CHAPTER VII.

THEORY OF THE DYNAMO—*continued.*

FIELD MAGNETS.

WE have hitherto taken for granted that a magnetic field was provided for the armature to revolve in, and the consideration of the magnets that produce this field was purposely left until after the generation of currents had been discussed; so that the general connection between the magnetising current and the armature might be considered. An outline of the connection between armature and field magnets is essential before the windings of those magnets can be understood. The armature supplies the current for the field magnets, which in their turn supply the field for the armature to revolve in.

Supply of Current to excite Field Magnets, Series and Shunt Machines.—This current may be supplied in two ways:—

(1) The *main* current can be made use of to magnetise the magnets on its way to the *outside* circuit, where it is doing the work we require.

(2) A separate current can be taken from one brush round the magnets and back to the other brush, without in any way affecting the main current in the outside circuit.

FIG. 72A.

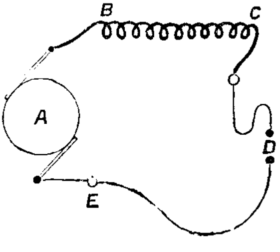


FIG. 72.

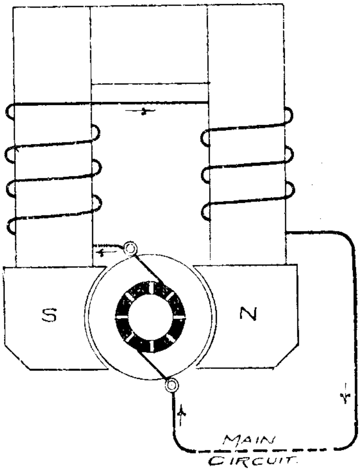


Fig. 72 shows No. 1 case and Fig. 72A shows a diagram of the circuit. All the current that is made in the armature traverses the magnet coil B C, then passes through D back to E and to the armature again. That is, the same current is flowing in the armature, in the field magnets, and in the outside circuit at the same time. All these three portions of the circuit are in series with one another. Hence this form of machine is called a *series* machine.

FIG. 73.

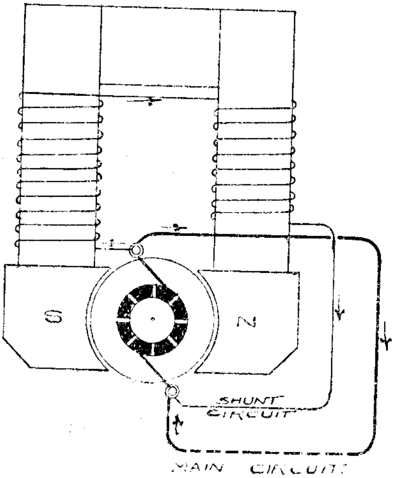


FIG. 74.

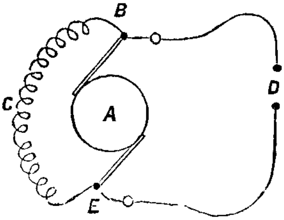


Fig. 73 shows No. 2 case and Fig. 74 a diagram of the circuit. The current passing round the magnet flows through a different circuit to the current in the outside circuit. The current flowing in the field magnet circuit simply runs between the brushes, and is totally independent of any other circuit there may or may not be. Since this circuit is in parallel, or as it is often called *in shunt* with the armature and outside circuit, the machine so arranged is called a *shunt* machine.

Compound Machines.—The type of machine used in the Navy is a mixture of the two, and is called a *compound* machine. Fig. 75 shows a compound machine, and Fig. 76 a diagram of its circuit.

It will be observed that in the series machine, where all the current ran through the coils that were magnetising the machine, the magnet coils had to be sufficiently large to stand the current, and at the same time had to be of very low resistance, since the energy lost in the coils is proportional to C^2R. This energy is expended in heating the coils. Since the maximum C is fixed for the particular machine, R must be made as small as possible, to reduce the loss in energy.

FIG. 75.

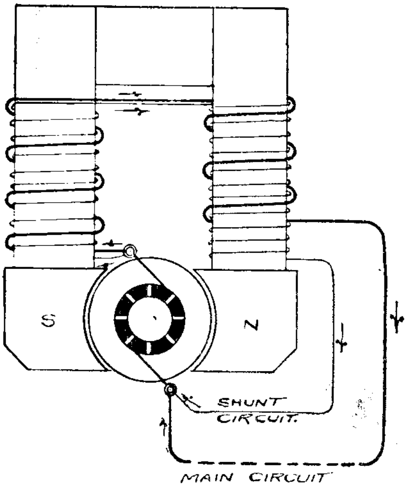
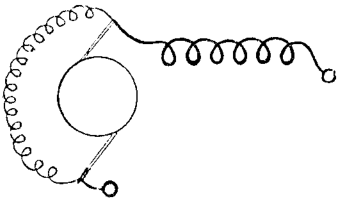


FIG. 76.



In the case of the shunt machine the reverse is the case, since the current through the shunt coils is controllable, and varies as $\frac{E}{R}$; therefore, assuming the D.P. to be constant (as it practically is), the loss of energy is proportional to

$$\frac{E^2}{R^2} \times R = \frac{E^2}{R}.$$

So that, by increasing the resistance of the coils up to the limit of providing sufficient current for magnetising the coils, the loss by heating will be reduced.

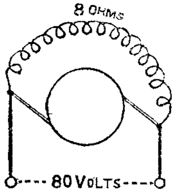
If, then, in the *compound* machine we are going to embody the two previous methods of magnetising the field magnets, we must be prepared to find two absolutely different sorts of magnetising coils; one of large wire, capable of carrying a large current with but little resistance, and another totally separate set of coils of comparatively high resistance. This we actually do find; they are called respectively the *series* and the *shunt* coils.

Service Requirements for Dynamos.—What we want in the Service is a machine that can *always be run at a constant speed*, and for that constant speed, *the same D.P. to be available at the brushes, whatever current may be flowing in the outside circuit.* For instance, the current required to burn one 80-volt 16 c.p. incandescent lamp is ·8 ampere; we may require in the daytime to burn 150 of these between decks, which will consequently take 120 amperes of current at a D.P. of 80 volts. After dark we may require another, say, 250 lamps to light up the ship fully. This would take an extra 200 amperes at 80 volts. Notice that we have now *increased the load* on the dynamo very considerably, but still require it to run at the *same* D.P. between its terminals.

Now, for this purpose the series machine must fail, for if we take the case of a machine made to give 80 volts, and, say, 400 amperes if required, then, if the series coils magnetise the field just enough to give 80 volts with 400 amperes magnetising the coils, it is absurd to expect the same coils to magnetise the field sufficiently to give 80 volts with only, say, the current required for the comparatively few lights used in the daytime. So this type of machine can never fulfil our requirements.

Discussion of the different Types.—The *shunt* dynamo we must examine a little more closely to see why such a machine fails. When the armature revolves in a magnetic field it cuts lines of force, and a certain total D.P. is generated. As soon as current flows in the armature certain reactions take place, and the more the current increases the more these reactions are felt. They will be explained in a more detailed form later on. Our purpose now is simply to arrive at a rough idea for the reasons for *compounding* a machine. We will consider, therefore, that these reactions produce the same effect as if they were all massed into a single resistance R which followed Ohm's Law. This is not strictly true, but for the present purpose of obtaining merely a general conception of the compound machine, the assumption is permissible. Assume, then, that the armature of our shunt machine has a resistance of ·05 ohm, and that, first of all, we work it on open circuit, and just get 80 volts at the brushes.

FIG. 77.



Suppose, again, the shunt coil has a resistance of 8 ohms, it will be taking 10 amperes; that is to say, on open circuit, 10 amperes will be flowing in the armature.

$$\text{Loss in D.P.} = C \times R = 10 \times {\cdot}05 = {\cdot}5,$$

in other words, we lose ·5 volt in the armature; therefore, if we have 80 volts at the brushes we must have made a total D.P.

$$= 80 + {\cdot}5, \text{ or } 80{\cdot}5.$$

Now, suppose we have 400 amperes flowing, then the loss in armature will be

$$= 400 \times 0{\cdot}5 = 20 \text{ volts.}$$

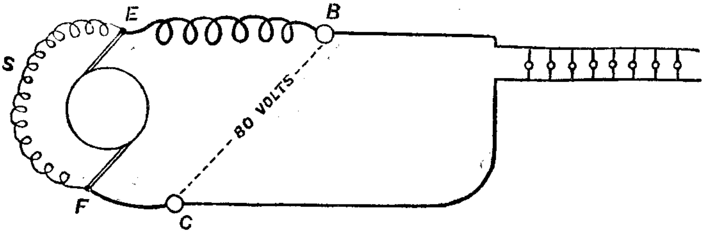
Therefore, even if we had the same number of lines of force enclosed, that is the same current in the shunt coil, we should only get

$$80{\cdot}5 - 20 = 60{\cdot}5 \text{ volts}$$

at the brushes. But 60·5 volts would only send $\frac{60\cdot5}{8}$ or 7·5 amperes round the shunt, so that from both these causes we find that the D.P. at the brushes will fall considerably. In fact, unless we have some means of increasing the strength of current in the shunt coils, we can never, for the same speed, get the same D.P. at the brushes if we increase the current running in the armature.

So we are practically in this position: we must keep the speed constant, that is the agreement, but we must make more total D.P. to allow for losses in the armature. To make more total D.P. we must increase the strength of the magnetic field *as the current increases;* and this is done by adding on series coils, that is, coils that the main current runs through. Consequently, as the main current increases and produces losses in the armature, so it in its turn increases the magnetism of the field magnets, increases the lines of force enclosed by the armature, thus producing more total D.P., which will make good the loss in the armature and leave us the same D.P. at the brushes. Fig. 78 will perhaps show this more clearly.

FIG. 78.



Suppose, as before, the resistance of the armature of a machine to be ·05 ohm, and that of shunt coil to be 8 ohms; and suppose series coils be added on with a resistance of ·01 ohm, and suppose the coils so arranged form a compound machine, so that a D.P. of 80 volts is always maintained at the terminals, we then get:—

When the machine is on open circuit, no current runs through series coils, therefore, D.P. at brushes is same as D.P. at terminals, viz., 80 volts, current through shunt $= \frac{80}{8} =$ 10 amperes.

$\therefore$ 10 amperes flow through armature.
$\therefore$ Loss of D.P. in armature $= 10 \times \cdot05 = \cdot5$ volt.
$\therefore$ Total D.P. made $= 80 + \cdot5 = 80\cdot5$ volts.

Now with 400 amperes running.

400 amperes run through series coils, therefore, loss of D.P. in series coils $= 400 \times \cdot01 = 4$ volts.

∴ D.P. at brushes = 80 + 4 = 84 volts; but 400 amperes also run through armature, therefore D.P. lost in armature = 400 × ·05 = 20 volts.

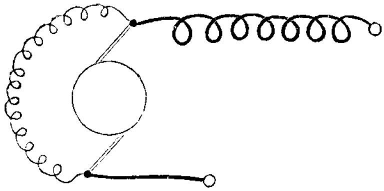
∴ Total D.P. made = 84 + 20 = 104 volts, that is, 23·5 volts more have to be made in the second case if the voltage at the terminals is to be kept at 80 volts. In other words, more lines of force have been added by series coils to make the extra voltage, so that a certain balance, viz., 23·5 volts, may be lost and yet leave 80 volts at the terminals. These extra lines are added by the series coils.

The case taken is an exaggerated one, and, as before remarked, not strictly true. But for beginners it is a convenient method of looking at and grasping the rough idea why series coils are required to keep a constant D.P. at the terminals of a compound machine.

Various Types of Compound Machines.—Compound machines, therefore, have two sets of coils, *series* and *shunt*. These coils admit of slight variation as to the exact places their ends are taken to.

I. Single Short Shunt.

FIG. 79.



As shown, Fig. 79, where the ends of the shunt wire go to the brushes, and the series coil runs from a brush to a terminal, the other terminal being connected to the opposite brush.

II. Single Long Shunt.

FIG. 80.

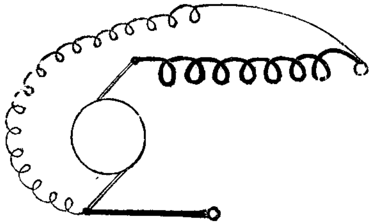
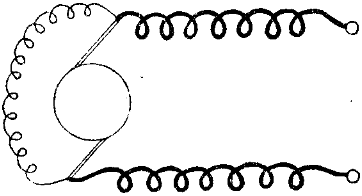


Fig. 80 shows the single long shunt where the shunt runs between one brush and the end of the series coil, the series coil being connected as before. The only difference is that the D.P. at the ends of the shunt wire remains constant whatever the current through armature may be, since in an 80-volt dynamo, it is always equal to $\frac{80}{\text{resist. of shunt}}$; whereas the resistance of the series coil in the former case necessitates a slight rise in D.P. at the brushes, and therefore a slightly increased current in the shunt coil, as the current through the armature rises.

III. Double Short Shunt.

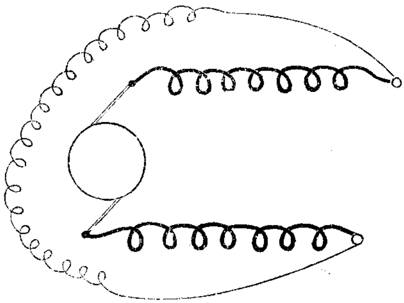
FIG. 81.



This case differs only from Case I. in that the series coil is divided between each brush and a terminal. This makes no difference electrically, but is convenient at times in manufacture, to save joining the series coil together. Case IV. is a combination

IV. Double Long Shunt.

FIG. 82.



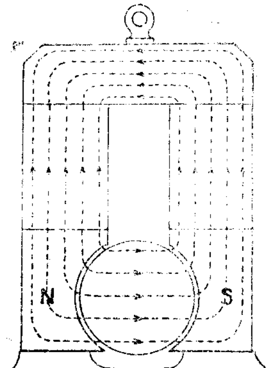
of Cases II. and III., where the shunt coil runs from the ends of the series coil. This is exactly the same as Case II. electrically, but embodies the convenience in manufacture of Case III.

Now with reference to the series and shunt coils it does not, electrically speaking, matter which are wound on a particular magnet leg first. In fact we find them wound on first or last indiscriminately, and later we shall see that in some types of dynamo the whole of the windings are placed on one of the magnet legs and none on the other.

To continue with the consideration of a two-pole compound dynamo, it is necessary to remember what has been previously learnt as to the reluctance of the total magnetic circuit of the machine.

Reluctance of the Magnetic Circuit, Two-Pole Dynamo.—In the first place, the magnet legs must be of very soft iron or mild steel, and should also be of large section, so that their permeability is not reduced by ever being near the saturation limit. The two magnet legs must be connected by a large soft iron yoke capable of easy removal to separate the magnet legs if required, but the surfaces must be truly machined so as to complete the internal magnetic circuit between the magnet legs with as little magnetic reluctance as possible. Again, the armature must be as close to the *pole pieces*—that is, the ends of the legs that embrace the armature—as possible, so as to reduce the air space through which the lines of force have to travel in order to complete the whole magnetic circuit, to the smallest limit. Fig. 83 shows the magnetic circuit of a two-pole dynamo, where it will be observed that the total magnetic reluctance may be divided up into—(1) the reluctance of the legs; (2) of the yoke; (3) of the contacts of the yoke and legs; (4) of the air spaces between the armature and pole pieces, and (5) the reluctance of the iron of the armature. Of these (4) is the most considerable.

Fig. 83.



Dynamos Mounted on Non-Magnetic Metal.—All machines rest on a bed of non-magnetic metal, such as gun-metal, zinc, &c., to prevent leakage of lines of force.

For convenience in most dynamos the coils, instead of being wound straight on to the legs of the magnets, are wound on to sleeves which fit over them.

Sleeves.—The convenience of the system is obvious, especially in the case where the legs and pole pieces of magnets are of large section, since in original winding and also in repair the sleeve may be much more conveniently mounted than the whole leg of the magnet.

If a sleeve is used, the sleeve itself is made of soft sheet iron, and the flanges of some non-magnetic substance, as wood or brass. The soft iron is used in order to offer little reluctance to the induction from the coils penetrating the sleeve to the core; and the flanges, being of non-magnetic substances, produce less leakage of the lines of force into the surrounding space. The flange is necessary to form an edge for the coil so as to prevent the end turns from slipping and becoming slack.

Winding of Field Magnet Legs.—Every care must be taken to prevent any of the coils touching metal, that is, being in communication with the body of the machine; the surface of the sleeve must therefore be covered with some form of insulator. The insulating surface should, at the same time, provide a fairly soft bed for the turns, and yet not be liable to be affected by moisture which may creep in and corrode the iron, since *iron mould* is one of the most fatal destroyers that can affect the cotton covering of the wire. A coat of thin varnished paper is usually put over the sleeve and then a layer of canvas. The insides of the flanges, if of metal, should be lined with vulcanite. If the inner end of the wire goes through the flange, the hole must be bushed with vulcanite to prevent the insulation of the wire being worn through by the sharp edges of the metal. In wooden flanges the inside end of the wire is let into a recess in the wood, so as to be well clear of the subsequent turns. If, as in the case of some machines, the inside end is simply laid close to the flange, and the succeeding layers wound past it, the end will have to be most carefully insulated to prevent short-circuiting of any of the layers of the coil as they cross the end. Between the shunt and series wires good insulation must be put, since the parts of the two coils closest to one another may be at a considerable D.P.

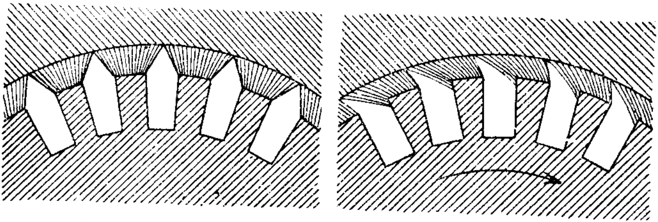
The legs are wound so that when joined up to the brushes the current that flows round them shall make the pole piece the right polarity.

The series wire is sometimes divided between the two legs, sometimes wound wholly on one; these differences resting entirely with the designers of the machine and having no electrical importance. If the series wire is on both legs, then a metallic strip is at times provided to join the two coils in series. This strip forms a handy place to disconnect the two coils. The shunt coils are similarly joined, only of course with a smaller connecting piece.

Laminated Pole Pieces.—When a toothed armature is placed in a magnetic field, the lines of force concentrate toward the teeth in the form of bunches, Fig. 84 (*a*), and thereby destroy the uniformity of the field.

If the armature is now revolved these bunches are taken along by the teeth until a position (*b*) is reached in which the lines have been distorted to the utmost, when they will commence to change over to the next following tooth of the armature.

(*a*) FIG. 84. (*b*)



Armature at rest. Armature in motion.

By the action of changing over from one tooth to the next the distribution of the magnetic lines of force is continually changing. This tends to set up Eddy Currents in the teeth and in the polar faces.

In order to prevent excessive heating from this cause it is necessary that the teeth be made numerous and narrow, and that the pole pieces be laminated.

Hitherto we have only considered the case of a two-pole machine of the old type, as that is the form of machine that has the simplest magnetic circuit. As, however, there are now very few two-pole dynamos in the Service, all modern machines having four or more poles, it is necessary to see how far the above remarks apply to multipolar machines.

The field must be equally strong all round the armature, otherwise one part of the armature would always be generating more E.M.F. and consequently doing more work than the other. It is, therefore, usual to divide both the series and shunt windings equally between all the pole pieces.

Also, for reasons connected with the running of dynamos in parallel, which will be explained in Chapter IX., it is necessary that the series winding should all be on one side of the armature, and all Service machines are now of the single short shunt, or single long shunt types.

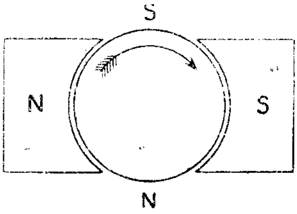
THE DYNAMO ENGINE.

Explanation of the Supply of any necessary Amount of Current, with Machine at a Constant Speed.—It will be as well here to touch on a difficulty often experienced, namely, that of understanding how a machine that runs at a constant number of revolutions can supply any current that may be required in the outside circuit. At the same time the action of the engine when joined to the dynamo will be considered.

We have previously stated that the fact of revolving the coils of an armature through a magnetic field creates a D.P. in the coils, and causes a current to flow in them if the outside circuit is completed.

Now this current flowing through the conductors of the armature produces a magnetic field in its iron core which is proportional to the current flowing. Examining the direction of flow of the current more carefully, we shall find that if the north and south poles are placed as shown in Fig. 85, and the armature revolves in the direction of the arrow, the effect of the current is to make a south pole at the top of the armature, at the two adjacent rectangles on whose commutator strip the brush is bearing, and a north pole at the bottom. Hence the distribution of polarity between the armature and field magnets of a dynamo revolving as shown by the arrow will be seen in Fig. 85. In fact the armature, when revolving, will always be having its south and north poles dragged away from the north and south poles of the magnets. Considerable power has to be applied to the shaft to do this. The more current we have running in the armature, the stronger this attraction will be, and the more power we must apply to the shaft. The current cannot exist in the armature without this back attraction.

FIG. 85.



If an independent current is passed through the armature, this back attraction will cause the armature to revolve and energy will be given out. In order to produce the current a greater amount of energy must be supplied to the armature to drag the current away from the attraction of the pole pieces.

Now, it will be seen that the amount of energy required to be given to the armature depends on the amount of current that is to be made, since the more current generated the more strongly will the armature be magnetised, and the back pull on the armature become greater.

Action of the Governor.—This energy is supplied by a steam engine coupled direct to the armature shaft, and a device to regulate the supply of steam called the *governor*. The governor is a mechanical arrangement fixed to the engine which regulates, by opening or closing a valve, the quantity of steam supplied to the engine, so as to keep the number of revolutions made by the latter constant at all loads.

When the engine is in motion with no load on it, the amount of steam required will be small, *i.e.*, just sufficient to overcome the friction. As the load on the engine increases the effect will be to diminish the speed. If now, automatically, we can allow more steam to enter the cylinder, we shall increase the mean pressure on the piston and therefore make the engines pick up their speed again. If some of the load is taken off, the engine, having now less work to do, revolves faster. To regulate these changes in speed consequent on alteration of load the governor is introduced. The *governor* automatically cuts off some of the steam supply, and the engine assumes its normal speed. Bearing in mind this fundamental principle of the governor, the student should now be in a position to consider the joint action of steam engine and dynamo in regulating the output of current.

How Constant Speed is obtained.—Suppose no current is being supplied to the outside circuit, then there is very little current in the armature, and very little attraction between the armature and field magnets. The engine therefore has but little load, very little steam is being supplied to the cylinders, and the engine is revolving at its normal number of revolutions. Now, supposing we switch on some lights, we have reduced the resistance in the outside circuit, therefore we get a current running through it, and the armature has to supply this. The attraction between the armature and field magnets increases, and the machine and the speed of the engine will tend to diminish. Immediately this happens the governor works, admits more steam, gives more push to the piston and connecting rods, and the armature is pushed round against the attraction of the magnets, and the machine once more runs at very nearly a constant speed.

We have always assumed that the D.P. at the terminals of a compound machine remains constant up to its full load, and have shown how this may be arrived at with the use of series and shunt coils. A convenient way of looking at the question of D.P., current, steam, and speed, is as follows:—

Current varies as Mean Pressure of Steam.—Electrical horse-power developed in the dynamo is nearly equal to the mechanical horse-power supplied to the armature spindle, neglecting friction and small losses.

$$\frac{E \times C}{\text{constant}} = \frac{P\,L\,A\,N}{\text{constant}}$$

where E is D.P. in volts, C current in amperes, P mean pressure of steam, L length of stroke, A area of piston, N number of revolutions; therefore,

$$E\,C \text{ varies as } P\,L\,A\,N;$$

but L and A are constant for the same engine; therefore,

$$E\,C \text{ varies as } P\,N;$$

but if E varies as the number of revolutions, so that if E is constant, the number of revolutions is constant; then for this speed,

$$C \text{ varies as } P$$

or current varies as mean pressure of steam.

Limit of Amount of Current.—Apparently, from the foregoing explanation, there is no limit to the current we can take out of a dynamo, providing we have sufficient steam and an engine strong enough to drive it. But there is a most important limit, and that is the current that the wires of the armature can safely stand without heating dangerously—that is, sufficiently to injure the insulation. This limit is fixed by the designers. In any dynamo therefore more than the proper amount *can* be taken out, but never *should be*, since the wires are too small to stand the extra heating, and damage to the armature is pretty certain to ensue.

Margin in the Number of Revolutions.—If, for example, the words 400 amperes, 80 volts, 320—330 revolutions are stamped on a dynamo, the meaning is that, "this machine will always supply " a D.P. of 80 volts at its terminals up to the limit of 400 amperes " that it is made for. Any current up to 400 amperes may be " taken from the machine according to the external resistance " used. 400 amperes should never be exceeded, otherwise extra " heating will damage the armature." The number of revolutions necessary to maintain a D.P. of 80 volts varies. When the dynamo is first started and is cool, the smaller of the two numbers stamped on the machine will suffice, but after running at full load for a little time the number of revolutions must be increased, to compensate for the increased resistance due to heat.

The following extracts from the Steam Manual are here quoted as bearing on this subject:—

Article 258, page 80.—The speed at which the electric light engines are to be driven is in all cases to be controlled by the governor value.

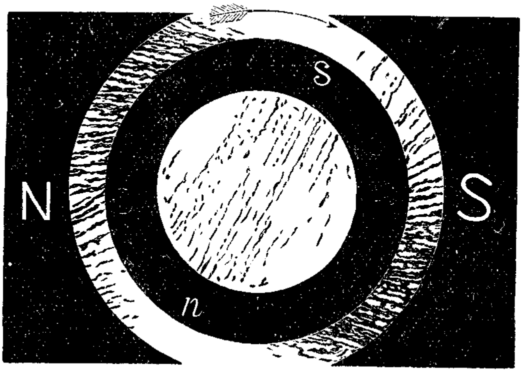
Article 553, page 169.—The electric light engine should be run at a speed to give, at the terminals of the machine, the voltage specified, but if, for any reason, it is desirable to exceed this voltage, there is no objection to the engine being run at 5 per cent. above the maximum revolutions marked on the dynamo, unless any undue distress is observed in the electric light engine, in which case the fact should be reported.

We will now consider the theoretical conditions which must be fulfilled in order that as little sparking as possible may be produced, as the brushes pass from strip to strip of the commutator.

REACTIONS IN ARMATURE.

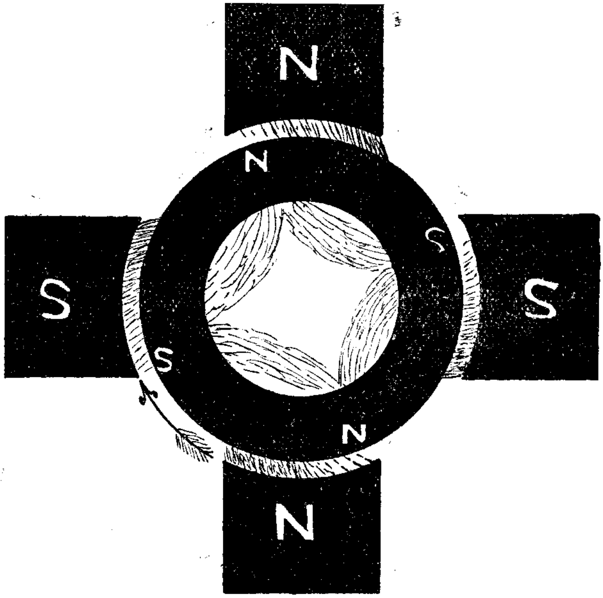
Reactions due to the Two Fields.—We have seen that current flowing in an armature produces magnetism in the armature core ; this is shown in Fig. 85, page 122, where a south pole is formed at the top of the armature and a north pole at the bottom. This magnetism of the armature is bound to affect the magnetic field, since we have now four poles producing fields instead of, as we have hitherto imagined, only two. A little thought will show that this particular distribution must lead to a thickening of the lines of force between the north field magnet and the south pole of the armature, and also between the south field magnet and the north pole of the armature, as shown in Fig. 86. The result of this is evident. Instead of the line of greatest magnetism running between the north and south poles of the field magnets, it will run between the places where the lines of force are thickest, or at a place slightly in advance (in the direction of revolution) of the old line.

FIG. 86.



The exact position evidently depends on the strength of the poles in the armature—that is, on the amount of the current flowing in the armature. Nor is this all. Since the line of greatest magnetic effect is displaced, the neutral line must also

FIG. 87.



be similarly displaced, the result being that the new neutral line is also in advance of the old.

The field distortion in a multipolar machine is of exactly the same character as above, the field being strengthened at the forward edges of the pole pieces, weakened at the after edges, reckoning in the direction of rotation.

In order that there may be no sparking between the brushes and the strips of the commutator, it is necessary that the brushes should be slightly in advance of the neutral line. This can be explained as follows:—

FIG. 88.

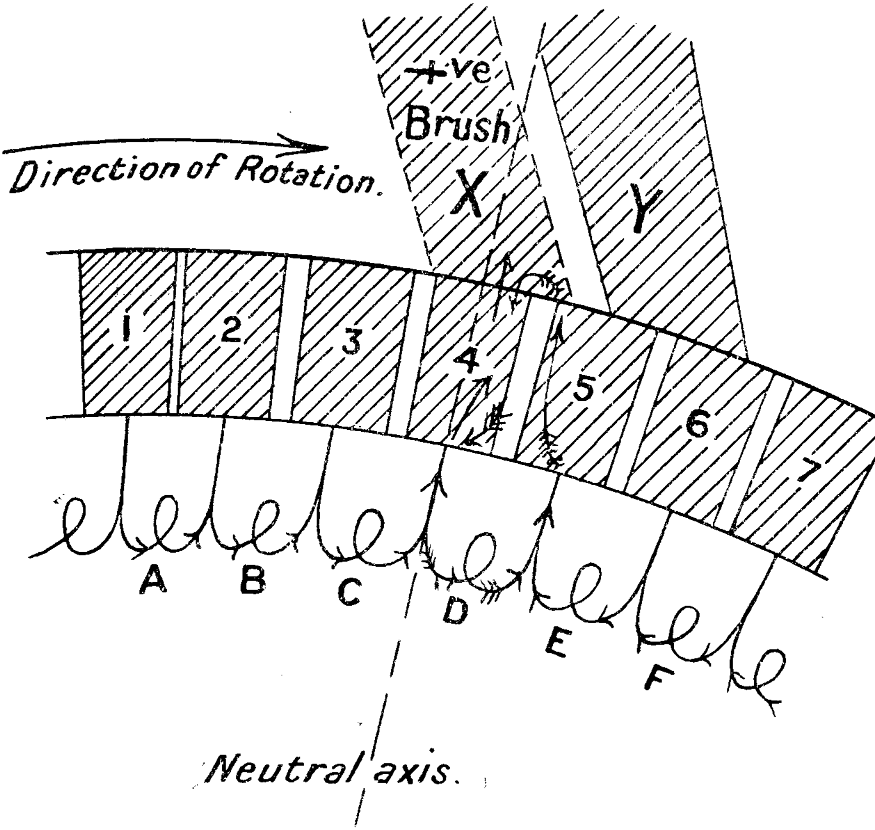


Fig. 88 represents the part of the commutator at the neutral axis, the armature coils being drawn diagrammatically between the commutator strips. The positive brush, that is the brush by which the current leaves the armature, is shown placed on the neutral axis at X, and the currents in the coils of the armature on each side of them are shown flowing towards the brush.

In order that there may be no sparking between the brush and the commutator strips, it is necessary that, as each strip leaves the brush, there should be no current passing from that strip to the brush. Now each coil on the armature is generating E.M.F. in one direction when it it on one side of the neutral axis, and in the other direction when on the other side of the neutral axis. But, owing to the inductance of the armature coils, which is large as they are embedded in iron, the reversal of current in each coil does not take place exactly as the coil passes the neutral axis, since the effect of self-induction is to delay the reversal of the current and keep it flowing in the same direction. Consequently, with the brush on the neutral axis as shown at X, when the coil D between strips 4 and 5 is short circuited by the brush, the inductance of the coil keeps the current flowing in the same direction as before, as shown by the feathered arrows, and there will be a spark as No. 5 strip leaves the brush.

It is therefore necessary that the current in the short-circuited coil should be reversed by the time that the strip leaves the brush. This is effected by shifting the brushes on past the neutral axis, so that the current has time to be reversed when the strip leaves the brush.

The brushes should not be shifted further forward than is just necessary to stop sparking, since, as will be shown later, it is disadvantageous to have more lead than is absolutely necessary.

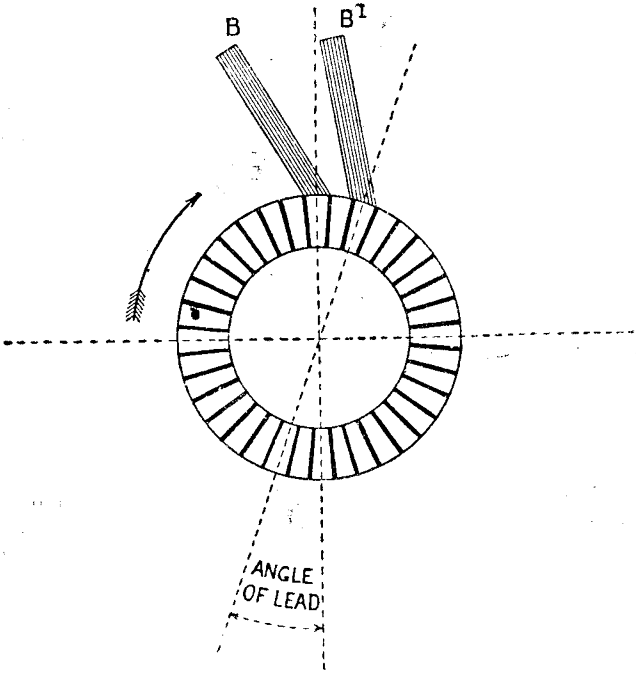
Angle of "*Lead.*"—We have seen that the position of the neutral line depends on the amount the field is distorted—that is, it depends on the strength of current running in the armature; and also that the neutral line, when the armature is carrying current, is always in *advance* of the neutral line of the machine when no current is flowing in the armature. As the current in the armature increases we should expect to have to shift the brushes on in the direction of revolution, both from the fact that the magnetic field is distorted, and also because the coil, short-circuited by the brushes, should be a little in advance of the neutral line. The angle through which the brush has been revolved to produce non-sparking is called the *angle of lead* (*see* Fig. 89).

The angle of lead of the brushes in earlier machines used to alter with every alteration of the load on the dynamo, that is the current that it is giving out, for the following reasons:—Firstly the field distortion depends on the amount of current in the armature, and consequently the neutral axis gets further forward as the load increases. Secondly, the distance that the brushes must be shifted forward of the neutral axis increases with the load, since there is more self-induction in the case of a heavy current than in the case of a small one.

Now, it is most important that dynamos should be able to run on varying loads with fixed brushes, as otherwise somebody would have always to be standing by them when running, and this condition has been fulfilled in all modern machines by the following means :—

Firstly.—The field distortion has been reduced to a minimum by having the field magnets saturated, that is, as strongly magnetised as possible, so that the magnetism of the armature is able only to make a very small alteration in the distribution of the field. By this means the neutral axis is kept practically always in the same position, whatever the load.

Fig. 89.



Secondly.—The inductance of the armature coils is neutralised in one or more of the following ways, so as to fulfil the conditions for sparkless commutation :—

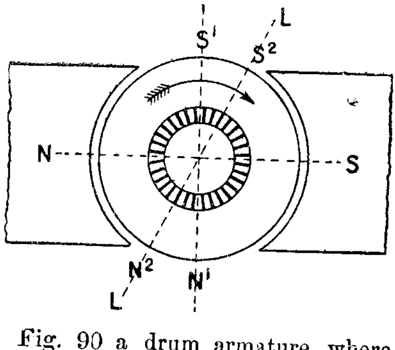
(1) By the use of carbon brushes. The resistance of carbon is considerably higher than that of copper, so that a large bearing surface on the commutator must be provided to carry the current without undue heating. The brush therefore covers several strips at a time, and so each coil of the armature is short-circuited for a longer time, and the inductance current has more time to die away. Also owing to the higher resistance of the carbon puts more resistance into the circuit of the short-circuited coil, and thus the inductance current tends to die away more quickly.

(2) By splitting up the windings. Instead of having a single winding on the armature, there are two or more windings in parallel, connected to separate commutator strips, so that the current transmitted by each commutator strip is only one half, or a smaller fraction, of the whole current. The inductive effect is thus halved, and sparking is less likely to take place. This method will be explained in Chapter VIII.

(3) By auxiliary poles. In some later machines of large output, an auxiliary pole is provided, between the poles of the main field magnets, and so placed that the armature coils pass through their field just at the moment of commutation. Their effect is to induce an E.M.F. in the armature coil which opposes the E.M.F. of self-induction, and so helps the reversal of the current. They are wound with series coils so that their strength rises with the load on the machine, and is always proportional to the strength of the inductance current that they have to counteract. They must, of course, be of the same polarity as the main pole just ahead of them in the direction of rotation, since they have to assist in the reversal of the current. Machines fitted with these auxiliary poles when once properly adjusted are almost entirely free from sparking at all loads.

Demagnetising Turns.—One of the largest causes of loss in the reaction between the armature and field magnets is the demagnetising effect of the armature on the field magnets. This is entirely due to brushes having lead.

Fig. 90.



Suppose in Fig. 90 a drum armature where N, S is the position of the magnets and L, L the line in which the brushes are placed, instead of having a north and south pole in the armature at N^1, S^1 respectively, these poles are shifted to N^2, S^2.

The magnetic effect of N^1, S^1 is at right angles to N and S, and therefore no *demagnetising* effect is produced, the only consequence is what is called a *cross magnetising* effect, at right angles to that produced by the field magnets. But if the neutral line is canted to N^2 S^2, then the magnetising effect may be divided into a cross magnetising effect along the line S^1, N^1, and a demagnetising effect along N, S at right angles to it. This effect, in some machines, tends seriously to reduce the flux of the field. Therefore, the larger the current in the armature the more magnetising force required to keep the field up to its proper strength, and therefore, in part, the necessity for series coils in the compound machine.

In later machines, fitted with the anti-sparking devices described above, so that they can run with fixed brushes, and a very small angle of lead, this effect is very small, or even in some cases entirely absent.

Other reactions, such as *hysteresis* and *eddy currents*, which have already been explained, take place in the armature and tend to cause loss of energy, but with these we are not practically concerned, as they affect the makers rather than the users of the machines.

EXCITING A DYNAMO.

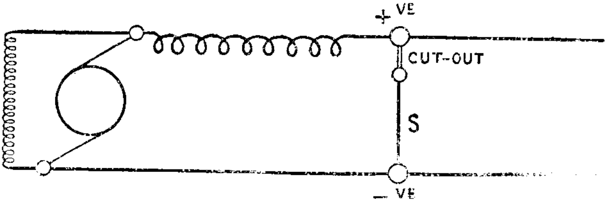
Residual Magnetism.—Another point to be considered is the original excitation of the machine. Having now some knowledge of the methods of joining up the magnets and armature, we will trace the way in which the machine on first starting magnetises its own coils. The magnets of a dynamo have always a small amount of residual magnetism left in them after stopping the machine, which remains to a greater or less extent during its period of rest. When the machine is started the armature cuts these residual lines and a slight D.P. is generated at the brushes; this causes a small current to run by the shunt coil round the magnets and increases their flux slightly. This increase in magnetism in turn adds lines of force to the field which in turn increases the D.P. made by it, and this action continues till the machine is fully excited.

Machines differ largely in their rapidity of excitation. Some excite rapidly, some with difficulty, and others with very great difficulty. The main differences lie in the reluctance of the magnetic circuit, chiefly due to the air gap; in the amount of residual magnetism, and the magneto-motive force required to induce flux in the field magnets at starting.

Failures to excite.—It is possible to imagine a case where so few lines of force exist in the magnetic circuit, that the armature on revolving would make so little D.P. that the current through the resistance of the shunt coil would be too small to produce any further increase in lines of force. Studying the curve of magnetism of soft iron given (page 56), it will be seen that at first an appreciable current is required to produce an increase of flux, if this current be too small it is conceivable that the magnets would not be further excited above their residual magnetism.

Exciting Compound Dynamos of Small Residual Magnetism.—In compound machines that excite badly, the usual practice is to short-circuit the terminals of the machine, using a cut-out in the circuit to prevent any accident from the passage of too much current. (*See* Fig. 91.)

Fig. 91.



Although we have a smaller number of turns in the series magnetising coil than in the shunt, since the wire is very much larger (*see* page 113), we shall now get a much reduced resistance in the electrical circuit. Assuming figures and taking the number of shunt coils to be 2600 of 10 ohms resistance, the series coil to be of 30 turns of ·002 resistance, and suppose the armature to be making ·001 of a volt. In the case of a shunt wire the ampere turns would be

$$2600 \times \frac{\cdot 001}{10} = \cdot 26.$$

In the case of the series coil the ampere turns would be—

$$30 \times \frac{\cdot 001}{\cdot 002} = 15,$$

or by using the series coils as temporary shunt coils nearly 70 times the magneto-motive force would be obtained.

If the brush leads of a machine be reversed, or the shunt coils be joined up to the wrong brushes, the machine will not excite, since all the current that is being made in the armature is running round the field magnets tending to excite them *against* their residual magnetism, consequently the armature reduces the field of the magnets instead of increasing it. If the leads be again replaced, such a machine will usually excite.

To ascertain the Polarity of a Dynamo.—The best methods of ascertaining *the polarity* of a machine are as follows :—

(I.) With the machine stopped.—Send a current through the galvanometer of a Menotti by joining the $+^{ve}$ pole to the free terminal, and, pressing the key, note the direction of swing of the needle. The needle will always swing this way if a $+^{ve}$ current enters the free terminal. Now join up the galvanometer only to the terminals of the machine, put on the brushes, and sharply revolve the armature by hand for quarter of a revolution, and note the direction of the swing, and from this direction judge whether the $+^{ve}$ or $-^{ve}$ terminal is connected to the free terminal of the galvanometer. When once the polarity of the machine has been found, mark the terminals $+^{ve}$ and $-^{ve}$, also mark the magnets north or south. Which brush the $+^{ve}$ current comes from depends on three things: (1) the direction of revolution; (2) the winding of the armature, whether right or left-handed; (3) the polarity of the magnet. (1) and (2) cannot alter. So (3) determines any subsequent change in positive and negative terminals. Therefore if the poles are once marked, a compass needle held near a pole piece will at any future time tell if the polarity has been altered.

(II.) With the machine running the same test cannot be applied, since a D.P. of 80 volts would be placed at the terminals of the galvanometer, which would fuse the wire.

A voltmeter, however, can be joined up to the terminals of the machine, and if it reads correctly it can be seen at once which is the positive and which the negative terminal of the machine, since the terminals of the voltmeter are marked.

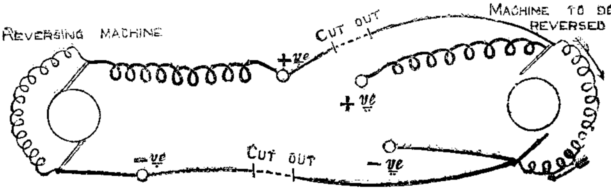
Method by using Lead Strips in H_2SO_4.—Another useful method of ascertaining the polarity is by placing two lead strips in series with a 50-candle power lamp into dilute sulphuric acid. In a short time a brownish deposit will appear on one, this is connected to the $+^{ve}$ pole. The reason of this is explained on page 304 when treating of secondary batteries.

If two wires from the terminals of the machine are put into water, very much more gas will be given off from the negative than from the positive, which provides another means of finding the polarity.

If a machine changes its polarity, reversing the leads will evidently keep the current flowing the right way in the outside circuit. But it is often more convenient to *reverse the polarity* so as to make the machine reassume its former polarity.

Reversing Polarity by means of a Second Dynamo.—This may be done in the following manner, with the aid of another machine. Lift *the brushes* off the commutator, and disconnect the main leads of the machine to be reversed. Join two leads with fusible cut-outs in them to the ends of the shunt wire; connecting $+^{ve}$ of reversing machine to the *old* $+^{ve}$ end of shunt wire; $-^{ve}$ of reversing machine to *old* $-^{ve}$ end of the shunt wire, as shown in Fig. 92.

Fig. 92.

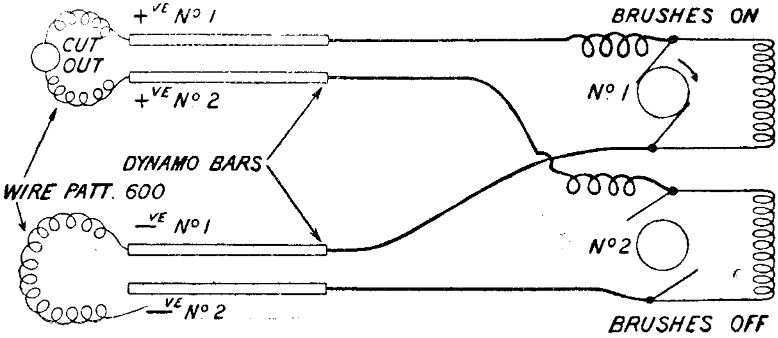


A D.P. of 80 volts is by this means brought to the ends of the shunt wire of the machine to be reversed, which is its normal amount, and therefore a strong yet safe current will flow round the shunt coils.

Precaution.—The pilot lamp should be disconnected during this operation, or else on breaking the circuit the large amount of self-induction of the current through the shunt coil will fuse the lamp.

Reversing Polarity of a Dynamo from the Switch Board.—In ships fitted with a Portsmouth switch board (*see* page 149), if one of the dynamos is reversed its polarity can be rectified as follows: Lift the brushes of the machine to be reversed and see that all the ship's circuits are disconnected at the switch board from its mains. Make a connection from the main dynamo bar of another machine which is running, to the main dynamo bar of the machine to be reversed by joining them with a short lead of pattern 600 wire with a medium sized cut-out in it. Make a similar connection for a few seconds between the return bars of the two dynamos, after which the machine will be found to have resumed its original polarity. By this method, as will be seen from Fig. 93, the current passes through both series and shunt coils in opposition. The number of turns, however, of the shunt winding is so many times that of the series, the current being the same through each, that the effect of the former need only be considered.

FIG. 93.



No 1 DYNAMO RUNNING.

No 2 DYNAMO TO BE REVERSED

Never reverse by the series wire if it can possibly be avoided If it should ever be necessary to do so, then a resistance must be inserted in series with it so as to avoid the danger of sending an excessive current through either machine.

CHAPTER VIII.

ARMATURE WINDINGS.

THE winding of a ring armature for a two-pole machine presents no difficulties at all, since there is only one possible sort of winding, namely, that shown in Fig. 71, page 108. The same may be said of a drum armature for a two-pole machine, but when we come to the consideration of windings for multipolar machines, several alternative plans suggest themselves.

FIG. 94.

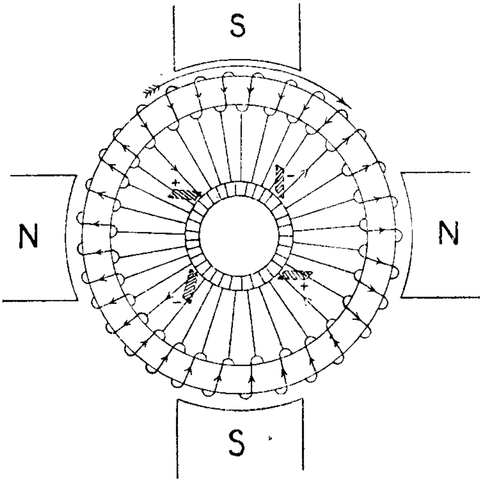
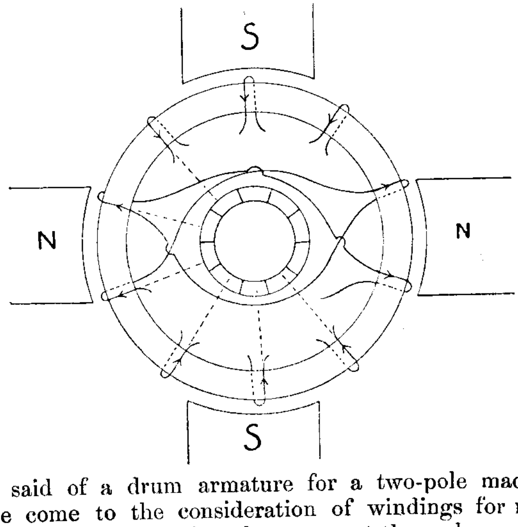


FIG. 95.

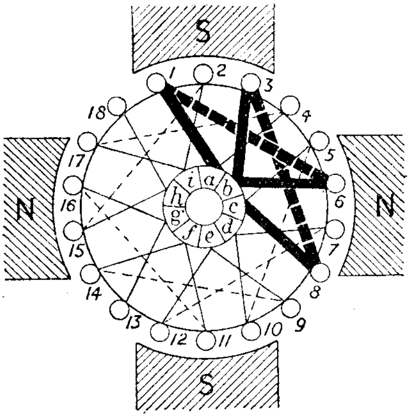


Consider the case of a ring armature such as that shown in Fig. 71, placed in a four-pole field instead of a two-pole field. It will be obvious from the direction of the induced E.M.F. in the different parts of the armature that, in order to get the full advantage of the two extra poles, it will be necessary to put on an extra pair of brushes, and so have one brush between each pair of poles. Fig. 94 shows this. In the drum armature that corresponds to this ring winding, the part of each turn that comes back inside the ring is brought back on the outside of the ring, not opposite, as in the case of a two-pole machine, but at a distance of one quarter of the circumference away, as shown in Fig. 69. The same argument applies to this, however, and it is necessary to have one brush between each pair of poles in this case also. It will be seen that in each of these cases there are four paths for the current in parallel through the armature.

Now let us suppose that in a ring armature, instead of the turns being connected in series right round the armature, each turn is joined in series with the turn that is in a similar position under the next pole piece of the same polarity, then to the turn next itself, then to that turn's opposite number, and so on right round the armature, as in Fig. 95. It will then be seen that two brushes only, placed between adjacent pairs of poles, are necessary, and that there are only two paths in parallel through the armature. The E.M.F. generated by this armature will be double that generated by the former, since the two halves of the armature are in series instead of being in parallel.

Exactly the same thing can be done in a drum armature, and in the case of drum armatures, a winding of the former sort is called a "lap" or "parallel" winding, and the latter a "wave" or "series" winding.

FIG. 96.



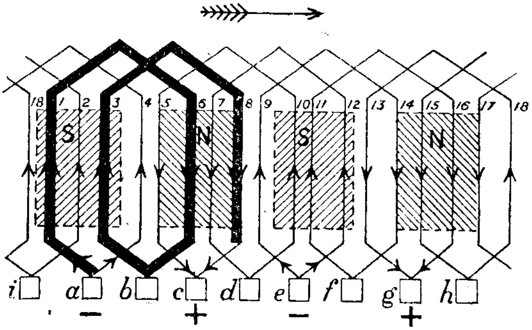
Lap winding.

In order to show clearly the various windings, and how the currents flow in them, it is most convenient to "develop," or flatten out the armature. The reader must imagine a fore and aft slit made along the surface of the armature, the "skin" of the armature being torn off and laid flat on the paper with the bars sticking to it. The bar on the right of each picture, therefore, would fold round the armature and lie next to the bar on the left of the picture, and this point must be borne in mind in tracing the windings in the figures following.

The pole pieces are shown dotted, to give an idea of the direction of the currents induced in the bars.

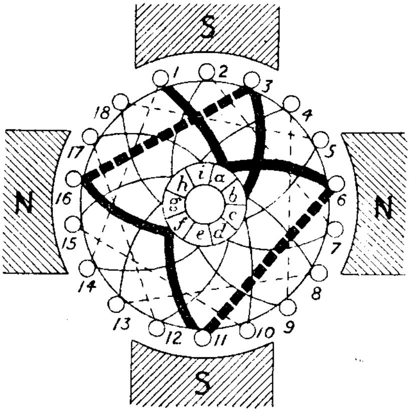
Lap Winding.—In the case of lap winding, the end of each coil, consisting of two conductors situated in fields of opposite polarity, is connected through a commutator strip to a coil lying within the same field as the former coil. The winding, consequently, forms a series of loops which overlap each other.

FIG. 97.



Development of lap winding.

FIG. 98.



Wave winding.

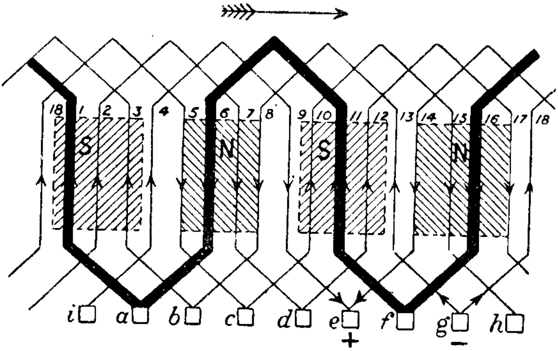
Figs. 96 and 97 represent a lap winding and its development for a four-pole drum armature.

Wave Winding.—In the wave winding the direction of connecting advances continually in one way, the end of each coil being connected to another having a corresponding position under the next pair of magnets.

The winding in consequence represents itself in a wave shape.

Figs. 98 and 99 represent a wave winding and its development for a four-pole drum armature.

FIG. 99.



Development of wave winding.

The pitch of a winding is the distance between any conductor on the armature and the next one it joins to. This is usually given in terms of the number of conductors spanned over. Thus if No. 2 conductor joins to No. 21, and No. 21 joins to No. 40, and so on, the pitch is said to be 19.

The "Front" pitch is the number of conductors bridged over by an end connection at the commutator end of the armature, and the "Back" pitch is the number bridged over at the other end.

The signs + and − are used to denote the direction in which the winding is carried by the end connections.

Thus, in the winding quoted above, which is a wave winding where No. 2 joins to No. 21 at the back, No. 21 to No. 40 at the front, and so on, both the front and back pitches are said to be + 19.

Suppose we have a lap winding, in which No. 2 joins to No. 19 at the back, No. 19 to No. 4 at the front, No. 4 to No. 23 at the back, No. 23 to No. 6 at the front, and so on, the back pitch is said to be + 19 and the front pitch − 17.

A winding is said to be *singly re-entrant* when, after going once round the commutator, it forms a closed coil, the last conductor joining the first. The symbol for this winding is ○.

It is said to be *doubly re-entrant* when, after using every alternate commutator bar and having been once round the commutator, it continues round again, so using the remaining bars, and ultimately joining or re-entering, on No. 1, from which the winding started. The symbol for this is ➰

Thus a *trebly re-entrant* winding is one which goes three times round the commutator before it re-enters the original conductor from which it started. The symbol for a trebly re-entrant winding is ➿

A Duplex, or Triplex, winding is one in which two, or three coils, each of which may be ○, ➰, or ➿, are wound side by side on the armature. If there is only one coil, the winding is said to be Simplex.

These can be represented graphically as follows:—

A Duplex, singly re-entrant is represented by ○○.

A Triplex, doubly re-entrant is represented by

➰ ➰ ➰

And so on.

Any one of the above systems may be wave or lap wound.

In the case of a ○ winding, the brush is of such a size as to bridge over two commutator strips at a time, but in the case of a ○○, where the two windings are in parallel, it must be twice this size. A ➰ is, electrically, exactly the same as a ○○, and the brushes for it must be of the same size. In one case there are two separate complete windings in parallel with one another, and in the other the two halves of the same winding that lie alongside each other are in parallel.

In all multiple windings the brushes must be of such a size that they can short-circuit at least one coil in each winding, but they may be larger if necessary. Thus in a ➰ ➰ winding, in which there are four times as many paths in parallel for the current as in a ○ winding, the brush must cover at least five commutator strips, and similarly for other windings.

A practical method of discovering whether the winding of an armature is Simplex or Duplex, Triplex, &c., is as follows:—Test with a Menotti between two adjacent commutator strips. If there is a swing, the winding is Simplex, but if there is no swing, it is either Duplex, Triplex, &c.

We will now consider the design of winding for any particular armature, beginning with Simplex.

For instance, for a  winding, we must arrange the number of conductors and the pitch of the winding so that the winding re-enters on itself after going once round the armature and using all the conductors. A little thought will enable anyone to find suitable numbers and pitches, but it is more convenient to have some guide, so the following formulæ are given :—

N is the number of conductors on the armature.
p the number of poles.
Y the mean pitch.
y_1 and y_2 the front and back pitches respectively.
R the re-entrancy (*i.e.*, in a singly re-entrant winding R = 1, in a doubly re-entrant R = 2, and in a trebly re-entrant R = 3).

For wave windings :—

To find N—

N $\pm$ 2 R must be divisible by p.

To find Y—

$$Y = \frac{N \pm 2R}{p}.$$

Front and back pitches need not be exactly the same, but they must be odd, and their sum must be equal to 2 Y.

For lap windings :—

To find N—

N must in all cases be an even number.

For  windings N must not be divisible by 4.

For  windings N must not be divisible by 3.

To find Y—

$$Y = \frac{N}{p} \text{ as nearly as possible.}$$

y_1 and y_2 must differ by 2 R, and must not be divisible by 2 R.

If Duplex or Triplex windings are required, the easiest way to design them is to consider each winding separately.

Thus, for a Duplex winding, consider only every other conductor and commutator strip, leaving out the intermediate ones entirely, and work out a winding with these data. This will leave every other conductor and commutator strip unoccupied, and then a precisely similar winding can be put on the armature using the vacant bars and strips.

The object of all these multiple windings is, of course, as explained in the last chapter, to reduce sparking by reducing the amount of current to be commutated as each strip on the commutator leaves the brush.

We will now proceed to give some examples of armature windings. In all the following examples, for the sake of avoiding confusion in the diagrams, much fewer conductors are used than would ever be used in an actual machine, but they will serve to indicate the method employed in designing windings.

Suppose a ○ wave winding is required for a four-pole machine.

$N \pm 2\,R$ must be divisible by 4.

If $N = 22$ these conditions are satisfied,

$$\text{and } Y = \frac{N \pm 2\,R}{p} = 6 \text{ or } 5.$$

We can therefore take pitches of 5 and 5, or 5 and 7.

Take 5 and 5.

The result is the ○ wave winding shown in Fig. 100.

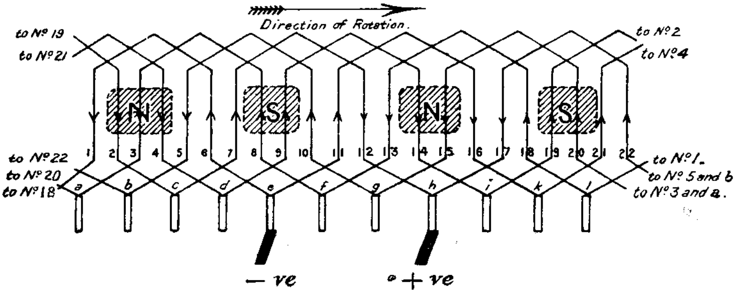
Since there are 22 conductors, there are 11 complete turns on the armature, and 11 commutator strips will be required.

It will be seen that the winding goes right round the armature, and re-enters on itself after using all the conductors and all the commutator strips.

Brushes must bear on the commutator strips that are connected to the turns that are on the neutral lines between the poles, that is, the strips *e* and *h*.

Only two brushes are required, as it is a wave winding.

Fig. 100.



We have hitherto only considered the E.M.F. generated in a complete turn on the armature, according to the way in which the magnetic flux through it is changing, but there is another way of considering this matter which will be found useful in diagrams of developed windings, and that is, to consider the E.M.F. developed in each bar separately.

If a conductor is moving from left to right over a N pole, the E.M.F. induced in it will be from top to bottom of the paper. If either the direction of movement or the polarity of the pole is changed, the direction of the E.M.F. will be the opposite, but if both are changed, it will be the same as in the first case.

It will be seen that this rule comes to the same thing as the other, but, in the case of diagrams of developed armatures, it provides a quicker means of putting down the direction of the current in each bar.

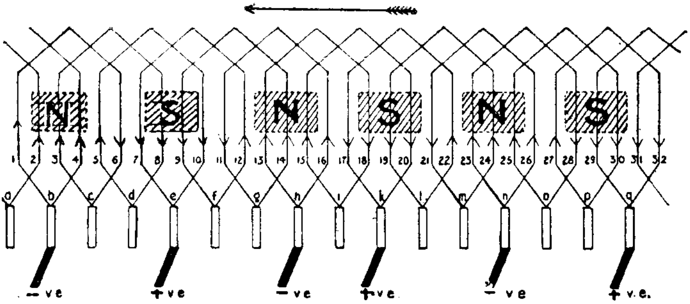
It will be seen in Fig. 100 that the currents in the bars Nos. 6 and 11 are both leaving commutator segment *e* and so the $-^{ve}$ brush is placed there.

Again the currents in Nos. 12 and 17 are both approaching segment *h*, and so the $+^{ve}$ brush is placed there.

Therefore we may formulate the rule that brushes are always placed on those commutator strips where the arrows representing the currents are either both approaching or both leaving.

Suppose now a six-pole ○ lap winding is required.

Fig. 101.



N may be any even number—take 32.

Forward pitch must be odd, and nearly equal to $\frac{N}{p}$:—take $+5$.

Backward pitch $=$ forward pitch $- 2$ R
$= 3$ back $= -3$.

So pitches will be $+5$ and -3.

The result is the ○ lap winding shown in Fig. 101.

Following the rule of placing the brushes wherever we find the arrows from both conductors approaching or leaving a commutator strip, we find that with a lap winding we require as many brushes as there are poles—in this case which has just been worked out, six brushes will be found necessary.

We can now appreciate the electrical difference between lap and wave winding.

Consider the wave winding we first constructed—Fig. 100.

Here only two sets of brushes are required.

Tracing the current through the armature we see that it has two paths to follow—

(*a*) From the $-^{ve}$ brush through bars 11, 16, 21, 4, 9, 14, 19, 2, 7, and 12, back to the $+^{ve}$ brush.

Or

(*b*) From the $-^{ve}$ brush through bars 6, 1, 18, 13, 8, 3, 20, 15, 10, 5, 22, and 17, back to the $+^{ve}$ brush.

So with the ○ wave winding we have two paths through the armature, and in each we have set up the accumulated D P due to half the armature bars.

Now consider the lap winding in Fig. 101.

Here six sets of brushes are necessary.

There are six paths through the armature.

$$\left.\begin{array}{l}(a)\\(b)\end{array}\right\}\text{From } -^{ve} \text{ at } b \text{ through }\left\{\begin{array}{l}1, 6, 3, 8, 5, 10 \text{ to } +^{ve} \text{ at } e.\\ 4, 31, 2, 29 \text{ to } +^{ve} \text{ at } q.\end{array}\right.$$

$$\left.\begin{array}{l}(c)\\ \\(d)\end{array}\right\}\text{From } -^{ve} \text{ at } h \text{ through }\left\{\begin{array}{l}16, 11, 14, 9, 12, 7 \text{ to } +^{ve}\\ \quad\text{at } e.\\ 13, 18, 15, 20, \text{ to } +^{ve} \text{ at } k.\end{array}\right.$$

$$\left.\begin{array}{l}(e)\\(f)\end{array}\right\}\text{From } -^{ve} \text{ at } n \text{ through }\left\{\begin{array}{l}26, 21, 24, 19, 22, 17 \text{ to}\\ \quad +^{ve} \text{ at } k.\\ 23, 28, 25, 30, 27, 32 \text{ to } +^{ve}\\ \quad\text{at } q.\end{array}\right.$$

All these paths are in parallel, and in each we have set up the D P due to only one-sixth of the armature bars.

Hence with the wave, or series winding, as it is called, we have the D P due to half the armature bars, and each bar must carry half the total current output, whilst with the lap, or parallel winding, each coil need only carry one-sixth of the total current, but the D P at the terminals is only that due to one-sixth of the armature bars.

Consequently we can say, speaking generally, that wave windings allow of high D P but small currents, whereas lap windings lend themselves to the production of large currents at a low D P.

Suppose a service 100-volt 1,000-ampere six-pole machine is to be designed.

If we wind it wave or series round, each bar will have to carry 500 amperes and will have to be of considerable size, but a large number will not be required to produce 100 volts since half the whole number will be in series.

If we wind the armature with lap or parallel winding, each coil will only carry about 170 amperes and can be small, but a large number will be required to generate 100 volts.

Most modern dynamos have multiplex lap wound armatures.

Since each winding offers as many paths to the current as there are poles, each coil carries a very small fraction of the whole output, and the coils can be kept of convenient size.

Fig. 102 shows a Triplex singly re-entrant (○○○) lap winding with 36 conductors, four pole, partly wound.

To find the pitch, consider only one winding.

This will have 12 conductors.

Forward pitch will therefore be $\frac{N}{p} = +3$.

$$\begin{aligned}(\text{Backward pitch}) &= (\text{Forward pitch} - 2\text{ R})\\ &= -1.\end{aligned}$$

But between each conductor of this winding there are two of other windings.

So pitch on the armature becomes $\left\{\begin{array}{l}+9.\\-3.\end{array}\right.$

Fig. 102.

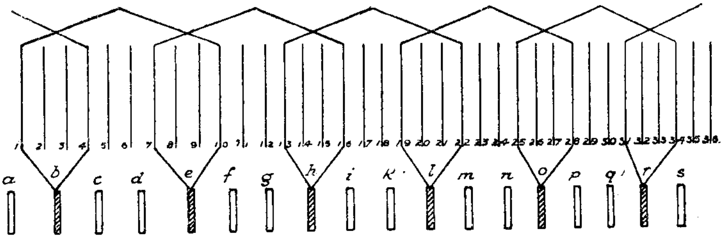


Fig. 102 shows one winding completed, having formed a closed coil after using every third conductor and every third commutator segment.

Two more windings similar to this one have to be wound on the armature. Broad brushes are then used, which bridge over at least four commutator strips, and there will thus be 12 paths through the armature in parallel.

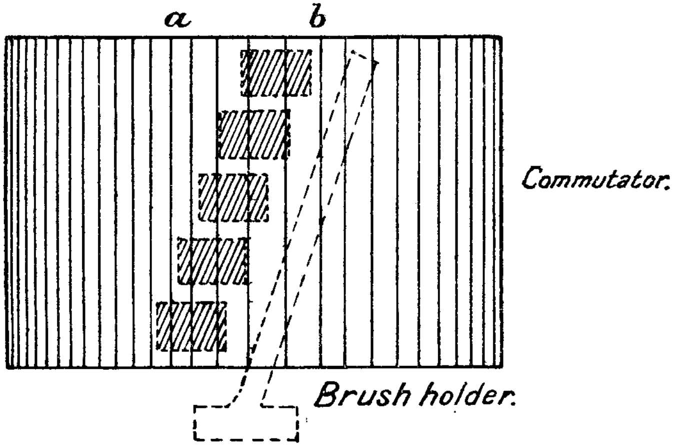
Windings are often spoken of by referring to the number of paths through the armature formed by them.

This winding would therefore be called a "twelve circuit winding" the winding on Fig. 101 is a "six circuit winding," and so on.

A formula that will often be found useful is as follows:—
"The difference between the number of conductors (N), and the "product of the mean pitch and the number of poles (Y × n) "gives the number of circuits in the winding." This formula follows from those already given.

In the case of the ○○○ winding in Fig. 102, the small number of commutator segments introduces an absurdity if the

Fig. 103.



broad brushes are put in, 70 per cent. of the coils being short-circuited. In practice, of course, windings of this type would never be used with less than about 100 commutator bars, generally considerably more, and the apparent incongruity disappears.

In order to bridge over a number of strips without having enormously wide brushes, the brush holders are sometimes "staggered," as in Fig. 103, which is exaggerated to show this more clearly.

Here the brushes are short-circuiting all bars between *a* and *b*, though each brush individually is only wide enough to cover two strips.

It has been mentioned that wave windings only require two sets of brushes, but it is often convenient to have more than two sets if large currents are to be collected.

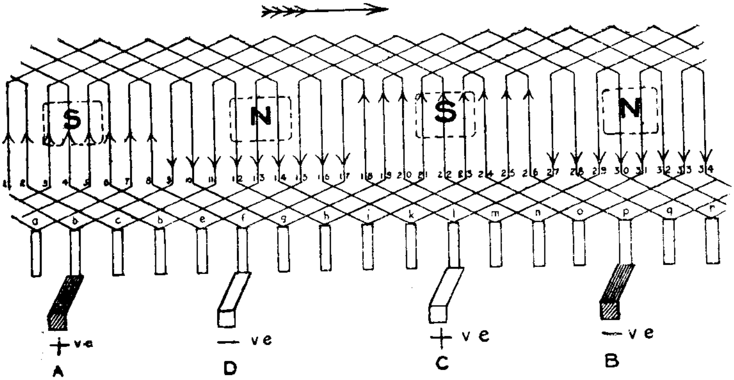
It is possible to introduce additional sets of brushes without lowering the E.M.F. at the terminals.

This is best shown by an illustration.

We will suppose a four-pole ○ wave winding with 34 conductors.

Then pitch = $\frac{N \pm 2R}{p}$ = + 9 or + 8, but 8 is even, so take + 9.

FIG. 104.



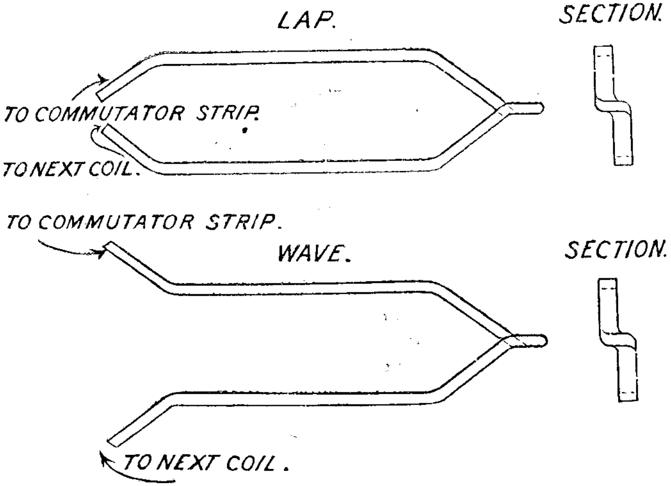
Following the rule of placing brushes where the currents both approach, or both leave a commutator segment, it is evident that brushes are required at A and B, and these are all that are absolutely necessary. But supposing more surface is required to collect current from, and brushes are placed at C and D. Then it will be seen that segment *f*, upon which brush D rests, is connected directly to segment *p*, upon which brush B rests, with only one coil (17 to 26) in between. This coil lies between the poles, and is cutting no lines of force, so electrically *f* is the same point as *p* at that instant. Consequently D and B are at the same potential, and can be joined to a common lead to the switchboard. The same reasoning applies in the case of A and C. Thus it will be seen that with a wave winding it is possible to have as many sets of brushes as there are poles, and at the same time to get the collective E.M.F. of half the armature bars at the terminals, in the same way as when two sets of brushes are used.

The alternative would be to have a very long commutator with a large number of brushes in each set, but a long commutator is expensive and mechanically weak, besides taking up a large amount of space, so wave wound machines with large current output are always fitted with several sets of brushes.

Formed Coils.—In all the latest type of multipolar dynamos with slotted armatures, end connections are done away with and Formed Coils used.

Each coil, instead of being made up of a long bar, a short bar, and two end connections, is made out of a single length of wire, which is forced into the requisite shape in a former. The side of each coil is shaped similar to an end connection, in order that each coil may fit neatly into its neighbouring coils. It will be noticed from Fig. 105 that when Formed Coils are used, the commutator strips are connected to the centre of the coils, instead of to the end of the long bar. The position of the brushes is therefore affected, and they must be moved, in a four-pole machine 45°, and in a six-pole 30°, and will be directly under the poles instead of between them.

FIG. 105.



The advantages of this system are :—

(1) Coils are simple to make.

(2) Fewer soldered junctions are required, and therefore there is less risk of a fault developing.

(3) Winding the armature is simplified.

(4) Repairs are more easily made.

The sole disadvantage is that the total length of the armature is slightly increased.

In large modern machines the most common practice is to put the conductors in two layers, an upper and an under. Formed Coils particularly lend themselves to a two layer arrangement.

All electrical and magnetic considerations point to the slots in the armature being narrow and numerous, but mechanical and manufacturing difficulties arise, if this is carried beyond a certain point, so the general practice is to group the conductors two or more in a slot.

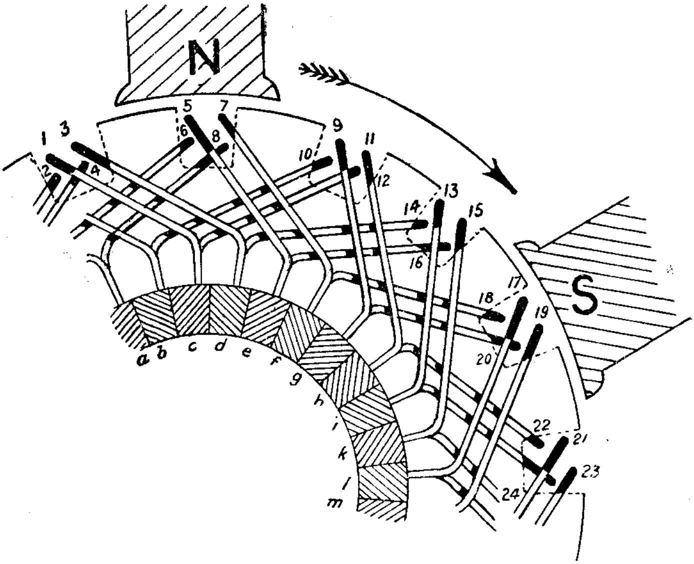
The standard arrangement in lap winding is to put four conductors in a slot.

Figs. 106 and 107 show such a winding.

The slots are spread out and exaggerated to show the arrangement of the coils.

The figure shows part of a six-pole machine with 18 slots, 36 commutator segments, and 72 conductors.

Fig. 106.

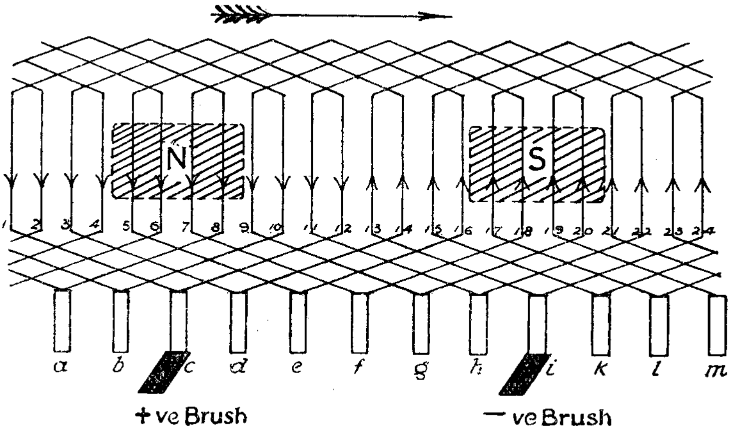


Below is a development of this portion of the armature winding, showing how the induced currents flow and where the brushes are placed.

The conductors and commutator segments are numbered and lettered similarly in the two figures.

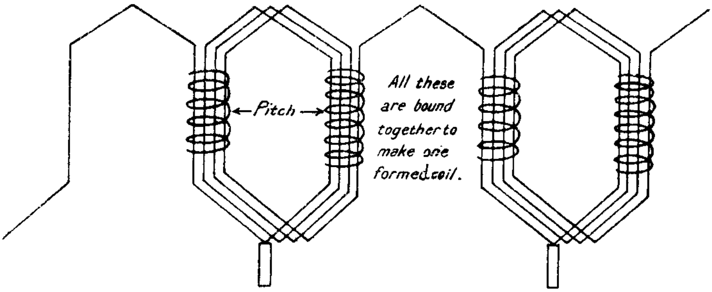
In practice the slots and conductors are, of course, grouped much closer together.

FIG. 107.



In many small motors in the Service a mixed winding is used. It is really a pure wave winding, but each element is composed of a number of turns of wire, lapping back on each other, bound up into one coil with the ends sticking out. (*See* Fig. 108.)

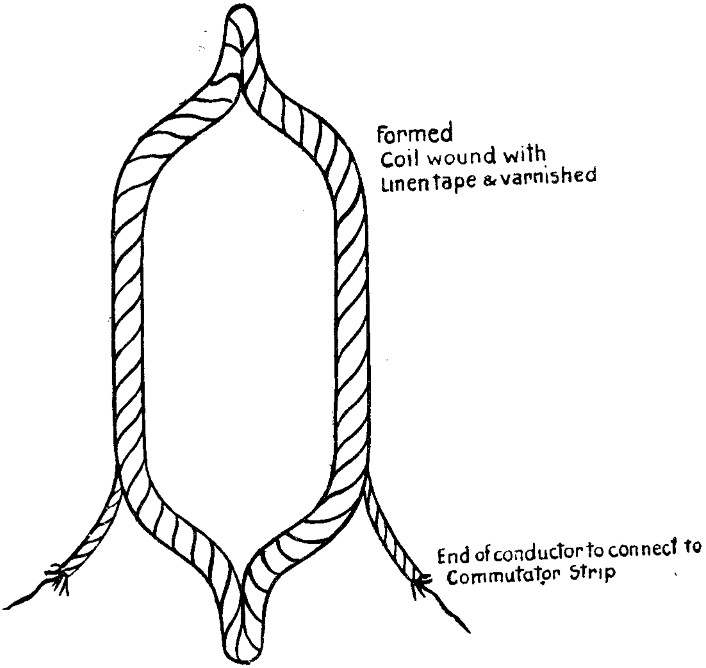
FIG. 108.



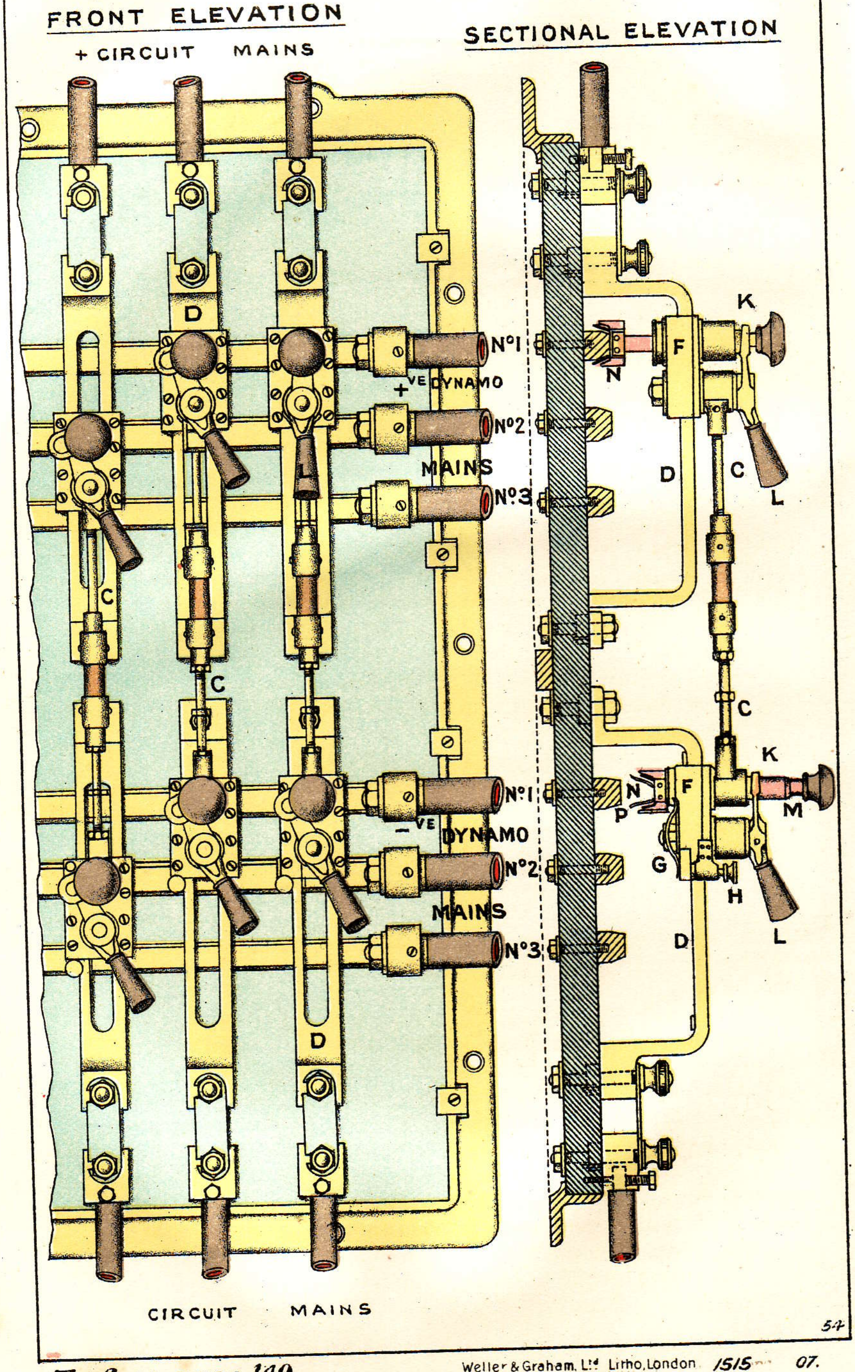
The coils when finished have the appearance shown in Fig. 109.

This arrangement enables small motors, with few slots and commutator segments, to be used with comparatively high voltages, since by this means the number of coils producing "back E.M.F." (*see* Chapter on Motors) is largely increased without increasing the number of commutator segments.

Fig. 109.


Formed
Coil wound with
Linen tape & varnished
End of conductor to connect to
Commutator Strip

PORTSMOUTH SWITCHBOARD.



FRONT ELEVATION

SECTIONAL ELEVATION

54

To face page 149.

Weller & Graham, Ltd Litho, London 1515 07.

CHAPTER IX.

SWITCHBOARDS AND PARALLEL RUNNING.

ALL ships larger than torpedo gunboats are fitted with more than one dynamo, and as it is necessary that any of the dynamos should be able to feed any or all of the circuits in the ship, all the circuits and all the leads from the dynamos are connected up to a switchboard in a central position.

Switchboards may be divided into two broad classes, separate machine boards and parallel boards.

The first class was fitted in all ships up to and including the earlier cruisers of the County class, in which motors were not used to any very great extent.

In these switchboards, each dynamo has a separate pair of bus bars, and the different circuits of the ship can be connected to any pair of bus bars. Each dynamo is thus quite separate from all the others, and though more than one may be in use simultaneously, yet there is no connection between them. The name "bus bar" is given to a long conductor in a switchboard, to which connections can be made in various places.

There are two patterns of separate machine board in the Service—the Portsmouth board, which is the older one, and the Clarke Chapman board, which is rather more modern.

The Portsmouth board, which was designed for three dynamos, is shown in Plate XIII.

It is designed for three dynamos and, as a rule, for six or more separate circuits. Only half the board is shown in the front elevation in the plate, but the remainder is exactly the same, all the circuits being similar.

The dynamo bus bars are mounted on a solid slate base, the cross-section of the metal being sufficient to avoid heating. The circuit bars D are fitted with sliding blocks F., the positive and negative block of each circuit being connected mechanically by a rod C C of adjustable length, but insulated from one another at the centre of the rod.

The sliders F F embrace the whole of the bar, thus ensuring a large contact surface, and are held in their exact position by stops G, worked by a thumb piece H. These stops are only fitted to the lower sliding blocks; the correct position of the slider on the upper part of the board being ensured by the length of the connecting rod C.

The contact N is fitted on the end of a plunger, and when pressed down into connection with the dynamo bar the spring hook K holds it in position, and good contact is obtained by further jambing down the plunger by a sideway motion of the handles L; the hook then presses on the inclined shoulder M of the plunger forcing the contact block N down on to the bevelled sides of the dynamo bar.

To break the circuit a sideway motion of the handle L allows the hook K to clear the shoulder M, and the spring forces the contact block N away from the dynamo bar with a very rapid motion, so preventing sparking; sparking pieces P are fitted to take any spark that is caused.

The action of the board is extremely simple; the connecting rods between the sliding blocks prevent any possibility of the same circuit having its main and return joined to separate dynamos by accident.

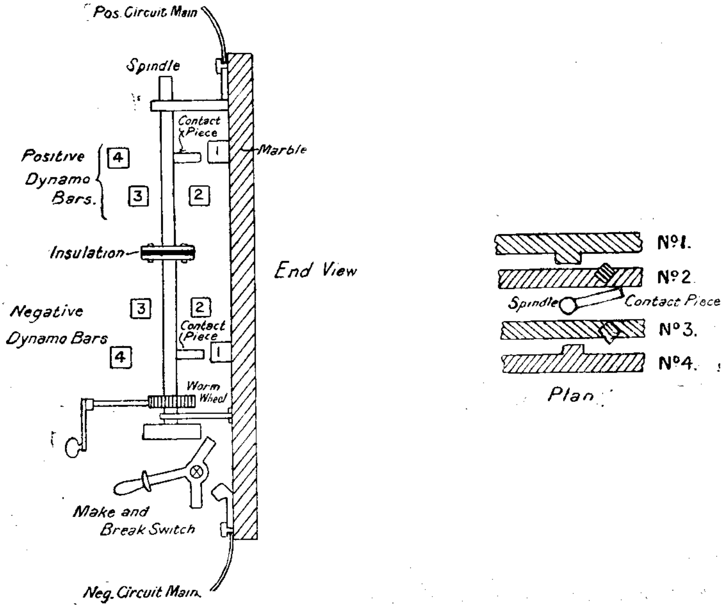
The cut-outs have washers and hexagonal nuts to secure them to the blocks, a convenient spanner being supplied to screw up the nuts.

Handles and pushes are made of hard wood instead of ebonite, and the size of the metal so designed as to avoid all heating.

The Clarke Chapman board, which was designed in three sizes, for two, three, or four dynamos, is fitted in all ships built between 1900 and 1904.

In place of the upright circuit bars with sliding blocks, there is a vertical spindle, pivoted at the top and bottom, and having the upper and lower halves insulated from one another. The spindle carries a worm wheel, with which is engaged a worm on a small horizontal shaft which protrudes to the front. A handle

FIG. 110.



can be shipped on this shaft, and the spindle revolved by means of the worm.

There is one of these spindles for each circuit, and the dynamo bars run horizontally the whole length of the board, the positive bars being at the top and the negative at the bottom. Two of them are between the spindle and the board, and the other two are outside the spindles, being secured to the board by brackets at their ends.

Round the upper part of the spindle are arranged four chopper contacts, all on the same level, and one secured to each dynamo bar. The spindle carries a projecting contact piece, which, when the spindle is revolved, goes into each contact in turn.

The negative bars and the lower half of the spindle have precisely similar fittings, and are so arranged that when the contact piece on the upper half is in the contact on the positive bar of any dynamo, the lower contact piece is in the contact of the negative bar of the same dynamo.

The positive main of the circuit is connected direct to the upper hinge of the spindle, and the negative main of the circuit is connected to the lower hinge of the spindle through a large chopper switch.

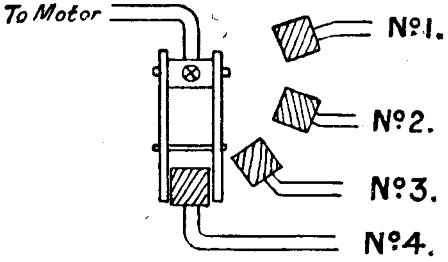
This chopper switch has a horn on it, which, when the switch is closed, engages in a slot in the lower part of the worm wheel on the spindle. This prevents the spindle being revolved while the switch is closed, and also prevents the switch being closed unless the slot is in line with it, and the contact pieces engaging fairly with the contacts on the dynamo bars.

Numbers are marked on the upper part of the spindle, which, when showing to the front, indicate the number of the dynamo to which the circuit is connected.

Fig. 110 shows the general arrangement of the Clarke Chapman board for four dynamos.

The great advantage of this switchboard over the Portsmouth board lies in the fact that the chopper switch provides a quick make and break for the circuits, and consequently no sparking takes place at the contacts on the dynamo bus bars.

FIG. 111.



The power circuits, *i.e.*, the circuits of large motors, in ships fitted with Clarke Chapman switchboards, are taken each from a large double-pole switch of the form shown in Fig. 111, which are grouped together on a "power switchboard."

Only one-half of the switch is shown in the figure, but the other half, to which the other lead to the motor is connected, is exactly the same.

The four blocks shown are connected to the dynamo bars of the lighting switchboard, so that the motor circuit can be put on to any dynamo.

In some ships the two halves of each motor switch are linked together, so that it is impossible to put the positive on to one dynamo and the negative on to another. In the earlier ships fitted with these switches this is not done, and the two halves of the switch are entirely separate.

Parallel Switchboards.

Owing to the large number of electric motors in ships built since 1904, it has been found necessary to have some means of coupling the ship's dynamos in parallel, in order to avoid sudden strains on any one machine, by distributing the load over several of them.

If a number of large motors are running with intermittent loads, as they would be when coaling ship, it is unlikely that the full load of every one will be on at the same moment, so that the total power to be supplied will be more or less steady. If one dynamo were used for the Temperley and another for the bollards, the machines would be at one moment supplying a large amount of power, and at the next moment running almost light, so that the engines and governors would be subjected to very severe strains.

Whereas, by joining the dynamos in parallel and supplying all the power in the ship from one pair of bus bars, the fluctuations of the load on any one machine are considerably reduced.

Also if, under ordinary conditions, there are two or more dynamos running in parallel with the ordinary load evenly distributed between them, there is a good margin of reserve output.

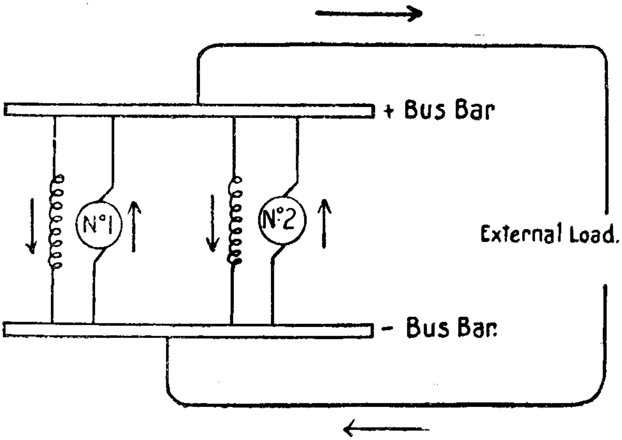
Very little more steam is used than if the same load were crowded on to one machine with no margin; brushes, commutators, &c., remain in better condition, and the reserve output is always available at a moment's notice for extra motors, lights, or other purposes

Against these advantages we must set the increased complication and cost of switchboards, the liability of the automatic safety arrangements to failure, and the necessity for a switchboard watch-keeper, who must be a highly trained and reliable man.

Before proceeding to describe the parallel switchboard and its fittings, it is necessary to examine the conditions under which dynamos can be run in parallel.

Consider first the case of two shunt dynamos running in parallel, and each giving out the same current, as in Fig. 112.

FIG. 112.



The arrows show the directions of the currents in the armatures and shunt coils.

Each armature is developing rather a larger voltage than the D.P. between the bus bars, since there is a certain C R drop in the armature itself.

Now suppose No. 2 dynamo to slow down slightly, so that it is developing rather less total E.M.F. than No. 1. The D.P. at its terminals must remain the same, as they are connected to the bus bars, but it will give out less current since C R must be less than before, and R is of course the same. As it slows down, it will give out less and less current until, when the total E.M.F. that it is generating is the same as the D.P. between the bus bars, there will be no current in its armature at all.

If it slows down any more, so that it generates less E.M.F. than the D.P. between the bus bars, No. 1 dynamo will send a current through its armature in the opposite direction to that shown by the arrow.

Its E.M.F. is then opposing the E.M.F. that is forcing current through it, and it will run as a motor in the same direction as before. It will be seen that the current through the shunt coils cannot be reversed, as they are connected up between the bus bars.

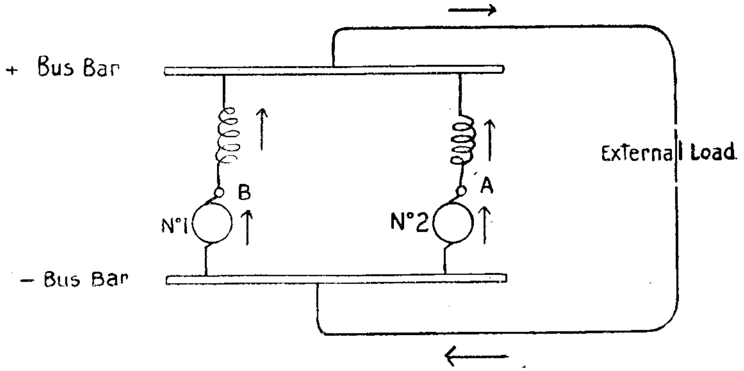
The effect, therefore, of a partial failure of one of the engines is that one machine will have an extra load thrown on it by running the other machine as a motor.

Now, let us consider the case of two series machines running in parallel, and each giving out an equal amount of current as shown in Fig. 113 (*see* next page).

Suppose now No. 2 machine slows down slightly. As in the case of the shunt dynamos, its E.M.F. will decrease slightly, and it will give out less current.

There will therefore, be less current through its field coil, and this will decrease its E.M.F. still more. This further decrease in the E.M.F. will cut down the current again, and the same process will go on rapidly until No. 1 sends a current through it in the opposite direction.

FIG. 113.



The arrows, as before, show the directions of the current.

This will reverse the magnetism of the field magnets, and it will consequently generate E.M.F. in the opposite direction. A very large current will then flow through the bus bars and both machines, since they are short-circuiting one another, and both of them will be burnt out.

It is, therefore, necessary to prevent the current in the series coils from being reversed in any circumstances, and this is done by joining the two points A and B by a lead called the "equalizer."

The series coils of the two machines will then be in parallel, and the current through them will always be in the same direction as the current in the outside circuit.

If one of them then slows down so that the current through it reverses, it will be reversed in the armature only, not in the field coil, and the dynamo will be run as a motor, as in the case of the shunt machine.

There are no series machines in the Service, but the same precautions are necessary with compound machines to prevent the current from being reversed in their series coils.

A parallel switchboard has therefore three bars—positive and negative bus bars, and an equalizer bar.

It is most important that machines when running in parallel should be controlled entirely by their governor valves, so that they shall share their load as far as possible between them. It is, however, necessary to have some means of controlling the voltage, independent of the governor, so a shunt regulator is in all cases fitted.

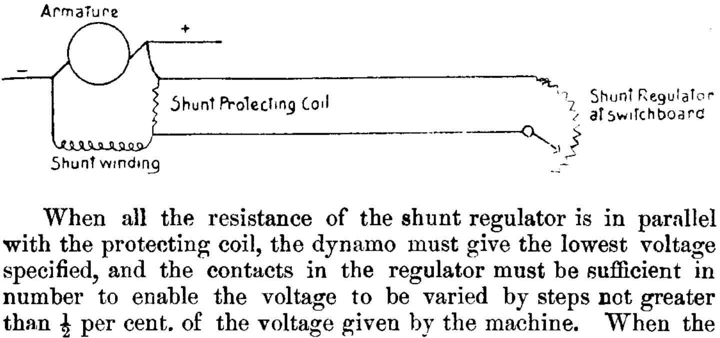
This consists simply of a variable resistance in series with the shunt windings of the dynamo, so that the excitation of the shunt field can be varied. The shunt regulator is always placed on the switchboard, so that it can be used when putting in or switching out the dynamo, and, as the machine may be some distance from the board, some safety arrangement is necessary to prevent any accident occurring from damage to the shunt regulator or leads between it and the dynamo.

If the circuit of the shunt windings were broken with the dynamo running, an accident might be caused in two ways. Firstly, the dynamo would lose its voltage, and so throw a sudden and very heavy load on the other machines; and secondly, since the inductance of the shunt winding is very large, the E.M.F. of inductance on the circuit being broken might cause an arc which would be very difficult to put out, or it might give the dynamo attendant a shock which would probably be fatal.

The safety arrangement that is fitted takes the shape of a "shunt protecting coil," which is mounted on the dynamo and is in parallel with the shunt regulator.

The shunt regulator is arranged to short-circuit this coil when in one extreme position, and, when in the other extreme position, the resistance in its circuit is so high that there is practically no current flowing in it, and all the current in the shunt coils then flows through the protecting coil. A diagram of these fittings is shown in Fig. 114.

FIG. 114.



When all the resistance of the shunt regulator is in parallel with the protecting coil, the dynamo must give the lowest voltage specified, and the contacts in the regulator must be sufficient in number to enable the voltage to be varied by steps not greater than ½ per cent. of the voltage given by the machine. When the regulator is short-circuiting the protecting coil, the dynamo must give the highest voltage specified.

The equalizer has another function besides that of preventing the current in the series coils from being reversed, and that is, to keep the load equally divided between all the machines on the board. This it fulfils as follows:—

Suppose two similar machines are running in parallel, and for some reason one of them is generating slightly more E.M.F. than the other, and so taking a larger share of the load.

Since the series coils are similar and in parallel between the equalizer and one bus bar, they will carry equal currents. The effect of this will be that the machine which is giving out more current will be under-compounded, and the other will be over-compounded, so that the tendency is to restore the balance. The machines should always be adjusted by means of their shunt regulators, so that the load is shared equally between them, and once this is done they tend to preserve these conditions, as explained above.

If two machines of different output capacity are to be run in parallel, it is possible to take the full load out of each if they are so adjusted by means of their shunt regulators, but if this is done the following point must be noted:—The series coils will carry equal currents if their resistances are the same, and if this is the case those of the machine of smaller output will be carrying more current than they were designed for. It may therefore be necessary, to avoid overheating, to shunt them so that the current through them shall not be too great.

The requirements of a parallel switchboard are as follows:—

All parallelling arrangements, including switches, regulators, and instruments, must be under complete control of the attendant, and it is convenient, but not of course necessary, to have the outside circuits controlled from the same position.

A complete and satisfactory system of safety arrangements must be fitted to guard against—

1. Overloads on the dynamos.
2. Reverse currents in the armatures.
3. Disconnecting of equalizer.
4. Putting on a stopped machine.

There must be no danger to the switchboard attendant.

The insulation must be good and must not deteriorate with heat.

The whole board must be as simple, light, and compact as possible while fulfilling the above requirements.

The parallel switchboards in the Service consist of two parts, which may be together if there is room, but are often separate, though in the same compartment. These two parts are—first the dynamo board, having one panel for each machine, and carrying all the safety arrangements mentioned above, and secondly the distributing boards, from which the external circuits are taken off. The two parts of the board are connected by the bus bars, which are, of course, common to all the panels, while the equalizer bar is common to the dynamo panels only.

The panels of the board are made of steel, the conductors, of course, of copper of high conductivity, while the insulation is all of micanite. No slate, ebonite, or marble is allowed to be used in the construction of these boards.

We will first describe the dynamo board. The two bus bars and the equalizer bar are, as we have said above, common to all the dynamo panels, and each panel carries also a shunt regulator, a double-pole switch for the dynamo mains, a single-pole switch for the equalizer, an ammeter, a voltmeter, and the various safety arrangements.

The three switches—positive, negative, and equalizer—may be arranged differently, *i.e.*, all separate, one three-pole switch or otherwise, but the above is the most usual arrangement. In any case, it is absolutely necessary that the equalizer switch should always be closed either before or at the same time as the other two, and that it should be impossible either to close the positive and negative while the equalizer is open, or to open the equalizer while leaving the others closed.

The usual arrangement is therefore as follows:—The positive and negative are put on by a double-pole switch, which when closed is held in place by a catch. A toe on the equalizer switch prevents this catch from engaging unless the equalizer switch is closed. This provides safety arrangement No. 3.

Safety arrangement No. 1 is provided as follows:—On each dynamo main there is an overload coil, generally with a movable core which is sucked in when the current reaches a certain value. When it is sucked in it strikes a lever, and releases the catch that holds on the double-pole switch.

It is necessary to have an overload coil in each main, since, in the case of earth leaks, it may happen that there is an overload in one lead only.

The overloads may either be quick working, tripping the switch immediately the current rises to certain value, or they may have a time arrangement, and only trip the switch when the overload has persisted for a certain period of time, ten seconds or thereabouts.

These latter are much more satisfactory, since the dynamo is not so likely to be thrown off the board by a momentary overload caused by starting a large motor, and they are being fitted in all later ships. The time arrangement generally consists of a dash pot on the core of the overload solenoid, which only allows it to move slowly.

The overloads are adjustable in all cases, so that they can be made to trip the switch at any predetermined current. This is arranged for by varying the distance through which the movable core of the solenoid has to be lifted. When it is farther away it will, of course, require a larger current to lift it up and trip the switch.

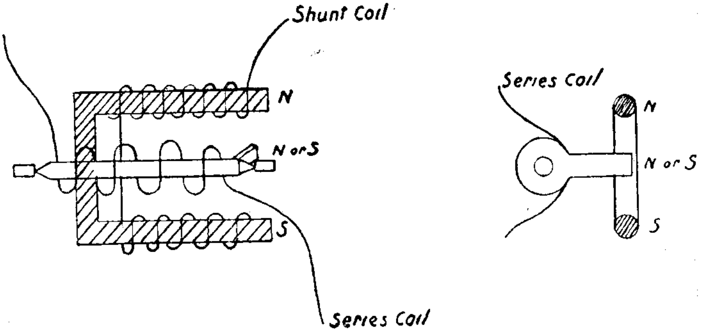
Safety arrangement No. 2, which guards against reverse current in the armature, consists of two parts, a series coil and a shunt coil. The series coil is in the return dynamo main, that is, the main on the opposite side to the series field coils, and it magnetises a core which is pivoted inside it. The shunt coil is connected directly across the bus bars, and magnetises a fixed horseshoe-shaped core. The current through the shunt coil is never reversed, since it is directly across the bus bars, but the current in the series coil is reversed if the current in the armature of the dynamo is reversed.

The arrangement of these coils is shown in Fig. 115.

When the armature is giving out current, the series coil makes the movable pole N, so that the arm on the pivoted core is held down, but when the current is reversed the arm is thrown up, and releases the catch of the double-pole switch.

The reverse current cut-out is always quick working, and comes into action as soon as a reversal occurs.

Fig. 115.



In some switchboards one of the overload coils is also made to do duty as the series coil of the reverse current cut-out, so that there are only two coils instead of three, and a certain amount of weight is saved.

The handle that works the double-pole switch does not move when the switch is tripped, but remains in the same position, and to put the switch on again it must be moved to the "off" position to engage with the switch arms and then back again, carrying them with it. This is to prevent the switch from being held on by hand if it has been tripped by one of the safety arrangements. It will be seen that this provides for safety arrangement No. 4, since if the double-pole switch of a stopped machine is closed it will immediately be tripped by the reverse current cut-out and freed from the handle, so that it cannot be held in the closed position.

The ammeter shunt is always in the return main, so that it carries the whole armature current; and not only that part of it that is going through the series coils.

The voltmeter is connected across the machine side of the double-pole switch, so that it shows the voltage of the machine whether it is on the board or not.

The shunt windings of the dynamo may be connected either across the machine side of the D.P. switch or across the brushes of the machine, making the dynamo a long shunt in the first case and a short shunt in the second. The second is the more usual form of connection. The shunt protecting coils are on the machine itself.

Putting on and taking off Machines.

In these operations, although the safety arrangements should always be kept in perfect working order, so as to avoid all chance of damage the following rules should always be observed:—

Though the switchboard watch-keeper has complete control of the board, he should not put on or take off a machine, or throw on or off a heavy load, without first warning the dynamo watch-keeper, who is responsible for the engine.

In putting on an extra machine, therefore:—

1. Tell the dynamo watch-keeper to start the machine, and ascertain when it is running at its proper speed, on the governor, cylinders clear of water, and everything correct. Let it run light for a few minutes, watching the voltmeter meanwhile to make certain of this.

2. Regulate the voltage of the switchboard to the normal amount, 100 or 80 volts, as the case may be.

3. Regulate the voltage of the new machine to three or four volts higher than that of the board.

4. Close the equalizer switch.

5. Close the double-pole switch, and the new machine will immediately take part of the load on the board.

6. Equalize the load between the machines on the board by means of the shunt regulators, raising or lowering the board voltage if necessary.

Note 1.—As soon as a machine is put on the board, its voltmeter will show the board voltage, as it will then be across the bus bars. The only guide to the individual E.M.F. of the machine will then be the ammeter.

Note 2.—If a load is put on a machine before it is warmed through, steam will condense in a cylinder, owing to a large amount entering while it is still cold. This will cause the engine to slow down and the voltage will consequently drop, and, if the relief valves do not clear the cylinders soon enough, the engine may be damaged. It is most important, therefore, that a machine should never be put on the board until it is reported ready by the dynamo watch-keeper.

In taking a machine off the board:—

1. Warn the dynamo watch-keeper.

2. Make certain that the load on the board is not too much for the machine or machines that will be left on.

3. Lower the voltage of the machine to be taken off by means of the shunt regulator. This will transfer the load to the other machines on the board.

4. When the load on the machine is well down below 100 amperes, open the double-pole switch.

5. Open the equalizer switch.

6. Stop the machine.

Note.—When the voltage of one machine is being lowered, the board voltage will drop slightly, as current is being taken, through the equalizer, from the series fields of the other machines. The board voltage will rise to its original value as soon as the double-pole switch is opened.

General Rules.

1. Never strain the dynamo by altering the load suddenly.

2. Never allow the dynamo watch-keeper ease down the engine until the machine is off the board.

3. Never attempt to close the switches of a stopped machine as, if the safety arrangements were to fail, much damage would be done.

4. The reverse current cut-out should be frequently tested by lowering the voltage of a machine that is being taken off the board until a reverse current passes through it and breaks the circuit. Whilst doing this, be ready to open the double-pole switch by hand at once if the reverse current mechanism fails to act.

5. If, from a bad governor or other cause, one machine comes off the board through an overload or reverse current, it is probable, if the load on the board is large, that the others will come off also. Before putting them on again, make certain that the load will not be too much for the first machine that is put on. Take off any heavy motor or lighting circuits, and put them on again when the dynamos are on.

6. Constant attention should be paid to contacts, which should be always be kept smooth and clean, to all nuts and bolts that might work loose, and to the sparking pieces on large switches, which should be the first to make, and the last to break, contact when the switches are opened or closed. Bad or shaky contacts always cause trouble through high resistance and overheating.

The distributing board consists simply of a number of switches by which the external circuits are connected to the bus bars. These switches, in the case of lighting circuits and searchlights, are simply double-pole chopper switches connecting the bus bars to the circuit mains through fusible cut-outs. Heavy motor circuits have double-pole switches with tripping arrangements like those for the dynamo switches, except that there is no reverse current tripping arrangement. Overload coils are fitted in each side, either of which will trip the switch.

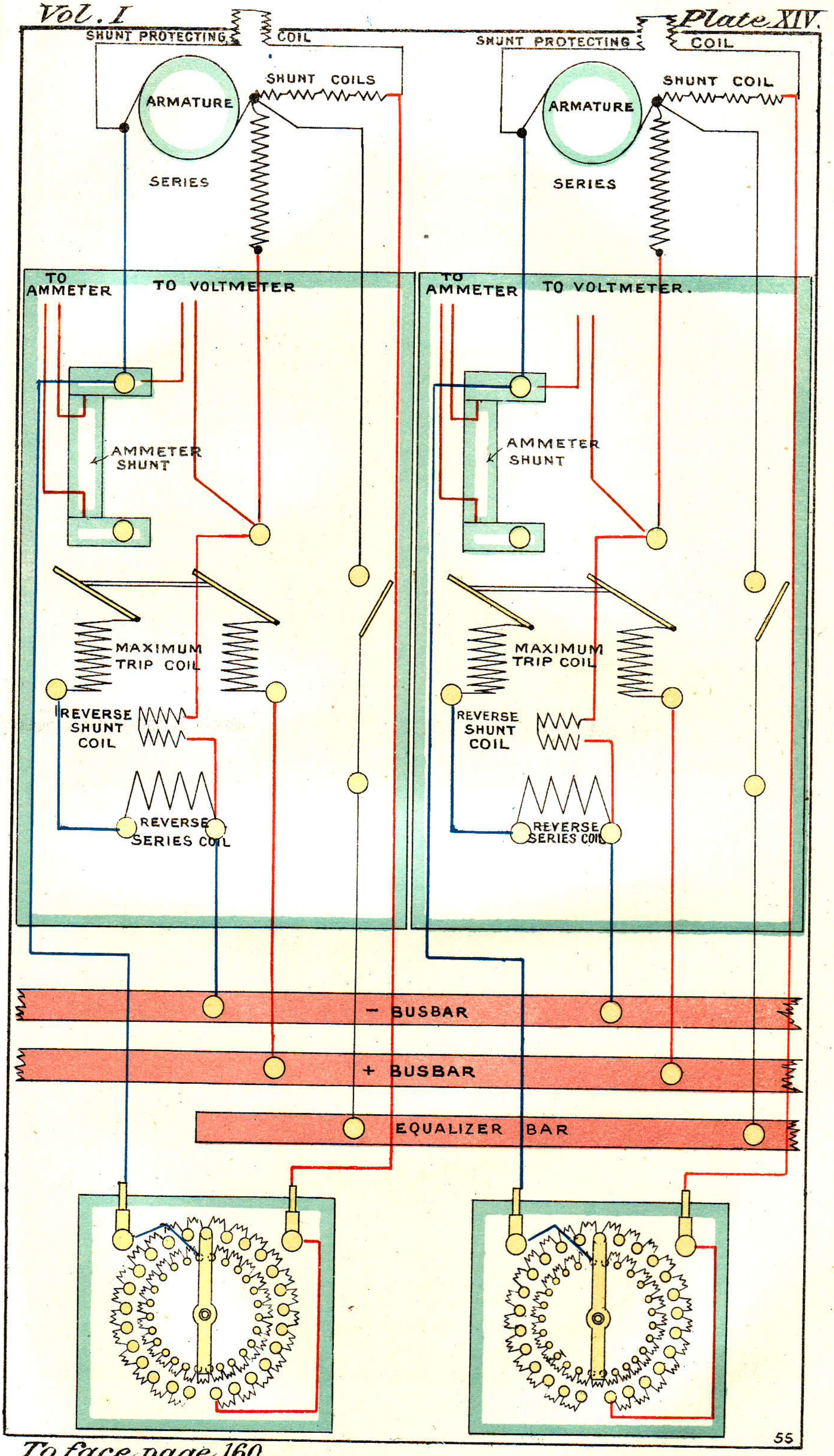
If a motor circuit breaker comes off, it should not be replaced immediately, but the motor man should be given time to centre his controller.

Plate XIV. gives a diagram of the arrangements of the dynamo panels of the parallel switch board fitted in H.M.S. "Vernon," which may be taken as typical of most parallel boards in the Service.

All switchboards are fitted with a pair of earth lamps, which are series with one another and connected across the bus bars. They are connected direct to the bus bars through single-pole switches on a parallel board; and on a separate machine board, they are fitted with a switch so that they can be connected to any pair of dynamo bars.

The middle point between the lamps is connected to earth, and when their switches are closed, the two lamps being in series will burn each at half brilliancy if there are no earth leaks anywhere in the ship. If, however, there is an earth anywhere on the circuits that are on the board, the lamp that is on the same side of the supply as the leak will be short-circuited and will go

Plate XIV.



To face page 160.

Weller & Graham Ltd Litho London. 1515 07

out, while the other one will get the whole voltage of the board and will burn at full brilliancy.

The earth leak can then be localised by breaking each circuit in turn. When the circuit on which the leak is is taken off, the lamps will again burn each at half brilliancy.

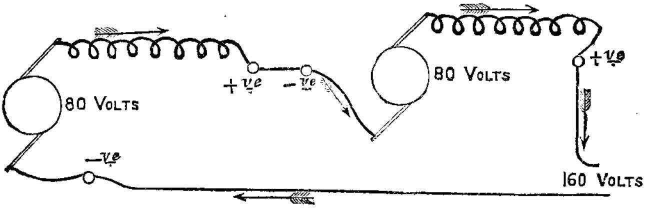
Further instructions for finding earth leaks will be given in Chapter XVI.

Running Dynamos in Series.

It is at times necessary to run two dynamos in series in order to get a greater D.P. than is ordinarily available, for burning searchlights at a long distance from the ship, or for other similar purposes. In joining them up to run in series, there are certain precautions which must be observed which will be best understood if we first point out how to join two simple series machines or two simple shunt machines in series, and then combine the points involved in joining up compound machines.

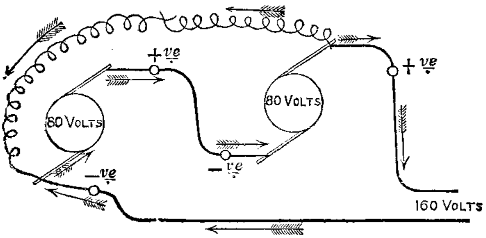
Two Series Machines in Series.—If two series machines are to be joined in series the case is very simple: the +ve of one machine has merely to be joined to the —ve of the next, and the main circuit taken from the end terminals of the two machines, as shown in Fig. 116.

FIG. 116.



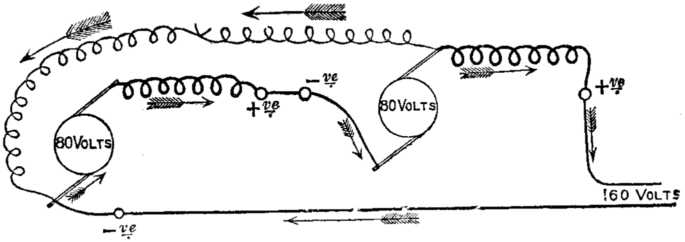
Two Shunt Machines in Series.—If two shunt dynamos have to be joined in series, the shunt wires may be joined in series forming one circuit, as in Fig. 117, provided that the machines are of the same type and size, to prevent the current in the shunt coil of one machine from being reversed, should that machine slow down or stop.

FIG. 117.



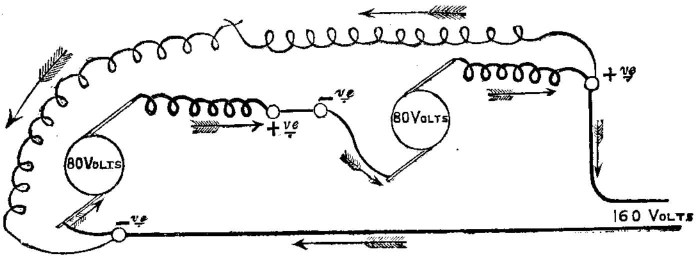
Two Compound Machines in Series.—If two compound machines are to be joined in series the two foregoing arrangements may be combined, as in Fig. 118.

FIG. 118.



or a long shunt combination may be made as in Fig. 119.

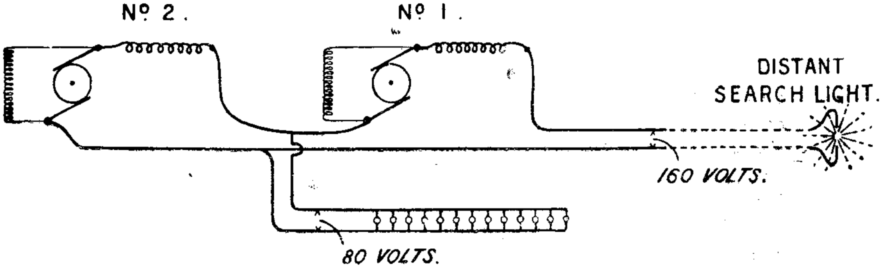
FIG. 119.



Precaution when joining Shunt or Compound Dynamos in Series.—In the case of both shunt and compound machines, the shunt wires should only be joined together in series as shown in Figs. 117, 118, and 119, when the two machines are of the same type and size. In this case the shunt wires will have the effect of dividing the total voltage generated equally between the two machines. If the circumstances of the case make it inadvisable to do this, the shunt wires should be left connected to their proper terminals; and in this latter case great care must be taken that the external circuit is broken before either dynamo is stopped, or their brushes lifted, otherwise the first machine stopped will be reversed by the current from the other.

An example will explain this more clearly. Suppose a ship to have two available dynamos, and that it is required to burn a searchlight at a considerable distance from the ship, thus necessitating a high voltage, and at the same time to keep the incandescent lights on board burning at the ordinary 80 volts; this might be effected as follows:—Join the two machines in series; this will give us the required voltage to burn the searchlight at a distance. The incandescent circuits of the ship may be left on one of the machines, as shown in Fig. 120.

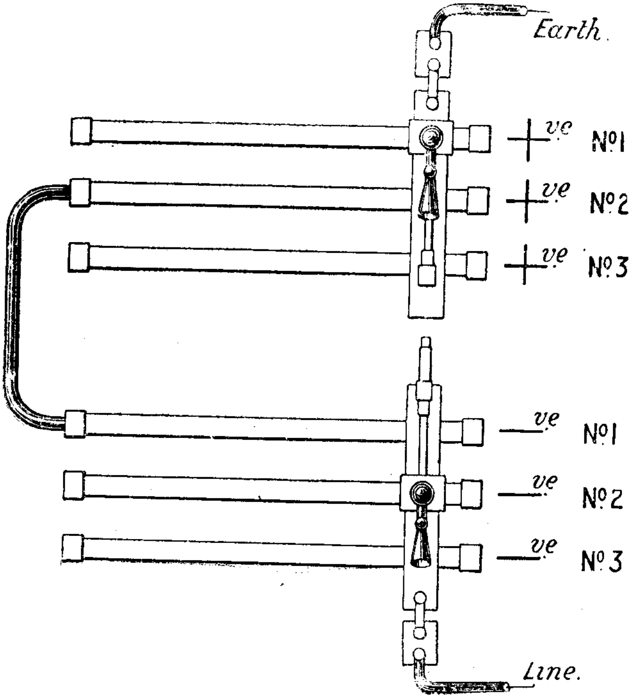
Fig. 120.



Assume in this case that the shunt wires of the two machines were connected together. Any alteration in the total voltage due to variations in resistance in the distant searchlight would be divided between the machines, and would cause unsteadiness in the incandescent lights. Consequently in this case it would be inadvisable to join the two shunt wires.

The necessary connections are easily made on a Portsmouth switchboard, as is shown in Fig. 121.

Fig. 121.



Suppose it is desired to connect Nos. 1 and 2 machines in series. Join the $+^{ve}$ dynamo bar of No. 2 with the $-^{ve}$ dynamo bar of No. 1 by means of a short lead of cable of sufficient current capacity.

The two machines are now in series; all that is then necessary will be to put the circuit bar to which the earth is joined in connection with the $+^{ve}$ of No. 1, and the searchlight cable to the $-^{ve}$ of No. 2. To do this the vulcanite insulator joining the two sliding blocks must be taken out, so that they can be plugged independently to the required circuits.

With a Clarke Chapman board the same thing can be done, but in this case it will be necessary to disconnect the two halves of the upright spindle, so that the upper half can connect with the positive bar of one dynamo and the lower half with the negative of another. This would probably be a long business, so that it might be better in this case to leave out the switchboard and make temporary connections for everything.

If it is required to join two dynamos in series in ships fitted with a parallel board, the connections at the back of the switchboard must be altered as follows:—

The equaliser switch must not be made, disconnect the tipping gear in connection with it, and remove the switch itself, or wedge it up so that it cannot possibly be moved.

Disconnect the machine from the $+^{ve}$ bus bar, and put the lead from the $+^{ve}$ of the machine to earth, keeping the main switch in the circuit.

Disconnect the $-^{ve}$ of the machine from the $-^{ve}$ bus bar, and join it to the $+^{ve}$ bus bar, keeping the main switch and reverse current breaker in circuit.

The lead to the searchlight can now be taken from the $-^{ve}$ bus bar, which will be at a potential above earth equal to the board voltage + the voltage of the special machine.

The dotted lines in Fig. 122 show the leads removed.

The following hints are here suggested as likely to be of use to those who have to deal with temporary connections and resistances. When handling dynamos or their circuits it is important that the operator should bear in mind that he is dealing with gear that a mistake on his part may ruin entirely:—

(1) Always think out what you are going to do before you start to do it, be perfectly certain of what you are doing, and make a small sketch of the connections.

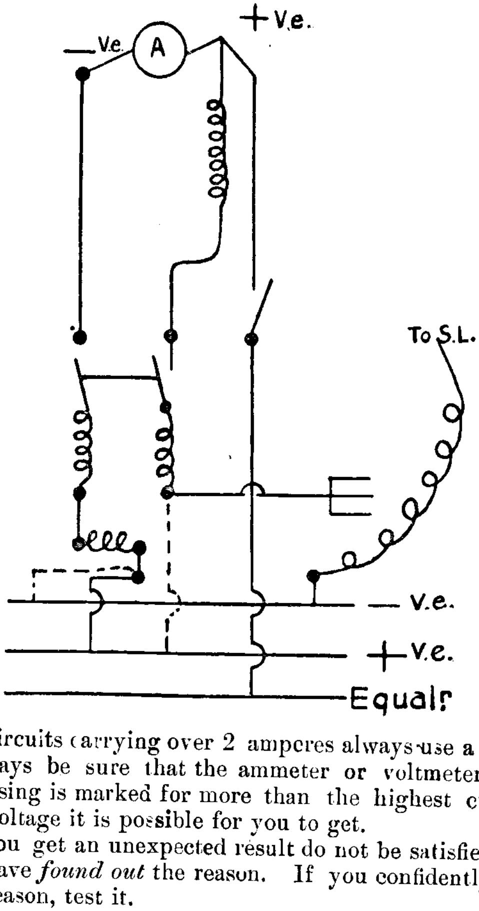
(2) Be quite certain that the wires and resistances will stand the current you are going to put through them, and also the greatest current that can possibly be put through them under the new conditions.

(3) In using current from a source of constant D.P. or low internal resistance always insert cut-outs in each wire.

(4) Put the cut-outs next to the machine or cell giving the current.

(5) Cover all the bare connections with linen tape if in a dry place, or india-rubber tape and solution if in a damp place.

Fig. 122



6) In circuits carrying over 2 amperes always use a switch.

(7) Always be sure that the ammeter or voltmeter you are using is marked for more than the highest current or voltage it is possible for you to get.

8) If you get an unexpected result do not be satisfied till you have *found out* the reason. If you confidently guess a reason, test it.

(9) Never disconnect the voltmeter wires from a voltmeter without first disconnecting them from the machine.

CHAPTER X.

MOTORS.

AN electric motor is a machine by means of which energy in the form of an electric current may be converted into energy in the form of mechanical motion.

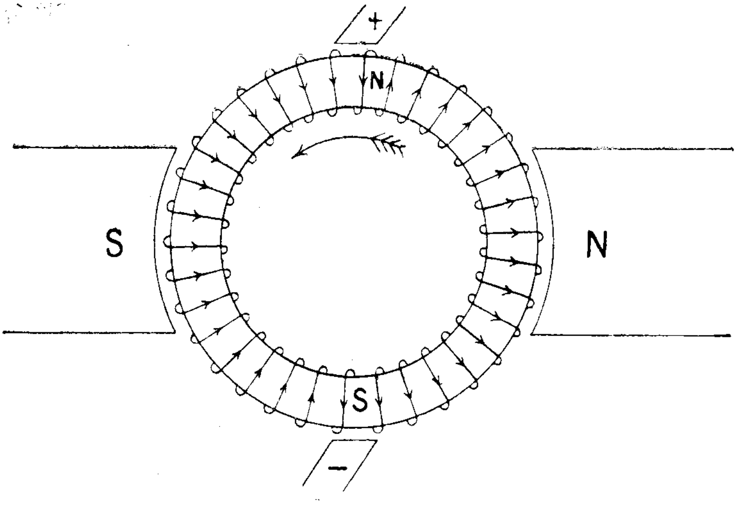
Electric motors are largely used in the Service, and their use is being greatly extended.

It is probable that electric motors will eventually supersede steam power for all machines other than the main engines and dynamo engines in ships, but that stage has not yet been reached. They are used, however, in later ships, for almost all machines outside the engine rooms.

An electric motor is precisely similar to a dynamo, and, in fact, a well-designed machine can be used as either a dynamo or a motor at will.

Let us consider the case of a machine with a ring armature and a simple winding such as that shown in Fig. 123.

FIG. 123.



It must be distinctly understood that this picture of a ring armature is only given instead of a drum armature for the sake of clearness. The poles in the armature are formed in just the same way in a drum armature, but it is impossible to show the windings on a diagram, as they all cross one another in the centre.

Nearly all modern motors have drum armatures, with the exception of a few very small ones, but the picture of a ring armature is given here as it makes the action of the motor easier to understand.

The brushes are shown bearing on the outside of the coils for the sake of clearness, instead of on the commutator, as they actually would be.

Action of a Motor.—Suppose now a current to be supplied to the armature, entering by the brush marked + and leaving by the other. It will divide, half of it going through one side of the winding, and the other half through the other side. We see, by examining the direction of these two halves of the current, that they both tend to produce a N. pole under the + brush, and a S. pole under the − brush.

These poles will be attracted by the fixed poles of the field magnets, and the armature will revolve. As it revolves, however, the current is commutated as in the case of the dynamo, and consequently, whatever the position of the armature, the current will be flowing as shown. The armature will therefore continue to revolve as long as current is supplied to it.

Back E.M.F.—Now as the armature revolves, it begins to act as a dynamo and to generate E.M.F. This E.M.F. is, by Lenz's Law, in such a direction that it opposes the movement that produces it, and it is therefore called the "back E.M.F." of the motor. It opposes the E.M.F. that is being applied to force current through the armature, and consequently, as it gets greater, that current will decrease.

What takes place then is this, when the current is first switched on to the armature, a large current flows, since the resistance of the armature is comparatively small. When the armature begins to revolve the back E.M.F. immediately begins to cut down this current. As the armature speeds up, the back E.M.F. gets larger and larger, and consequently the current less and less, until a point is reached when there is only just enough current flowing to keep the armature moving at a steady speed against the work that it is doing, and not enough to make it speed up any more. The armature will then go on revolving at that steady speed, and the current will remain the same as long as the load is unaltered.

Variation of Current with Load.—If the motor is doing no external work, the only resistance to motion will be the friction of the bearings, &c. Consequently the armature will speed up until the back E.M.F. is very nearly equal to the applied E.M.F., and the current will be very small indeed. A motor running light, therefore, takes very little current.

Suppose now a load to be thrown on the motor. The first effect of it will be to slow the motor slightly, and this, of course, reduces the back E.M.F. The current therefore rises and thus produces a greater turning effort, or "torque" as it is called, by strengthening the poles formed in the armature. A position of equilibrium is therefore again reached, but with a larger current flowing than before.

If the load is again increased, exactly the same thing happens. The motor slows slightly, thus decreasing the back E.M.F., and the current rises until the torque once more balances the load.

We thus see that an electric motor is a self-governing machine, and the current always varies with the work that the machine is doing.

We have hitherto considered only the armature, without reference to the field magnets, but it becomes necessary to examine how these are wound so as to produce the requisite magnetism.

They may be either series, shunt, or compound wound, as are dynamos; but as motors wound in these different ways behave differently in certain circumstances, the different sorts will be considered separately.

We must first examine the relation between the back E.M.F. developed by the armature and the work that the motor is doing.

Power and Efficiency.—Let E be the E.M.F. applied to the brushes.

Let e be the back E.M.F. developed in the armature.

Let R be the resistance of the armature.

Let C be the current flowing.

If the armature is held so that it cannot move, and current is switched on to it, the current will be given by the equation, $C = E/R$ (Ohm's Law).

As soon as the armature begins to move, however, the back E.M.F. e must be taken into account, and subtracted from the applied E.M.F. in order to find the E.M.F. that is producing the current.

The equation for the current will then be—

$$C = \frac{E - e}{R} \quad . \quad . \quad . \quad (1)$$

If we multiply each side of equation (1) by the quantity C R, we shall get a second equation—

$$C^2R = E\,C - e\,C,$$

or as it may be written—

$$E\,C = e\,C + C^2R \quad . \quad . \quad . \quad (2)$$

Now we know that E C is the power that is being supplied to the motor (*see* Chapter III.). And we also know that C^2R is the power that is being used up in heating the conductors in the armature (*see* Chapter III.). The quantity e C must therefore be the amount of electrical energy that is converted into mechanical motion, and reappears as the external work done by the motor.

This quantity e C is, of course, expressed in watts, and if we want to express it in H.P. we must divide it by 746.

If $W =$ total power supplied to the armature, and

$w =$ mechanical power exerted by the armature, the ratio of mechanical power exerted by the armature to the total electrical power supplied to the armature, or, as it is called, the "electrical efficiency" of the armature, is equal to w/W, or eC/EC, or e/E.

It is usual for motors to be designed to run with an electrical efficiency of from 85 to 90 per cent. That is, the speed of the armature is such as to make the back E.M.F. 85 to 90 per cent. of the applied E.M.F.

The maximum amount of work that can be got out of a motor is being done when it is running at such a speed that e is one-half E, as can be easily proved, and in that case the electrical efficiency is 50 per cent. Motors, however, are never run at this efficiency, as it entails too much power being used up in heating the conductors, which would probably be damaged through overheating.

Value of "e."—Now let us consider what e depends on. It depends, as in all cases of electro-magnetic induction, on the rate of change of magnetic flux through the coils of the armature. It depends, therefore, firstly on amount of flux provided by the field magnets, and secondly, on the rate at which the armature is revolving. If we call the flux density of the field N, and the number of revolutions per minute of the armature n, we may say that e varies as Nn.

We are now in a position to investigate the behaviour of different kinds of motors under varying loads.

A shunt motor has the ends of the field windings connected directly across the supply of current, so that, as long as the voltage of supply remains constant, the strength of the field magnets will remain the same, neglecting armature reactions, which will be considered later.

A series motor, on the other hand, has the windings of the field magnets in series with the armature, and the strength of the field will vary with every variation of the armature current.

We will now take an example.

Shunt Motor under Varying Load.—Shunt motor, with an armature resistance of ·02 ohm, creates a back E.M.F. of 10 volts per 100 revolutions; voltage of supply 80 volts, it requires 100 amperes to pull a certain load.

$$C = \frac{E - e}{R} \quad \therefore \quad 100 = \frac{80 - e}{\cdot 02}$$

$$\therefore e = 78 \text{ volts} \qquad \text{and the speed} = 780 \text{ revolutions.}$$

Suppose the load be doubled, the motor would then require 200 amperes to provide sufficient torque.

$$C = \frac{E - e}{R} \quad \therefore \quad 200 = \frac{80 - e}{\cdot 02}$$

$$\therefore e = 76 \text{ volts} \qquad \text{and speed} = 760 \text{ revolutions.}$$

Thus the speed has only fallen from 780 to 760 revolutions although the load, and therefore the current flowing, has been doubled.

The above is not strictly true, since an increased current through the armature affects the armature reactions which slightly reduce the strength of the field magnets, unless they are very powerful. But it is practically true, and a shunt motor is therefore very constant in speed even with largely varying loads.

Series Motor under Varying Load.—With a series motor, however, the case is different. When it is running light, and C is therefore very small, the current in the series coils is very small, and so, consequently, is N. But when C is very small, e must be very nearly equal to E, and since e varies as N n, n must be very large at no load.

That is to say, a series motor races when running light.

As the load increases, e decreases slightly, and C, and therefore N, increase; but the product N n must decrease in proportion as e decreases, and therefore, since N increases with C, n must decrease largely.

That is to say, the speed of a series motor falls off rapidly as the load increases.

Speed Regulation.—There are two methods of altering the speed at which a motor runs—firstly, by altering the current through the armature, and secondly, by altering the current through the field windings.

Let us first consider these two methods in the case of a shunt motor.

First method.—Suppose we have a shunt motor running on a certain load, being supplied, say, at 100 volts, and taking 20 amperes in the armature. If the resistance of the armature is ·1 of an ohm, and there is a resistance in series with the armature of ·5 of an ohm, 10 volts will be expended in heating this resistance (Ohm's Law, $E = CR = 20 \times \cdot 5 = 10$), which will leave 90 volts at the terminals of the armature, so that the back E.M.F. is 88 volts.

Now let this resistance of ·5 ohm be suddenly cut out, the field being kept constant. This will put the whole pressure of 100 volts direct on to the armature, and since the back E.M.F. is only 88 volts, the current will immediately rise to $\frac{100 - 88}{\cdot 1} =$ 120 amperes. This largely increased current will increase the torque, and the motor will begin to speed up. As it speeds up, the back E.M.F. will rise, and gradually cut down the current until equilibrium is again reached, and the motor is once more running at a steady speed. The current at the end, however, will be more than the original 20 amperes, since the motor when running faster is exerting a greater power.

The second method is by altering the strength of the field, when by decreasing the field the speed is increased, and *vice versâ.*

This at first appears impossible, as apparently more power is obtained from the motor for a less power put in. Of course, this is not so, the extra power when the field is reduced being obtained by an increased current through the armature.

Consider a shunt motor with an armature resistance of ·02 ohm running with a steady load on an 80-volt supply and generating a back E.M.F. of 78 volts. The current through the armature is then $\frac{80 - 78}{\cdot 02}$ or 100 amperes.

Now the back E.M.F. depends on the speed and field of the motor.

Suppose that the field be reduced so that only 76 volts back E.M.F. is generated.

The armature current then becomes $\frac{80 - 76}{\cdot 02}$ or 200 amperes, so that by a small reduction of two volts back E.M.F. we have doubled the armature current.

As this current has increased in a much greater proportion than the field has been reduced, the torque which depends on the product of the two will be greatly increased, and will thus cause the motor to go faster.

Though the motor is running faster, the torque or turning force required is the same as before (except for friction), since the actual load is the same.

But the field has been reduced in the proportion of 78 to 76, and the current must therefore increase in the proportion of 78 to 76, that is, from 100 amperes to 103 amperes, to get the same torque.

The speed will therefore *increase* until the back E.M.F. has increased sufficiently to reduce the current to the new value required, 103 amperes. When this balance has been obtained the speed will remain constant, e being then slightly less than the original 78 volts.

Although the torque required remains the same for any speed of a motor with a steady load, yet the rate of doing the work and therefore the power expended must vary. Thus, in the above case the power given out by the motor, or e C, has increased with the speed, for e falls but very slightly and C increases considerably for every increase of speed.

Now let us consider these two methods in the case of a series motor.

If resistance is put in series with the armature, it must also be in series with the field, and the current which goes through both is reduced. The reduction in the armature current tends to slow the motor, while the reduction in the field current tends to speed it up. The former, however, has always more effect than the latter, so that the net effect is to slow the motor down.

The second method, namely, reducing the field, can be used in two ways—either by putting the field coils in parallel instead of series, or by shunting them with a low resistance.

Suppose a series motor is running on a certain load with its field coils in series with one another. All the current that is flowing in the armature is then flowing also through each field coil. If the field coils are then put in parallel, the armature current will divide between them, and each coil will only take half the current. The armature current will then increase as in the case of the shunt motor when the field is reduced, but when the motor, after speeding up, is again running at a steady speed, there will be less current than at first through each field coil, though there is more through the armature.

If the field coils are shunted with a low resistance the effect is the same as above. The current through the field coils is reduced, since the armature current divides between the field coils and the resistance, while the armature current is increased. Both these changes tend to speed up the motor.

Reversing a Motor.—We will now consider the question of how to reverse the direction of rotation of a motor. If the current is reversed at the terminals of the motor, it is reversed both in the armature and the field coils. The result is that the poles that are formed both in the armature and field magnets are reversed, and consequently the attractions are the same as before, and the armature will still revolve in the same direction. If the direction of rotation is to be changed, the current either in the field magnets or in the armature must be reversed, not both together.

Armature Reaction.—It will be evident from Fig. 110 that the field provided by the field magnets will be strengthened at the after edges, and weakened at the forward edges, of the pole pieces, reckoning in the direction of rotation. The effect of this will be that the neutral line will be shifted back through a small angle, against the direction of rotation, instead of forward as the case of a dynamo. The brushes, therefore, must also be shifted backwards a little, to ensure proper commutation, and the angle through which they are shifted is called the "trail" of the brushes.

Now it is evident that if the motor is reversed, the field distortion will be in the opposite direction, and consequently the trail will be in the opposite direction. It is therefore necessary to design the motor so that the distortion of the field shall be as small as possible, so that it shall be possible to run the motor in either direction without moving the brushes. This is effected by means of the first two methods described for dynamos on page 128. Auxiliary poles are not used, as a rule, for motors.

Compound Motors.

It has been pointed out that a series motor races on a light load.

Series Motor with Limiting Shunt Turns.—To prevent this racing becoming excessive, a few shunt turns are wound in the *same direction* as the series turns, so that a certain current must always pass through them, and however much the current through the series turns is decreased, the field cannot decrease beyond a certain limit, and therefore the speed cannot rise above a certain amount. The turns are called "limiting shunt" turns.

There is another form of compound motor which, though not used in the Service, will be briefly described here.

Differentially wound Shunt Motor.—Although a shunt motor is very nearly constant in speed with varying loads, it is not absolutely so. So that, when absolutely constant speed is required, means must be adopted to reduce the strength of the field when the load is increased and the current in the armature rises sufficiently to compensate for the slight decrease in speed that occurs under ordinary conditions.

This is accomplished by winding a few series turns round the field magnets so as to *oppose* the shunt coils magnetically. The effect of these series turns in weakening the field becomes greatest when the armature current is greatest, that is, when the greatest load is on and the motor tends to go slowest.

Starting a Motor.

Starting Torque.—The starting torque of a motor depends on the strengths of the magnet field and of the armature field, consequently with a series motor, since, on switching on, the maximum current will at once flow through both armature and field magnets, the starting torque will be very great. Series motors are therefore always used in cases where the motor has to start under a heavy load, such as boat hoists, ammunition hoists, &c.

"*Burning out.*"—One of the chief dangers to contend with when starting a motor is that of "burning out" the armature owing to an excessive current passing before any back E.M.F. is generated to cut it down. In a small series motor this is not very serious, as the series coil is always in the circuit to act as a resistance, and its inductance will prevent the current rising too quickly.

But, with a shunt motor, the danger is very great. The armature, while at rest, simply short circuits the mains and field magnet coils; thus with a voltage of supply of 100 volts and an armature resistance of ·05 ohm, the current flowing will be $\frac{100}{\cdot 05}$ or 2,000 amperes. This amount of current would largely reduce the voltage at the brushes owing to the increased loss in the leads, and since the field magnet coils are also practically short-circuited, the current passing through the shunt coils will be very small; consequently there would be but little magnet field to attract the motor armature, and it would therefore not start with sufficient quickness to prevent this large current burning it out.

Precautions when Starting.—Precautions must, therefore, be taken to ensure the field magnets being properly excited. This may be done by first switching on the field magnet circuit, and then, when the field magnets are excited, switching on the current to the armature motor, which, owing to the action of the *two* fields, would then at once revolve, creating a back E.M.F., and so prevent an excessive current rising.

Starting Resistances.—The more usual method is to insert in *series with the armature* "starting resistances" sufficient to prevent an excessive current passing through it, even if the armature should hang up. Thus the full magnet field and a small armature field will be obtained, and the motor will revolve. As the motor gathers speed and so develops a back E.M.F., these resistances can be gradually cut out, until none are left in the circuit.

It will thus be seen that the starting torque of a shunt motor is not good; first because the magnet field can never rise beyond the normal unless the D.P. of supply increases; and, secondly, the armature field, owing to the starting coils, must be small.

Starting resistances are also used with series motors where the combined resistance of the magnet coils and the armature is so low, that an excessive current might pass if the motor hung up on starting.

Stopping a Motor.

Mechanical Brakes.—In many kinds of machinery worked by motors, it is desirable that the gear should bring up quickly when the switch is centred. This can be effected mechanically, either by separate brake or by one brought into action automatically when the circuit is broken. The disadvantage of the latter is that there are only two positions for the brake, either "off" or "on," and no graduation of the braking effect can be used as with a separately worked brake.

Short-circuiting the Brushes.—An extremely good braking effect can also be obtained by short-circuiting the brushes of the armature, when—if a field is retained for it to revolve in—it becomes a dynamo on short circuit revolving only by its own inertia. The current developed, owing to the low resistance of the circuit, being a very strong one, the resistance to motion becomes very great, as in the case of a dynamo giving out a large current.

In the case of a shunt motor, the shunt winding must be kept connected across the mains when the brushes are short-circuited, so as to provide a field for the armature to revolve in.

In the case of a series motor, either the series coils may be included in the short circuit between the brushes, in which case the armature provides the current for exciting the field, or else the series coils may be connected across the mains in series with a resistance, and the brushes simply joined together. The former method is more generally used.

Motor Starters and Controllers.

Certain motors, such as those for fans, driving machines in workshops, running pumps, &c., which are only required to run at a steady speed when in use, are provided with a "motor starter" for switching them on.

Those motors of which the speed must be capable of control while they are running, such as boat hoists, coal hoists, stokehold fans, &c., are provided with "controllers" for starting and regulating.

Shunt Motor Starter.—The requirements of a starter for a shunt motor are:—

(1) The first motion of the starter must switch on the full current to the shunt field coils

(2) "Starting resistances" must be put in series with the armature at first, and cut out as the motor gathers speed.

The necessity for the above has already been pointed out.

(3) It must not be possible to leave the switch in any position but that of "full on."

The reason for this is that the starting resistances are not intended to carry current for any length of time, and although they will carry the current for the short time taken to start up the motor, if they are left in the circuit they will be overheated and possibly burnt out. This requirement is fulfilled as follows:—The switch arm, which switches on the shunt and cuts out the starting resistances by sweeping over a number of contacts, has a spring on its spindle which always tends to keep it in the "off" position. When it reaches the "full on" position, it is held there by an electro-magnet, which attracts a small iron armature on the switch arm itself.

The winding of this magnet is in series with that of the shunt field. Consequently, unless the switch is in the "full on" position and held by the electro-magnet, it will be returned to the "off" position by the action of the spring. The electro-magnet is called the "no-voltage release."

(4) If the voltage of the supply should fail at any time when the motor is running, the switch must return to the "off" position.

This is necessary, as otherwise the motor would be burnt out when the supply came on again. This requirement is fulfilled by the no-voltage release, which no longer holds the switch when the supply fails, and the spring then returns the switch to the "off" position.

(5) If the circuit of the shunt winding should be broken when the motor is running, the switch must return to the "off" position.

This is also effected by the no-voltage release, which is in series with the shunt winding. The necessity for it is obvious, since, if the field is destroyed when the motor is running, there will be no back E.M.F., and a very large current will pass through the armature.

(6) Should too heavy a load be thrown on the motor, producing a larger current than the armature can carry, the switch must return to the "off" position.

This is effected as follows:—The lead of wire carrying the current to the armature takes several turns round the core of an electro-magnet. The armature of this magnet can be adjusted at different distances from the magnet, so that is only attracted when the current reaches a certain strength. When it is attracted, it is made to short-circuit the coil of the no-voltage release, so that the switch arm is thrown back by the spring. This arrangement is called the "overload cut-out."

Fig. 124.

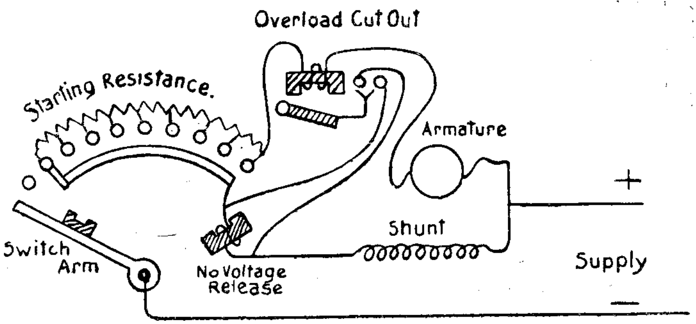


Fig. 124 shows diagrammatically the circuit of a typical shunt motor starter. There are many different forms of starters in the Service, but they all embody the principles enumerated above.

Series Motor Starter.—As was said on page 173, small series motors require no starting resistances, but this is not the case with large ones. The starter for a large series motor consists simply of the starting resistances, but sometimes an overload cut-out and no-voltage release are also fitted. In this case, however, the coil of the no-voltage release is connected directly across the supply mains in series with a resistance.

Controllers.—Controllers differ from starters in the following particulars:—Since the motor is required to be able to run at different speeds for some time, the resistances that are put in series with the armature must be capable of carrying current for long periods without damage. Also it must be possible to leave the controller in any position without its returning to the "off" position. A controller generally contains a reversing switch, so that the motor can be run in either direction.

In some cases where it is important that the motor should not be allowed to run backwards under the load when the current is cut off, the overload cut-out, instead of cutting off the supply altogether, puts such a resistance in the circuit that enough current passes through the armature to hold it steady, though not enough to revolve it. Various controllers that are in the Service will be described in the next chapter.

Magnetic Blow-out.—When a circuit carrying a heavy current is broken, the current tends to continue to flow, owing to inductance in the circuit, and sometimes forms an "arc," as it is called, across the gap. If this is allowed to take place the contacts are rapidly burnt away, since the arc is formed of the metal of the contacts, which is volatilised by the great heat that is developed.

It is most important that this action should not be allowed to take place in motor controllers, which are exceedingly liable to it, as heavy currents have to be dealt with, and consequently, in controllers for large motors, a device called a magnetic blow-out is generally fitted.

This is simply a large electro-magnet, generally excited by a coil which is in series with the armature, and so placed in the controller that any contacts, between which arcing is likely to take place, are always in a strong magnetic field.

This magnetic field acts upon the arc in exactly the same way that it acts on a conductor carrying a current, and tends to move it so that it will enclose the maximum number of lines of force. The effect of this is that the arc is drawn out to such a length that the D.P. between the contacts will no longer maintain it, and it consequently goes out.

Motor Generators.

If a dynamo is driven by an electric motor instead of by an engine, the whole apparatus is called a motor generator.

Motor generators are used in the Service when a supply of electricity is required at a different voltage to that supplied by the ship's installation.

Thus, if the ship's dynamos give 100 volts, and a supply at 20 volts is required for working bells, &c., it is obtained from a small 20-volt dynamo driven by a 100-volt motor.

Motor generators are used in the Service for firing guns and working bells, telephones, and fire control instruments.

There are several different sorts of motor generators—

(1) Two entirely separate machines with their shafts coupled together.

(2) Two machines separate electrically, but built together in one casting, though with separate armatures and pole pieces.

(3) A machine with one armature and set of pole pieces, but two separate windings on the armature, each with its own commutator and brushes.

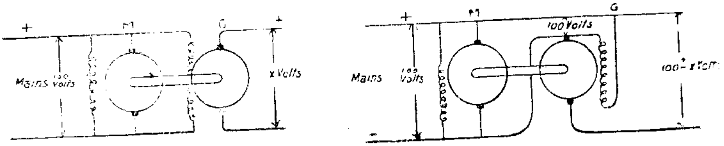
The small motor generators which were at first supplied for working fire control instruments, and those that are now supplied for telephones, are of the first type, the generators being self-exciting shunt dynamos.

The motor generators now supplied for guns, bells, and fire control instruments are of the second type, the field of the generator being supplied from the ship's mains. A rheostat is put in series with the generator field, so that the voltage given by the generator can be varied within certain limits.

Motor generators of the third class are not at present used in the Service.

If the armature of the generator is placed in series with the ship's mains, so as either to add or subtract its voltage from that of the mains, the machine is called a "Booster."

FIG. 125.



Motor Generator

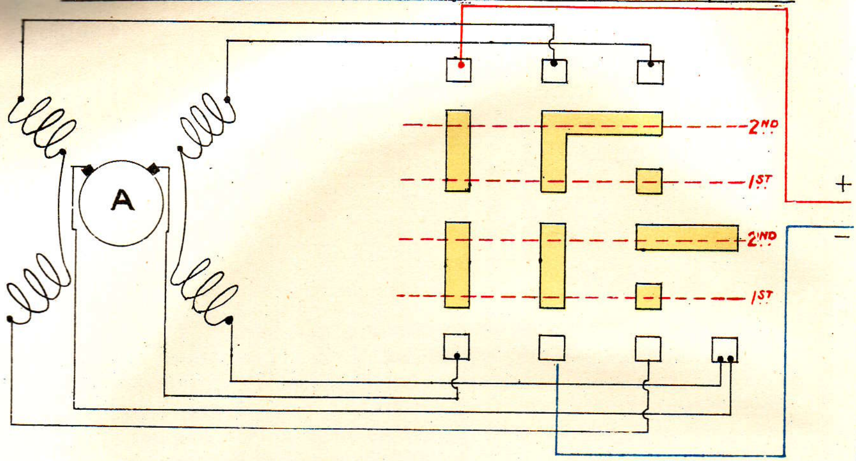
Booster

Fig. 125 shows the connections of a motor generator and booster respectively. Both the motor and the generator fields are shown as fed from the mains in each case.

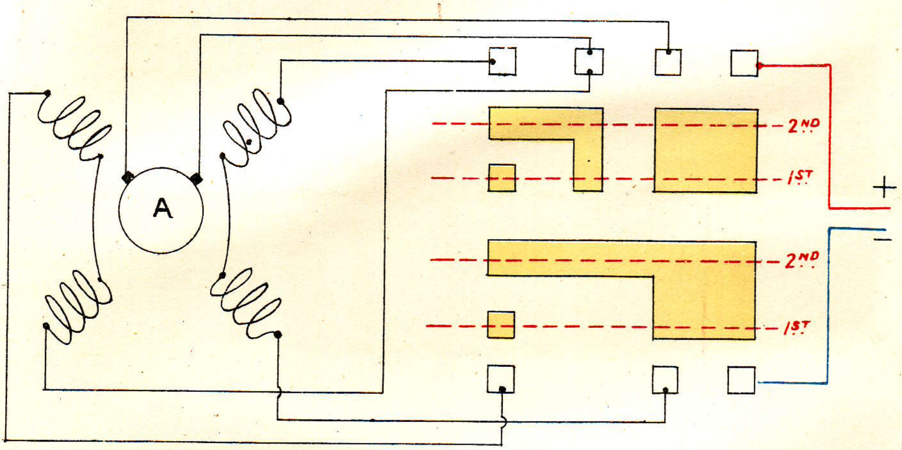
Boosters are used in some cases for charging secondary batteries, and also in some electrically worked gun mountings, as will be described in the next chapter.

In some of the later ships which are being fitted with 220-volt installations instead of 100 volts, they will probably be used for supplying current for searchlights.

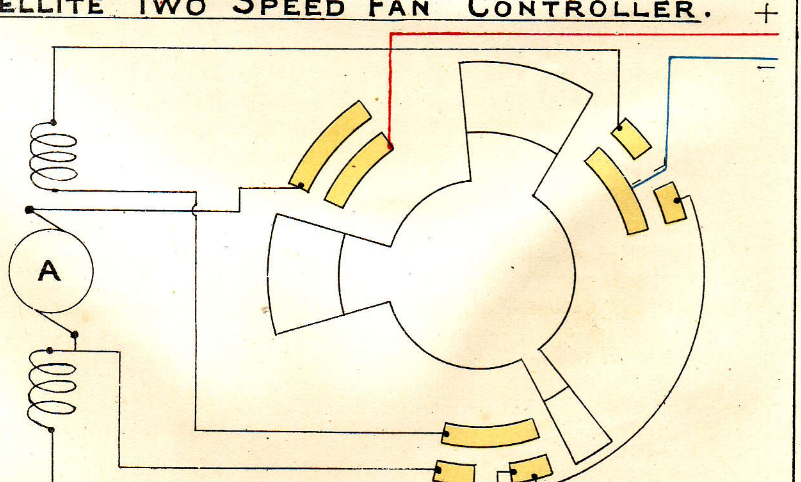
ASTON TWO SPEED FAN CONTROLLER.



SCOTT'S TWO SPEED FAN CONTROLLER.



STELLITE TWO SPEED FAN CONTROLLER.



CHAPTER XI.

SERVICE MOTORS AND CONTROLLERS.

It is proposed to deal with Service motors and controllers under three heads :—

1. Motors for fans.
2. Motors for capstans, coal and boat hoists, &c.
3. Motors for gun working.

Fan Motors.

In all the latest ships the ship ventilating is done by small fans, such as 12-inch, driven by series motors of from 1½ to 2½ H.P., taking from 10 to 20 amperes at 100 volts.

They are generally four-pole motors, and are, as a rule, fitted with a controller, which allows them to be run either at half or at full speed.

No starting resistance is necessary for series motors of this size, and the two speeds are obtained by putting the field windings in series for the low speed, and in parallel for the high speed.

Plate XV. shows the circuits of three controllers of this type.

The Scott and Aston controllers each consist of a drum with contact pieces on it of the form shown in the plate, and a row of brushes bearing on each side of the drum. The brushes are shown in green, and the position of each when bearing on the drum is shown by the dotted lines.

In the Stellite controller the contact pieces are fixed, and the controller handle carries three insulated brushes radially on its spindle, which make contact between them.

In each case the motors have four poles, and where only two field coils are shown each represents the coils on two of the poles in series with one another. None of these controllers are fitted with either overload or no-voltage cut-outs, or any protecting device, except fusible cut-outs. As fans are only required to run in one direction, no reversing arrangement is fitted.

In some of the older cruisers, which have rather larger fans driven by motors of from 3 to 4 H.P., a Scott's three-speed controller is fitted, which is very similar in general arrangement to the two-speed controller of the same maker. The three speeds are obtained as follows :—First speed, all four field coils in series ; second speed, two in series and two in parallel ; third speed, all field coils in parallel. As in the case of the smaller controllers, no protecting device or starting resistances are fitted.

In ships in which the large fans for engine rooms and stokeholds are driven by motors, motors of from 6 to 10 H.P. are used. These are of such a size that they must be fitted with starting resistances. Two controllers for this type of motor are shown on Plate XVI.

The upper diagram in the plate represents Scott's three-speed controller for a 10-H.P. motor. There is only one row of brushes bearing on the controller drum, and the connections are made as shown. The main switch, which is shown on the left of the diagram, is put on by the first motion of the drum by means of a cam on its spindle, and is held in its place by the attraction of the no-voltage release coil. The cam only pushes it on as the drum is being turned towards the starting position, and as soon as that position is reached the switch is free to go off again, except for the no-voltage coil.

In the starting position of the controller the armature field coils and starting resistance are all in series.

On the first speed the starting resistance is short-circuited and the field coils are still in series.

On the second speed the field coils are put in parallel.

On the third speed the field coils are in parallel and shunted by a low resistance.

An overload release is provided, the effect of which is to break the circuit of the no-voltage coil and so release the main switch. When the overload goes, the controller must be put right back to the "off" position before the motor can be started again.

The lower diagram on Plate XVI. represents the circuit of a controller for a 10-H.P. motor made by the Thames Electrical Engineering Company.

This controller has two separate handles, a starting handle and a controlling handle.

The controlling handle cannot be moved until the starting handle is "full on," and the first motion of the controlling handle locks the starting handle in that position.

When the controlling handle is put right back it releases the starting handle, which is then returned to the "off" position by a spring.

There are eight positions for the controlling handle, which is shown in the "off" position on the plate. The first motion, which locks the starting handle, does not move the contact piece appreciably from the position shown, but in the second position a resistance is put in parallel with the field coil. This resistance is gradually reduced as the controlling handle is turned further.

As at first fitted, this controller had no overload or no-voltage releases, but both of these are being fitted to those now in the Service. They will probably be very similar to those in the Scott's three-speed controller.

The disadvantage of this controller is that if the controlling handle is put too far back towards "slow speed" the starting handle is released, and the motor must be started up again; but a little care will obviate this.

Old Type Large Fans.—In the Niobe class cruisers, and some other ships built at about the same time, 42-inch fans were fitted for ship ventilating, which were driven by motors.

The motors were 11 H.P., and they were wired in pairs, as shown in Fig. 126.

SCOTT'S 3 SPEED FAN CONTROLLER

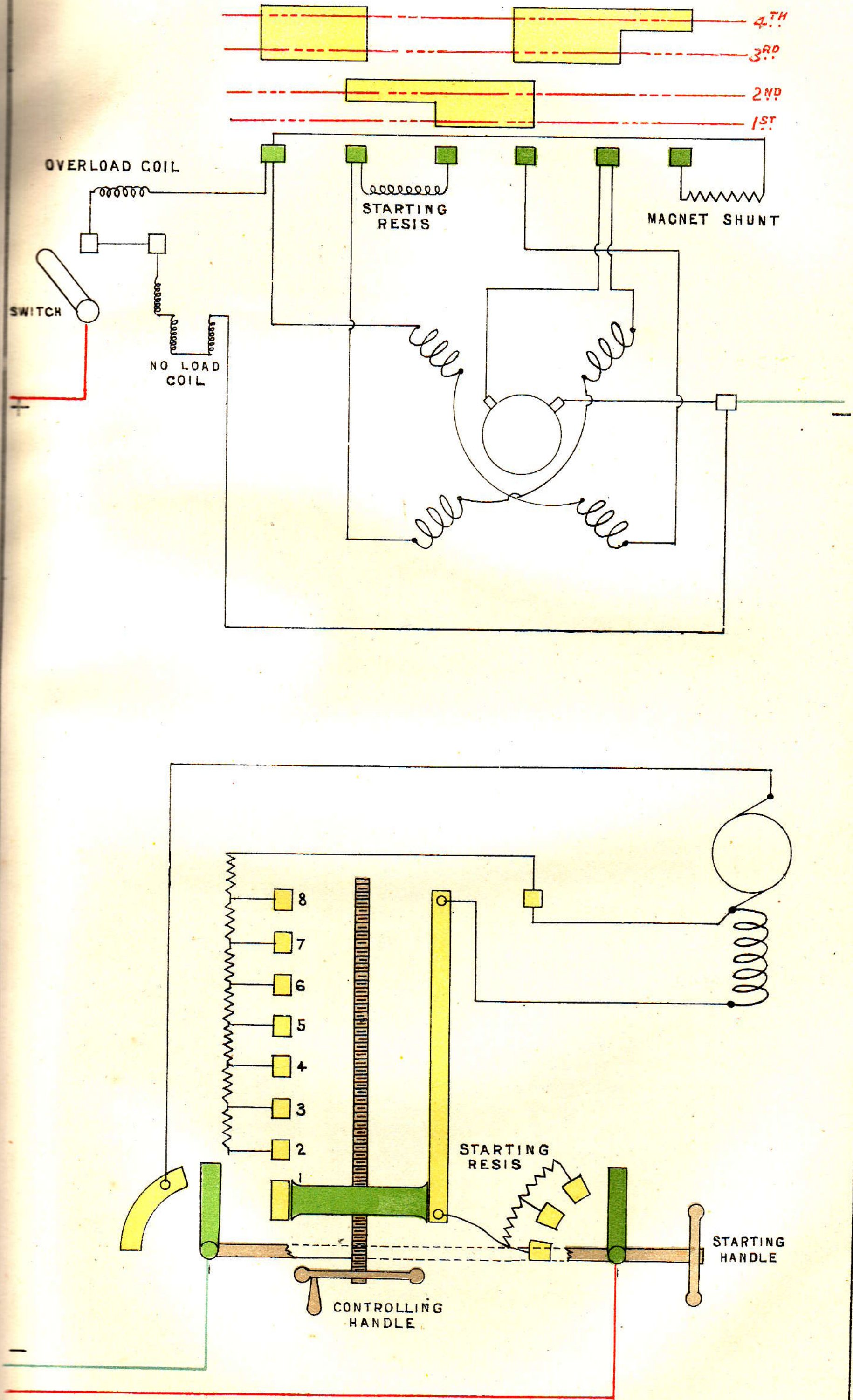
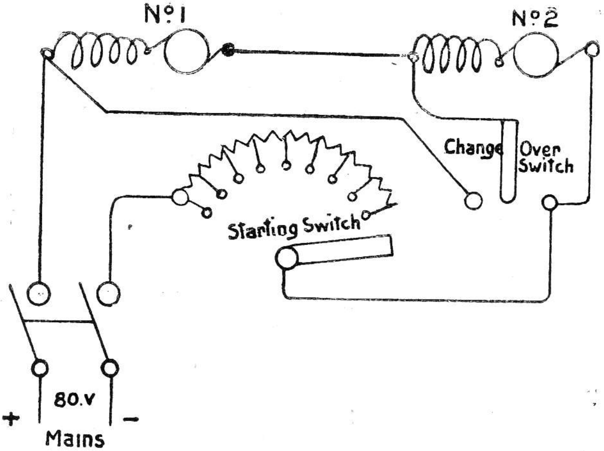


Fig. 126.



With the change-over switch in the central position, as shown, the two motors are in series across the mains, and as each motor then gets only half the applied voltage, they both run at half speed.

If the change-over switch is put over to one side or the other, it short-circuits one of the motors, and the other can then be run at full speed on the full voltage of the mains.

Care must be taken that the double pole switch is not made unless the starting switch is right back.

The starting resistances are of such a size that the motors can be run with them in the circuit, if it is desired to run them at less than half speed.

Lundell Motors.—These motors, whose construction is very simple and cheap, are largely used in small sizes, up to 3 H.P.

Fig. 127.

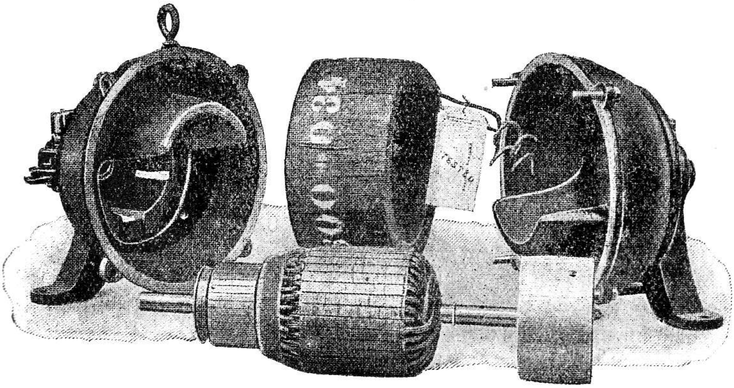


Fig. 127 shows one of them taken to pieces to show the details of construction.

There is only one field coil, and the casing of the motor, which is made of iron, forms part of the magnetic circuit. The field coil is concentric with the armature, and the iron of the casing is so shaped that two opposite poles are formed one on each side of the armature.

These motors may be either shunt or series wound.

Capstan and other large Motors.

Siemens' After-Capstan Controller.—This is the simplest of all the controllers for large motors. A diagram of its circuit is shown in Plate XVII.

The controller drum has two halves which are exactly the same, one on each side of the off position, and there are thirteen brushes bearing on it.

The reversing switch is separate, but worked by the same spindle.

On the first movement of the controller the contacts N and O are connected, and the circuit is completed through all the resistance, and the motor runs at slow speed.

Further movement cuts out resistances until A contact is connected to the drum, all resistances being then cut out and the motor runs at full speed.

The magnetic brake is connected in shunt direct between the mains at slow speed, and is in series with the resistances at faster speeds.

All the resistances are buried in sand to prevent their short-circuiting when they are hot and have expanded.

There is no overload arrangement in the controller itself, but an automatic circuit breaker is fitted in the main. Care must be taken that, if this circuit breaker has gone off owing to an overload, it is not replaced until the controller is in the "off" position.

Some of the older Siemens' capstan controllers, instead of being of the drum type, have contact pieces on a flat plate, and brushes on an arm pivoted in the centre of the plate, but the circuit is very similar to that described above.

Laurence Scott's Capstan Controller.

There are two forms of this controller in the Service, of which the more modern design, fitted in some of the "County Class" cruisers, is shown diagrammatically in Plate XVIII.

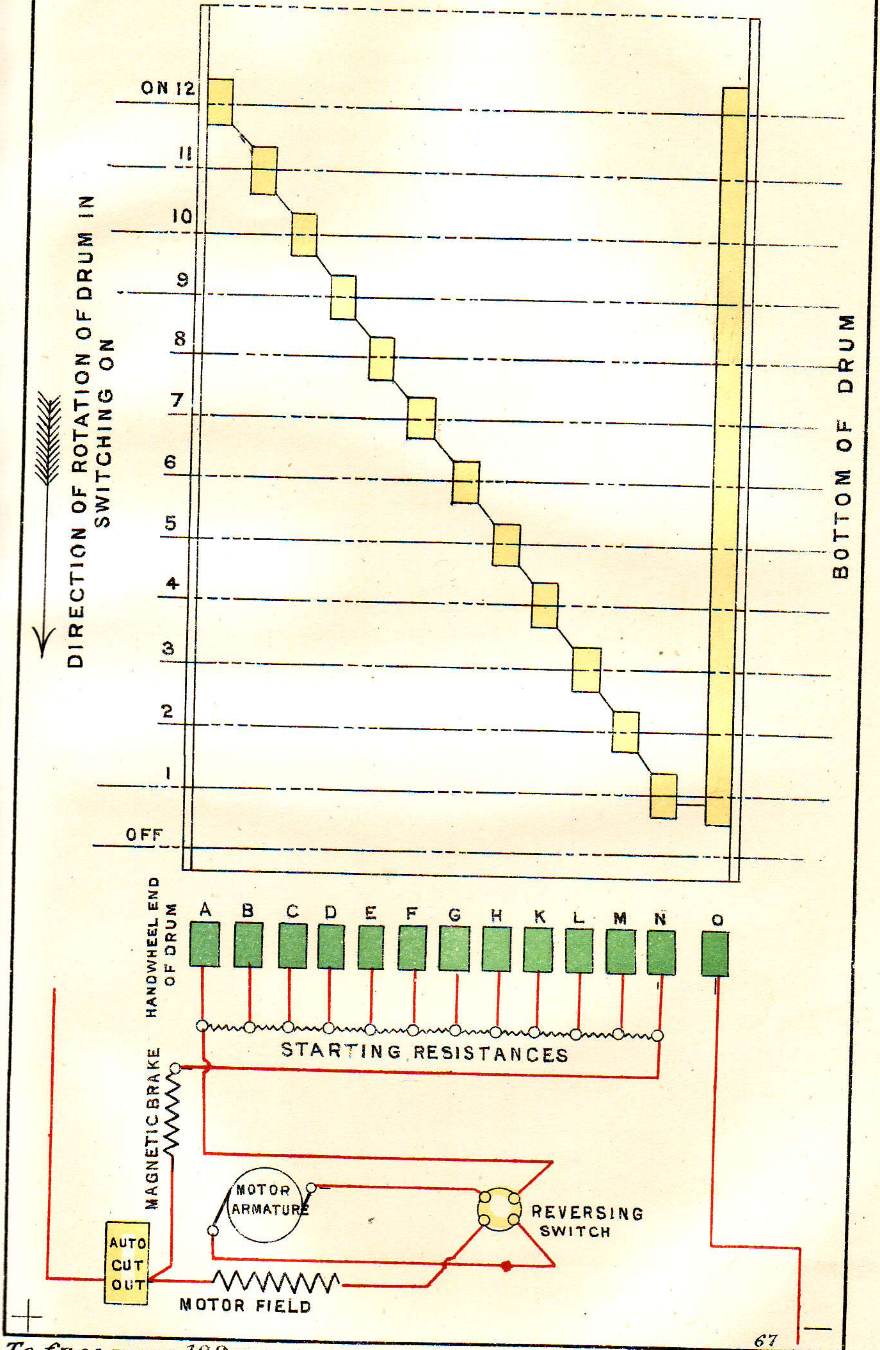
The motor is a series motor of 30 H.P., with limiting shunt coils that prevent it running at over 1,000 revolutions per minute when there is no load on it.

There are two drums in the controller—the controlling drum which is worked by the handle, and the reversing drum. Both drums have cogged wheels on their spindles, and these wheels gear into one another, so that, when the controlling drum is revolved, the reversing drum revolves also.

The drums are shown developed in the plate, and each can revolve through nearly 180° in either direction from the "off"

SIEMENS AFTER CAPSTAN CONTROLLER.

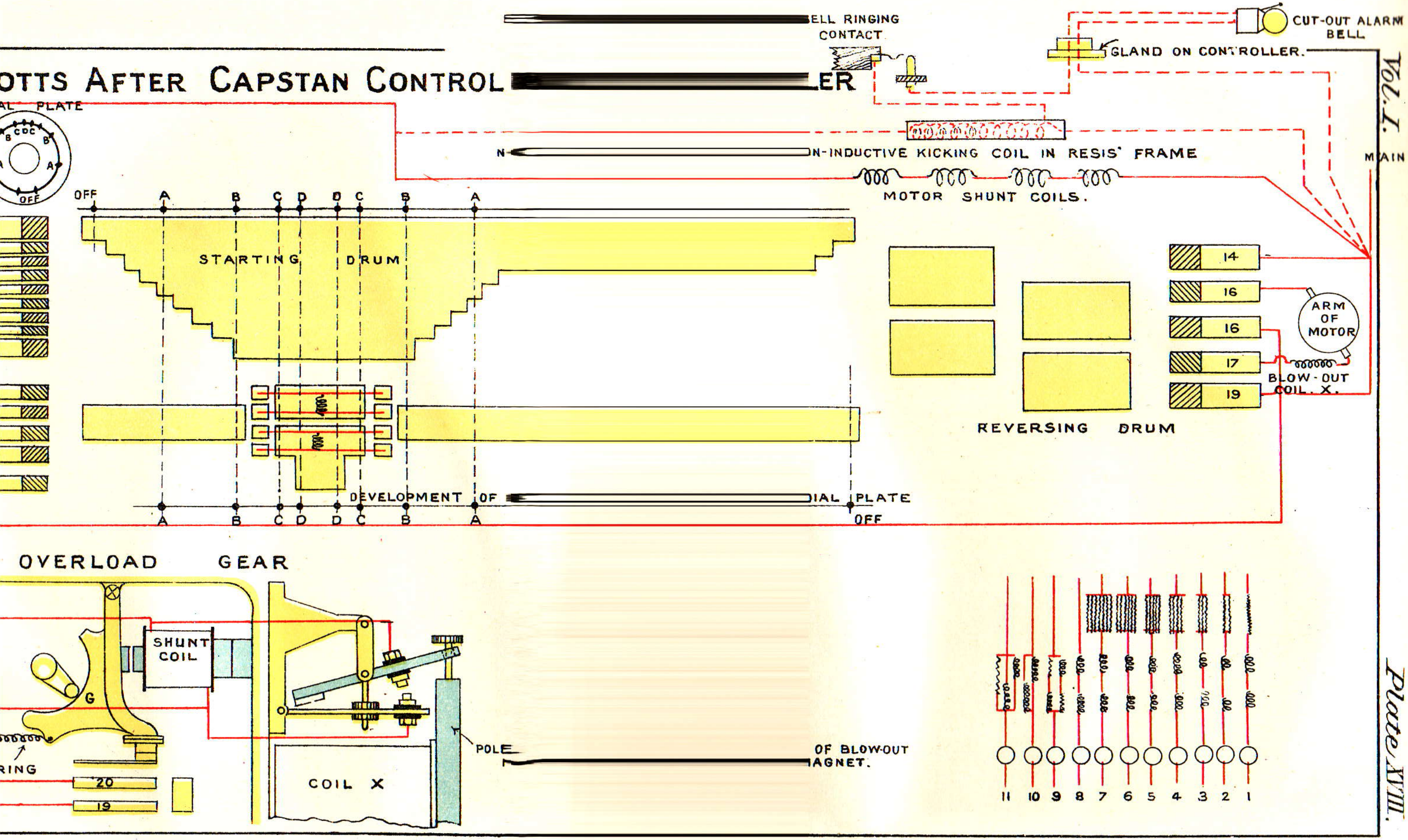
DIAGRAM OF CONNECTIONS.



To face page 182.

Weller & Graham. Ltd Litho, London. 1515. 07

OTTS AFTER CAPSTAN CONTROL ER



Vol. I.

Plate XVIII.

position. There are 14 brushes that make contact on the controlling drum, and five on the reversing drum. The reversing drum has four contact pieces on it, two of which are in the circuit all the time the drum is on one side of the "off" position, while the other two are in the circuit when the drum is turned the other way. The two sides of the contacts on the controlling drum are exactly the same, so that the controlling arrangements are the same whichever way the motor is running.

There are 11 positions for the controlling drum on each side of the "off" position, giving 11 speeds, and these are obtained as follows :—

On the first step, current is supplied to the armature and field coils, all in series through one starting resistance. On each step from the second to the seventh, another starting resistance is put in parallel with the first, and on the eighth they are all short-circuited.

On the ninth step, the field coils are put in parallel, each with a resistance in series with it, instead of in series with one another as they were before.

On the tenth step these resistances are short-circuited, and on the eleventh the field coils are shunted with a low resistance of about ·05 of an ohm.

The action of the overload is as follows :—On the lower end of the spindle of the controlling drum is a cam, which, when the controller is anywhere between the "off" position and the fourth step on either side, bears against the hinged arm G and keeps it in the position shown. When in this position it makes contact between the brushes marked 19 and 20 in the plate, and it is kept in that position by the attraction of the no-voltage release coil, which is in series with the limiting shunt turns.

The blow-out magnet is made to take the place of an overload coil, and, when the current exceeds a certain value, a small pivoted armature is attracted and completes a circuit which short-circuits the no-voltage release coil. This allows the arm G to be pulled over by a spring, and the contact between Nos. 19 and 20 brushes is broken.

The effect of this is that the circuits of the 5th, 6th, and 7th starting resistances, and the lead that short-circuits them, are broken, as is also the circuit of the magnet shunt if it is in use, and only the first four starting resistances are left in parallel in the circuit. These resistances will allow enough current to flow through the motor to hold it against the load, but not enough to damage it. To replace the overload, the controlling drum must be moved back to the fourth step, in which position G is pushed back into place by the cam on the spindle.

When G is released, it completes the circuit of an alarm bell, which is placed on deck beside the controller handle, so that the man working the controller shall know when the overload has gone.

The shunt coils of the motor are joined up between the brush marked 1 and the negative main, so that they are switched on by the first motion of the controller. In order to prevent their being damaged by the E.M.F. of inductance when the current is switched off from them, a non-inductive resistance is connected in parallel with them. This resistance is called a kicking coil. When the current is switched off from the field coils, the inductance tends to keep the current flowing, and, if the kicking coil were not fitted to provide a path for it, it would spark across the contacts in the controller and damage them.

Since this kicking coil is across the mains when the motor is running, all parts of it are at a different potential. Two leads are taken off from two places close together, to provide current at a low voltage for ringing the cut-out alarm bell.

The blow-out magnet is wound in series with the armature, and is so placed that all the brushes bearing on the controller drum are in a strong magnetic field.

An automatic brake is fitted, which is pulled off by the magnetism of the field magnets. When the magnets are not excited the brake holds the motor, and it cannot revolve.

The older type of Scott capstan controller is similar to the above, but the motor has no limiting shunt turns, and the arrangement of the overload is slightly different. The controlling and reversing drums are exactly the same.

Clarke Chapman's Coal and Boat Hoist Controller.

These controllers are fitted in a large number of ships which have electrically-driven coal and boat hoists. The motors are simple series motors, and the controller gives seven speeds.

The controller consists of one drum with a row of 15 brushes bearing on it. It is divided into three parts, as shown on the dotted lines on Plate XIX., and these three parts are all insulated from one another, though the contact pieces on any one part of the drum are all in connection with one another through the body of the drum. It will be convenient to refer to the three parts of the drum as the positive, negative, and reversing drums respectively, as shown in the plate from right to left.

The positive and negative mains are connected to the brushes marked + and —, and the connections to the motor are made as shown.

A magnetic brake is fitted, and on the first step of the controller the brake circuit is connected directly across the mains, so that the brake is taken off.

On the second step, the armature and field magnets are connected in series with the mains through one starting resistance.

The third to seventh steps each add another starting resistance in parallel with the first, and the eighth step short-circuits them all.

The overload coil is in series with the field winding, and a diagrammatic view of the overload arrangements is shown in the corner of the plate.

When the overload goes, it breaks the circuit of the fourth, fifth, and sixth starting resistances and of the short-circuiting

CLARKE, CHAPMANS BOAT HOIST CONTROLLER.

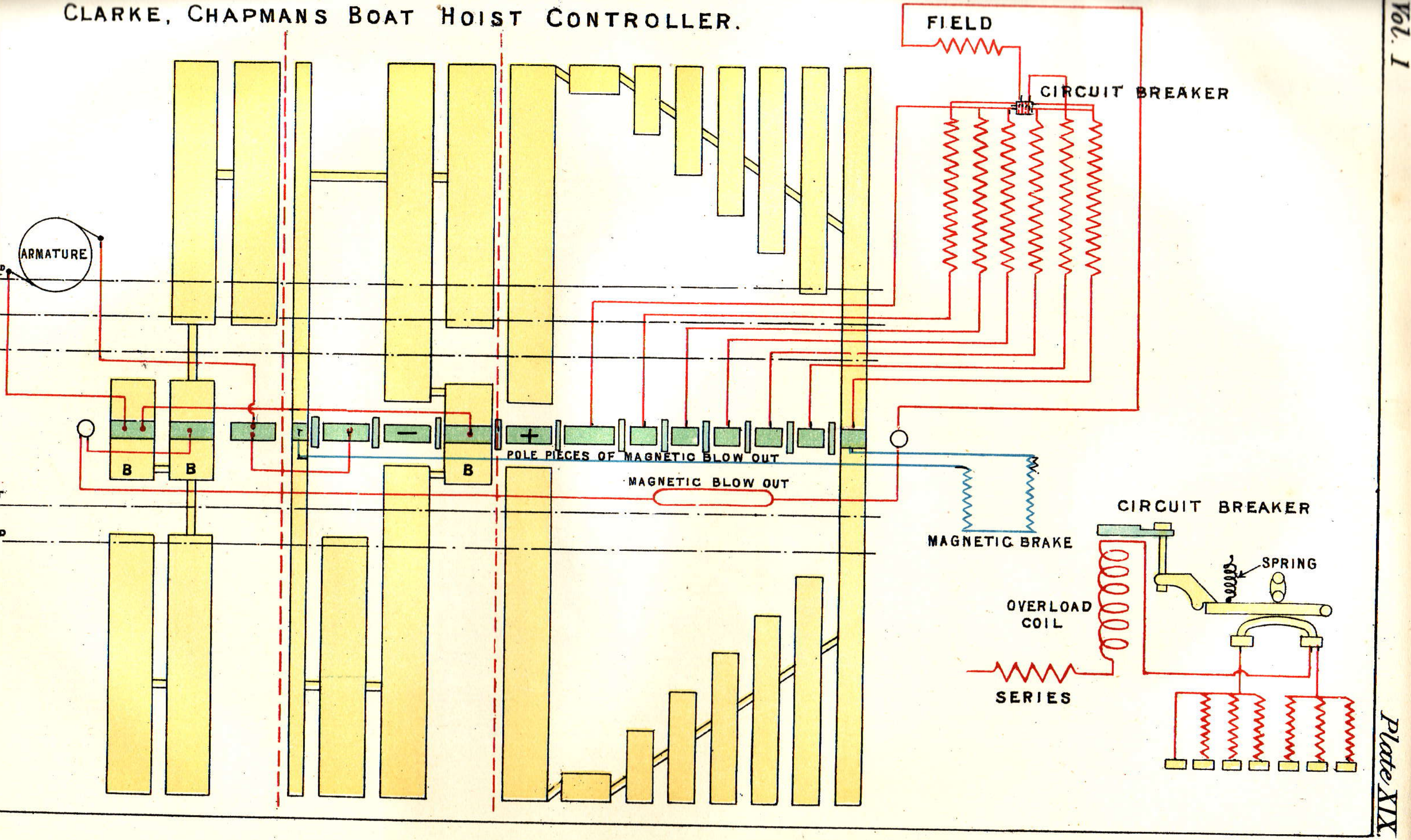


Plate XIX.

lead, and leaves the first three starting resistances in the circuit. This allows enough current to pass through the motor to prevent its running backwards under the load, but not enough to damage it. To replace the overload, the controller must be returned to the "off" position.

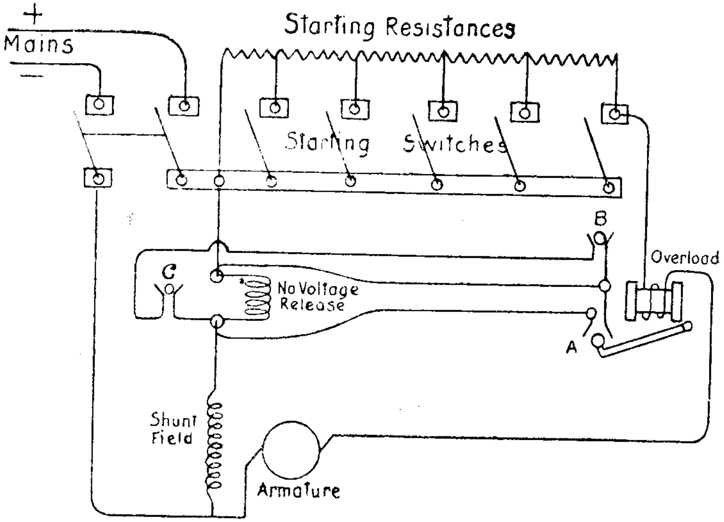
In order that the inductance of the brake circuit shall not cause any damage when the current is switched off, the blow-out coil, field winding, and one starting resistance, in series with one another, are put in parallel with the brake coil by means of the contacts marked B, just before the positive and negative supply mains are cut off. These form a kicking coil for the brake magnet.

The blow-out magnet is wound in series with the armature, and has a large number of poles, which are placed, as shown in the plate, between all the brushes where sparking is likely to take place.

Electrically-driven air compressors are being fitted in some modern ships. The motor is a 40-H.P. shunt wound motor, and a diagram of the circuit of the starter is given in Fig. 128.

The starter consists of one double-pole and five single-pole switches.

Fig. 128.



The double-pole switch, which is put on first, puts into the circuit the field, in series with the no-voltage release, and the armature in series with all the starting resistances. The single-pole switches, which are put on in order from left to right, short-circuit the starting resistances one by one.

Each switch, when on, is held on mechanically by the switch that was put on before it, and cannot be put on until all those before it are on.

The first switch, *i.e.*, the double pole, is held on by the attraction of the no-voltage release coil, but this coil is normally short-circuited by the two contacts B and C in series with one another, so that the switch will not remain on unless either B or C is broken.

B is broken when the last switch is put on, and C is broken by means of a push button placed just under the double-pole switch.

The procedure in starting the motor is therefore as follows:—First push the button, so as to put the no-voltage release into action, and then put on the double-pole switch, which will be held on. Keeping the button pressed, put the single-pole switches on one by one. Each will be held in place by the one before it, and the last one breaks the contact at B, so that the button can then be released. The button must be kept pressed all the time while switching on, as otherwise the double-pole switch will be released, and in coming off will bring all the others off with it.

The overload, whose coil is in series with the armature, when it comes into action short-circuits the coil of the no-voltage release by the contact at A, and so releases the double-pole switch. If an overload occurs while starting the motor, the release will act just the same, as the contact at A is independent of the other two at B and C.

Motors for Coaling Bollards.

Ships of the King Edward VII. class and later classes are fitted with coaling bollards on the boat deck, which are worked by motors of about 30 H.P.

The motors are shunt wound, and run continuously while the bollard is in use, being fitted with starters of the usual description and the safety arrangements described in the last chapter.

The bollards are driven through friction clutches, which require careful adjustment to run properly.

The motors must in all cases be started light, and no load must be put on them until they are running at their normal speed.

Motors for Gun-working.

Controller for Twin 6-inch Mounting.

The twin 6-inch turrets in the cruisers of the County Class are fitted with electric motors for training.

There are two patterns of training gear, the Vickers pattern and the Elswick pattern.

A diagram of the circuit of the Vickers pattern is shown in Plate XX.

The apparatus consists of two parts—the controller, which is placed in the sighting position in the turret, and the reverser, which is down below, beside the motor.

Vol. I.

To face page 187.

CONTROLLING GEAR FOR TURRET TURNING MOTOR.
TWIN 6 INCH MOUNTING

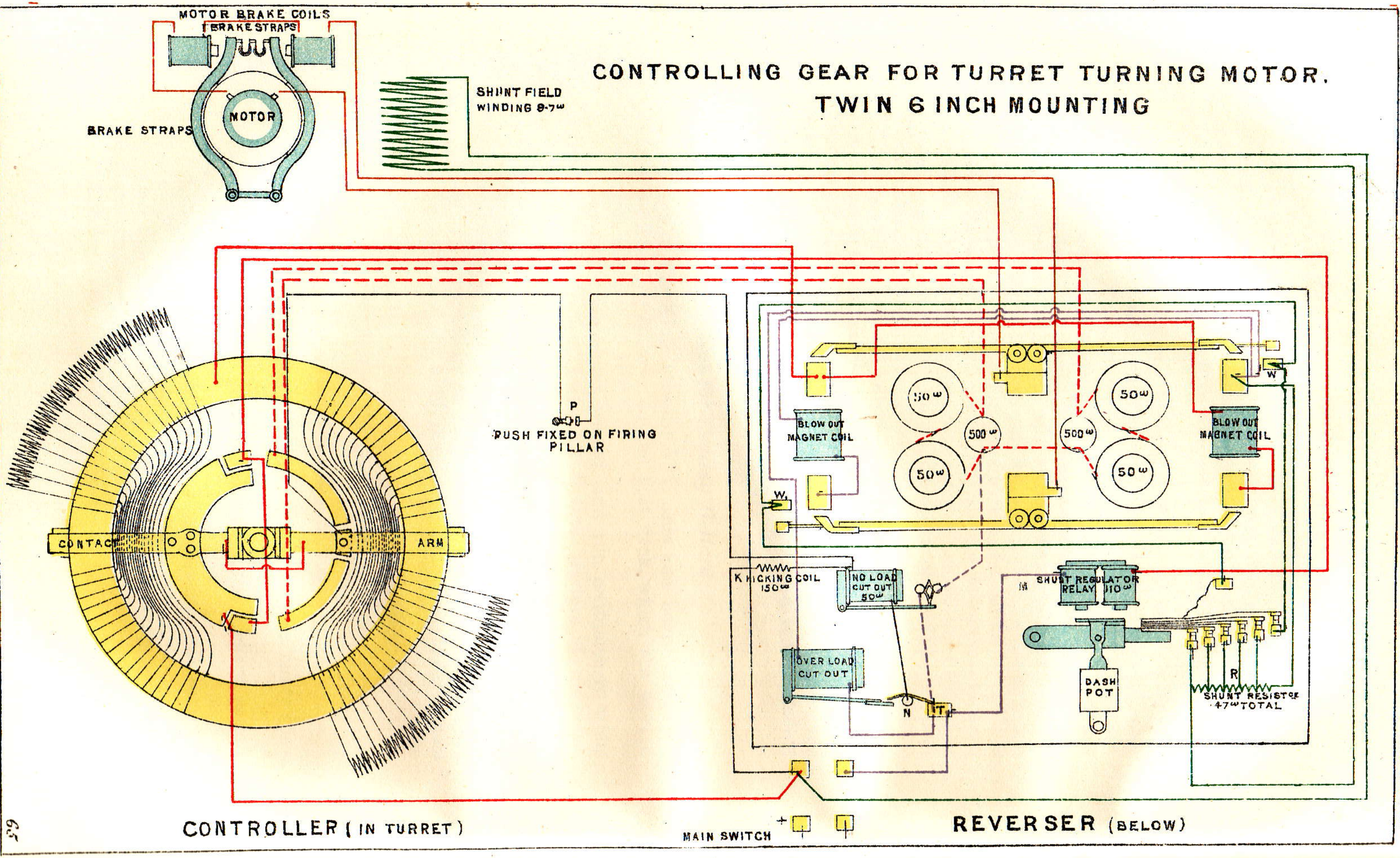


Plate XX.

Weller & Graham Ltd Litho London

1915

65

The motor is shunt wound, and gives 10 H.P. at 1,000 revolutions per minute, and at this speed, which is its fastest, it will revolve the turret through its whole arc of training, 270° in 30 seconds. It is fitted with a magnetic brake, whose coils are in series within the armature; 30 amperes through these coils are required to bring the brake off.

The large switches in the reverser are worked by relay coils whose circuits are completed through the controller. Only one of these switches can be on at any time, one of them being put on when the controller handle is put over one way, and the other when it is put over the other way.

The first motion of the controller excites one or other of these relay coils, and the starting resistances are then cut out by the further motion of the controller.

A no-voltage release is provided, whose armature, when attracted, completes the circuit of the relay coils. Unless it is attracted and held up in place, these circuits are broken, and neither of the large switches in the reverser can be actuated.

The no-voltage release coil is placed in series with the kicking coil that is provided for the shunt winding, whose resistance is high, about 150 ohms. When the armature of the no-voltage cut-out is down, the current that flows through the no-voltage and kicking coils in series is not sufficient to lift it up, though it is enough to hold it when it is lifted. A push is fixed on the pillar of the controller, and if this is pressed when the controller is in the central, or "off" position, it short-circuits the kicking coil, and energises the no-voltage coil sufficiently to lift up the armature, which will then be held there, when the push is no longer pressed.

These arrangements ensure that current can never be put on to the motor unless the controller is first returned to the "off" position.

An overload cut-out is fitted in series with the armature of the motor, and when its armature is attracted it breaks the circuit of the no-voltage coil, so that the large switch in the reverser comes off.

The shunt coils of the motor are excited as soon as the double-pole switch is made, and in series with them are the shunt regulating resistances R. In the normal position, with neither of the large switches in the reverser made, all these resistances are short-circuited by the shunt regulating switch except the last one, which is left in the circuit to prevent the shunt coils getting too hot when the motor is not running. This last one is short-circuited, through the blocks W, as soon as either of the large reverser switches is made.

The shunt regulating switch is worked by a relay coil whose circuit is completed on the last step of the controller. The switch is fitted with a dash pot, so that when it is attracted by the relay it moves up slowly, and the shunt resistances are put into the circuit one by one.

In the Elswick pattern of twin 6-inch mounting the motor is shunt wound, and runs continuously all the time that the turret is in use. It is fitted with a starter of the usual form, with safety arrangements as described in the last chapter.

The reversing and controlling of the turret are performed by mechanical gearing worked by the training wheel in the sighting position, which it is not necessary to describe here.

Ward-Leonard System of Motor Control.

This system is fitted to the turret training motors of the "Powerful" and "Terrible," and to the training and elevating motors of the turrets of the "Invincible," the details in each ship being slightly different.

The general principles of the system are as follows:—

In the lower part of the turret, below the armoured deck, is a motor generator, consisting of a shunt motor driving a separate generator. The field of the generator can be controlled and reversed by means of a switch in the turret, and the armature of the generator is connected directly to the armature of the turret training motors, whose field is constantly excited from the ship's mains.

The motor generator is kept constantly running all the time that the turret is in use.

If there is no current in the generator field, the generator will, of course, be generating no E.M.F., and the training motor will not move.

If a small current is allowed to pass through the generator field, a small E.M.F. will be generated, giving a small current in the training motor, which will then move slowly.

As the current in the generator field is increased, so will the E.M.F, and consequently the speed of the training motor, increase.

If the current in the generator field is reversed, the E.M.F. generated will, of course, be in the opposite direction and the training motor will run the other way.

The advantage of this system is that the only current that is being dealt with in the controller is the comparatively small current of the generator field, and there is consequently very little loss of power in resistances, &c., and the controller can be quite small.

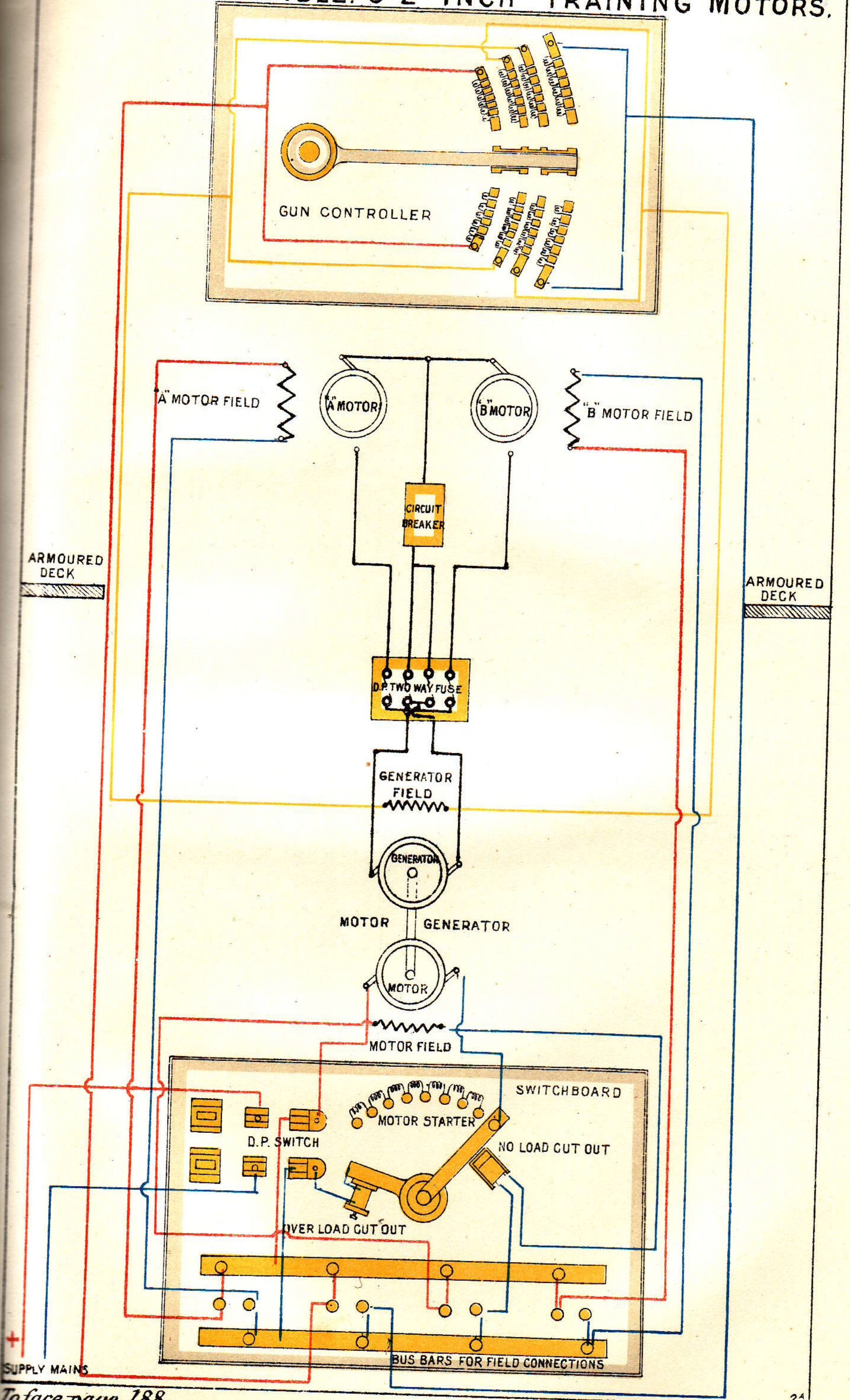
Also, by having a sufficient number of steps in the rheostat that controls the generator field, the control can be made very delicate indeed.

The disadvantage lies in the extra weight of machinery required. The generator must be of such a size as to develop the same power that the training motor takes at full load, and the motor that drives it must of course be also of the same power. There is therefore three times as much machinery as if motors were used direct off the mains.

The advantages, however, are considered to outweigh the disadvantages.

Plate XXI. shows the Ward-Leonard system as fitted to the turret training motors of H.M.S. "Terrible."

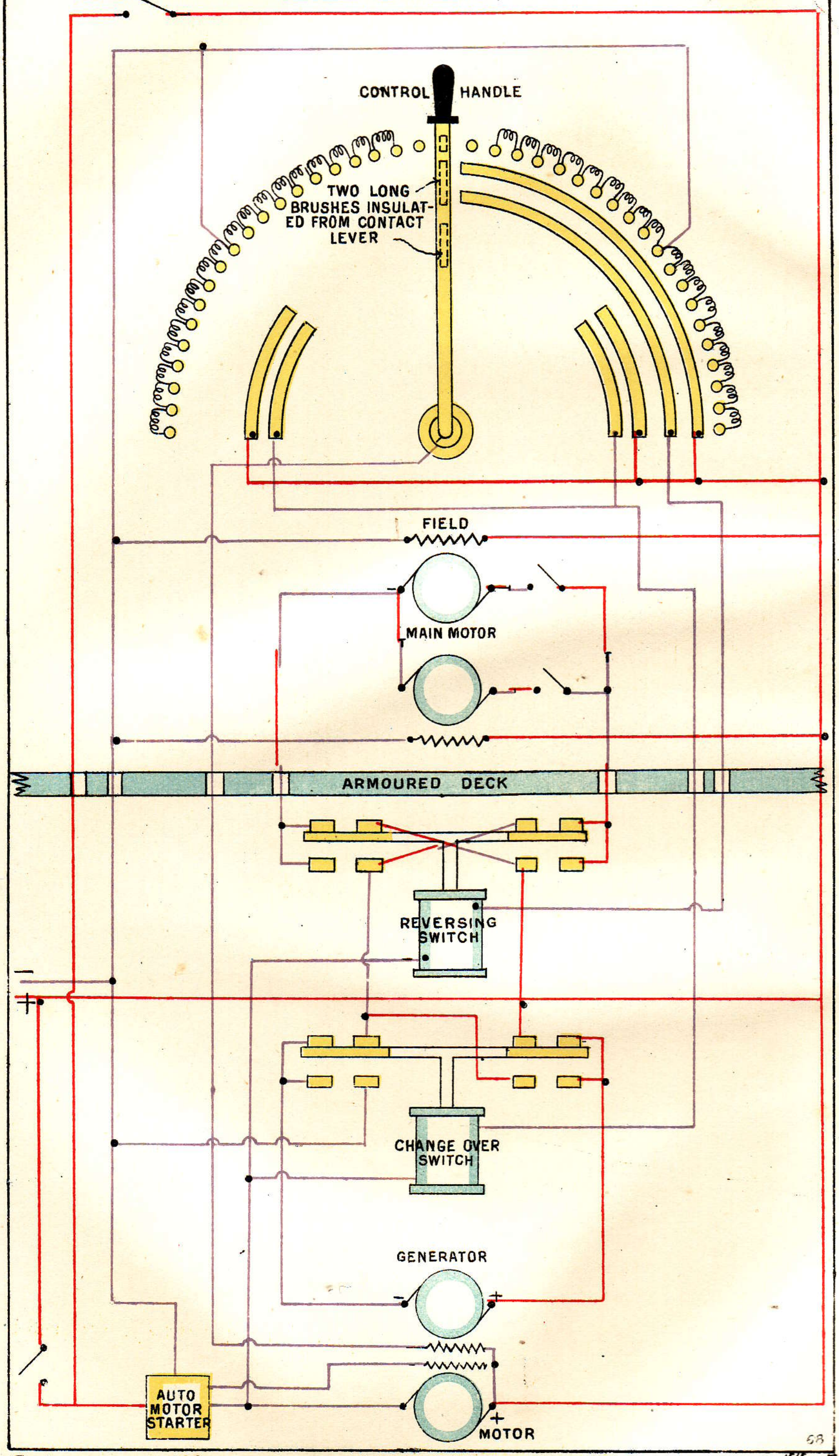
H. M. S. TERRIBLE. 9·2 INCH TRAINING MOTORS.



To face page 188.

Weller & Graham, Ltd. Litho, London 1515 07

CEIPEL SYSTEM OF TURRET TRAINING.



To face page 189.

There are two training motors, and they are connected in parallel direct to the armature of the generator through an automatic circuit breaker. At the bottom of the plate is shown the switchboard for the turret, on which are a double-pole switch for the mains, a starter for the motor of the motor generator, and bus bars for the various fields.

When the double-pole switch is put on, it feeds both the motor starter and the field bus bars.

The starter is of the ordinary form described in the last chapter, fitted with both overload and no-voltage releases.

The field bus bars have four pairs of leads going from them—two for the training motor fields, one for the motor field of the motor generator, and one feeding the controlling switch in the turret, and thence the generator field.

The controller is so arranged that as it is put over one way, a gradually increasing current is sent through the generator field in one direction, and if it is put over the other way the direction of the current is reversed.

Geipel and Lange Turret Training Gear.

This gear, shown diagrammatically in Plate XXII., is fitted to the turrets of H.M.S. "Powerful." It is an improved form of Ward-Leonard gear, and works on the same principle, but is arranged in a different manner.

There are two motors, as in the "Terrible," and their armatures are connected in parallel through an electrically operated reversing switch, to an electrically operated change-over switch.

These two switches are operated by means of solenoids working against springs, so that when there is current in the solenoid the switch is in one extreme position, and when there is no current it is in the other extreme position.

The solenoid of the reversing switch is excited by means of a contact on the controller handle, all the time that the controller handle is on one side of the "off" position, and not when it is on the other side.

The solenoid of the change-over switch is excited by means of another contact on the controller handle, as soon as the handle gets halfway over to its extreme position on either side of the "off" position.

The current always goes through the field of the generator in the same direction, and the reversal of the training motors is effected by means of the reversing switch mentioned above.

The full voltage that can be given by the generator is only one half that of the ship's mains, for which the training motors are wound. In the "Powerful" the training motors are wound for 80 volts, and the generator gives a maximum of 40 volts.

During the first half of the travel of the controlling handle, when the solenoid of the change over switch is not excited, the motors are supplied direct from the brushes of the generator, through the change-over switch, and the voltage of the generator gradually increases as the current through its field is increasing.

As soon as the change-over switch is actuated, which happens when the controller handle is halfway over and the generator is developing its maximum voltage, its effect is to put the training motors direct across the ship's mains, but with generator in series with, but in opposition to, the mains. The generator then becomes a negative booster.

From that point until the controller handle reaches its extreme position, the voltage of the generator is gradually decreased from its maximum down to zero.

It will thus be seen that, although only a 40-volt generator is used, the voltage applied to the training motors is gradually varied from 0 up to 80 volts.

The starter for the motor generator is worked by means of a solenoid, and the circuit of this solenoid can be completed either by a push in the turret itself, beside the controller, or by a push beside the motor generator itself.

The advantage of this gear over that fitted in the "Terrible" is that, as the generator has only to develop one-half the power required by the training motors, the motor generator can be made much smaller, and weight can be thus saved.

Gun-working Gear of H.M.S. "Invincible."

H.M.S. "Invincible" is being fitted with electric machinery for working 12-inch guns.

Two different systems are being fitted, one designed by Elswick and the other by Vickers.

The training and elevating motors are in each case controlled on the Ward-Leonard system.

In the Elswick turret, the other motors, for the hoists, rammers, breech mechanism, &c., are all worked by hand controllers, which have various safety arrangements and automatic cut-offs and reversing switches.

In the Vickers' turret, the motors for hoists, rammers, and breech mechanism have electrically worked controllers, actuated by push buttons. The lifting and traversing motors in the shell room have hand controllers.

Full descriptions and diagrams of these circuits will be found in an Addenda to the Hydraulic Manual.

CHAPTER XII.

SERVICE MACHINES AND THEIR MANAGEMENT.

A GOOD many of the older ships in the Service have two-pole dynamos, but as these are all obsolescent, it is not considered necessary to describe them here. Two of the older multipolar machines will be briefly described, and then two of the most modern.

Siemens Six-pole 600-ampere Dynamo.—The body of this dynamo is built up of two mild steel plates, forming the upper and lower halves of an irregular hexagon. The lower half rests on brackets; the upper half, with its three poles, can be removed, so as to enable the armature to be taken out. The six legs with their pole pieces are bolted on to this framework, thus forming complete magnetic circuits to the armature in the centre, the poles being alternately north and south. Three of the legs carrying series as well as shunt coils are made larger than the other three. All six poles have shunt coils wound upon them, and these shunt coils are all connected in series; one end of the shunt wire being joined to the negative terminal of the machine and the other to the outer ring conductor, and therefore to the positive pole. The three series coils have their ends joined to the inner and outer ring conductors, which are two large copper rings encircling the face of the machine and serving to distribute the current between them. The inner ring conductor is connected to the three positive brushes, and the outer one is in connection with the positive terminal of the machine. Thus the current flows from the three positive brushes to the inner ring conductor, through the three series coils in parallel to the outer ring conductor, thence to the positive machine terminal through the external circuit to the negative machine terminal, whence it is distributed to the three negative brushes.

The machine is thus of the "long shunt" type.

The armature is laminated with a large number of slotted wrought-iron discs keyed to the shaft with three keys. Axial holes are fitted for ventilation. There are 118 armature bars, each made in two pieces to prevent eddy currents, and sunk one beneath the other into the slots of the core, and kept in place by a metal packing piece.

These machines having wave wound armatures, require merely two sets of brushes.

Since, however, the brush area must be large to collect the total output, 600 amperes, to avoid having a long commutator, as would be the case with only two sets of brushes, each set is divided into three, placed 120° apart and electrically connected.

The total resistance of the shunt circuit is 73 ω. Near the tip of each pole piece is a coil consisting of $6\frac{1}{2}$ turns of broad copper strip, size 1 inch by ·3 inch, insulated from each other by tape and varnish, and from the magnets by layers of micanite and glazeboard. These six coils, joined two in series and three in parallel, form the series winding, with a resistance of ·00055 ω.

The armature has 76 slots. It is of the usual laminated type mounted on a "quill" or framework. The commutator consists of 152 segments. There are four conductors in each armature slot, making 304 in all. The winding is a simple lap winding (○) with a pitch of 13 slots (+ 51, – 49 in conductors) composed of former wound coils.

Each coil consists of nine copper strips each ·06 inch by ·14 inch, laid together and cotton-braided over all. These are grouped four in a slot, the two upper ones being bound up together with tape, and well insulated from the lower pair, which are similarly bound. The D.P. between the two conductors bound together is, of course, practically inconsiderable, so the cotton braiding is sufficient insulation.

Each slot is filled as follows:—

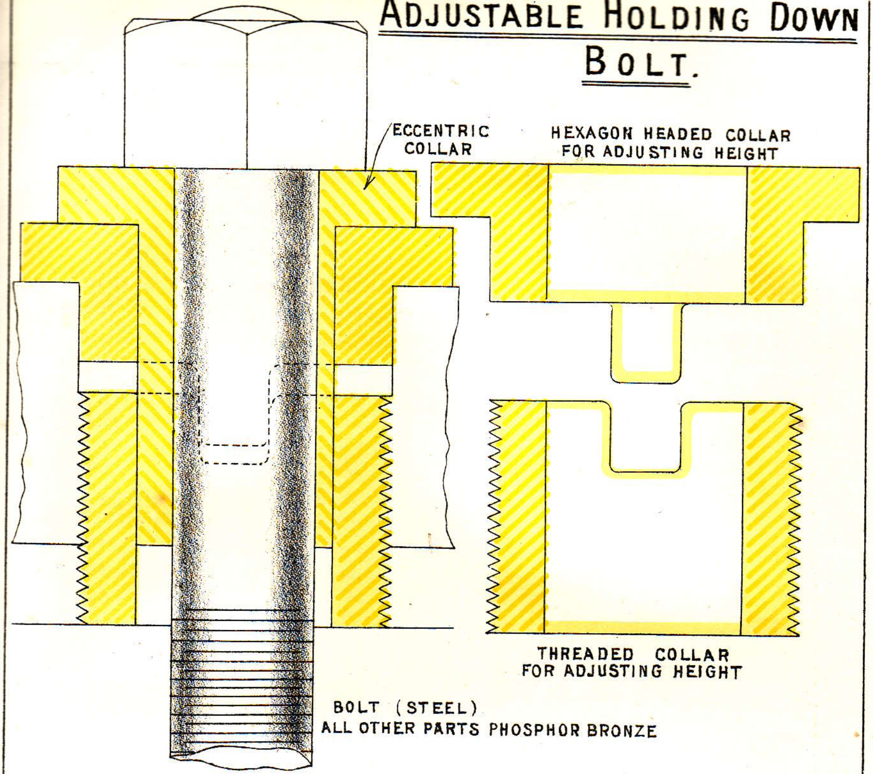
A layer of glazeboard is first put at the bottom as a foundation, ·035 inch thick.

A "trough" of ·012-inch glazeboard is then made in the slot, as described in Fig. 133. Into this is placed the lower pair of conductors, taped, "armalaced," and varnished. Armalac is a hard, durable, and waterproof varnish, extensively used in field and armature windings. A layer of ·035-inch glazeboard separates these conductors from the upper ones, which are then placed in the slot. The upper lips of the glazeboard trough are now turned in over the conductors, and the slot is filled in with two layers of micanite and a $\frac{3}{32}$-inch layer of glazeboard, over which the binding strips lie. Plate XXIII. shows this in section. Binding strips are made of No. 18 nickeline wire.

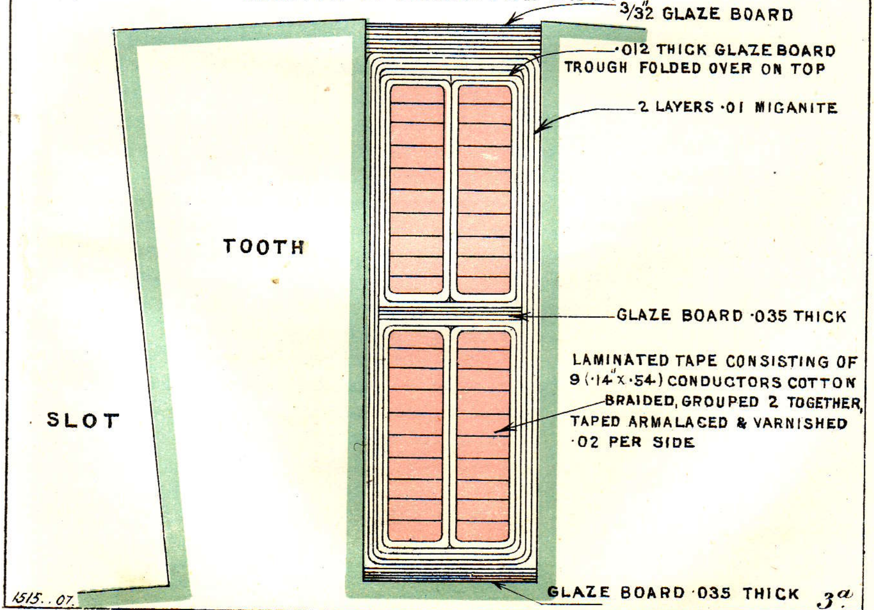
As regards the electrical circuits of the machine, taking the fields first. The shunt circuit leaves the $+^{ve}$ terminal of the machine, goes through the six shunt coils, all in series, away to the shunt regulator at the switchboard, and back to the $-^{ve}$ collecting ring. The machine is thus a short shunt design. A protecting coil, of wire wound on a porcelain former, is placed at the dynamo, between the leads to the shunt regulator.

The series coils lie between two heavy copper rings, two in series, three in parallel. The ring at the commutator end is joined to the $-^{ve}$ brushes of the machine, and also to the terminal for the equaliser connection. From this copper ring the current passes through the series coils to a ring at the coupling end of the machine. This ring is connected to the $-^{ve}$ terminal of the dynamo, and so to the switchboard mains. Considering now the armature circuit, since the armature is ○ lap wound, with six poles, there are six paths in parallel through the armature. The output of the machine is 1,000 amperes at 100–105 volts, so each conductor must carry 166 amperes. The conductors are ·075 square inch in cross section, giving a current density in the

ADJUSTABLE HOLDING DOWN BOLT.



105 KWT. GENERATOR
SECTION OF ARMATURE SLOT



1515..07.

3a.

To face page 194.

coils of 2,195 amperes per square inch. The armature keeps very cool on full load, well below the specified maximum temperature rise. There are six brush holders, each containing eight carbon brushes of standard Service size.

Since the different sets of brushes of the same polarity are run in parallel, it is necessary that the D.P. between adjacent brush-holders should be the same, or heavy local currents will be set up between the different sets of brushes. This necessitates very careful setting of the magnet ring on the engine bed plate, because if the armature is the least bit out of centre, the voltage will be highest where the clearance is least, and *vice versâ*. The magnet frames are therefore fitted with adjustable holding-down collars, which enable slight adjustments to be made, both in the vertical and horizontal directions, independently of the armature bearings.

The armature is centred, as nearly as possible, by measuring the clearance between the pole pieces and the armature. All connections are then taken off the brush holders. The shunt winding can then be excited, either separately or from any two adjacent brushes. The dynamo should then be started. The current used for exciting the shunt should not make any appreciable difference to the two brushes to which it is connected, but if the voltage between adjacent brush-holders be noted, it may be found that the voltages are not the same all round, and the magnet ring must be given slight adjustments by means of the holding-down collars, *i.e.*, if the top brushes show a higher voltage than the bottom ones, the magnet ring must be raised slightly. Also, if the right hand brushes show a higher voltage than the left, the magnet ring must be moved slightly to the right. The smaller clearance, of course, gives the higher voltage.

The adjustable bolt is shown in Plate XXIII. Horizontal adjustment is obtained by revolving the eccentric collar, by means of its hexagon head.

Vertical adjustment is effected by turning the key gland with a spanner on its hexagon head. This turns the screwed socket and raises or lowers the magnet ring. The nut on the head of the bolt is screwed down after the adjustments are correct, and locks all parts securely in position. All four collars must, of course, be moved the same amount, in order to maintain the axes of armature and magnet ring in the same line.

The voltage between adjacent brushes should, when the adjustments are made, not vary more than 1 or 2 per cent.

If flats appear on the commutator, they are very likely to be caused by the armature being out of balance in this way, and tests should be made to see if this is so.

If the machine is run without an equaliser connection, *i.e.*, not in parallel with other machines, a further compensation for the armature being out of balance can be made.

The leads from the $-^{ve}$ brushes are led to points nearly opposite on the series ring.

If this ring is removed, each brush will feed a pair of series coils.

Suppose the armature falls a little, due to wear in the bearings. More E.M.F. is generated at the lower brushes, since the clearance will be smaller there. But the current from the lower brushes passes through the upper field coils, creating a stronger field there, and tending to restore the balance.

When the machine is run in parallel with others, however, all the brushes must be joined to the equaliser ring, and this compensation is sacrificed.

The other modern dynamo to be described is Laurence Scott's 210-k.w. generator, which is being fitted in H.M.S. "Inflexible" and "Indomitable." It is designed to give 2,000 amperes at 100 to 105 volts, and the 1,000 ampere, 220 volt, machines for H.M.S. "Invincible" are very similar, being made from the same castings, the difference being in the windings.

A section of one of these machines is shown in Plate XXIV. on a scale of $1\frac{3}{8}$ inches to 1 foot.

The armature is 4 feet in diameter, and is built up of charcoal iron stampings in the form of rings, whose internal diameter is 3 feet. The stampings are clamped together and carried on a cast-iron spider which is keyed to the shaft, and to this spider is also bolted the frame that carries the commutator.

It will be seen that the active length of the armature conductors, that is, the length that is embedded in the slots, is only 6 inches, the remainder of the length shown being the end connections.

There are 12 principal poles, and 12 auxiliary poles interspaced between them, the pole pieces being part of the magnet ring casting, with laminated pole faces bolted on. The winding of the fields is shown in Plate XXV., the series in red and the shunt in green. It will be noticed that the machine is a short shunt, the shunt winding being connected between the negative and the equaliser ring conductors, and that the series winding is in four parts which are in parallel with one another.

The auxiliary poles, as explained in Chapter VII., are wound with series turns only, while the principal poles carry both series and shunt.

There are 12 sets of brushes, all carried on one rocker, whose position can be adjusted by means of worm gearing.

The shunt protecting coils are carried on the dynamo itself, wound on porcelain formers and covered with a casing of perforated zinc. One of them is to be seen on the right of the dynamo in Plate XXIV.

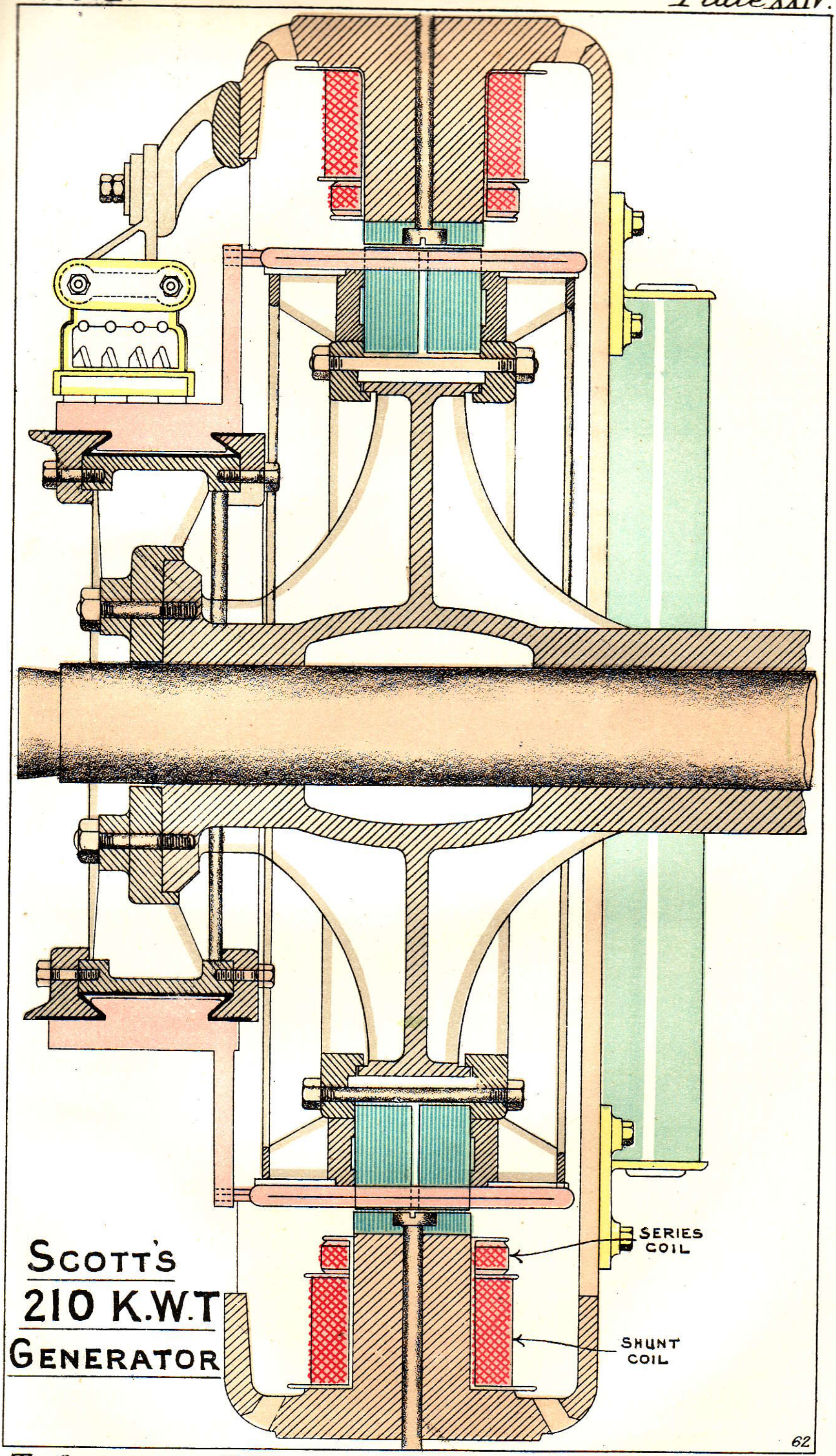
The commutator is built up separately on its own frame, and this frame is then bolted on to the spider of the armature.

The brushes are carbon, and the brush holders of the standard Service form, with the brushes set radially to the commutator.

Motors.

Motors may be broadly classified as follows:—

Enclosed motors, in which the armature, field coils, commutator, brushes, terminals, and entire electrical circuit are completely

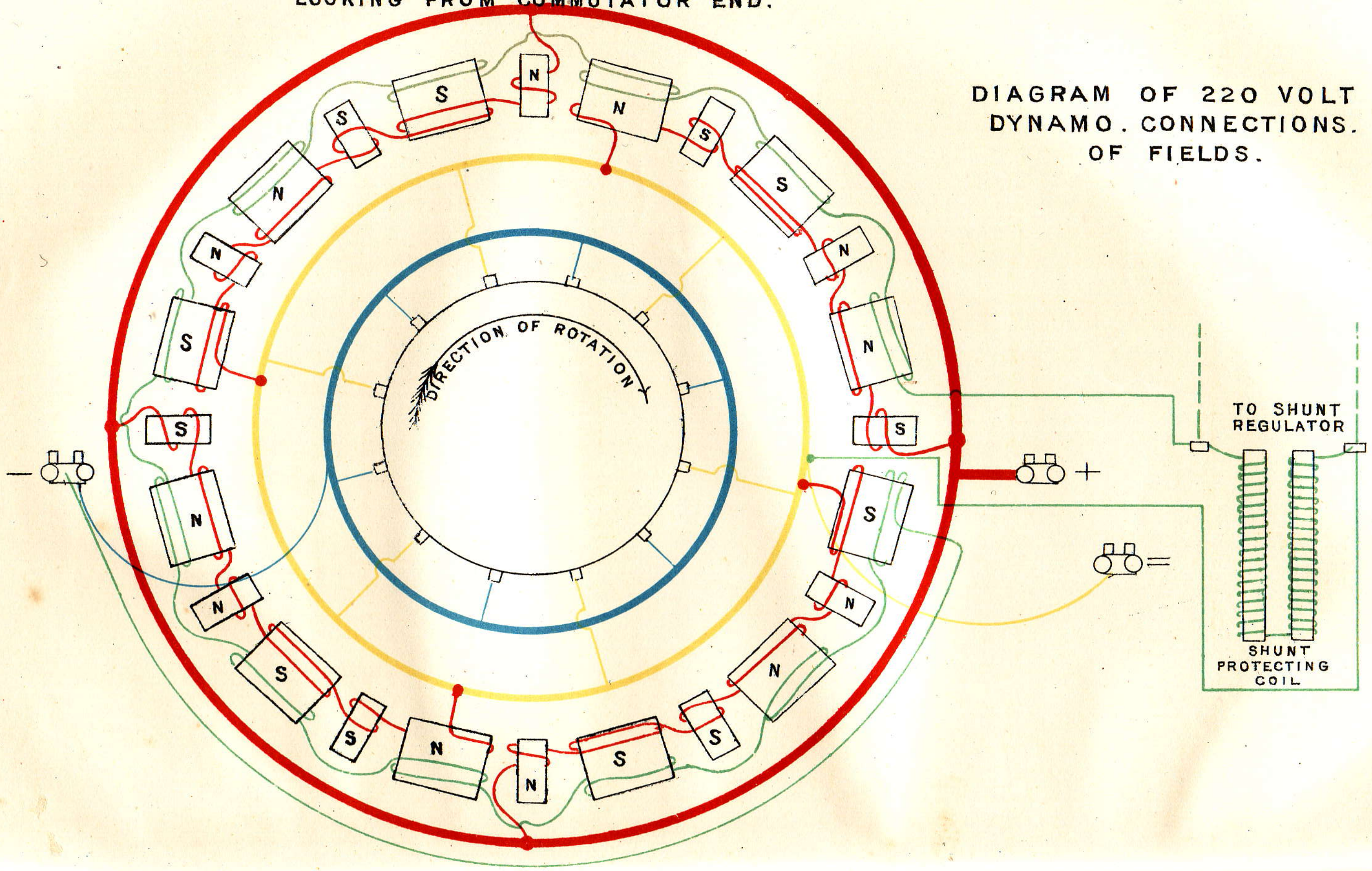


Scott's
210 K.W.T
Generator

Weller & Graham, Ltd Litho, London. 1515 07.

DIAGRAM OF 220 VOLT DYNAMO. CONNECTIONS OF FIELDS.

LOOKING FROM COMMUTATOR END.



enclosed in a watertight casing, of which the field casting of the motor forms part.

Protected motors, in which the armature, field coils, commutators, brushes, terminals, and entire electrical circuit are enclosed by a casing which shields these parts from contact with external objects, but allows complete access of air to all parts of the motor.

Open motors, in which there is no casing at all.

All the directions for care, maintenance, and repair of electrical machines given below, apply equally both to dynamos and motors.

There are two principles which must be observed in the care of electric machinery, if the maximum efficiency is required with the minimum of trouble.

The first is that absolute cleanliness of all parts, particularly the commutator and brush gear, is essential.

The second is that any defect or fault, however trifling, should at once be investigated and remedied.

Neglect of either of these precautions will invariably cause rapid deterioration of the machinery and endless trouble to those in charge of it.

The commutator must be kept quite smooth and true. A periodical examination of the commutator and brush gear should be made when the machine is standing, and if at any time blackening is noticed on the commutator, on starting up again it should be well polished. Fine glass cloth is the best thing to use. The polishing may be done while the machine is running on its ordinary work.

If taken in time, half a minute's application of this glass cloth will put things right, whereas neglect may necessitate grinding of the commutator.

The cloth may advantageously be placed under a strip of wood, about 2 inches wide, cut to fit the circumference of the commutator.

No emery should ever be used on any part of a dynamo or motor, except when grinding the commutator, and then special precautions are necessary, which will be enumerated later. The particles of emery, which are absolutely indestructible, if allowed to lodge on the commutator or brushes, will quickly cause them to wear unevenly, and, of course, if they get into the bearings, the brasses will be ruined.

Commutators should be rubbed occasionally with a clean rag very slightly greased with a good mineral oil, or special commutator lubricant. This, with the application of the glass cloth, will be found to make the commutator run quietly and without any wear.

The commutator, brushes, and brush gear must be kept clean and free from dust, a pair of bellows or a jet of compressed air being used for the purpose. The working faces of carbon brushes should be kept clean and free from metallic particles and deposit so that a clean surface of carbon rubs against the commutator.

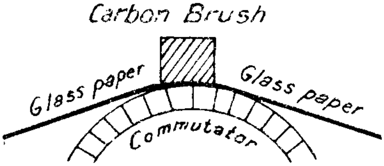
When stopped.—One particular part of the commutator must not be cleaned with anything except oil or a cleaning solution, or a "flat" will be formed.

All cleaning solution should be carefully removed when the commutator is clean.

If the whole of the commutator requires cleaning, or the mica requires taking down, the brushes must be removed and a long strip of glass paper used so as to wear away all parts of the commutator equally.

Carbon brushes must slide easily in the holders or frames which support them, and the springs must be adjusted so as to secure an even and continuous pressure of the carbon blocks in the commutator. The brushes must bed accurately on the surface of the commutator. This can be ensured by laying a long strip of glass paper between the brushes and the commutator, with its smooth side towards the commutator, when the machine is at rest. The glass paper should then be pulled backwards and forwards under the brushes, being at the same time kept in tension, so that its smooth side keeps a firm bearing on the commutator, the carbon brushes being pressed on to the cutting surface of the glass paper by their springs (*see* Fig. 129). By continuing this operation for a short time, the brushes will be cut to a clean surface which just fits the commutator. By loosening the springs the brushes can be withdrawn for inspection, and in this way it is easy to see when a satisfactory surface has been obtained.

FIG. 129



Brush holders for carbon brushes are now always made in the standard Service form, which consists of a frame with slots in it in which the brushes are placed so that they slide radially to the commutator. They are kept pressed against the commutator by means of springs, and are connected electrically to the brush holder by means of a piece of flexible copper wire, long enough to enable the brush to be removed from the slot and examined without being disconnected. With these brush holders, once the brush has been properly bedded, it should require no more attention until it is so worn away that it has to be replaced.

In some of the older motors that had only to run in one direction, such as fan motors, a different form of brush holder is fitted, in which the brush is held firmly at the end of an arm which is pivoted at the other end, the pressure on the commutator being obtained by a coiled spring on the pivot of the arm. Brushes in these holders require rather more careful bedding than others, since the angle at which they bear on the commutator varies with the size of the brush and the amount that it is worn.

Wire gauze brushes should have their faces clean and true; no straggling wires, or unevenness of the bearing surface, should be allowed. If the brushes get dirty and oily, cleaning them in caustic potash and then thoroughly rinsing them in water will remove all grease.

In setting wire gauze brushes in the holders, the strips of the commutator should be counted, and the brushes are usually placed at exactly equal distances apart on the commutator. This rule is not, however, true for all types of machines, as, for instance, the Westminster four-pole dynamo, where the brushes are in two sets 90° apart. If the brushes do not bear evenly they should be placed in a wooden former which can be easily made, and filed up true. No more pressure should be put on the brushes than necessary to keep them bearing on the surface of the commutator.

When new brushes are put in, great care must be taken to make them bed accurately in the first instance. If this is done, they will work for a long time with very little attention, and without sparking.

Sparking should never be allowed to continue, as the inevitable result is roughening of the commutator, which in its turn causes more sparking, and so on until the surface of the commutator is utterly ruined.

If sparking cannot be easily and quickly remedied, another machine should be started and the load taken off the defective machine.

If sparking occurs, it will probably be due to one of the following causes:—

1. *Brushes and Brush holders:*—
   - (*a*) Rocker not at correct position.
   - (*b*) One pair of brushes taking too much current, due to the other pair not bearing properly or having a bad connection.
   - (*c*) Brush holder put on on a slue.
   - (*d*) Brush holder put on wrong way round.
   - (*e*) Brush holder not rigid.
   - (*f*) Insufficient pressure on brush.
   - (*g*) Brush not free in holder.
   - (*h*) Brush not bedded down properly.
   - (*i*) Edge of brush broken away.
   - (*j*) Dirt collected on edge of brush.

2. *Commutator:*—
   - (*a*) Dirty.
   - (*b*) Mica insulation standing up above the copper of the strips.
   - (*c*) A "flat" place on the commutator which has been formed by continuous sparking or improper use of emery cloth.

(*d*) A shoulder having been formed round the commutator, against which one of the brushes is bearing.

(*e*) Commutator not running true, due to having been turned up by the centres on the shaft instead of by the journals.

3. *Armature:—*

(*a*) Too much lateral play in the bearings, causing knocking.

(*b*) Armature taking too much current, due to an overload or an earth.

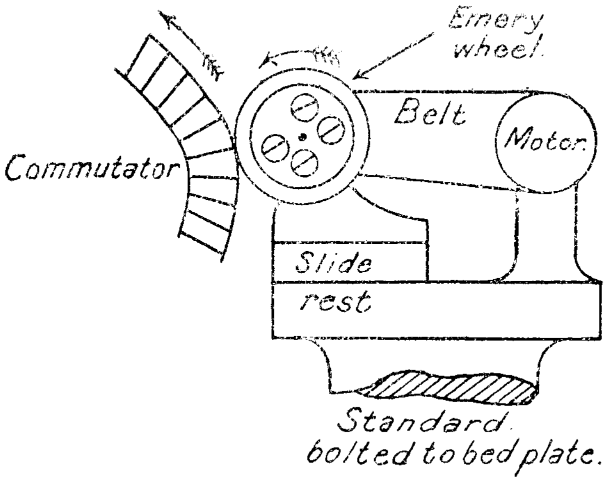
(*c*) A broken coil or end connection. (This will cause a heavy sparking in one place which will eat away the commutator strip, and which is easily distinguishable from sparking due to other causes.)

(*d*) An earth in the armature, combined with an earth somewhere on the outside circuit as well. The appearance of sparking due to this cause is similar to that caused by (*c*), but it can be distinguished by testing for earths with the machine stopped and switched off.

In all recent installations a tool called a *commutator grinder* is supplied. It consists of an emery wheel driven by a small motor. The whole is mounted on a slide rest similar to that of a lathe. The slide rest is mounted on a standard which is fitted to the bed plate of the dynamo by the makers, and is so arranged, that when bolted in position, the slide rest moves accurately parallel to the axis of rotation of the dynamo.

To use the grinder, the dynamo is started running light at a moderate speed.

Fig. 130.



An emery wheel is secured to the flanged holder, and the motor, which is shunt wound ½ B.H.P., at 1,400 revolutions per minute, is started in such a direction that the touching surfaces of the commutator and emery wheel move in opposite directions. The wheel is used just like a lathe tool. Light cuts are taken off with it, and the feed is performed very gradually, by hand.

The emery wheel wears away very rapidly when in use, and consequently the feeding must be done continuously all the time that the wheel is travelling along the length of the commutator. It is thus impossible to get an absolutely cylindrical surface with one cut, and so, after the irregularities have been removed, the commutator must be gauged with calipers at every point of its length and light cuts taken off at different places, if necessary, until the surface is a true cylinder.

When the commutator has been trued up in this way, it should be examined to see that the copper surfaces of the strips have not been burred over the mica between them, so short-circuiting the commutator. Before grinding the commutator, the brushes should be removed entirely with their holders so as to keep them clear of metallic dust. For the same reason paper should be pasted over the end connections at the commutator end, or the grinding will fill the interstices with metal particles and cause trouble.

The bearings should be very carefully protected from the emery and metallic dust by being completely wrapped up and covered with cloth or canvas.

The whole machine, commutator, brushes and holders, should be carefully blown out with an air jet, and thoroughly cleaned after grinding.

In older ships which are not supplied with facilities for commutator grinding, if the commutator gets rough or untrue, a hand rest must be rigged up, and the commutator turned carefully with a hand tool, only a very light cut being taken off it.

In the case of a motor, some means must be provided to drive the armature round if it is necessary to grind or turn down the commutator. This could probably be done by means of a belt from another motor.

DEFECTS IN DYNAMOS.

We will now consider fully the causes of failure of dynamos, the symptoms that enable us to locate them, and subsequently their repair.

If a machine heats abnormally, or if there is a smell of burning insulation from it, switch off and stop at once, starting another machine to take its place.

If the lights flicker intermittently, look to the governor, it is probably not being properly lubricated.

Should a machine fail to excite, a series of tests as follows should be systematically undertaken to determine the cause :—

(i) See that the pilot lamp and voltmeter are properly connected up; this makes certain that the machine itself, and not its instruments, is at fault. Then see that all connections are correctly made, and that the brushes bear properly on the commutator and are in their right positions on it. Touch the pole pieces with an iron spanner or other implement to make certain whether any magnetism is being generated.

(ii) Short-circuit the machine by joining two leads of wire (Patt. 600 or larger) from the main terminals to a fusible cut-out. This should send a large current through the series wire, and may assist the shunt wire to induce magnetism into the field magnets. The cut-out should fuse and the machine excite; if this does not occur, the fault must lie in either the field magnets or the armature.

(iii) Stop the machine; test the coils as follows, breaking no connections except those mentioned until after the continuity tests are complete. Disconnect the main leads from the terminals and also the pilot lamp and voltmeter wires. Lift the brushes off the commutator. Test the series coils and then the shunt coils for continuity with a test battery. In a long shunt dynamo this may be done in a single operation by testing from brush to brush. If correct, next test the shunt and series coils for non-contact, in doing which it will be found necessary to disconnect the end of the shunt wire that is joined to the series coil. Make good this latter connection, and test both coils for insulation from earth, that is, from the iron of the magnets or the steel armature shaft of the dynamo. Should a fault be discovered during either of these tests each shunt and series coil should be disconnected, one at a time, and tested carefully to ascertain which one is faulty. Now test for insulation of the armature by joining one testing lead to the shaft and touching any of the commutator strips with the other.

If the fault is still undiscovered, proceed as follows:—

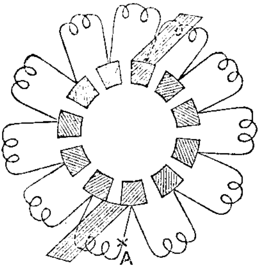
(iv) Separately excite the field magnets. To do this see the brushes raised, and then join the main terminals of the machine to the main terminals of another dynamo, using a cut-out. In a ship where the dynamos are widely separated this may be conveniently done by joining their two main bars on the switchboard by a piece of Patt. 600 wire, and their two return bars in the same way, through a cut-out which will fuse if too much current passes. In ships fitted with a parallel switchboard, it may be done by lifting the brushes, and then closing the main switches on the board. It is most important to *lift the brushes* of the faulty machine, otherwise there is a danger of running it as a motor. The pilot lamp should be disconnected, or it may be fused when the current is broken owing to self-induction of the shunt coil, and a high, non-inductive resistance should be joined up across the terminals of the shunt coil, to act as a kicking coil, and protect the insulation from being punctured. Three incandescent lamps, in series, may be conveniently used for this purpose.

If the faulty machine now excites, which can be found out by touching one of its field magnets with a spanner, the cause of its failing to do so before must have been the total loss of its residual magnetism. If, on the contrary, the shunt coils get heated this will show that there is a short-circuit in them, the part heated being the sound part and the cold part the part short-circuited.

If the cause is neither of the latter, we can say that nothing is wrong with the magnet coils, and we proceed as follows:—

(v) Revolve the armature by steam, keeping the field magnets separately excited, put on the brushes, and put a small load of about one-fifth of its total capacity on the machine. If the machine now produces D.P., look for the following indications of a fault. Supposing a bright flashing spark occurs at the brushes at regular intervals, this will show that an armature coil or bar is broken. The reason is as follows:—

Fig. 131.



Imagine a break at A (Fig. 131). It is evident that in the particular position shown it practically does not affect the running of the armature; the coil is short-circuited by the brush, and each half of the armature is contributing its share of the current. But as the coil with the break leaves the brush the circuit on that side of the armature is broken, a spark occurs, and immediately the resistance of the armature is doubled, so that a flicker in the light and a spark at the brush will occur every time that the broken coil passes the brush. In a dark dynamo room the strip belonging to the broken coil can be seen by the flash of the spark, since the light emitted by the spark is so instantaneous that the commutator appears stopped. If the commutator be revolved slowly it can be marked with a quick dab of chalk every time the spark occurs, the commutator strip in connection with the broken coil can be easily found, and the necessary repairs undertaken.

The machine should only be run for a few minutes, and should then be stopped and the armature felt carefully to detect any heating. Suppose, again, that one of the coils or bars be found to be hot, this will indicate that that particular coil or bar is short-circuited, probably at the end connections, for the following reason:—If a coil or bar be short-circuited, as in Fig. 132, the main current will not flow through it, but the D.P. the coil or bar is itself generating will cause a large current to flow round the short-circuited portion, and will heat the coil.

FIG. 132.

If there is an appearance or smell of burning in a drum armature, the fault will generally be found to be due to a contact between adjacent long and short bars.

Should the dynamo not excite when separately excited as above described, the fault is probably in the commutator, and is due to a general leakage from one strip to the next all round it.

Having now run through the general lines of testing a machine, we will consider how to repair it in case of failure under any of the above heads.

REPAIR OF DYNAMOS AND MOTORS.

Starting with the field magnets, and having found the individual coil in which the fault is: if it cannot be seen, the coil will have to be unwound till the place is exposed.

If the shunt and series wires are touching, but neither of them making earth, the fault must be in the layers where the shunt and series meet.

If the shunt or series coils are touching the machine, the fault may lie in any turn near the flange, if the flange be of metal; but if the underneath coil, either series or shunt, be touching the metal, it is probably touching the sleeve on which the coils are wound.

The magnets should be treated with care, and if the two halves of the magnet ring are separated, they should be kept from concussion or any blow which would tend to harden the iron.

It would probably be beyond the resources available aboard ship to re-wind the coils of a large dynamo or motor, but it may frequently have to be done in the case of small motors.

To re-wind a coil, remove the sleeve and mount it either in a lathe (if the gap is large enough), or between posts temporarily rigged up. Next get a reel (such as those supplied with Naval Service wire), and wind off the shunt coil (if on top). Care must be taken in unwinding that the wire is immediately wound tightly and evenly on the reel; otherwise, each succeeding turn will chafe the insulation of the former layers. The insulation between the successive layers of the shunt wire should be kept, as it will be useful in re-winding.

Careful note of the direction of winding should be taken, so that in re-winding the wire may be put on the same way as before.

When all the shunt wire is off, the series wire, if defective, must also be removed, or *vice versâ.*

When the coil has been unwound, the insulation of the sleeve and flanges should be looked to; also the bushes through which the wires are rove. Any insulation that has absorbed oil should be discarded, and new insulating material substituted. For insulating the sleeves, a layer of thin varnished paper, covered with thin canvas soaked in hot paraffin wax, will be found a good substitute easily procured on board.

Between the series and the shunt wire good insulation should be placed, especially in places where the D.P. between the two is great. Against the flanges, canvas well saturated with paraffin wax will be found to answer, should such insulation as Willesden paper, &c. not be procurable.

If the wires lead through bushes in the flanges, they should be served with linen to protect the cotton covering, which is otherwise liable to damage. Each layer of the shunt coil should be insulated from the next by a layer of linen coated with shellac varnish.

The turns should be evenly laid on, and all inequalities guarded against. The hollows due to the spiral winding of the wire near the flanges should be filled in with linen or cotton-fibre, to prevent successive layers dropping into them. The same number of turns to each layer should be laid on as in the original winding. No metal implement should be used in contact with the wire; but a wooden "drift" will be required.

In order to get the turns on with the requisite uniform tension the reel off which the wire is being unwound should be fitted with a brake, which can be conveniently improvised from a piece of rope and a weight suitably applied.

It is necessary to secure the last two turns of a shunt winding to prevent them from flying back, if disconnected from the block. It is therefore well to secure them to their next turn, and also to the layer below.

Varnish the outside layers over with shellac to keep them damp-proof. Then test the coils for non-contact and insulation. If too much shellac has been used, a slight swing will probably be obtained with the insulation test. This will, however, disappear when the spirit in the varnish evaporates.

Should any doubt exist as to which end the positive current should enter by to produce the required polarity, the direction should be tested. With the upper coils the direction of the current may be traced by eye; through those out of sight a current may be passed, and the polarity tested by the attraction or repulsion of a magnetic needle.

If a magnet has been wound the wrong way, it is not necessary to unwind it. Reversing the direction of the current through it by reversing its connections will change its polarity.

Repairs of Armatures.—In an armature three kinds of faults may occur. *Firstly*, an armature bar or connection may be broken; we have already shown how this fault may be located by the spark caused as the commutator connected to the faulty coils passes under a brush. *Secondly*, two end connections, or commutator strips, may be touching, which will cause a short-circuit between two opposite conductors; faults of this nature will generally be made visible by the burning of insulation. *Thirdly*, there may be an earth leak in any part of the armature.

In any case the drum should be mounted, with its shaft on trestles of a convenient height for working, and so that it can be easily revolved.

The best way to locate a broken coil in an armature is as follows:—Send a current through the armature by connecting to two *opposite* strips on the commutator two leads from the lighting mains, one of which has a low resistance, such as a yard arm group, in it to prevent too much current from flowing. Then with a low-reading voltmeter (Century or Combined Testing Set) measure the voltage between every pair of *adjacent* commutator strips. If one coil is broken, the whole voltage applied to the armature will be read between the strips to which its ends are connected. If one or more coils are short-circuited, there will be no drop of voltage between the strips to which their ends are connected.

Should there be a fault in the bar, it may be repaired by taking off the driving bands, lifting the bar out, re-insulating and replacing it. If, however, it lies in either of the end connections, it may be necessary to strip the drum and thoroughly to overhaul the armature.

To do this disconnect the commutator, by breaking all the soldered joints to the lugs, using resin as a flux.

Note the pitch and type of winding.

Strip off the driving bands, keeping the mica insulation, and remove the long bars by breaking the soldered joints and lifting the bars up.

If any of the bars are defective in insulation, they must be re-taped, the ends being first tinned ready for re-soldering; after re-taping, the bars should be coated with black varnish.

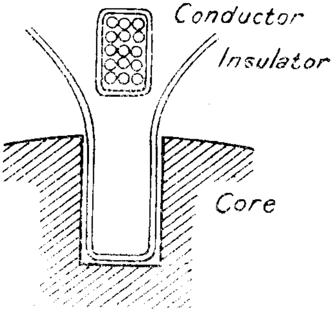
If a new bar is required, it is best made from the core of an electric light cable of suitable current capacity, hammered into a rectangular shape, the ends being well sweated together.

The end connections, if faulty, must also be re-taped.

If these connections are clamped together, as in the old Siemens machines, the insulation on the collars and round the sleeve of the clamps must be looked to and repaired, if necessary, and the insulation between the flat ends of the strips must be renewed, if required. The end connections may then be built up and tested for non-contact and insulation. To compress these to the diameter of the winding, it is most convenient to make brass bands with lugs riveted on, with nuts and bolts for tightening them up.

Slotted core armatures are usually insulated with mica in conjunction either with a form of coarse oiled silk, called "Empire cloth," or with a form of cardboard known as "Presspahn," or sometimes with a thin red fibre. The first mentioned is the best but is also the most expensive, the other two being more or less absorbent. Empire cloth is made in various degrees of fineness according to the size of slot in which it is to be used. Mica is generally used in small armatures in the form of mica cloth, which consists of a layer of mica protected on one side by fine cloth. In insulating the slots, the insulation should be cut so as to project slightly from the ends of the slot, and also above the surface of the core (*see* Fig. 133), the surplus being cut off afterwards.

FIG. 133.



The end connections may now be slipped over the spindle, and when secured in place each one must be very carefully tested for non-contact from its neighbours, and to see that all of them are insulated from the shaft. The short bars can now be put in place round the drum, and clamped with brass bands, a layer of canvas being put between the bands and the bars to protect the insulation of the latter. The ends of the short bars are next sweated to the inside ends of the end connections, and the junctions insulated with tape, after which a further test for non-contact and insulation should be made. When this has been done, the long bars should be placed between the short bars, and sweated to the outside strips of the end connections.

The long bar which should be secured to any particular end connection is easily found by counting on the pitch from the short bar which is connected to it.

Leave the junctions of the long bars to the near end strips till last, so that, before making these, a final test through for non-contact and insulation may be made. When all the junctions are completed, test the whole for insulation.

Good insulation, such as mica, should be placed between the long and short bars, where the junctions of the short bars with the end strips are made.

The next operation is to put on the binding bands. First, varnish the whole armature, then put on a layer of linen a little broader than the band will be when finished; on this put strips of mica stuck down and held temporarily with a turn or so of twine. Now cut some German silver strips about ½ inch broad and once-and-a-half the breadth the band will be. Place, say, six or eight of these at equal distances round the armature; mount the armature between centres and bind on wire over the insulation and German silver strips, keeping a good strain on it, temporarily fixing the end with a little solder. When the wire has been wound on to the required breadth, solder the end and cut the wire. Now bend up the German silver strips to grip the wire and prevent it falling abroad, and with a good hot iron and composite candle for a flux, sweat the whole of the turns of wire into a solid band.

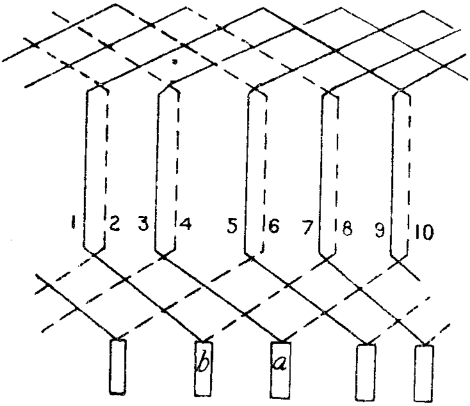
As each band is put on, test it for non-contact with the winding; when all are on, varnish the whole over.

The only thing that now remains to be done is to slip on the commutator and sweat the lugs to the long bars; this, if both bars and lugs have been tinned, will be found an easy matter.

In motors or generators which are wound with formed coils, a repair is usually a simpler operation. If a new winding is required, as will be the case if the armature has "burnt out" (*i.e.*, the coils have become heated to such an extent that the insulation is destroyed), the armature must be mounted on trestles, or it may be convenient to place small fan motor armatures in the lathe. The connections to the commutator should then be broken, with a soldering iron, and the binding strips cut off the armature.

If only one coil is to be re-insulated or replaced, it will be necessary to lift out of the slots the upper conductors of every

Fig. 134.

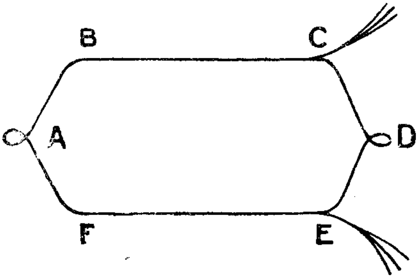


coil which spans the defective one. Supposing in Fig. 134 that No. 1–8 coil has to be removed. The upper conductor in each slot is shown by a full line, the lower conductor by a dotted one. Thus it is evident that No. 1 conductor will lift out quite easily, but to get No. 8 out it is necessary to lift Nos. 3, 5, and 7, and to slip No. 8 out from underneath them. If the whole drum is to be re wound, all the upper conductors should first be lifted, and, as the lower conductors thus become accessible, they in their turn can be lifted, and the coils, as they become free, can be removed from the armature. If the fault is merely a defect in insulation, the defective coil may be re-taped, re-varnished, and slipped under the lifted conductors into its place again, the coils being pressed home, and the new binding strips put on.

If, however, new coils are required they should be made as follows:—

Take one of the old coils and find out how many wires in parallel it is composed of, the length of wire required, and how many turns there are in a coil. Then measure the length of the

Fig. 135.

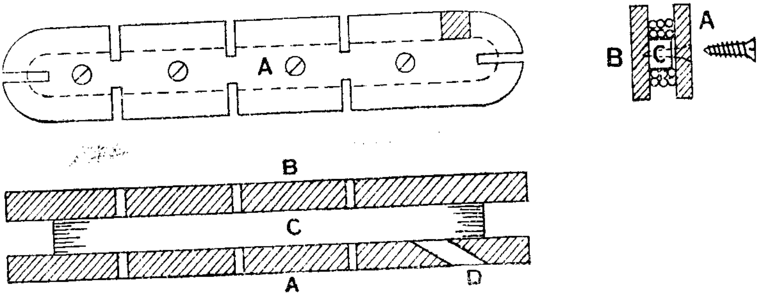


coil (*see* Fig. 135), where the length to be measured is the perimeter A B C D E F.

Suppose the coil is made up of six wires in parallel, and there are two turns in each coil, the ends coming out as in Fig. 135 at C and E. We must now make a former to wind the coil on (Fig. 136).

Fig. 136.

Former for Coil Winding.



This figure shows the wooden former.

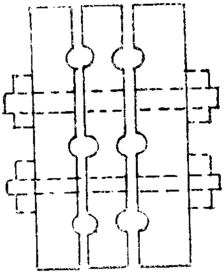
Two pieces of wood, B and C, are secured together as shown. C is a strip of wood of such a length that the coils, if stretched out straight, would just slip over its ends. It is secured to B, which forms a flange on one side of it; and A can be secured to the other side of it to form the other flange.

The width of C just allows of the breadth of a formed coil lying between A and B.

Another instrument is also required. This is a die plate, made of fibre (Fig. 137), with holes in it to take each wire. The

Fig. 137.

Die Plate.

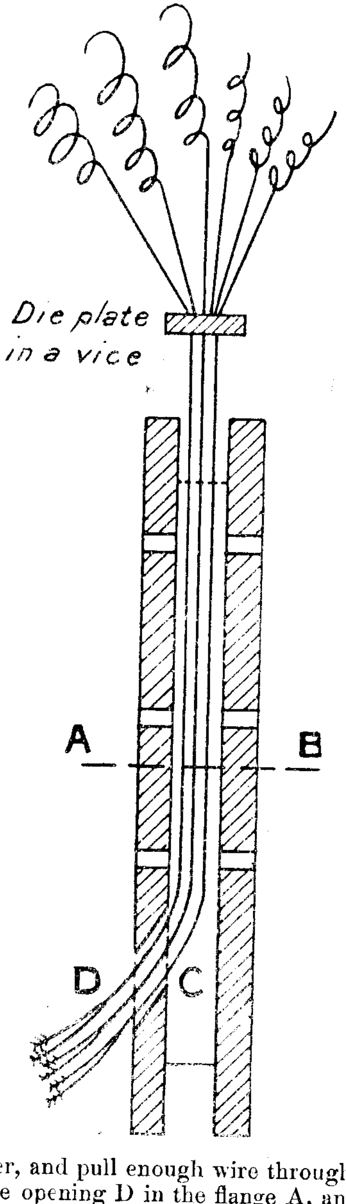


wires are run through these holes to guide them and keep them taut while winding.

The plate must not be made of any other substance than fibre, or it will tear the insulation off the wires. As a further security, the edges of the holes should be bevelled.

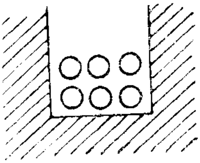
To wind a coil, first reeve the ends of as many wires as are required—six in this case—through the holes in the die plate, and set up the bolts through the plate till the wires will pull through it at a moderate tension. Secure the die plate in a vice.

FIG. 138.



Take the former, and pull enough wire through the die plate to pass through the opening D in the flange A, and leave an end of a few inches projecting. Settle the wires carefully in the groove between A and B, being careful that they are kept symmetrical as they left the former, and that they lie in the groove evenly and regularly. The groove should be just wide enough to allow the proper number of wires to lie side by side in

FIG. 139.



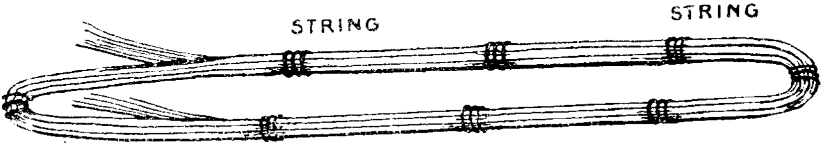
each layer, presenting the cross section shown in Fig. 139. This will tend to produce a coil of rectangular cross section, and every effort should be made to maintain this form.

Turn the former round the axis A B, drawing the wires through the die plate, and forcing them with a piece of wood into place in the former.

When the proper number of turns have been given, insert pieces of string through the slots in the flanges A and B, *under* the coil in the former, and bring the two ends up round the coil, and secure them. The coil will now have eight bindings of string round it, which bindings are not in any way foul of the wooden former.

The flange A can now be unscrewed from C, and the coil can be slid out of the groove, presenting the appearance shown in Fig. 140.

FIG. 140.



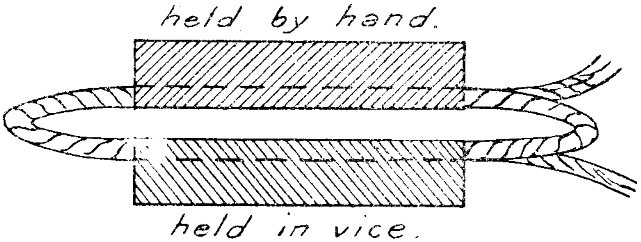
It is then taped with linen tape, each turn covering half the preceding one. The string bindings are removed as the tape binding gets to them. The coil is now made, but requires opening out to span the correct number of slots on the armature.

To do this two pieces of wood are shaped out with a groove in each piece just large enough to take the coil.

The length of each piece is the length of the slots in the armature.

One piece of wood is placed groove upwards in the vice, and the coil placed in it (*see* Fig. 141).

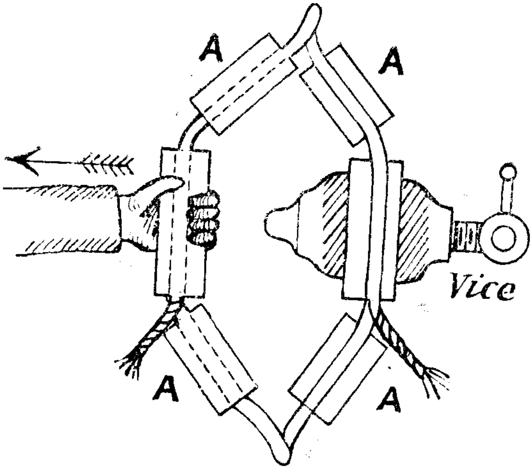
FIG. 141.



The upper part of the coil is then placed in the groove in the other piece of wood.

If the upper piece of wood is pulled over towards the operator, the coil will be spread out into the form shown in Fig. 142.

FIG. 142.



A foot rule should be placed across the coil while it is being drawn out, in order to ensure the coil being given the correct span.

Before the coil is opened out in this way, small grooved blocks of wood A_1A should be put on the coil to keep the end connections straight while the coil is being spread. The coil will then take its shape evenly and symmetrically.

The wooden blocks are then removed from the coil, which is thoroughly dried and then varnished.

When dry, the coil is ready to be placed on the armature.

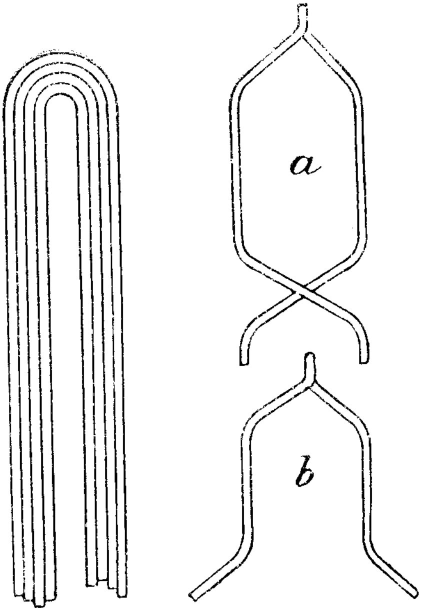
Before actually placing the coil, the ends of the wires should be tinned, to facilitate their connection to the commutator lugs.

The making of formed coils requires several implements in the shape of wood formers, &c., but once these are made they will do for every coil of that type. For instance, if a fan motor requires a new coil, the wood formers, &c. must be made, but if any coil in any motor of the same pattern in the ship goes wrong, all the apparatus is at hand for quickly and efficiently making any number of new coils, so if occasion arises to make a new coil, the apparatus should be carefully preserved, and labelled with the type and size of armature whose coils it fits.

In large armatures, such as those of the ship's generators practically the same plan can be used, but since the coils are not endless, as in the case cited above, the methods will naturally require slight amendment.

The coils should be made of several copper strips, as in the 100-k.w. machine (described on page 194), and should first be bent round into the form shown in Fig. 143, and then taped.

Fig. 143.



Wooden blocks should then be grooved as described above, and the coils formed as before, being afterwards dried and varnished and the ends tinned. The direction of forming is, of course (*a*) for lap, and (*b*) for wave winding.

Defects to be Reported.

In order to prevent a damaged armature or field coil being put away as a spare without the defect being made good or reported, in all cases where dynamos and motors in connection with gun and torpedo armament become damaged, a full report is to be furnished giving details of the defect and its cause ; also the action taken in respect to repairs, and the disposal of the defective parts.

Spare Armatures and Field Coils.

Spare armatures and field coils for motors and dynamos are supplied to ships in strong air-tight zinc-lined wood boxes, each box being clearly marked with the name of the ship, and the contents of the box, whether armature or field coil, and the machine for which it is intended.

The bright parts of the shafts of armatures are coated with a mixture of white lead and vaseline before the armature is packed.

All boxes are fitted with an insulated lead passing through the zinc lining and stowed in a small pocket sunk in the box and closed with a watertight lid. The outer end of this is for attachment to the testing lead, and the inner end in the case of field coils, is soldered to one free end of the coil, and in the case of armatures, is soldered to a piece of bare copper wire which is lapped round the commutator.

The shafts of spare armatures are also earthed to the zinc casing, and earthed sheets of brass are sprung into the interior of field coils, so that either can be tested for insulation without opening up the box.

Lubrication of Dynamos and Motors.

Great care is necessary in order that electric machines may be kept properly lubricated. The instructions laid down in the Torpedo Drill Book for the oiling of dynamos and motors are to be strictly adhered to in all cases.

Distribution of Responsibility for Machinery.

The following Circular Letter is included as laying down the distribution of responsibility for the efficiency of electrical and other machines in His Majesty's ships :—

Circular Letter No. 38. N. 5241/06.

My Lords Commissioners of the Admiralty having had under consideration the question of the distribution of responsibility for the efficiency of various machinery and electrical and mechanical appliances on board His Majesty's ships, are pleased to approve of the following scheme, which has been under trial with satisfactory results in ships of the Channel and Atlantic Fleets since 1903, being brought into operation in all ships of the fleet in which gunnery or torpedo lieutenants are borne. In other ships the present arrangements are to be continued.

2. The changes now introduced are based on three general principles:—

(*a*) That those who use the machinery are to be held responsible for its working, care, and maintenance.

(*b*) That the engineering staff should carry out large mechanical repairs to all machines.

(*c*) That the torpedo officer is the electrical expert of the ship, and his staff should carry out electrical repairs.

3. Accordingly, the following procedure is to be adopted in future:—

The engineer officer will have charge of and be responsible for all machinery, however driven, in the engine and boiler rooms (except as regards the electrical efficiency and repair of dynamos), and all steam, oil, or gas-driven machinery, wherever situated. Except as detailed above, his responsibility will end at the main shut-off valves in hydraulic pumping engines, at the dynamo coupling in electrical generating machinery, and at the main shut-off valve in the air compressors whether steam or electrically driven. He will also have charge of any hydraulic machinery, not detailed in paragraphs 5 and 6 as being under the care of the gunnery or torpedo lieutenant, and the water pipes and fittings in connection therewith.

4. The engineer officer is to be regarded as the mechanical expert of the ship, and, under the captain's directions, he may be empowered to inspect any of the mechanical fittings not in his charge, and report to the captain on their efficiency.

5. The gunnery lieutenant will have charge of and be responsible for all guns, gun mountings, and machinery in connection with them, including firing gear and night sights, except when the machinery referred to is a steam, oil, or gas engine.

6. The torpedo lieutenant will have charge of and be responsible for all torpedoes, torpedo tubes, and gear in connection with them, outside the point where the engineer officer's responsibility ends. He will have charge of and be responsible for all electrical machinery in the ship not in the care of the engineer or gunnery officer. He will also have charge of all lighting and power circuits wherever situated, his responsibility ending at the motor terminals when the motors are in charge of other officers. He is further to have charge of all bell and communication circuits, and is to repair all electrical instruments.

7. The torpedo lieutenant is to be regarded as the electrical expert, and is to be responsible for the electrical efficiency of the ship. Under the captain's directions he may be empowered to inspect any of the electrical fittings or machinery of the ship, and report to the captain on their efficiency.

8. Except as indicated in the next paragraph, no change will be made in the engine room complement as a result of the introduction of this scheme, but the captain will be responsible that the necessary engine room staff is told off as may be required to assist

the gunnery and torpedo officers in the care of the machinery under their charge. In general, one engine room artificer and one stoker should be assigned to the gunnery and torpedo lieutenants respectively for this purpose. These ratings should be regarded as lent only, and they are to be available for general engine room duties when required. In particular, the engine room artificers told off to the gunnery and torpedo lieutenants should be at the service of the engineer officer for executing repairs to hydraulic pumping engines and air compressors.

9. An exception to the foregoing rule is, however, rendered necessary by the great increase in the hydraulic machinery of armoured ships of later design than those of the "King Edward VII." and "Duke of Edinburgh" classes. In the later battleships and cruisers, including "Warrior" class, the engine room complement will be increased, so as to admit of the necessary ratings being assigned to the lieutenant (G.) for hydraulic work in these ships.

10. The engineers' workshop, in charge of the engineer officer, is to be considered the main workshop for all mechanical repairs that may be necessary throughout the ship, and the engineer officer is to carry out all mechanical repairs of any nature which cannot be dealt with by the armourers or torpedo staff. The gunnery and torpedo staffs are not to be required to carry out large mechanical repairs, and the captain will be responsible that the engineer officer carries out such repairs expeditiously with the engineering staff when duly requisitioned.

11. If the gunnery department require any repairs which necessitate the use of the main workshop machines, the gunnery officer will requisition the engineer staff, who will, after consultation with the officer in charge of the machinery, direct and carry out the necessary work.

12. If any machinery in the charge of the engineer or gunnery officer fails electrically, the torpedo staff is to be requisitioned to repair it. Similarly, if any of the electrical machinery outside the engine room develops a mechanical fault which the torpedo staff is unable to repair, the engineering staff is to be requisitioned, and they will direct and carry out the necessary work.

13. If an electrically driven machine under the charge of the engineer or gunnery officer develops a fault, such as an earth leak, which impairs the electrical efficiency of the ship, the torpedo officer, after representing the fact to the engineer or gunnery officer, as the case may be, will make good the defect.