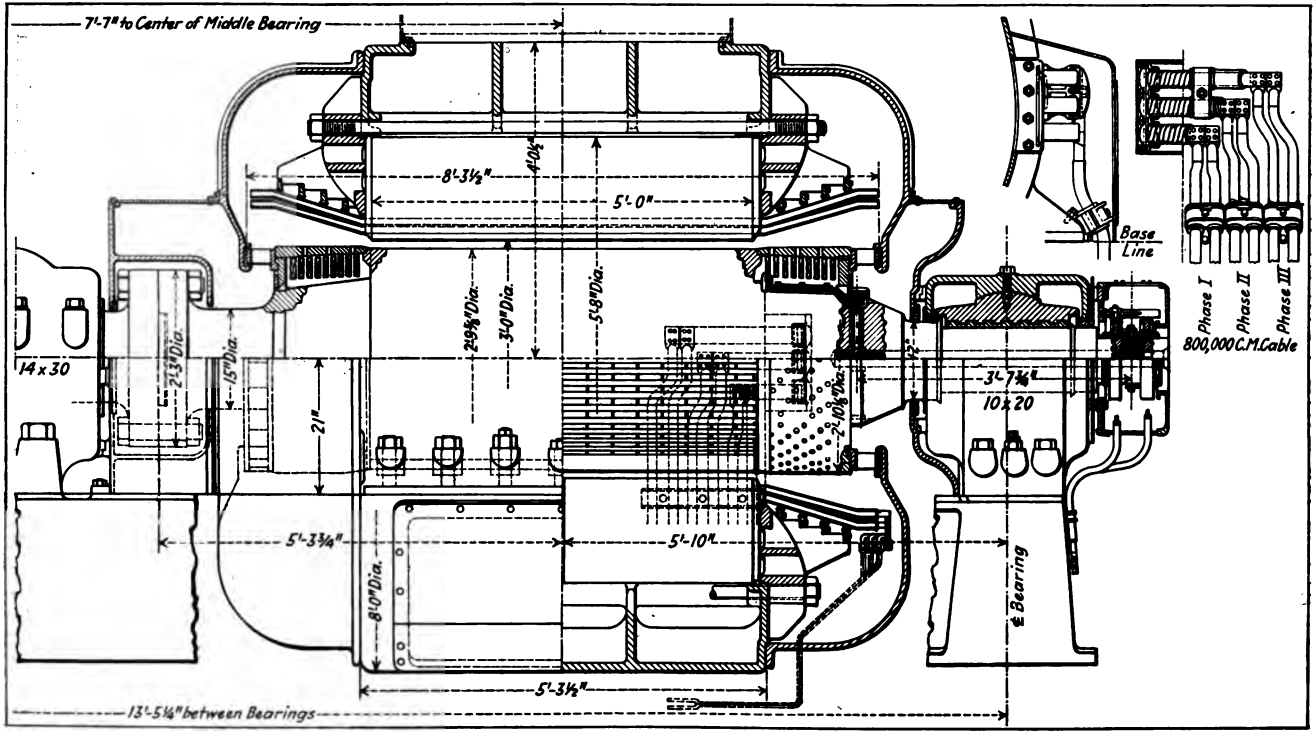


FIG. 40.—U. S. S. *Jupiter:* Assembly of Main Generator

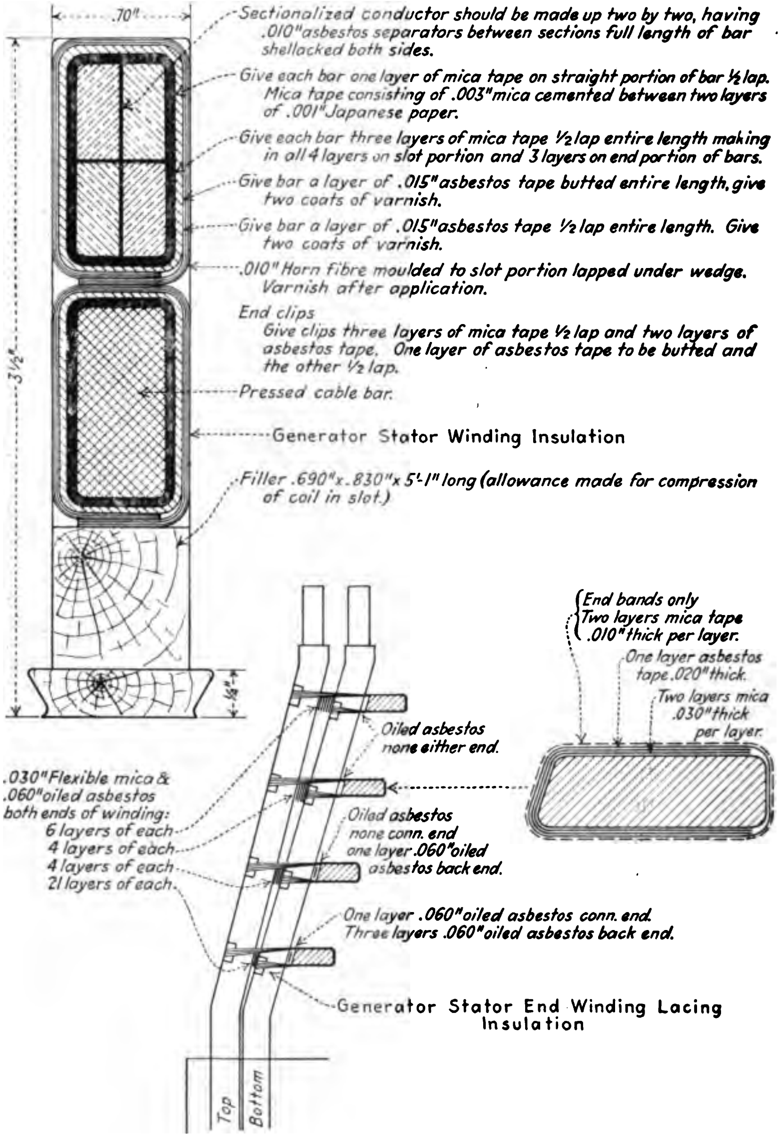


FIG. 41.—U. S. S. *Jupiter:* Generator Stator Winding Insulation

short circuit in the generator. It has not been a success and will not be used in future installations. The asbestos on the end connections is subject to continuous bombardment by a stream of air saturated with salt moisture when the turbine is running and, being very hygroscopic, it absorbs this moisture with consequent lowering of the value of the insulation. When the machine is idle, the inside of the generator becomes a condenser, due to changes in engine room temperature, and moisture is deposited on these coils. This difficulty was overcome by thoroughly varnishing the end connections to make them impervious to moisture and by fitting steam coils for heating the generator when it is idle so as to prevent moisture from depositing. The air intake for the generator was also blanked off from the bilge and ducts were run up into the upper part of the engine room so as to secure dry air for ventilation.

FIG. 42.—Generator Rotor for U. S. S. *Jupiter*

The generator rotor, shown in Fig. 42, is a solid steel forging having radial slots machined in it to receive the rotor windings. The insulation of the rotor coils consists of mica and asbestos. It is necessary to use a protective covering of asbestos in this case on account of the high temperature in the rotor; the insulation is, however, entirely covered and protected. Fans for ventilating the generator are attached to each end of the rotor.

Air for ventilation is drawn from the engine room through the end bells at each end of the generator and then discharged by the fans into the air gap between the rotor and stator; it then passes through radial ducts in the stator and is collected in a casing around the stator and finally discharged from the top of the stator into a duct leading to the forced draft blowers in the fireroom.

FIG. 43.—Stator for U. S. S. *Jupiter*

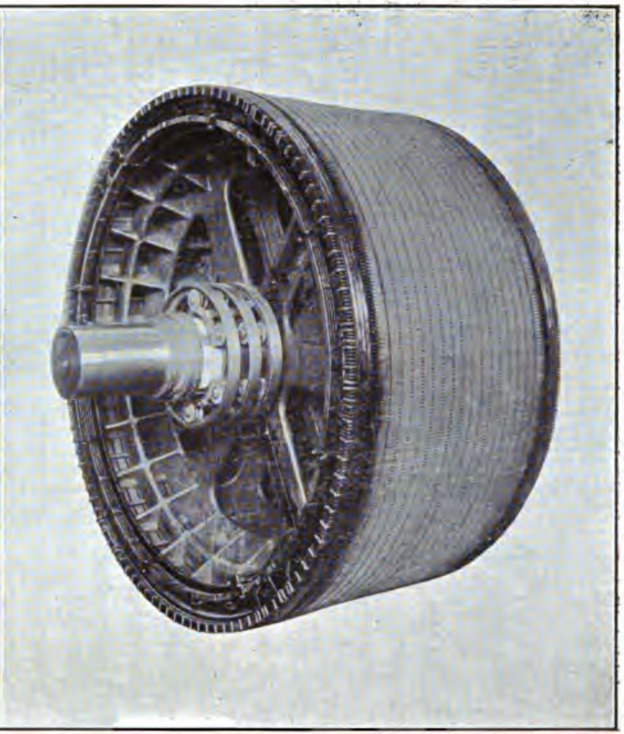


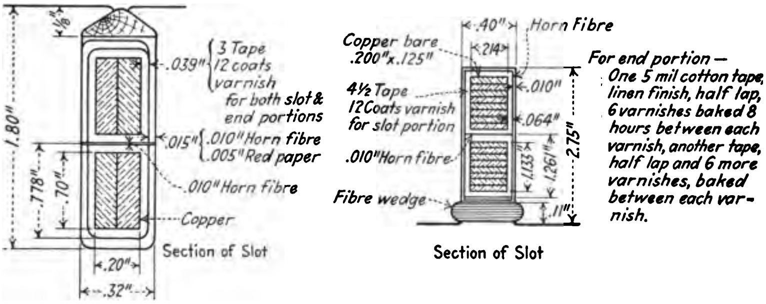
FIG. 44.—Rotor for U. S. S. *Jupiter*

The generator bearing is similar to the turbine bearings except that the pedestal for supporting it is entirely independent of the stator instead of being mounted on it.

MAIN MOTORS

The two main motors are mounted in watertight pits recessed into the inner skin of the ship. They are induction motors of the definite wound type; Figs. 43 and 44 show the stator and rotor, respectively.

The rotor windings connect to three slip rings which are connected to the water cooled rheostats. These slip rings can be short circuited by a slider working on the shaft and operated by a lever in front of the switchboard. The short circuiting device consists of a brass segment under each ring and a corresponding segment on the slider. The segments on the slider are made up of thin brass strips which are interleaved to form a spring which will have to be compressed as it slides under the solid segment of the ring; this insures good contact for the short circuit. To prevent burning these contacts there are provided auxiliary contacts which consist of carbon blocks on the solid segments and brass contact fingers on the slider; these fingers are renewable and are arranged to make and also break the circuit before the main contacts.



Motor Rotor Winding Insulation — Motor Stator Winding Insulation

FIG. 45.—U. S. S. *Jupiter:* Motor Winding Insulation

The motor winding insulation is shown in Fig. 45. It will be seen that it consists entirely of fibrous insulation, which is well varnished. While this insulation has been entirely satisfactory it is not believed that it is really suitable as the motor temperature is higher than it should be for this type of insulation; also this insulation is hygroscopic unless it is thoroughly protected by varnish.

The motor frame is surrounded by a sheet metal housing connecting to a duct on top of the stator which leads to the blower room of the forced draft blowers. It was intended that the blowers should draw air through the motors and thus ventilate them but this arrangement is not satisfactory as the blowers are seldom used and the lagging on the motors really only serves to hold the heat in.

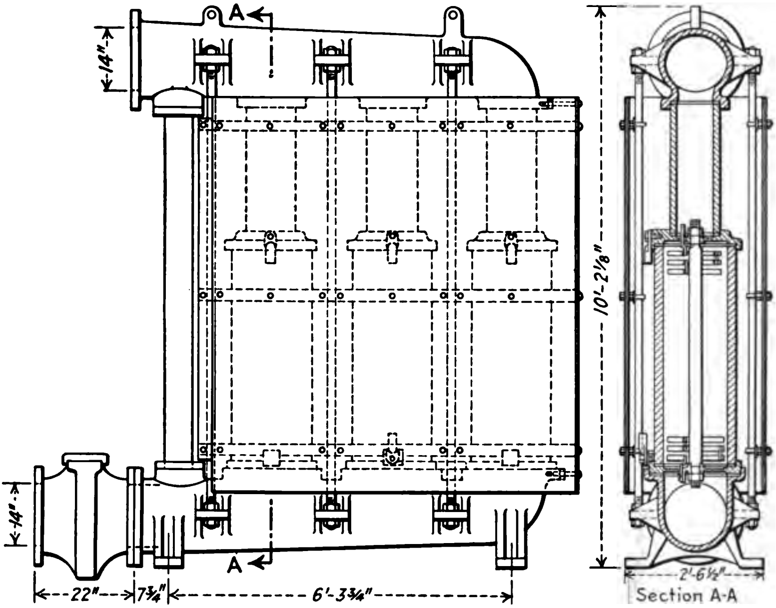


Fig. 46.—Water Cooled Rheostat on U. S. S. *Jupiter*

The motor bearings are of the spherical, self-alining type and are adjustable in the supports at each end of the motor frame. They are self-oiling, being fitted with oil rings which dip in reservoirs in the lower part of the bearing.

Rheostats

The water cooled rheostat is shown in Fig. 46. There are two of these, one being located on each side of the main switchboard.

The rheostat consists of a top header, bottom header, three large porcelain cylinders, three small porcelain cylinders and three non-inductive resistances. The resistances are made of calorite and consist of spiral coils laid up on a wooden spindle and having the connections of alternate coils reversed so as to make the resistance non-inductive. The large porcelain cylinders rest on rubber gaskets on the bottom header; the resistances are placed inside these cylinders. A rubber gasket and a brass ring are placed on the top of each large cylinder and a small cylinder rests on each of these. The top header rests on rubber gaskets on top of the small cylinders. Water from the circulating pumps enters the bottom header, passes through the cylinders and out through the top header. The circulating water forms a part of the

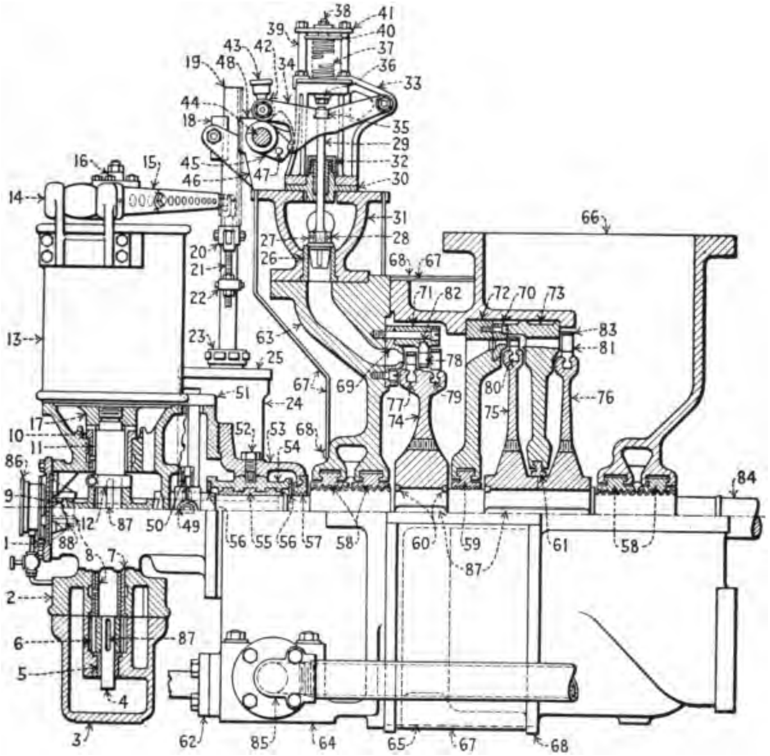


FIG. 47.—3-Stage Turbine used to Drive Auxiliary Generator on U. S. S. *Jupiter*

Bill of Material for Turbine Shown in Fig. 47

Part No.	Name of Part
1.	Gage Board
2.	Gear Casing
3.	Oil Pump Casing
4.	Governor Shaft
5.	Bushing
6.	Gear
7.	Lower Bushing for Governor Shaft
8.	Babbitt Lining
9.	Worm Wheel
10.	Bushing Upper for Governor Shaft
11.	Babbitt Lining
12.	Split Collar
13.	Governor Dome
14.	Bracket for Governor Lever
15.	Governor Lever
16.	Transmission Bearing
17.	Governor Bracket (Rotating)
18.	Guide for Rack
19.	Piston Rod and Rack
20.	Clamp
21.	Clevis
22.	Floating Lever
23.	Gland
24.	Hydraulic Cylinder
25.	Cylinder Head
26.	Valve Seat
27.	Valve
28.	Pin
29.	Valve Stem
30.	Stuffing Box
31.	Valve Casing
32.	Gland and Nut
33.	Stand
34.	Lever
35.	Collar Pin and Sleeve
36.	Spring Support
37.	Spring
38.	Adjusting Screw
39.	Stud
40.	Traveling Nut
41.	Cap
42.	Cam Roller
43.	Grease Cup
44.	Cam Shaft
45.	Cam
46.	Cam Shaft Bracket
47.	Pin on Cam
48.	Cap for Cam Shaft Bracket
49.	Emergency Governor
50.	Trip Finger for Emergency Governor
51.	Emergency Governor Bracket
52.	Set Screw
53.	Bearing Cap
54.	Bearing (Turbine End)
55.	Babbitt Lining in Bearing
56.	Oil Guard
57.	Oil Deflector
58.	Packing Sleeve
59.	Packing Sleeve
60.	Cross Key
61.	Packing Sleeve
62.	Connection to Oil Pump
63.	Turbine Head (Upper Half)
64.	Turbine Head (Lower Half)
65.	Turbine Shell (Lower Half)
66.	Turbine Shell (Upper Half)
67.	Lagging
68.	Cleat
69.	First Stage Nozzle
70.	Second Stage Nozzle
71.	Intermediate Segment
72.	Diaphragm, 2nd Stage
73.	Nozzle Diaphragm, 3rd Stage
74.	First Stage Wheel
75.	Second Stage Wheel
76.	Third Stage Wheel
77.	Bucket Blade, 1st Wheel, 1st Stage
78.	Bucket Blade, Intermediate, 1st Stage
79.	Bucket Blade, 2nd Wheel, 1st Stage
80.	Bucket Blade, 2nd Stage
81.	Bucket Blade, 3rd Stage
82.	Space Block for Intermediate, 1st Stage
83.	Bucket Cover
84.	Turbine Shaft
85.	Connection to Reduction Gear
86.	Oil Pressure Gage
87.	Key
88.	Bushing for Gage Board

Bill of Material for Auxiliary Turbo-Generator Shown in Fig. 48

Part No.	Name of Part
1.	Gear Casing (Lower)
2.	Gear Casing (Middle)
3.	Gear Casing Cover
4.	Babbitt
5.	Oil Deflector
6.	Holder for Oil Deflector
7.	Bearing 4" x 8"
8.	Oil Guard
9.	Oil Supply Pipe
10.	Bolt for Coupling Flanges
11.	Adjusting Screw
12.	Shims
13.	Thrust Plate
14.	Cover
15.	Bearing 5" x 8"
16.	Stud for Flexible Gears
17.	Gears (Flexible)
18.	Hub
19.	Key for Shaft and Gears
20.	Bearings 6" x 9"
21.	Oil Guard
22.	Oil Deflector
23.	Washer
24.	Air Shield
25.	Coupling Gland
26.	Shaft for Gears
27.	Bearing 4" x 8"
28.	Dash Pot
29.	Cover
30.	Bolt for Coupling Flanges
31.	Collar
32.	Shaft and Pinion
33.	Cover for Oil Tank
34.	Nozzle for Oiling Gears
35.	Cooling Coil
36.	Cover for Oil Tank
37.	Cover

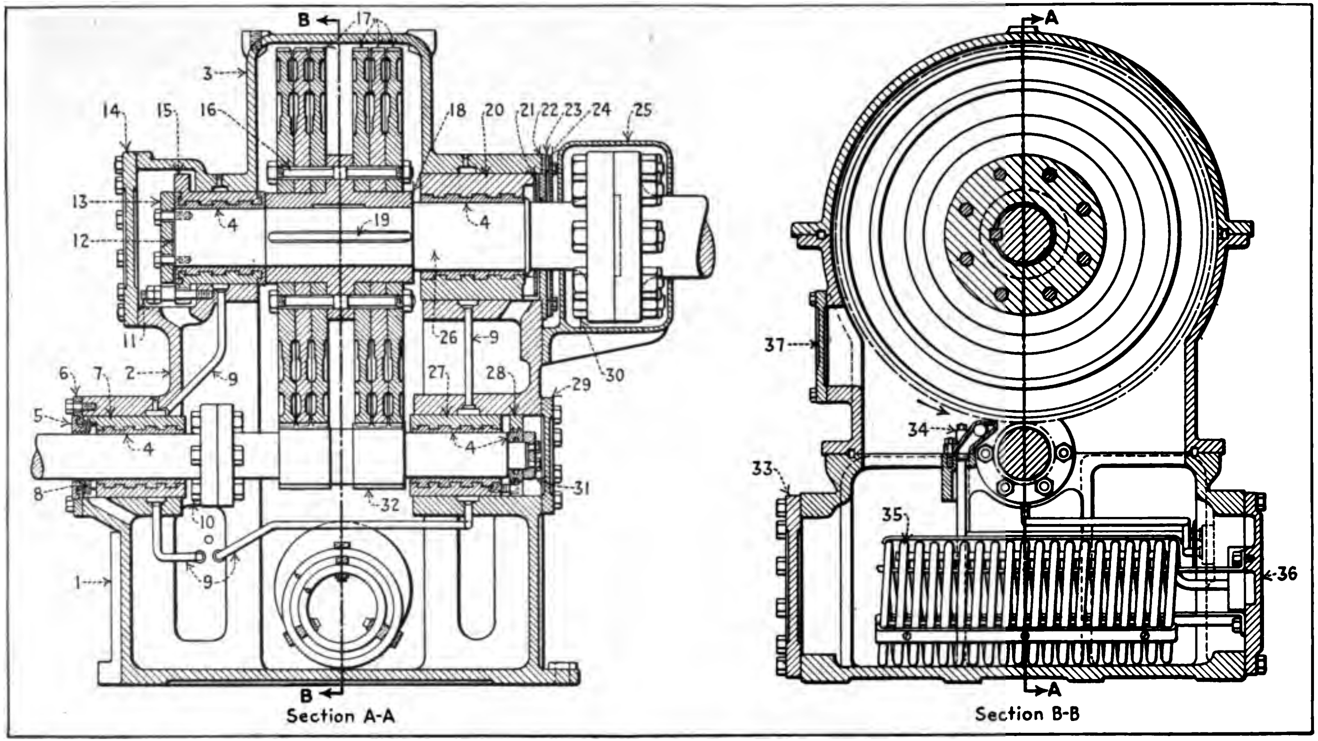


FIG. 48.—U. S. S. *Jupiter:* Sections Through Reduction Gearing of Auxiliary Turbo-Generator

electric circuit when the resistances are in use. These can be used continuously, if desired.

Auxiliary Turbo Generator

The auxiliary generator, shown in Figs. 47, 48 and 49, is a 2-pole, 3-phase, geared set. The gear ratio is approximately 6 to 1; the speed reduction between the generator and motors is 18 to 1; the turbine runs at a speed of 5,000 revolutions per minute, the generator at 828 revolutions per minute and the motors at 45

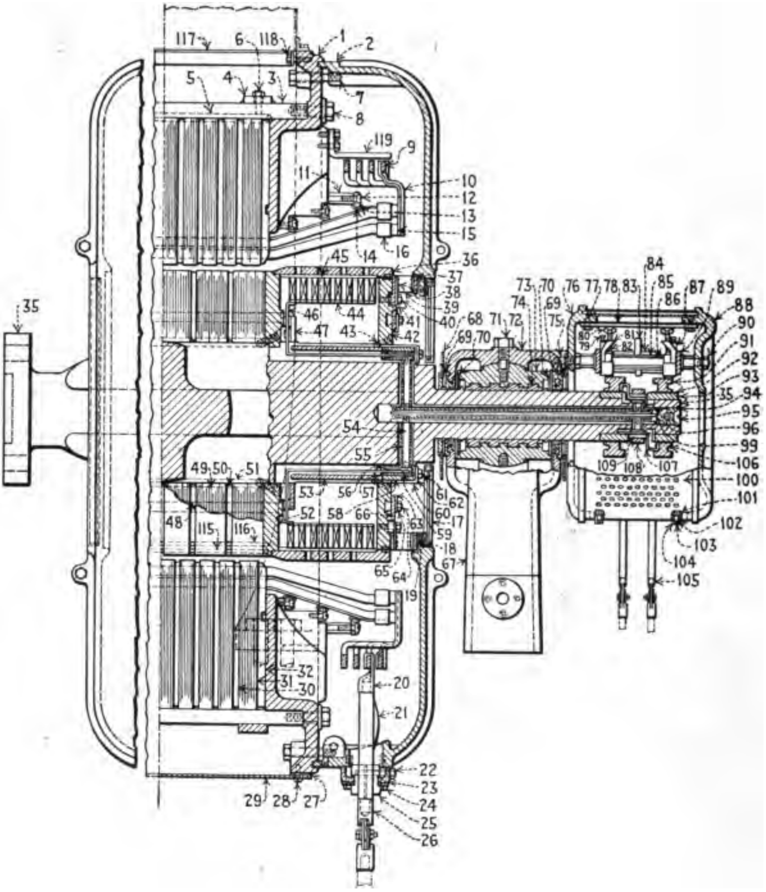


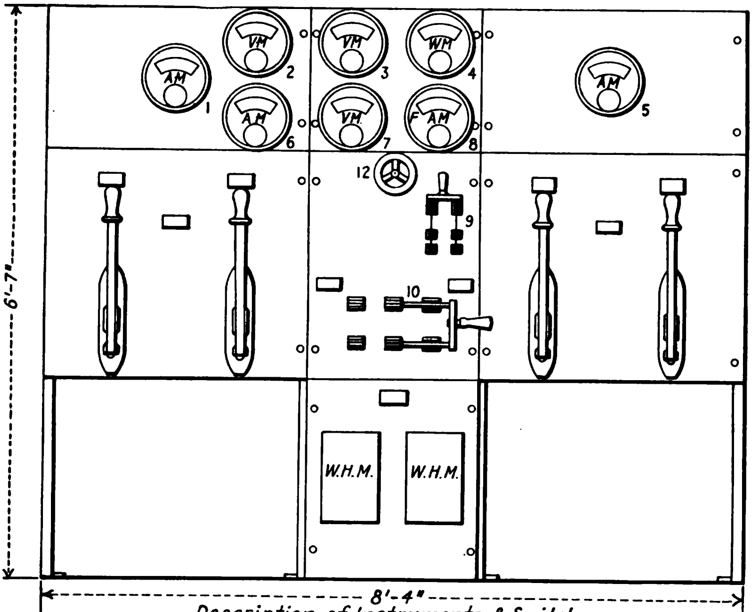
Fig. 49.—Auxiliary Generator on U. S. S. *Jupiter*

revolutions per minute. The turbine is rated at 450 kilowatts and the normal voltage is 450 volts.

Bill of Material for Auxiliary Generator Shown in Fig. 49

Part No.	Name of Part
1.	Stator Frame Flange (Combined)
2.	End Shield
3.	Rib
4.	Stator Frame Ring
5.	Key 21" Long
6.	½" Bolt. Thirteen for Stator Frame Ring
7.	¾" Bolt. Ten 4½" Long for Shields
8.	1" Bolt. Eight 3½" Long for Flanges
9.	Connection Strip
10.	Connections
11.	Stud for Binding Band
12.	½" Screw Fillister Head. Thirteen 1¼" Long for Binding Bands
13.	Binding Band
14.	Insulation
15.	Stator Coil Winding
16.	Clip
17.	Wire Screen
18.	Lug
19.	5/16" Cap Screw. Eighteen ½" Long for Wire Screen
20.	Terminal
21.	Cable. 640,000 C.M., Extra Flexible
22.	½" Bolt. Thirteen 2½" Lonb for Clamping
23.	Connection Board
24.	½" Bolt. Thirteen for Connection Board
25.	Bushing
26.	Cable Connector
27.	Lagging
28.	5/16" Screw, Round Head. Eighteen 1" Long for Lagging
29.	Lagging
30.	Space Block
31.	Punchings
32.	Space Block
33.	Cover Plate
34.	½" Bolt. Thirteen 1¾" Long for Cover Plate
35.	Shaft
36.	Retaining Ring
37.	Fan Shroud
38.	Rivet
39.	Fan Blade
40.	½" Bolt. Thirteen 1¾" Long for Fan
41.	Lockwasher
42.	Centering Ring
43.	Retaining Screw
44.	Rotor Coil
45.	Insulation
46.	Connection Strip
47.	Clamping Ring
48.	Rivet
49.	Punchings
50.	Space Block
51.	Key. ¾" x 1" x 2' ⅝" Long
52.	End Plate
53.	Lead Wedge
54.	Terminal
55.	Bushing
56.	Insulation
57.	Insulation
58.	Lead Wedge
59.	Screw, Flat Head No. 14. Twenty-four for Connection Strip
60.	Clamp
61.	⅜" Bolt. Sixteen ¾" Long for Clamp
62.	Lockwasher
63.	Lockwasher
64.	Balancing Weight Bolt
65.	½" Nut. Thirteen ½" Thick for Balancing Weight Bolt
66.	Balancing Weight
67.	Standard
68.	Air Shield
69.	Oil Deflector
70.	Oil Guard
71.	Set Screw
72.	Cap
73.	Bearing
74.	Babbit for Bearing
75.	¾" Bolt. Ten for B. H. Rigging
76.	Brush Holder Yoke
77.	⅜" Bolt. Sixteen ⅝" Long for Support
78.	Support
79.	Thumb Screw
80.	Wing Screw
81.	Spring Fulcrum
82.	Spring
83.	Barrier
84.	Bushing
85.	Bushing
86.	Bushing
87.	Brush Holder
88.	Guard
89.	Bus Ring
90.	⅝" Nut. Eleven ⅝" Thick for Stud
91.	Collector Ring
92.	Shell Insulation
93.	Collector Shell
94.	Plug
95.	¾" Screw, Flat Head. Ten 1¼" Long for Plug
96.	Wedge
97.	Insulation
98.	Connection Rod
99.	Insulation
100.	Cover
101.	Globe Nut
102.	Eye Bolt
103.	Slotted Lug
104.	Hinge
105.	Cable Connector
106.	Rivet
107.	Collector Lead
108.	Clamp
109.	Cover
110.	Bushing
111.	Bushing
112.	Terminal
113.	Washer
114.	Beading
115.	Coil Wedge
116.	Coil Wedge
117.	Air Piping Support 1½" x 1½" Angle
118.	⅜" Bolt. Sixteen for Air Piping Support
119.	Winding Support

This set is installed as a "stand-by" in case of failure of the main set and ordinarily is not used as it can not be run in parallel with the main set. It has a governor for speed control but there is no adjustable feature to it so that speed changes must be made by the throttle. Excitation is furnished by the same sets as for the main turbo generator.



Description of Instruments & Switches on Switch Board.

1 - Ammeter
2 - Voltmeter
3 - Voltmeter
4 - Wattmeter
5 - Ammeter
6 - Ammeter
7 - Voltmeter
8 - Field Ammeter
9 - Field Switch 250 V.- 200 A
10 - Lever Switch 250 V. - 800 A
11 - Lever Switch 600 V. - 2000 A
12 - Field Rheostat

FIG. 50.—Main Switchboard on U. S. S. *Jupiter*

MAIN SWITCHBOARD AND WIRING

The main switchboard is shown in Fig. 50 and a diagram of the wiring in Fig. 51. The switchboard contains all the instruments, levers, etc., necessary for the control of the engines except the levers for short circuiting the rheostats which are located in front of the switchboard, one on each side, and the speed control stand which is directly in front of the center of the board. All control levers are within easy reach of one man. There are the following switches, levers, instruments, etc.:

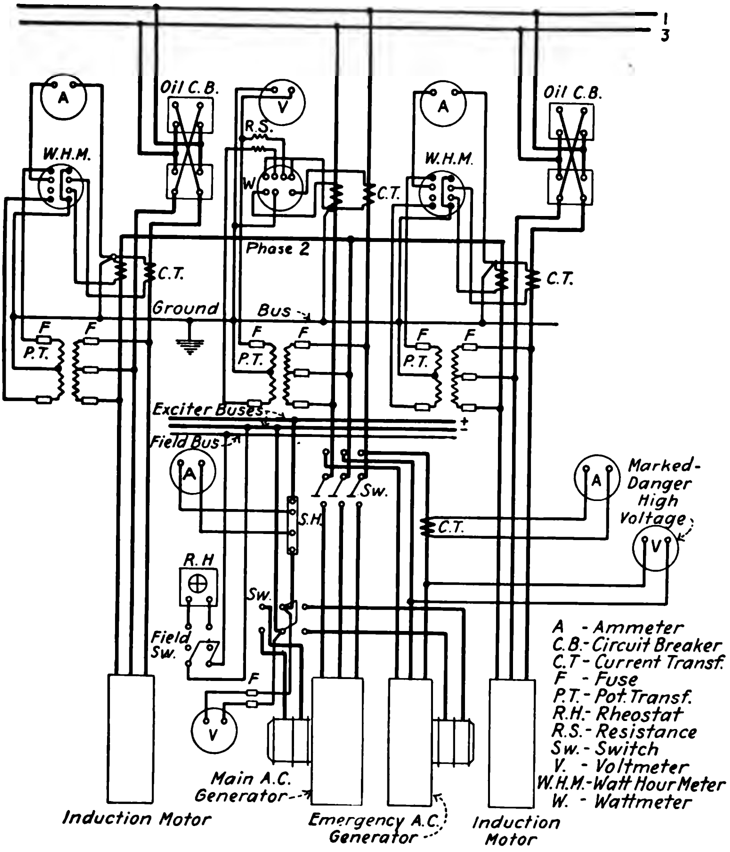


FIG. 51.—Wiring Diagram for Main Switchboard on U. S. S. *Jupiter*

(*a*) 1 "ahead" oil switch for each main motor.
(*b*) 1 "astern" oil switch for each main motor.
(*c*) 1 exciter field switch.
(*d*) 1 double-throw field switch for supplying main or emergency generator.
(*e*) 1 double-throw generator cut-out switch for connecting either main or emergency generator to the main buses. (Located on the back of the switchboard.)
(*f*) 1 field ammeter for main or emergency generator.
(*g*) 1 field voltmeter for main or emergency generator.
(*h*) 1 voltmeter for main generator.

(*i*) 1 ammeter for main generator.
(*j*) 1 voltmeter for emergency generator.
(*k*) 1 ammeter for emergency generator.
(*l*) 1 indicating wattmeter for main generator.
(*m*) 1 ammeter for each main motor.
(*n*) 1 integrating wattmeter for each main motor.
(*o*) 1 rheostat for exciter field.
(*p*) 1 turbine speed control stand. (Located in front of switchboard.)
(*q*) 1 short circuiting lever for each main motor. (Located alongside the motors.)

The following interlocks are provided:

MECHANICAL

(1) "Ahead" and "astern" oil switches are interlocked so that both can not be closed at the same time.

(2) Both the "ahead" and "astern" oil switches are interlocked with the rheostat short circuiting levers so that the oil switches can not be closed until after the rheostats have been cut in. After an oil switch has been closed, it is then possible to cut out the rheostats.

ELECTRICAL

(1) The short circuiting levers are locked by under current relays which will not permit short circuiting the rheostats until the current in the main circuit has fallen to a predetermined value. This lock does not prevent moving the levers to cut in the "rheostats."

From the wiring diagram (Fig. 51) it will be seen that the leads are as simple as possible. The main buses can be supplied by either the main or emergency generator. The generator disconnecting switch is double-throw, so that it is impossible to connect both generators at the same time; the same arrangement is applied to the field supply switch for the generators. Of the three leads to the main motors, one is taken direct and the other two pass through the "ahead" and "astern" switches to give proper direction of rotation to the motors.

OPERATION OF THE MACHINERY

(1) *Getting Under Way, Coming to Anchor or Maneuvering Alongside Ships or Docks.*—For this condition, the rheostats would be kept cut in; this ararngement gives the simplest possible operating conditions.

(*a*) To go "ahead," close the "ahead" switch or switches.

(*b*) To go "astern," open the "ahead" switches and close the "astern" switches.

Either motor can be stopped, started, or backed independently of the other and the results obtained in ship handling are much better than can possibly be obtained with other types of machinery.

(*c*) Speed changes are made by changing the setting of the speed control wheel as desired.

(2) *Cruising.*—For this condition the rheostats must be short circuited; the change would be made to this condition with the ship going ahead with rheostats in.

(*a*) To go "ahead standard speed," open the exciter field switch and set the turbine for slow speed. As soon as the under-current relays unlock, move the levers to short circuit the rheostats. Close the exciter field switch. As soon as the generator field has built up, bring the turbine up to the desired speed. This operation requires a total of about 25 seconds.

(*b*) To go "astern," open the "ahead" switches, move the levers to cut in the rheostats and close the "astern" switches. The total time required is about 4 seconds.

From this it will be seen that even when the machinery is in the cruising condition the ship can be almost instantaneously reversed. There are colliers in the United States Navy practically identical with the *Jupiter* and which are fitted with reciprocating engines and also geared turbines. None of these ships compares at all favorably with the *Jupiter* in handling alongside ships or docks.

TRIALS

The following table gives the results of the official trials of the ship, conducted shortly after commissioning:

Duration of Trial	48 Hours	24 Hours
Date of trial	Feb. 14-14	Feb. 18-14
Speed in knots	14.99	10.01
Draft, mean, feet and inches	27′ 9″	27′ 7½″
Displacement, in tons	19,452	19,350

	48 Hours	24 Hours
Pressures (gage):		
Main steam boilers, pounds	193.8	193.9
Engine room, pounds	185.8	186.44
Turbine, pounds	168.4	180.56
First stage, pounds	56	8.5
Forced lubrication, pounds	30	30
Oil to governor relay, pounds	80	75
Steam seals, pounds	5	5
Auxiliary exhaust pressure (absolute)	23.2	23.7
Air pressure to boilers, in inches of water	.7	....
Vacuum, inches	28.2	28.5
Revolutions, or double strokes per minute:		
Starboard motor	116.72	77.077
Port motor	116.72	77.077
Main turbine	2,130	1,410
Condensate pumps	3,600	3,600
Dry-air pumps	112	113
Circulating pumps	193	196
Feed pumps	22	17
Blowers	329	....
Temperature, in degrees Fahrenheit:		
Main injection	55	55
Overboard discharge	78	72
Hottest bearing (middle)	133	115
Oil from cooler	99	85
Feed water	192	216
Field amperes, main generator	251.5	184
Field volts, main generator	101.4	69.4
Volts, main generator	2,581	1,524
Amperes, starboard motor	725	395
Amperes, port motor	755	413
Amperes, main generator	1,480	808
Kilowatts, starboard motor	2,692.7	712.5
Kilowatts, port motor	2,833.1	751.3
Kilowatts, total	5,525.8	1,463.8
Shaft horsepower, starboard shaft	3,603	1,054
Shaft horsepower, port shaft	3,549	961
Shaft horsepower, total (torsion meter)	7,152	2,015
Water consumption data:		
Total pounds per hour	105,764	40,066
Pounds per hour, auxiliaries	22,212	15,246
Pounds per hour, turbine	83,552	24,820
Pounds per hour per shaft horsepower (turbine)	11.68	12.316
Fuel consumption data:		
Pounds of coal per hour	11,900	5,050
Pounds of coal per hour per shaft horsepower	1.662	2.5056
Pounds of coal per hour per sq. ft. H. S.	.613	.261
Tons per day	127.39	54.082
Kind of coal	New River and Geo. Creek	
Quality of coal	Run of mine	Run of mine
Slip of propeller, percent	9.9	8.74
Shaft horsepower per sq. ft. grate surface	15.9	4.48
Knots per ton of coal	2.82	4.43

CHAPTER XI

The U. S. S. New Mexico

THE *New Mexico* is a battleship having a displacement of 32,000 tons at a 30-foot draft. She is 624 feet long overall and has a beam of 97 feet 4½ inches. She was designed for a speed of 21 knots but made a speed of 21.31 knots on standardization and developed 31,300 shaft horsepower at 170 revolutions per minute of the propellers and 2,070 revolutions per minute of the main generators.

The main propelling machinery consists of two alternating current turbo generators, four induction motors, two 300-kilowatt direct current generators for excitation and motor driven auxiliaries, two motor generator boosters, a main switchboard, an exciter switchboard, ventilating blowers for the main motors and the necessary wire and cable for connecting up the generators and motors to the switchboards.

The weight of the machinery is as follows:

4 main motors	479,046	pounds	
2 turbo generators	566,958	"	
2 boosters	4,800	"	
1 main switchboard	39,840	"	
Cable	20,256	"	
Total	1,110,900	"	= 500 tons

GENERAL ARRANGEMENT OF MACHINERY

The general arrangement of the machinery in the three engine rooms and the motor rooms is shown in Fig. 52, which gives a single line wiring diagram of the main alternating current and direct current wiring and also gives the location of the main operating switches and levers. All of the main engine auxiliaries, two of the main motors and the alternating and direct current switchboards are located in the central compartment. The two generators are located in compartments outboard of the center engine room and the outboard motors are located in compartments abaft the generator rooms. Communication between motor rooms and generator rooms is provided for through a watertight door. Each main motor is connected directly to a propeller shaft.

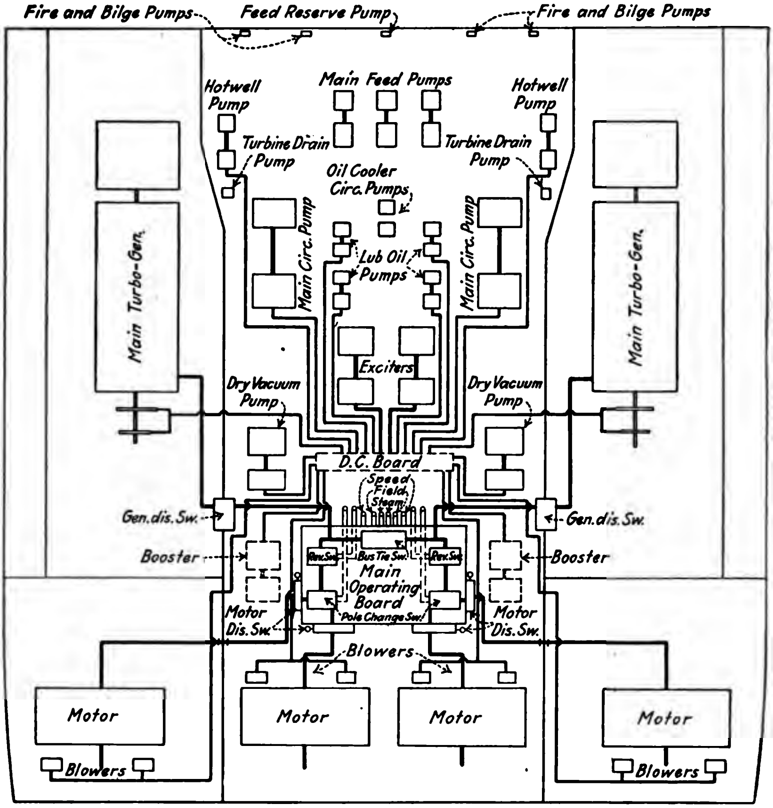


FIG. 52.—U. S. S. *New Mexico:* Arrangement of Machinery

GENERAL DESCRIPTION

The main motors are provided with pole changing switches which can be thrown to give them 24 poles or 36 poles; since the generators are 2-pole, this will give speed reductions of 12 to 1 and 18 to 1, respectively. The alternating current switchboard is provided with a tie switch so that one generator can be used to drive all four motors.

For speeds up to 15 knots, one generator is used to drive four motors, the latter being on the 36-pole arrangement; the limit of speed with this arrangement is the maximum speed of the generator.

From 15 knots to 17 knots, one generator is used to drive four motors, the latter being on the 24-pole arrangement; the limit of speed with this arrangement is the load on the generator. The generators are required to stand 25 percent overload but this requirement can not be met when one generator is driving since full load will be reached at a reduced speed of the generator and, consequently, the full ventilation of the generator will not be obtained.

From 17 knots to full speed, two generators are used, each driving two motors. In this case the two sides of the ship are entirely independent of each other in every way.

When one generator is used to drive, the speeds of the four motors must always be the same although the motors on either side of the ship can be kept at standstill or backing while the motors on the other side are going ahead; also, when one generator is being used, it is always necessary temporarily to remove power from all motors to make changes in the direction of rotation of either pair of motors since the generator circuit is always killed by taking power off the generator field before opening or closing any of the main switches.

The motors are always backed on the 36-pole arrangement since that gives a higher torque for reversal than the 24-pole arrangement.

The two motors on one side of the ship are always handled as a unit but either one of them can be disconnected when desired.

Motor generator boosters are located in the main generator field circuit for giving the desired changes in field current. The field current comes from the 300-kilowatt exciters and passes, in series, through the generator of the booster; by varying the field of this generator and by reversing its field so as to "buck" or "boost" the exciter voltage, any desired voltage can be impressed on the slip rings of the main generator field.

This arrangement makes it possible to use exciters of the same size as the ship's light and power generators, thus making spare parts interchangeable and also making it possible to use the ship's generators for excitation without complication.

The exciters, being constant voltage machines with this arrangement, can be used to furnish power for purposes other than excitation since this load amounts to only about 55 kilowatts on each exciter at the full power of the ship. The remainder of the available power is used to run the main circulating pumps, main condensate pumps, main air pumps, forced lubrication pumps, and ventilating blowers for the main motors.

The exciters are made non-condensing and exhaust against a back pressure of ten pounds per square inch gage. The exhaust steam is used in the low pressure stages of the main turbines, thus giving a very fine efficiency.

The speed of the propellers is varied by changing the speed of the main turbines; the latter are under the control of a governor at all times and the speed changes are accomplished by varying the setting of the governor.

MAIN TURBINE

A section of the main turbine is shown in Fig. 53. It is a 10-stage, General Electric-Curtis turbine. The first stage is velocity compounded, having two rows of moving buckets, and the other stages are pressure compounded, having a single row of moving buckets on the wheel.

The wheels are pressed on the shaft and keyed. The tenth stage wheel is secured against a shoulder on the shaft and the first stage wheel is secured by a cross key in the wheel and shaft, thus preventing fore and aft motion of the wheels. The wheels are separated approximately 0.01 inch by crushing pieces inserted between the wheels. The blades are secured to the wheels by dovetails, as shown in Fig. 53.

The intermediate segment, carrying stationary blading, in the first stage of the turbine is secured to the casing by conical-headed through bolts, thus preventing any damage due to their coming loose and getting into the moving parts of the machinery.

All stages except the first have complete peripheral admission. The first stage expanding nozzles are secured to the steam chest by countersunk, cheese headed screws; sufficient metal is peened

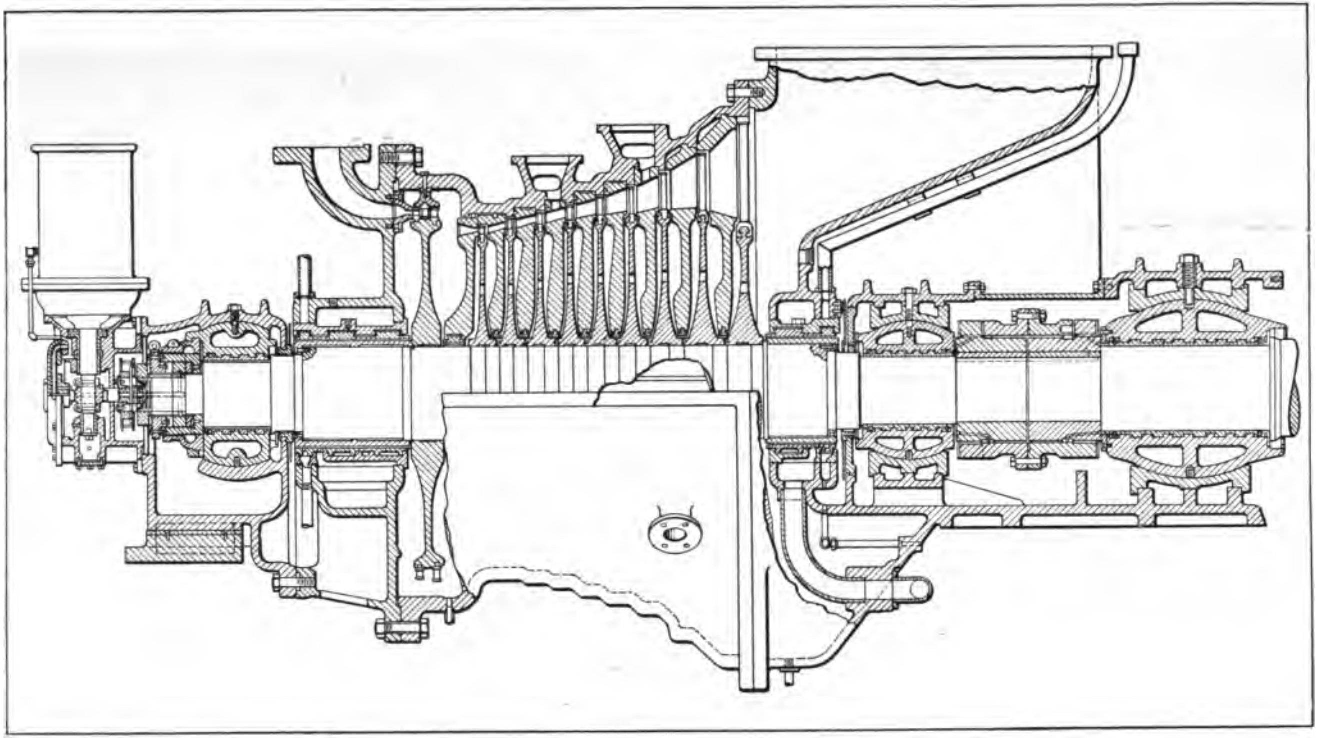


FIG. 53.—U. S. S. *New Mexico:* Section of Main Turbine

over the heads of these to prevent them from getting into the machinery in case of breakage. The admission nozzles for the remaining nine stages are cast into diaphragms which separate the successive stages. These diaphragms are split through the horizontal plane and are secured in the casing against shoulders. The lower half of each diaphragm may be rolled out without lifting the rotors. When the casing is lifted, the top half of the diaphragm may be lowered by backing off a screw on each side which takes the weight of the diaphragm when it is lifted from the lower half. Leakage past diaphragms, along the shaft, is prevented by packing rings of the labyrinth type, made of soft brass.

The turbine casing is split in a horizontal plane and also in a vertical plane at both high pressure and low pressure ends. This makes it possible to lift off the portion of the turbine casing covering the blading without disturbing the exhaust trunk of the turbine and also without removing the steam chest at the high pressure end of the turbine.

The shaft openings in the casing at each end are sealed by labyrinth packing rings which are supplied with sealing steam from the turbine itself when the turbine is not loaded sufficiently to give steam pressure high enough for this purpose; when the pressure falls too low, sealing steam is supplied from the main steam line through a reducing valve. There is an unloading valve on the steam sealing line between the high pressure end and low pressure end which maintains the proper pressure on the sealing line by spilling the excess steam into the eighth stage of the main turbine.

The turbine casing is drained, through valves, by a drain pump located in the center engine room.

A flexible jaw coupling, which is totally enclosed by a housing contained in the middle bearings, couples the turbine to its generators.

The turbine is provided with a bearing at each end mounted on brackets which are integral with the turbine casing. The bearings, which are of the self-alining type, are supplied with forced lubrication from pumps located in the center engine room. These pumps also supply oil pressure for operating the main governor hydraulic relay. The bearings are also water cooled and are supplied with water by the main circulating pump or oil cooler circulating pumps. The cooling coils consist of copper coils imbedded in the babbitt of the bearings. The bearing at the high pressure end carries the turbine thrust bearing, which is of the plain, collar type. The outside shell of the thrust bearing is provided with worm and worm wheel attachment for moving the turbine in the fore and aft direction, to give proper clearance between the buckets and nozzles. There is a clearance indicator at the end of the turbine shaft.

The turbine casing has two openings, one into the fifth and one into the eighth stage, for the admission of exhaust steam, either from the exciting units or from the exhaust line of the ship. These openings are provided with stop check valves and also automatic trip valves. The stop valves are provided so that steam can be admitted to either stage as desired; the "check" feature is added to prevent steam by-passing from the fifth stage to the eighth stage in case both valves should be open and the steam in the fifth stage of a higher pressure than that corresponding to the auxiliary exhaust pressure. The trip valves are operated by the emergency governor. The exhaust line is also provided with a valve for by-passing exhaust steam direct to the main condenser. This valve can be locked open by hand so that the exhaust steam passes direct to the main condenser continuously; it is also spring loaded and set at ten pounds pressure so that pressure in excess of this will relieve itself into the main condenser. This valve is also directly operated by the main turbine governor so that, when the main turbine governor closes all valves on the steam chest, further motion of it will open this by-pass valve, thus admitting the exhaust steam direct to the condenser and by-passing the main turbine. This valve is shown in diagram in Fig. 54.

The emergency governor consists of a ring mounted on the main shaft and held in place by a spring. This ring is slightly unbalanced so that overspeeding the turbine will force the heavy side out against the pressure of the spring and trip the trip valves of the fifth and eighth stages of the turbine and the main throttle valve, thus shutting off all sources of supply of steam to the turbine. At the same time it throws a control valve on the hydraulic relay which closes all the admission valves on the steam chest so that steam will be shut off the turbine even if the main throttle should stick when it is tripped. The steam valves can also be tripped by a hand pull located in the center engine room.

The main governor is driven by a worm gear from the high pressure end of the turbine shaft. It is of the flyball type, the weights being mounted on knife edges and working against a spring. This governor is adjustable and can be set to give any desired speed from 700 revolutions to 2,200 revolutions; when once set it will maintain that speed regardless of changes in load.

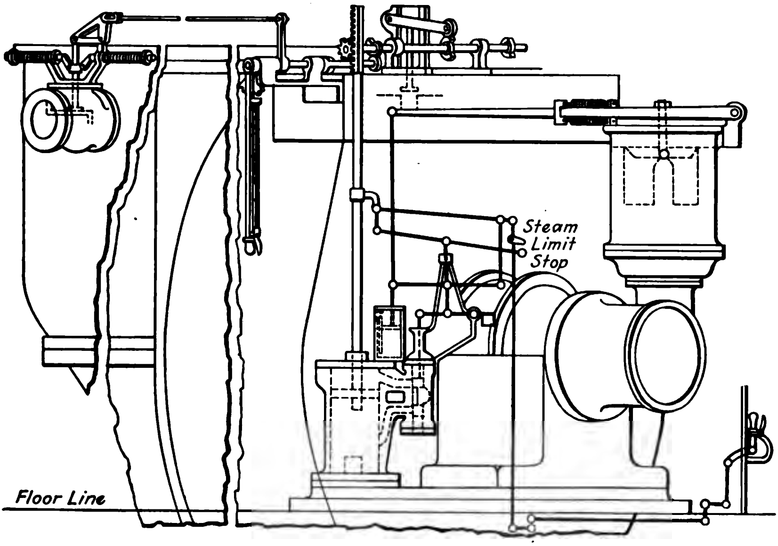


FIG. 54.—U. S. S. *New Mexico:* Diagram Showing Arrangement of Connections of Operating Mechanism

A diagrammatic sketch of the governor and its control gear is shown in Fig. 54. The governor weights operate the pilot valve of a hydraulic relay, which in turn admits oil pressure to a piston driving a rack; this, in turn, drives a pinion which is mounted on a camshaft. Motion of these cams opens successive valves in the steam chest of the turbine, thus admitting the desired amount of steam. The control mechanism for the governor is moved from the center engine room by means of rods and bell cranks, as indicated in Fig. 54. The effect of the motion of this transmission system is to shift the fulcrum about which the governor weights

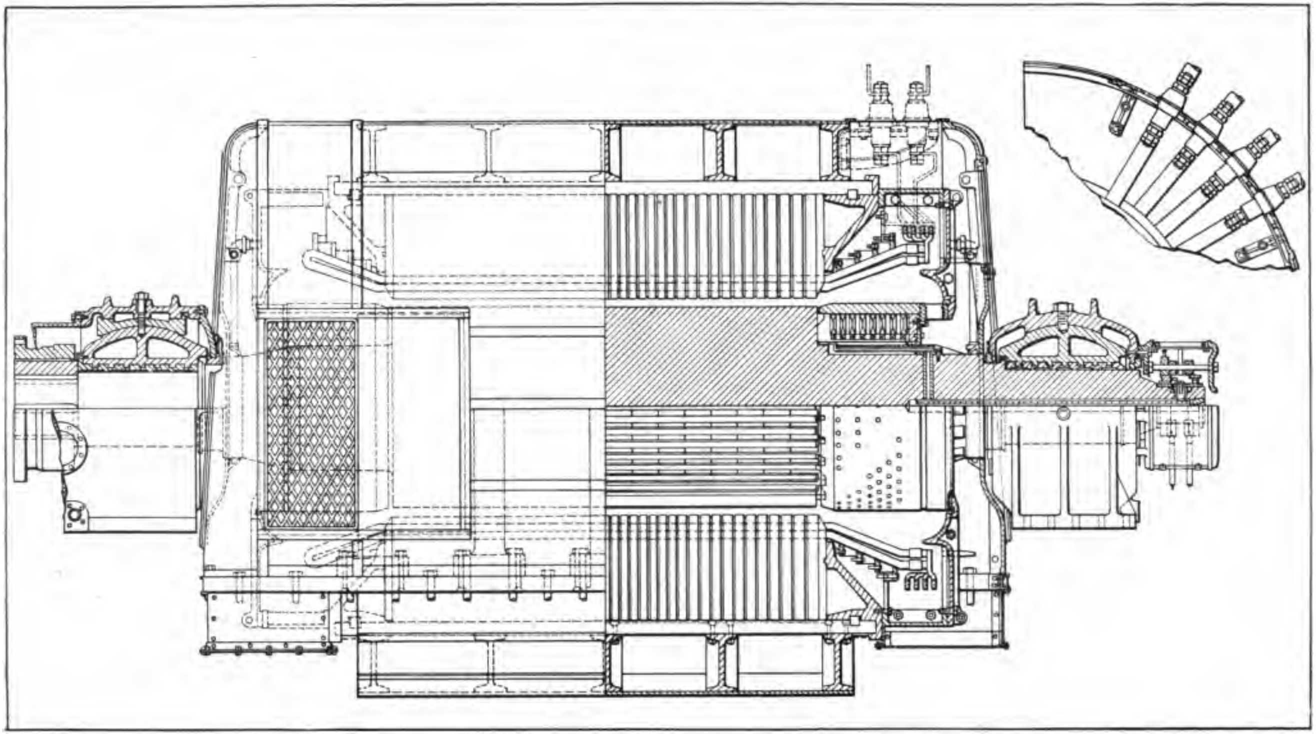


FIG. 55.—U. S. S. *New Mexico:* Section of Main Generator

act and thus to give a different speed for each setting of the fulcrum.

In addition to the system of bell cranks for setting the fulcrum, there is another system of bell cranks and rods coming from the center engine room which operates a stop shown diagrammatically in Fig. 54. The effect of this stop is to limit the motion of the governor for any given setting, thus limiting the amount of steam that the turbine can take for that setting. This steam limit is necessary in connection with the turning of the ship as was explained in Chapter III.

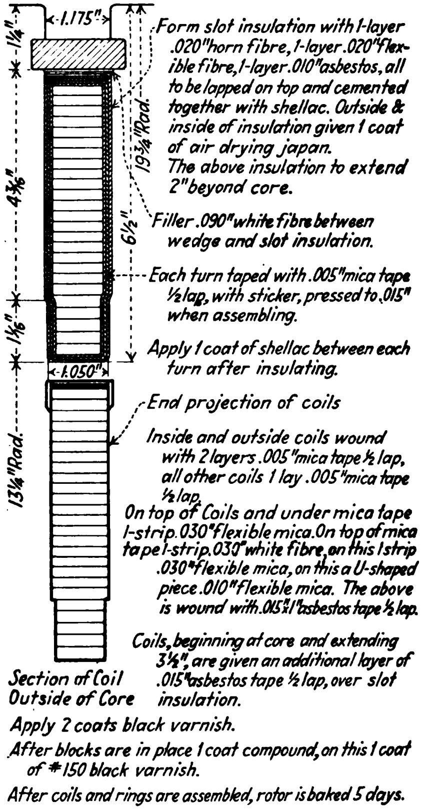
MAIN GENERATOR

A cross section of the main generator is shown in Fig. 55 and the assembled rotor is shown in Fig. 56. The generator is normally rated at 11,500 kilowatts at 80 percent power factor and has an overload rating of 25 percent. It is quarter-phase, two-pole and designed to run at about 2,100 revolutions per minute.

FIG. 56.—Rotor of Main Generator for U. S. S. *New Mexico*

The stator windings of the two phases are arranged as shown in Fig. 28 and described in Chapter IV. Both ends of each independent winding are brought to the terminals of a double throw switch, which, when in one throw, puts the winding in the diametral or parallel connection and, with the generator operating at designed speed and field strength, gives 3,000 volts; with the switch in the other throw, the windings are thrown into the square or series connection and this arrangement at designed field and speed of the generator gives 4,242 volts.

The windings are arranged in this way so as to give the maximum efficiency of the generator when one generator is driving four motors and also when it is driving only two motors, as explained in Chapter IV. In the first case the low voltage connection is used and this utilizes the increased current path when using four motors. When using the high voltage connection, only two motors are driven from one generator, thus cutting the current path down to one-half its value in the other case. The switches for making this change in "set up" are mounted on the outboard bulkheads of the center engine room and are operated in the center engine room; they are called the "generator disconnecting switches."



Form slot insulation with 1-layer .020" horn fibre, 1-layer .020" flexible fibre, 1-layer .010" asbestos, all to be lapped on top and cemented together with shellac. Outside & inside of insulation given 1 coat of air drying japan. The above insulation to extend 2" beyond core.

Filler .090" white fibre between wedge and slot insulation.

Each turn taped with .005" mica tape ½ lap, with sticker, pressed to .015" when assembling.

Apply 1 coat of shellac between each turn after insulating.

End projection of coils

Inside and outside coils wound with 2 layers .005" mica tape ½ lap, all other coils 1 lay .005" mica tape ½ lap.

On top of Coils and under mica tape 1-strip .030" flexible mica. On top of mica tape 1-strip .030" white fibre, on this 1 strip .030" flexible mica, on this a U-shaped piece .010" flexible mica. The above is wound with .015" x 1" asbestos tape ½ lap.

Coils, beginning at core and extending 3½", are given an additional layer of .015" asbestos tape ½ lap, over slot insulation.

Section of Coil Outside of Core

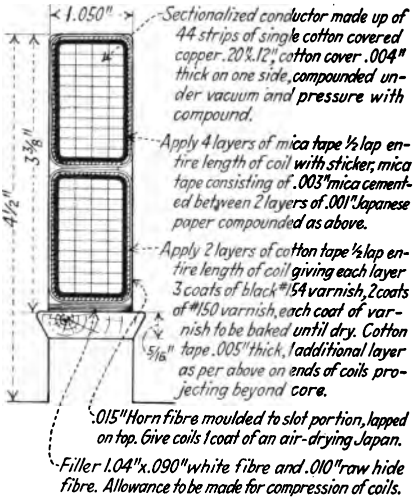
Apply 2 coats black varnish.

After blocks are in place 1 coat compound, on this 1 coat of #150 black varnish.

After coils and rings are assembled, rotor is baked 5 days.

FIG. 57.—U. S. S. *New Mexico:* Generator Rotor Winding Insulation

The generator rotors are designed with a large factor of safety in regard to heating in order to take care of the condition that exists in backing when over-excitation is applied to the main field. The slip rings for admitting exciting current to the field and the ventilating fans are not shown in the drawing of the rotor given in Fig. 56 but are shown in Fig. 55. The slip rings are at the end of the generator away from the turbine and are external to the bearings, thus reducing the length of the rotor; the cable connections to the slip rings are led through slots in the shaft. The ventilating fans are attached to each end of the rotor as shown in Fig. 55. Air is taken in around the shaft at each end of the generator and, after being discharged by the fans, is directed by guide vanes to the air gap between rotor and stator; it then passes through radial ducts in the stator, is collected in an annular chamber around the stator and is finally discharged through an exhaust duct to the main deck of the ship. The rotor is a solid steel forging having radial slots machined in it to secure the rotor windings. The rotor windings are insulated by mica and asbestos. A section of the rotor winding is shown in Fig. 57.



Sectionalized conductor made up of 44 strips of single cotton covered copper .20"×.12", cotton cover .004" thick on one side, compounded under vacuum and pressure with compound.

Apply 4 layers of mica tape ½ lap entire length of coil with sticker, mica tape consisting of .003" mica cemented between 2 layers of .001" Japanese paper compounded as above.

Apply 2 layers of cotton tape ½ lap entire length of coil giving each layer 3 coats of black #154 varnish, 2 coats of #150 varnish, each coat of varnish to be baked until dry. Cotton tape .005" thick, 1 additional layer as per above on ends of coils projecting beyond core.

.015" Horn fibre moulded to slot portion, lapped on top. Give coils 1 coat of an air-drying Japan.

Filler 1.04"x.090" white fibre and .010" raw hide fibre. Allowance to be made for compression of coils.

End clips
Give clips 4 layers of mica tape ½ lap and 4 layers of black cloth and 1 layer of cotton tape (varnish filled) ½ lap.

Finally 2 coats of #150 varnish after assembling, each coat baked 15 hours.

FIG. 58.—U. S. S. *New Mexico:* Generator Stator Winding Insulation

The insulation of the main generator stator winding consists mainly of mica with fibrous material on the end windings. The entire insulation of the coils is treated to make it moisture proof. The generator stator windings are provided with thermo-couples for measuring the rise in temperature; the leads from these thermo-couples are taken to the main switchboard in the center engine room. A section of the stator winding is shown in Fig. 58.

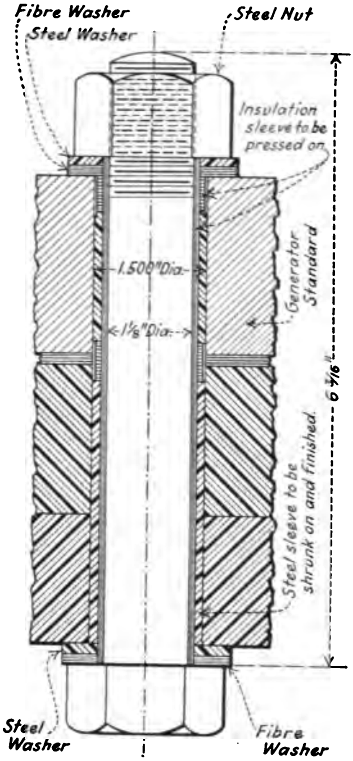


FIG. 59.—U. S. S. *New Mexico:* Method of Insulating Bolts Securing Generator in place

The generator bearings are of similar design to the turbine bearings. They are supported on pedestals which are mounted on foundations built in the ship and are not attached to the generator casing. The pedestal at the end of the generator rests on insulation and is secured by insulated bolts, one of which is shown in

Fig. 59; by insulating one end of the generator, the possibility of having circulating current through the rotor and bearings is prevented. These currents do not usually occur in turbo generators but when they do they are very troublesome and cause rapid deterioration of the "babbitt" in the bearings; it is therefore best to make sure they can not occur.

Main Motors

The overall dimensions and the details of the main motors are shown in Figs. 60, 61, 62, 63 and 64. The motors are of the double squirrel cage type which has already been described in Chapter IV. These are the first large motors of this type that have been built. They are rated at 7,250 horsepower each, at 167 revolutions per minute, which corresponds to a speed of 21 knots of the ship.

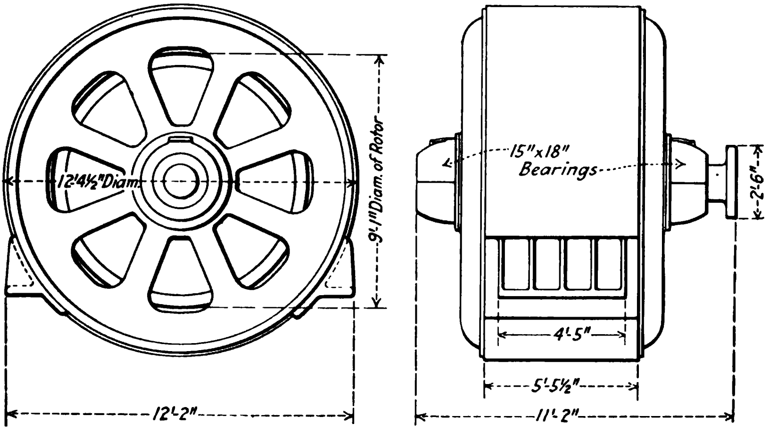


Fig. 60.—U. S. S. *New Mexico:* Main Induction Motor

The motor stator windings are arranged to provide for pole changing; the pole changing switches are located in the center engine room. One throw of these switches will give 24 poles on the stator of the motor and the other throw will give 36 poles. The arrangement of the stator winding to provide for pole changing is shown in Figs. 24, 25 and 26 and has already been described in Chapter IV.

The stator is shown in Fig. 61 and the method of securing the stator end winding is shown in Fig. 63. The insulation is similar

Fig. 61.—Main Motor Stator for U. S. S. *New Mexico*

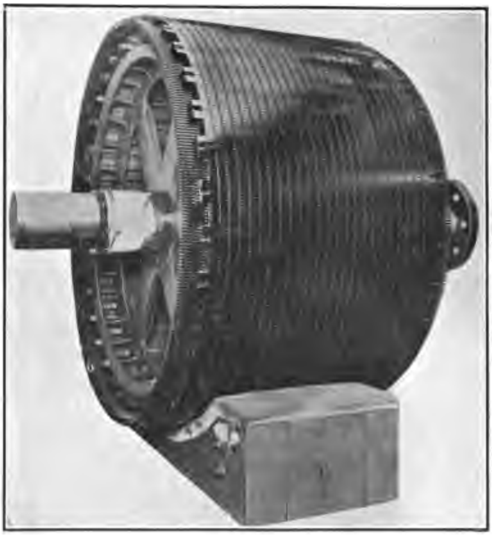


Fig. 62.—Main Motor Rotor for U. S. S. *New Mexico*

FIG. 63.—U. S. S. *New Mexico:* Method of Securing Stator End Winding

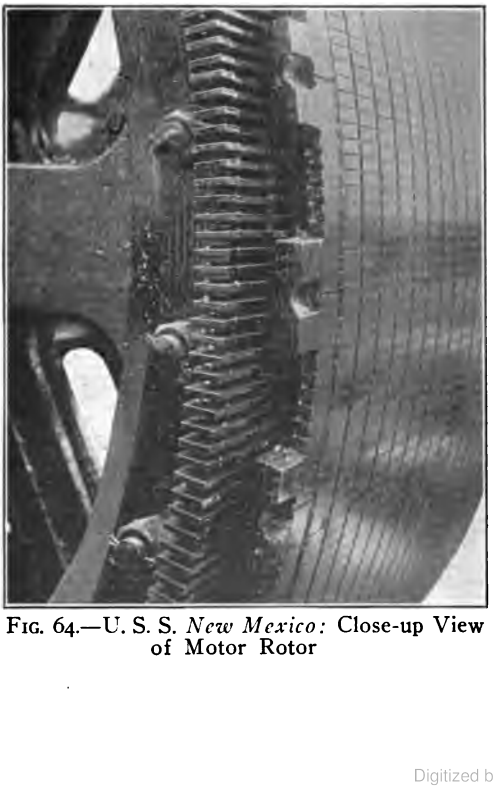
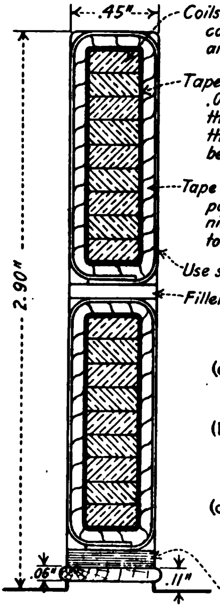


FIG. 64.—U. S. S. *New Mexico:* Close-up View of Motor Rotor

to that of the generator stator, consisting mainly of mica, except for the end windings which are provided with fibrous insulation, the whole being treated to make it moisture proof. A section of the stator winding is shown in Fig. 65.

The motor rotor is shown in Figs. 62 and 64. The rotor winding is a double squirrel cage winding. This type of motor has been described in Chapter IV and the details of the rotor slot are shown in Fig. 12. Each slot in the rotor consists of one slot near the periphery of the rotor and one deeper in the iron of the rotor, the two being connected by a long, narrow air gap. Each of these slots is provided with an independent squirrel cage. The squirrel cage in the outer slot is composed of high resistance bars and that of the inner slot is composed of low resistance bars. The high resistance bars are made of German silver and the low resistance bars of copper. The bars are wedged tightly into the slots in both cases without insulation. Each squirrel cage has the end of its bars connected by short circuiting rings; in the case of the high resistance bars this short circuiting ring is divided



Coils made up of 9 turns of .225" x .110" double cotton covered rectangular copper. Cotton cover .007" on one side. Coils treated with varnish and dried at a temperature that will not soften the bonding.

Tape the slot part and around the bend of the coil three times with .005" mica tape ½ lap. Extend each successive tape slightly farther than the previous one so as to avoid an abrupt change from the taped to the untaped section of the coil. Tape consisting of .003" mica cement between two layers of .001" Japanese paper compound as above.

Tape the coils all over with .005" linen finished tape butt joint on the slot part and ½ lap on the end. Give five dippings and bakings in varnish. This treatment of tape and varnish repeated twice making a total thickness of .051" on one side.

Use slot armor of .010" horn fibre moulded to the coil and overlapping on the top.

Filler .06" oil press board.

Supplementary Explanation of Insulation.

(a.) *The slot part of the coil is taped with mica tape ½ lap three times, the first taping extending approximately 3" around the bend. The second taping 2½" and the third taping 2".*

(b.) *Three treatments of tape and varnish are then applied, each treatment consisting of .005" linen finished tape, butt joint on the slot part and half lap on the ends, and three dippings of varnish, and two dippings and bakings of varnish are then applied.*

(c.) *After the coils are assembled and connected, the windings are sprayed with varnish and baked; the stator frame with the windings in place being put into an oven. It is then taken out and this treatment repeated.*

Filler .09" oil press board.

FIG. 65.—U. S. S. *New Mexico:* Motor Stator Winding Insulation

into segments connected by flexible copper connections to provide for expansion caused by the rush of current that takes place when the motor is reversed. This method of construction is shown in Fig. 64.

Reversal of the motors is accomplished simply by reversing the connections of the two leads of one phase of the motor. This is accomplished by reversing switches located on the alternating current switchboard in the center engine room.

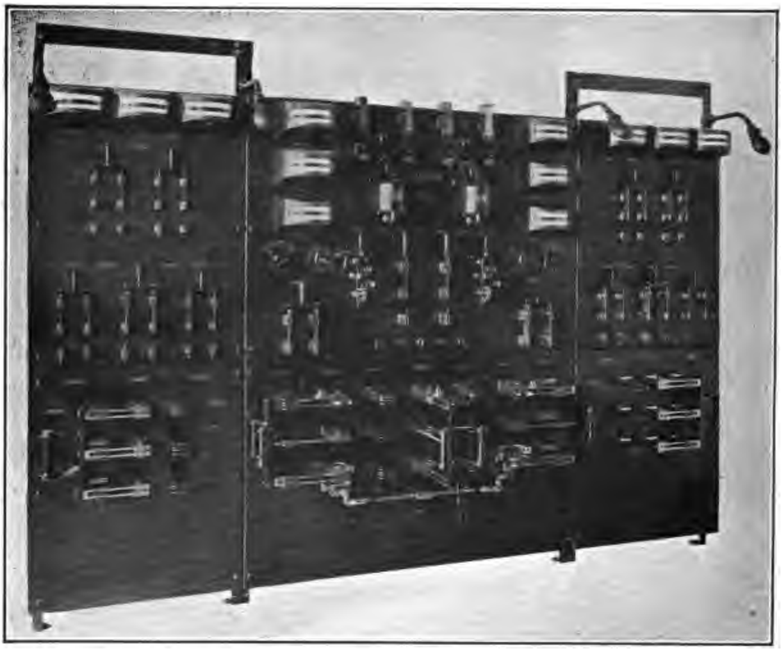


FIG. 66.—U. S. S. *New Mexico:* Direct Current Exciter and Auxiliary Switchboard

The main motors are ventilated by suction blowers located one on each side of each motor on top of its casing; these draw air through the motor and discharge it into ducts which lead up to the atmosphere on the main deck.

EXCITER SWITCHBOARD AND EXCITATION

The exciter switchboard is shown in Figs. 66 and 67. A diagram of the exciter switchboard and direct current wiring is given in Fig. 68. From this wiring plan it will be seen that there are two buses for supplying the auxiliaries. One of these buses can be supplied by either of the exciters and the other is supplied by the after distribution board. This makes it possible always to have two live buses in the engine room for the engine room auxiliaries. The switch supplying each of these units is made double throw, so that if anything goes wrong with one circuit the auxiliaries may be quickly transferred to the other bus without stopping the operations.

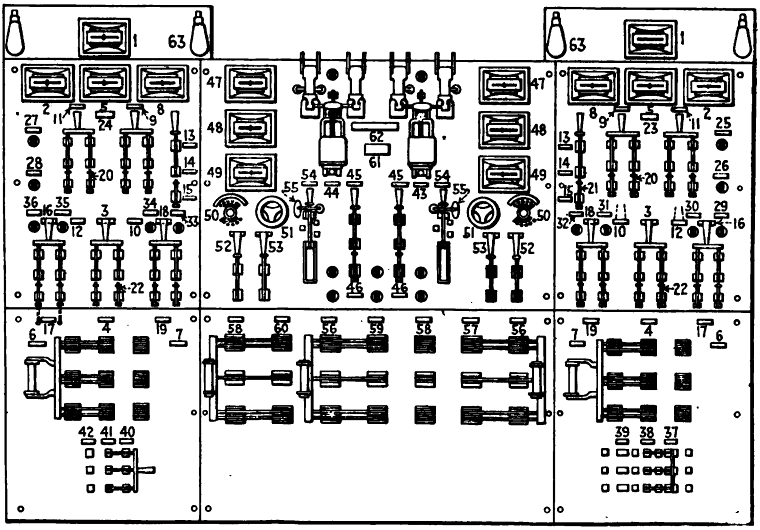


FIG. 67.—U. S. S. *New Mexico:* Instrument Diagram of Exciter Switchboard

The booster is a motor generator set, the motor end of which is a constant speed motor and the generator end of which has a separately excited, reversible field. The leads to both motor and generator are shown in Fig. 68. The field current for excitation of the main generator passes in series through the booster generator and regulation of the strength of the main field current is obtained by varying the voltage of the booster generator. This either bucks or boosts the voltage of the 300-kilowatt generator, according to the throw of the field lever. The range of the booster generator is about 60 volts in either the buck or boost direction.

The booster motor starting switch is interlocked with the main field switch so that the former must be closed before the latter and, conversely, the latter must be opened before the former; this prevents possible damage to the booster generator commutator by passing current through it while the machine is standing still

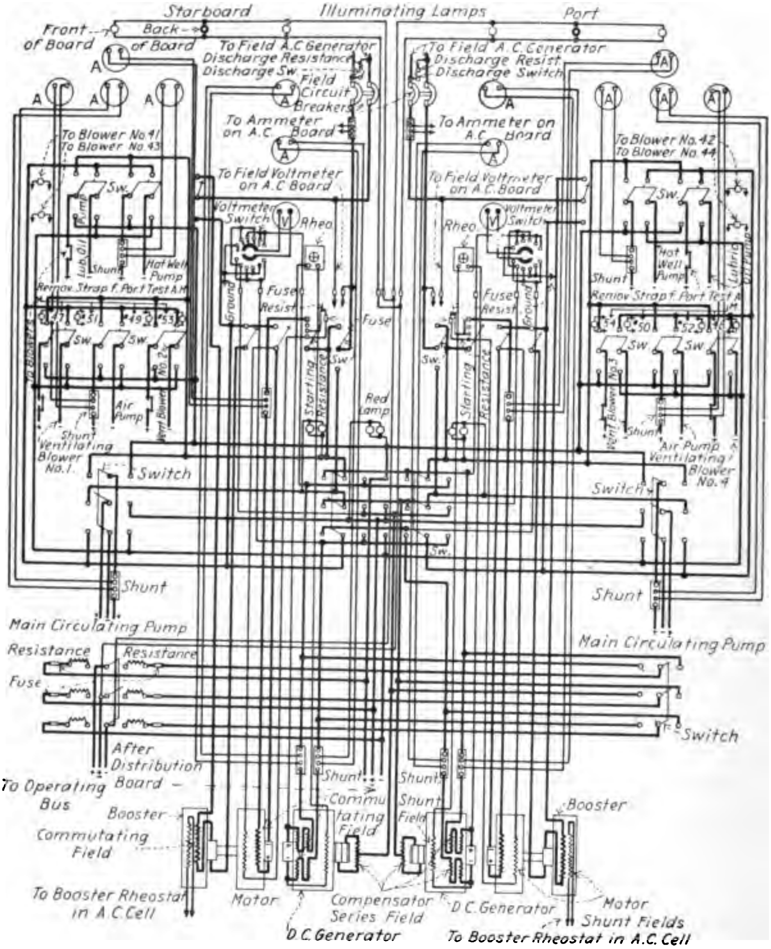


FIG. 68.—U. S. S. *New Mexico:* Diagram of Exciter Switchboard and Direct Current Wiring

and also prevents the possibility of causing the booster generator to run away by opening the motor starting switch.

Exciting current can be taken through either booster from either exciter. The arrangement of the switches does not make it possible to take exciting current from the after distribution room but temporary jumpers are provided so that in a few seconds this connection can be made. In this case provision is made to lock closed the circuit breakers of the generators supplying the after distribution room.

The board is also arranged so that it is possible to use the 300-kilowatt units in the engine room for exciting the main generator field direct by short circuiting the booster in case of trouble with it. In this case the power for driving the engine room auxiliaries on the side of the ship where the booster is disabled would have to be taken from the after distribution room.

Provision is also made for supplying the ship's circuit from either of the exciters; when cruising at slow speeds there will not be much direct current used, and it is possible to cut out the ship's generators and run only on the two exciting units. This gives very economical operation, as it not only provides for very efficient generation of the power by using the exciter exhaust in the main turbine but it allows all the dynamo condenser auxiliaries to be shut down.

The exciter switchboard, in addition to the other direct current switches mounted on it, has also the main field switches which are solenoid operated and are controlled from the main switchboard. These switches are located at the top of the center panel shown in Fig. 66. They are provided with magnetic blow-out to reduce the arcing on opening the main field and are also provided with auxiliary switches which short circuit the main field through a discharge resistance previous to the opening of the main field switch. These switches are arranged for hand operation in case of failure of the solenoid operated feature. They are also arranged so that they can be tripped out by balanced relays located on the main switchboard.

All other switches on the exciter switchboard are of the knife blade type.

Indicating lamps are placed to show which bus is alive, thus facilitating the operation of the switching and lessening chances of mistake.

The main exciter supply switches and buses are arranged so that the exciters can not be thrown in parallel on the same bus or in parallel with the ship's circuit. It is preferable to keep the auxiliary supply on each side of the ship entirely independent of each other and therefore no equalizers are provided.

No circuit breakers are provided in the supply lines from the exciters because the main fields are on these lines and the quick opening of a circuit breaker would cause such a great rise of potential in the field circuit that it would burn up the circuit breaker and might puncture the field insulation.

The following table gives the name and use of all switches, instruments, etc., on the exciter switchboard (the "part numbers" refer to Fig. 67):

Part No.	Description of Apparatus	Name Plate Inscription
1.	DH-3 ammeter, 150-0-150 amp. scale with shunt	Booster Motor
2.	DH-3 ammeter, 200 amp. scale with shunt	Air Pump
3.	D-27 lever switch, d-p., d-t., 250 volt, 135 amp.	Air Pump Bus No. 1
4.	D-27 lever switch, d-p., d-t., 250 volt, 135 amp.	Air Pump Bus No. 2
5.	DH-3 ammeter, 1,500 amp. scale with shunt	Main Circulating Pump
6.	D-27 lever switch, t-p., d-t., 250 volt, 1,200 amp.	Main Circulating Pump —Bus No. 2
7.	D-27 lever switch, t-p., d-t., 250 volt, 1,200 amp.	Main Circulating Pump —Bus No. 1
8.	DH-3 ammeter, 100 amp. scale with shunt	Hotwell Pump
9.	D-27 lever switch, d-p., d-t., 250 volt, 65 amp.	Hotwell Pump — Bus No. 1
10.	D-27 lever switch, d-p., d-t., 250 volt, 65 amp.	Hotwell Pump — Bus No. 2
11.	D-27 lever switch, d-p., d-t., 250 volt, 65 amp.	Lubricating Oil Pumps —Bus No. 1
12.	D-27 lever switch, d-p., d-t., 250 volt, 65 amp.	Lubricating Oil Pumps —Bus No. 2
13.	D-27 lever switch, s-p., d-t., 250 volt, 350 amp.	Booster
14.	D-27 lever switch, s-p., d-t., 250 volt, 350 amp.	Generator Field
15.	D-27 lever switch, s-p., d-t., 250 volt, 350 amp.	Bus

Part No.	Description of Apparatus	Name Plate Inscription
16.	D-27 lever switch, d-p., d-t., 250 volt, 135 amp.	Ventilating Blower No. 1 (or 4) Bus No. 1
17.	D-27 lever switch, d-p., d-t., 250 volt, 135 amp.	Ventilating Blower No. 1 (or 4) Bus No. 2
18.	D-27 lever switch, d-p., d-t., 250 volt, 135 amp.	Ventilating Blower No. 2 (or 3) Bus No. 1
19.	D-27 lever switch, d-p., d-t., 250 volt, 135 amp.	Ventilating Blower No. 2 (or 3) Bus No. 2
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	
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. 47
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. 48
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
39.	D-27 control bus transfer switch, t-p., d-t., 250 volt, 65 amp., with resistance	To Control Bus Selector Switch
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, 2,000 amp. scale with shunt	Positive Ammeter
48.	DH-3 ammeter, 2,000 amp. scale with shunt	Negative Ammeter

Part No.	Description of Apparatus	Name Plate Inscription
49.	DH-3 voltmeter, 300 volt scale	Starboard (or Port) Voltmeter
50.	Voltmeter transfer switch, d.-p., 6-t.	VOLTAGE Bus: Pos. Neg.—Pos. Neu. —Neu. Neg. Grounds: Pos. Grd.—Neu. Grd. —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., 4-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, 1,800 amp.	Port Exciter
57.	D-27 lever switch, t-p., 6-t., 250 volt, 1,800 amp.	Bus No. 1 Starboard
58.	D-27 lever switch, t-p., 6-t., 250 volt, 1,800 amp.	Starboard Exciter
59.	D-27 lever switch, t-p., 6-t., 250 volt, 1,800 amp.	After Distribution Board
60.	D-27 lever switch, t-p., 6-t., 250 volt, 1,800 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	

MAIN SWITCHBOARD

The main switchboard, the main alternating current wiring and the direct current wiring for electric locks are shown in Figs. 69 to 77, inclusive. Figs. 69 to 75, inclusive, show various views of the structure of the main switchboard and of the arrangement of disconnecting switches and of the interior of the board itself, together with the mechanical interlocks between switches.

From these views it will be seen that the main switchboard is a cell structure, built up on angles and carrying panels for mounting instruments on its forward face. The remaining part of the switchboard is enclosed with grille work; there is a door at each end which gives access to the passageway down the middle of the cell. This passageway gives access to the mechanical interlocks

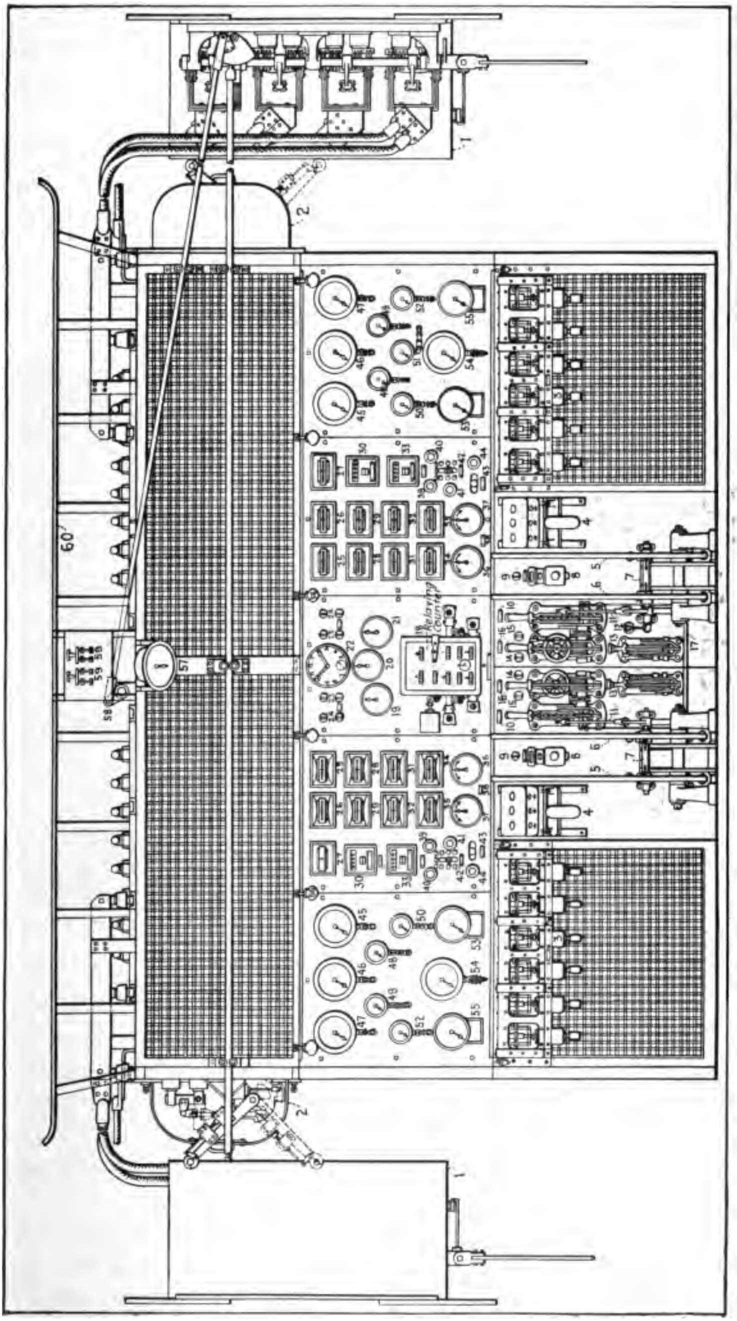


FIG. 69.—U. S. S. *New Mexico:* Diagram of Main Switchboard

located inside the structure, to all the oil switches and to the bus tie switch. The latter is the only switch that is actually operated from the inside of the cell structure.

Fig. 74 shows the various operating levers on the front of the switchboard. Fig. 69 shows the front of the main switchboard with all instruments and levers. All the levers used in the operation of the engines are shown in these views. By referring to Fig. 77, the purpose of all the electric switches used in the various operations can be seen. The switchboard is located in the after end of the center engine room and the operator faces aft when handling the switches.

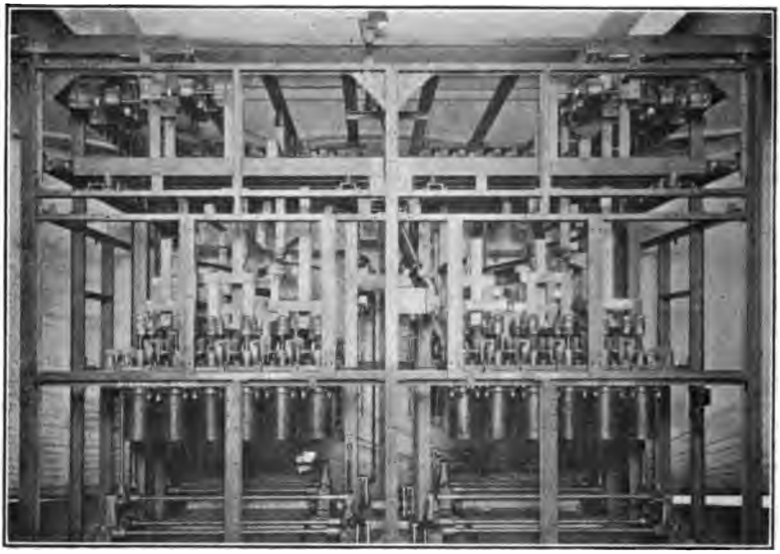


FIG. 70.—U. S. S. *New Mexico:* Propulsion Control Equipment, Front View with Panels Removed

There is a disconnecting switch for each main generator. These are operated in the center engine room and are mounted on the outboard bulkheads on each side as shown in Fig. 69. These switches are of the knife blade type mounted on large brass plates which are bolted to the bulkhead and form a part of it. These plates are necessary since single conductor cable is used to connect the generator to the main switchboard; it is necessary to replace the part of the bulkhead surrounding the cable with non-magnetic material to prevent its overheating and causing losses in the circuits. The insulators for this switch are heavy molded blocks of bakelite, which is very tough and is not susceptible to breakage by shock or vibration. The switches are double throw, one position being for low voltage and the other for high voltage. The reason for using double throw switches has already been discussed in Chapter IV. These switches are interlocked as described below.

FIG. 71.—U. S. S. *New Mexico:* Interior View of Control Cell for Ship's Propelling Machinery

The bus tie switch, also of the knife blade type, is mounted inside the cell structure and is operated at that point. It connects the starboard and port buses so that either generator can run all four motors when desired. The bus tie switch and the two generator disconnecting switches are mechanically interlocked in such a manner that only two of them can be thrown in at any one time. This makes it impossible to connect the two generators to the same bus and thus put them in parallel. They are also mechanically interlocked so that the generator disconnecting switches can be thrown into the low voltage position only when the bus tie switch is closed, and into the high voltage position only when the bus tie switch is open; this interlocking makes it certain that the generators will always be operated in the most efficient way, as has already been described in Chapter IV and illustrated by Fig. 28.

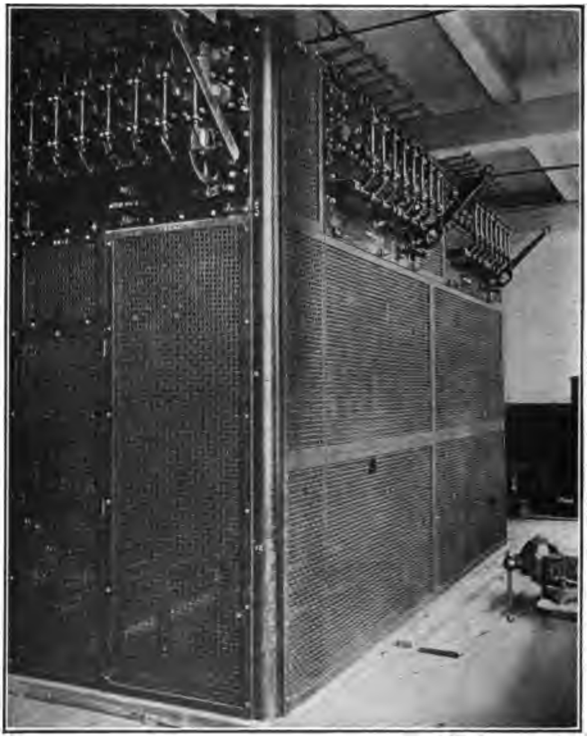


FIG. 72.—U. S. S. *New Mexico:* Exterior View of Control Cell for the Propulsion Control Equipment, Port and Rear View

The motor disconnecting switches are mounted at the top of the cell structure on each side and at the back. These switches and the levers for operating them are shown in Fig. 72. These switches are also of the knife blade type.

None of the knife blade switches can be operated when alive.

How this is prevented will be explained later on in this chapter when the subject of electric locks is discussed.

The reversing switches are of the laminated brush type and are oil break. They have auxiliary contacts and are intended to be large enough to break full load current, but in the actual operation this is never done, as the field is always opened before moving them. The ahead and astern switches are mounted in the same oil tank. This switch is shown in Fig. 75. It will be seen that there is a brush on each side, the two arms being pivoted at the center. The arrangement of the levers is such that one of these arms is moved up and the other down at the same time, one closing for the ahead direction and when moved in the opposite way the other closes for the astern direction. The function of this switch is merely to reverse the connections of two leads (one phase) to the motor. A third lead is, however, inter-

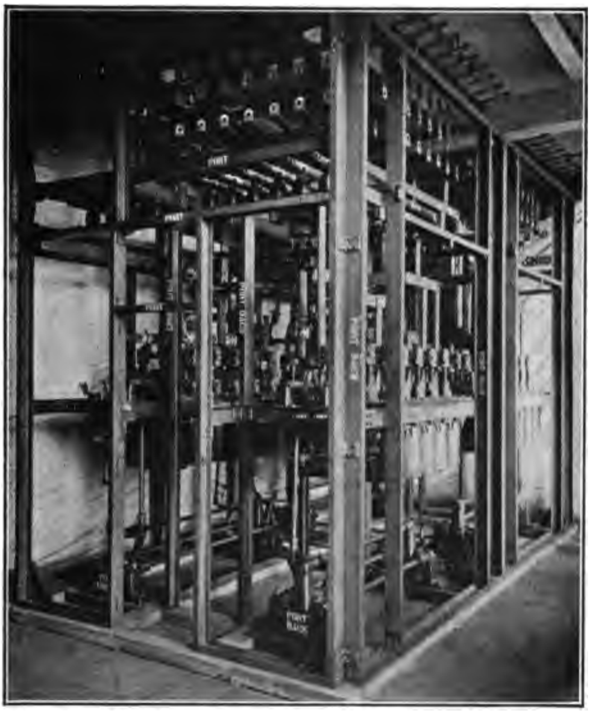


Fig. 73.—U. S. S. *New Mexico:* Propulsion Control Equipment, Partial Back View with Grille Work Removed

rupted by this switch, as, otherwise, opening this switch would still leave one phase connected to the motor, which would then run as a single phase motor, if it were already running. The fourth lead to the motor passes direct from the bus to the motor and is not interrupted by the reversing switch. The reversing switches for the two motors on one side of the ship are operated by the same lever on the front of the switchboard.

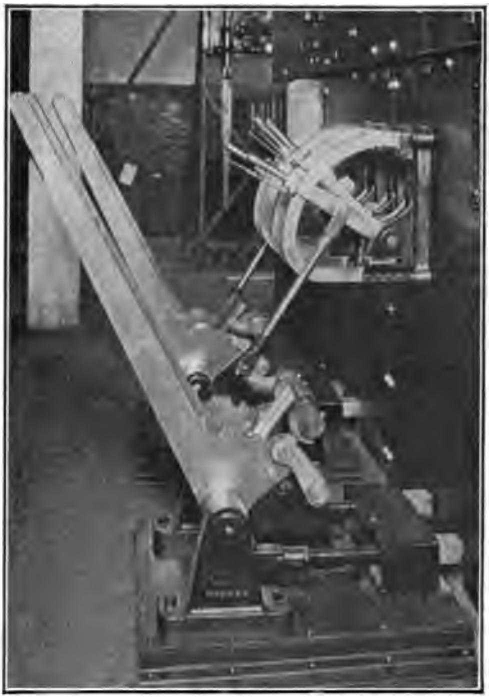


FIG. 74.—U. S. S. *New Mexico:* Main Switchboard, Partial View of Control Levers

The pole changing switches are in every respect similar to the reversing switches. Contact of the laminated brushes on one side connects the motor for 24 poles and contact on the other side for 36 poles. The switches for the two motors on one side of the ship are operated by one lever on the front of the switchboard.

The pole changing and reversing switches are mechanically interlocked with the field lever so that they cannot be moved unless the field lever is in the open position. They are also interlocked with each other so that the reversing lever cannot be thrown in the astern position except when the pole changer is in the 36-pole position, thus always insuring maximum torque for backing.

The main field switches have already been described under the subject of the "exciter switchboard"; they are operated by the outboard small levers shown in the center panel of the main switchboard.

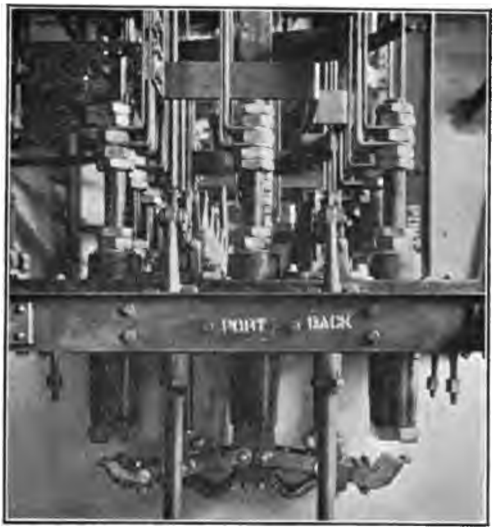


FIG. 75.—U. S. S. *New Mexico:* Propulsion Control Equipment, Detail of Oil Switch

The speed levers are the two small inboard levers at the center of the main switchboard. They are connected by bell cranks and rods to the governor control gear, as shown in Fig. 54 and previously described under the subject of the "main turbines." These levers are moved by worms working over quadrants but they can also be moved by lifting the worms out of engagement when large changes of speed are desired. The speed levers and field levers are mechanically interlocked so that the speed lever must be moved to the slow speed position before the field switch can be opened; also, the speed cannot be increased very greatly without carrying the field lever with it and increasing the excitation on the main field of the generator. This interlock insures that the generator will always be at low speed before reversal of the motors is attempted.

The steam limit levers are mounted directly underneath the field and speed levers; they consist of short arms moving on notched quadrants. The motion of the steam limit levers is transmitted by rods and bell cranks to a stop on the operating gear of the main governor. This lever can be set to allow any desired number of valves to open on the main turbine, and when once set the amount of power that can be developed by the turbine is limited by the amount of steam that the given number of valves will pass. The necessity for these levers has been explained in Chapters IV and V. The relative position of the steam limit stop and governor operating mechanism is always shown at the main

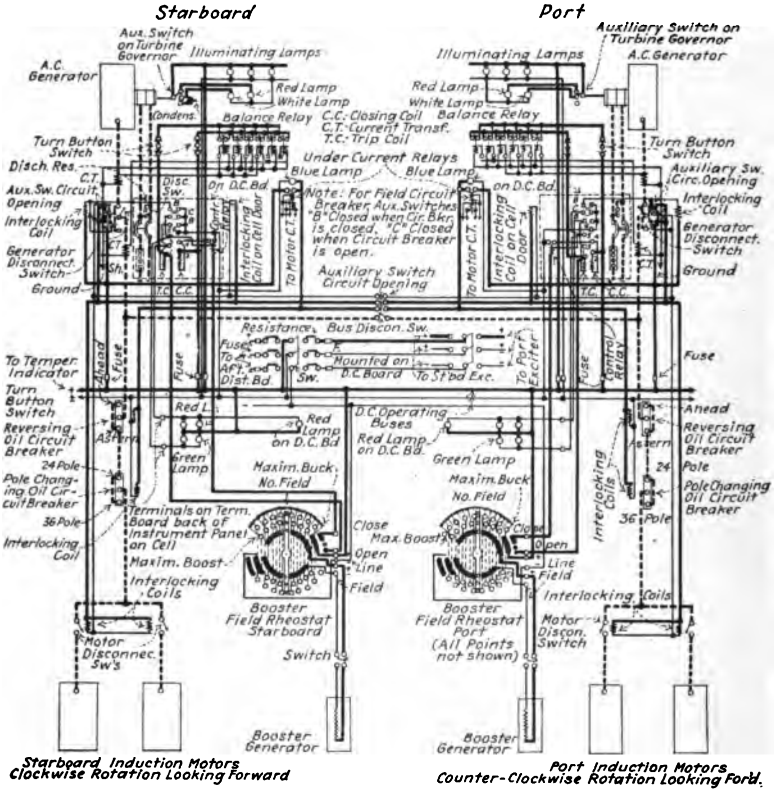


FIG. 76.—U. S. S. *New Mexico:* Control and Interlock Wiring

switchboard, as will be explained later on in this chapter under the subject of electric locks.

The electric locks, indicating lamps, booster field control and main field switch control wiring are shown in Fig. 76. The buses

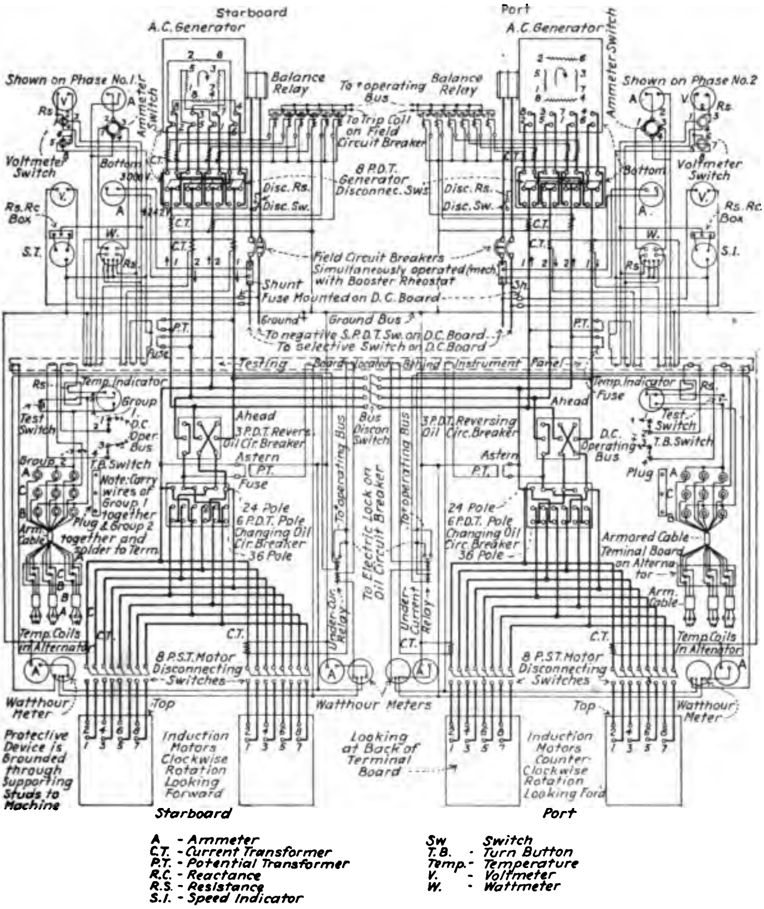


FIG. 77.—U. S. S. *New Mexico:* Main Alternating Current Wiring

for these are supplied by a double throw, transfer switch and a double throw, ordinary knife blade switch. The transfer switch supplies current either from the exciter bus or from the after distribution room. In transferring from one to the other the circuit is not interrupted but resistances are inserted directly in the two circuits so as to make it safe to transfer from one to the other. This is necessary since there will always be a slight difference in potential between the ship's circuit and the exciter circuit. The supply bus from the exciter is fed through a double throw switch which can be thrown on either exciter.

The booster field rheostat and main field switch control are shown in Fig. 76. The first motion of the field lever closes the contact for the closing coil and this closes the main field switch; further motion of the lever reduces the strength of the booster generator field until the middle point of the rheostat is reached at which point the booster generator field takes no current. During this part of the field lever movement the booster voltage "bucks" the exciter voltage. The next motion of the field lever reverses the connections of the booster field and the booster voltage will now "boost" the exciter voltage; further movement of the lever increases the strength of the booster field. Reverse motion of the lever reverses this procedure, the last motion of the lever being to close the contact for the tripping coil which opens the field switch.

The main field switch, when closed, electrically locks the main generator disconnecting switch, motor disconnecting switches and the door to the cell structure of the main switchboard, which are on the same side of the ship as the field switch. This insures that none of these switches will be moved while the circuits are alive. There is a red lamp for indicating when it is closed and a green lamp for indicating when it is open. When only one generator, and consequently one field switch, is in use, the bus tie switch will always be closed. The bus tie switch is provided with an auxiliary switch which connects the two interlocking systems on the two sides of the ship so that either field switch will then operate all locks.

There is a balance relay in each main generator circuit as shown in Fig. 77; the connections from this relay to the trip coil of the main field switch are shown in Fig. 76. This relay is normally in the open position and is held rigidly so by the solenoids in each circuit. In case of short circuit on either of the phases of the generator itself, the motors or the cables, the pull on the solenoids of this relay will become unbalanced, and the contacts in the direct current circuit will be closed, tripping out the main field switch, thus taking all power off the damaged circuit.

Under-load relays are also provided for each generator circuit. These are shown in Fig. 77 and their connections to the electric locks are shown in Fig. 76. The solenoids of these relays are adjustable and can be made to open at any desired value. Until this relay opens, the reversing and pole changing levers are locked so they cannot be moved. A blue lamp indicates when this circuit is closed.

White and red lamps are provided on each side of the board to show the relative position of the steam limit stop and the main governor control gear. The white light indicates an opening of about ⅛ inch (this is adjustable) between the stop and governor gear. When both lamps are lighted this indicates contact between the stop and governor gear; when the white light goes out, leaving only the red lamp on, it indicates that the governor gear is hard up against the stop. This enables the operator to keep his steam limit properly adjusted for each speed of the ship.

The following table gives the name and use of all switches, instruments, gages, levers, etc., on the main switchboard (the "part numbers" refer to Fig. 69):

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 gage	Main Steam
46.	Steam gage	Main Turbine, Steam Chest
47.	Steam gage	Main Turbine, First Stage
48.	Steam gage	Exciter Exhaust
49.	Steam gage	Auxiliary Exhaust
50.	Pressure gage	Oil to Turbines
51.	Pressure gage	Feed Water
52.	Pressure gage	Oil to Governor
54.	Vacuum gage	Main Condenser

GENERATOR EQUIPMENT

Part No.	Description of Apparatus	Name Plate Inscription
1.	Generator disconnecting switch, 8-p., d-t. * (A) Auxiliary switch, d-p., c.o. ...... * (B) Magnetic locking device	Generator Disconnecting Switch
3.	Balance relay	Balance Relay

Part No.	Description of Apparatus	Name Plate Inscription
6.	Reversing lever mechanism	Ahead—Astern
	* (A) K-31 oil circuit breaker, 3-p., d-t., 5,000 volt, 3,000 amp.	
	* (B) Magnetic locking device	
7.	Interlock between reversing and pole-changing levers	
10.	Field control mechanism	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., 2,400 amp., 5,000 volt, operating mechanism and auxiliary switch	
17.	Across-ship interlocking shaft for 12	
23.	Red bull's eye lamp for field switch	Generator Field, closed
24.	Green bull's eye lamp for field switch	Generator Field, open
25.	H-2 ammeter, 15 amp. with 10,000 amp. scale	Generator Ammeter
26.	H-2 voltmeter, 150 volt with 6,000 volt scale	Generator Voltmeter
27.	DH-3 temperature indicator (70-250 deg. F.) scale	Generator Temperature Indicator
27.	DH-3 temperature indicator (20-120 deg. C.) scale	Generator Temperature Indicator
28.	DH-3 field ammeter, 600 amp. with shunt	Generator Field Ammeter
29.	DH-3 field voltmeter, 300 volt	Generator Field Voltmeter
31.	H-2 indicating wattmeter, 110 volt, 4 amp., 20,000 kw. scale	Generator Wattmeter
	* (A) E-18 current transformer, 3,000/5 amp.	
	* (B) AQ-1 potential transformer, 4,400/110 volt, 200 w.	
	* (C) Fuse support with fuse holder and fuse, 4,400 volt	
32.	H-4 speed indicator, 110 volt, 1,000-2,600 r.p.m. scale	Generator Speed Indicator
39.	Ammeter transfer switch	Generator Ammeter Transfer Switch
40.	Voltmeter transfer switch	Generator Voltmeter Transfer Switch
41.	Balance relay cut-out switch	Balance Relay Cut-Out Switch
42.	Temperature indicator transfer switch	Temperature Coils
43.	Temperature indicator test switch	Test
44.	Temperature indicator supply switch	Indicator Supply
58.	Interlock between generator disconnecting switches and bus section switch	
59.	Booster generator field switch	Booster Generator Field

MOTOR EQUIPMENT

Part No.	Description of Apparatus	Name Plate Inscription
2.	Motor disconnecting switch, 8-p., s-t., 600 amp., 5,000 volt	
	* (A) Magnetic locking device	
5.	Pole-changing lever mechanism	24 Poles—36 Poles
	* (A) K-31 oil circuit breakers, 6-p., d-t., 5,000 volt, 1,500 amp.	
	* (B) Magnetic locking device	
8.	Under current relay	Under Current Relay
9.	Blue bull's eye indicating lamp for 8	
18.	Revolution counter	
19.	Stop clock—average starboard shafts	
20.	Stop clock—average all shafts	
21.	Stop clock—average port shafts	
30.	IS-4 watthour meter, 110 volt, 5 amp.	Motor No. 1 (or 3)
33.	IS-4 watthour meter, 110 volt, 5 amp.	Motor No. 2 (or 4)
	* (A) W-2 current transformer, 800/5 amp.	
	* (B) AQ-1 potential transformer, 4,400/110 volt, 200 w.	
	* (C) Fuse support with fuse holder and fuse, 4,400 volt	
34.	H-2 ammeter, 5 amp. with 1,600 amp. scale	Motor No. 2 (or 3) A.C. Ammeter
35.	H-2 ammeter, 5 amp. with 1,600 amp. scale	Motor No. 1 (or 4) A.C. Ammeter
36.	Direction indicator motor No. 2 (or 3)	
37.	Direction indicator motor No. 1 (or 4)	
53.	Electrical speed indicator motor No. 2 (or 3)	
55.	Electrical speed indicator motor No. 1 (or 4)	

* Located inside cell.

MISCELLANEOUS EQUIPMENT

Part No.	Description of Apparatus	Name Plate Inscription
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	

List of Mechanical and Electrical Locks on the Alternating Current and Direct Current Switchboards

ALTERNATING CURRENT SWITCHBOARD

Mechanical

(1) The bus tie switch and the two generator disconnecting switches are interlocked so that only two of them can be closed at any one time.

(2) The bus tie switch and the two generator disconnecting switches are interlocked so that when the bus tie switch is closed, the generator disconnecting switches can be closed only in the low voltage position and when the bus tie switch is open the generator disconnecting switches can be closed only in the high voltage position.

(3) The generator field switch lever is interlocked with the reversing and pole changing switches so that the latter two can not be moved from either the open or closed position unless the field switch is open; when the bus tie switch is closed, one field lever will lock the switches on both sides of the ship; when the bus tie switch is open, each field lever locks only the switches on its own side of the ship.

(4) The field levers and speed levers are interlocked so that the speed lever must be brought to a low speed position before the field can be opened and, conversely, the field must be increased, if a large increase of speed is made.

(5) The reversing switches and pole changing switches are interlocked so that the reversing switches can not be thrown to the "astern" position unless the pole changing switches are in the 36-pole position.

(6) Motor disconnecting switches are locked when closed so they can not be opened by shock.

Electrical

(1) When the main field switch is closed, the switchboard cell doors, generator disconnecting switches and motor disconnecting switches are locked so that they can not be moved whether they are in the "open" or "closed" position; when the bus tie switch is closed, one field lever locks both sides of the ship; when the bus tie switch is open, each field lever locks only the door and switches on its own side of the ship.

DIRECT CURRENT SWITCHBOARD

Mechanical

(1) The field switches are interlocked with the booster motor starting switches so that the starting switch must be closed before its corresponding field switch can be closed; conversely the field switch must be open before the starting switch can be opened.

Electrical

(1) There are no electrical locks on the direct current switchboard, but all switches that open the main field circuit are marked with red handles as a warning not to open them without first making sure that the main field switch is open.

OPERATION OF THE MACHINERY

Three conditions of normal steaming were described in the beginning of this chapter and the operation of the machinery for both ahead and astern motion of the ship will be described for each of these conditions. The first condition is with one generator and four motors, the latter being arranged for 36 poles; the second condition is with one generator and four motors, the latter being arranged for 24 poles; the third condition is with two generators and four motors, the latter being arranged for 24 poles. The operation is as follows:

(1) *Getting Under Way with One Generator, the Motors Being on the 36-Pole Connection.*—Before reporting ready to get under way, the generator that it is desired to use would be tested out and then set to run at low speed; the bus tie switch would be closed and the generator disconnecting switch would be closed in the low voltage position. The field switch of the generator and the pole changing and reversing levers would be open. On receiving a signal "Ahead,"

(*a*) The pole changing switch would be thrown in the "36-pole" position.

(*b*) The reversing lever would be thrown in the "Ahead" position.

(*c*) The field switch would be closed and brought up to the desired field strength.

(*d*) The turbine would then be brought up to the desired speed.

(2) *Reversing.*—With the ship going ahead under conditions described above, under (1), on receiving a signal "Astern,"

(*a*) The field switch would be opened and the speed lever brought to low speed at the same time.

(*b*) As soon as the under-current relay operates, the reversing levers would be thrown to the "Astern" position.

(*c*) The field switch would then be closed and over-excitation applied to the generator until the motors have reversed and come up to synchronous speed, when the field would be reduced to its normal value.

(*d*) The speed of the turbine would then be brought up to whatever is desired.

(3) *Getting Under Way with One Generator, the Motors Being on the 24-Pole Connection.*—In this case, getting under way is exactly as described under (1), except that the pole changing switches would be thrown into the 24-pole position.

(4) *Reversing.*—Assuming the ship to have gotten under way with conditions as described above under (3), on receiving a signal "Astern,"

(*a*) Open the field switch and throw the speed lever to low speed at the same time.

(*b*) Throw pole changers to 36-pole position.

(*c*) Throw reversing switches to "Astern" position.

(*d*) Apply over-excitation to the field of the main generator until motors have come into synchronism, and then reduce field to normal value.

(*e*) Bring turbine up to desired speed.

(5) *Getting Under Way with Two Generators.*—In this case the bus tie switch would be open and the two generator disconnecting switches would be closed in the high voltage position. Field switches would be open; generators would be running at slow speed and pole changing and reversing switches would be open. If signal "Ahead" is received, the operations carried out would be exactly as described under (3), except that it would be performed on two generators instead of one.

(6) *Reversing.*—After having gotten under way with conditions as above described under (5), if a signal "Astern" were received, the operations would be exactly as described under (4), except that they would be carried out for two generators instead of one.

TRIALS

The *New Mexico* held two sets of official trials. On the first trials, the ship had been out of dock for about seven weeks and required an excessive horsepower to make her speed, so she was docked and a second set of trials run. The water rates were not so good at two points on the second trials as on the first due to the fact that at these speeds the ship was "bucking" a heavy head sea. The ship did not quite come up to her guaranteed water rates at any speed except ten knots.

The following tables give the water rates obtained on the two trials and also data obtained on the second trials. Water rates include the steam for excitation, main air pumps, main condensate pumps, main circulating pumps, forced lubrication pumps and main motor ventilating blowers, as well as for the main turbines.

Speed.	Water rate, first trial.	Water rate, second trial.
Full speed	12.29	12.01
19 knots	11.926	12.33
15 knots	11.667	12.475
10 knots	14.223	13.96

	4-hour full power trial.	4-hour 19-knot trial.	4-hour 15-knot trial.	1-hour. 10-knot trial.
Steam at boilers, pounds gage	278.6	274.8	273.8	....
Turbines, pounds gage	272.1	274.2	274.6	277.5
Turbines first stage, pounds gage	139.7	104.4	86.4	42.5
Vacuum, inches	29.	29.5	29.8	30.
Barometer, inches	30.83	30.77	30.92	30.79
Fireroom air pressure, inches of water	4.1	3.4	2.3	1.7

	4-hour full power trial.	4-hour 19-knot trial.	4-hour 15-knot trial.	1-hour. 10-knot trial.
Feed water temperature, degrees F.	182.8	189.7	203.4	208.9
Main generators, volts	4,257.	3,740.	2,915.6	1,950.
amperes	1,873.5	1,565.	2,206.2	1,600.
field, volts	171.7	152.15	143.8	118.
field, amperes	318.25	285.6	290.	245.
revolutions per minute	2,042.	1,825.5	2,012.5	1,450.
Main motors, amperes	994.5	860.3	572.5	417.5
revolutions per minute	167.69	152.2	115.35	80.49
Slip of propellers, percent	16.	14.97	13.24	14.83
Speed, in knots	21.08	19.37	14.98	10.26
Shaft horsepower (from curve)	31,197.	23,233.	9,648.	3,690.

CHAPTER XII

The California, Maryland and West Virginia

THE machinery of the *California, Maryland* and *West Virginia* is similar to that of the *New Mexico,* but there are some differences. Owing to the arrangement of the machinery compartments, the wiring layout in particular is entirely different. These ships were originally designed to use electric propulsion so that all its advantages are utilized, instead of merely adapting the machinery to a ship already designed as was the case with the *New Mexico.* This chapter will, therefore, cover only those points in which the machinery differs from that of the *New Mexico.*

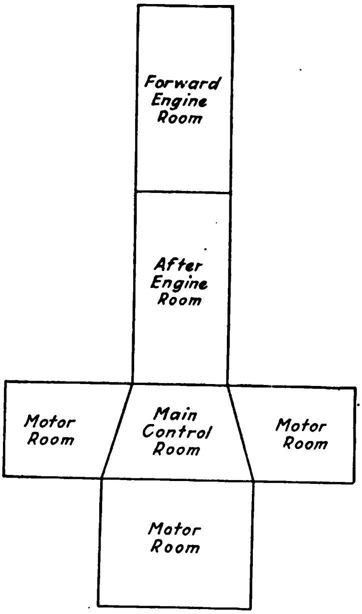


FIG. 78. — U. S. S. *California, Maryland,* and *West Virginia:* Arrangement of Machinery

The arrangement of machinery compartments is shown in Fig. 78. The turbo generators and all auxiliaries, except forced draft blowers for the boilers, are located in two adjoining engine rooms, one forward of the other, on the centerline of the ship. In these compartments are also located the ship's generators, the exciters and the direct current switchboards; the main switchboard is located in the main control room which is just abaft the after engine room. Two of the main motors are located in a compartment abaft the main control room and the other two are located in compartments alongside the main control room.

The propelling machinery is of the same horsepower as that of the *New Mexico* and the "general description" of the machinery of the *New Mexico* given in Chapter XI applies equally well to these ships.

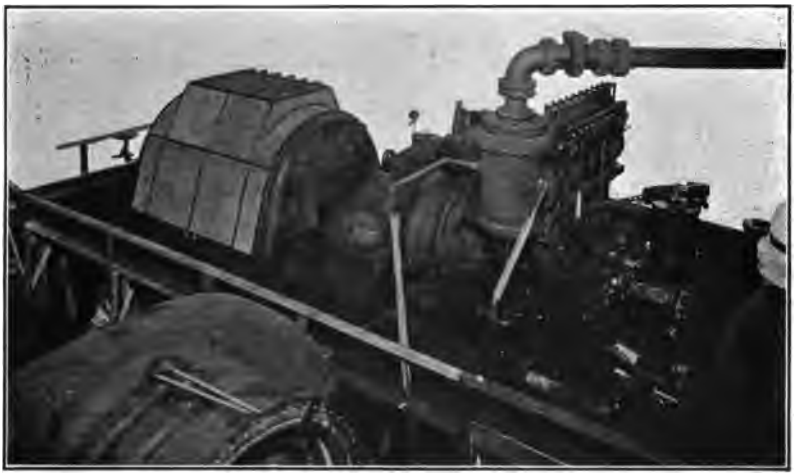


FIG. 79.—U. S. S. *California:* Propulsion Unit No. 2 Assembled for Test; 10-Stage Curtis Steam Turbine, 2,065 R. P. M., Direct Connected to 10,600 Kilowatt Alternating Current Generator

MAIN TURBINE

The turbine and its details are shown in Figs. 79, 80, 81 and 82; it is similar to that of the *New Mexico,* the most important difference being that it is arranged for downward exhaust. The main condenser is located beneath the turbine and this makes all arrangements for disassembly and repair very simple; it also makes the turbine middle bearing, coupling and turbine gland much more accessible than where the condenser is overhead.

Fig. 82 shows the auxiliary oil pump which is fitted to the end of the shaft driving the governor. This pump will supply sufficient oil to lubricate the main turbo generator and to operate the hydraulic relay for the governor very slowly. In case of failure of the forced lubrication pumps, the supply of oil to the main motors is automatically shut off and all the oil supplied by the auxiliary pump is used for the main generator. This is an improvement over the *New Mexico* where the only provision for an emergency supply of oil to the generator is a gravity feed from the supply tanks in the engine room. The turbine bearings are not water cooled as on the *New Mexico* but are provided with a more liberal oil supply.

FIG. 80.—U. S. S. *California:* View of Assembled Turbine Rotor for Propulsion Unit No. 1

The auxiliary exhaust and exciter exhaust connection to the main turbine is shown in Fig. 83. The non-condensing turbo generator exhausts into the auxiliary exhaust line through a constant back pressure valve set at 10 pounds gage pressure. The auxiliary exhaust passes through a constant back pressure valve set at 10 pounds gage pressure, then through a strainer, then through a butterfly valve controlled by the main governor, then through a quick closing valve actuated by the emergency governor, then through one of two stop check valves and into the fifth or eighth stage of the main turbine.

Fig. 81.—U. S. S. *California:* Hydraulic Operating Mechanism and Operating Governor for Propulsion Unit No. 1

Fig. 82.—U. S. S. *California:* Spiral Gear Driven Oil Pump for Propulsion Unit No. 1

The auxiliary exhaust also has a by-pass to the condensers and this is fitted with a constant back pressure valve set at 15 pounds gage pressure. The valve set at 10 pounds keeps this pressure on the auxiliary exhaust line unless the supply to the main turbine is shut off, in which case the pressure will rise to 15 pounds and the exhaust will pass into the condenser.

The back pressure valve from the non-condensing exciter is provided so that in case this machine is being used in port and the exhaust is being used in the evaporators a constant pressure will be maintained on the exciter exhaust.

The butterfly valve is really the first admission valve of the turbine and it is opened by the main governor before any of the admission valves on the turbine are opened, and is closed after they are all closed.

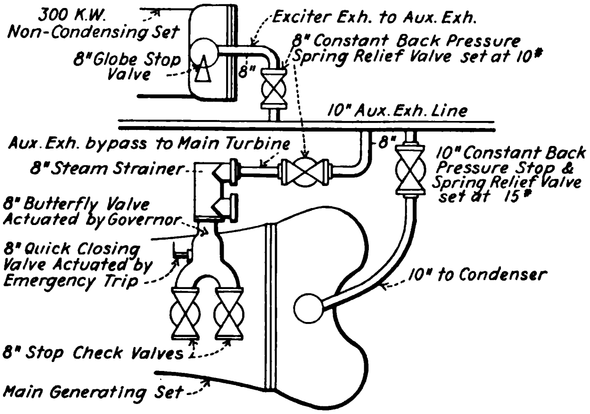


FIG. 83.—U. S. S. *California:* Auxiliary Exhaust and Exciter Exhaust Connections to Main Turbine

The quick closing valve is provided so that the emergency governor can shut off all steam supply to the turbine in case of over-speeding.

Two openings are provided in the turbine casing so as to utilize the auxiliary exhaust at the most economical point; the openings are closed by stop valves which are provided with "checks" to prevent steam by-passing in case they should both be open at the same time or in case the pressure in the turbine casing should be higher than that in the exhaust line.

The method of controlling the speed, the steam limits, etc., are similar to those used on the *New Mexico.*

MAIN GENERATOR

The main generator is shown in Figs. 84 and 85. It is practically identical with that of the *New Mexico* except as to ventilating arrangements. The air intake and outlet are provided with quick closing valves which are operated by levers on the generator casing as shown in Fig. 85. The valve for closing the air outlet is shown in Fig. 84; it consists of a series of shutters connected

FIG. 84.—U. S. S. *California:* View of Alternator Showing Air Discharge Damper

FIG. 85.—U. S. S. *California:* Alternator Stator Ready for Shipment

together like a Venetian blind and operated by a single lever. These valves are provided so that in case of fire in the generator, all air can be shut off and steam can be admitted to the interior of the air casing to smother the fire.

MAIN MOTORS

The main motor is shown in Fig. 86. The stator and its windings are practically identical with that of the *New Mexico.* The contactors used for short circuiting the rotor winding can be seen mounted on the frame of the motor. Direct current heaters are placed in the base of the stator.

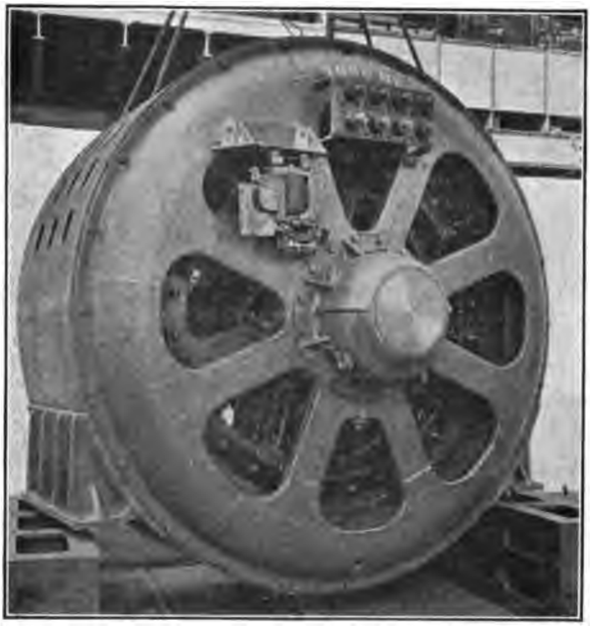


FIG. 86.—U. S. S. *California:* Main Motor

The rotor of this motor has already been described in Chapter IV and a section of the rotor winding is shown in Fig. 16. It is entirely different from that of the *New Mexico.*

The definite wound part of the rotor winding connects to slip rings carrying brushes which connect to solenoid operated contactors mounted on the frame of the motor. These contactors are operated by direct current and are controlled by motion of the field lever on the main switchboard. As explained in Chapter IV, the definite winding is not short circuited until the motors have been brought "into step" with the generator; also the act of short circuiting takes place with 150 percent over-excitation on the generator so as to insure sufficient torque for bringing the motors "into step" with the generator under the new condition. After the motors come "into step," the excitation is reduced to normal.

In the reverse movement of the field lever, the field switch and contactors open simultaneously so that it is not possible to open the field switch and leave the contactors closed.

The definite winding on the rotor is arranged to work with a stator arranged for pole changing in a similar manner to that described in Chapter IV and illustrated by Fig. 27, except that in this case the definite winding is arranged to give equivalent squirrel cage action with the stator arranged for 24 poles instead of 36 poles; this is done because these ships are arranged to back on 36 poles as is the case with the *New Mexico,* and the equivalent squirrel cage winding is not suitable for backing.

The motors are always started in either the ahead or astern direction with the stator winding arranged for 36 poles and with the definite winding on the rotor "open circuited" so that only the high resistance squirrel cage winding is effective; after the motor is "in step" with the generator the definite winding can be short circuited. If the motors are backing the 36-pole connection can not be changed; but, if they are going ahead, a shift can be made from 36 poles to 24 poles, if desired. In this case it will be immaterial whether the contactors are closed or not since the definite winding of the rotor becomes an equivalent squirrel cage when the stator winding is arranged for 24 poles.

It will be noted that the motors can neither be started nor reversed when the stator winding is arranged for the number of poles which converts the definite winding of the rotor into an equivalent squirrel cage; the squirrel cage will be of very low resistance and would therefore not give sufficient torque to reverse the motor.

Thermo-couples for measuring the temperature rise of the stator coils are fitted on the motors as well as on the generators.

The motor bearings are arranged for ring lubrication as well

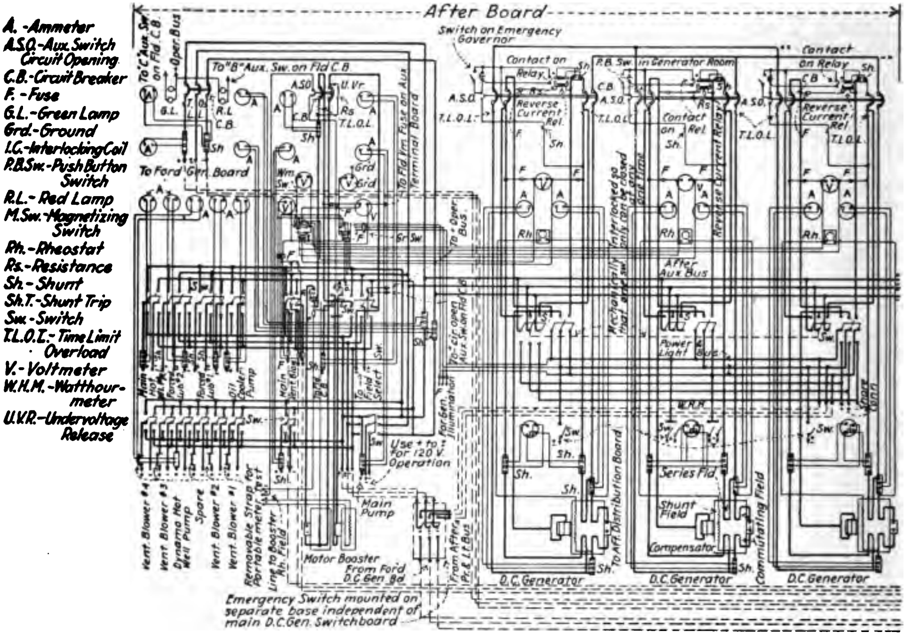


FIG. 87.—U. S. S. *California:* Direct Current

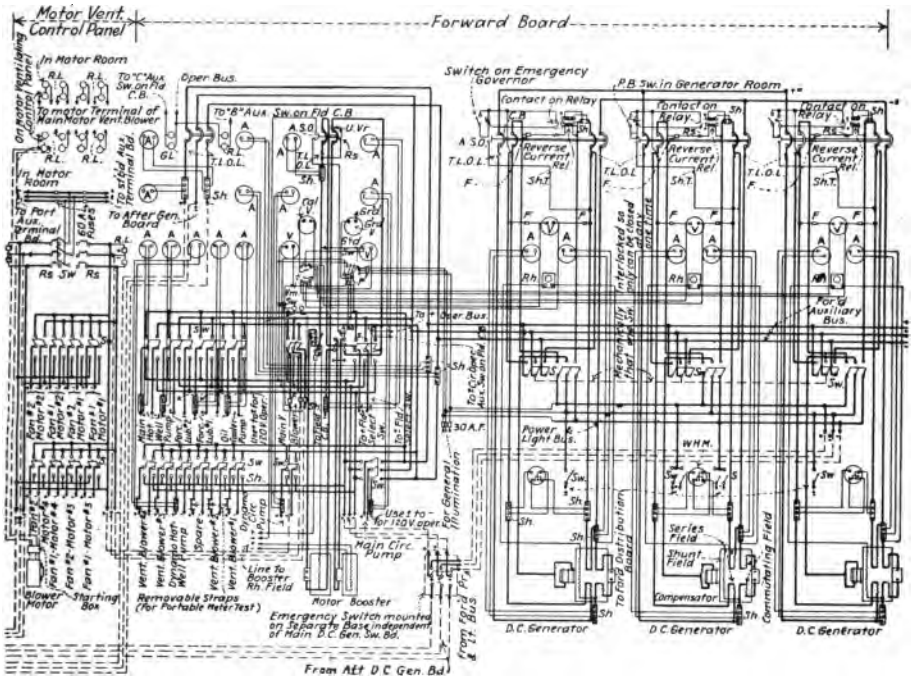
as forced lubrication so that they can run independently of the lubricating system in case of failure of the latter.

SWITCHBOARDS

There is a direct current switchboard in each engine room for the 300 kilowatt generators and also for the motor driven auxiliaries and for excitation. There is a direct current switchboard in the control room for controlling the ventilating blowers for the main motors and also for supplying direct current to the "control circuit." There are two terminal and testing boards in the control room for controlling the control circuits, instruments, etc. There is a main switchboard in the main control room for controlling the main turbo generators and motors. Each of these boards and the wiring will be described below.

DIRECT CURRENT WIRING

The direct current wiring is shown in Fig. 87. From the diagram it will be seen that any one of the generators in an engine room can be used for furnishing excitation and power for the motor driven auxiliaries or for supplying current to the ship's distribution boards. When a generator is being used to



Switchboard Wiring, Back View

supply the auxiliary bus, it is connected in by a knife blade switch and there is no circuit breaker in the circuit; when used to supply the ship's power and light bus, the current passes through a circuit breaker. Generators can be run in parallel on the power and light bus but not on the auxiliary bus; this is prevented by interlocking the three generator switches so that only one can be closed at a time. This interlock can be released by hand, if desired, so that in an emergency a generator could be paralleled before cutting it out so as not to interrupt the supply of excitation.

The connections from the ship's power and light bus to the distribution boards are in duplicate and each set is provided with switches so that, in case of trouble on one lead, it can be cut out and the distribution board can still be supplied although at reduced capacity.

The switches for supplying the auxiliaries are double throw; one throw is to the auxiliary bus of the room in which the auxiliary is located and the other throw is to a stand-by bus. This stand-by bus is supplied through a double throw switch, one throw of which connects to the light and power bus in the same room as the auxiliary and the other throw to the auxiliary bus in the other engine room. This really provides three sources of supply for excitation and auxiliaries.

If only one engine room is in operation, the double throw switch for the stand-by bus will be on the light and power bus. If both engine rooms are in operation, the double throw switch for the stand-by bus will be on the other engine room's auxiliary bus. This latter arrangement is the better of the two and will always be used when the ship is ready for full power but can not be used when cruising since only one engine room will be in use.

The current for the stand-by bus will come through a circuit breaker in both cases, but the ship's power and light bus breaker will be set for only a normal overload, whereas the breaker on the lead from the auxiliary bus will be set at such a high value that nothing less than a dead short circuit will open it. It was thought to be necessary to have this breaker since the flooding of one engine room would put a short circuit on the auxiliary bus of the other engine room.

The switch for supplying the blower control panel in the main control room is fused since these auxiliaries are not located in the same compartment as the switchboard and it was thought best to give some protection against damage to the long leads to the ventilating blowers. However, these fuses will not blow under anything less than a short circuit and spare fuses are kept in place on the switchboard. There are indicating lamps to show whether or not these fuses have blown.

All the switches on the blower control panel are double throw so that any ventilating blower can be supplied from the auxiliary bus in either engine room. The switch for supplying the control circuit is also located on this panel. This is a transfer switch so that it makes contact with one bus before leaving the other; this momentarily parallels the supply buses from the two engine rooms, so resistances are inserted in series between the two contacts to take care of any small difference in voltage on the two buses. A transfer switch is used on this circuit since the control circuit should never be opened, as will be seen later. The two buses supplying this panel have indicating lamps so that the operator will always know which is alive. Indicating lamps are also provided both on the control panel and in the motor rooms to show when the blowers are running.

All auxiliaries are provided with circuit breakers at their starting panels; these are really the only protection that is given a generator, when it is supplying the auxiliary bus, but it is believed to be quite adequate.

Two of the generator switches in the after engine room are made double throw so as to provide for a shore connection; one of these switches energizes the power and light bus and the other energizes the auxiliary bus. This will provide for power in both engine rooms since the auxiliaries in an engine room can run off either auxiliary bus and the ship's service can be supplied since the two distribution rooms can be connected together.

To improve the economy and to increase the range of speed, the main circulating pumps, forced lubricating pumps and excitation for the main field are arranged so that, at low powers, they can be run off the 120-volt circuit. In order not to unbalance the 300 kilowatt generators too much, some of these are arranged to be between positive and neutral and others to be between neutral and negative. Furthermore, the arrangement is reversed in the two engine rooms so that if the auxiliaries in both engine rooms are run from one engine room the load will be exactly balanced.

FIELD AND BOOSTER WIRING

The field and booster wiring is indicated in Fig. 87, but, owing to the importance of this circuit, it is thought best to show it separately in Figs. 88a and 88b.

The supply switch for the booster and the field is electrically locked so that it can not be opened unless the field switch is open.

The field circuit passes through a single pole, double throw switch for changing the field from the 120-volt circuit to the 240-volt circuit and *vice versa;* this switch is mechanically interlocked with the field lever so that it can not be opened unless the field switch is open. Both this switch and the field lever are located on the main switchboard.

In case of failure of the booster set, it can be short circuited and the excitation taken direct from the 300-kilowatt generator which will have its voltage varied to suit. This will necessitate transferring the auxiliaries to the stand-by bus, or emergency bus,

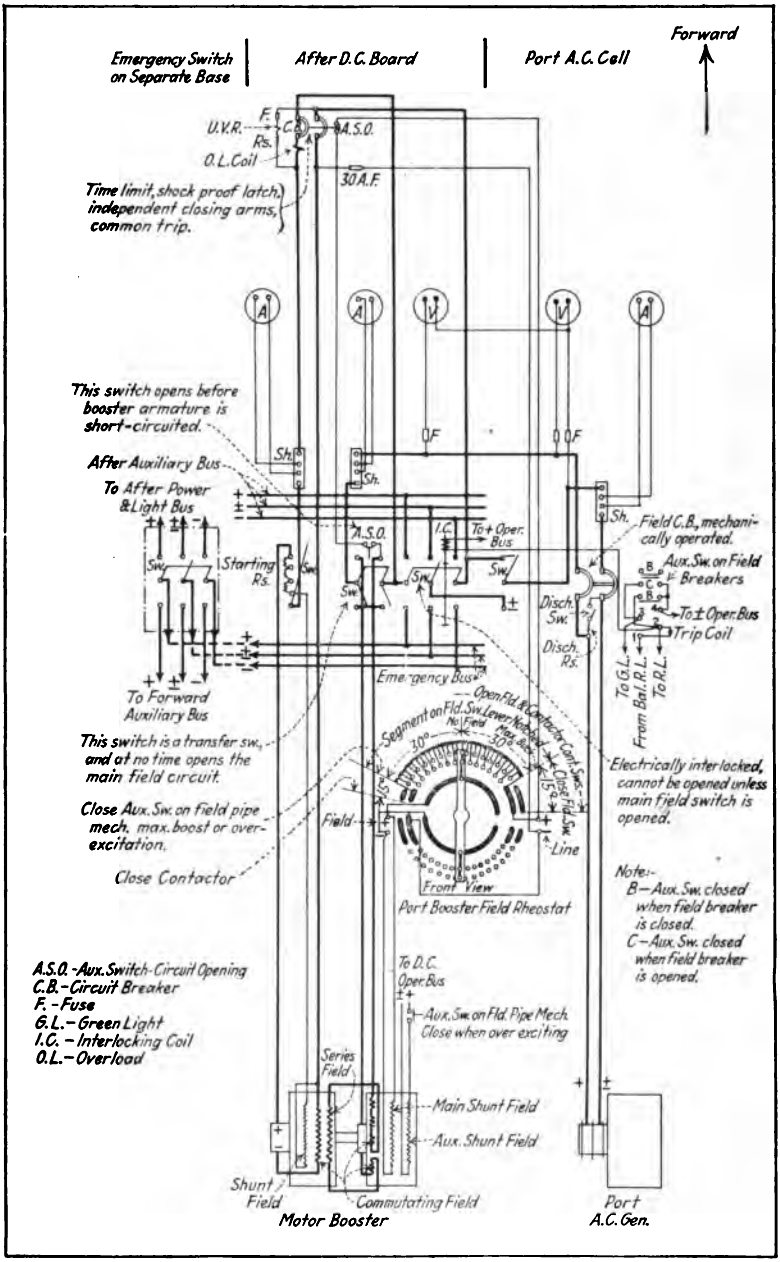


FIG. 88 a.—U. S. S. *California:* Field and Booster Wiring, Port Side

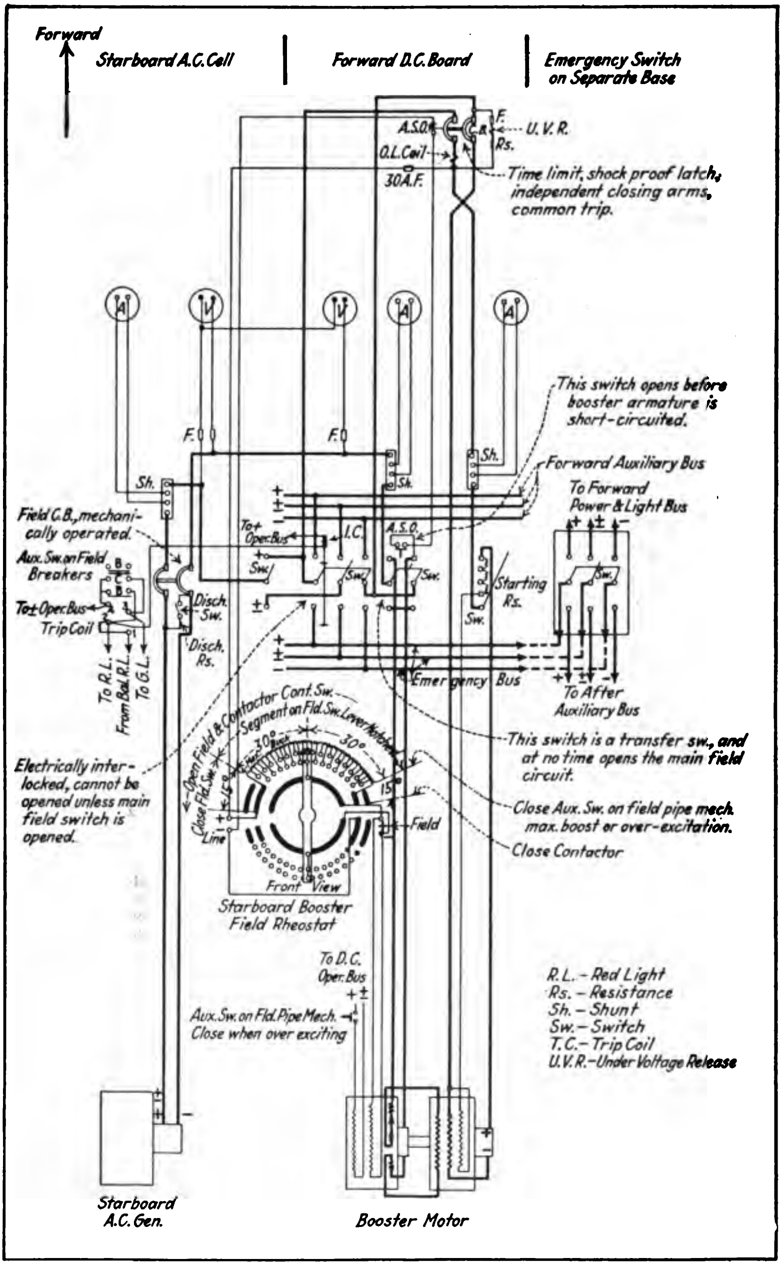


FIG. 88 b.—U. S. S. *California:* Field and Booster Wiring, Starboard Side as it is designated in Fig. 87. The short circuiting of the booster is accomplished by the transfer switch shown in Fig. 88. The first motion of this switch opens the field of the booster; further motion closes the short circuit (this momentarily short circuits the booster generator on itself but this will do no harm since its field is open); further motion opens the connection to the booster generator and entirely disconnects it from the line.

In case trouble develops in the booster, the proper procedure for cutting it out would be first to get all the auxiliaries off the generator to be used for excitation, then gradually reduce the voltage of this generator and, at the same time, move the main field lever to maintain proper field strength. When the generator voltage has been reduced until it is the same as that on the main field, the booster can be cut out by the transfer switch without causing any jump in the main field current. Of course, in a sudden emergency, where it would be necessary to get the booster off the line without delay, it could be short circuited without waiting for anything else since the main field will safely carry the current due to 240 volts.

While not absolutely necessary, it is desirable that the booster set should always be started up before the main field switch is closed. This will prevent any possibility of burning spots on the commutator of the booster generator by having current pass through it at standstill.

The booster motor is provided with circuit breaker protection. This circuit breaker has an auxiliary switch which opens the field circuit of the booster generator and prevents any possibility of the latter running away when the circuit breaker opens. In case of opening of this circuit breaker, there would be a sudden rise in the voltage on the main field circuit as in the case where the booster was short circuited.

The lever for opening and closing the field switch also operates the booster generator field rheostat and the short circuiting contactors for the main motors.

As shown in Fig. 88, when going in one direction the first 15 degrees of motion of the field lever closes the field switch, during the next 30 degrees of motion the field of the booster is reduced and this increases the main field. Further motion reverses the direction of the booster generator field and causes it to boost the supply voltage and this continues for the next 30 degrees of motion when maximum boost is reached. At the same time, the field lever comes up against a stop which must be lifted before further motion can take place; after the stop is removed, further motion will close the contactors on the main motors. This stop is placed in the field lever travel to insure that the operator will not inadvertently close the contactors before the motors have pulled into step as indicated by the instruments.

After the contactors are closed the excitation must be reduced to prevent overheating of the main field. This is insured by a spring on the field lever which will pull it back, if the operator should leave it in the over-excited position.

Reverse motion of the field lever reduces the excitation and its final motion is to open the contactors and the main field simultaneously. Just before the field switch is opened, an auxiliary switch is closed which short circuits the field through a discharge resistance.

Green indicating lights to show when the field is open and red indicating lights to show when it is closed are placed on the main switchboard and also on the generator switchboards in each engine room.

Generator and Auxiliary Switchboards

The switchboard for the after engine room, shown in Fig. 89, is identical with the one in the forward engine room except that the generator supply switches at the bottom of two of the panels are made double throw to provide for the shore connection.

There is a panel for each generator and two for the auxiliaries.

All circuit breakers on this board are shock proof and have time limit attachments. In addition, the generator circuit breakers have reverse current trips and shunt trips.

The connections to these switchboards are shown in Fig. 87.

Switchboard for Motor Ventilation Control

This switchboard is shown in Fig. 90. It is located in the main control room. The connections to it are shown in Fig. 87.

Alternating Current Wiring

The main alternating current wiring and switches are shown in Fig. 91.

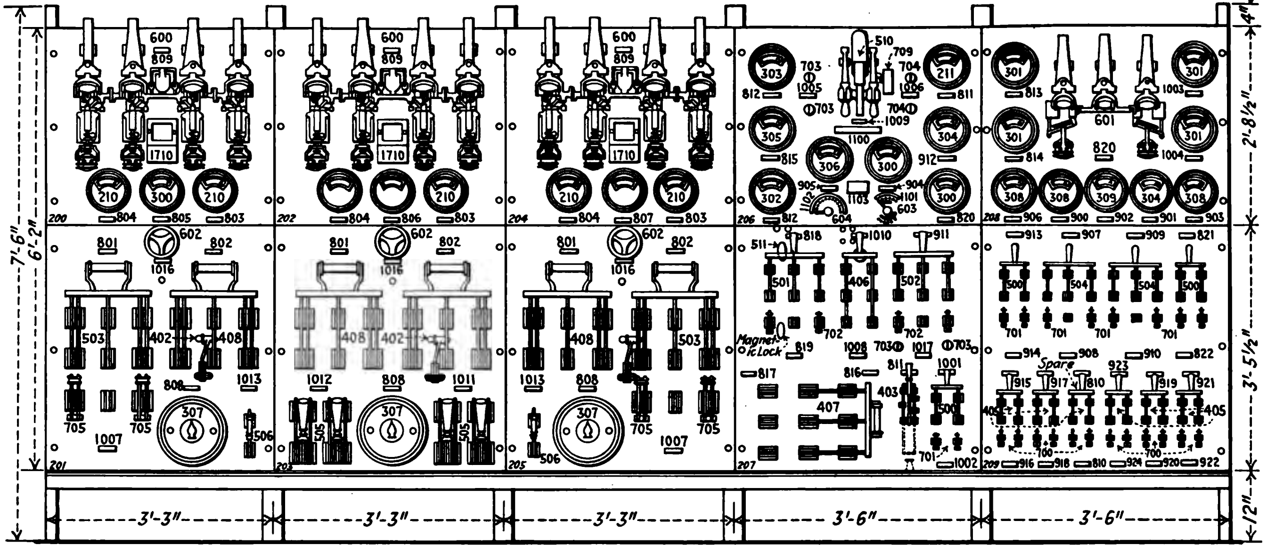


FIG. 89.—U. S. S. *California:* Switchboard for After Engine Room

Bill of Material for Switchboard Shown in Fig. 89

Part No.	Name of Part
200.	Panel 2' 8½" x 3' 3" x 1¾", Bevel ¼"
201.	Panel 3' 5½" x 3' 3" x 1¾", Bevel ¼"
202.	Panel 2' 8½" x 3' 3" x 1¾", Bevel ¼"
203.	Panel 3' 5½" x 3' 3" x 1¾", Bevel ¼"
204.	Panel 2' 8½" x 3' 3" x 1¾", Bevel ¼"
205.	Panel 3' 5½" x 3' 3" x 1¾", Bevel ¼"
206.	Panel 2' 8½" x 3' 6" x 1¾", Bevel ¼"
207.	Panel 3' 5½" x 3' 6" x 1¾", Bevel ¼"
208.	Panel 2' 8½" x 3' 6" x 1¾", Bevel ¼"
209.	Panel 3' 5½" x 3' 6" x 1¾", Bevel ¼"
210.	2000 Ampere Ammeter 2000 Ampere Shunt
211.	200-0-200 Ampere Ammeter 200 Ampere Shunt
300.	300 Volt Voltmeter
301.	2000 Ampere Ammeter 1500 Ampere Shunt
302.	350 Volt Voltmeter
303.	500 Ampere Ammeter 500 Ampere Shunt
304.	100 Ampere Ammeter 100 Ampere Shunt
305.	1200 Ampere Ammeter 1200 Ampere Shunt
306.	300-0-300 Volt Voltmeter
307.	2000 Ampere 120/240 Volt Wattmeter 2000 Ampere Shunt
308.	150 Ampere Ammeter 150 Ampere Shunt
309.	80 Ampere Ammeter 80 Ampere Shunt
402.	Mechanical Interlock for 2 of 408 and 1 of 503
403.	250 Volt 150 A. S. P. S. T. Starting Switch
405.	250 Volt 65 A. D. P. D. T. Lever Switch
406.	250 Volt 375 A. D. P. D. T. Lever Switch (broken Back)
407.	250 Volt 1000 A. T. P. D. T. Lever Switch
408.	250 Volt 1000/2000 A. T. P. S. T. Lever Switch
409.	Auxiliary Switch for 406 S. P. C. O.
500.	250 Volt 135 A. D. P. D. T. Lever Switch
501.	250 Volt 375 A. T. P. D. T. Lever Switch
502.	250 Volt 375 A. T. P. D. T. Lever Switch
503.	250 Volt 1000/2000 A. T. P. D. T. Lever Switch
504.	250 Volt 135 A. T. P. D. T. Lever Switch
505.	250 Volt 3000 A. T. P. S. T. Lever Switch
506.	250 Volt 600 A. S. P. S. T. Lever Switch
510.	250 Volt 200 A. D. P. T. IR. BKR. T. L. OL. and U. V. R.
600.	250 Volt 1250/500 A. S. P. T. L. OL. and SHUNT TRIP
601.	250 Volt 1250/500 A. T. P. Time Limit Load
602.	Rheostat Mechanism
603.	6 Point D. P. Voltmeter Switch
604.	11 Point S. P. Ground Switch
700.	Switch Stop for 405
701.	Switch Stop for 500 and 504
702.	Switch Stop for 501 and 502
703.	Red Indicating Lamp
704.	Green Indicating Lamp
705.	Switch Stop for 503
706.	150 A. N. E. C. S. Enclosed Fuse 250 Volt
707.	600 A. N. E. C. S. Enclosed Fuse 250 Volt
708.	Auxiliary Switch for 510
801.	Ships Service—Light and Power
802.	Main Drive Auxiliaries
803.	Positive
804.	Negative
805.	Generator No. 4
806.	Generator No. 5
807.	Generator No. 6
808.	Watthourmeter
809.	Main Equalizer
810.	Spare (No Marking)
811.	Booster Motor
812.	A. C. Generator Field
813.	Total Amperes Aft
814.	Total Amperes Aft
815.	Main Circulating Pump
816.	Main Circulating Pump—For'd
817.	Main Circulating Pump—Aft
818.	Booster—Aft
819.	Booster—For'd
820.	Forward Auxiliary Bus
821.	Main Hotwell Pump—Aft
822.	Main Hotwell Pump—For'd
900.	Forced Lubrication Pump No. 1
901.	Forced Lubrication Pump No. 2
902.	Dynamo Hotwell Pump
903.	Main Hotwell Pump
904.	Calibrating
905.	Grounds
906.	Oil Cooler Pump
907.	Forced Lubrication Pump No. 1—Aft
908.	Forced Lubrication Pump No. 1—For'd
909.	Forced Lubrication Pump No. 2—Aft
910.	Forced Lubrication Pump No. 2—For'd
911.	Main to Motor Ventilating Blowers—Aft
912.	Dynamo Circulating Pump
913.	Oil Cooler Pump—Aft
914.	Oil Cooler Pump—For'd
915.	Ventilating Blower No. 1—Aft
916.	Ventilating Blower No. 1—For'd
917.	Ventilating Blower No. 2—Aft
918.	Ventilating Blower No. 2—For'd
919.	Ventilating Blower No. 3—Aft
920.	Ventilating Blower No. 3—For'd
921.	Ventilating Blower No. 4—Aft
922.	Ventilating Blower No. 4—For'd
923.	Dynamo Hotwell Pump—Aft
924.	Dynamo Hotwell Pump—For'd
1001.	Dynamo Circulating Pump—Aft
1002.	Dynamo
1003.	Total Amperes For'd
1004.	Total Amperes For'd
1005.	A. C. Generator Field In
1006.	A. C. Generator Field Out
1007.	Shore Connection
1008.	Booster Generator Disconnected
1009.	Booster Motor

Part No.	Name of Part
1010.	Booster Generator In
1011.	Aft Distribution Switchboard
1012.	Aft Distribution Switchboard
1013.	Aft Distribution Switchboard
1014.	Booster Generator Field
1015.	General Illumination
1016.	Field Rheostat
1017.	Main to Motor Ventilating Blowers—For'd
1018.	Main to Motor Ventilating Blowers
1019.	Spare Fuses—Main to Ventilating Blowers
1100.	California
1101.	Voltage Generator No. 4—Generator No. 5—Generator No. 6 Booster—For'd bus—Blank
1103.	Made for Bureau of Steam Engineering by General Electric Company. Volts D. C. 120-240, 300 K.W.
1710.	R. B. Reverse Current Relay for 600
1102.	Aft Main Bus Aft Auxiliary Bus Blank Ground, Ground, Ground Ground, Ground, Ground For'd Auxiliary Bus Ground, Ground, Ground, Blank

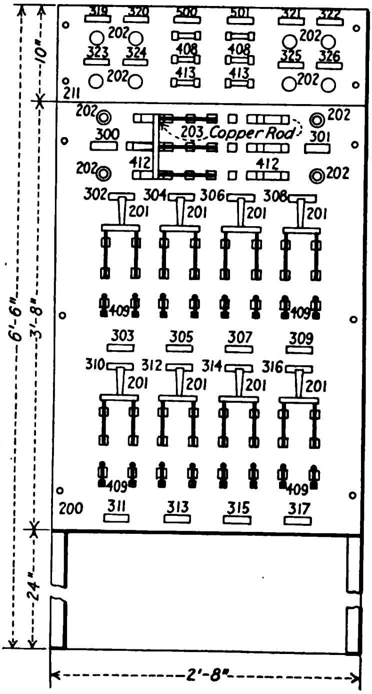


FIG. 90.—U. S. S. *California:* Switchboard for Motor Ventilation Control

Bill of Material for Switchboard Shown in Fig. 90

Part No.	Name of Part
200.	Panel 3' 8" x 2' 8" x 1½", Bevel ¼"
201.	Sw—D27 D. P. D. T. 250 Volts 65 Amperes
202.	Indicting Lamp Red
203.	Sw—D27 F. P. D. T. 250 Volts 65 Amperes
204.	Resistance
211.	Panel 10" x 2' 8" x 1½", Bevel ¼"
300.	Control—For'd Bus
301.	Control—Aft Bus
302.	Fan. No. 1, Motor No. 1—Outb'd St'b'd—For'd Bus

Part No.	Name of Part
303.	Fan. No. 1, Motor No. 1—Outb'd St'b'd—Aft Bus
304.	Fan. No. 2, Motor No. 1—Outb'd St'b'd—For'd Bus
305.	Fan. No. 2, Motor No. 1—Outb'd St'b'd—Aft Bus
306.	Fan No. 1, Motor No. 2—Inb'd St'b'd—For'd Bus
307.	Fan No. 1, Motor No. 2—Inb'd St'b'd—Aft Bus
308.	Fan No. 2, Motor No. 2—Inb'd St'b'd—For'd Bus
309.	Fan No. 2, Motor No. 2—Inb'd St'b'd—Aft Bus
310.	Fan No. 1, Motor No. 3—Inb'd Port—For'd Bus
311.	Fan No. 1, Motor No. 3—Inb'd Port—Aft Bus
312.	Fan No. 2, Motor No. 3—Inb'd Port—For'd Bus
313.	Fan No. 2, Motor No. 3—Inb'd Port—Aft Bus
314.	Fan No. 1, Motor No. 4—Out'b Port—For'd Bus
315.	Fan No. 1, Motor No. 4—Outb'd Port—Aft Bus
316.	Fan No. 2, Motor No. 4—Outb'd Port—For'd Bus
317.	Fan No. 2, Motor No. 4—Outb'd Port—Aft Bus
319.	Fan No. 1, Motor No. 1—Outb'd St'b'd
320.	Fan No. 2, Motor No. 1—Outb'd St'b'd
321.	Fan No. 1, Motor No. 2—Inb'd St'b'd
322.	Fan No. 2, Motor No. 2—Inb'd St'b'd
323.	Fan No. 1, Motor No. 3—Inb'd Port
324.	Fan No. 2, Motor No. 3—Inb'd Port
325.	Fan No. 1, Motor No. 4—Outb'd Port
326.	Fan No. 2, Motor No. 4—Outb'd Port
408.	60 Ampere Fuse
409.	Switch Stop for 201
413.	60 Ampere 250 Volts N. E. C. S. Fuse Block
500.	Starboard Control Bus
501.	Port Control Bus

There is an 8-pole, double throw disconnecting switch for each generator; these switches are similar to those used on the *New Mexico* and serve identical purposes.

The same may be said of the 8-pole, single throw, disconnecting switch for each main motor, the 3-pole, double throw, reversing switches for each pair of motors, the 6-pole, double throw, pole changing switches for each pair of motors, and the 4-pole, single throw, bus tie switch for connecting one generator to four motors.

Balance relays and under-current relays similar to those on the *New Mexico* are also fitted.

The main difference between the alternating current wiring of the *New Mexico* and that of the *California* is the additional leads of the *California's* motors to the contactors. Temperature coils are also furnished for the main motors as well as for the generators.

CONTROL WIRING

The direct current wiring for controlling the electric locks, indicating lamps and electrically operated switches is shown in Fig. 92. This wiring is mainly in the main control room.

The supply of current comes from either the forward or after engine as already explained under "Direct Current Wiring."

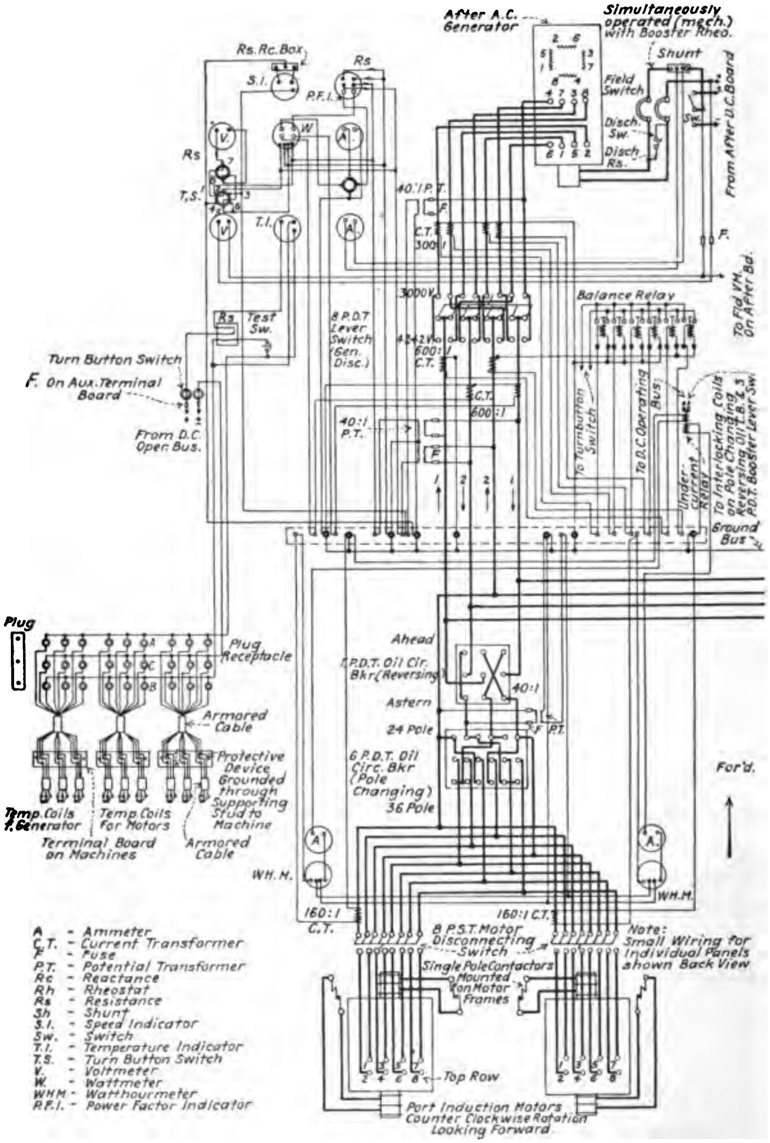
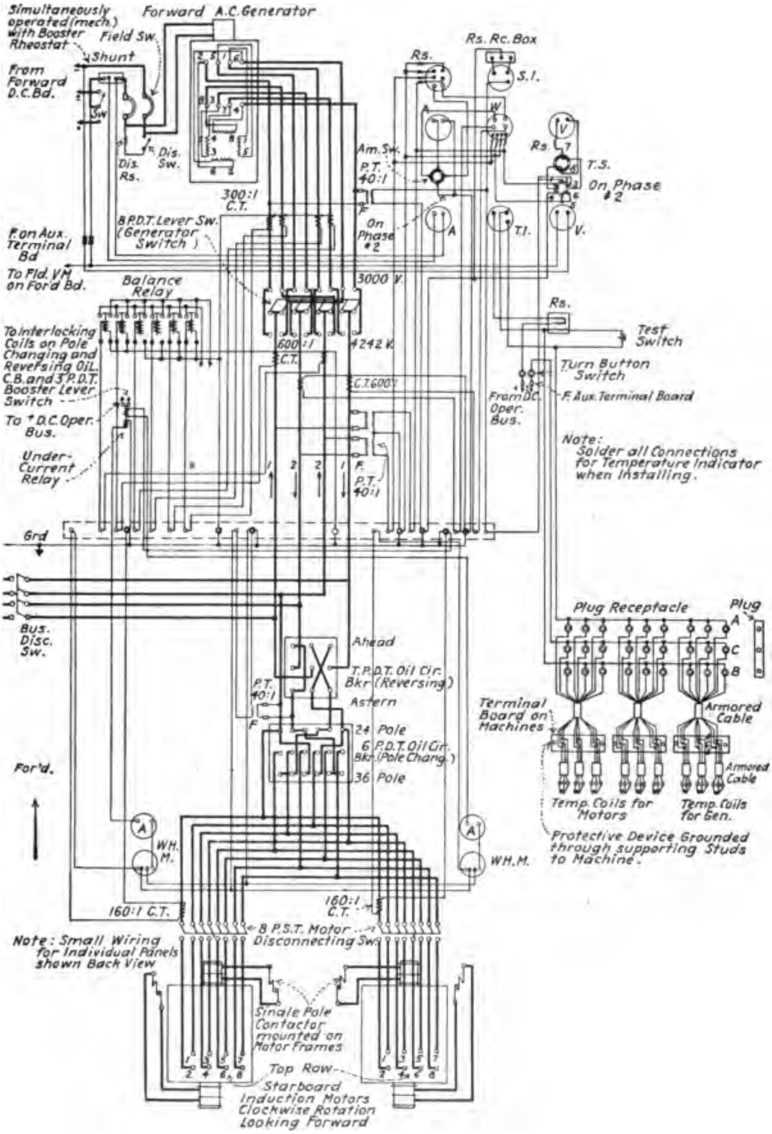


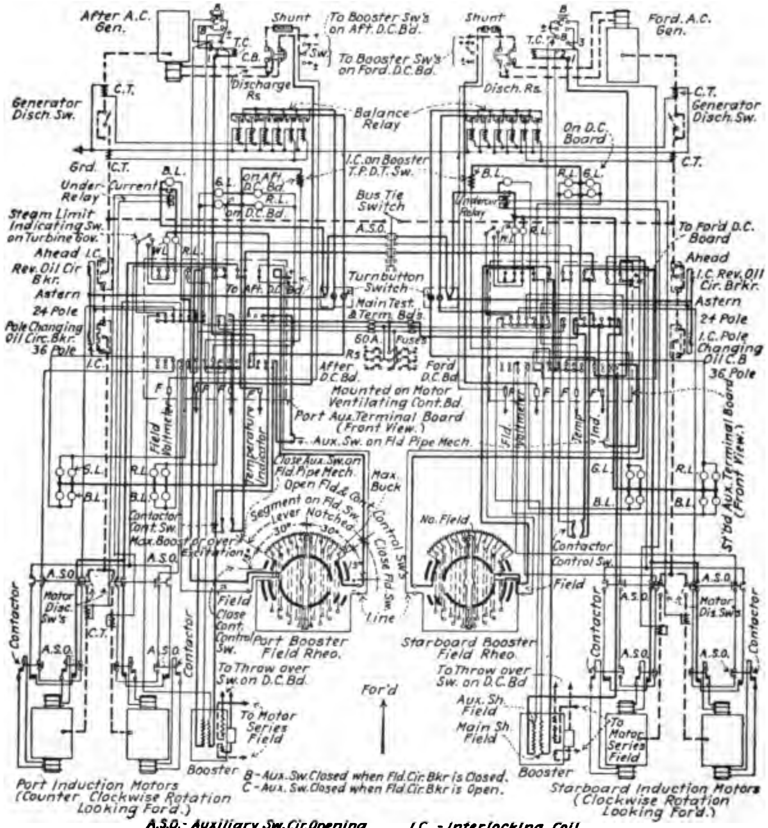
FIG. 91.—U. S. S. *California:* Main



Alternating Current Wiring and Switches

After passing through the double throw supply switch, the circuit divides and passes through heavy fuses to the two boards.

In addition to the indicating lamps, which have already been mentioned, there are lamps for indicating whether the motor con-



A.S.O. - Auxiliary Sw. Cir. Opening
B.L. - Blue Lamp
C.B. - Circuit Breaker
C.T. - Current Transformer
F. - Fuse
G.L. - Green Lamp
Grd. - Ground

I.C. - Interlocking Coil
R.L. - Red Lamp
Rs. - Resistance
Sw. - Switch
T.C. - Trip Coil
W.L. - White Lamp

FIG. 92.—U. S. S. *California:* Direct Current Control Wiring

tactors are open or closed, to show the position of the steam limit lever and to show when the undercurrent relays release.

When the main motor disconnecting switches are opened they open auxiliary switches which interrupt the circuits to the contactors and also to the indicating lamps.

The reversing switches and pole changing switches are electrically locked until released by the opening of the under-current relays which are set to open at a predetermined value of the line current.

The balanced relay is arranged to trip the field switch in case of unbalance in either of the phases.

When the bus tie switch is closed it cross connects the control wiring of the two terminal boards so that one field lever will control the contactors on all four motors.

TERMINAL AND TESTING BOARDS

These boards contain the connections for the control wiring shown in Fig. 92. There are two of them and they are located in the main control room. They are shown in Figs. 93, 94, 95 and 96. These figures show the switching which makes it possible to isolate any individual circuit that is grounded or otherwise gives trouble. Provision is also made for testing for grounds and for checking any of the instruments on the main switchboard by temporarily inserting a test meter into the circuits.

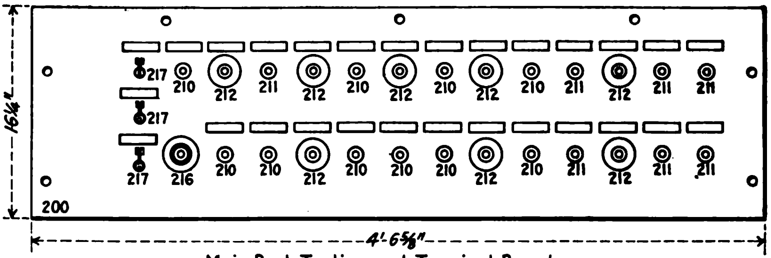
Experience gained on the *New Mexico* indicates that these boards will greatly facilitate checking up trouble with the small wiring on the switchboards and also make it very simple to install meters for the trials.

MAIN SWITCHBOARD

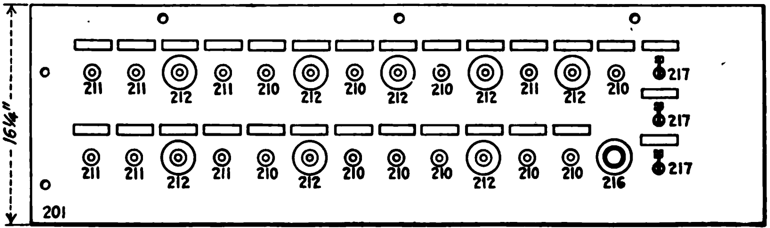
The complete main switchboard is shown in Fig. 97. A view with the front panels removed is shown in Fig. 98 and a view of the operating levers is shown in Fig. 99.

The table with Fig. 97 gives the names of all the operating levers, etc. Fig. 99 shows the operating levers as they are actually mounted on the board. It will be noted that the arrangement is better than that on the *New Mexico* as all levers are easily accessible. The steam limit lever has been brought up on a level with the field and speed levers; also the field selective switch has been placed on the main switchboard.

The bus tie switch, generator disconnecting switches and motor disconnecting switches are all operated by levers which

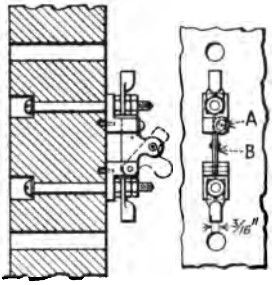


Main Port Testing and Terminal Board

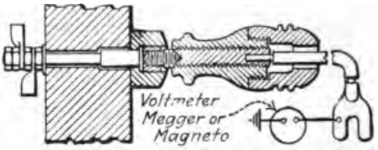


Main Starboard Testing and Terminal Board

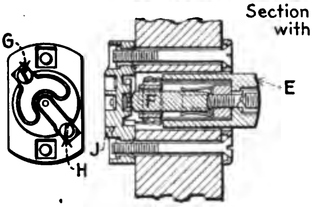
FIG. 93.—Testing and Terminal Boards



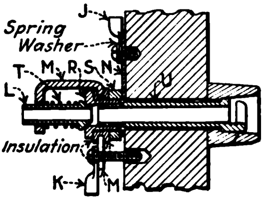
Section of Cut-out Switch 215



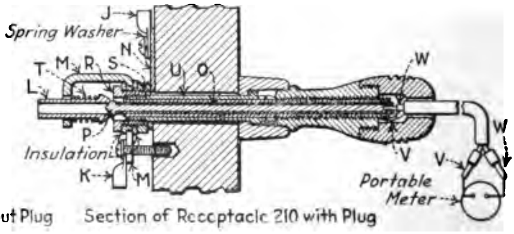
Section of Receptacle 211 with Plug for Same



Section of Receptacle 212
(Use same plug as for 211)



Section of Receptacle 210 without Plug



Section of Receptacle 210 with Plug

FIG. 94.—Details of Cut-out Switch and Receptacles

NOTES

Receptacles 210 and accompanying plugs provide for insertion of portable meters in secondary circuit of each current transformer for checking present meters or obtaining new readings. This is accomplished as follows: With plug out, secondary current from transformers enters terminal K, passes through M, T, L, R, S, and N, and leaves terminal J. Spring T assures positive contact between L and R. With plug in, secondary current from transformers enters terminal K, passes through M, T, L, P, W, to one meter stud and then from other meter stud through V, O, U, R, S and N, and leaves terminal J going through circuit instruments back to transformers. Leads V and W must be attached to portable meter before inserting plug in receptacle. This prevents opening secondary of current transformer when L leaves R.

Receptacles 211 and accompanying plugs are used for testing potential and grounds or attaching a portable meter.

Receptacle 212 is used as a grounding terminal or fuse receptacle, and tests for grounds or potential are made with this receptacle in connection with plug assembled with receptacle 211.

When 212 is used as a grounding terminal F is a solid metal plug, which may be removed from plug E if ground is not desired for testing, or any other purpose, but there is no danger of opening secondaries of current transformer since their common connection comes to and leaves same terminal G, otherwise F is a fuse in which case line comes to G, goes through F, leaves through H.

Cutout switches 215 are used for distributing control circuits to various pieces of apparatus in cell and for isolating any control circuit in case of grounds. Test for grounds should be made at the main control switch on front of ventilating control switchboard by touching one side of megger or magneto to switch stud and connecting other stud of megger or magneto to ground. If ground is indicated, open and close cutout switches on terminal boards until the proper switch is opened which removes indication of ground and isolates the grounded section.

Each cutout switch is provided with a name plate, of which the small letters apply to connections to upper studs and larger letters to connections to lower studs. Blade B is locked closed by means of screw and washer A.

Name plates for auxiliary terminal boards are made of engraved bakalite, letters filled in with white enamel. For main testing and terminal boards name plates are made of engraved white metal, with white line border and letters, dull black background.

can be handled from the floor; those for the generators are on the front of the switchboard and those for the motors on the sides of the board. All these switches are mechanically interlocked with the reversing switches so they can not be moved unless the latter are open; this insures an absolutely dead circuit. On the *New Mexico* these switches are interlocked with the main field switches and it is possible to operate so rapidly that current will be flowing when the disconnecting switches are opened.

All of these switches are positively held in either the open or closed position so they can not be opened or closed by shock or short circuit.

The bus tie switch is interlocked with the reversing switches so that they can not be operated unless the bus tie switch is fully closed or fully open. The bus tie and generator disconnecting switches are interlocked so that only two can be closed at one

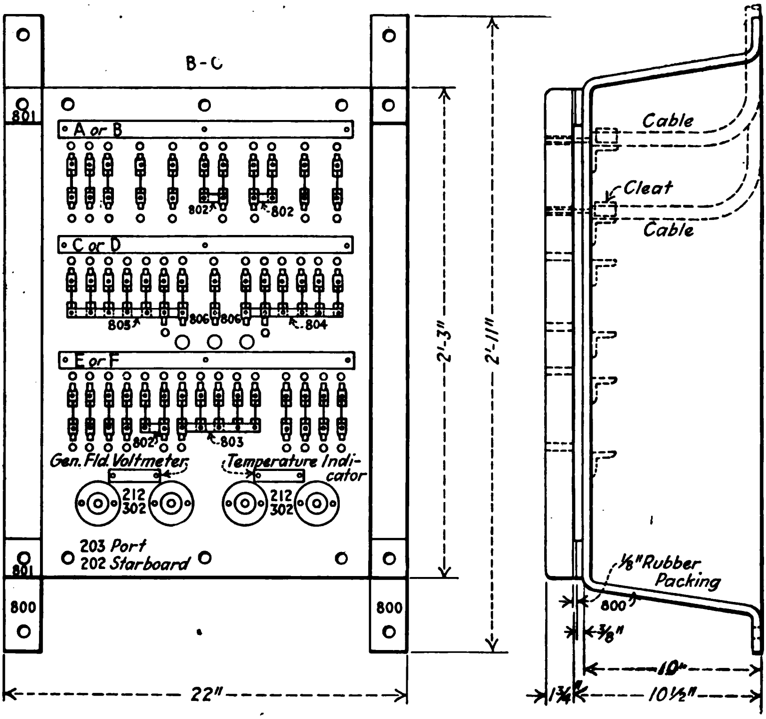


FIG. 95.—Auxiliary Terminal Boards

Bill of Material for Auxiliary Terminal Boards Shown in Fig. 95

Part No.	Name of Part	Part No.	Name of Part
200.	Panel 16¼" x 4' 6⅝" x 1¾", Bevel ¼"	210.	Current Testing Receptacle
		211.	Pot. Testing Receptacle
201.	Panel 16¼" x 4' 6⅝" x 1¾", Bevel ¼"	212.	Pot. Testing and Grounding Receptacle
202.	Panel 2' 3" x 18" x 1¾", Bevel ¼"	215.	Pot. Cut Out Switch
		216.	Relay Cut Out Switch
203.	Panel 2' 3" x 18" x 1¾", Bevel ¼"	217.	2 Volts 10 A. S. P. S. T. LEVER SWITCH

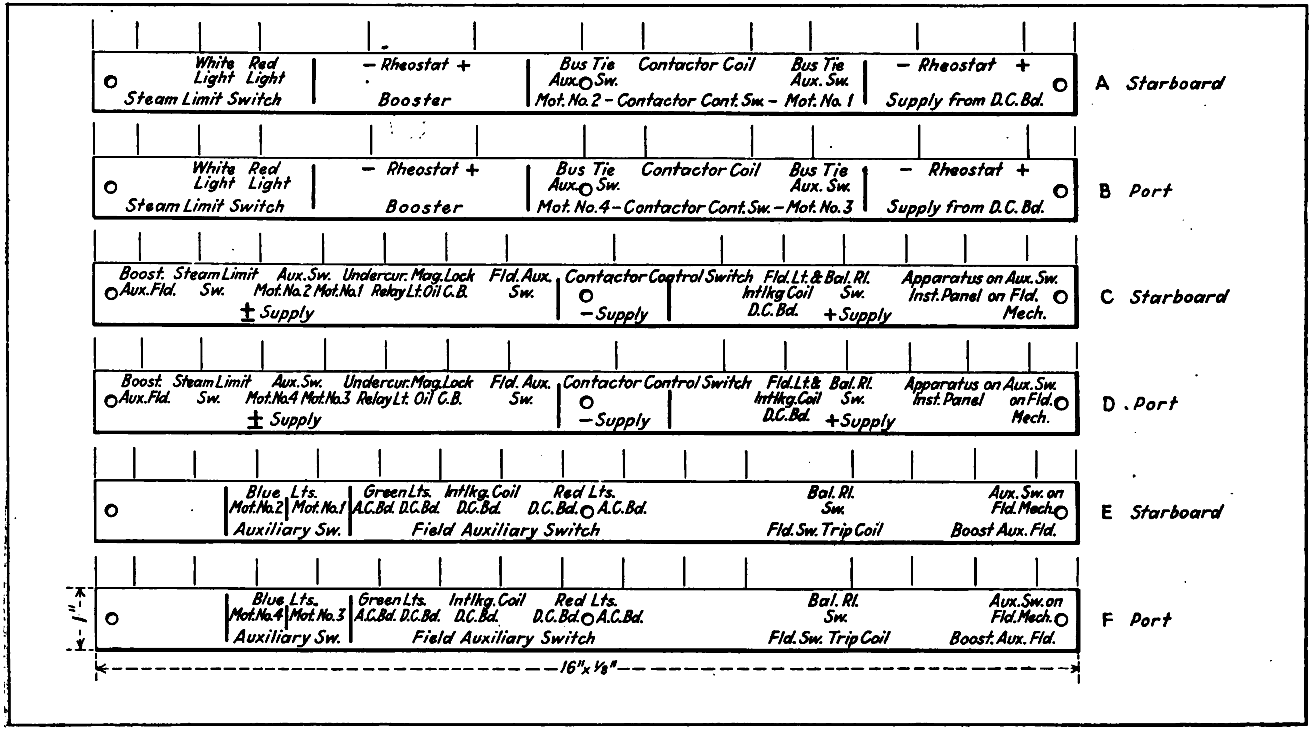


FIG. 96.—Label Plates for Port and Starboard Auxiliary Terminal Boards

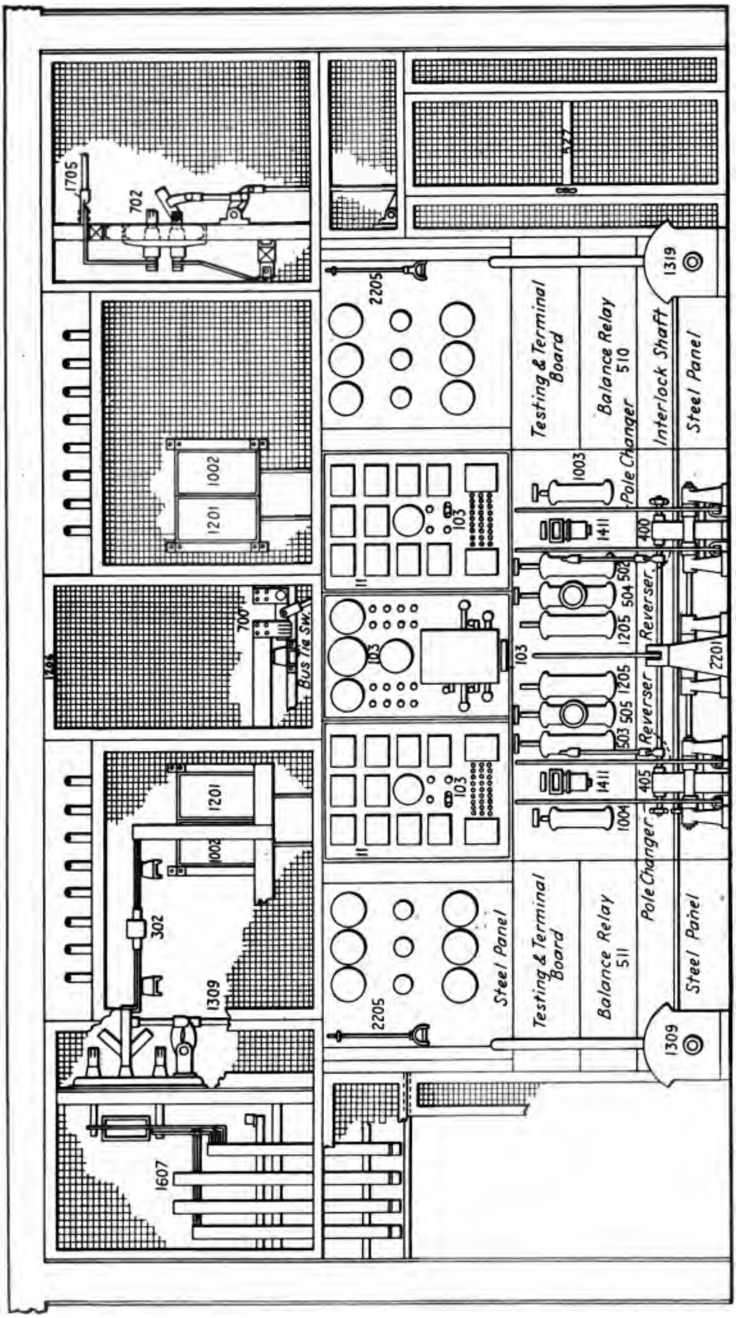


FIG. 97.—U. S. S. *California*: Assembly of Main Switchboard

Bill of Material for Main Switchboard Shown in Fig. 97

Part No.	Name of Part
103.	Instruments Name Plates
302.	Current Transformer 3000 Amperes
303.	Current Transformer 1500 Amperes
304.	Potential Transformer A. Q. I. 4000/110 Volts 200 W.
307.	Current Transformer 800 A. W.-2
308.	Potential Transformer A. Q. I. 44000/110 Volts 200 W.
403	Oil Circuit Breaker 5000 Volts, 1500 Amperes
404.	Switch Mechanism
405.	Operating Lever Mechanism for 403 Port
406.	Operating Lever Mechanism for 403 Starb'd
407.	Magnetic Locking Device for 403
501.	Booster Field Rheostat Starb'd
502.	Field Control Lever Starb'd
503.	Field Control Lever Port
504.	Steam (Speed) Control Lever Starb'd
505.	Steam (Speed) Control Lever Port
506.	Booster Field Rheostat Port
507.	Cell Door Port
510.	Balance Relay St'b'd
511.	Balance Relay Port
525.	Auxiliary Power Panel Assembly
526.	Testing Terminal Board
527.	Cell Door Starb'd
700.	Bus Tie Switch 5000 Volts, 2400 Amperes 4 P. S. T.
701.	Motor Disconnecting Switch Port End
702.	Motor Disconnecting Switch St'b'd End
703.	Motor Disconnecting Switch Port Front
704.	Motor Disconnecting Switch St'b'd Front
711.	Auxiliary Switch (C. O.). For Motor Disconnecting Switches
1000.	Field Switch 240 Volts, 400 Amperes A. D. P. S. T.
1002.	Field Selective Switch 240 Volts, 375 Amperes S. P. D. T.
1003.	Field Selective Operating Lever Starb'd
1004.	Field Selective Operating Lever Port
1005.	Pipe Mechanism for 1002 Port Starb'd
1100.	Generator Disconnecting Switch 8 P. D. T. Port
1101.	Generator Disconnecting Switch 5000 Volts 1500 Starb'd
1121.	Pipe Support for Generator Disconnecting Switch Mechanical Interlock
1201.	Contactor Control Switch
1203.	Field Control Pipe Mechanism
1205.	Steam Limit Lever Starb'd Port
1206.	Grille Work Front
1207.	Frame Work (Front Extension)
1210.	Steel Panels
1213.	Frame Work Front
1215.	Field Control Pipe Mechanism
1301.	Pipe Mechanism for Steam and Speed Control St'b'd
1302.	Pipe Mechanism for Steam and Speed Control Port
1303.	Oper. Lever for Motor Disconnecting Switch End Port
1304.	Oper. Lever for Motor Disconnecting Switch End St'b'd
1305.	Oper. Lever for Motor Disconnecting Switch Front Port
1306.	Oper. Lever for Motor Disconnecting Switch Front St'b'd
1307.	Interlock Mechanism Field and Field Selective Levers St'b'd
1308.	Interlock for Field and Field Selective Levers Port
1309.	Oper. Mechanism for Generator Disconnecting Switches St'b'd
1310.	Interlock bet. Generator Disconnecting and Bus-tie Switches
1311.	Cell Partition
1319.	Oper. Mechanism for Generator Disconnecting Switches St'b'd
1405.	Frame Work Port End of Cell
1406.	Frame Work St'b'd. End of Cell
1407.	Pot. Trans. Base and Supports
1408.	Pot. Trans. Base and Supports
1409.	Pot. Trans. Base and Supports
1410.	Supports for Current Trans.
1411.	Under Current Relay for Mag. Lock 407
1500.	Bureau Name Plate
1605.	Interior Frame Work
1606.	Supp.—Connections to Generator Disconnecting Switch St'b'd
1607.	Supp.—Connections to Generator Disconnecting Switch Port
1630.	Arrang. of Bus Bars and Support
1705.	Cable Terminals—Motor
1712.	Tank Lifter
1713.	Tank Lifter
1714.	Tank Lifter
1715.	Tank Lifter
1800.	Set of Connections for Pot. Trans.
1803.	Interlock between Starb'd Motor Disconnecting Switch and Pole Changing Oil Circuit Breaker
1804.	Field Switch 240 Volts, 400 Amperes D. P. S. T. Port
1810.	Field Switch 240 Volts, 400 Amperes D. P. S. T. St'b'd
2200.	Hands Off Signal
2201.	Oper. Mechanism for Bus-tie Switch
2202.	Mechanical Interlock
2203.	Mechanical Interlock
2204.	Mechanical Interlock
2205.	Emergency Trip Handle

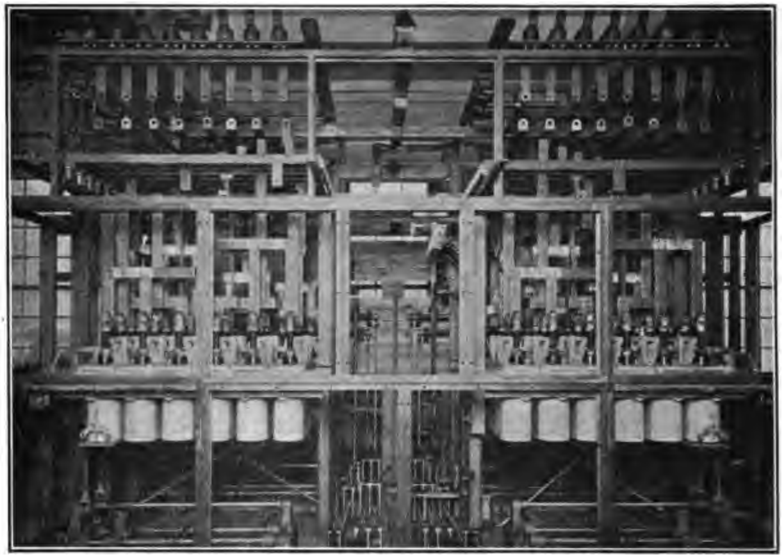


FIG. 98.—U. S. S. *California:* Front View of Control Cell Panels with Grille Removed

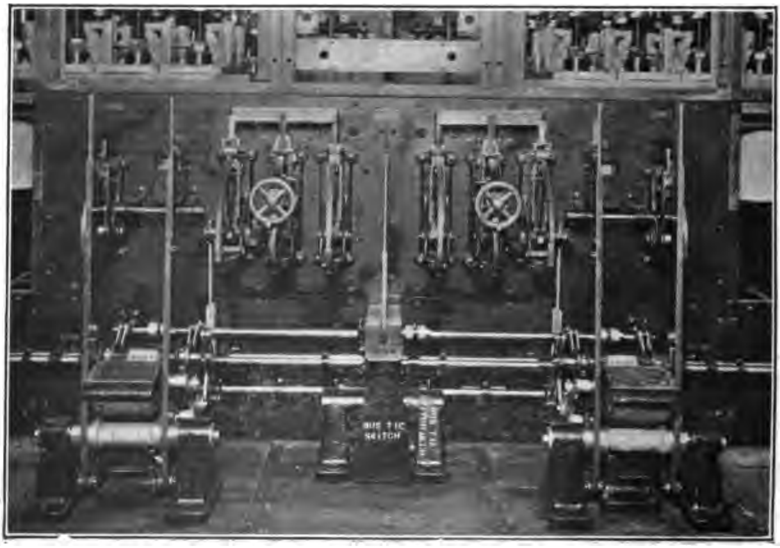


FIG. 99.—U. S. S. *California:* View Showing Operating Levers

time and also so that a disconnecting switch can be closed only in the low voltage position when the bus tie switch is closed and in the high voltage position when the bus tie switch is open.

The speed and field lever interlock is similar to that on the *New Mexico;* this is also true of the interlocks between the field lever and the reversing and pole changing levers.

The pole changing and reversing levers are mechanically interlocked so that the reversing levers can be thrown to the "astern" position only when the pole changers are in the 36-pole position. They are also interlocked so that in going ahead the ship must be started by first throwing the "ahead" and 36-pole switches and then changing to the 24-pole switch, if desired. These interlocks make it necessary always to back with the 36-pole combination and also to start ahead with it. In case it is desired to use the 24-pole combination in going ahead, the shift can be made after starting ahead. This insures that all backing and starting will be done with the high resistance squirrel cage motor.

The field switch is mechanically operated instead of by solenoids as in the case on the *New Mexico.* This switch is mounted on the bulkhead of the control room just forward of the switchboard; it has a tripping coil so that it can be opened electrically by the balance relay.

Locks and Interlocks

All of the locks that have been described in connection with the various switchboards are listed in Fig. 100, which also contains a single line wiring diagram to show the relation of the various switches.

Operation of the Machinery

The three conditions of normal steaming are identical with those described for the *New Mexico.* The operation of the machinery in the ahead and astern directions is also the same but, owing to the dissimilarity of the main motors, there is a slight difference in the actual operations performed by the field lever, so a description will be given of reversing under each condition.

(1) *Getting Under Way With One Generator, the Motors Being Arranged for 36-Poles.*—Close the generator disconnecting switch on one generator and also the bus tie switch.

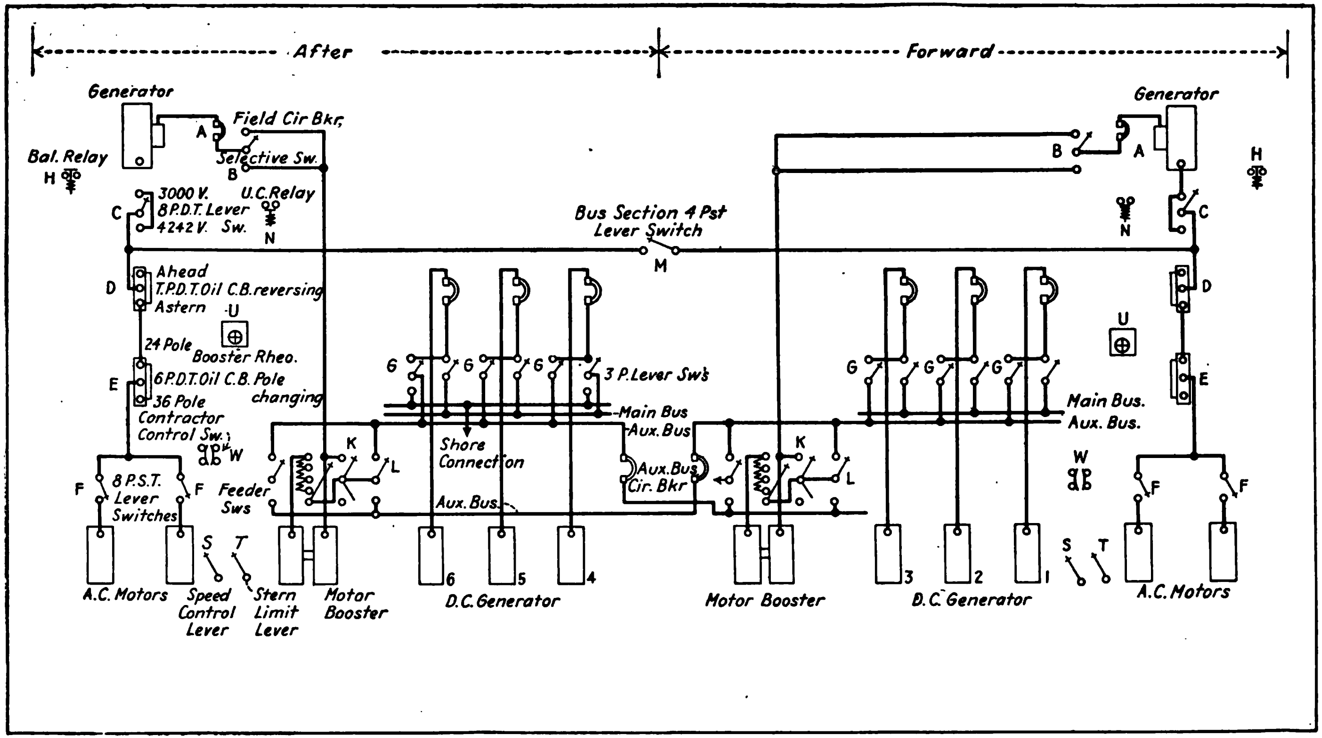


FIG. 100.—U. S. S. *California:* Arrangement of Locks and Interlocks

Fig. 100—Notes

(1) Field circuit breaker A is electrically tripped by balance relay H when there is an unbalance in line or generator.

(2) Speed lever S is provided with an adjustable stop which prevents its operation in advance of the field lever A. A similar stop on the field lever prevents it from being thrown to the "Field Off" position unless the speed lever is thrown to the low steam position.

(3) Lever for field selective switch B is mechanically interlocked with lever for field circuit breaker A so that selective switch cannot be operated unless circuit breaker is open.

(4) Booster field rheostat U and field circuit breaker A are mechanically interlocked in effect since their mechanisms are operated simultaneously by the same lever.

(5) Lever switch L is electrically interlocked with field circuit breaker A so that it cannot be opened until circuit breaker is open, but can be closed independent of circuit breaker.

(6) Contactor control switch is operated by same lever as field circuit breaker. It opens simultaneously with field breaker and is closed at end of over excitation stroke after motors have pulled into step and a stop has been relieved.

(7) Motor disconnecting switches F are mechanically interlocked with their respective pole changing oil circuit breaker D, so that motor disconnecting switches cannot be opened or closed unless their respective pole changing oil circuit breaker is in open position. This interlock prevents opening or closing motor disconnecting switches under load, but does not prevent running of one motor while the disconnecting switches of the other motor are open.

(8) Bus tie switch M and generator disconnecting switches C are mechanically interlocked so that any two only can be closed at same time.

(9) Bus tie switch M and generator disconnecting switches C are mechanically interlocked so that when bus tie switch is open the generator disconnecting switches can be thrown into high voltage position only.

(10) Bus tie switch M and generator disconnecting switches C are mechanically interlocked so that when bus tie switch is closed either of the generator disconnecting switches can be thrown into low voltage position only; bus tie switch cannot be opened unless both generator switches are opened.

(11) Bus tie and generator disconnecting switches are mechanically interlocked with levers of reversing oil circuit breakers so that they cannot be operated unless reversing breakers are open (see interlock No. 13).

(12) Levers for pole changing and reversing oil circuit breakers E and D are electrically locked so that they cannot be operated until current has fallen to a predetermined value as controlled by an under current relay N.

(13) Levers for pole changing and reversing oil circuit breakers E and D are mechanically interlocked with lever of field circuit breaker A so that they cannot be operated unless field lever is in off position.

(14) Levers for pole changing and reversing oil circuit breakers E and D are mechanically interlocked with levers for field circuit breakers A so that when either field is used alone the oil circuit breakers on the opposite side are also locked against operation. In other words, when using one generator, both fields must be open to unlock and therefore the one not in use should be secured in the open position by a stop.

(15) Levers for oil circuit breakers are mechanically interlocked with levers for bus tie switch so that they cannot be operated unless bus tie switch is in either extreme position.

(16) Lever for pole changing and reversing oil circuit breakers E and D are mechanically interlocked so that D cannot be thrown in ahead position unless E is in 36 pole or off position. This interlock, how-

ever, may be voluntarily relieved but should not until ship is actually moving ahead.

(17) Levers for pole changing and reversing oil circuit breakers E and D are mechanically interlocked so that reversing lever cannot be thrown into astern position unless the pole changing lever is in 36 pole or off position, also the pole changing lever cannot be thrown into the 24 pole position when the reversing oil circuit breaker is in the astern position; this makes it impossible to back in the 24 pole position.

(18) Lever switches G on aft or forward boards are mechanically interlocked so that only one switch on either board can be in at any one time, but in case of emergency this mechanical lock can be relieved, by hand, so that any other switch may be thrown in.

The field switch would be open and the turbine running at slow speed. On receiving a signal "ahead":

(*a*) Throw pole changers to 36-pole position.

(*b*) Throw reversing levers to "ahead" position.

(*c*) Close field switch and put on over-excitation until motors are in step. Lift the stop and continue the motion of the field lever until the contactors are closed, then reduce the field to normal strength.

(*d*) Bring the turbine up to the desired speed.

(2) *Reversing.*—With the ship going ahead under conditions described above under (1), on receiving a signal "astern,"

(*a*) Move the speed lever to low speed position and open the field at the same time; the contactors will also open.

(*b*) As soon as the under-current relays release the locks, throw the reversing levers to the astern position.

(*c*) Close the field switch and put on over-excitation. As soon as the motors come into step, lift the stop and move the field lever until the contactors close, then reduce the field to its normal strength.

(*d*) Bring the turbine up to the desired speed.

(3) *Getting Under Way with One Generator, the Motors to Be on the 24-Pole Connection.*—Arrangements would be made as described above under (1). On receiving a signal "ahead,"

(*a*) Throw the pole changers to the 36-pole position.

(*b*) Throw the reversing levers to the "ahead" position.

(*c*) Close the field switch and put on over-excitation until the motors are in step, then lift the stop and continue the motion of the field lever until the contactors are closed, then reduce the field strength to normal.

(*d*) Bring the turbine up to the desired speed. After the ship has gathered speed ahead, the change can be made to the 24-pole condition.

(*e*) Move the speed lever to the low speed position and open the field at the same time; the contactors will also open.

(*f*) As soon as the under-current relays release the locks, throw the pole changers to the 24-pole position.

(*g*) Close the field switch and put on over-excitation until the motors come in step, then lift the stop and move the field lever till the contactors close and then reduce the field to normal strength. (It is not necessary to close the contactors since they are not effective on the 24-pole combination but they should always be closed so as to make the operation the same in all cases.)

(*h*) Bring the turbine up to the desired speed.

(4) *Reversing.*—Assuming the ship to have gotten under way as described above under (3), on receiving a signal "astern,"

(*a*) Move the speed lever to the low speed position and open the field at the same time; the contactors will also open.

(*b*) As soon as the under-current relays release the locks, throw the pole changers to the 36-pole position and the reversing levers to the "astern" position.

(*c*) Close the field switch and put on over-excitation. As soon as the motors come into step, lift the stop and move the field lever until the contactors close, then reduce the field to its normal strength.

(*d*) Bring the turbine up to the desired speed.

(5) *Getting Under Way with Two Generators and the Motors to Be on the 24-Pole Combination.*—In this case, the bus tie switch would be left open and the generator disconnecting switches would be closed in the high voltage position. If a signal "ahead" is received, the operations would be performed exactly as described above under (3), except that they would be performed on two generators instead of on one.

(6) *Reversing.*—After having gotten under way with conditions as described above under (5), if a signal "astern" is received, the operations would be performed exactly as described above under (4), except that they would be performed on two generators instead of on one.

CHAPTER XIII

The Tennessee, Colorado and Washington

THESE ships are all sister ships of the *California* and their machinery compartments are identical with those of the *California*. The propelling machinery is being furnished by the Westinghouse Company and differs very considerably from that of the *California* in its details, although the general arrangement is the same. The number of units used, the grouping of the units, the propeller speed and the generator speed are the same in both cases.

MAIN TURBINE

A cross section of the main turbine is shown in Fig. 101 and a photograph of the turbine coupled to a water brake is shown in Fig. 102. It is of the semi-double-flow type and has both impulse and reaction elements. The steam first flows through the impulse wheel, then through the single flow, reaction element and then divides and flows through the two double flow elements.

A dummy piston is located between the impulse wheel and the adjacent low pressure, reaction stage.

The turbine cylinder is of cast iron and is divided in the horizontal plane. It is arranged for downward exhaust. There is an external pipe for cross connecting the two double flow elements.

The arrangement of auxiliary exhaust connections to the main turbine is shown diagrammatically in Fig. 103. This arrangement is very similar to that of the *California*. The exciter exhausts to the auxiliary exhaust line through a constant back pressure valve. The auxiliary exhaust connects, through a constant back pressure valve, to the cross connection between the two low pressure reaction stages of the turbine; there is a stop check valve at the connection and the line is provided with a butterfly valve, actuated by the emergency governor. The auxil-

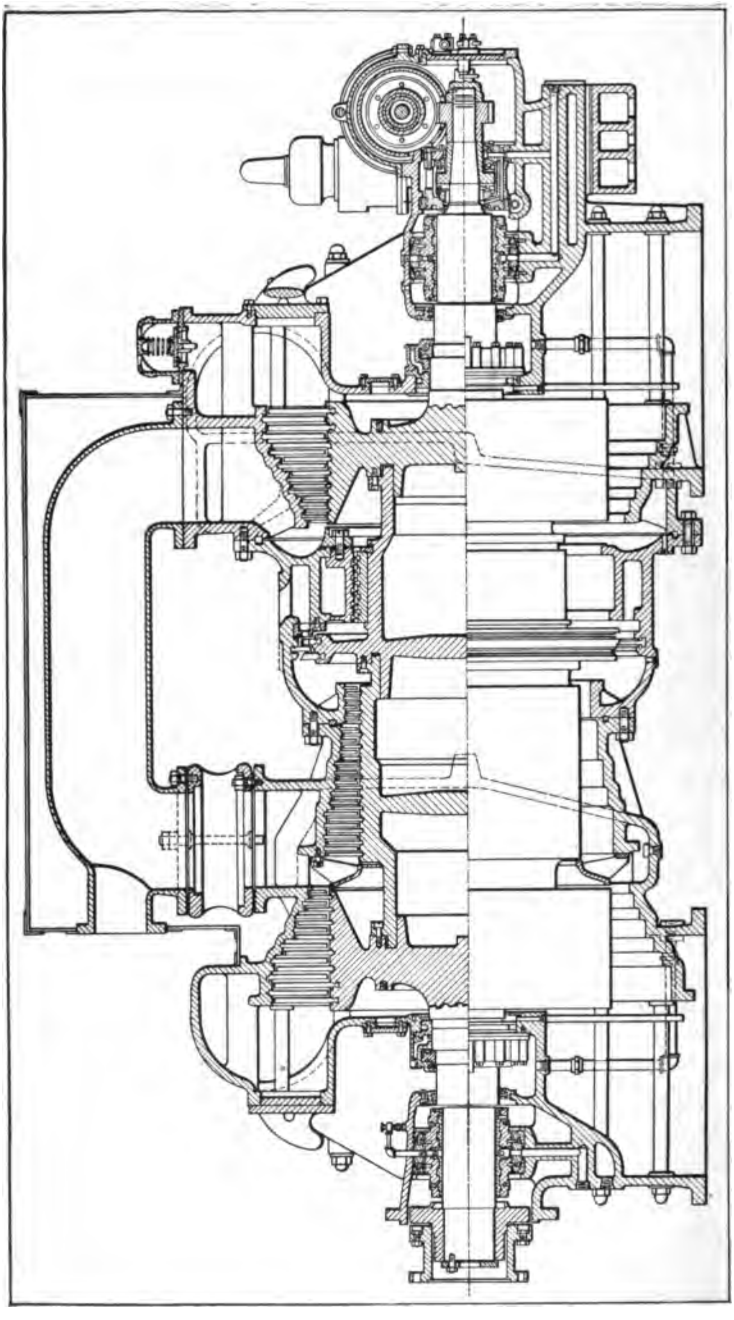


FIG. 101.—U. S. S. *Tennessee*: Section Showing Main Turbine

iary exhaust line is also provided with connections, through constant back pressure valves, to the main and dynamo condensers. There is also a by-pass valve controlled by the main and emergency governors which by-passes the auxiliary exhaust from the main turbine to the main condenser when the governor shuts all steam off the turbine, when the emergency governor trips or when the oil supply fails. With this arrangement of valves the auxiliary exhaust can be used in the feed heaters, the evaporators, and the main turbine, or sent direct to the condensers. The constant back pressure valve between the exciter and the auxiliary exhaust line is fitted so that there will be a constant pressure on the exciter exhaust when the auxiliary exhaust is not being used in the main turbines.

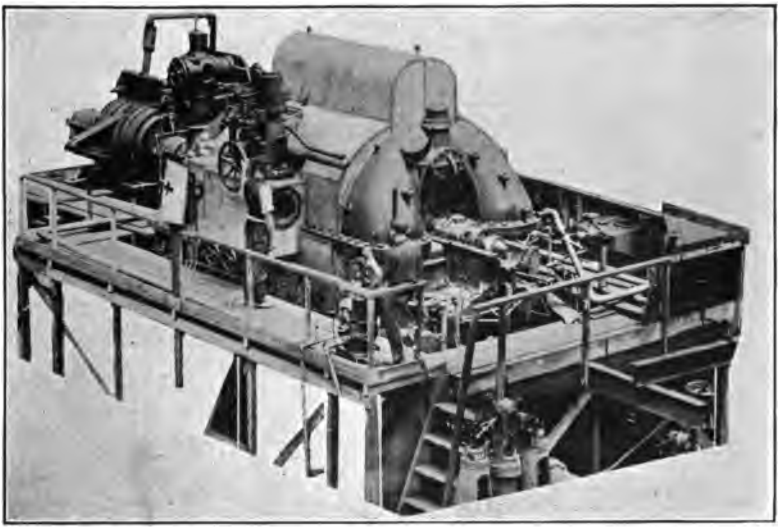


FIG. 102.—U. S. S. *Tennessee:* Main Turbine Coupled to a Water Brake

The steam chest is provided with hand operated valves for admitting steam to the expanding nozzles. The number of valves to be open at any time will depend on the maximum speed to be maintained. If these valves are properly operated, the proper inlet pressure to the nozzles will be maintained and the maximum efficiency of the turbine will be obtained.

The glands are of the labyrinth type and are sealed by both water and steam.

The bearings are of the spherical, self-alining type and are divided horizontally. The thrust bearing is of the Kingsbury type and is arranged for adjusting the rotor endwise. The lubrication is forced feed, being supplied by forced lubrication pumps in the engine rooms. There is no emergency pump on the turbine, so one of the forced lubrication pumps is driven by a steam turbine and controlled by a pressure regulator which will automatically start up this pump in case of failure of the electric driven pump.

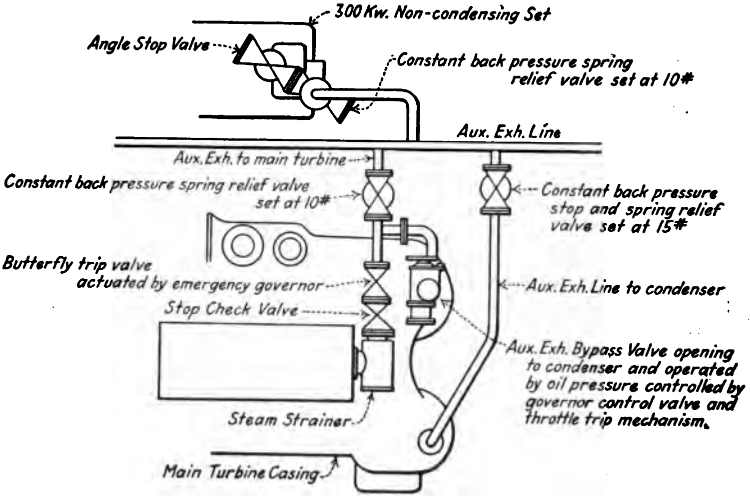
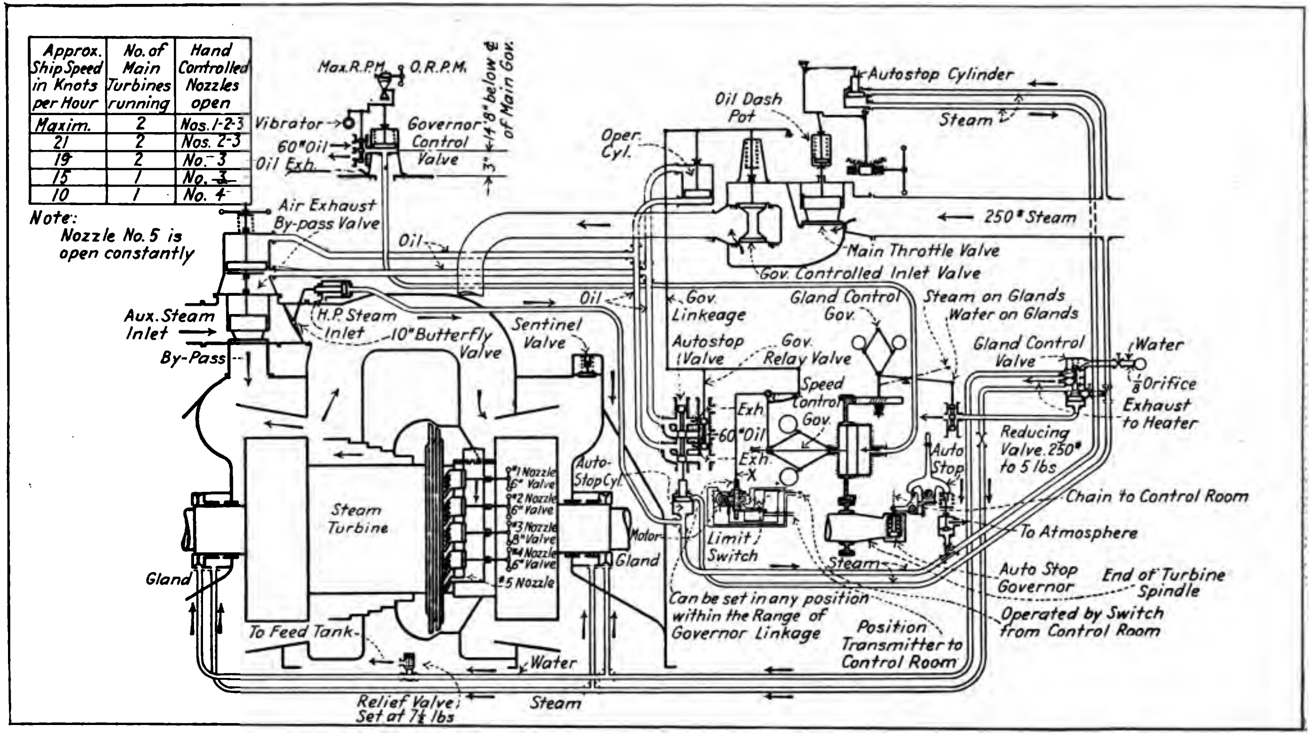


FIG. 103.—U. S. S. *Tennessee:* Diagram Showing Arrangement of Auxiliary Exhaust Connections to Main Turbine

The turbine is coupled to the generator by a flexible coupling which is arranged to take any unbalanced thrust of the generator; this is different from the *California*, where a thrust collar is provided on the generator shaft.

The speed control system, the main and emergency governors, the steam limit device and the gland control system are shown in Fig. 104.

The details of the operation of the speed control are as follows:



Approx. Ship Speed in Knots per Hour	No. of Main Turbines running	Hand Controlled Nozzles open
Maxim.	2	Nos. 1-2-3
21	2	Nos. 2-3
19	2	No. 3
15	1	No. 3
10	1	No. 4

Note:
Nozzle No. 5 is open constantly

Fig. 104.—U. S. S. *Tennessee:* Main Turbine Control Mechanism

Oil from the forced lubrication system at not less than 60 pounds per square inch gage pressure is admitted to the upper port indicated on the "governor control" (see Fig. 103) which is located in the main control room. The floating lever of the "control" is set to the desired position by a worm wheel and oil will be admitted through a piston valve to the under side of the main piston, causing this to lift until the oil pressure is balanced by spring pressure. The lifting of this piston causes the piston valve to lift at the same time, shutting off the oil supply to the under side of the piston, so that a balance will be obtained. Therefore, for any position of the lever handle there will be a corresponding position of the piston and a corresponding pressure under the piston. A motor driven vibrator constantly moves the valve up and down a small amount, causing a fluctuation of pressure under the piston, with a resultant small movement, thus eliminating any tendency towards sticking.

The oil pressure from the piston is communicated through a pipe to a piston on the governor. The governor is revolved through gearing by the main turbine shaft and, being of the fly-ball type, the weights will exert a pull, which will balance the pressure on the piston. For every oil pressure there will be a definite corresponding speed at which the weights will just balance the pressure of oil on the piston. The angles of the governor arms and links are so arranged that a slight change in speed will cause the governor to move from one extreme position to the other for any given oil pressure.

The governor is connected through linkage to the floating lever of a hydraulic relay which operates the main governor controlled inlet valve. A part of the linkage consists of a bell crank made in two parts but held together by means of a spring; this permits the motion of the governor to continue after it comes up against the steam limit stop as will be explained later.

This bell crank is connected to one end of the floating lever, the middle of which is connected to the oil relay plunger and the other end of which is connected to the operating gear on the governor controlled inlet valve. Oil is admitted at the center of the oil relay and if the governor weights move outward, due to an increase in turbine speed, the floating lever will be raised, allowing oil to pass into the top of the operating cylinder of the inlet valve and to pass out from the bottom of it at the same time, causing the piston in this cylinder to move downward and, by means of the lever indicated, to shut the governor controlled inlet valve, thus shutting off steam from the turbine. The return connection to the end of the floating lever at the same time moves the relay piston back to a position where oil is cut off, so that for every governor position there will be a corresponding position of the operating cylinder and of the inlet valve as well.

As has already been stated, a part of the connecting linkage between the governor and floating lever consists of a divided bell crank held together by a spring. A link from the floating lever connection engages at its lower end with a "steam limit stop" in such a manner as to be free always to move downward but only upward as far as the limit will permit. Thus the governor can always move its end of the floating lever to shut off steam but can only move it in the direction of admitting steam as determined by the steam limit. After reaching this limit, further motion of the governor will separate the two parts of the bell crank but will not have any effect on the turbine speed. The position of the steam limit stop is controlled by a small motor which is operated from the control room where the position of the stop is shown by an indicator and a red signal lamp.

Connected to the end of the turbine spindle is the automatic stop governor. This stop consists of an eccentric weight held in place by a spring. When the turbine speed reaches a predetermined point this weight flies out, causing the disengagement of the catch on the lever indicated, allowing a steam valve to open and releasing the pressure from under the piston of the automatic stop cylinders, one of which is shown connected to the main throttle valve and the other of which is shown connected to the automatic stop valve. These two stop cylinders are supplied with steam from a small pipe connection from the main steam line, so that, when the automatic stop governor trips, the pressure underneath the piston is reduced, causing the pistons to move downward their full amount. The automatic stop cylinder and automatic stop valve cause the oil pressure to build up in the top of the operating cylinder of the inlet valve and to exhaust from the bottom, thus causing the inlet valve to close. At the same time the cylinder on the main throttle valve releases the catch connected to the handwheel operated lever, allowing the spring on the main throttle valve to force this valve shut. The throttle valve cannot be opened again until the turbine has slowed down sufficiently for the automatic stop valve lever to be again caught on the trigger and the handwheel has been revolved to the closed position, re-engaging the catch on the main throttle valve.

The main turbine shaft glands, as stated above, are supplied with both steam and water, the steam being taken from the main steam line through a reducing valve and used at a pressure of about 5 pounds gage. The water is taken from the feed line between the feed pump and the feed water heater. This water connection is provided with a plug which has a 1/8 inch orifice, thus limiting the amount of water which can be used by the gland system. This water supply to the glands is kept at the proper pressure by means of a relief valve set at 7½ pounds, the excess water passing through the relief valve back to the feed tank.

The valve for shifting from "steam" to "water" on the glands is operated by a small governor driven through gearing from the main turbine spindle. This governor is adjusted to operate at between ⅓ and ½ full speed. Below this speed the weights are in the "in" position and the steam relay plunger or piston valve is in its top position. This allows steam to exhaust from under the piston shown on the gland control valve; since the upper part of this cylinder in which this piston operates is supplied with high pressure steam, the piston will drop, allowing the steam to pass, as indicated, through the reducing valve to the glands. When the governor speed reaches the predetermined amount, the governor moves toward the outer position and the steam relay piston to the lower position. This cuts off the escape of steam from under the gland control valve piston; the valve then rises its full amount, shutting off the opening into the gland steam line and, at the same time, admitting water from the high pressure line, referred to above, to the glands. An indicator on this gland control valve shows whether it is in the water or steam position. This gland control valve is fitted with a by-pass around it on both the steam and the water lines, so that it is possible to supply steam or water to the glands by hand in case it is desired to disconnect this valve for cleaning or inspection.

A spring is fitted on the top of the governor controlled inlet valve, connected through the lever to the operating cylinder. This spring tends to close the valve so that in order to hold it off its seat, the pressure in the bottom of the operating cylinder will have to be a few pounds higher than that in the top. A pipe connects the oil pipe of the operating cylinder to a similar cylinder on the auxiliary exhaust by-pass valve, so that, when the main governor controlled inlet valve is open, the pressure underneath the piston of the operating cylinder, being connected to the top of the operating piston of the auxiliary exhaust by-pass valve, will hold this valve shut since the closing pressure will be greater than the opening pressure. When, due to a speeding up of the main turbine, the governor causes the governor controlled inlet valve to shut, the pressure in the top of its operating cylinder will become greater than that in the bottom, which, in turn, will cause the pressure in the bottom of the auxiliary exhaust by-pass valve cylinder to be greater than that on top, thus opening the by-pass valve as desired. This by-pass valve may also be opened at any time by hand but it cannot be held shut, if the piston tends to open it.

MAIN GENERATOR

A cross section of the main generator is shown in Fig. 105. The generator rotor is shown in Fig. 106. The method of winding the generator stator is shown in Fig. 107 and the complete stator is shown in Fig. 108.

The main generator is two pole, three phase. The speed, rating, etc., are the same as for the sister ships, *California* and class.

The maximum designed voltage is 3,400.

Rotor: The turbo generator is generally in accordance with standard construction. The generator rotor is of the radial slot type. The rotor is a solid forging of low chrome nickel steel. The body of the rotor and shaft are forged in one piece. The rotor coils are held in the slots by brass wedges. The end connections are supported against centrifugal force by forged steel rings.

Stator: The stator core is built of laminations of electric sheet steel annealed and varnished. Paper is placed at intervals in the core to further break up eddy currents. The stampings

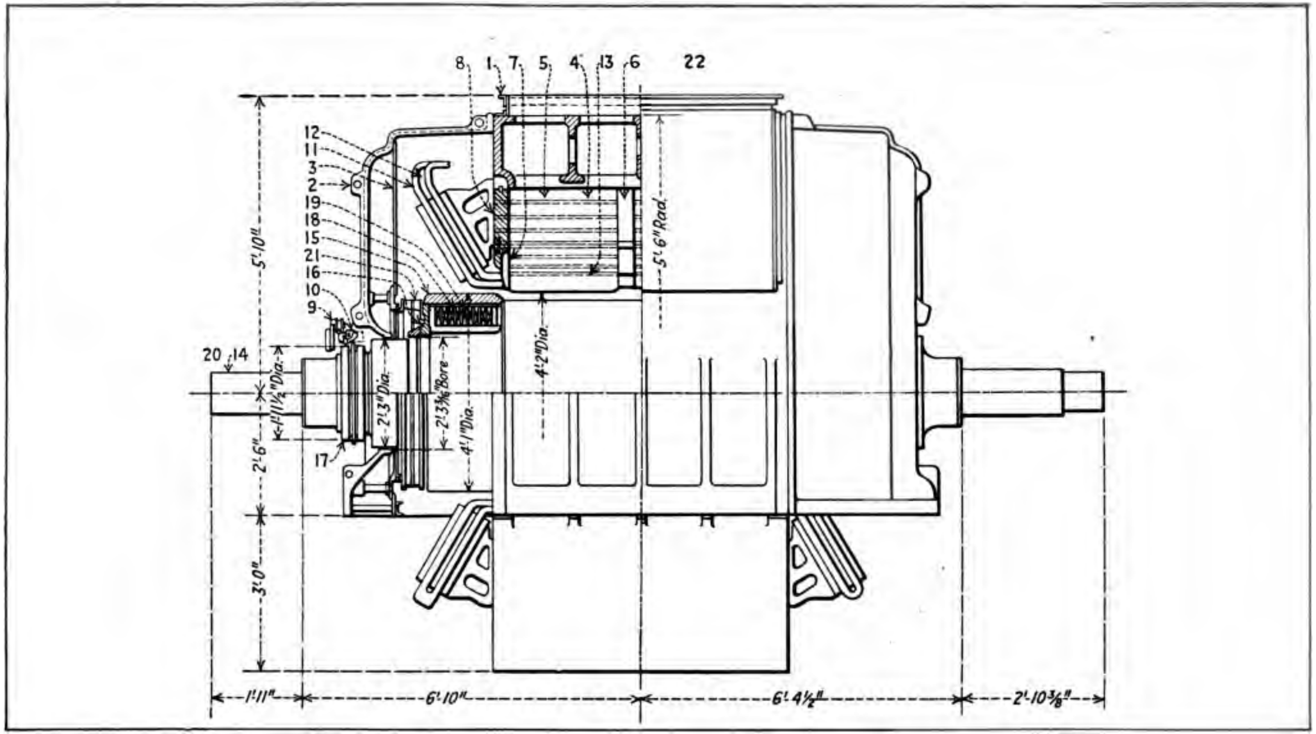


FIG. 105.—U. S. S. *Tennessee:* Main Generator

Bill of Material for Main Generator Shown in Fig. 105

Part No.	Name of Part
1.	Frame
2.	End Bell
3.	Inner Partition
4.	Armature Assembly
5.	Armature Punching
6.	Vent Plate
7.	Finger Plate
8.	End Plate
9.	Brush Holder Assembly
10.	Brush Holder
11.	Armature Coil and Insulation
12.	Wiring Around Frame
13.	Thermo Couple Connections
14.	Field Assembly and Shaft
15.	Field Coil Retaining Ring
16.	Rotating End Plate
17.	Collector
18.	Field Coils
19.	Rotating Part Assembly
20.	Rough Turned Shaft
21.	Blower
22.	Outline

have rectangular punchings through which the air is circulated for cooling. The laminations are assembled in a cast iron frame of sufficient section to insure ample rigidity and also of ample strength to care for short circuits. The laminations are clamped between cast iron end plates properly cored to allow of proper air circulation.

Insulation: The insulation of the rotor body is a mica trough, made of plate mica. The insulation between turns consists of flexible mica between thin paper and treated asbestos. The upper turns of the coil are wrapped with half-lapped mica tape to insure against grounding by creepage. The upper insulation in the slot consists of flat pieces of mica. The insulation on the ends of the coil is the same between turns as in the rotor body; the coils are individually wrapped with half-lapped asbestos tape, treated with varnish and baked.


FIG. 106.—U. S. S. *Tennessee:* Main Generator Rotor

FIG. 107.—U. S. S. *Tennessee:* Method of Winding Generator Stator

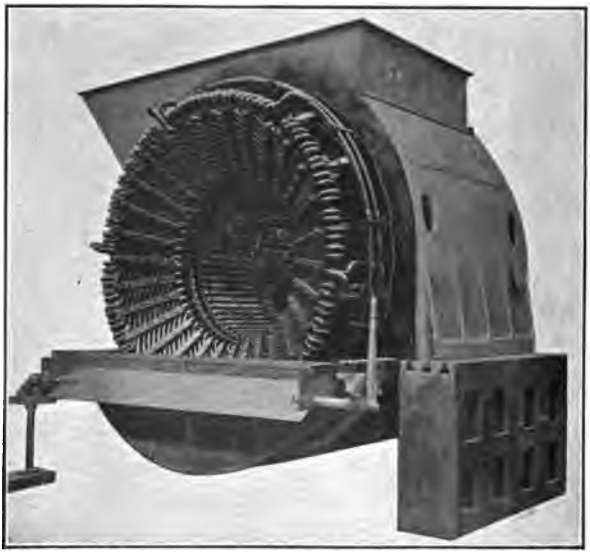


FIG. 108.—U. S. S. *Tennessee:* Main Generator Stator Complete

The stator coils are placed in open slots and are secured in position by means of fibre wedges. The insulation on the individual parts of the stator coil consists of half-lapped mica tape around each strand of the conductor, this tape being for the purpose of breaking up eddy currents. The coil has but one turn, so that insulation between turns, other than that needed to prevent grounding, is unnecessary. After the strands were taped, the straight part was dipped in bakelite and then put into a form and hot pressed. The entire coil was then impregnated in a special gum for the purpose of excluding air pockets and adding to the strength of the coil. The straight part was then insulated with mica folium, which, after being wrapped around the coil, was ironed in a machine made especially for the purpose. This should give a coil which is extremely solid in the slot part and one that will withstand high temperatures, since most of the insulation is mica. The ends of the coil are wrapped with a sufficient number of layers of treated tape to insure against breakdown. Varnish was used to fill the pores of the tape after each layer was wrapped. The final coil ends were wrapped with

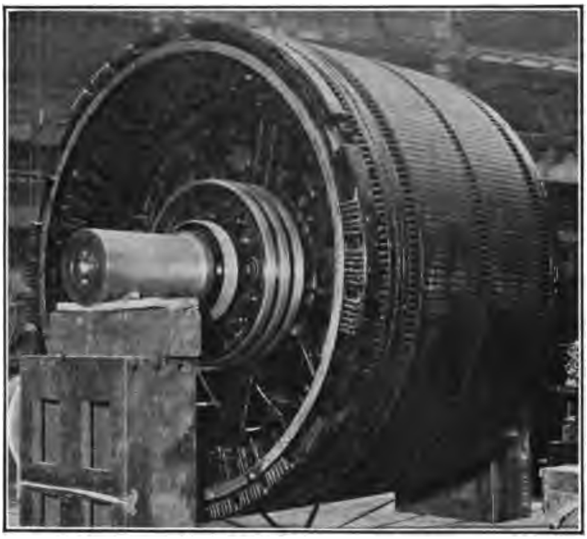


FIG. 109.—U. S. S. *Tennessee:* Rotor of Main Motor

tape and treated with varnish. The coil ends are rigidly supported in the manner shown in Fig. 107.

Ventilation: The ventilating fans are secured to each end of the rotor for creating a pressure of air in the end bells, this pressure being sufficient to drive the required amount of air through the axial ventilating slots to the center opening through which the air escapes. It will be noted that this differs from the *California* where the ventilating slots were radial.

FIG. 110.—U. S. S. *Tennessee:* Method of Winding Main Motor Stator

Bearings: The bearings are similar to those used on the turbine and are lubricated from the forced lubricating oil system.

MAIN MOTORS

The revolutions per minute and rating of the main motors are the same as those of the *California.* They are three phase and the stators are wound for both 24 poles and 36 poles, the two windings being entirely independent of each other. The rotors are of the definite wound type and the rotor windings are arranged as shown in Fig. 27 and described in Chapter IV.

The motor rotor is shown in Fig. 109. The method of winding the stator is shown in Fig. 110 and the complete motor, with ventilating ducts and fans, is shown in Fig. 111.

Frame: The stator frame is cast steel with circular and cross ribs to obtain proper stiffness. The cross ribs of the frame are dovetailed for supporting the laminations. The outer part of the frame is covered with sheet metal for the purpose of directing the flow of the air required for ventilation. The frame has brackets at either end for supporting the bearings; the openings in the brackets are covered with mesh doors.

FIG. 111.—U. S. S. *Tennessee:* Main Motor Complete

For the purpose of maintaining the motor at the proper temperature, when not in operation, so as to prevent sweating, heating elements for connection to the 240 volt direct current circuits are located between the laminations and the outer sheet metal lagging.

Brackets: The brackets for supporting the rotor bearings are of cast steel, machined to fit the frame without depending upon dowel bolts for maintaining the proper position of the bracket. Jack screws are provided to facilitate the removal of the bracket from the frame. The brackets are fastened to the frame by means of tap bolts. The center of the bracket is open and drilled for bolts for supporting the bearing housing. Provision is made, by means of eight jack screws, for adjusting the position of the bearing housing after the motor has been assembled. When the housing is in the correct position the ring of bolts will be tightened and the jack screws can then be backed off, if desired. Cross arms are provided on the brackets at the collector end of the motor for carrying the rotor and stator connections.

Bearings: The bearing housing is of cast steel, split and arranged so that the parts may be moved axially for the removal of the bearing shells. The bearing shells are of cast iron with spherical seats and split horizontally. The shells are lined with babbit. Eye bolts are provided so that the weight of the bearing and housing may be taken off the shaft when it is desired to remove the bearing. The bearings are lubricated by oil brought in through the bottom of the spherical seat, then passing through a copper tube to the top of the shaft. Oil slingers are provided on the shaft to prevent creepage of oil and proper drain passages are provided to carry the oil to the overflow. Oil rings are also provided so as to make the motor independent of the forced lubrication system in an emergency.

Rotor: The rotor spider is of cast steel pressed and keyed on the shaft. The cross arms of the spider are dovetailed to carry the secondary laminations. The spider carries the coil supports which are bolted to it by tap bolts. Two fans are provided at either end to assist the ventilation of the motor.

Collector: The collector is mounted on the shaft. The rings are of bronze bolted separately to the supporting ring. The collector rings are insulated from the rest of the machine with micarta bushings, giving ample creepage space, and after assembly were impregnated with varnish to fill up crevices where dirt or moisture might collect. The rotor connections are bolted to the inner periphery of the rings.

Brush Gear: The brush arms are supported by a ring bolted to the brackets. The arms are insulated from the ring by micarta. Provision is made for placing of barriers between the collector rings, if this should be found desirable.

Stator Punchings: The stator punchings are of the segmental type, dovetailed into the frame. They are arranged for axial ventilation, the air entering at both ends of the motor. The punchings are held between finger and end plates, the latter being fastened with tap bolts and through bolts.

Rotor Punchings: The rotor has segmental punchings dovetailed into the spider and arranged for axial ventilation with a central opening for the exit of air. The end plates are bolted to the spider.

Windings: There are two independent windings in the stator, one for each set of poles. One set of slots accommodates both of these windings, there being two coil sides of each set of coils placed in the slot, one directly above the other.

The rotor has a three phase, two parallel, star connected winding with balancer connections suitable for operation on the 24-pole winding. This winding has already been described in detail in Chapter IV.

Insulation: Both sets of the stator coils are of the diamond formed type and are completely insulated before being placed in the slots. A single 36-pole formed coil is composed of a single strap, taped overall with one layer of cotton tape, overlapped on the coil ends but not overlapped on the straight portions which lie in the slot. The 24-pole formed coil differs from the 36-pole coil in that it is composed of four single conductors wound in parallel with the individual conductors insulated with mica tape to reduce the eddy currents in the copper. The four conductors are taped together with cotton tape from end to end, the tape overlapping only on the coil ends, similar to the 36-pole coil described above.

The rotor coils are of the diamond type and consist of two straps connected in parallel after being placed in the slots. Each strap is completely formed and insulated before assembly in the machine. The reason for insulating these straps separately is to permit the use of partially closed slots in the rotor and at the same time retain all of the advantages of being able to insulate the formed coils outside of the machine.

The remainder of the description pertaining to the insulation of the coils of these motors is general and applies to the coils of both rotor and stator unless otherwise stated.

The straight parts of the coils imbedded in the core are subjected to the highest temperature of the motor and require the best kind of insulation from the heat resisting standpoint. Consequently, the imbedded portions of the coil are wrapped with several thicknesses of mica folium, reinforced with extra heavy mica plate, which extends all around the coil. This covering is first applied loosely by hand and the coil is then placed in a special machine equipped with electrically heated bars, which revolve under spring pressure, around the wrapper. This softens the bond and permits the wrapper under the pressure of the bars to slide on itself, resulting in an extremely solid and compact insulation. The coil is then placed in a cold press and pressed to the required dimensions. The covering tapers down to the strap a good safe distance away from where the end plates will come, in order to insure a good connection between the insulation of the straight parts of the coils and the insulation of the coil ends.

The coil ends are surrounded by air and do not require as high a heat resisting insulation as the straight part of the coils. They are covered by a number of layers of bias treated tape; this has great flexibility which permits it to adjust itself to a snug fit at all bends and corners of the strap. The fabric is of close texture, giving considerable mechanical strength to withstand the stresses set up in the coil ends due to abrupt changes of load on the motor. It is thoroughly impregnated with insulating varnish before being applied to the coils. An additional coating of insulating varnish is applied after each wrapping in order to seal the joints between the half overlapping tape. This tape is joined to the insulation of the straight parts of the coils with a specially prepared cement.

The last covering for the coil ends consists of one layer of overlapped cotton tape. Micarta strips are placed on the sides of the coil ends under the cotton tape to serve as spacers between adjacent coils after assembly. This outside covering is thoroughly filled by means of several successive treatments of insulating varnish, each coating being baked on for a long period with the final result that the coil ends possess a coating impervious to moisture and capable of withstanding salt deposits and foreign particles of dirt which may eventually find their way into the motor through the ventilating system.

All of the insulation, except where the cross connections join, having been put on the coils, is again placed in molds and pressed.

The part of the coil which spans the ventilating duct in the center of the core is armored with a copper sheet as an extra protection against erosion.

The slots are lined with a very tough paraffined fish paper cell to protect the insulation of the formed coil from injury in the assembling operations. This cell laps over the top of the last coil under the micarta wedges which are driven in from the ends of the slots. The individual formed coils are separated from each other by micarta spacers, any additional space in the slot being filled in with mica plate leaving no room for coil movement.

The figure of eight connectors joining the coil ends are insulated with several alternate layers of drilling and bias treated tape. The last covering is overlapped cotton tape treated in the same manner as the last layer of cotton tape on the coil ends.

The cross connections and balancer connections are insulated with the same material as the coil ends. In addition they are spaced from each other and protected from the cleats by micarta spacers.

The stator coil supports are insulated in the same manner as the coil ends. The rotor coil supports are covered with several layers of drilling, each layer being held in place by one layer of cotton tape, not overlapped. Each layer of drilling and tape is dipped in insulating varnish and baked before the succeeding layer is applied. Micarta strips are held in place over the top layer of drilling with cotton tape. The entire support then receives a number of dippings and bakings.

Each bottom stator coil is fastened by means of a heavy copper wire to the bottom coil support. This coil support consists of an insulated steel ring held in place by brackets bolted to the frame. Another insulated steel ring support is placed between the independent stator windings and is held in place by copper wires which extend around the ring and the individual coil ends of both stator windings. Thus, it is seen that all coil extensions are grouped into a single mass which is rigidly supported from the motor frame.

The rotor coil extensions rest upon a wide support, the insulation of which has been given previously, and are drawn down by extra heavy bands. This banding is separated from the coils by layers of treated fuller board.

LIQUID RHEOSTATS

The motors are reversed by inserting resistance in the rotor windings and reversing the connections of two of the phases. The motors are reversed on 24 poles since the rotor has an equivalent squirrel cage winding when the stator is connected for 36 poles. The method of reversing these motors has been described in Chapter IV and the torque characteristic curves are shown in Fig. 10.

The resistances consist of liquid rheostats which are located in the main control room and which connect to the slip rings of the motors. An outline of one of these rheostats is shown in Fig. 112.

The rheostat consists of two tanks, one mounted above the other and connected together. The liquid, which consists of a solution of sodium carbonate, is contained in the lower tank and is circulated through the upper tank by the motor driven centrifugal pump. The upper tank has two overflows one of which may be closed by the operating valve. The lower internal overflow fixes the minimum level of the electrolyte in the upper tank, at which point all of the three long electrodes are partially immersed. This gives the point of maximum resistance in the rotor circuit. Each lead of the rotor is connected to the three interleaved groups of electrodes. Insulating barriers are placed between the three long electrodes, the tops of the barriers being above the level of the electrolyte when the maximum resistance is in circuit. At this point the rheostat may have double the normal rotor voltage on it during reversal of the main motors; the use of barriers is an additional protection against flashing. In addition the distance between the electrodes is such that the maximum possible potential per unit distance is well within what has been found permissible by experience in similar rheostats. The fact that the longer electrodes are always immersed insures that the rotor circuit can never be opened with the consequent insulation

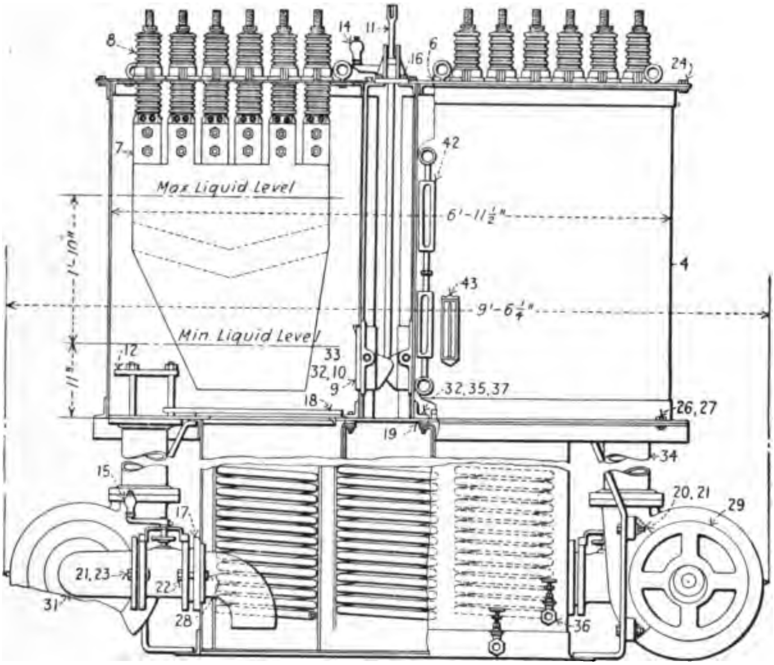


FIG. 112.—U. S. S. *Tennessee:* Liquid Rheostat Used When Reversing Main Motor

Bill of Material for Liquid Rheostats Shown in Fig. 112

Part No.	Name of Part
4.	Tank
6.	Cover
7.	Electrode Assembly
8.	Insulator Assembly
9.	Valve Details
10.	Valve Details
11.	Valve Operating Details
12.	Barrier
13.	Cooling Coils
14.	Emergency Valve Details
15.	Pump Valve
16.	Cover Plates
17.	Fittings
18.	Trap Door
19.	Collar (item 8)
20.	¾" x 3" M. B. Tap Bolt
21.	¾" Hex. I. Nut
22.	¾" x 2" M. B. Tap Bolt
23.	¾" x 2" M. B. Tap Bolt
24.	½" x 1¼" M. B. Tap Bolt
25.	½" Hex. I. Nut
26.	⅝" x 1¼" M. B. Tap Bolt
27.	⅝" Hex. Nut
28.	⅜" x 1" M. B. Tap Bolt
29.	Motor
30.	Pump
31.	6" C. I. Flanges Elbow 90°
32.	⅜" Hex. I. Nut
33.	⅜" x 1¼" M. B. Tap Bolt
34.	2' 6¾" of 6 W. I. Pipe th'd both ends
35.	⅜" x 3" M. B. Tap Bolt
36.	Nelson 1" Bronze Gate Valve
37.	⅜" Lock Washer
38.	Copper Details
42.	Water Gage
43.	Thermometer

stresses that might be thrown on the rotor, if this were done. It also prevents insulation stresses on the stator during switching as the energy stored in the stator may be dissipated in the rotor resistance.

The pump runs continuously and there is always a vigorous circulation of the electrolyte. This effectively prevents the formation of gas bubbles on the electrodes which might cause a variation of the resistance by reducing the effective area. The pumps for each pair of rheostats can be cross connected so that one pump can supply both rheostats in an emergency.

When the lower overflow is closed by the operation of the valve, the level of the electrolyte in the upper chamber rises until the upper fixed overflow is reached. At this point the minimum resistance is in circuit and the short circuiting switch for the rotor leads may be closed. The electrolyte continues to circulate and, if the short circuiting switch is not closed, there is very little additional loss.

The three groups of electrodes are mounted on substantial insulated conductors, the leads for the three phases being brought up through the top of the tank for connecting to the cables. The top of the tank is closed and provided with a vent pipe to allow of the escape of any vapors from the electrolyte. The design is such that rolling or pitching of the ship will not materially affect the resistance in the rotor circuit and splashing is also prevented by the closed top.

A cooling coil is fitted in each rheostat, the cooling water being supplied from the water service.

SWITCHBOARDS

There is a direct current switchboard in each engine room for the 300-kilowatt generators and also for the motor driven auxiliaries and for excitation. There is a main switchboard in the control room for controlling the main motors and turbo generators. There are two direct current switchboards alongside the main switchboard; these are for controlling the motor ventilating blowers, rheostat circulating pumps, etc. Each of these switchboards and the wiring is described below.

DIRECT CURRENT WIRING

The direct current wiring is shown in Fig. 113. This arrangement is practically the same as that of the *California* but there are some minor differences. All the auxiliaries are run off the 240-volt circuit at all times. The arrangement of the short circuiting switch for the booster is also slightly different but accomplishes the same purpose. The main field switch does not close any contactors for the main motors since they are not provided with them.

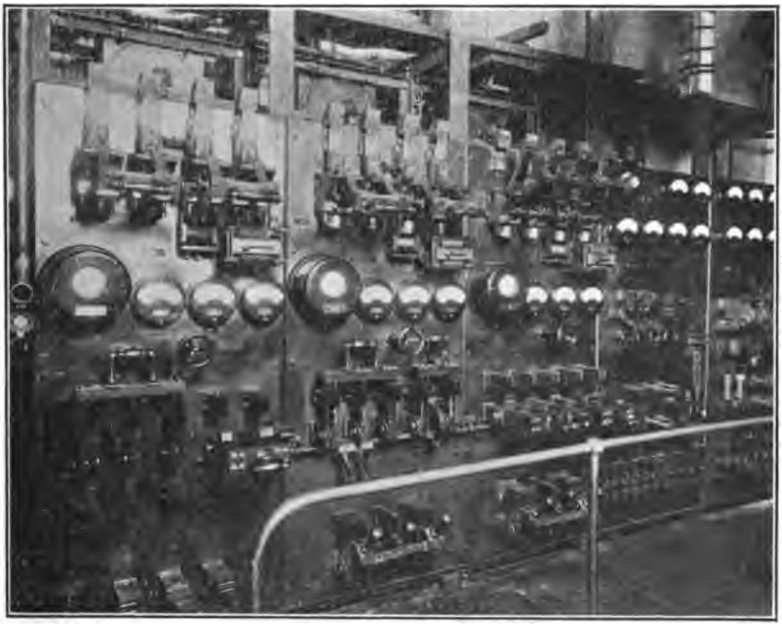
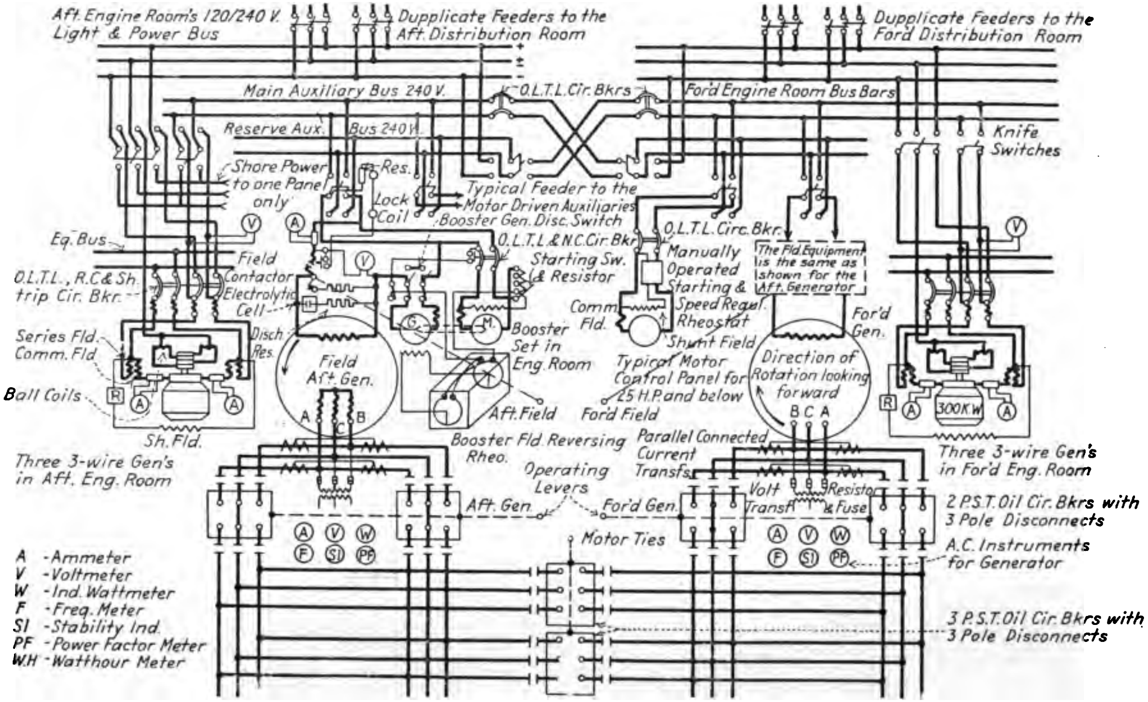


FIG. 114.—U. S. S. *Tennessee:* Generator and Auxiliary Switchboard

GENERATOR AND AUXILIARY SWITCHBOARD

This switchboard is shown in Fig. 114. There is one of these in each engine room. The connections to it are given in Fig. 113. The arrangement of interlocks is identical with that of the *California.*


Aft. Engine Room's 120/240 V. Light & Power Bus
Dupplicate Feeders to the Aft. Distribution Room
Dupplicate Feeders to the Ford Distribution Room
Main Auxiliary Bus 240 V.
O.L.T.L. Cir. Bkrs
Ford Engine Room Bus Bars
Reserve Aux. Bus 240 V.
Knife Switches
Shore Power to one Panel only
Res.
Lock Coil
Typical Feeder to the Motor Driven Auxiliaries
Booster Gen. Disc. Switch
O.L.T.L. Circ. Bkr.
O.L.T.L. & N.C. Cir. Bkr.
Starting Sw. & Resistor
Manually Operated Starting & Speed Regul. Rheostat
The Fld. Equipment is the same as shown for the Aft. Generator
Eq. Bus
Field Contactor
Electrolytic Cell
O.L.T.L., R.C. & Sh. trip Cir. Bkr.
Series Fld.
Comm. Fld.
Disch. Res.
Ball Coils
Field Aft. Gen.
Booster Set in Eng. Room
Comm. Fld.
Shunt Field
Typical Motor Control Panel for 25 H.P. and below
Ford Gen.
Direction of Rotation looking forward
300 K.W.
A C B
B C A
Sh. Fld.
Aft. Field
Ford Field
Booster Fld. Reversing Rheo.
Parallel Connected Current Transfs.
Three 3-wire Gen's in Aft. Eng. Room
Three 3-wire Gen's in Ford Eng. Room
Operating Levers
Aft. Gen.
Ford Gen.
Volt Transf.
Resistor & Fuse
2 P.S.T. Oil Cir. Bkrs with 3 Pole Disconnects
Motor Ties
A.C. Instruments for Generator
3 P.S.T. Oil Cir. Bkrs with 3 Pole Disconnects
A - Ammeter
V - Voltmeter
W - Ind. Wattmeter
F - Freq. Meter
SI - Stability Ind.
PF - Power Factor Meter
W.H. - Watthour Meter

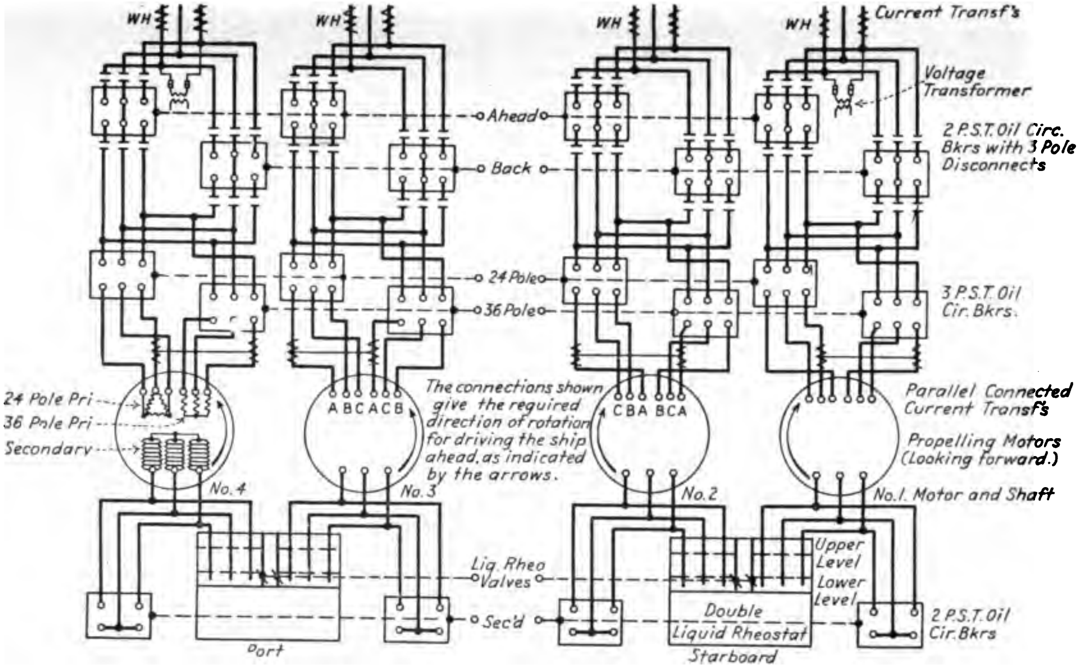


FIG. 115.—U. S. S. *Tennessee:* Diagram of Connections, Control Room and Motor Rooms

CONTROL ROOM WIRING

The control room wiring, shown in Fig. 115, includes the main alternating current wiring and also the direct current wiring for the blower motors, etc. The arrangement of the latter is practically identical with that of the *California* except that there are additional switches for the rheostat circulating pumps and the small vibrator motor used for keeping the pressure of the oil to the governor pulsating.

The alternating current wiring is arranged with a separate bus for each main motor. All switches used in this circuit are oil switches. The following switches are provided:

4 36-pole pole changers.
4 24-pole pole changers.
4 ahead switches.
4 astern switches.
4 short circuiting switches for the rheostats.
4 generator switches.
2 tie switches.

Some of these switches are provided with disconnects so that the entire switch can be removed from the circuit and repaired. Since there is a separate bus for each motor this can be done at any time without affecting more than one motor. The type of switch used is shown in Fig. 116. All the switches are similar to this one.

The arrangement of levers for operating the switches is entirely different from that of the *California* class since a separate lever is provided for each set of switches instead of combining them; for example, the "ahead" and "astern" switches on the *California* are operated by two different throws of the same lever, while on the *Tennessee* a separate lever is provided for each. The following list gives the levers used in operation:

2 36-pole pole changer levers.
2 24-pole pole changer levers.
2 ahead levers.
2 astern levers.
2 short circuiting levers.
2 generator levers.
1 tie lever.
2 field levers.
2 speed control wheels.
2 rheostat valve operating levers.

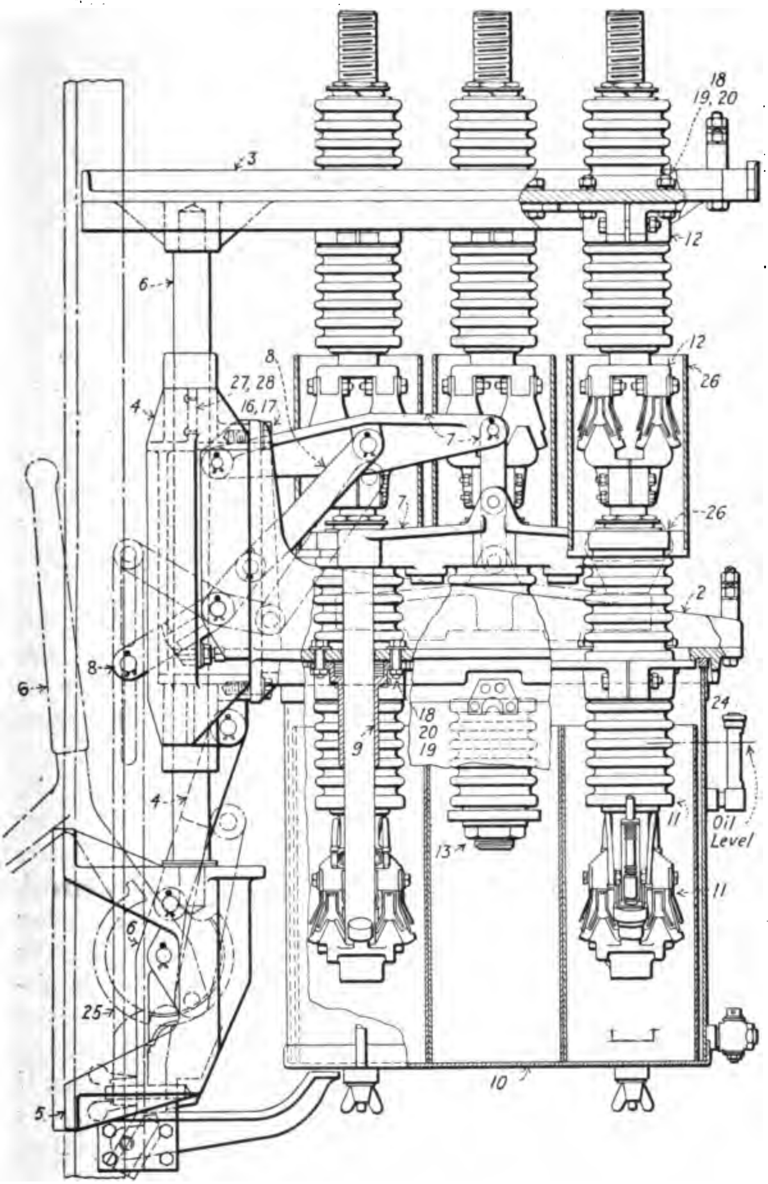


FIG. 116.—U. S. S. *Tennessee:* Assembly of 1,600 Ampere Oil Circuit Breaker with Disconnects

Bill of Material for Oil Circuit Breaker Shown in Fig. 116

Part No.	Name of Part	Part No.	Name of Part
2.	Supporting Frame for Breaker	13.	Middle Pole Tie Assembly
3.	Supporting Frame for Disconnects	15.	Tank Lifter Assembly
4.	Sliding Bracket and Lifting Link	16.	5/8" x 1½" M. B. Tap Bolt
5.	Disconnecting Mechanism Bracket	17.	5/8" Lock Washer
6.	Breaker Disconnecting Details	18.	3/8" x 1½" M. B. Tap Bolt
7.	Main Lever and Crossbar	19.	3/8" Hex. Nut
8.	Breaker Closing Lever and Links	20.	3/8" Lock Washer
9.	Lifting Rod Guide	24.	Oil, 15 Gals.
10.	Tank	25.	Operating Link
11.	Stat'y and Moving Contact Assembly	26.	Insulation Details
		27.	Name Plate
12.	Disconnecting Contact Assembly	28.	3/32" Esc. Pin

The following description gives the use and method of operating each of the oil switches:

Pole Changers.—These switches are operated in pairs—that is, one lever operates the pole changers for a pair of motors. There is one lever for each pair of 24-pole changers and another lever for each pair of 36-pole changers. They are made 2-pole to make them easy to operate. It is not necessary to make them 3-pole as they are between the motors and the reversing switches and the latter have 3-pole disconnects.

Reversing.—These switches are operated in pairs—that is, one lever operates the reversing switches for a pair of motors. There is one lever for each pair of ahead switches and another lever for each pair of astern switches. They are made 2-pole to make them easy to operate but they are provided with 3-pole disconnects.

The switches can be disconnected simply by lowering them by a lever as shown in Fig. 116. They must be open before they can be lowered; after they are lowered the oil tanks can be removed for overhaul. Moreover, after a switch has been lowered, it can be disconnected from the operating lever and the other switch on that lever can then be worked by itself. In order completely to disconnect any motor, it will be necessary to disconnect (lower) both the ahead and astern switches as each has one phase running straight through to the motor. However, any motor can be disconnected by means of the generator switches, if both generators are running so that the tie switches are open. As this would always be the case in action, this is the most important condition.

Generator.—These switches are operated in pairs—that is, one lever operates both switches for one generator and another lever operates both switches for the other generator. They are made 2-pole to make them easy to operate but they are provided with 3-pole disconnects. They can be disconnected simply by lowering them by a lever. They must be open before they can be lowered; after they are lowered, the oil tank can be removed for overhaul. Also, after a switch has been lowered, it can be disconnected from the operating lever and the other switch on that lever can then be worked by itself. If the tie switches are open (both generators running), disconnecting one generator switch would be the quickest way to disconnect any particular motor; this method could not be used if only one generator is in use because each generator switch then supplies one motor direct and also another motor (on the other side of the ship) through a tie switch. If only one generator is in, the switches of the other generator should invariably be kept disconnected (lowered) as otherwise one phase of that generator will be alive due to the fact that the generator switches are 2-pole.

Tie.—Both tie switches are operated by one lever. These switches are 3-pole; they can be disconnected simply by lowering them by a lever. They must be open before they can be lowered; after they are lowered, the oil tanks can be removed for overhaul. After a switch has been lowered it can be disconnected from the operating lever and the other switch on that lever can then be worked by itself.

Short Circuiting.—These switches are operated in pairs—that is, one lever operates the short circuiting switches for a pair of motors. They are made 2-pole to make them easy to operate and there is no necessity for making them 3-pole.

All these switches are operated in oil and are capable of breaking full load currents.

In order to prevent improper operation of the switches, interlocks are provided as shown in Fig. 117. The interlocks for each lever are as follows:

36-POLE POLE CHANGER

(1) Cannot be closed unless field lever is open. (Both field levers when tie switch is closed.)

This interlock prevents closing the main circuit with load on by closing the pole changer.

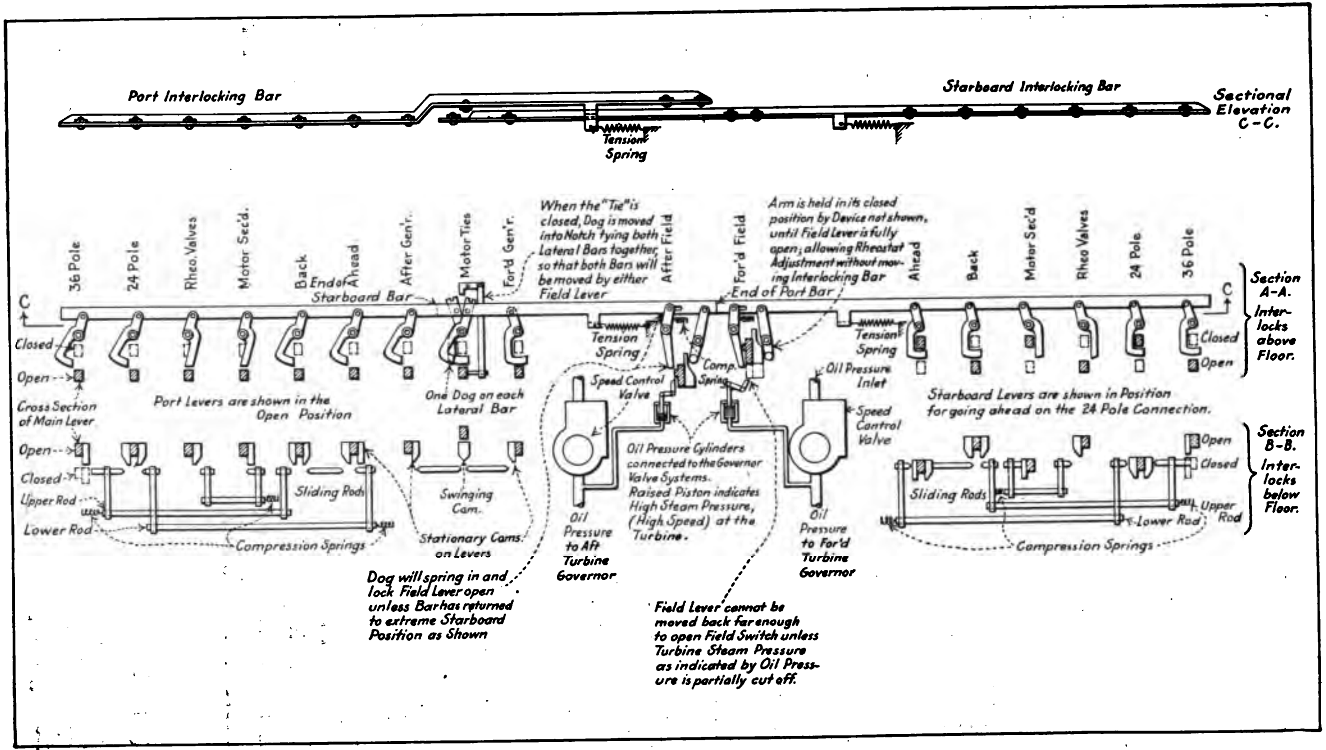
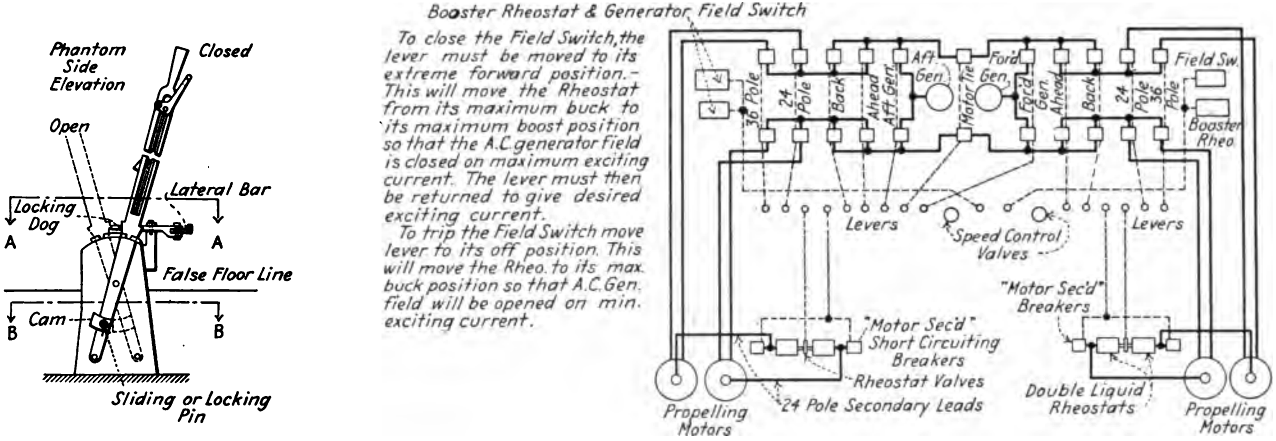


FIG. 117a.—U. S. S. *Tennessee:* Scheme of Lever Interlocking in Control Room



To close the Field Switch, the lever must be moved to its extreme forward position.– This will move the Rheostat from its maximum buck to its maximum boost position so that the A.C. generator field is closed on maximum exciting current. The lever must then be returned to give desired exciting current.

To trip the Field Switch move lever to its off position. This will move the Rheo. to its max. buck position so that A.C. Gen. field will be opened on min. exciting current.

FIG. 117b.—U. S. S. *Tennessee:* Side Elevation of Interlocking Levers and Schematic Diagram of Alternating Current Power Circuits

Fig. 117—Lever Interlocking in Control Room

Table 1—Sequence of Manipulations

TO OPERATE WITH ONLY ONE GENERATOR

Start and Run on 24 Poles

"Tie" and either "After Gen." or "For'd. Gen." closed. All others open.
Disconnects of idle gen. to be open, unless it is desired to have gen. standing by for immediate service in case of emergency.
Set Speed Control "Slow."
Close both "24 pole."
Close both "Ahead."
Close "Field."
Close both "Rheo. Valves."
Allow liquid in both Rheos. to reach max. height.
Close both "Motor Sec'd."
Open both "Rheo. Valves."
Adjust speed control to desired speed.

To Get Under Way from Standstill and Run on 36 Poles

Start on 24 poles as listed above, then change over to 36 poles as listed below.

Changes from Run on 24 Poles. To Run on 36 Poles

Adjust speed control to get the ship going *thru the water* at the desired speed; then—
Set Speed Control "slow."
Open "Field."
Open both "Motor Sec'd."
Open both "24 Pole."
Close both "36 Pole."
Close "Field."
Adjust speed control to desired speed.

Stop from 24 Pole Running

Set Speed Control "slow."
Open "Field."
Open both "Motor Sec'd."
Open "Ahead." *

Reverse from 24 Pole Running

Stop, as above; then
Close "Back." *
Close "Field."
Close both "Rheo. Valves."
Allow liquid in both Rheos. to reach max. height.
Close both "Motor Sec'd."
Open both "Rheo. Valves."
Adjust speed control to desired speed.

Stop from 36 Pole Running

Set Steam Control "slow."
Open "Field."
Open both "36 Pole."
Open "Ahead." *
Close both "24 Pole."

Reverse from 36 Pole Running

Stop, as above; then
Close "Back." *
Close "Field."
Close both "Rheo. Valves."
Allow liquid in Rheos. to reach max. height.
Close both "Motor Sec'd."
Open both "Rheo. Valves."
Adjust speed control to desired speed.

* Manipulate Port, Starboard, or both levers according to signal.

TO OPERATE WITH BOTH GENERATORS ("Tie" open.)

Sequences of manipulation are the same as for operating with only one generator except that both "Fields" and both Speed Controls must be manipulated.

Fig. 117—Lever Interlocking in Control Room

Table II—Interlocking Table—Tie Breaker Open

Lever	Conditions Required Before Lever Can Be Closed	Locking Accomplished When Lever is Closed	Conditions Required Before Lever Can Be Opened
Motor Ties.	Either “Gen’r.” open. Both “Fields” open. Both “Rheo. Valves” open. Both “Motor Sec’d.” open.	(See other table.)	....
After Gen’r.	“After Field” open. Port “Rheo. Valves” open. Port “Motor Sec’d.” open.	If both “Gen’r.” levers are closed, the “Motor Ties” is locked open.	“After Field” open. Port “Rheo. Valves” open. Port “Motor Sec’d.” open.
For’d. Gen’r.	“For’d. Field” open. Starb’d “Rheo. Valves” open. Starb’d “Motor Sec’d.” open.		“For’d. Field” open. Starb’d. “Rheo. Valves” open. Starb’d “Motor Sec’d.” open.
24 Pole.	“Field” open. “Rheo. Valves” open. “Motor Sec’d.” open. “36 Pole” open.	“36 Pole” open.	“Field” open. “Rheo. Valves” open. “Motor Sec’d.” open.
36 Pole.	“Field” open. “Rheo. Valves” open. “Motor Sec’d.” open. “24 Pole” open. “Back” open.	“24 Pole” open. “Back” open. “Ahead” open if initially open or if subsequently opened.	Same as for “24 Pole.”
Ahead.	“Field” open. “Rheo. Valves” open. “Motor Sec’d.” open. “Back” open. “24 Pole” closed. (“36 Pole” open.)	“Back” open.	Same as for “24 Pole”
Back.	“Field” open. “Rheo. Valves” open. “Motor Sec’d.” open. “Ahead” open. “36 Pole” open.	“Ahead” open. “36 Pole” open.	Same as for “24 Pole.”
Field.	“Rheo. Valves” open. “Motor Sec’d.” open.	“36 Pole” open or closed. “24 Pole” open or closed. “Back” open or closed. “Ahead” open or closed. “Gen’r.” open or closed. “Motor Ties” open or closed.	Low oil pressure in Governor system, indicating a slow speed setting of turbine.
Rheo. Valves.	“Field” closed.	Same as for “Field” and in addition “Field” open.	No Restrictions.
Motor Sec’d.	“Field” closed. “Rheo. Valves” closed.		No Restrictions.
Turbine Speed Control.	No Restrictions.	“Field” closed.	No Restrictions.

Fig. 117—Lever Interlocking in Control Room

Table III—Interlocking Table—Tie Breaker Closed

Lever	Conditions Required Before Lever Can Be Closed	Locking Accomplished When Lever is Closed	Conditions Required Before Lever Can Be Opened
Motor Ties.	(See other table.)	Port and Starboard Interlocking Bars connected so that they move as one bar.	Both "Fields" open. Both "Rheo. Valves" open. Both "Motor Sec'd." open.
For'd. or After Gen'r.	Other "Gen'r." open. Both "Fields" open. Both "Rheo. Valves" open. Both "Motor Sec'd." open.	Other "Gen'r." open.	Same as for "Motor Ties."
Port * 24 Pole.	Both "Fields" open. Both "Rheo. Valves" open. Both "Motor Sec'd." open. Port * "36 Pole" open.	Port * "36 Pole" open.	Same as for "Motor Ties."
Port * 36 Poles.	Both "Fields" open. Both "Rheo. Valves" open. Both "Motor Sec'd." open. Port * "24 Pole" open. Port * "Back" open.	Port * "24 Pole" open. Port * "Back" open. Port * "Ahead" open if initially open or if subsequently opened.	Same as for "Motor Ties."
Port * Ahead.	Both "Fields" open. Both "Rheo. Valves" open. Both "Motor Sec'd." open. Port * "Back" open. Port * "24 Pole" closed (Port * "36 Pole" open.)	Port * "Back" open.	Same as for "Motor Ties."
Port * Back.	Both "Fields" open. Both "Rheo. Valves" open. Both "Motor Sec'd." open. Port * "Ahead" open. Port * "36 Pole" open.	Port * "Ahead" open. Port * "36 Pole" open.	Same as for "Motor Ties."
For'd or After Field.	Other "Field" open. Both "Rheo. Valves" open. Both "Motor Sec'd." open.	Both "36 Pole" open or closed. Both "24 Pole" open or closed. Both "Back" open or closed. Both "Ahead" open or closed. Both "Gen'r." open or closed. "Motor Ties" closed. Other "Field" open.	Low oil pressure in corresponding turbine governor system; indicating a slow speed setting of turbine.
Port * Rheo. Valves.	Either "Field" closed.	Same as for "Field" except "Both Fields" open.	No Restrictions.
Port * Motor Sec'd.	Either "Field" closed. Port * "Rheo. Valves" closed.		No Restrictions.
For'd or After Turbine Speed Control.	No Restrictions.	Corresponding "Field" lever closed.	No Restrictions.

* Locking for the Starboard Levers is identical with that for the Port Levers.

(2) Cannot be closed unless astern switch is open.

This prevents closing the astern switch on the 36-pole condition which would give a big rush of current since the 36-pole condition does not provide for rheostat connection.

(3) Cannot be closed unless 24-pole pole changer is open.

This prevents closing the 24-pole and 36-pole switches at the same time.

(4) Cannot be opened unless field lever is open. (Both field levers when tie switch is closed.)

This prevents interrupting main circuit with load on by opening the pole changer.

24-POLE POLE CHANGER

(1) Cannot be closed unless field lever is open. (Both field levers when tie switch is closed.)

Same reason as for (1) of 36-pole pole changer.

(2) Cannot be closed unless 36-pole pole changer is open.

This prevents both pole changers being closed at the same time.

(3) Cannot be closed unless valve lever is open.

This insures that the motors will always be started up with the maximum rheostat resistance in the secondary circuit.

(4) Cannot be closed unless short circuiting switch is open.

This interlock prevents having the short circuiting switch in when operating. This switch would nullify the effect of the resistance, if it were closed.

(5) Cannot be opened unless field lever is open. (Both field levers when tie switch is closed.)

Same reason as for (4) of 36-pole pole changer.

(6) Cannot be opened unless valve lever is open. (Both valve levers when the tie switch is closed.)

This insures that the valve lever will always have been opened an appreciable time before any other levers on the board are opened or closed, thus making sure that all the water in the rheostat tank will have run out, thus giving the maximum resistance for operating the motor.

(7) Cannot be opened unless short circuiting switch is open. (Both short circuiting switches when tie switch is closed.)

This interlock follows on account of the methods used for securing the other interlocks. It does have a certain value in that it insures that the short circuiting switch will always be opened before transferring from the 24-pole condition to the 36-pole condition, thus getting all the levers ready to answer a signal to back.

VALVE LEVER

(1) Cannot be closed unless field lever is closed. (Either field lever when tie switch is closed.)

This insures that the valve lever will not be closed until after field has been established, since, if the valve lever were closed first and field established afterward, it would amount to doing away with the resistance entirely as the rheostat tank would probably be nearly up to the maximum level by the time field would be established.

SHORT CIRCUITING SWITCHES

(1) Cannot be closed unless valve lever is closed.

(Operator should wait till rheostat tank is at its maximum level position before closing short circuiting switch; gage glass on tank will show height of liquid.)

This insures that the short circuiting switch will not be closed until the liquid is at its maximum level and consequently the minimum resistance, thus insuring against large rushes of current due to putting motor out of step with generator by suddenly changing the resistance of a secondary.

(2) Cannot be closed unless field lever is closed. (Either field lever when tie switch is closed.)

ASTERN SWITCH

(1) Cannot be closed unless field lever is open. (Both field levers when tie switch is closed.)

Same reason as for (1) of 36-pole pole changer.

(2) Cannot be closed unless ahead switch is open.

This prevents closing ahead and astern switches at the same time.

(3) Cannot be closed unless 36-pole pole changer is open.

This prevents backing on the 36-pole connection which connection does not provide for resistance in the motor secondaries.

(4) Cannot be closed unless valve lever is open. (Both valve levers when tie switch is closed.)

This prevents backing except when full resistance is in the motor secondaries.

(5) Cannot be closed unless short circuiting switch is open. (Both short circuiting switches when tie switch is closed.)

This prevents an attempt being made to back with the rheostat short circuited.

(6) Cannot be opened unless field lever is open. (Both field levers when tie switch is closed.)

Same reason as for (4) of 36-pole pole changer.

(7) Cannot be opened unless valve lever is open. (Both valve levers when tie switch is closed.)

Same reason as for (6) of 24-pole pole changer.

(8) Cannot be opened unless short circuiting switch is open. (Both short circuiting switches when tie switch is closed.)

Same reason as for (7) of 24-pole pole changer.

(9) Cannot be disconnected unless switch is open. (Any one of the four motors can be disconnected independently of the others.)

This prevents the disconnection being made on a live switch.

(10) Cannot be closed until it has again been raised.

This prevents connection being made when the switch is alive.

(11) Oil tank cannot be removed until switch has been lowered.

AHEAD SWITCH

(1) Cannot be closed unless field lever is open. (Both field levers when tie switch is closed.)

Same reason as for (1) of 36-pole pole changer.

(2) Cannot be closed unless astern switch is open.

This prevents closing ahead and astern switches at the same time.

(3) Cannot be closed unless 24-pole pole changer is closed.

This insures that in going ahead the motor will always be started up on the 24-pole connection; change can be made to 36-pole connection when desired but should not be done until ship has picked up her speed ahead through the water.

(4) Cannot be closed unless valve lever is open. (Both valve levers when tie switch is closed.)

This insures starting up the motors with maximum resistance in the secondaries.

(5) Cannot be closed unless short circuiting switch is open. (Both short circuiting switches when tie switch is closed.)

This will prevent the short circuiting switch from being closed on starting up and thus short circuiting the rheostat resistance.

(6) Cannot be opened unless field lever is open. (Both field levers when tie switch is closed.)

Same reason as for (4) of 36-pole pole changer.

(7) Cannot be opened unless valve lever is open. (Both valve levers when tie switch is closed.)

Same reason as for (6) of 24-pole pole changer.

(8) Cannot be opened unless short circuiting switch is open. (Both short circuiting switches when tie switch is closed.)

Same reason as for (7) of 24-pole pole changer.

(9) Cannot be disconnected unless switch is open. (Any one of the four motors can be disconnected independently of the others.)

This prevents the disconnection being made on a live switch.

(10) Cannot be closed until it has again been raised.

This prevents connection being made when the switch is alive.

(11) Oil tank cannot be removed until switch has been lowered.

CONTROL VALVE

Turbine speed can be raised or lowered without restriction.

FIELD LEVER AND BOOSTER RHEOSTAT

(The same lever opens and closes the main field and raises and lowers the rheostat resistance of the booster field.)

(1) The field switch is closed with maximum voltage across generator field. In closing, the lever travel reduces the bucking voltage of the booster to zero and then boosts the voltage above the exciting bus voltage of 240. The field switch is closed at the extreme forward position of the lever travel and is brought back to give the desired exciting voltage. The field switch is not

tripped until the lever has been brought back the whole way to the open position so that practically the entire lever travel is utilized for getting voltage variation.

(2) The field lever cannot be opened (can be closed) unless steam is partially cut off corresponding to a predetermined oil pressure in the governor control system and consequently to a predetermined low speed of the turbine.

(3) At the point where the field is opened the booster has bucked the excitation voltage down to approximately 50 volts.

(4) The field lever cannot be closed unless the valve lever and the short circuiting lever are open. (Both valve levers and both short circuiting levers if tie switch is closed.)

(5) With the tie switch closed, one field lever cannot be closed unless the other field lever is open.

TIE SWITCH

(1) Cannot be closed unless both field levers are open.
This prevents closing the tie switch on a live circuit.
(2) Cannot be closed when both generator switches are closed.
This prevents paralleling the two generators.
(3) Cannot be opened unless both field levers are open.
This prevents opening the tie switch on a live circuit.
(4) Cannot be lowered (disconnected) unless it is open.
This prevents disconnection being made when switch is alive.
(5) Cannot be closed until it has again been raised.
This prevents connection being made when switch is alive.

(6) Oil tank cannot be removed until switch has been lowered.

GENERATOR SWITCHES

(1) Cannot be closed when other generator switch and tie switch are closed.

This prevents paralleling the two generators.

(2) Cannot be closed unless field lever is open. (Both field levers when tie switch is closed.)

This prevents the switch from being closed when alive.

(3) Cannot be opened unless field lever is open. (Both field levers when tie switch is closed.)

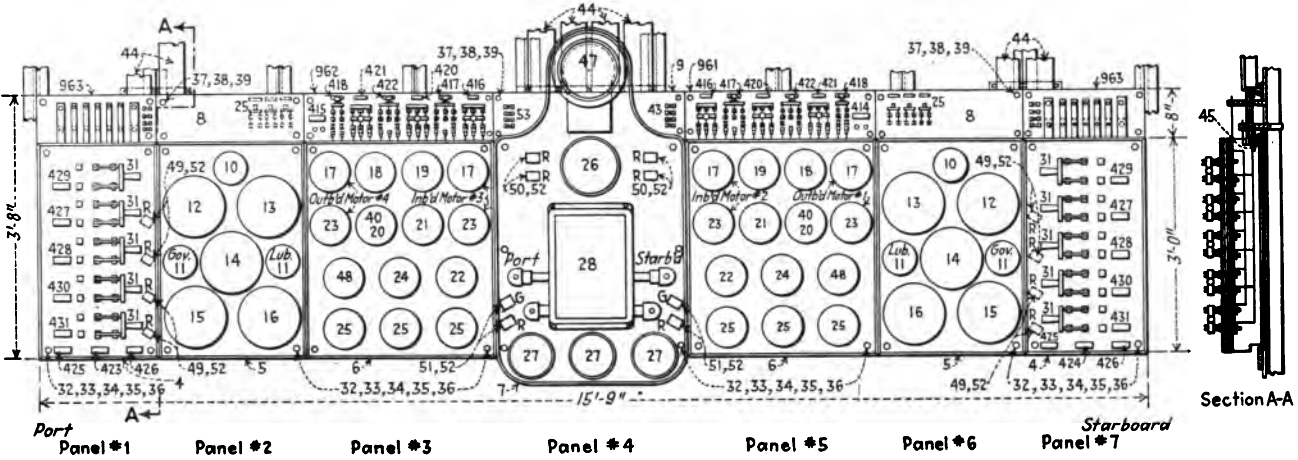


FIG. 118.—U. S. S. *Tennessee:* Instrument Panels for Main Switchboard

Bill of Material for Main Switchboard Shown in Fig. 118

Part No.	Name of Part
4.	Panel 3' 0" High x 1' 9" Wide x 1½", ¼" Bevel—Ebony Asbestos Wood
5.	Panel 3' 0" High x 2' 1" Wide x 1½", ¼" Bevel—Ebony Asbestos Lumber
6.	Panel 3' 0" High x 2' 8½" Wide x 1½", ¼" Bevel Ebony Asbestos Wood
7.	Panel 4' 11½" High x 2' 8" Wide x 1", ¼" Bevel—Ebony Asbestos Wood
8.	Panel 8" High x 2' ⅞" Long x 1". Ebony Asbestos Lumber
9.	Panel 8" High x 2' 7⅞" Long x 1". Ebony Asbestos Lumber
10.	4½" Feed Water Gage 0-560 lbs. 280 lbs. Working Pressure
11.	4½" Oil Pressure Gage 0-160 lbs. 80 lbs. Working Pressure
12.	8½" Steam Gage 0-300 lbs. 250 lbs. Working Pressure
13.	8½" Steam Gage 0-560 lbs. 280 lbs. Working Pressure
14.	8½" Combined Vacuum and Pressure Gage 30 inches to 300 lbs. 100 lbs. Working Pressure
15.	8½" Vacuum Gage 0-30 Inches
16.	8½" Combined Vacuum and Pressure Gage 30 Inches to 40 lbs. 10 lbs. Working Pressure
17.	Ammeter—Type SM—8 1/3 Amperes. Coil 0-2000 Amperes Scale
18.	Ammeter—Type SM—12½ Amperes. Coil 0-4000 Amperes Scale
19.	Voltmeter—Type SM—133 1/3 V. 0-4000 Volt Scale
20.	Ammeter—Type SX—0-400 Amperes Scale
21.	Voltmeter—Type SX—0-400 Volt Scale
22.	Wattmeter—Type SC (Cynamometer Type) Single Phase 10 Amperes, 100 Volts Coils. 0-15000 Kilowatt Scale
23.	Watthourmeter—Type OA—Single Phase 10 Amperes, 100 Volts Coils, 7200 Kilowatt Gear Train
24.	Frequency Meter—Type SD—120 Volts. Marked in R. P. M. with 3 Scales. 1000-2400 for Turbine, 80-200 for Motor (24 Poles), 60-130 for Motor (36 Poles).
25.	Shaft and Turbine Speed Indicator and Cutout Sw.
26.	Time Clock
27.	Stop Clocks
28.	Four Shaft Revolution Counter
29.	Name Plates
30.	Filister Head Brass Machine Screw
31.	Knife Switch, 75 Amperes, 250 Volts. 2 P. D. T.
32.	Cap Nut
33.	Chamfered Washer
34.	Soft Rubber Washer
35.	Bevel Washer
36.	½" x 2½" Machine Bolt
37.	¼" x 2" M. B.—Tap Bolt
38.	¼"—20 Hex. I Nut
39.	Washers
40.	Terminals for Item 20
41.	Wiring Cleats
42.	150 Feet 102 R. I. F. P. Wire with Rubber Compound
43.	Fuse
44.	Resistance Boxes each with 2 Resistance Tubes for 2 Lamp Circuits
45.	Ins. Tube
46.	Block
47.	Rudder Indicator
48.	Power Factor Meter—3 Phase—Type SI—10 Amperes, 100 Volts Coils
49.	Candelabra Base Lamp Receptacles Red Lenses
50.	Candelabra Base Lamp Receptacles Red Lenses
51.	Set of Candelabra Base Lamp Receptacles Red and Green Lenses
52.	Candelabra Lamps, 8 Candlepower, 140 Volts

Name Plate Designations

Part No.	First Line	Second Line	Third Line
414.	For'd A. C. Gen.	St'b'd Motors	
415.	After A. C. Gen.	Port Motors	
416.	Generator	Cur. Trans.	
417.	Generator	Volt Trans.	
418.	Gen. Field	Voltmeter	
420.	Inb'd Motor	Cur. Trans.	
421.	Outb'd Motor	Cur. Trans.	
422.	W'H'R Meter	Voltage	
423.	Port	Motor Feeders	
424.	Starboard	Motor Feeders	
425.	Aux. Bus	After Eng. Room	
426.	Aux. Bus	For'd Eng. Room	
427.	Blower No. 1	Heaters	Outb'd Motor
428.	Blower No. 2	Outb'd Motor	
429.	Rheo. Pumps	Gov'n'r Valve	
430.	Blower No. 1	Heaters	Inb'd Motor
431.	Blower No. 2	Inb'd Motor	

Gage & Electrical Instrument—"Dial Markings"—Starb'd Side

Items

10. Forward Feed System
11. Forward Oil Supply to Governor
11. Forward Forced Lubrication Oil Supply
12. Forward Main Turbine Steam Chest
13. Starboard Main Steam
14. Forward Main Turbine, First Stage Inlet
15. Forward Main Condenser
16. Forward Main Turbine Aux. Exhaust
17. Motor 1 Outb'd Starb'd

Items

17. Motor 2 Inb'd Starb'd
18. For'd A. C. Generator
19. For'd A. C. Generator
20. For'd A. C. Gen. Field
21. For'd A. C. Gen. Field
22. For'd A. C. Gen.
23. Motor 1 Outb'd Starb'd
23. Motor 2 Inb'd Starb'd
24. For'd Turbine Motor, 26 Pole, 24 Pole
48. For'd A. C. Gen.

Gage & Electrical Instrument—"Dial Markings"—Port Side

Items

10. After Feed System
11. After Oil Supply to Governor
11. After Forced Lubrication Oil Supply
12. After Main Turbine Steam Chest
13. Port Main Steam
14. After Main Turbine, First Stage Inlet
15. After Main Condenser
16. After Main Turbine
17. Motor 4 Outb'd Port

Items

17. Motor 3 Inb'd Port
18. Aft A. C. Generator
19. Aft A. C. Generator
20. Aft A. C. Gen. Field
21. Aft A. C. Gen. Field
22. Aft A. C. Gen.
23. Motor 4 Outb'd Port
23. Motor 3 Inb'd Port
24. Aft Turbine Motor, 36 Pole, 24 Pole
48. Aft A. C. Gen.

This prevents the switch from being opened when alive.

(4) Cannot be lowered (disconnected) unless it is open.

This prevents the disconnection being made when the switch is alive.

(5) Cannot be closed until it has again been raised.

This prevents connection being made when the switch is alive.

(6) Oil tank cannot be removed until switch has been lowered.

MAIN SWITCHBOARD AND CONTROL ROOM DIRECT CURRENT SWITCHBOARDS

The direct current switchboards for the control room and the instrument panels for the main switchboard are shown in Fig. 118. The connections to these boards are given in Fig. 115. The assembled main switchboard and operating levers are shown in Fig. 119. A cross section of the control room is shown in Fig. 120. This shows the relative position of the main switchboard, operating levers and water cooled rheostats.

OPERATION OF THE MACHINERY

The following tabular list of operations gives all possible conditions of performance:

FIG. 119.—U. S. S. *Tennessee:* Assembly of Main Switchboard and Operating Levers

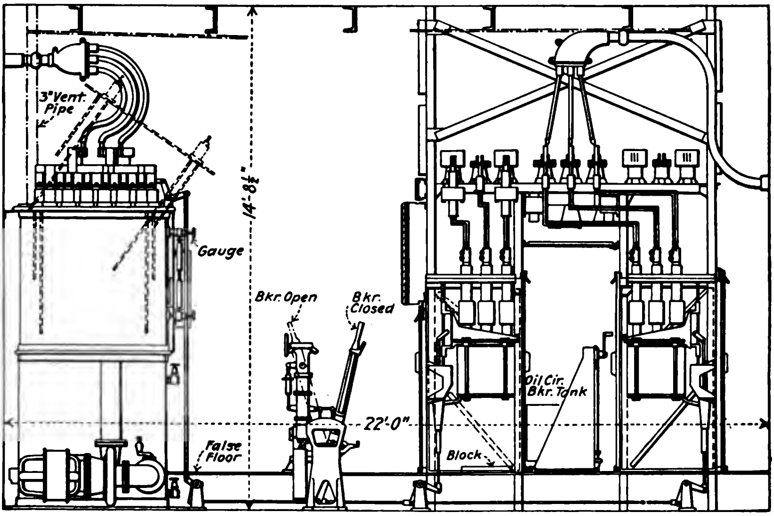


FIG. 120.—U. S. S. *Tennessee:* Cross Section of Control Room Looking to Port

Condition 1.—Starting up—Either one or two turbo generators.

(If starting up with one turbo generator, the tie switch will be closed; if starting up with two turbo generators, the tie switches will be open. Either one or both sets of generator switches will be closed depending on whether one or two turbo generators are to be used; if only one generator is used, the switches of the other generator should be opened and lowered so as entirely to disconnect that generator.)

(*a*) See that all levers, including main field, are open.

(*b*) Move speed wheel to slow speed.

(*c*) Start turbine from engine room by throttle and as soon as governor has taken control of the turbine open throttle wide.

(*d*) Put on field.

(*e*) Bring turbine up to full speed and then to over-speed, trying out the emergency trip.

(*f*) As soon as turbine speed has dropped, set speed wheel to slow speed.

(*g*) Open throttle.

(*h*) Take off field.

(*i*) Close 24-pole levers.

The turbine is now ready for operation.

Condition 2.—To go ahead.

(Assume all operations under *Condition 1* to have been performed.)

(*a*) Close ahead lever.

(*b*) Close field lever.

(*c*) Close valve lever.

(*d*) Close short circuiting lever when the water in the rheostat has risen to the maximum level in the tank.

(*e*) Bring up to desired speed.

(*f*) Open valve lever.

Condition 3.—To change from 24 to 36 poles.

(This will be done only after the ship has picked up speed by going ahead on the 24-pole connection.)

(*a*) Set speed wheel for slow speed.

(*b*) Open field lever.

(*c*) Open short circuiting lever.

(*d*) Open 24-pole lever.
(*e*) Close 36-pole lever.
(*f*) Close field lever.
(*g*) Adjust speed.

Condition 4.—To back (when going ahead on 36-pole connection).

(The same conditions will apply when going ahead on the 24-pole condition, except that it will then be unnecessary to change the pole levers.)

(*a*) Set speed wheel for slow speed.
(*b*) Open field lever.
(*c*) Open 36-pole lever.
(*d*) Open ahead lever.
(*e*) Close 24-pole lever.
(*f*) Close astern lever.
(*g*) Close field lever.
(*h*) Close valve lever.
(*i*) Close short circuiting lever when liquid in rheostat has risen to maximum level.
(*j*) Bring up to desired speed.
(*k*) Open valve lever.

Condition 5.—To go ahead after having been backing.

(*a*) Set speed wheel for slow speed.
(*b*) Open field.
(*c*) Open short circuiting lever.
(*d*) Open astern lever.
(*e*) Close ahead lever.
(*f*) Close field.
(*g*) Close valve lever.
(*h*) Close short circuiting lever when liquid in rheostat has risen to maximum level.
(*i*) Bring up to desired speed.
(*j*) Open valve lever.

Condition 6.—To stop.

WHEN OPERATING ON 24 POLES

(*a*) Set speed wheel for slow speed.
(*b*) Open field lever.

(*c*) Open short circuiting lever.

(*d*) Open ahead lever. (This leaves ship in position to go either ahead or astern with minimum number of levers to be operated.)

WHEN OPERATING ON 36 POLES

(*a*) Set speed wheel for slow speed.

(*b*) Open field lever.

(*c*) Open 36-pole lever.

(*d*) Open ahead lever.

(*e*) Close 24-pole lever. (This leaves the ship ready to go ahead or astern by closing the minimum number of levers.)

Note: The 36-pole condition on the motors should never be established until after the ship is going ahead *through the water* at the desired speed; otherwise, a large rush of current might follow an attempt to change from the 24-pole condition to the 36-pole condition. For example, if the ship had been backing until she had acquired a speed astern of, say, 10 or 12 knots, and she was then started ahead on the 24-pole condition and an attempt was then made to shift to the 36-pole condition without waiting for the ship to pick up speed ahead, a large rush of current would follow, due to the fact that the motors would drop out of step during the act of changing from the 24-pole condition to the 36-pole condition.

The ahead lever can not be closed until after the 24-pole lever has been closed. The ahead connection on 36 poles can not, therefore, be established until the 24-pole lever has been closed and then opened. This insures that the ship will always be started on the 24-pole connection—that is, on the rheostats.

CHAPTER XIV

United States Battle Cruisers and Battleships Nos. 49-54

THE horsepower for these vessels is so much greater than that for previous battleships, being 180,000 shaft horsepower for the battle cruisers and nearly 60,000 shaft horsepower for battleships Nos. *49-54*, that it is necessary to modify somewhat the methods used for control.

In the case of battleships Nos. *49-54*, the number of main generators, the number of main motors and the general arrangement of machinery are the same as for previous battleships. There are, however, no motor driven auxiliaries in the engine rooms.

The most important change from previous methods which has been made in these battleships is the substitution of power operated for hand operated switches in the main control room. This was done because the switches will be so large that it will be impossible to operate them by hand with the desired rapidity. Hand operation will, of course, be provided for emergency use; but the system of power operation provided will make these ships easier to handle under normal conditions than the older battleships, as all control levers will be very small and easy to move. The actual movement of a switch will also be faster than when moved by hand.

The system used will be an electro pneumatic one; control valves will be moved by electric solenoids and the valves will control the admission of air to a cylinder which will operate the desired switch or switches. This system makes it very necessary that the supply of both electricity and air for control purposes be made very reliable. There will be three sources of supply of electricity, one from each engine room and one from a storage battery located in the main control room. There will also be three sources of supply of air, one from the steam driven compressors in the engine rooms, one from the main supplied by the ship's service compressors located in the compressor rooms, and one from motor driven compressors located in the main control room.

In the case of the battle cruisers, the number of units is twice what it is in the battleships. There are four main generators, two in each engine room, and eight main motors, two on each shaft.

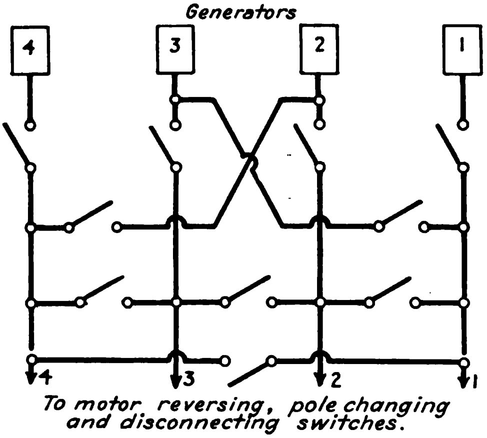
Since there are two motors on each shaft, it is possible to concatenate them instead of providing them with pole changing to obtain the two speed reductions desired, and this method has been used by the Westinghouse Company in the ships which it is supplying; the General Electric Company uses pole changing.

In order to be able to use one, two or four generators, or three generators in an emergency, the "set up" switching is more complicated than in the case of the battleships where two generator disconnecting switches and a bus tie switch are sufficient for this purpose.

Fig. 121 shows the arrangement of "set up" switching necessary on the battle cruisers and also gives a list of the various combinations that can be made. Normally the ship will be run by one, two or four generators. If one generator is used, it will run all four shafts. If two generators are used, one will run the starboard shafts and the other the port shafts. If four generators are used, each will run one shaft. In this way the load will always be the same on all generators. Three generators make an awkward combination as it would be necessary to have one of them run a shaft on each side of the ship, in order to keep the power on both sides the same, and this generator would have to run at a different speed from the others and would be differently loaded. This combination would only be used in case of emergency where it was desirable to make as much speed as possible with one generator broken down.

By referring to Fig. 121, it will be seen that there are eleven combinations of generators that can be made besides those possible with three generators. In addition to the generator combinations it will be possible to use either of the two motors on each shaft up to a speed of 25 knots except where concatenation is used and in that case the choice of motors will be between 19 and 25 knots.

It will readily be seen that it is necessary to provide some means of showing visually to the operator just what the effect of



Selections	Speeds	Generators			
1	Full	4	3	2	1
2	Up to 25-Knots	4		3	
3		3		2	
4		4		2	
5		3		1	
6		4		1	
7		2		1	
8	Up to 19-Knots	4			
9		3			
10		2			
11		1			
12	Special	4	2		1
13		2	3		1
14		4	3		1
15		4	2		3
16		1	3	2	1
17		4	3	2	4
		8-7	6-5	4-3	2-1
		Port Motor		Stb'd Motor	

FIG. 121.—United States Battle Cruisers: Arrangement of Set-up Switches and List of Combinations

any combination of switches will be, and this will be done by providing a small diagram with indicating lights which will be controlled by the position of the switches. In addition, interlocks will be provided so that it will be impossible to make improper combinations, such as paralleling generators. This combination of switches has nothing to do with the operation of the machinery after the proper "set up" has been made. The control of the machinery will be practically as simple as in the case of the battleships.

The control system of the battle cruisers for operating switches is practically the same as that for battleships *49-54*—that is, electro pneumatic.

CHAPTER XV

The Wulsty Castle

THE *Wulsty Castle* is a 10-knot cargo vessel of the Chamber's Castle Line. She has a cargo capacity of about 6,000 tons. Her length between perpendiculars is 356 feet 3 inches, beam 48 feet 9 inches, and load draft 24 feet.

The machinery of the *Wulsty Castle* may be taken as typical of the Ljungstrom system of electric propulsion as applied to low powered cargo vessels. The machinery consists of:

2 625-kilowatt turbo generators.
2 785-horsepower induction motors.
1 main switchboard.
2 liquid rheostats.
2 auxiliary switchboards.
Motor driven auxiliaries.

GENERAL DESCRIPTION

With this system of propulsion, the turbo generators are run at constant speed and variations in speed are accomplished by means of liquid rheostats in the secondaries of the main motors. This method of speed control is suitable only for a ship that does not require changes of speed, and in reality provides only for maneuvering around docks, etc., since it is uneconomical to reduce the speed of an induction motor by inserting resistance in its secondary. However, this method of control is satisfactory for this type of ship and it is not in any way a necessary part of the Ljungstrom system which could be adapted to variable frequency, if desired.

The ship has only a single screw with both main motors geared to the propeller shaft. The two generators are run in parallel to supply the motors; this can readily be done since the generators are always run at constant speed. If variable frequency were used, it would be necessary to have each generator supply its own motor on a separate propeller shaft.

MAIN TURBINES

The main turbine is of the radial flow type, consisting of two disks carrying concentric intermeshing rings of reaction blading. The two disks revolve in opposite directions and each one carries an alternator on its shaft; each turbine is in reality two turbines. It will be seen that this type of turbine is really only suitable for driving electric generators, since it is only in that way that the energy developed by the two wheels can be combined; the two generators are permanently paralleled and act as if they were only one machine. An arrangement of mechanical gears can be worked out for this turbine, but it is very complicated. The use of the electric generator is the ideal way of extracting energy from this machine and electric propulsion really makes it possible to use it for marine purposes.

Since the two disks of this turbine revolve in opposite directions the virtual blade speed is twice the actual blade speed. Moreover, since the turbine is of the radial flow type, with the steam expanding from the center of the turbine outward to its periphery, the condition is ideal for taking care of the rapidly increasing volume of steam as it expands. These two points make this turbine very interesting and, while it is at the present time only in its infancy, it offers great possibilities in the way of improvement in economy and reduction in weight and space. The construction of this turbine, however, offers many difficulties and brings up problems not met with in other turbines. The manufacturers claim to have overcome all these and the operation of the *Mjolner* and the *Wulsty Castle* has demonstrated that this is true for small turbines at least. Owing to the comparative newness of this turbine a description of its details will be given.

Blading.—The turbine consists of two turbine disks with a number of concentrically arranged blade rings fixed on each disk. The blade rings of one disk run between the blade rings of the other disk at the same speed of revolution but in the opposite direction. The live steam enters at the center of the turbine and passes through the blade rings radially outward. Although there are no fixed blades, the blades of one disk act as guide blades for the steam going to the blades of the other. It is seen that the relative velocity between blades and guide blades is twice as high as would be the case if one set were stationary and therefore the work done in each blade ring is four times as great. Consequently, due to the moving guide blades, only one-fourth the number of blade rings will be required to develop the work ordinarily obtained from the steam. This accounts for some of the saving in weight and space claimed.

The steam enters at the center of each turbine disk (disks are practically identical) inside of the innermost blade ring through a number of holes in the body of the disk as shown in Fig. 122.

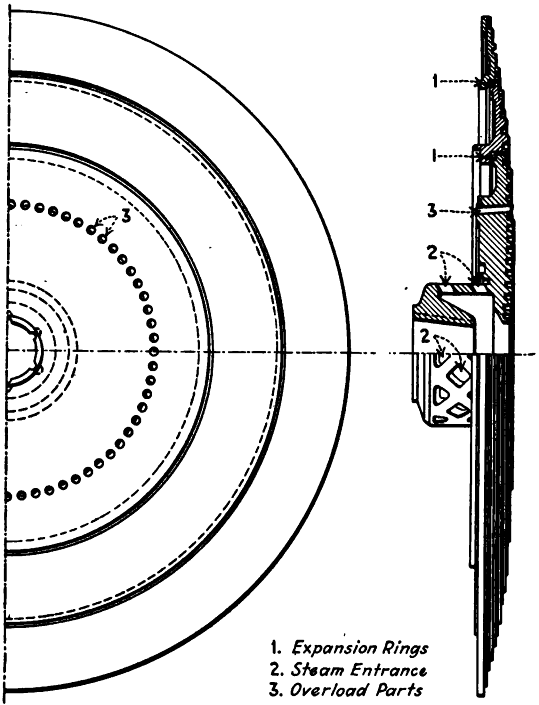


FIG. 122.—*Wulsty Castle:* Cross Section of a Turbine Disk

As the steam increases in volume by expansion the length of the turbine blades must be proportioned to meet this increase in volume. The cross section of a pair of turbine disks with blade rings showing this blade proportioning would appear as shown in Fig. 123.

In turbines of large powers requiring very large quantities of steam, single blades in the wide rings would not have sufficient tensile strength to withstand the stresses set up by the centrifugal force at high speeds of rotation. In order to get around this difficulty the widest blade rings are divided into sections as shown in Fig. 124. Something like Fig. 125 would result in large turbines if full length blades were used. In Fig. 124 the sections are connected to strengthening rings which are attached to the outer edges of the blade rings.

The manufacturers feature their design and workmanship of blade rings and blades. Fig. 126 shows the complete blade ring system for a 1,000-kilowatt turbine. It will be observed that this has the continuous full length blades.

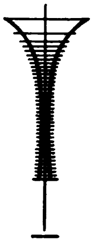


FIG. 123.—*Wulsty Castle:* Turbine Blade Ring Showing Proportioning to Meet Increase in Steam Volume

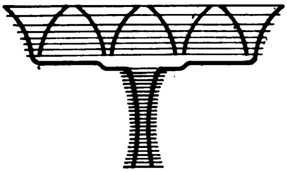


FIG. 124.—*Wulsty Castle:* Method of Dividing Blade Rings to Provide Sufficient Blade Strength for Turbines of Large Power

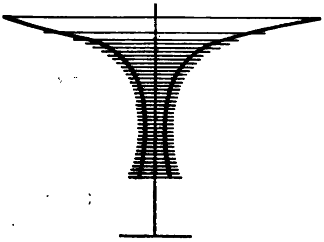


FIG. 125.—*Wulsty Castle:* Type of Blade which would be Required in High Power Turbines where Full Length Blades are Used

The method of assembling blades and rings is shown by Fig. 127. The nomenclature is as follows:

Turbine disk	1
Seating ring	2
Calking strip	3
Expansion ring	4
Rolling ridges	5 and 6
Tightening strips	7
Calking strips	8
Strengthening rings	9
Dovetail profile	10
Turbine blades	11

The ends of the blades are given the proper shape to fit into punched slots and are then welded to the disk by spot welding.

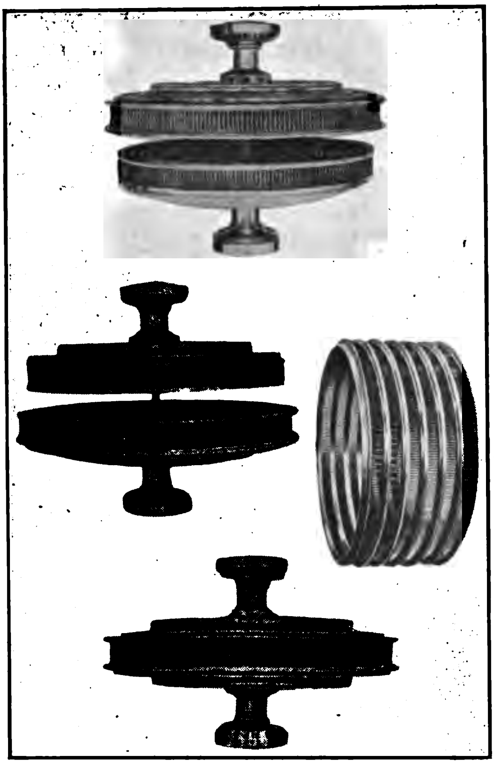
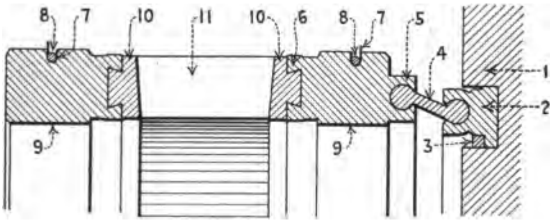


FIG. 126.—*Wulsty Castle:* Complete Blade Ring System with Disks and Journals for a 1,000 Kilowatt Turbine



1. *Turbine Disc*
2. *Seating Ring*
3. *Caulking Strip*
4. *Expansion Ring*
5 and 6. *Rolling Ridges*
7. *Tightening Strips*
8. *Caulking Strips*
9. *Strengthening Rings*
10. *Dovetail Profile*
11. *Turbine Blades*

FIG. 127.—*Wulsty Castle:* Section showing Blade Rings and Strengthening Rings

During the welding the disks are held on a mandrel and the blades are kept in their proper positions by means of thin sheet iron strips in which are punched holes of the same cross section as the blades and at a distance corresponding to the pitch and spacing of the blades. These strips are put in place at the time of assembling the blades and rings, the angles of the blades are thus adjusted and the blades prevented from being thrown out of place during welding. When the welding is completed the sheet iron strips are cut away and the welding disks turned down to a finish of the profile shown by 10 in Fig. 127. Outside these welding rings strengthening rings are fastened. The strengthening rings are first given a cross section shape as shown by 12 of Fig. 128, then the projecting edges (6) are rolled down to fit over the dovetailed rim of the welding ring. The expansion ring is also secured by rolling down the edges (5) on the outer side of the strengthening ring. The seating ring (2) edges are likewise rolled down over the outer bulbed circular ridge of the expansion ring. Finally the tightening strips (7) are placed in the grooves and calked in by the calking strips and the blade ring is completely assembled as shown by Fig. 127. The surfaces (9) and the outer edges (7) of the tightening strips are finished off and the blade rings inserted into their proper grooves in the turbine disk and secured there by the calking strips (3).

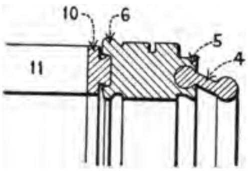


FIG. 128.—*Wulsty Castle:* Method of Assembling Blade Rings

Turbine Disks.—Fig. 122 shows a turbine disk made in several sections. It is made in the latter way to avoid the stresses and alterations in shape due to the influence of the varying and irregularly distributed steam temperatures and pressures. This occurs most frequently when starting up. It is when steam is first admitted to the turbine that variations in pressure, temperature and load are most likely to occur. Even under uniform running there would be high pressure, high temperature steam in contact with the center of the disk, while at the circumference or outer blades the steam would be at low pressure and lower temperature. Under such conditions a plane disk would take a dished shape. A very thick disk which would not dish would be subjected to internal stresses which would be liable to crack the material. The sections shown in the disk of Fig. 122 are joined by means of expansion rings (see 1, Fig. 122), which allow for any expansion or contraction and prevent stresses from taking place in the material.

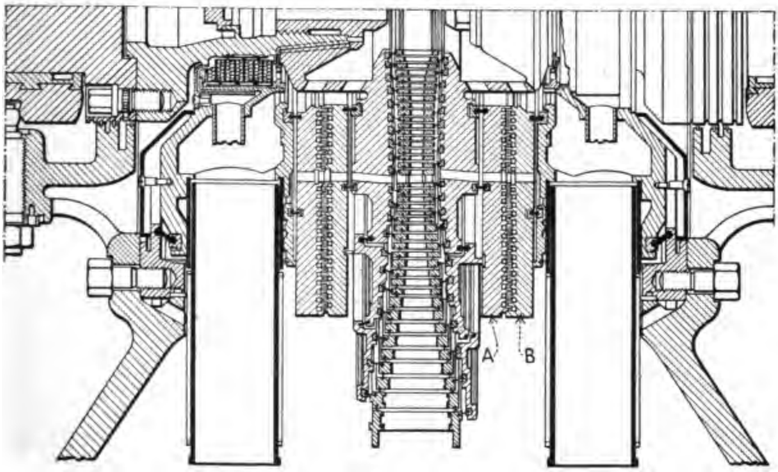


FIG. 129.—*Wulsty Castle:* Longitudinal Section of 1,000 Kilowatt Turbine, Lower Part

In each hub of each turbine disk are a number of holes for admitting steam to the blades (see 2, Fig. 122); some holes are also arranged farther out on the disk to allow full pressure steam to be admitted to the blades which ordinarily use expanded steam (see 3, Fig. 122). This is for full power or overload work and corresponds to the usual practice of by-passing the high pressure turbine.

The center hole of the turbine disk is tapering and the hub is secured to the shaft by means of a number of round keys, which are held in place by a locking device screwing into the end of the shaft.

In order to avoid play between the hub and the shaft due to unequal heating, the shaft is made hollow inside the casing; this serves to make the changes in temperature in shaft and hub follow one another rapidly.

Axial Thrust.—The counteracting of the axial pressure on the inner side of the turbine wheel is accomplished by the aid of two dummy disks provided with concentric labyrinth packings. One disk is placed at the back of the turbine wheel and the other attached to the stationary steam chests as shown by *A* and *B* in Fig. 129. Steam is admitted between the dummy disks from the center of the turbine and the inner labyrinth packings have the full steam pressure. In the remainder of the packings the pressure gradually drops as the distance of the packings from the center increases until finally, outside the outermost, it drops to condenser pressure.

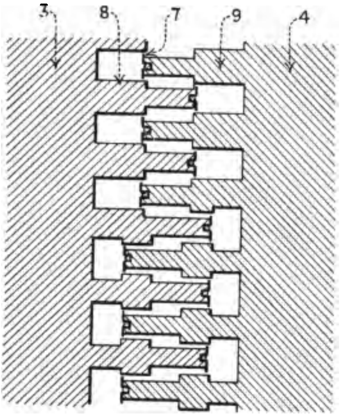


Fig. 130.—*Wulsty Castle:* Enlarged Details of Labyrinth Packing of a Dummy Disk

The packings are divided into two sections as shown in Fig. 129. Any axial motion of the rotating wheel affects the clearances in these sections, so that a motion increasing the passages in the outer section will not be increasing them in the inner section, and *vice versa.* This causes the labyrinth disk on the turbine wheel to take the position (axially) required for making the steam pressure on the entire dummy disk to equal the steam pressure on the side of the turbine disk to which the blade rings are fastened. Therefore no thrust bearings are used.

In Fig. 130 the labyrinth disks (3 and 4) are fastened to the turbine wheel and the steam chests by means of expansion rings shown in Fig. 129. The tightening strips (7) are calked into the annular projections (8) which fit into grooves (9). Due to the proportions of the metal in the two labyrinth disks, the expansion is expected to remain constant and consequently cause no change in the clearances.

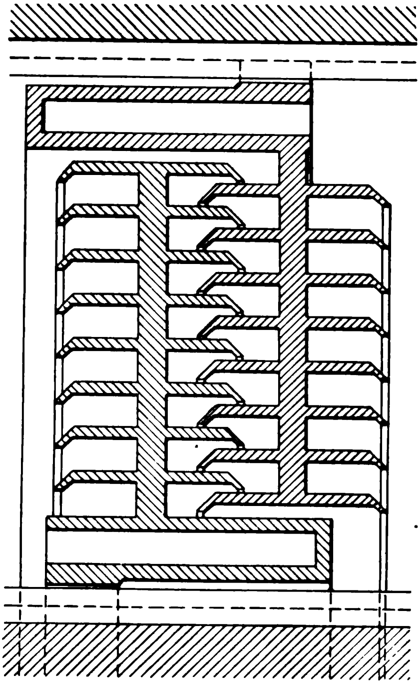


Fig. 131.—*Wulsty Castle:* Cross Section of Two Labyrinth Rings of Shaft Packing

Shaft Packings.—Another design of labyrinth packing is used to prevent air from getting into the turbine around the shaft. Fig. 131 shows the cross section of two labyrinth rings. Every other ring is fixed to the shaft. Those not fixed to the shaft are secured to the stationary stuffing box around the shaft. The rings are held by feathers which prevent them from turning. The packing edges of the rings are very thin and are set at an angle of 45 degrees; if by accident these edges come in contact with the ribs of the next ring, there will be no damage done, the edge merely wearing off until contact ceases.

The thickness of all the rings is the same; therefore the clearances between ribs is expected to be constant, either hot or cold, as the expansion and contraction will remain constant in each. The clearances are therefore made very small and consequently the leakage is expected to be very small. There are special pipes fitted to the packing boxes so that leaking steam may be sent to the feed water heater and some of its heat utilized.

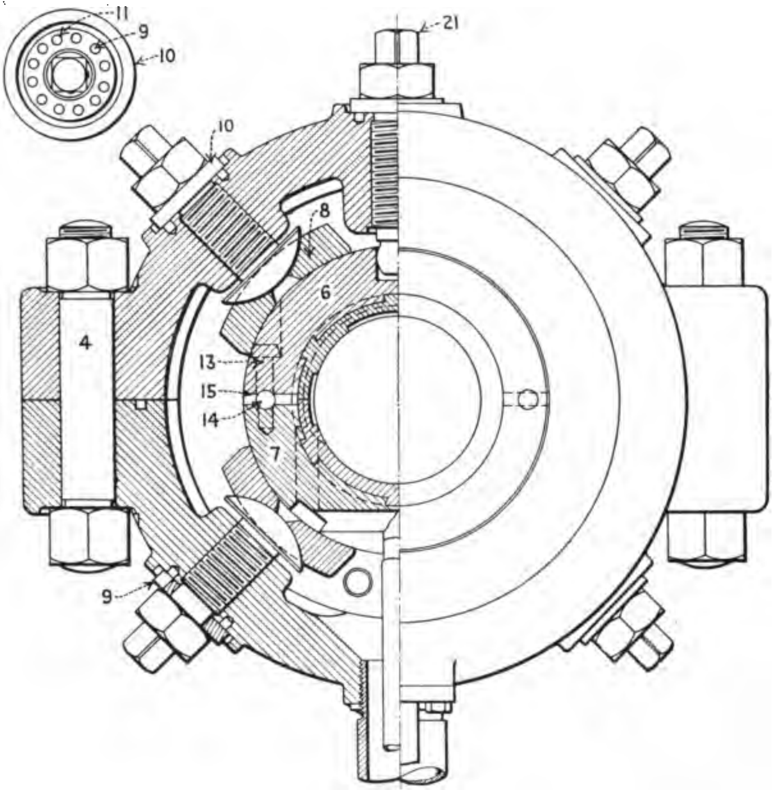


FIG. 132.—*Wulsty Castle:* Cross Section of Main Bearings

Main Bearings.—A cross-section of the bearing with its adjusting screws is shown by Fig. 132. The bearing consists of two halves (6) and (7) with bearing boxes. The halves rest against adjusting screws through intermediary washers (8). The adjusting screws are locked by means of set screws (9) and locking washers (10). There are twelve holes in the washer and only eleven in the bearing surface on which it rests. This allows for very accurate adjustment of bearing without too fine a threading of adjusting screws.

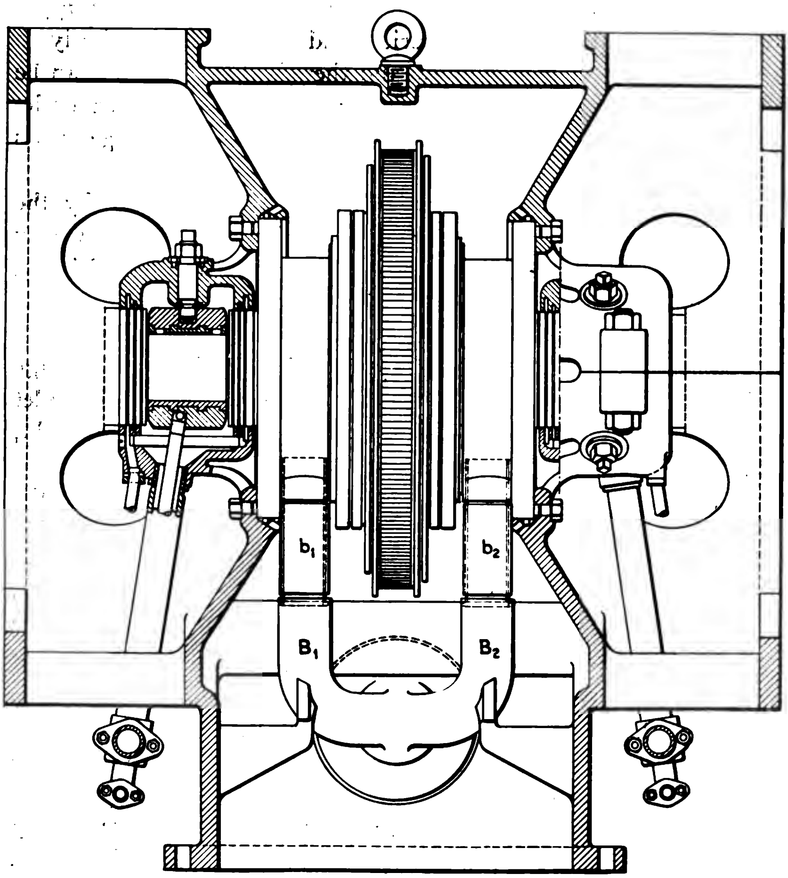


Fig. 133.—*Wulsty Castle:* Longitudinal Section of 1,000 Kilowatt Turbine

The bolts (4) which hold the upper and lower halves of the bearing boxes together are tapered and fit accurately in reamed holes, thus at the same time serving as securing dowels for the cap. After the bearing boxes are adjusted, which is usually done during erection of the turbine in the shop, they will keep that position accurately and never need to be changed.

To prevent the bearing from slipping axially and from being turned by friction, another adjusting screw (21) is used. It has a spherical end which fits into a corresponding recess in the upper half of the bearing. The spherical end is made eccentrically to the axis of the adjusting screw and therefore the bearing can be shifted axially by turning the screw, which is afterward locked by a washer and set screw in the same way the main adjusting screws are locked.

The two halves of the bearing are fastened together by the screws (13), which have their relative position fixed permanently by the dowel pins (14) and (15). The anti-friction metal is put into the bearing halves in the usual manner.

Steam Inlet and Discharge.—The high pressure steam enters through the steam inlet passage of the turbine casing, this passage being located within the steam discharge passage. The inlet passage branches off here into two pipes B_1 and B_2 (Fig. 133), which join steel pipes b_1 and b_2 and communicate with the chambers of the steam chests in the turbine casing. From here the steam is admitted through the hubs to the center of the turbine wheels.

By means of overload valves, the stems of which are accessible outside of the turbine casing, steam can be admitted when desired into the overload channels. The overload valves are constructed to act automatically when conditions necessitate. The exhaust steam passes from the outermost blade ring through the annular space between it and the turbine casing and through the discharge passage into the condenser below.

Lubrication.—The lubrication is by means of the usual rotary gear oil pump driven off the vertical governor shaft by worm gearing. The pump is mounted in the oil tank together with an oil cooler and a hand oil pump.

Governor.—The governor is a centrifugal one mounted on the same vertical shaft as the oil pump. As mentioned above, this shaft is worm driven from the turbine shaft. The motion of the governor sleeve is transmitted to a throttling governor valve by means of an oil relay.

An emergency governor is fitted to each of the main shafts of the turbine outside the bearing boxes. It acts by means of a releasing device or trigger on a slide valve, which cuts off the oil pressure from the oil cylinder of the governor valve, should the speed become excessive.

WULSTY CASTLE'S TURBINES

Steam is supplied to these turbines at a pressure of about 220 pounds per square inch (gage) and a temperature of about 550 degrees F., which represents about 150 degrees F. of superheat. The turbines run at a speed of 3,600 revolutions per minute and are each rated at 625 kilowatts. Each turbine has 39 blade rings of which 20 are mounted on one disk and 19 on the other. The external diameter is 28 inches, the overall length 17½ inches, and the weight 448 pounds.

FIG. 134.—*Wulsty Castle:* A Ljungstrom Turbo Alternator in Course of Erection

GENERATORS

Each turbine has two generators which are commonly referred to as one generator since they are permanently connected in parallel and have their fields in series; they will be referred to from now on as one unit.

The generators are 2-pole, 60-cycle, 3-phase, 650-volt, delta-connected machines rated at 625 kilowatts each. One of the generators is shown in Fig. 134.

Ventilating fans are attached to the generator rotor for supplying the necessary air for cooling the generator windings; the exhaust from the generators is led to the fireroom where it supplies a Howden's forced draft system under the boilers at a pressure of about $\frac{9}{16}$ inch of water.

Excitation for the fields is furnished by direct current generators mounted on the turbine shafts; provision is also made for exciting either or both generators from the ship's 20-kilowatt generating set.

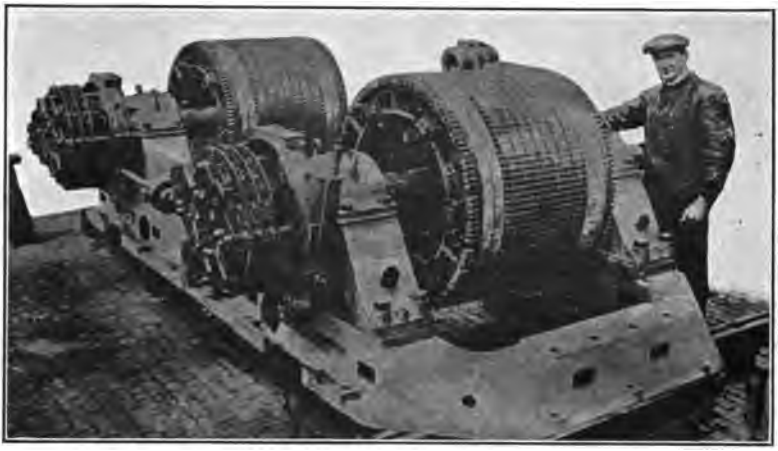


FIG. 135.—*Wulsty Castle:* Rotors of Main Induction Motors

MAIN MOTORS

There are two main motors geared to the same propeller shaft. They are of the definite wound rotor type of induction motor, each rated at 785 horsepower, and have a speed of about 714 revolutions per minute at full power. They are 10-pole and have an efficiency of about 95 percent and a power factor of about 87.5 percent at full power.

The bearings are of the spherical type and are arranged for forced lubrication.

Ventilation is provided by fans mounted on the rotor spider.

The motors are shown in Figs. 135 and 136. The collector rings for connecting the secondary winding to the liquid rheostats and also the lever for short circuiting the secondary winding are shown in Fig. 135.

The gears for connecting the motors to the propeller shaft are shown in Fig. 137. The reduction ratio is 9.4 to 1, giving about 76 revolutions per minute of the propeller at full power.

The thrust block is of the Michel (pivoted, segmental) type and is incorporated in the gear case.

Two gear driven oil pumps are mounted on the ends of the pinion shafts and they supply forced lubrication for the motor bearings, gear bearings and thrust bearing.

FIG. 136.—*Wulsty Castle:* Main Motors in Course of Erection

SWITCHBOARD AND WIRING

The switchboard is equipped with an oil switch for each generator and for each motor so that either generator or either motor can be cut out, if desired. There is also an oil switch for reversing the motors. There is also a maneuvering wheel for controlling the reversing switch, the liquid rheostats and the exciter fields.

Interlocks prevent closing the main motor switches, unless the maneuvering wheel is in the stop position, and also prevent closing the motor short circuiting switches, unless the maneuvering wheel is in either the full ahead or full astern position.

An ammeter is provided for each generator, a voltmeter is provided for the common bus and a voltmeter is provided for each exciter.

The wiring, switches, etc., are shown in Fig. 138. The reverse current relay between the generators shown in this figure was originally installed on the ship but has since been removed.

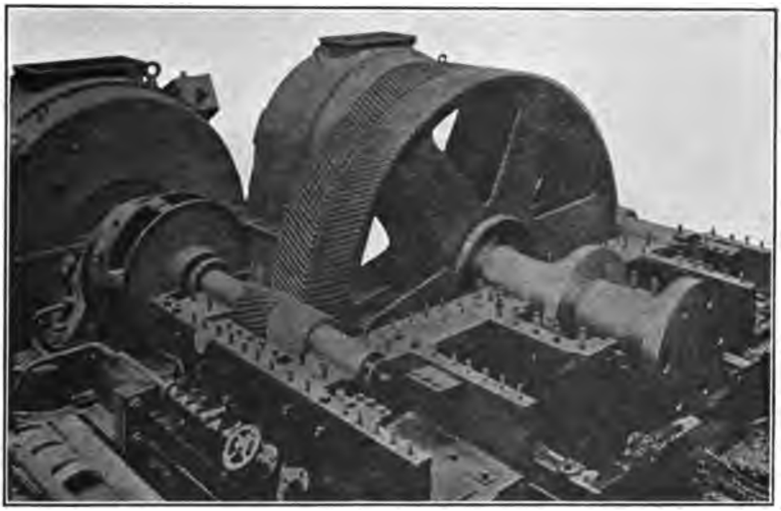


FIG. 137.—*Wulsty Castle:* Reduction Gearing with Cover Removed

LIQUID RHEOSTATS

There are two of these rheostats, one for each main motor. One of them is shown in Fig. 139. As will be seen, it consists of electrodes of cone shaped nickel castings dipping into an electrolyte of K O H. Two 1½ horsepower motors circulate this liquid through coolers.

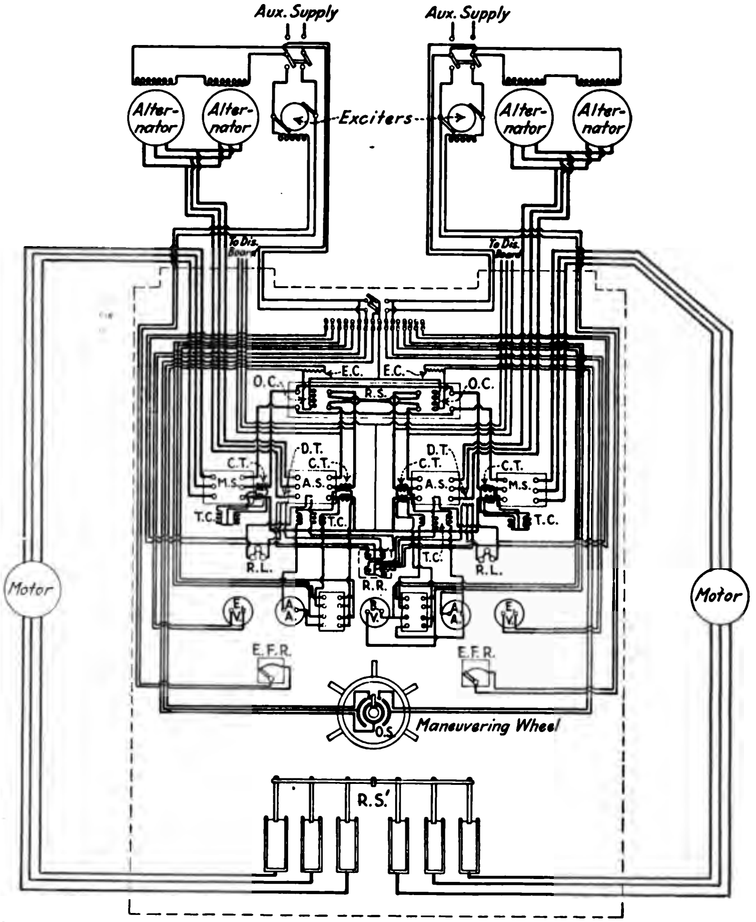
When the maneuvering wheel is in the stop position, the tips of the cones are raised clear of the liquid, thus breaking the secondary circuits of the motors.

OPERATION

The two turbo generators are run in parallel. They are first brought up to speed and synchronized and then connected to the bus.

The turbines are never throttled for the purpose of reducing the speed of the ship; this is always done by manipulating the liquid rheostats in the secondaries of the motors.

Reversal is effected by reversing two phases of the main motor circuits and at the same time inserting the resistance into the secondaries of the motors.



A.S.	*Alternator Oil Switch*
M.S.	*Main Motor Switch*
R.S.	*Reversing Sw., Elect. Operated*
O.C.	*Operating Coil for Switch*
E.C.	*Economy Resistance (inserted when core is up)*
C.T.	*Current Transformer*
T.C.	*Oil Switch. Trip Coil*
D.T.	*Transformer for Reverse Gear*
R.R.	*Reverse Relay*
R.L.	*Lamps (Pilot Lights) used as Resistance in Reverse*
B.V.	*Bus Bar Voltmeter*
E.V.	*Exciter Voltmeter*
A.A.	*Alternator Ammeter*
O.S.	*Operating Sw. for Main Reversing*
E.F.R.	*Exciter Field Regulator*
R.S.'	*Liquid Rotor Starter*
I.W.	*Integrating Wattmeter*

FIG. 138.—*Wulsty Castle:* Diagrammatic Sketch of Electrical Connections

Referring to Fig. 138, it will be observed that the first motion of the maneuvering wheel from the stop position in either direction closes the reversing switch for ahead or astern running as the case may be. The necessary direct current for operating the automatic reversing switch, it will be seen, is supplied, through a change-over switch, from either exciter. Further motion of the wheel (*a*) cuts out the operating coil of the reversing switch and closes the economy coil circuit, (*b*) lowers the tips of the cones into the electrolyte and starts up the main motors, (*c*) adjusts the shunt regulators of the exciters to meet the changing load conditions, (*d*) locks the main motor switches to prevent them being reclosed should they open with an overload, and finally (*e*)

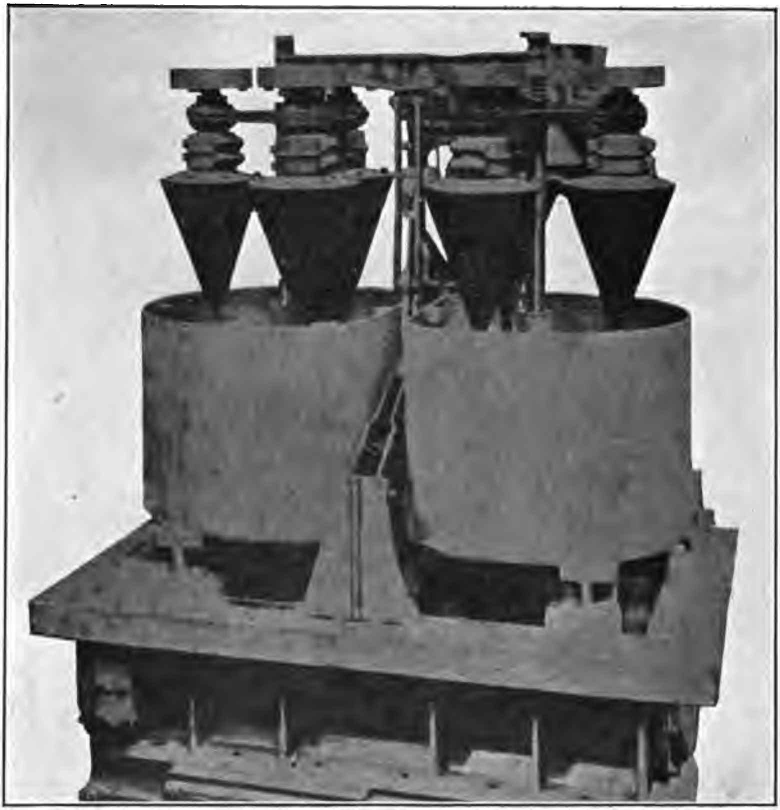


FIG. 139.—*Wulsty Castle:* Variable Liquid Resistance for Controller

in the full speed position unlocks the main motor short circuiting hand lever. The speed, then, varies as the angle through which the wheel has been turned from the stop position, 120 degrees representing full speed. From about 15 revolutions per minute any speed can be obtained up to 76; a special locking arrangement enables the wheel to be clamped in any desired position. A suitably adjusted counterbalance weight allows the wheel to be turned freely. The time required to reverse the propeller from full speed ahead to full speed astern, or *vice versa,* is merely the time required to turn the wheel from one extreme position to the other and is approximately 10 seconds.

Considerable difficulty was at first experienced in bringing the motors up near enough to synchronous speed to enable them to be safely short circuited. To surmount this difficulty, a hand operated, non-inductive, grid type buffer resistance can be placed in parallel and operated in conjunction with the liquid controller when short circuiting the rotor windings.

AUXILIARIES

Practically all of the auxiliary machinery in this plant is motor driven, three-phase squirrel cage motors of substantial construction being used. Two small switchboards, for the control of these motors, are mounted on the after engine room bulkhead. Most of these motors are not equipped with starting devices and are therefore usually run up with the generators, in preference to switching them directly across full line voltage. Two 17-horsepower motors drive the main circulating pumps for the condensers at 1,730 revolutions per minute, while two 14-horsepower motors operate the combined kinetic air and condensate pumps at the same speed. The 20-horsepower boiler feed pump motor runs at 3,515 revolutions per minute and is equipped with a star-delta starting device. Two small motors, of 1½ horsepower each, circulate the electrolyte of the main motor controllers and run at 1,100 revolutions per minute. A 33-horsepower motor, speed 1,720 revolutions per minute and fitted with an auto-starter, drives the ship's lighting dynamo while at sea, and a 700 revolutions per minute 12-horsepower motor, fitted with a star-delta starter, operates the ship's steering gear. This last motor normally runs light and is loaded only when the steering wheel on the bridge is moved, this movement being transmitted to the steering compartment by means of telemotor gear.

GENERAL PARTICULARS OF SIX HOUR, FULL POWER TRIAL WITH SHIP MOORED AT QUAY, SUNDERLAND, ENGLAND

Wednesday, July 3, 1918.

Time p.m.	Revs. per min.		Volts	Port turbine			
	Turbine	Propeller shaft		Amperes	Before valve		Vacuum by Kenotometer
					Pressure	Temp. deg. F.	
1.30	Synchronized both turbines						
2.0	3,600	75	660	700	190	555	28.9
3.0	3,600	75	660	700	190	582	28.9
4.0	3,600	74	650	700	190	578	28.9
5.0	3,550	75	630	680	210	579	28.9
6.0	3,550	74	630	630	200	581	28.9
7.0	3,550	74	650	650	195	589	28.9
8.0	3,525	75	630	630	195	588	28.9
9.30	Shut down						
Averages	3,568	74.5	644	670	195	579	28.9

Time p.m.	Starboard turbine				Temp. of sea deg. F.	Kilowatts		
	Amperes	Before valve		Vacuum by Kenotometer		Port	Starboard	Total
		Pressure	Temp. deg. F.					
1.30	Synchronized both turbines							
2.0	600	190	560	28.7	58	696	595	1,291
3.0	600	190	590	28.7	58	696	595	1,291
4.0	600	210	590	28.7	58	687	589	1,276
5.0	670	210	580	28.7	58	645	638	1,283
6.0	700	200	574	28.7	58	600	660	1,266
7.0	680	200	580	28.7	58	646	665	1,311
8.0	685	195	585	28.7	58	600	652	1,252
9.30	Shut down							
Averages	648	199	580	28.7	58	653	628	1,281

Designed normal full load output of both turbines			1,250	kilowatts
Actual output of both turbines on trial			1,281	"
Power used by auxiliaries as measured on trial:				
Two circulating pumps	27.4	kilowatts		
Two air or kinetic pumps	27.0	"		
One boiler feed pump	15.2	"		
Electrical steering gear	6.2	"		
Lighting circuits	4.2	"		
Total for auxiliaries	80.0	kilowatts	80	"
			1,201	kilowatts
Less energy absorbed in motors of 95 percent efficiency	60.0	kilowatts		
Less energy absorbed in gearing of 98 percent efficiency	24.0	"		
	84.0	kilowatts	84	"
Balance or net power on propeller shaft			1,117	kilowatts

1,117 kilowatts = 1,117 ÷ 0.746 = 1,496 shaft horsepower.

CHAPTER XVI

Diesel Electric Drive

THIS method of propulsion has been very little used up to the present, having been confined to yachts and other small vessels. It is now being proposed for larger vessels and it is quite probable that there will shortly be some installations made in cargo vessels.

The point at which the dividing line occurs between the Diesel electric drive and turbo electric drive was fixed at 3,000 shaft horsepower in Chapter I, but this point will really depend on the size in which reliable Diesel engines can be built. There is no doubt but what the adoption of electric drive in connection with Diesel engines will give a great impetus to the development of the marine Diesel engine, since it will no longer be subject to the handicaps which are imposed on it when it is connected directly to the propeller. The most important of these handicaps are the limitations on the revolutions, the necessity for reversal and the necessity for starting under load, all of which are done away with by the use of electricity.

With the Diesel electric drive, as with the turbo electric drive, the first point to be decided will be whether to use alternating or direct current. In Chapter II it was decided that alternating current was more suitable for the turbo electric drive, but it will now be shown that the reverse is true for the Diesel electric drive.

From the point of view of maneuvering, direct current has the advantage; speed regulation can be accomplished simply by varying the generator field, and reversal is also simpler. The switching operations would be simpler with direct current, since it would not be necessary to open the main circuit for reversal. Alternating current machinery would be about 5 percent more economical than direct current machinery and would be somewhat more reliable, since there would be no commutators on the main units. However, it will usually be necessary to run several units, either in series or parallel, to get the required power, owing to the limitations as to size of the Diesel engine; this reason alone makes alternating current unsuitable. Alternating current generators can not be run in series and parallel operation is not satisfactory for marine propulsion on account of the difficulty of changing speed; in this case it is complicated by the fact that Diesel engines themselves are really not suitable for parallel operation.

The above limitations make the use of direct current and series operation the most suitable for Diesel electric propulsion. This is a very flexible arrangement and has several advantages. By running two or more generators in series, the difficulty of accurate governing with Diesel engines is done away with because accurate governing is not necessary. Another advantage of the series arrangement is that, if it is desired to run at reduced speed and power, one generator can be cut out and the remainder run at normal voltage, speed and load, thus giving a very fine economy at reduced speeds. There are limits, of course, to the number of generators that can be run in series on account of the excessive voltage generated, but there will be no difficulty in this respect for vessels in Class 1 of Chapter I.

Excitation for the generators and motors would be furnished by independent direct current units which would be interchangeable with the ship's power and lighting units. The method of separate excitation gives perfect control of the speed and is also ideal for reversal. It would not be necessary to open the main circuit at all during reversal; it would only be necessary to reverse the generator field. In large installations it would also be necessary to insert resistance in the main circuit, but this would be short circuited immediately after reversal. By controlling the field strength of the generators, reversal could be accomplished without carrying excessive current in the system. Speed control of the propeller would be accomplished by varying the field strength of the motors or generators, or both.

The normal arrangement would consist of two or more Diesel engine generators in series and one or two motors on the propeller shaft, depending on the horsepower of the installation. The motors would also be arranged for series operation and one would be cut out, if the load were sufficiently reduced.

For example, suppose a plant to consist of three generators and two motors. All would be in operation in series at full power. If it is desired to operate with two generators, they would be run at the same speed as before and each would carry the same volts, amperes and load as before, so that the efficiency of the generators and engines would be unchanged. If we assume the propeller load to vary as the cube of the revolutions (or speed of the ship), then the propeller would run at about 87 percent of full speed. The two motors would be run in series as before and would take the same current as before, but the field strength would be only about 77 percent of what it was before and there would be only a slight falling off in motor efficiency.

If it is desired to reduce the speed still further, two generators would be cut out; the third would be run as before and give the same efficiency as before. The propeller would run at about 70 percent of full speed and only one motor would be used. This would carry full load current and approximately full field, and it would carry two-thirds of its normal full load, since only one motor is in operation. Its efficiency would be somewhat reduced, but, owing to the fact that the losses would be confined to one motor, the overall efficiency would not drop off very much.

The speed of the ship in the three cases would be 10 knots (assumed), 8.7 knots and 7 knots. Here then we have a 10-knot ship which is capable of slowing to 7 knots with very little falling off in efficiency. This shows, also, how very reliable such a ship would be on account of the duplication of generators and motors.

For obtaining speeds intermediate between 10 and 8.7 and between 8.7 and 7 and below 7 knots the field of the motors or generators would be changed according to the conditions of operation, the arrangement always being such as not to require more than normal full field. If using three generators and two motors, speed would be reduced by reducing the field of the generators without changing that of the motors. If using two generators and two motors, speed could be reduced by increasing the field of the motors, since in this case the motors are using only 77 percent normal excitation. If using one generator and one motor, it would be necessary to reduce the generator field to reduce the speed, since the motor would have practically full field. These are the conditions that would obtain in steady running. For speed reduction for maneuvering purposes only, it might be simpler to use generator field control entirely.

During reversal, full field would be kept on the motors and the field of the generators would be regulated to provide full load current at all times, thus giving full load torque for reversal. For emergency reversal it would be desirable to use more than full load current and this could be done for a short time, the current being reduced to normal as the ship loses headway.

The Diesel electric drive has a peculiar advantage when used for cargo vessels on account of the flexibility of the machinery arrangement. It is possible to locate the generators on the upper deck and the motors can be placed well aft so that the cargo space

	Diesel Electric Drive	Triple Expansion Plant
Indicated horsepower	1,400	1,400
Weight of plant installed, tons	220	300
Fuel used per hour per horsepower, pounds	.45	1.25
Fuel used per hour, barrels	1.9	5.4
Fuel used per day at sea, barrels	45.6	129.6
Fuel used per day in port, barrels	8	26
Lubricating oil per day at sea, gallons	40.3	7
Lubricating oil per day in port, gallons	8.4	3
Lubricating oil per year, barrels	278.2	52
Cost lubricating oil, per gallon	$0.29	$0.43
Cost lubricating oil, per year	$3,338.40	$939.00
Cost of fuel oil, per barrel	$1.85	$1.60
Cost of fuel oil per day at sea	$87.32	$207.36
Cost of fuel oil per day in port	$14.80	$41.60
Days at sea	270	270
Days in port	95	95
Water used per day for power plant, tons	....	3.75
Fuel used per day, tons	6.74	18.64
Weight of fuel carried, tons	220	650
Weight of water carried, tons	50	170
Cost of water, per ton	$1.00	$1.00
Cargo carried in deadweight tons, tons	3,400	3,000
Cargo space in cubic feet	155,832	116,000
Cargo space (40 cubic feet per ton), tons	3,900	2,900
Fuel used in one year, barrels	13,504	37,462
Water used in year for power plant, tons	....	1,125
Total cost of fuel, water and lubricating oil for one year	$28,321.40	$62,004.12
Net profits of ship based on steam plant economy at $50 per deadweight ton	$170,000.00	$150,000.00
Total net profits, including fuel saved	$203,682.72	$150,000.00

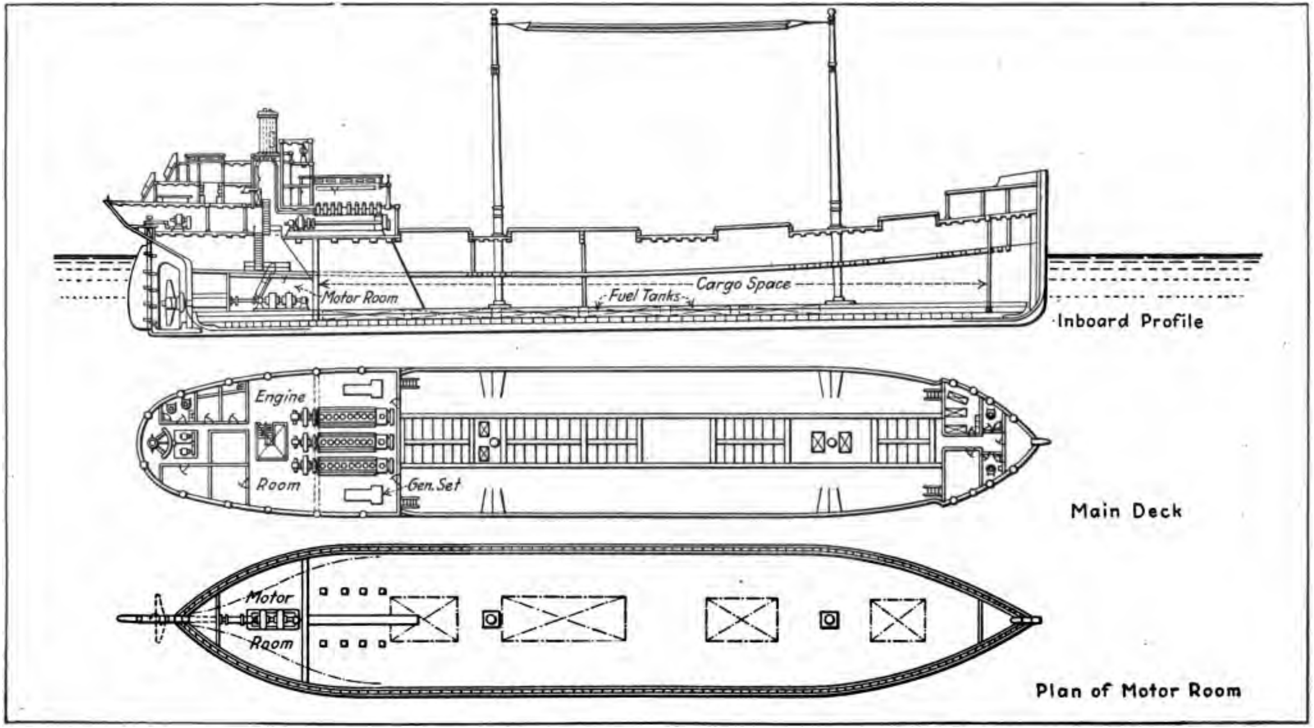


FIG. 140.—Profile and Deck Plans Showing Machinery Arrangement of a Converted Ferris-type Hull

is almost entirely undisturbed. Fig. 140 shows an arrangement that has been proposed for a cargo vessel. It consists of three 500-horsepower Diesel generators driving two motors on one propeller shaft. The table on page 267 is an estimate that has been made comparing the Diesel electric drive proposed for these vessels with a reciprocating engine installation.

Over a period of a year in the operation of the vessel, taking the present cost of fuel and water, she would have an increased carrying capacity of 400 tons, and would net her owners about $53,682 additional, through the saving in coal, water and weight, or a net gain in the commercial efficiency of the ship of about 35.7 percent.

CHAPTER XVII

Care and Upkeep

THE care and upkeep of a steam electric plant on board ship offers certain difficulties that are not encountered in a similar plant ashore, and for that reason the experience gained from the operation of the *Jupiter* and the *New Mexico* may be useful to prospective operators of similar plants. The principal enemies of this type of plant are salt water and heavy shocks, and to these may be added coal dust on ships carrying coal as a cargo.

Salt moisture will find its way into the ventilating systems and salt is likely to be deposited on the end windings of generators and motors. These windings should be examined frequently and any salt found should be removed by gasoline. About once a year these end windings should be sprayed with varnish. The varnish used should be air drying; the simplest way to apply this is to use a compressed air sprayer at a pressure of from 25 to 30 pounds.

All connections on the generators, motors and switchboards should be examined at the end of a run and before getting under way to see that they are all tight.

The interior of both generators and motors should be examined to see that they are not acting as condensers when idle, thus accumulating moisture on the windings. If heaters are provided and used, this should not occur. The following table gives the routine that has been laid out for the *New Mexico* and covers all necessary inspections and tests:

(*A*) Daily:

(1.) Jack over main generators, main motors and auxiliary machinery (operating forced lubrication system while this is being done).

(2.) Operate governor mechanism under oil pressure by movement of pilot valve.

(3.) Examine, oil and clean governor control transmission mechanism.

(4.) Dry out turbine by running turbine drain pumps fifteen minutes.
(5.) Inspect generators and motors for moisture (including ventilation ducts, air pockets under generators and fan housings over motors).
(6.) Examine high tension leads and terminals for dirt and moisture.
(7.) Move all generator and motor disconnecting switches.
(8.) Move pole changing and reversing oil switches.
(9.) Move switches on exciter switchboard.
(10.) Operate field control switches.

(*B*) Weekly:
(1.) Move all auxiliaries by power.
(2.) Operate exciters and test overspeed trips and back pressure relief valves.
(3.) Operate main throttle and stage valve trips by hand gear.
(4.) Make insulation test by bridge megger of all electrical circuits and machines.
(5.) Make insulation test of main generator bearing standards to ground.

(*C*) Quarterly:
(1.) Examine stator coils of main generators and motors for dryness and preservation of insulating material, particularly for condition as regards presence of oil or salt or cracking of varnish.
(2.) Take bridge gage readings of main generators and air gap measurements of main motors.
(3.) Clean generators and motors by vacuum cleaner.
(4.) Take air gap measurements of auxiliary motors and examine for condition of armature and field windings.
(5.) Overhaul collector rings, brush rigging, brushes and commutators.
(6.) Examine by test all bus bar securing bolts and connections.
(7.) Examine all leads and connections of instruments and instrument transformers.

(8.) Examine all high potential cables and their supports and go over all terminal connections.
(9.) Inspect carefully high potential insulators.
(10.) Go over contact adjustment of all main switches with feelers.
(11.) Open oil switches and compensators for examination as to quantity and condition of oil.

Note:
- (*a*) Whether carbonization has taken place.
- (*b*) Whether burning of contact fingers or bar has occurred.
- (*c*) Whether moisture is present.

See:
- (*a*) That contacts are fitted and adjusted to make and break at same time.
- (*b*) That contacts have even make and break over entire surface.
- (*c*) That auxiliary contacts are adjusted to take the arc.
- (*d*) That links and springs are in smooth working order.
- (*e*) That oil switch supports are secure and switches in alinement.

(12.) Determine insulation resistance of high potential windings and leads by calculation, using high resistant voltmeter method.
(13.) Go over holding down bolts on generators and motors and staybolts in motor rotors.
(14.) Inspect bearings and note effectiveness of oil guards in preventing oil entering windings.
(15.) Check turbine shell expansion (longitudinal).
(16.) Take turbine wheel clearance in first stage and check against clearance indicator.
(17.) Remove governor casing and inspect mechanism for condition and adjustment.

(*D*) Semi-annually:
(1.) Calibrate all electrical instruments.
(2.) Inspect resistance grids.

- (3.) Inspect flexible jaw coupling between turbines and generators.
- (4.) Overhaul self-closing throttle valves.

(*E*) Annually:

- (1.) Spray with high grade insulating varnish all stator end connections.
- (2.) Spray auxiliary motor brush connections and field and armature windings.
- (3.) Remove transil oil from oil switches and compensators —renew or filter same.
- (4.) Lift turbine casings for wheel and diaphragm inspections.
- (5.) Examine shaft packing and steam seals.

(*F*) After Overhaul:

- (1.) Run drying out heat run on generators and motors until all insulation resistances show above 5 megohms.
- (2.) Operate hand tripping gear with turbine turning over.
- (3.) Operate overspeed safety devices on main turbines, taking tachometer readings of speeds at which emergency trips function.
- (4.) Calibrate steam lever at no load.
- (5.) Test by hand gear spring loaded exciter exhaust valves.
- (6.) Turn over main motors by power ahead and astern.

(*G*) Before Getting Underway:

- (1.) Make insulation resistance test.
- (2.) Examine switchboards and leads for cleanliness and for tightness of connections.
- (3.) Operate all switches, field control circuits and interlock circuits.
- (4.) Examine oil switch mechanism.
- (5.) Trip out turbine by hand gear.
- (6.) Trip out turbines by overspeed trips, operating governor pilot valve by hand in doing so.
- (7.) Trip exciters by overspeed trips.
- (8.) Try out boosters.
- (9.) Try main motors ahead and astern.

(*H*) In Operation:

(1.) Take oil temperature readings frequently until settled down—then hourly.
(2.) Take field resistance by voltmeter ammeter reading until constant temperature is reached.
(3.) Take ground tests hourly on exciter switchboard circuits.
(4.) Read thermometers half hourly on ventilation exhaust outlets and regulate blowers for air supply accordingly.
(5.) Adjust setting of steam limit levers at each change of speed.
(6.) Inspect hourly for oil or moisture on windings—noting oil guards.
(7.) Inspect ventilation ducts for moisture—in bad weather continuous rounds—in fair weather once each watch.
(8.) Inspect collector rings and brushes, main generators, hourly.
(9.) Read turbine clearances half hourly.
(10.) Daily—test for stray current generator standards.

(*I*) Upon Securing:

(1.) Take insulation tests while windings are warm.
(2.) Examine windings for dirt, oil or salt.
(3.) Clean rotors and end windings of motors by vacuum cleaner.
(4.) Examine switchboards for dirt and loose connections.
(5.) Go over oil switch mechanism.
(6.) If to be secured for a considerable period, seal up motors after cleaning.