UNITED STATES NAVY SYNCHROS

DESCRIPTION AND OPERATION

15 DEC. 1944

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UNITED STATES NAVY SYNCHROS - Description and Operation

1. The purpose of this publication is to provide to all Naval activities necessary information and operational characteristics of Navy synchros.

2. It is believed that it will be most useful to the technicians on shipboard and in naval bases who maintain and repair Synchro systems.

3. This pamphlet does not supersede any existing publication.

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Rear Admiral, U. S. Navy
Chief of the Bureau of Ships

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Chief of the Bureau of Ordnance

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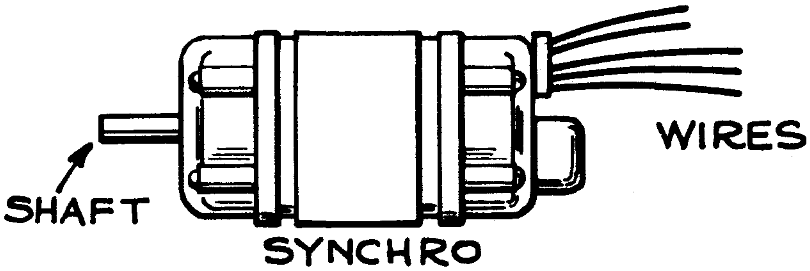
INTRODUCTION

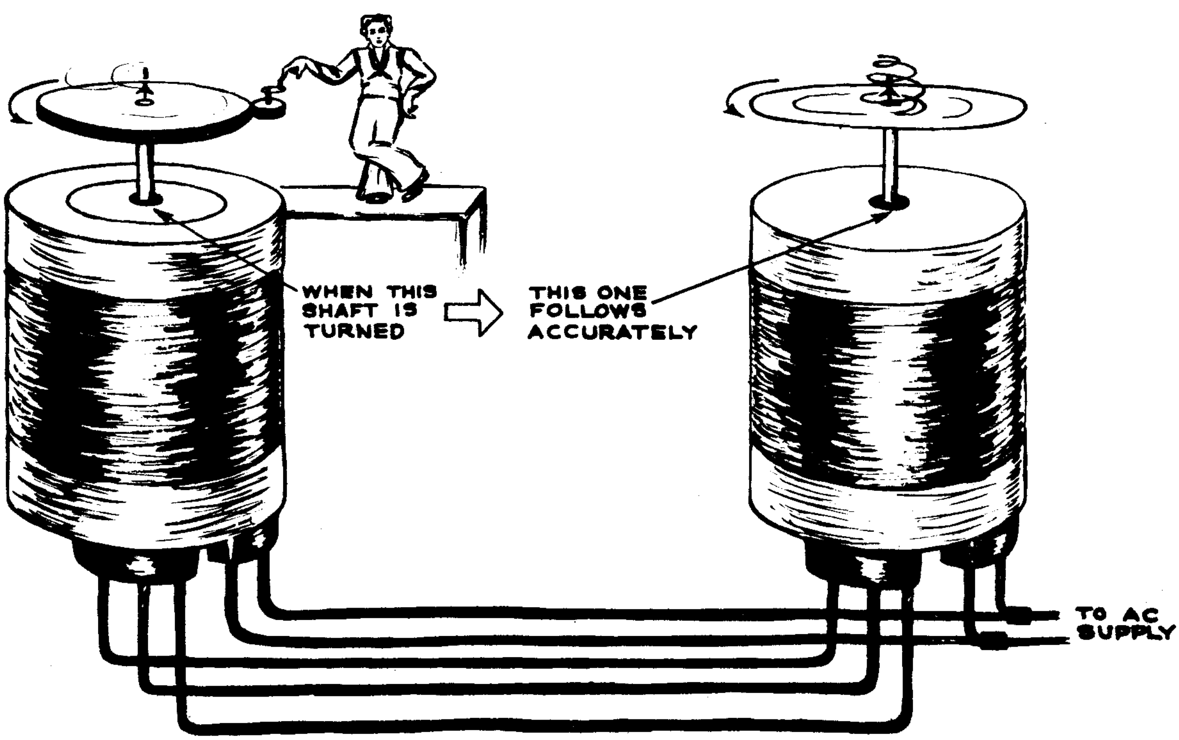
A **SYNCHRO** looks something like this:



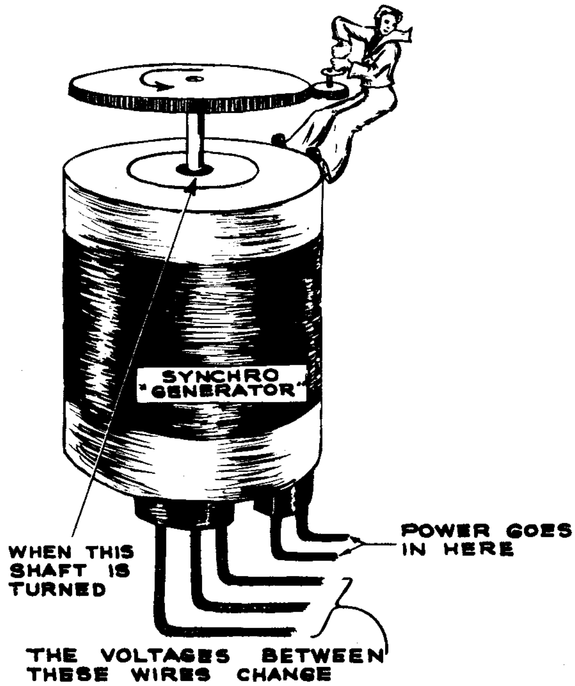
G. E. would call it a **SELSYN;** to Kollsman its a **TELETORQUE;** the Bendix version is **AUTOSYN;** but in the Navy its a **SYNCHRO.** Since this booklet is directly concerned with The Navy Synchro, it will be called by the Navy name.

The same general principles apply to all machines of this type regardless of *what* they're called.

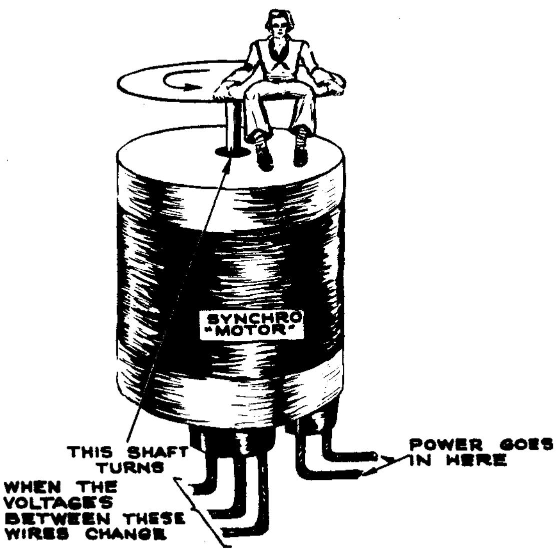
When two Synchros are connected together electrically they form the simplest kind of **Synchro system.** The purpose of such a system is to connect two shafts together so that, when one is turned, the other turns in the same way:



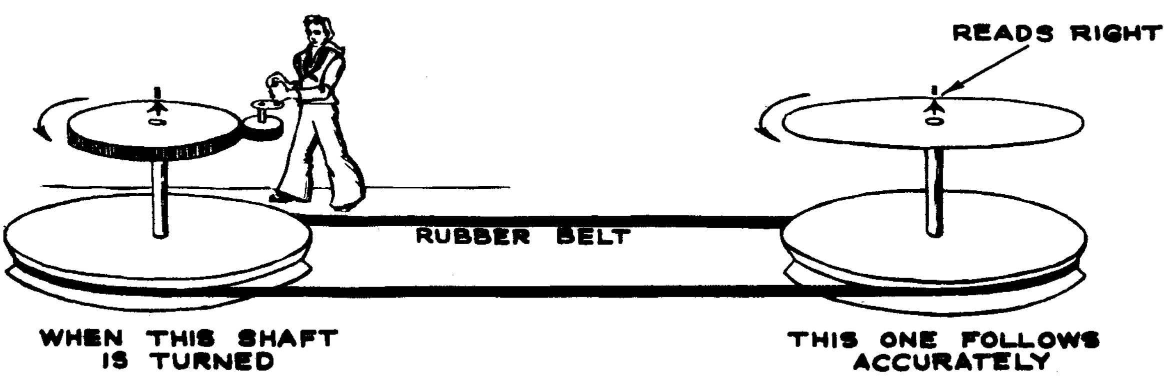
The unit whose shaft *is turned* is called the Synchro "Generator." Its output voltages change when its shaft is turned:



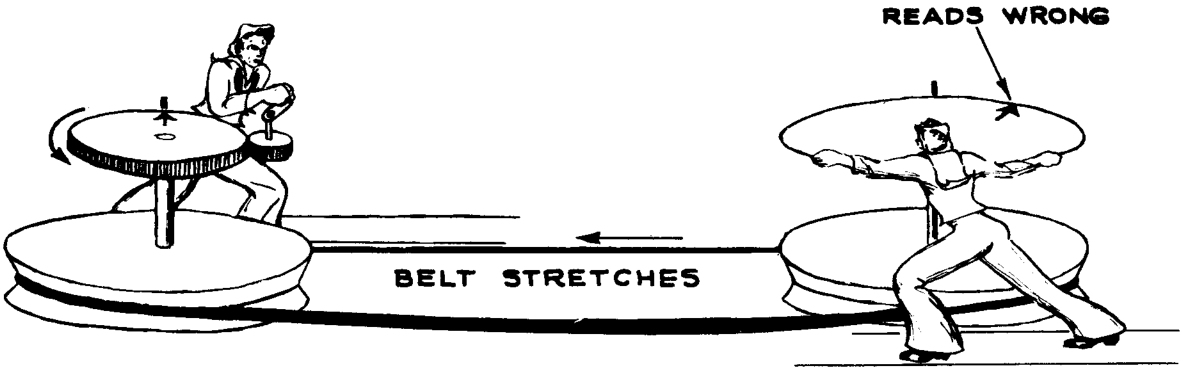
The unit whose shaft *turns* in response to these changing voltages is called the Synchro "Motor."



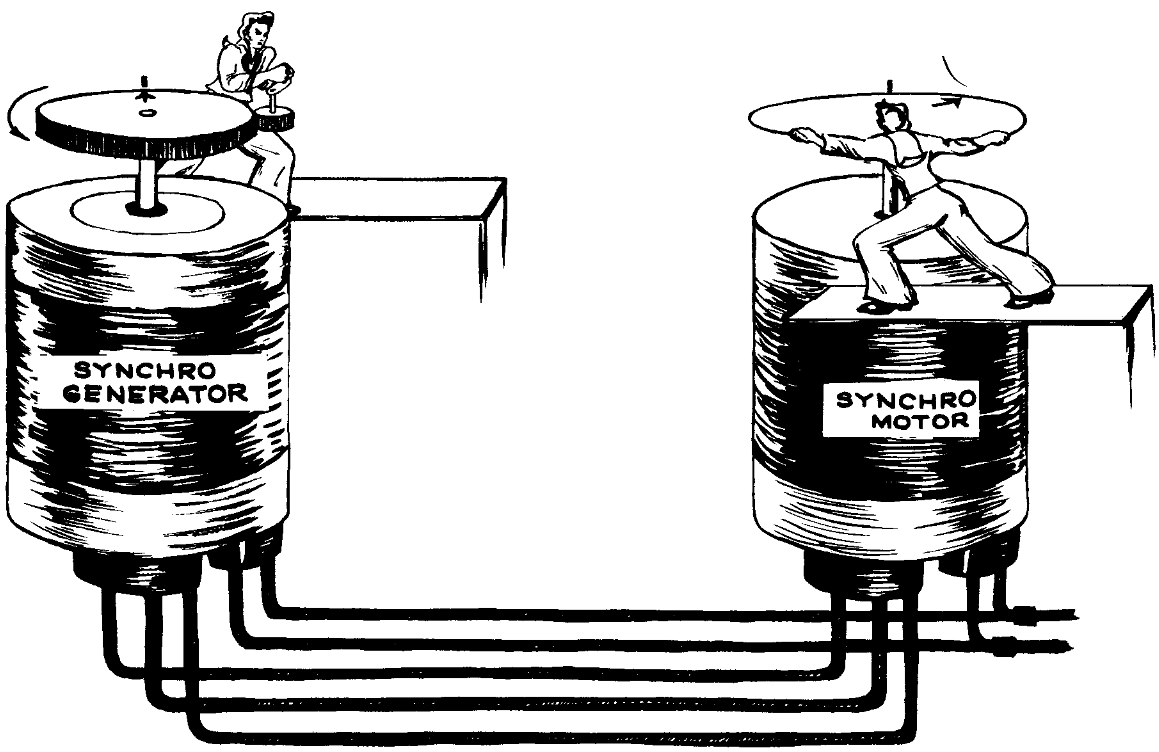
A Synchro system acts very much like two pulleys connected together with a rubber belt. As long as the right-hand pulley turns freely, the other one is easy to turn:



But if something holds the right-hand one back, it no longer follows accurately, and the other one is harder to turn:

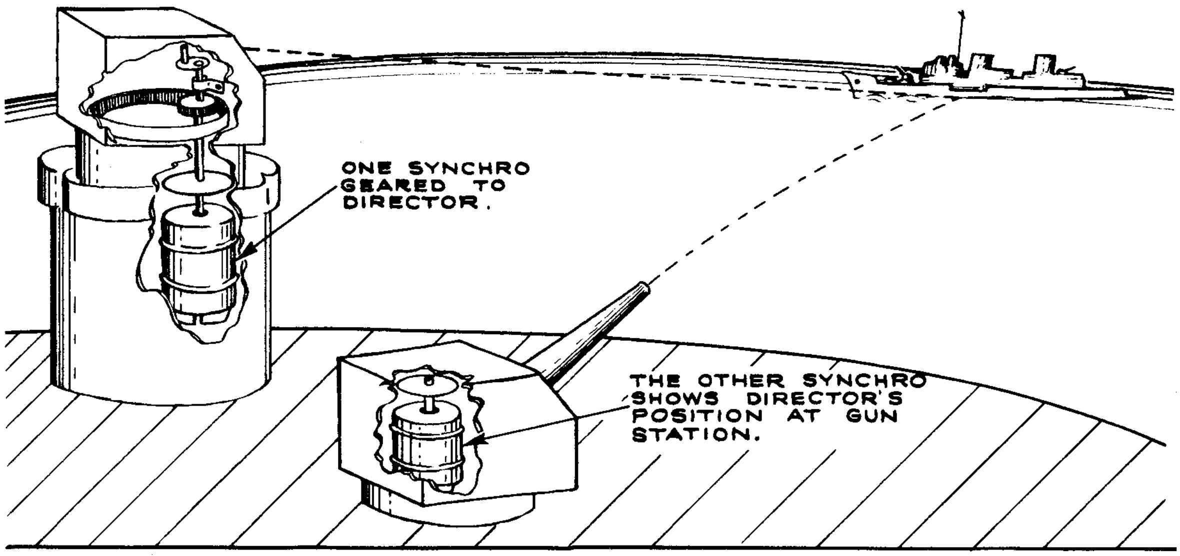


If anything holds back the Motor's shaft in a Synchro system, it doesn't follow accurately, and the Generator's shaft is harder to turn:



The advantage of a Synchro system over any kind of a mechanical arrangement is that the two shafts can be a long distance apart. The only connection needed between them is a few electrical wires, and only a small amount of electrical power is required to operate the system. This makes it possible to do many things that would be impossible or impractical with a purely mechanical system.

For example, a Synchro system can be used to transmit a training order from a Gun Director to a Gun. A Synchro Generator is mounted in the Director and geared to it so that its shaft turns whenever the Director is turned. A Synchro Motor is mounted near the gun, and a dial mounted on its shaft constantly indicates the Director's position.

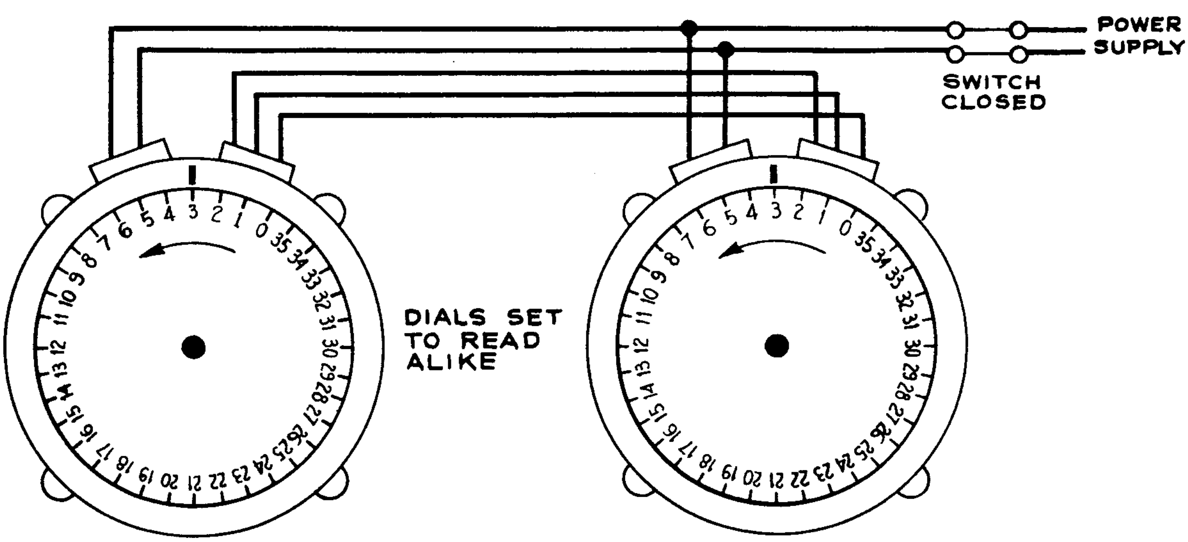


When the Director is trained on a target, the dial on the Motor turns and the gun is trained until its position agrees with that shown on the dial. This aims the gun in the direction of the target.

SYNCHROS ARE SELF-SYNCHRONIZING

An important feature of Synchros that should be clearly understood is that they are **"self-synchronizing."** (This is where the name "Synchro" comes from.)

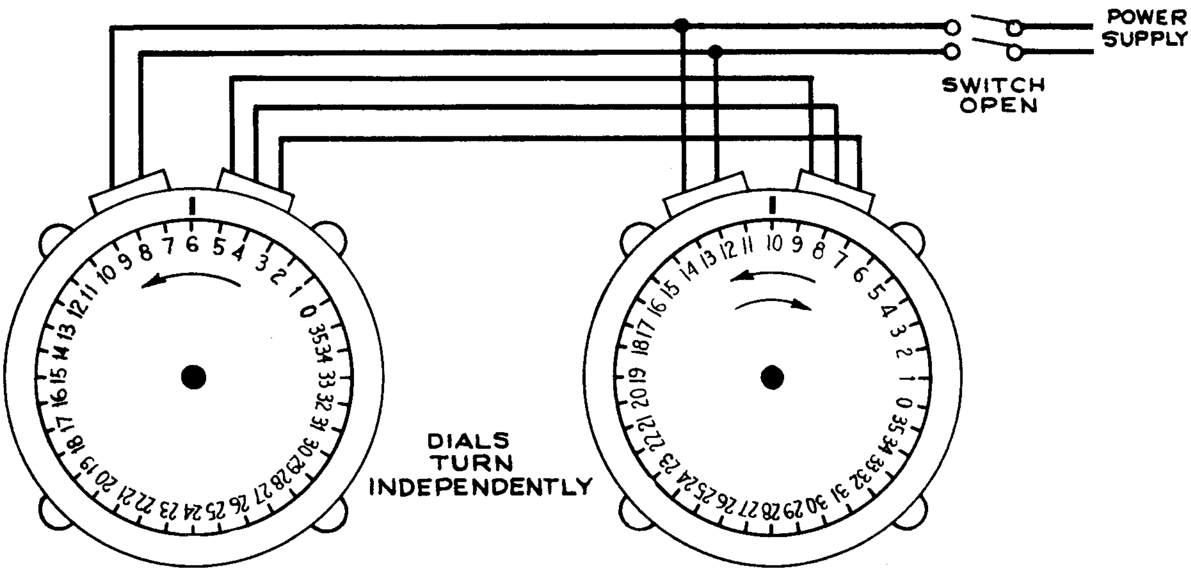
To see what this means, suppose that a Synchro Motor and Generator are connected together electrically with power applied, and dials are locked on the two shafts in such a way that they read the same, like this:



INTRODUCTION

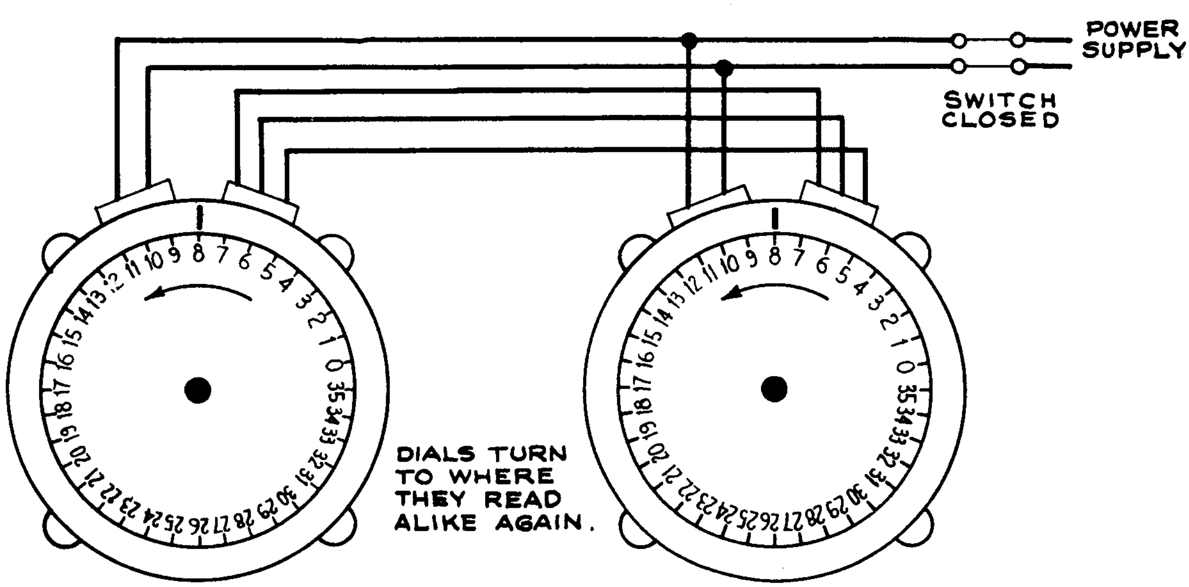
Whenever the Generator's shaft is turned, the Motor's shaft follows, so the dials continue to read the same as long as power is connected.

Now suppose the power switch is opened like this:



Because there is no longer any electricity supplied to the system, there is nothing to make the Motor's shaft turn, so the Generator can be turned to any position at all without affecting it.

Now see what happens if the switch is closed again:



The two dials may read entirely different numbers before the switch is closed, but as soon as this happens they rapidly turn to positions where they read the same, and the Motor's shaft will continue to follow accurately again as long as power is supplied.

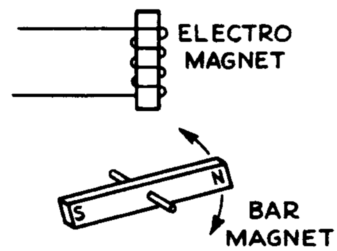
FUNDAMENTALS

To make the operation of a Synchro system easier to understand it will be approached gradually. The following section will show how DC voltages can be used to turn a shaft to any desired position. DC is not used in a Synchro system, but the operation of these simpler arrangements is somewhat similar to that of a Synchro Motor, and will help to understand it.

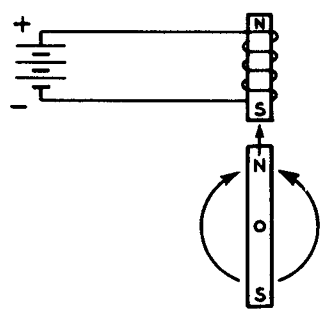
HOW DC VOLTAGES CAN BE USED TO POSITION A SHAFT

The problem is to take a shaft and to mount it in such a way that its position can be changed by varying an electrical voltage.

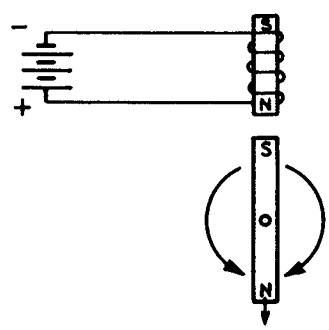
Using One Coil: Perhaps the simplest way to do this is to fasten a bar magnet to the shaft, and to place an electro-magnet nearby like this:



If a DC voltage is applied to the coil of the electro-magnet, one end of the bar magnet is attracted strongly towards it,.and the shaft turns to a position like this:



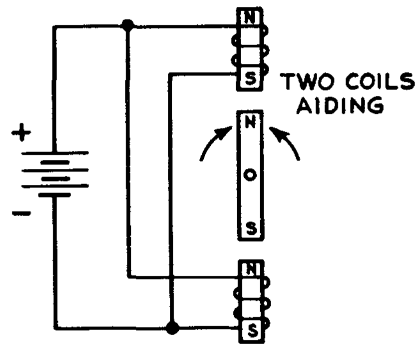
If the polarity of the voltage is reversed, the shaft takes the opposite position:



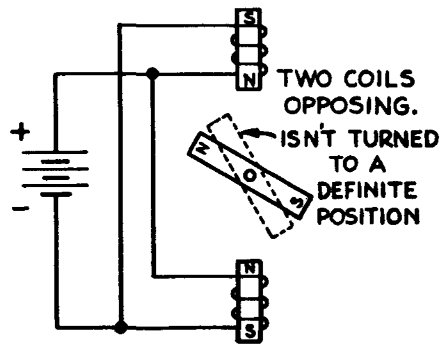
Varying the applied voltage affects only how strongly the magnet is attracted, but does not effect its final position. Apparently, to obtain complete control over the magnet's position, more than one electro-magnet is needed.

Using Two Coils: Placing two electro-magnets in line with each other won't work.

They either *aid* each other, in which case the operation is the same as with a single coil,

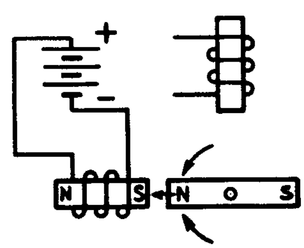


or they *oppose* each other, in which case the bar magnet isn't attracted.

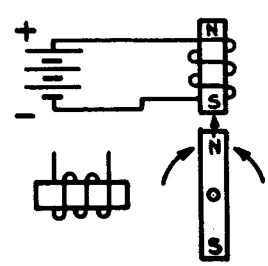


Now consider what happens if the two electro-magnets are placed at right angles:

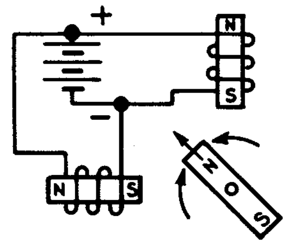
If the voltage is applied only to one coil, the magnet takes this position:



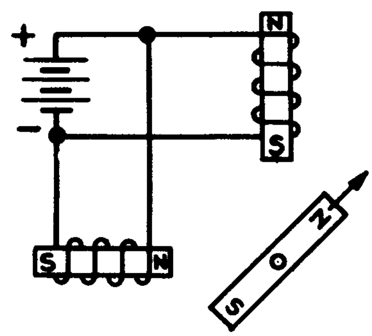
If it is applied only to the other, the magnet turns to here:



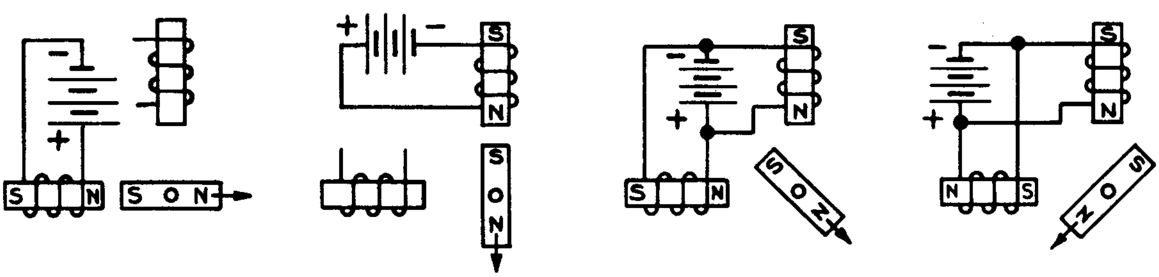
If it is applied to both coils at once, the magnet is attracted equally to each one and comes to rest half-way between:



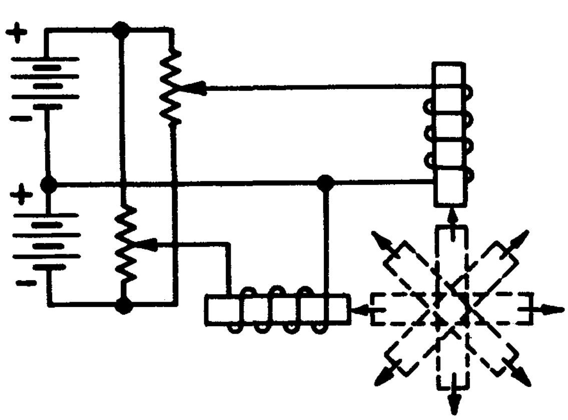
If the polarity of the voltage applied to one of the coils is reversed, the ends of the bar magnet are repelled equally by the two coils, and it takes this position:



By reversing the polarity of the applied voltage in each of these cases, the position of the magnet is reversed and so it can be turned to four other positions like this:



Finally, if the *magnitude* of the voltage applied to each coil is varied as well as the polarity, the bar magnet can be turned to any position around the circle, like this:



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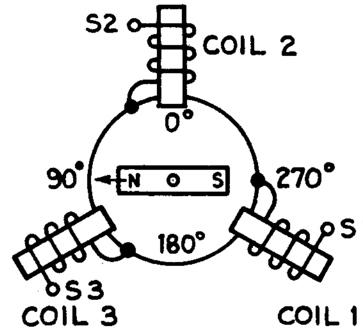
Using Three Coils: An arrangement that gives somewhat greater accuracy, and is more nearly like a Synchro Motor, is obtained by using three electromagnets.

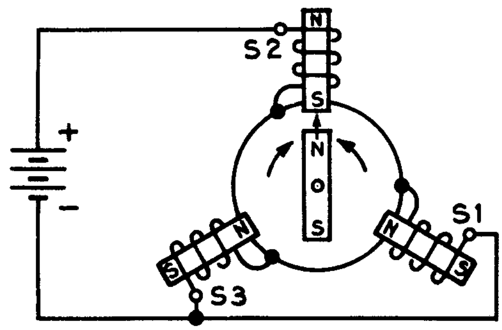
A convenient way to connect them is like this: (assume that all three coils are alike).

The three free ends of the coils will be called "S1, S2, and S3" as shown (because this ties in nicely with the standard markings on a Synchro Motor).

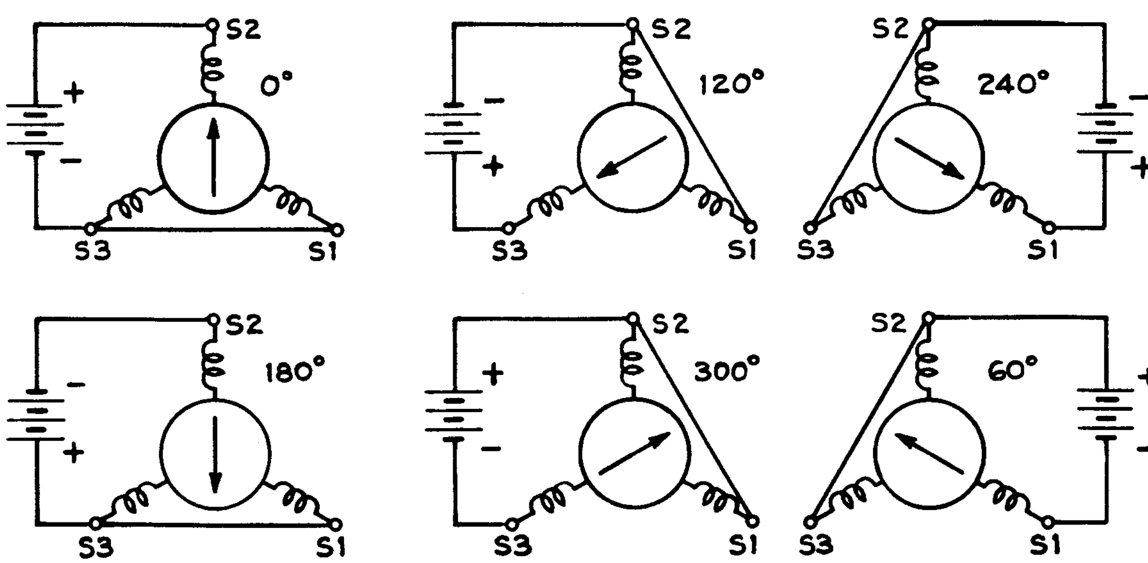


Now, if S1 is connected to S3 and a voltage is applied between S2 and S1-S3, one end of the magnet will be attracted to coil 2, and the other end will be attracted equally to coils 1 and 3, so it will point to 2 like this:

(This will be called the 0° position.)



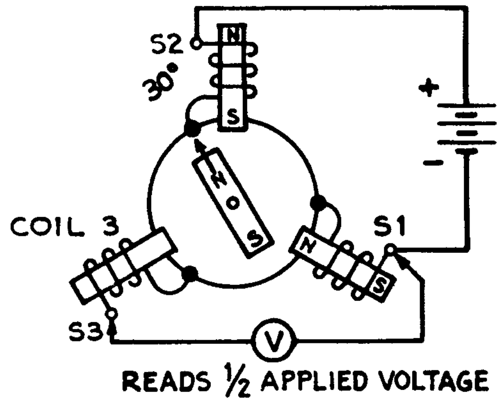
By applying the voltage between any one terminal, and the other two tied together, the shaft can be made to assume any one of these six positions: (The arrow point is at the N end of the magnet.)



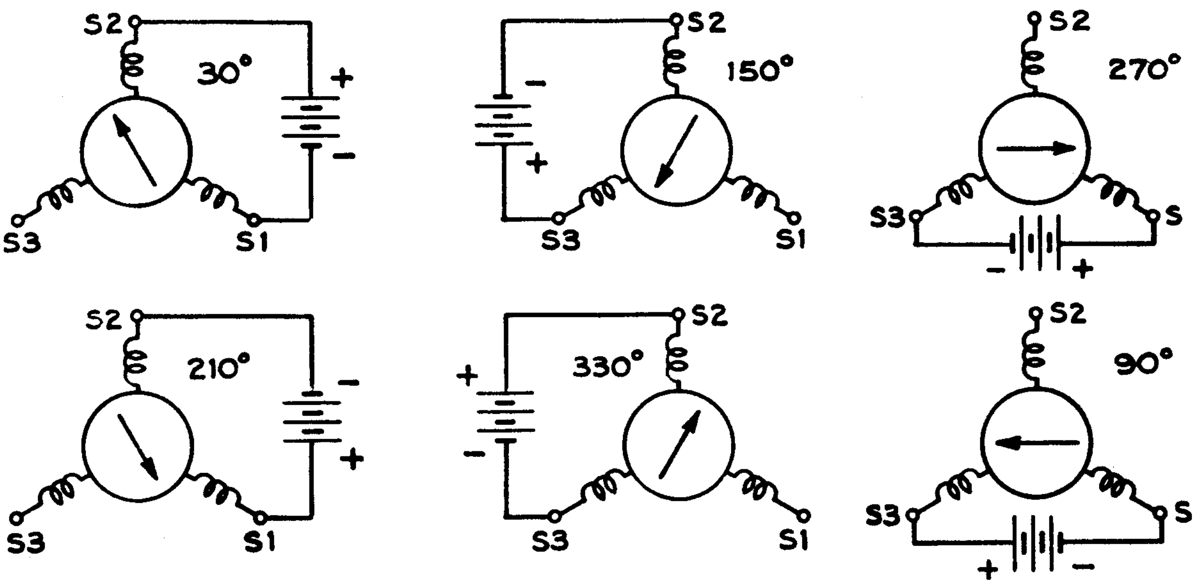
Now consider what happens when the voltage is applied between S1 and S2, and S3 is left open:

One end of the magnet is attracted to coil 1, and the other end is attracted equally to coil 2, so it splits the difference and points to 30°.

Notice that one-half the total voltage drop occurs across coil 1, and there is no drop across coil 3 (since there is no current flowing through it). Therefore a voltmeter connected between S1 and S3 reads one-half the applied voltage.

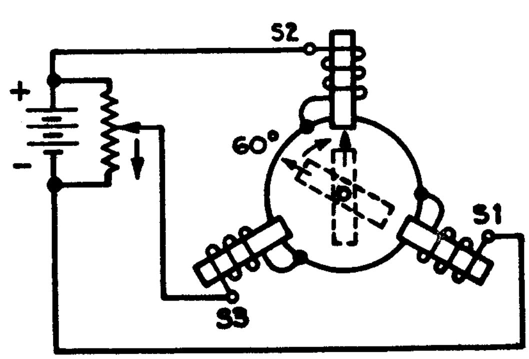


By applying the voltage between various pairs of terminals, the shaft can be made to assume any one of these six positions:



Finally, suppose a fixed voltage is maintained between S1 and S2, and the voltage between S2 and S3 is varied from 0 to this same value, like this:

With no voltage between S2 and S3 the magnet points to 60°. As the voltage is increased it turns clockwise, reaching 30° when the voltage from S2 to S3 is one-half that from S1 to S2, and reaching 0° when the two voltages are equal.

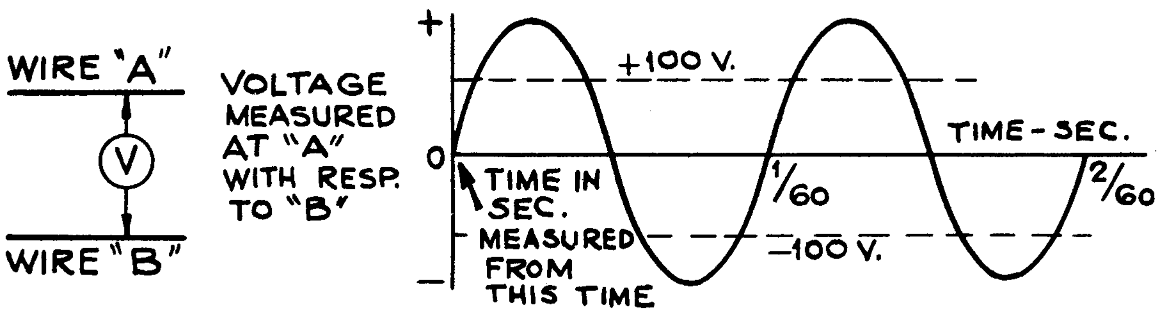


By applying the right combination of voltages to these three coils it is possible to make the magnet, and the shaft to which it is attached, turn to any desired position. This is quite similar to the way a Synchro Motor works, except that, in a Synchro, AC voltages are used in place of DC. The next section will discuss the effects that result from the use of AC voltages.

THE EFFECT OF USING AC VOLTAGES

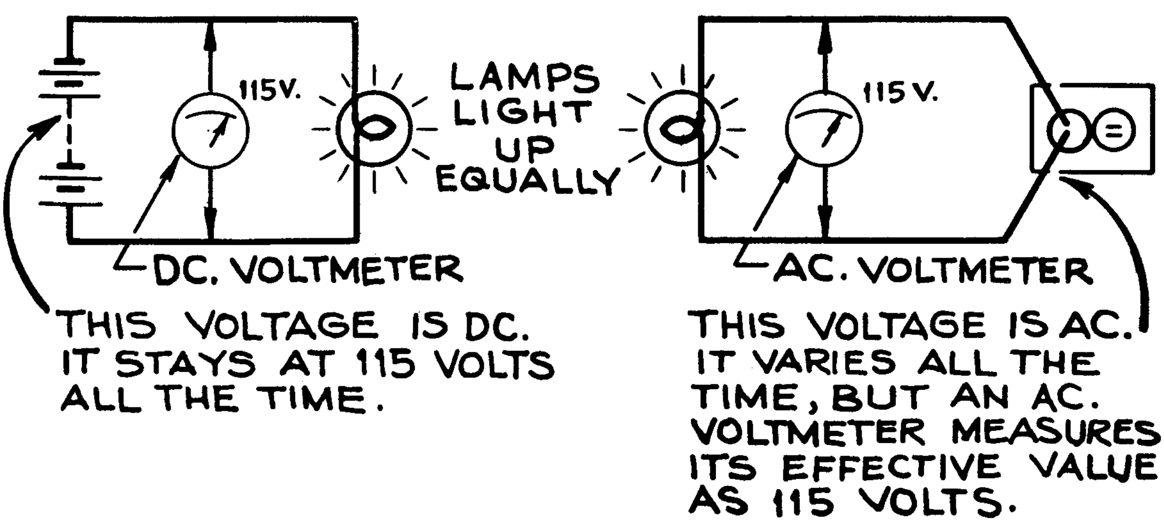
Practically, 60 cycle AC voltages are used in a Synchro system. To understand how this affects its operation, consider some of the characteristics of AC voltages.

What is Meant by a "60 Cycle AC Voltage": To say that the voltage between the two wires of an AC supply is "60 cycles, AC" means that voltage is changing all the time, going through a complete set or "cycle" of values 60 times every second. If the actual voltage between two such wires is measured with a very high-speed voltmeter that shows its various values accurately, and the resulting values are plotted against time, the graph looks like this:



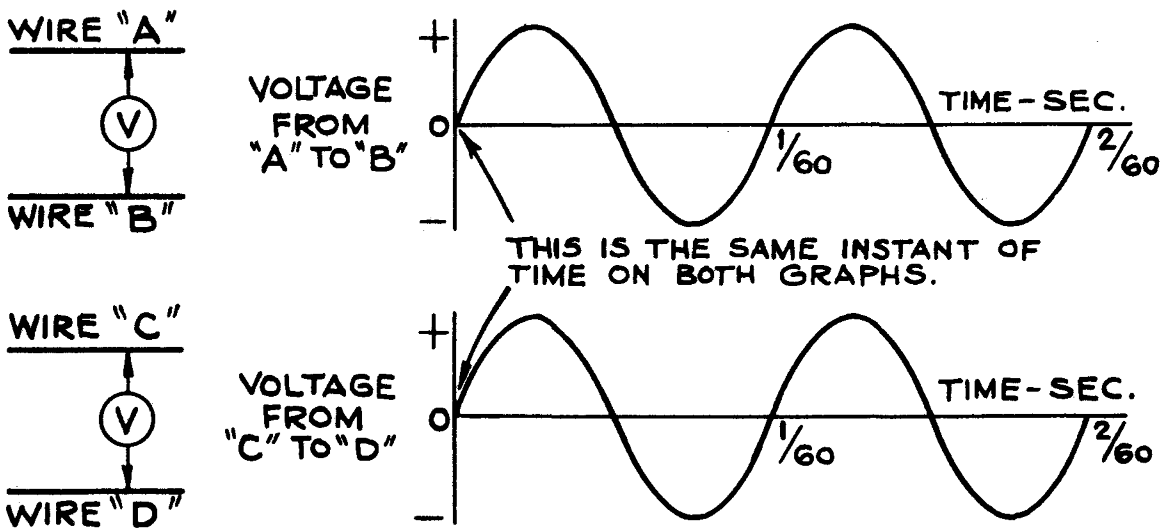
This graph says that the voltage is zero at a certain time, rises to over 100 volts positive at a little later time, then falls back to zero; goes just as far negative as it did positive, and then comes back to zero again. This process is repeated over and over again, 60 times every second.

To say, in addition, that the magnitude of this AC voltage is 115 volts, doesn't mean that it stays at that value, but means simply that this *varying* voltage will light up a lamp connected to the two wires, or heat up a soldering iron just as much as would a *constant* voltage of 115 volts.

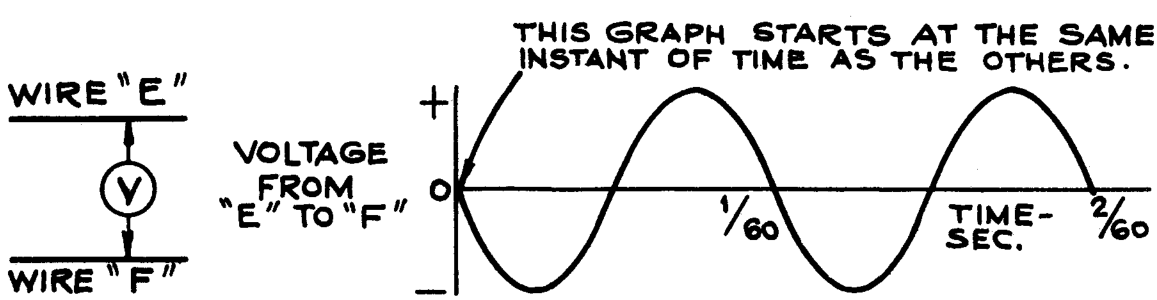


A Way of Indicating Phase Polarity: It is often necessary, in discussing AC circuits, to compare the polarities of two voltages. Since the polarity of an AC voltage is positive half the time and negative the other half, it doesn't mean anything to say that one voltage is positive and another negative (unless a particular time is stated). Instead, the idea of *phase relation* is used.

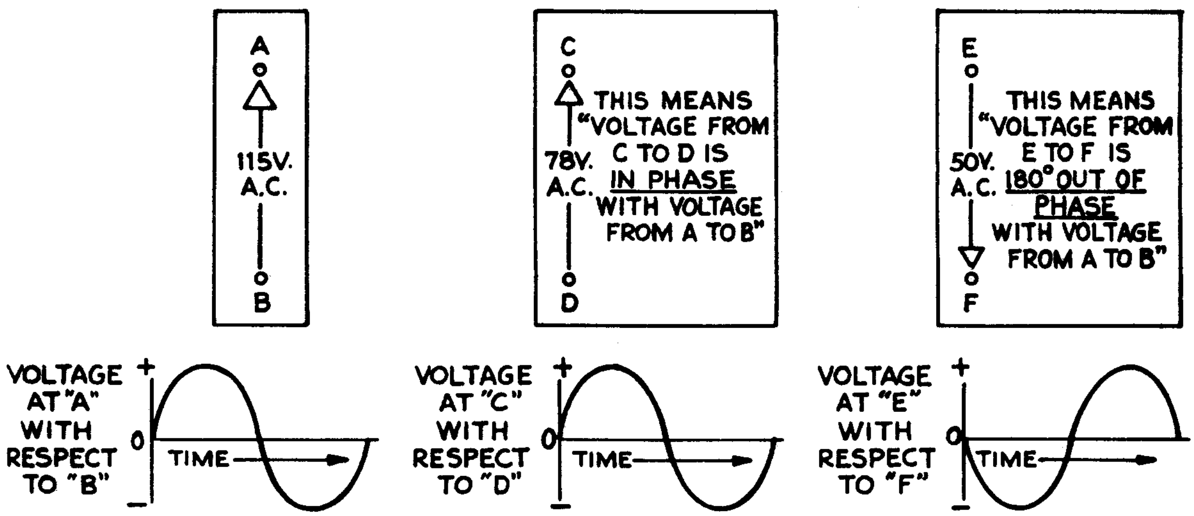
If two AC voltages vary in such a way that they are both positive during the same time, and both negative during the same time, they are said to be *in phase* with each other. For example, the voltage measured at wire "C" with respect to wire "D" is *in phase* with the voltage from "A" to "B" if it varies like this:



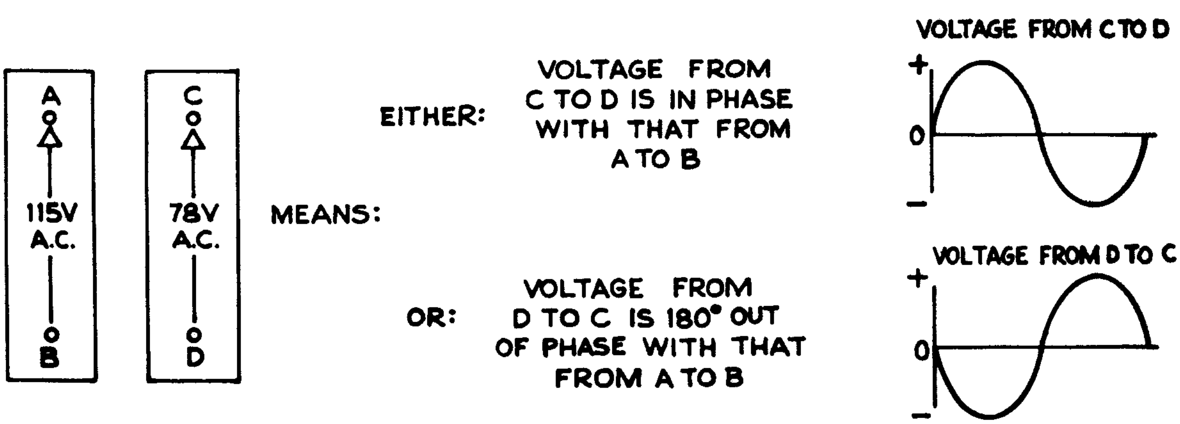
If two AC voltages vary in such a way that one is positive when the other is negative, they are said to be *180° out of phase* or in *phase opposition*. For example, the voltage from "E" to "F" is 180° out of phase with the two voltages shown above if it varies like this:



Throughout the rest of this booklet a simple method of showing this "phase polarity" relation is needed. It will be shown by means of an open-headed arrow, like this:



Notice that it means the same thing to say "The voltage from *C* to *D* is *in phase* with that from A to B," or as to say "The voltage from *D* to *C* is *180° out of phase* with that from A to B."



Reversing the connection to an AC supply reverses the *phase* of the resulting voltage just as reversing the connections to a DC supply reverses the *polarity*.

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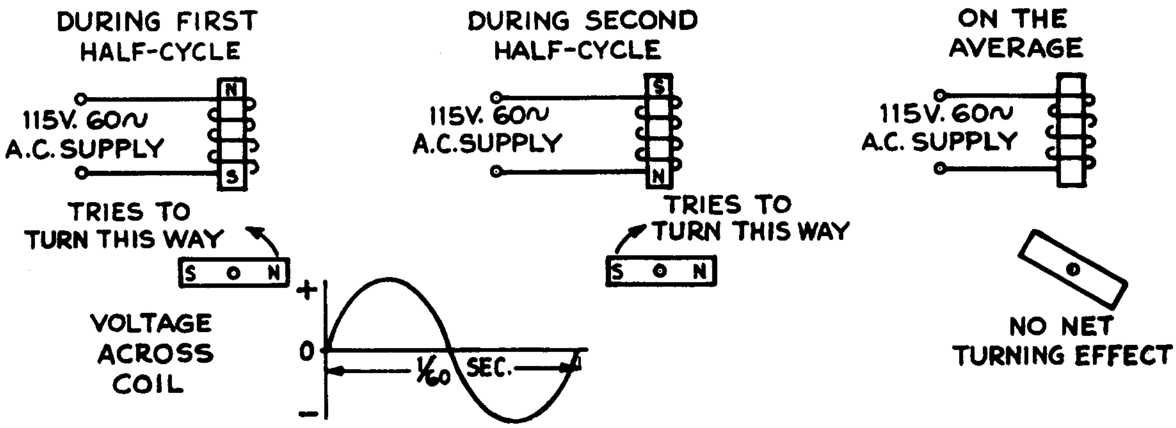
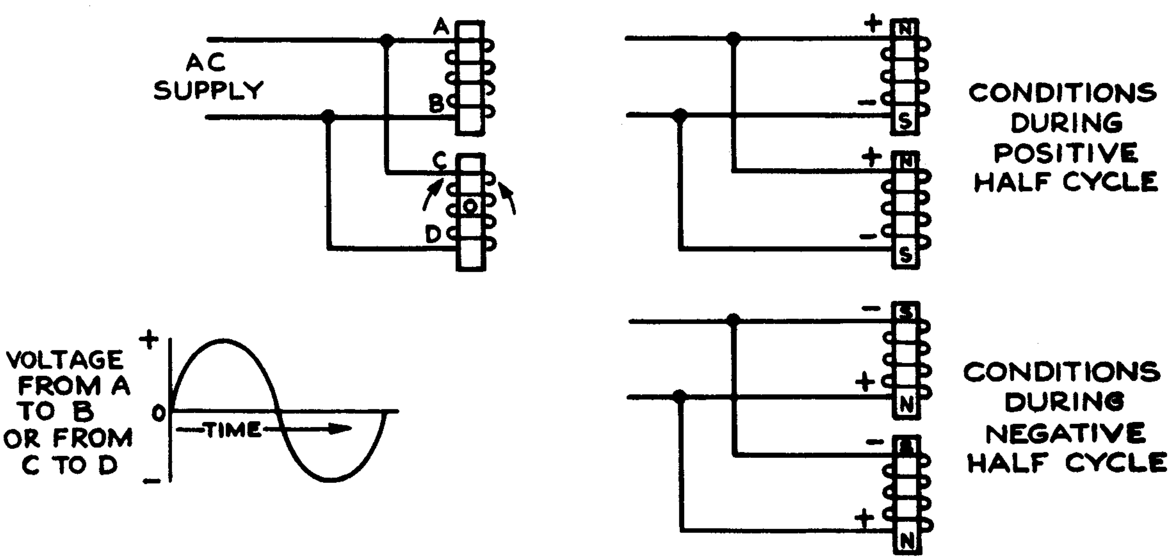
Using an AC Coil: Now consider what happens if a fixed AC electro-magnet is used with a bar magnet.



(The current through a coil like this actually doesn't reverse at exactly the same time as the applied voltage, but it will make the following discussion simpler if this is assumed.)

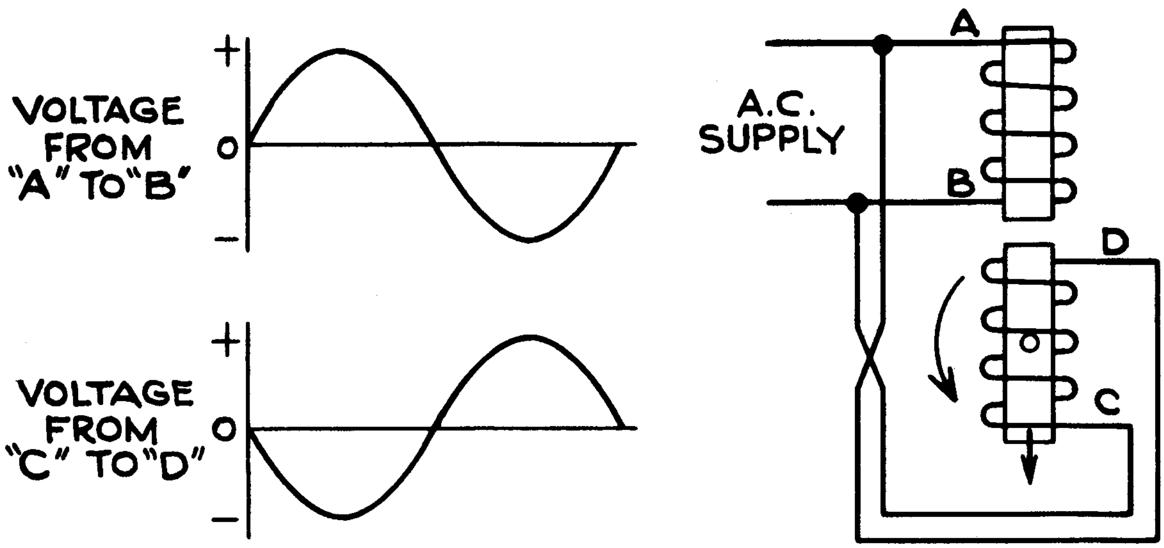
The polarity of the electro-magnet changes during each half-cycle of the applied voltage, so that the bar magnet is pulled in one direction half the time, and in the other direction the rest of the time. This all happens so fast that the bar magnet can't follow the changes, so that the pulls simply cancel each other and the actual turning effect is zero.

Replacing the Bar Magnet with Another AC Coil: In order to get a system that works with AC voltages applied, an electro-magnet must be mounted on the shaft in place of the bar magnet, like this:



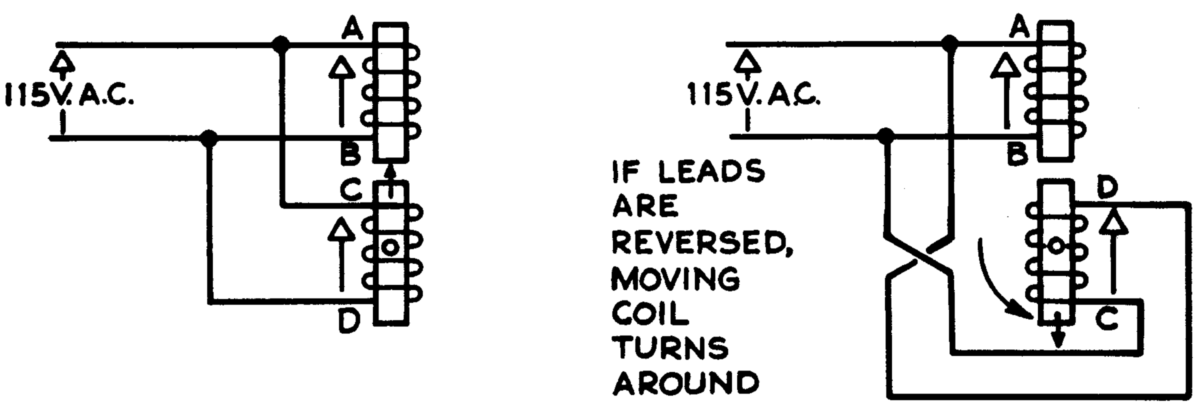
During the positive half-cycle the bottom end of the fixed coil attracts the top end of the rotating coil, and it turns to the position shown. Since the voltage applied to *both* coils reverses during the negative half-cycle the bottom end of the fixed coil still attracts the top end of the rotating coil so it stays in this position.

If the connections to the rotating coil are reversed, so that the polarity of the voltage from C to D is always opposite to that from A to B, the D end of the rotating coil is attracted to the B end of the fixed coil, so it turns around like this:



In short, this AC-operated, rotating electro-magnet works, with the AC fixed coil, just about the same way as the bar magnet worked with a DC fixed coil. It points either directly towards, or directly away from the fixed coil, depending on the phase relation between the voltages applied to the two coils.

Now consider the operation of these two electro-magnets using the "arrow" method of showing relative phase:



ARROWS ALWAYS TEND TO POINT SAME WAY

Notice that, when the two coils are wound in the same direction, they always tend to turn so that the arrow heads point in the same direction.

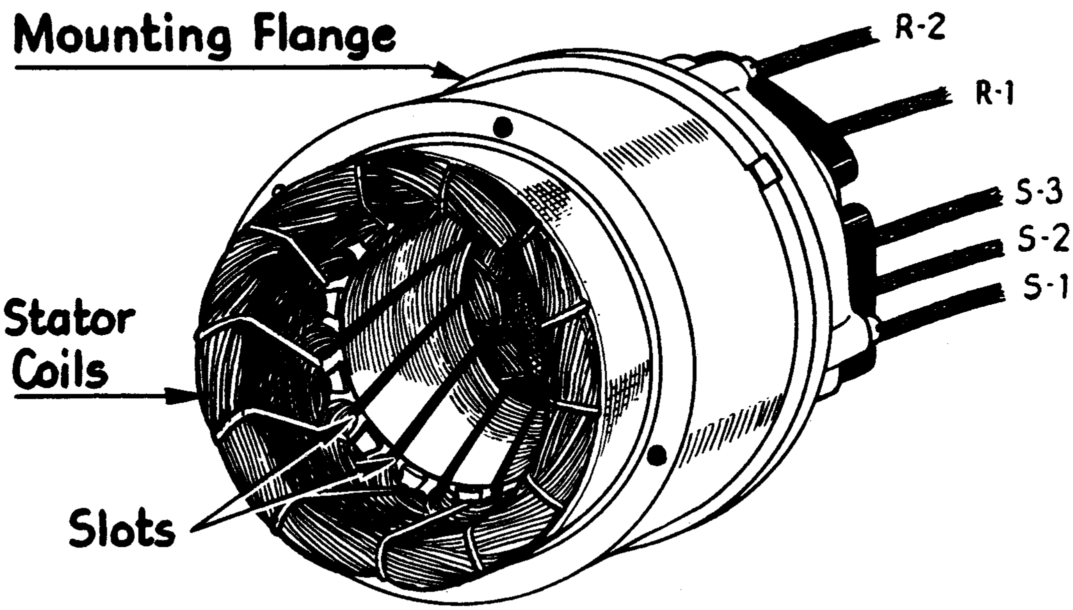
Since *one* AC electro-magnet can be used to turn a rotating coil to either one of *two* positions, it shouldn't be too hard to see how *three* AC electro-magnets can be used to turn a coil to *any* position, just as three DC coils were used to turn a bar magnet to any position. A Synchro Motor or Generator is essentially just three fixed electro-magnets positioned around a fourth which is mounted on a shaft. The next section will describe how these units are built and how they work.

SYNCHRO MOTORS AND GENERATORS

THE CONSTRUCTION OF A SYNCHRO MOTOR OR GENERATOR

Before going into the detailed operation of a Synchro Motor and its use with a Synchro Generator to form a Synchro system, the construction of these two units will be described. Except for a few details, the construction of a Motor is the same as that of a Generator.

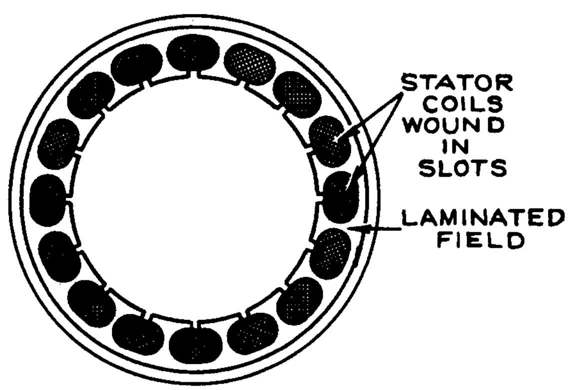
The Stator: The fixed part of a typical Motor or Generator (called the STATOR) looks like this:



The Stator of a Typical Synchro Motor or Generator

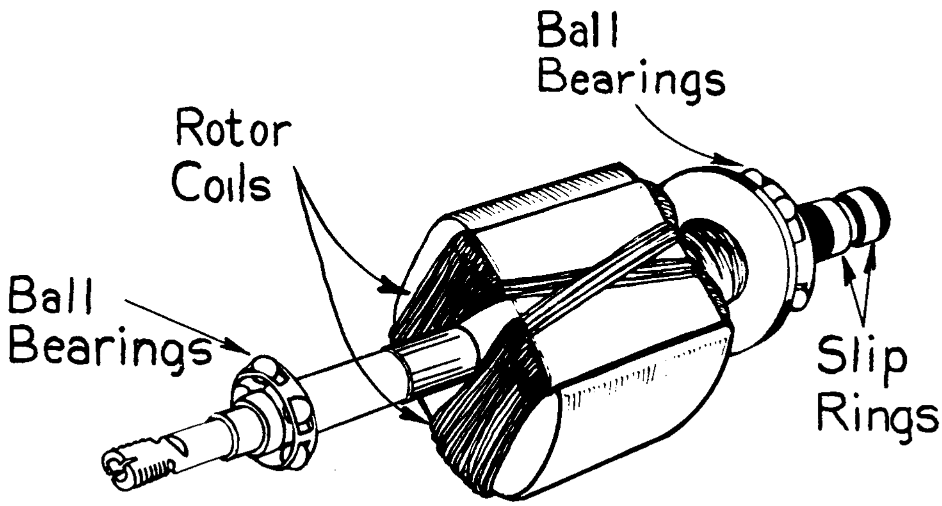
It is made by winding a number of coils in slots around the inside of a laminated iron field structure, very much like an ordinary AC motor.

These coils are divided into three groups spaced 120 degrees apart around the inside of the field. Actually the groups overlap somewhat so that the attractive force tending to pull the rotor into position is the same for all positions of the rotor.



Cross Section of Stator

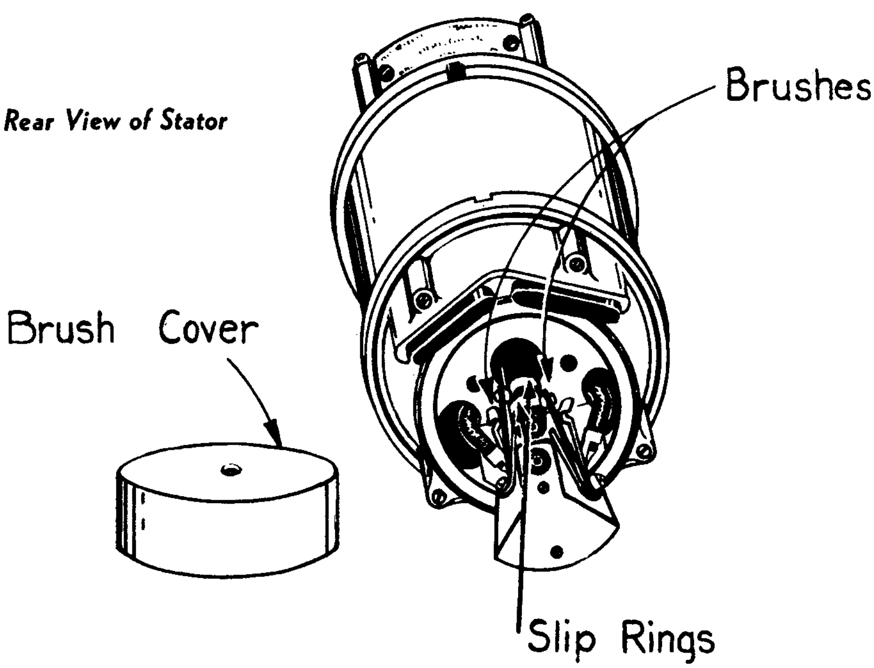
The Rotor: The part of a Motor or Generator that turns (called the ROTOR) is made by winding a single coil of wire on a soft iron core. This core is mounted on a shaft so that the axis of the coil is perpendicular to the shaft. The ends of the core are carefully shaped to get best performance, and the shaft is mounted on ball-bearings to keep friction low. The rotor of a typical Synchro Generator looks something like this:



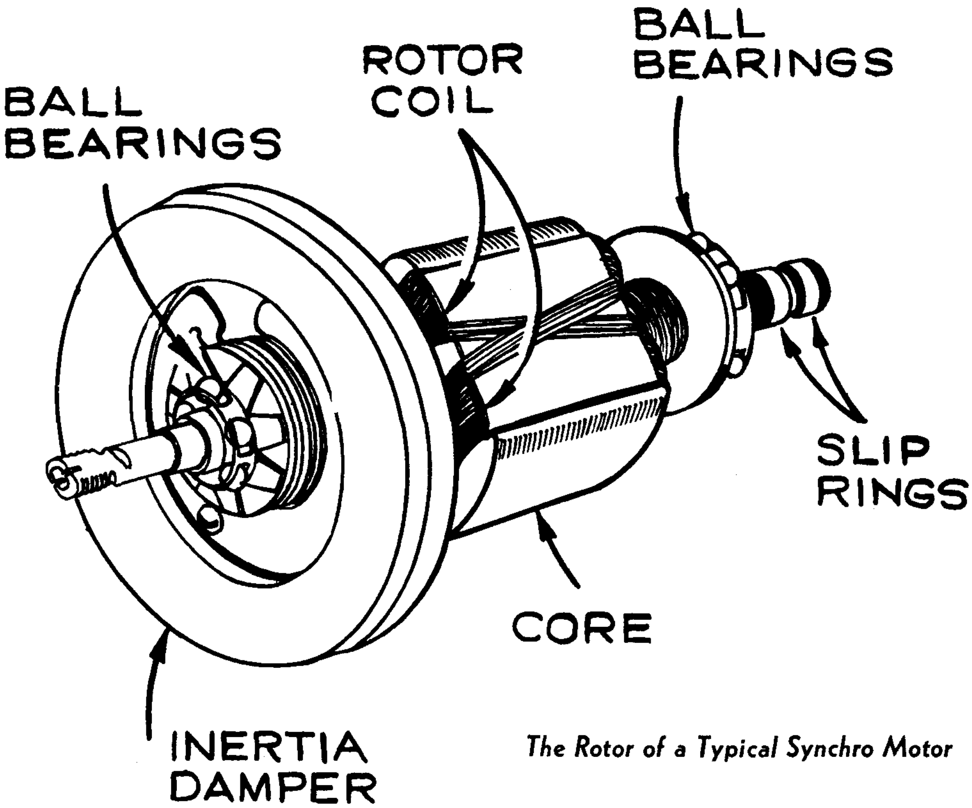
The Rotor of a Typical Synchro Generator

This rotor turns around inside the stator, and connection to the rotor coil is made by means of two brushes which ride on slip rings mounted on one end of the shaft like this:

Rear View of Stator



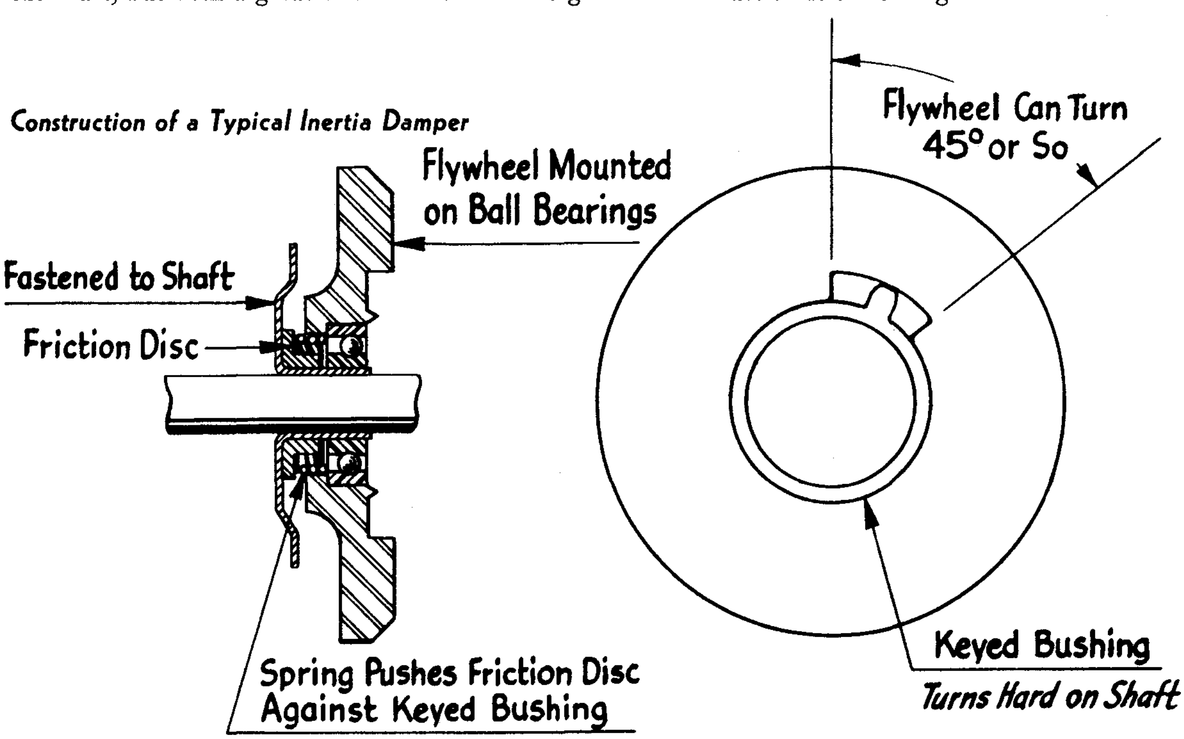
The rotor of a Synchro Motor is made very much the same, but differs in one important respect. Due to the fact that it is quite similar in some ways to an ordinary AC motor, a Synchro Motor has a tendency under certain conditions to "take off" and oscillate violently, or spin continuously at a high speed. This is particularly likely to happen when its shaft is suddenly turned, as, for example, when power is first applied to the system. To prevent this a heavy metal flywheel called an "inertia damper" is mounted on one end of the shaft, like this:



The Rotor of a Typical Synchro Motor

This flywheel is mounted so that it turns freely on the shaft for 45° or so, and then runs into a keyed bushing. This bushing is fastened to the shaft through a friction disc so that it can turn on the shaft, but with a great deal of friction. The general construction is something like this:

Construction of a Typical Inertia Damper



For slow changes in the position of the shaft the flywheel simply follows along without much effect. If the shaft tries to turn suddenly, the flywheel tends to stand still, so the friction disc acts as a brake, slowing down the motion of the shaft. Thus the shaft never gets going fast enough to start oscillating or spinning. If oscillation or spinning occurs it is a pretty sure sign that something is wrong with this damper.

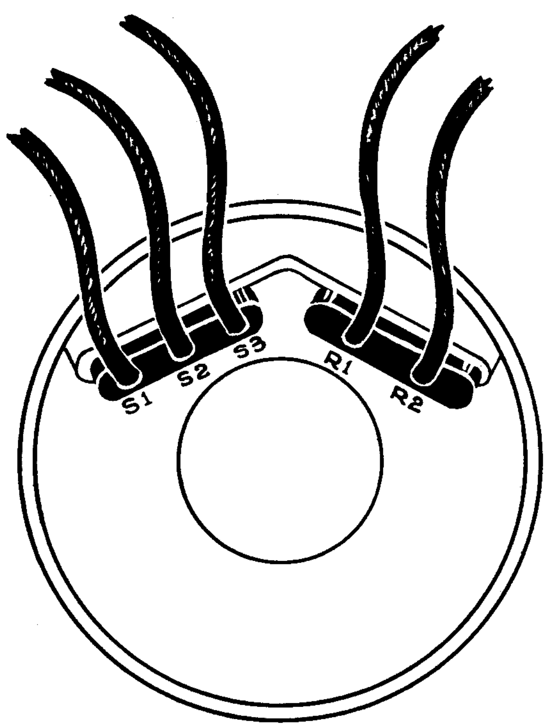
The Difference Between a Synchro Generator and a Synchro Motor: The difference between these two units is in their *application.* Electrically a Generator of a given size is identical with a Motor of the same size. Actually a Generator is simply a Motor with the inertia damper and certain other refinements left off. These are needed on a Motor, but not on a Generator and would simply increase its cost if added.

A Synchro Generator is always used in a position where its shaft is driven by some large unit. In such a position it can't possibly oscillate or spin, so no damper is needed. A Synchro Motor, on the other hand, is always used in a position where its shaft drives a small dial or operates a switch. In such a position a damper must be used.

Never try to use a Generator in a Motor position, it will oscillate or spin.

Use a Motor in a Generator position only in an emergency when no Generator is available. A Motor is unnecessarily expensive for such applications, and its use represents a waste of material.

Lead Markings: Synchro Motors and Generators are made in a number of sizes and types, but the rotor and stator connections are marked in the same way on all standard units. The wires connecting to the two ends of the rotor coil are marked R1 and R2, and the three wires connecting to the three free ends of the stator coils are marked S1, S2 and S3. Looking at the back of a Synchro these leads are always arranged in this order:

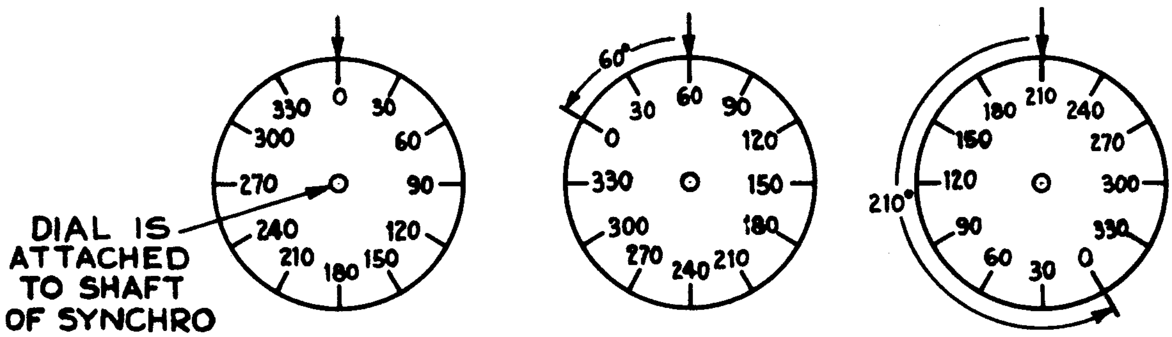


Rear View of Stator

THE OPERATION OF SYNCHRO MOTORS AND GENERATORS

Before taking up the operation of a complete Synchro system, in which two Synchros are connected together, the operation of a unit by itself will be described.

The Standard Way of Describing Shaft Position: There is a standard way of describing the position of a Synchro rotor which makes it possible to connect any unit mechanically, and be sure that it will turn to the correct position when connected electrically to a standard Generator. The position which the rotor takes when it is lined up with the stator coil connecting to S2 is called the "electrical zero" position. Other positions are measured in degrees, assuming that you are looking at the *shaft end* of the unit, and that the shaft turns *counter-clockwise* for an increasing number of degrees. The easiest way to think of it is to assume that a "standard dial" is mounted on the shaft like this:



If dial is set to read 0° when the rotor is on "electrical zero."

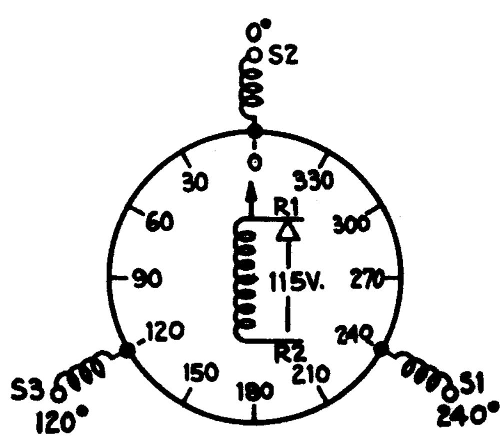
It reads 60° when the rotor is in the standard 60° position.

And 210° when the rotor is in the standard 210° position.

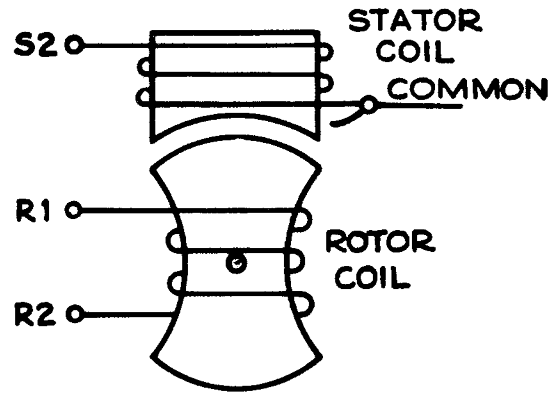
A Synchro Diagram: In order to make it easier to analyze the operation of a Synchro Motor or Generator, it will be represented by a diagram like this:

Think of the rotor coil as turning around an axis in the center of the diagram, and that the arrow on the R1 end of the rotor points to the number which indicates the electrical position of the rotor.

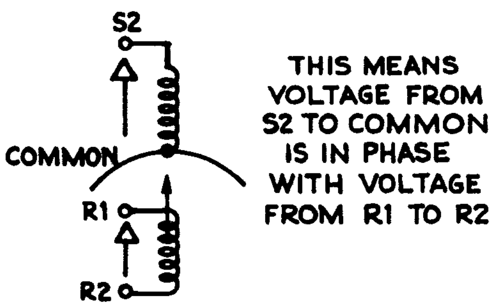
Also assume that the rotor coil is wound in the same direction, going from R1 to R2, as is each of the stator coils going from outside to inside, as shown at the top of the next page. (The rotor is shown in the 0° position.)

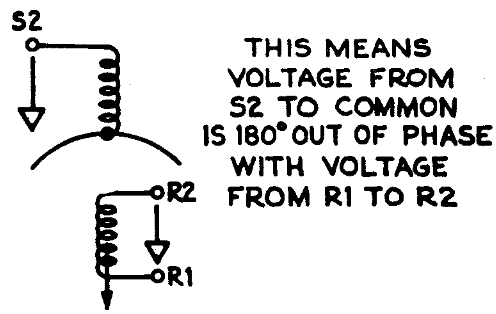


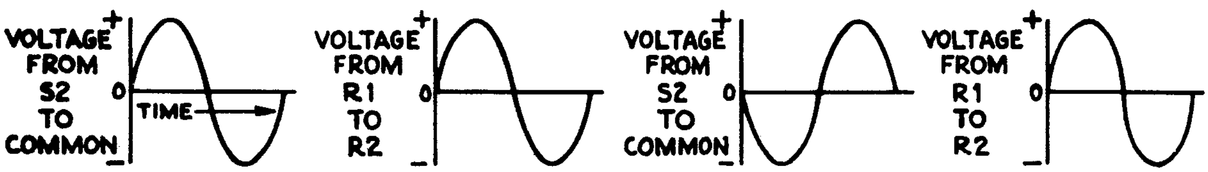
The stator coil shown on this diagram actually represents a number of coils on the stator of the Synchro. Each group of coils is mounted on the stator and connected in such a way that its effect on the rotor can be represented quite accurately by a single coil in the position shown.



The system of showing phase polarity that was described in a previous section can be used very nicely to show the relations between the various voltages in a Synchro unit. For example, the voltages across coil 2 and the rotor are related like this for two different rotor positions:

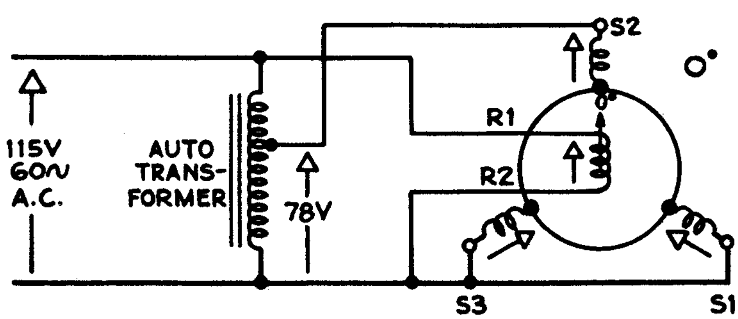






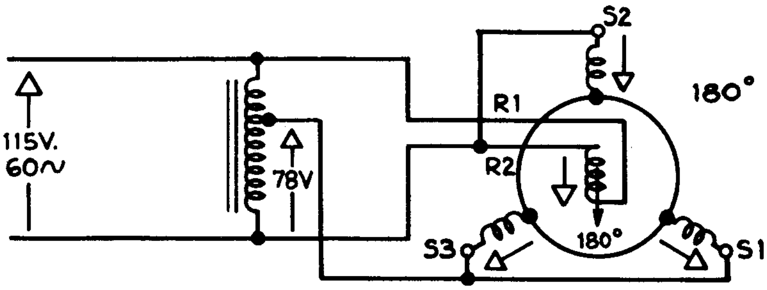
The Voltages Required to Position a Synchro Motor: (Note: The following discussion of the voltages required to turn a Motor's shaft to various positions applies equally well to a Generator, except that, without a damper, a Generator's shaft will tend to oscillate if connected this way.)

In order to make a standard Synchro Motor turn to electrical zero, 115 volts AC (effective value) must be applied to the rotor leads, with no voltage between S1 and S3, and 78 volts applied between S2 and S1-S3 in such a way that the voltage at S2, (measured with respect to S1-S3) is *in phase* with the voltage measured at R1 with respect to R2. One way this could be done, practically, would be to short S1 to S3, and make other connections like this:

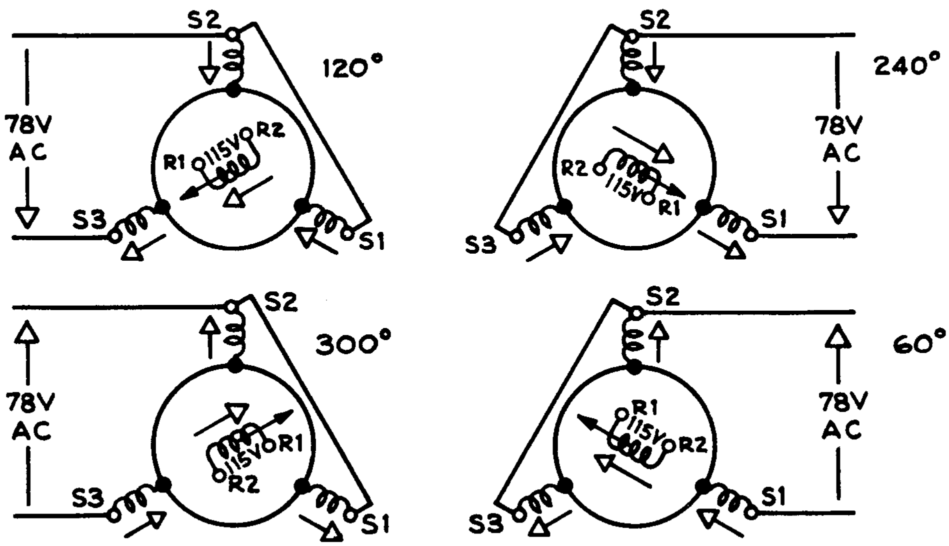


When a Synchro Motor is connected like this, the shaft turns to a certain position ("electrical zero"), and cannot be moved from there as long as the supply is connected. The reason for this is that the R1 end of the rotor is attracted strongly to the lower end of coil 2. The R2 end of the rotor is attracted equally to the upper ends of coil 1 and coil 3, so the rotor turns to 0°.

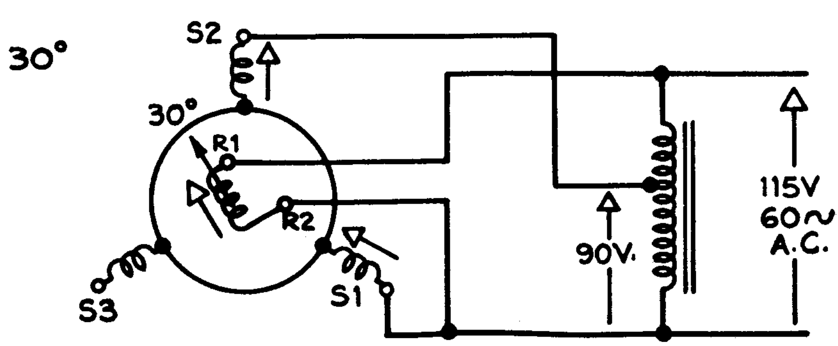
If the leads to the 78 volt supply are reversed, the phase of the voltages across the stator coils is reversed, and the rotor coil reverses its position, pointing to 180° like this:



If other pairs of stator leads are shorted together, and 78 volts applied as shown, the rotor can be made to turn to four other positions like this:

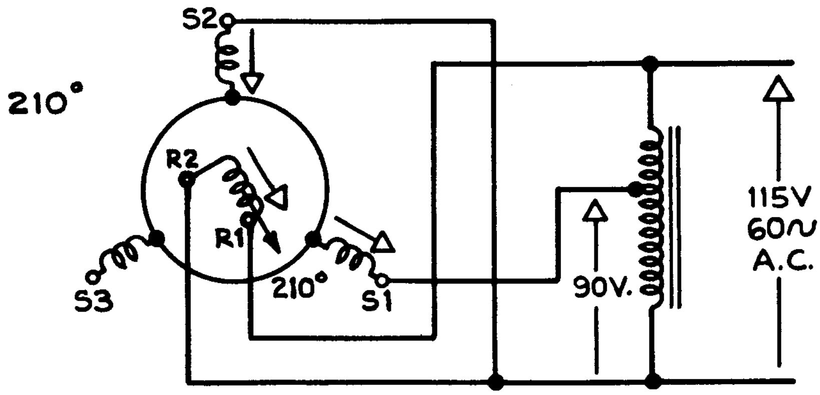


Now suppose S3 is left open, and 90 volts is applied between S2 and S1 (it has to be 90 volts to get the same attraction as before), like this:

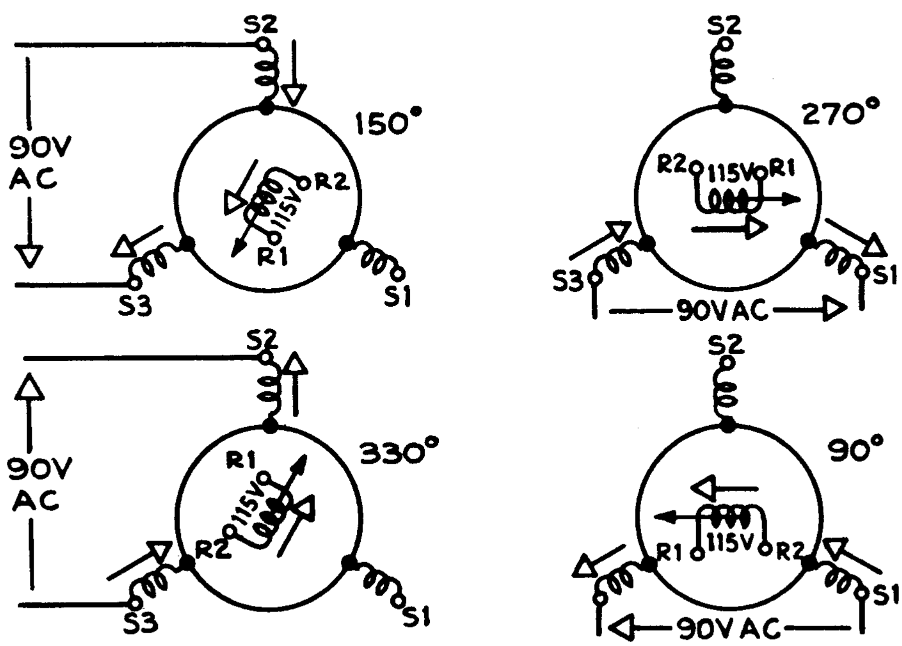


The R1 end of the rotor is attracted to coil 2, and the R2 end is attracted equally to coil 1, so it takes a position half-way between, and points to 30°. Since S3 is open, the voltage between S3 and either S1 or S2 is 45 volts.

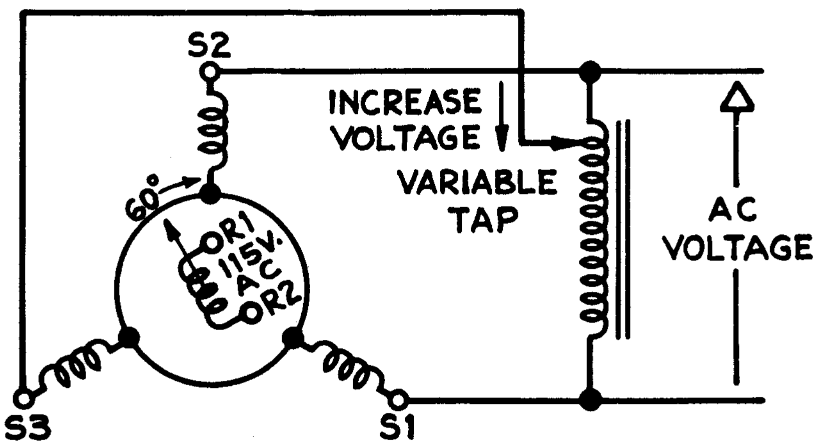
The position of the rotor can be reversed by reversing the 90 volt supply leads like this:



And four similar positions can be obtained by connecting the 90 volt supply to various pairs of stator leads:



Now suppose that a fixed voltage, in phase with the voltage from R1 to R2, is maintained between S2 and S1. Then another voltage, also in phase with R1-R2, is applied between S2 and S3 and gradually increased from zero volts until it is equal to the voltage from S2 to S1.



With no voltage between S2 and S3 the rotor will point to 60°. As the voltage is increased, the R2 end of the rotor will be attracted more and more by the current flowing in coil 3, and it will turn towards the 0° position, reaching it when the voltage from S2 to S3 equals that from S2 to S1.

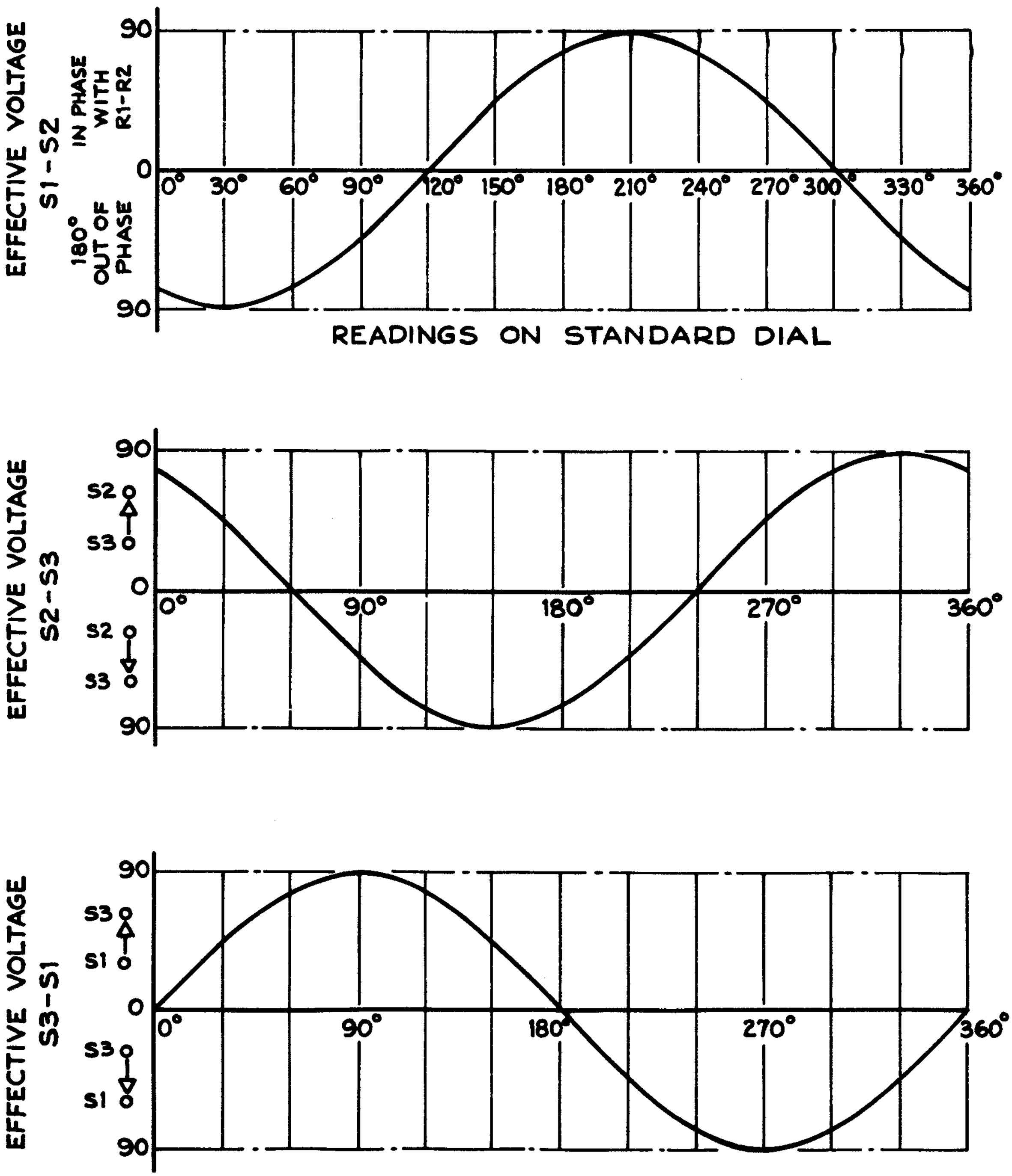
The Stator Voltages For Any Rotor Position: By using stator voltages intermediate between those that have been described it is possible to make the rotor of a Synchro assume any position around the circle. The voltages needed to make the rotor assume all possible positions are plotted out on the opposite page.

Notice that these graphs show the *effective* value of the voltage (the value that would be measured with an ordinary AC voltmeter) between various pairs of stator leads. These voltages are shown *above* the zero line when they are *in phase* with the voltage from R1 to R2, and *below* the line when they are *180° out of phase* with that voltage. They are plotted for each position of the rotor, as shown by the readings on a standard dial attached to the shaft.

To check this against what has been discussed previously, notice that, to turn the shaft to 0°, the voltage from S3 to S1 is 0, there is 78 volts between S2 and S3, and 78 volts between S1 and S2. By increasing the voltage between S1 and S2 to 90 volts, and decreasing each of the others to 45 volts, the shaft is turned to 30°. If S2-S3 falls to 0, and each of the others goes to 78 volts, the shaft turns to 60°; and so on. For each position of the shaft there is a certain definite value and phase condition of each of the three voltages.

Due to the way the rotor and stator windings are arranged on a standard Synchro, these curves have the shape of a sine-curve. In other words the graphs *look like* time-graphs of sinusoidal voltages. They show something entirely different, however, and should not be confused with time-graphs. In thinking about a Synchro system, remember that all of the voltages in the system are AC, varying positive and negative 60 times per second; that they are either in phase, or 180° out of phase with each other; and that their effective values vary, for various positions of the rotor, as shown on these graphs.

A Synchro is not a three-phase machine and none of the ideas that apply to three-phase motors or generators can be applied to a Synchro.

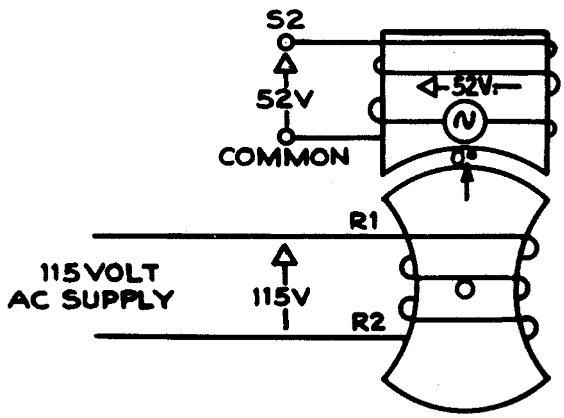


The Stator Voltages Required to Turn a Synchro Motor to Any Position

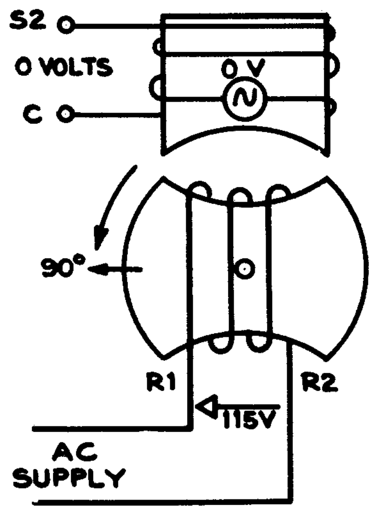
The Voltages Induced in the Stator Coils of a Synchro Motor or Generator: Up to this point only one feature of the operation of a Synchro has been discussed: How its shaft can be turned to any desired position by changing the voltages applied to its windings. An effect that has not been mentioned before, the voltages induced in the stator coils, plays a very important part in the operation of a Synchro system.

To understand this, consider for example the voltage induced in stator coil 2 when the rotor coil of a Synchro Motor or Generator is connected to the 115 volt AC supply, and its stator leads are left open:

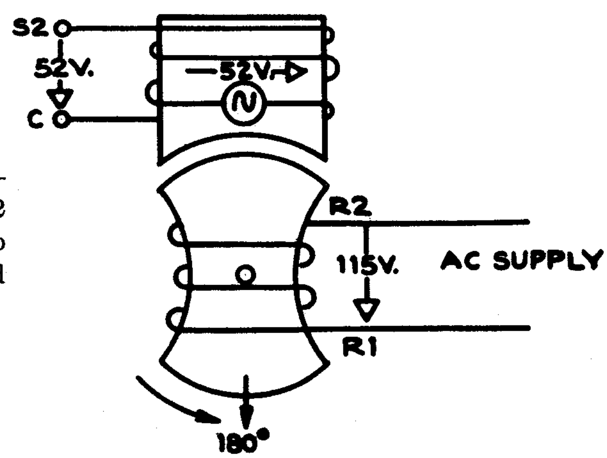
An AC current flows in the rotor coil, and it acts as the primary of a transformer, inducing a voltage in the secondary (coil 2). This induced voltage can be represented by a little AC generator connected in series with coil 2 as shown. The magnitude of the induced voltage depends on the number of turns in the two coils, and on how closely they are coupled together. In a standard Synchro a voltage of 52 volts is induced in stator coil 2 when the rotor is lined up with it (shaft in the 0° position).



When the stator circuit is open, no current flows there, and there is no internal drop in the coil. Thus the voltage measured from S2 to the Common connection is equal to the induced voltage. Since the stator coil is wound in the same direction as the rotor coil, the voltage from S2 to C is in phase with the voltage applied from R1 to R2.

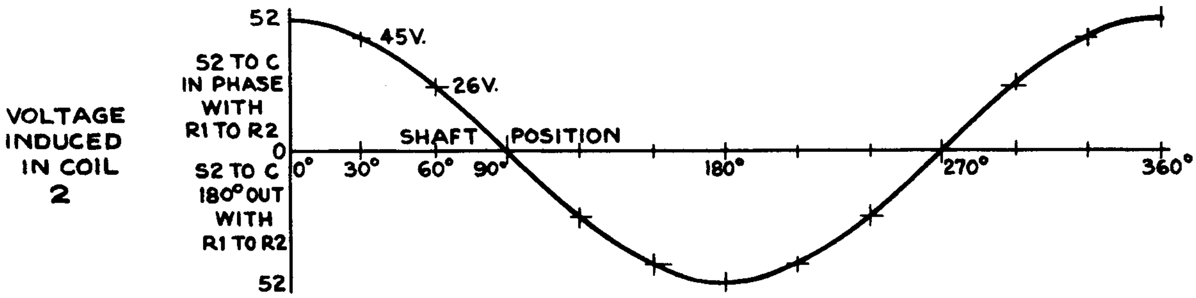


Consider what happens to this voltage as the shaft is turned. As the rotor coil turns away from the 0° position, the coupling between the coils decreases and as a result the induced voltage falls off. When the shaft reaches the 90° position the rotor coil is perpendicular to coil 2 and the induced voltage is zero, like this:



As the shaft continues to turn, the induced voltage increases again, but now the voltage from S2 to C is 180° out of phase with that from R1 to R2. When the shaft reaches 180° the induced voltage is 52 volts with reversed phase.

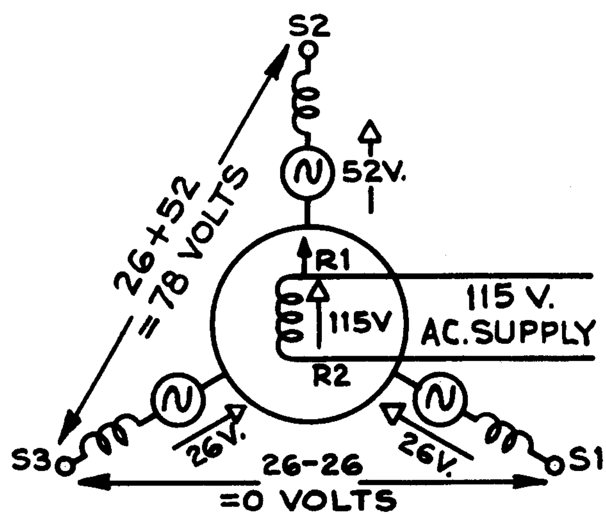
A graph showing how the voltage induced in coil 2 varies as the shaft is turned looks like this:



A similar voltage is induced in each of the other two stator coils which reaches a maximum of 52 volts when the rotor coil is in line with it, and varies in the same way as the rotor is turned away.

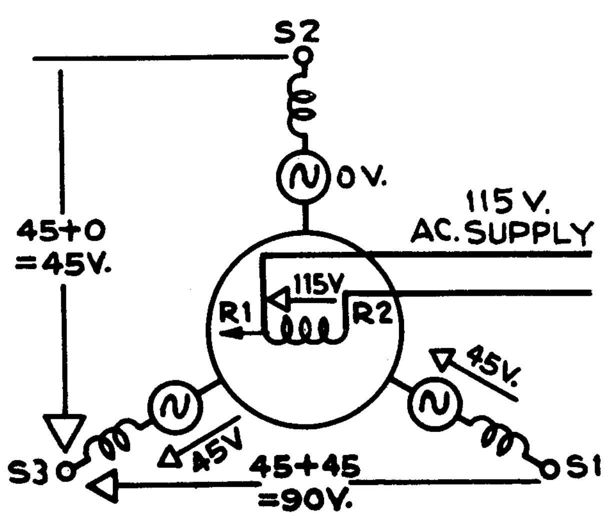
The Voltages Between Stator Leads With No External Connection: The voltages that appear between the open stator leads with no load result from the addition of these three induced voltages. To see how they add up, consider a few cases:

When the shaft is in the 0° position like this, 52 volts is induced in coil 2, and 26 volts in each of the others. Thus the voltage between S1 and S3 is zero (26 volts added to 26 volts with the opposite phase) and the voltage between S2 and S1 or S3 is 78 volts (52 volts added to 26 volts).



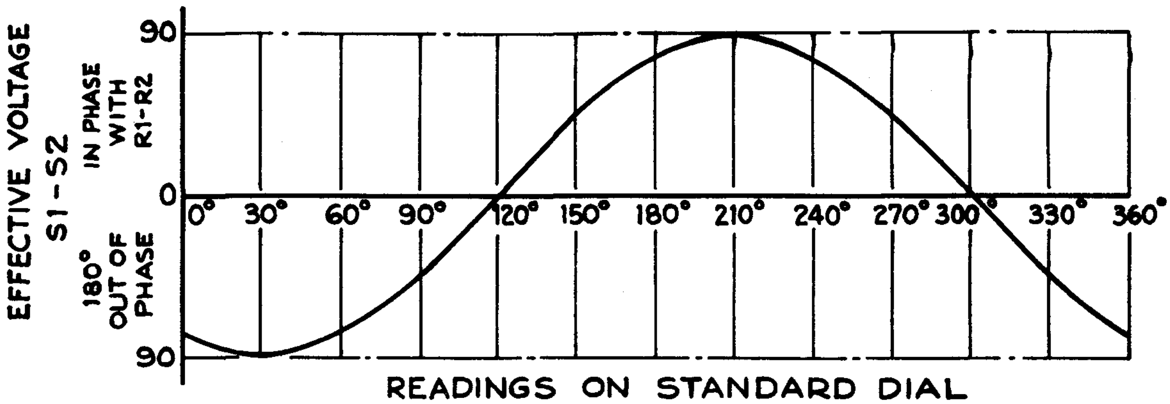
When the shaft is turned to the 90° position the voltages change like this:

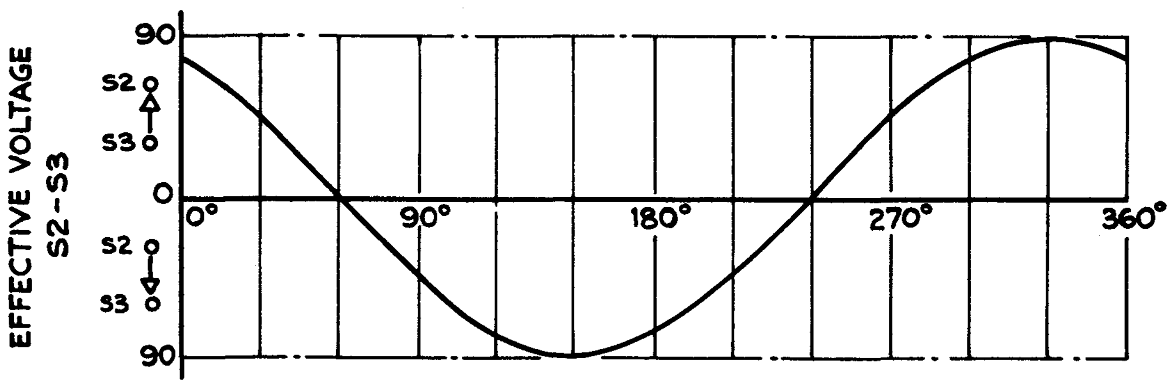
In this case the rotor is perpendicular to coil 2, so no voltage is induced in it. A voltage of 45 volts is induced in coil 3 and in coil 1 (it is less than 52 volts because the rotor is not quite in line with either coil). Thus the total voltage between S1 and S3 is 90 volts, and there is 45 volts between S2 and either of the other leads.

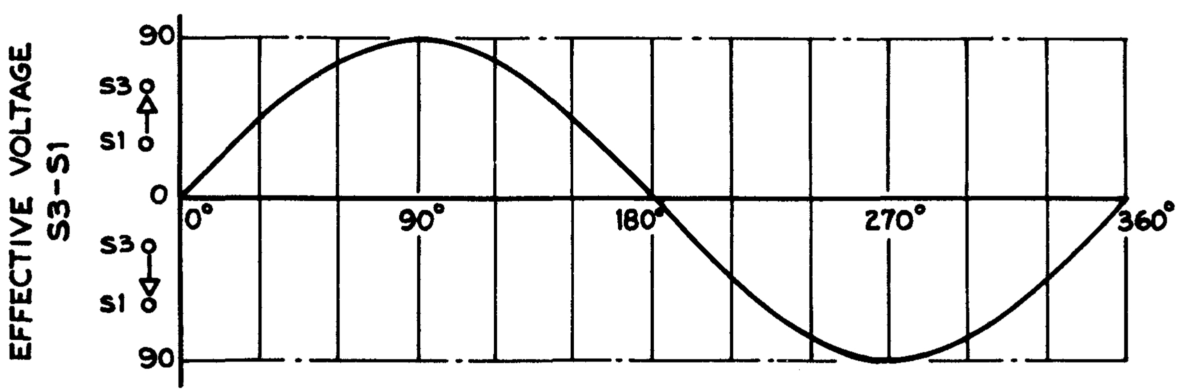


The important point is this: No matter what position the shaft of a Synchro is turned to, voltages are induced in its stator coils and as a result voltages appear between its leads which are equal and opposite to the voltages that would be applied to turn it to that position.

The graphs on page 31 which were used to show the voltages that must be *applied* to the stator leads to turn the shaft to any position, can just as well be used to show the voltages that *appear* between stator leads due to voltages induced in the stator coils. These are the voltages that appear between stator leads when they are not connected to anything, power is supplied to the rotor, and the shaft is turned to the indicated positions.





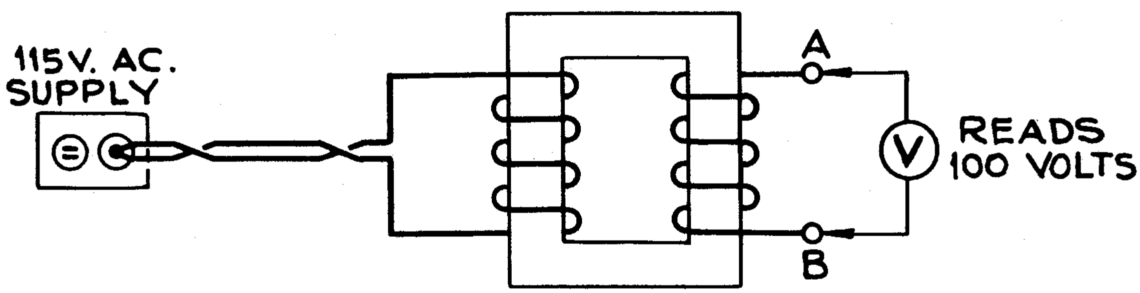


THE OPERATION OF A COMPLETE SYNCHRO SYSTEM

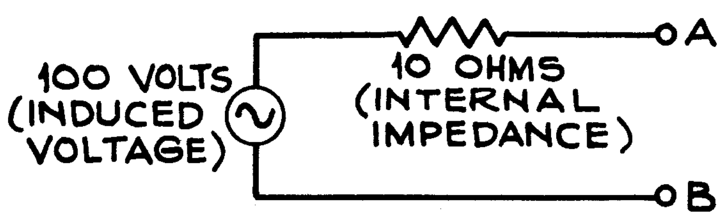
FUNDAMENTALS

Electrically a Synchro Motor or Generator is a Transformer: From what has just been discussed it should be fairly evident that a Synchro is, from an electrical standpoint, simply a single-phase transformer with variable coupling between its one primary (the rotor winding) and each of its three secondaries (the stator windings). To understand what happens when two Synchros are connected together, it will help to discuss the action of a simple two-winding transformer.

The Operation of a Simple Transformer: When two coils are wound together on an iron core, and one of them is connected to an AC supply, a voltage can be measured between the ends of the other coil. If the coils have the right number of turns, the output voltage can be made equal to 100 volts, with 115 volts applied like this:



When considering the current that flows in the secondary circuit with various loads, it simplifies things to replace the transformer with a constant-voltage AC generator in series with an impedance like this:

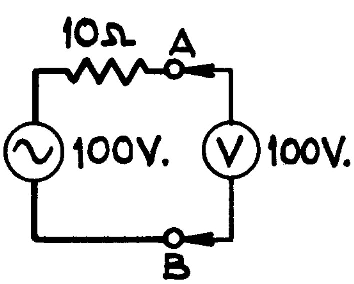


The AC generator represents the voltage induced in the secondary of the transformer. Its voltage is constant (100 volts in this case) regardless of the current that flows in the secondary circuit. It depends only on the voltage applied to the primary, the turns-ratio, and the coupling between the two coils.

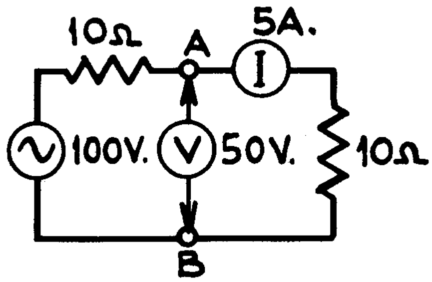
The series impedance (10 ohms in this case) represents the internal impedance of the transformer. It takes care of the fact that, when current flows in the secondary circuit, the output voltage decreases. Its value is determined by the size of the wire used to build the transformer, the size of the core, and the general construction of the transformer. It is related directly to the *size* of the transformer. A *large* transformer for a certain job has a lower internal impedance than a *small* transformer.

If the right values of induced voltage and impedance are selected, this circuit gives the same output, under any conditions, as does the actual transformer.

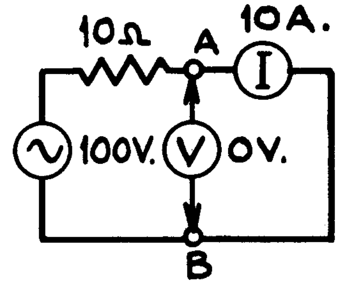
Consider what happens, for example, when a load is connected across the secondary of this transformer (to keep it simple, assume that the load impedance adds directly to the internal impedance):



With no load, no current flows in the secondary circuit so the output voltage equals the induced voltage.

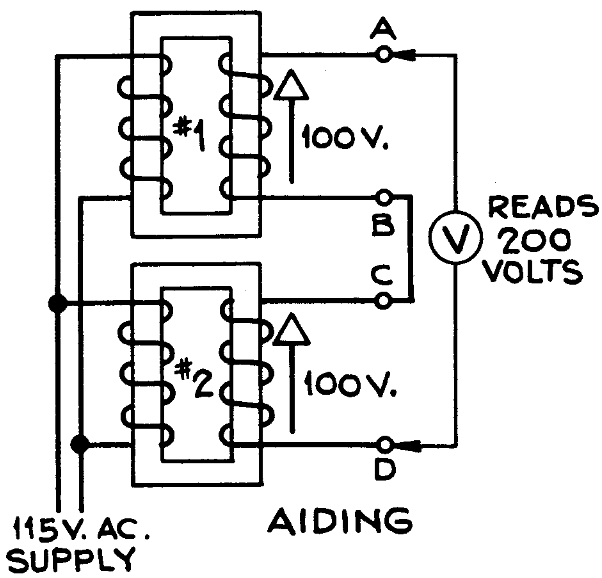


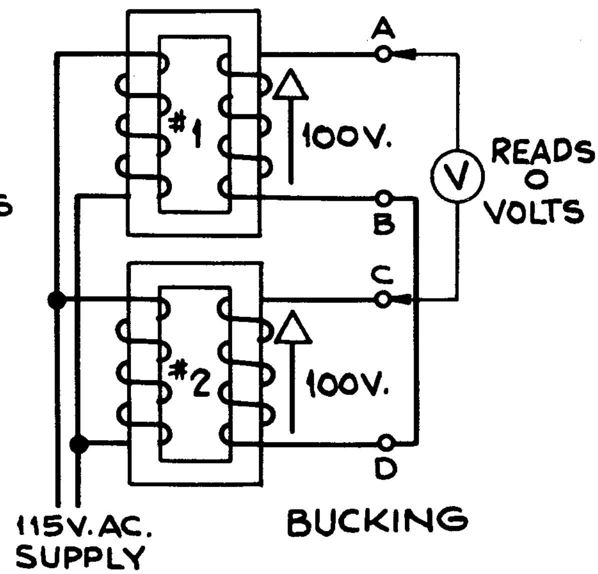
With a 10 ohm load, 5 amps. flows and the output voltage is reduced to 50 volts due to the drop across the internal impedance.



When the output terminals are short-circuited, 10 amps. flows and the output voltage is 0.

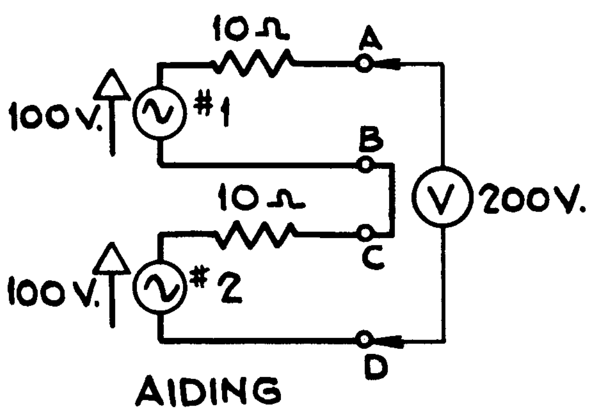
Connecting Two Transformers Together: Suppose that two transformers similar to the one described are connected with their secondaries in series, like this:

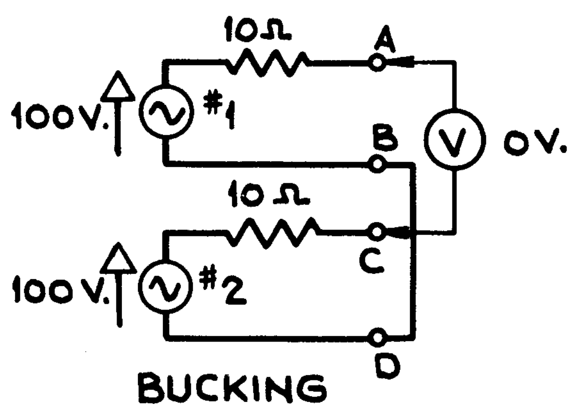




If they are connected in one way, the two voltages *add*. If one is reversed, they cancel each other and the net voltage is zero.

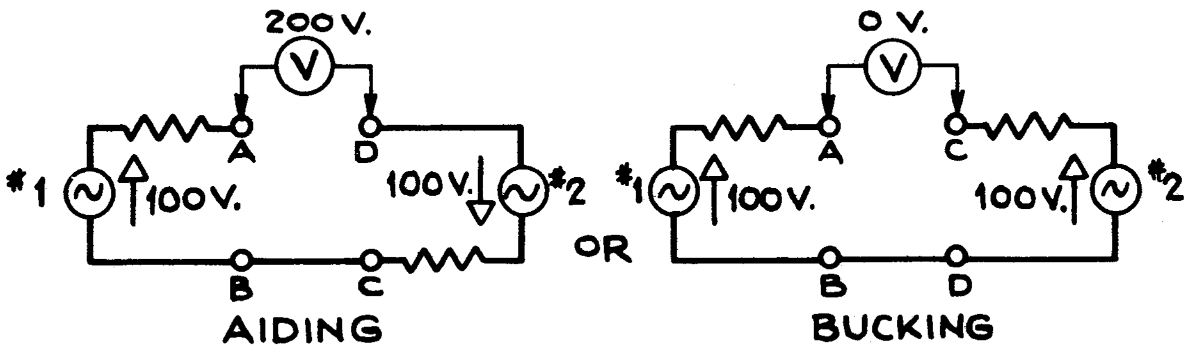
Using the simplified circuit to represent the transformers, this same fact could be shown this way:



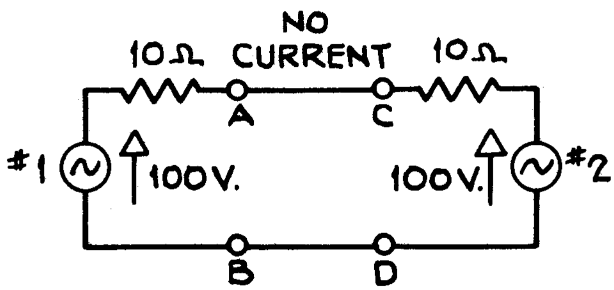


A COMPLETE SYSTEM

Or the same connections could be drawn like this:

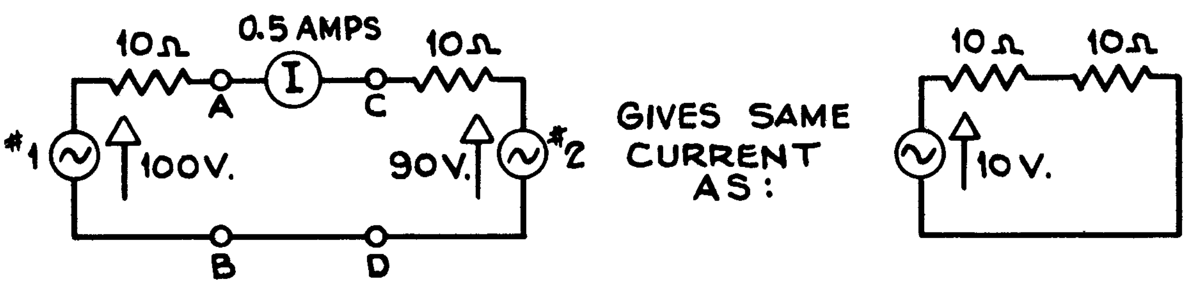


Consider what happens when terminals A and C are connected together in the "Bucking" case:



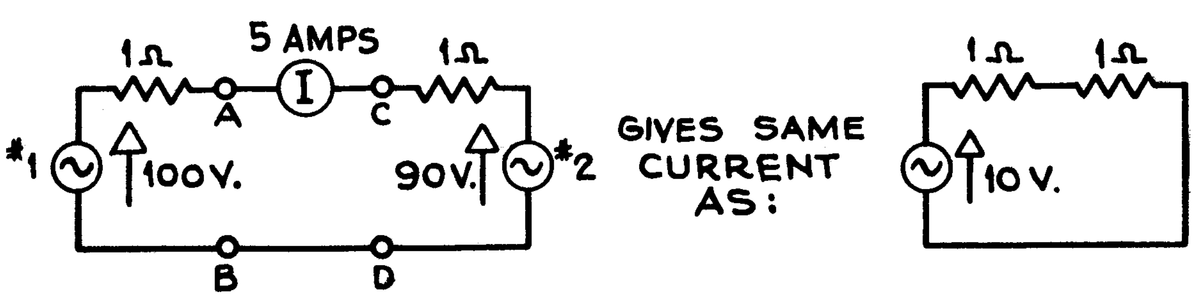
Since the two voltages are equal and have opposite phase as you go around the circuit, they add to zero, so no current flows.

If the voltage induced in the secondary of one transformer is now reduced to 90 volts, it no longer completely cancels the other voltage, and current flows:



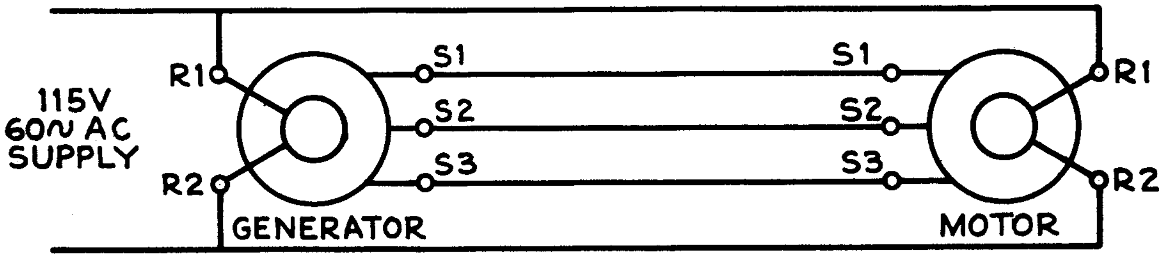
The strength of the current is determined by the difference between the two voltages and by the total impedance around the circuit.

If larger transformers, with lower internal impedances, were used, the same unbalanced voltage would give a higher current:



HOW A SYNCHRO MOTOR FOLLOWS A GENERATOR

The simplest Synchro system consists of one Synchro Generator connected to one Synchro Motor like this:

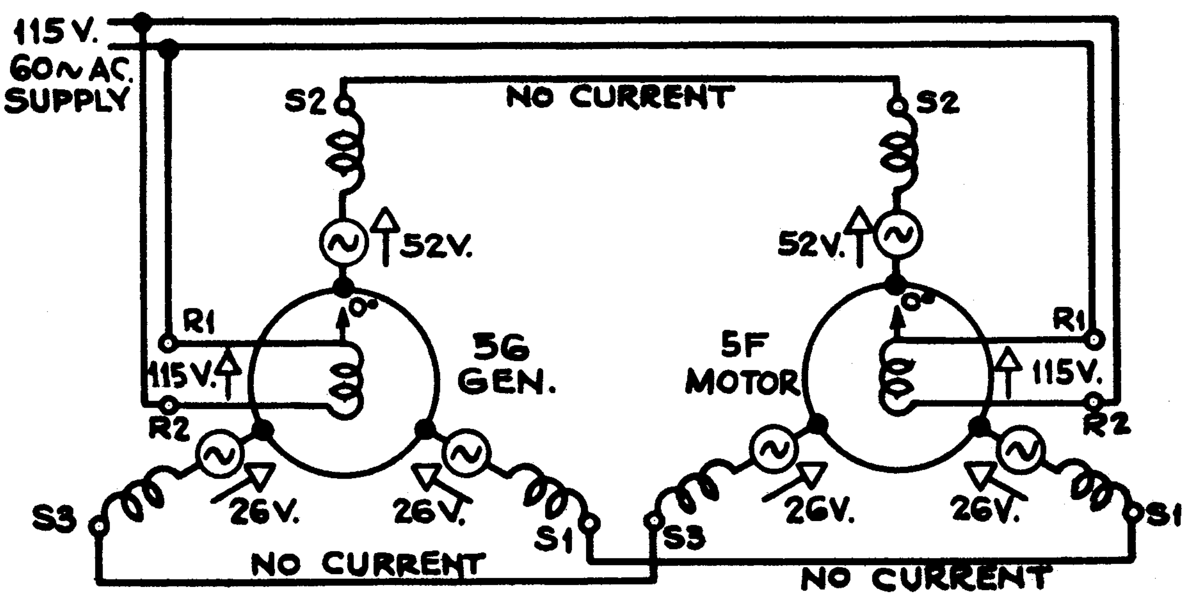


(This simplified type of diagram will be used throughout the rest of the pamphlet wherever *connections* are important, rather than conditions *inside* the Synchros.)

With this connection, whenever the Generator's shaft is turned, the Motor's shaft turns too so that its "electrical position" is the same as that of the Generator's shaft. That is, when the Generator is turned to electrical zero, the Motor turns to 0° also; if the Generator is turned to 30° the Motor also turns to 30°. Even if the Motor is disconnected from the Generator completely, and reconnected at some later time, its shaft will then turn to correspond exactly with whatever position the Generator's shaft has at that time.

Practically, a Synchro Generator is always used as the unit whose shaft is turned, and a Synchro Motor is used as the unit whose shaft follows, but it is well to remember that the difference is purely mechanical, electrically the two units are identical.

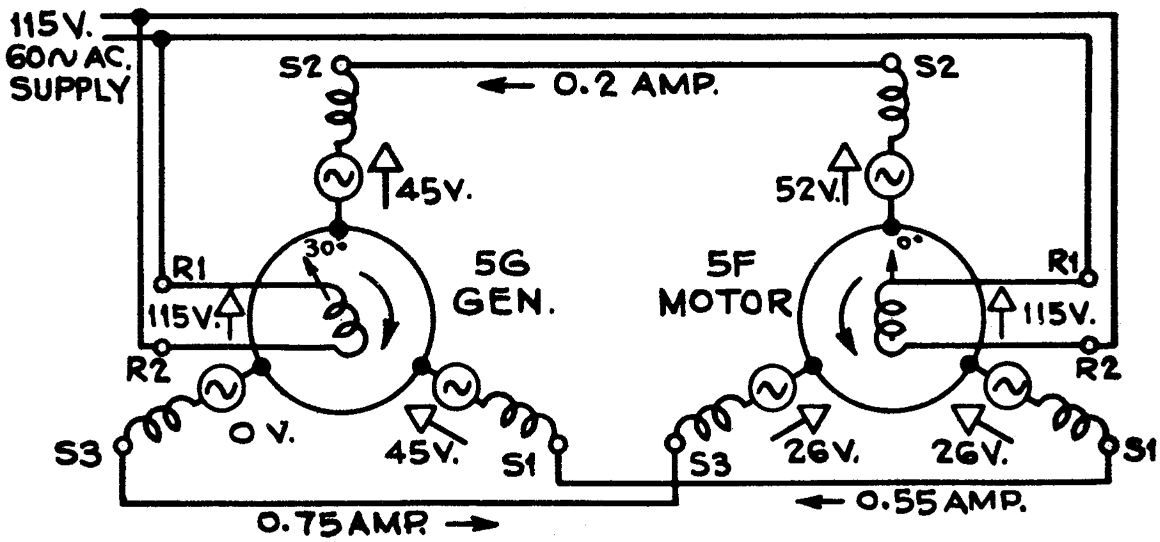
When Both Shafts Are in the Same Position: Consider the internal conditions in each of the two units when both shafts are turned to the 0° position, like this:



On this diagram the voltage induced in each of the stator windings is indicated, its phase being shown as usual. Assuming that both Generator and Motor are on 0°, the voltages induced in the Motor windings will be the same as those induced in the Generator windings. Starting from the common stator connection on the Generator and tracing the circuit up through the S2 lead and around to the same connection on the Motor, it can be seen that the total voltage in that circuit is zero (52 volts added to 52 volts with the opposite phase). Since this condition is true for each of the three stator wires, there is no total voltage in any of these circuits, so no current flows.

A COMPLETE SYSTEM

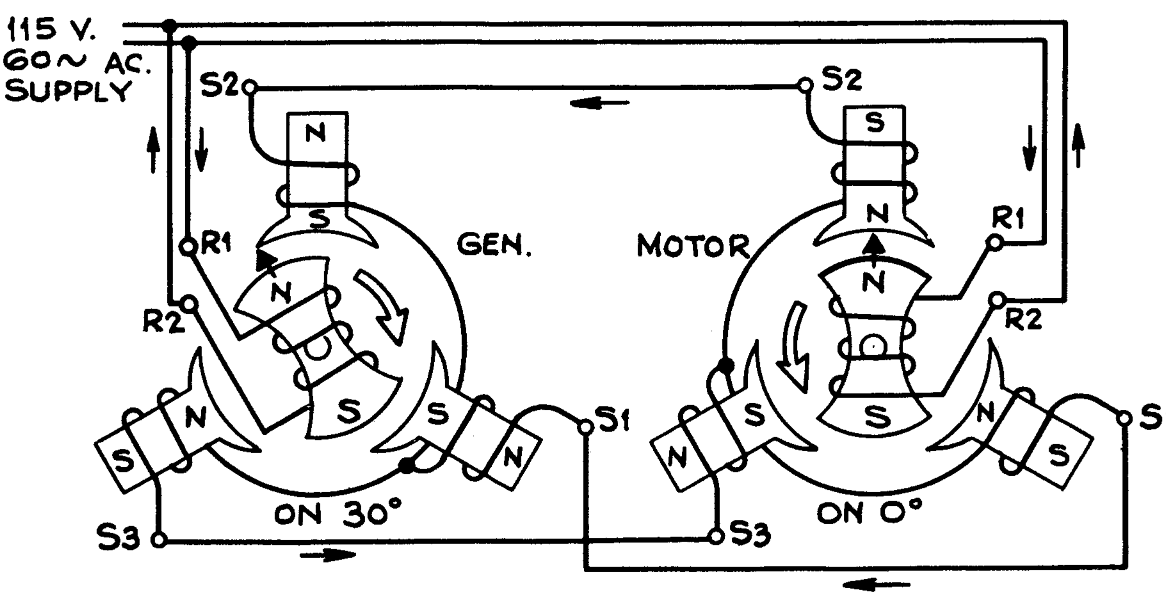
When the Shafts Are in Different Positions: Now consider what happens when the shaft of the Generator is turned to 30° while the Motor's shaft is held on 0°:



In this case none of the voltages are balanced, and currents flow in all three stator leads. The currents are strongest in the circuits where the voltage unbalance is greatest. The effect of these currents flowing in the stator coils of the Motor is to produce a strong attractive force trying to turn the Motor's shaft toward the same position as the Generator. So, if the Motor's shaft is free to turn (as it usually is) it turns to 30°.

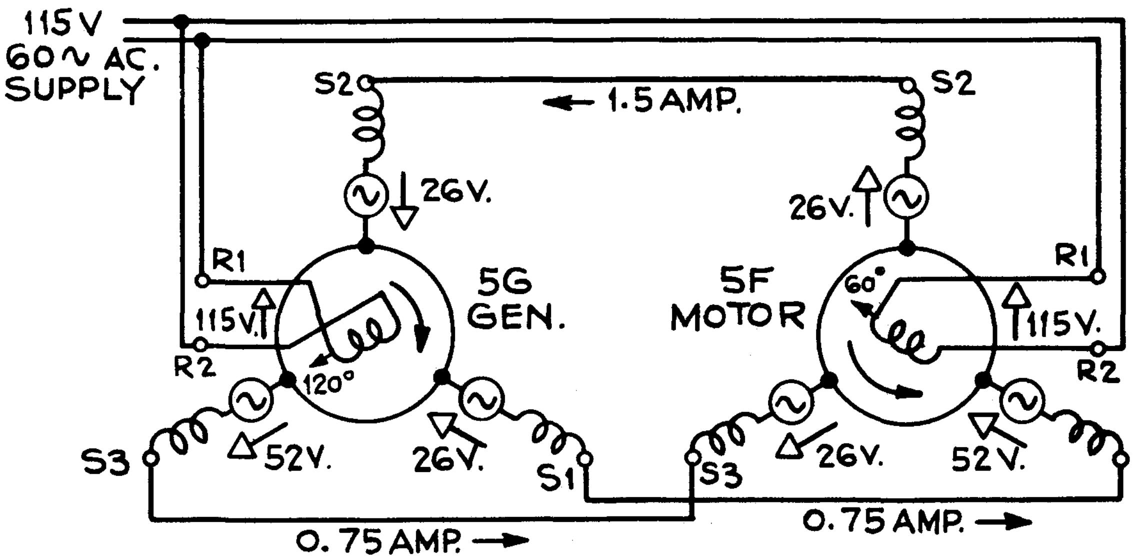
The currents in the Generator's stator also cause a pull on the Generator's shaft trying to turn it back toward the Motor's position. Since the Generator's shaft is usually being turned by something, this pull shows up as a load on the thing that is turning it.

The turning effect of these currents can perhaps be understood better by considering a "snapshot" showing conditions inside the two Synchros at a particular instant in the cycle of these AC currents:



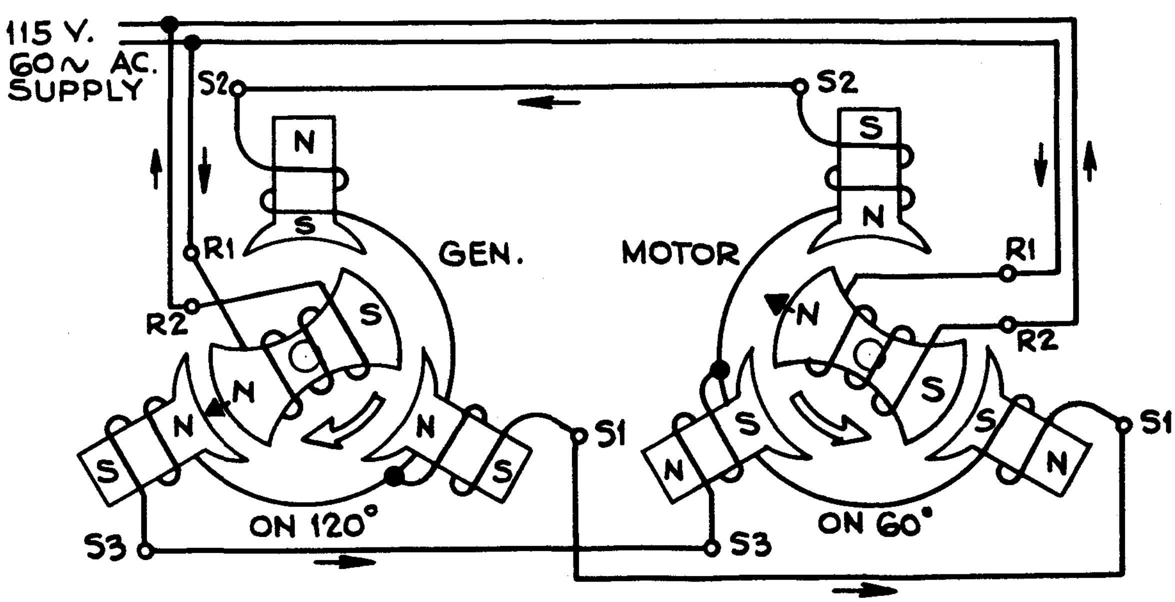
By considering the magnetic polarities it can be seen how the same currents that pull the Generator's rotor toward 0°, pull the Motor's toward 30°.

Another example may help to show how the same general idea works for *any* case where the two shafts are in different positions. Suppose that the Motor's shaft is held on 60° while the Generator's shaft is turned to 120° like this:



In this case the two shafts are 60° apart, so the unbalanced voltages are greater than in the previous case and more current flows. As a result the magnetic pull tending to turn the two shafts back to the same position is greater than before.

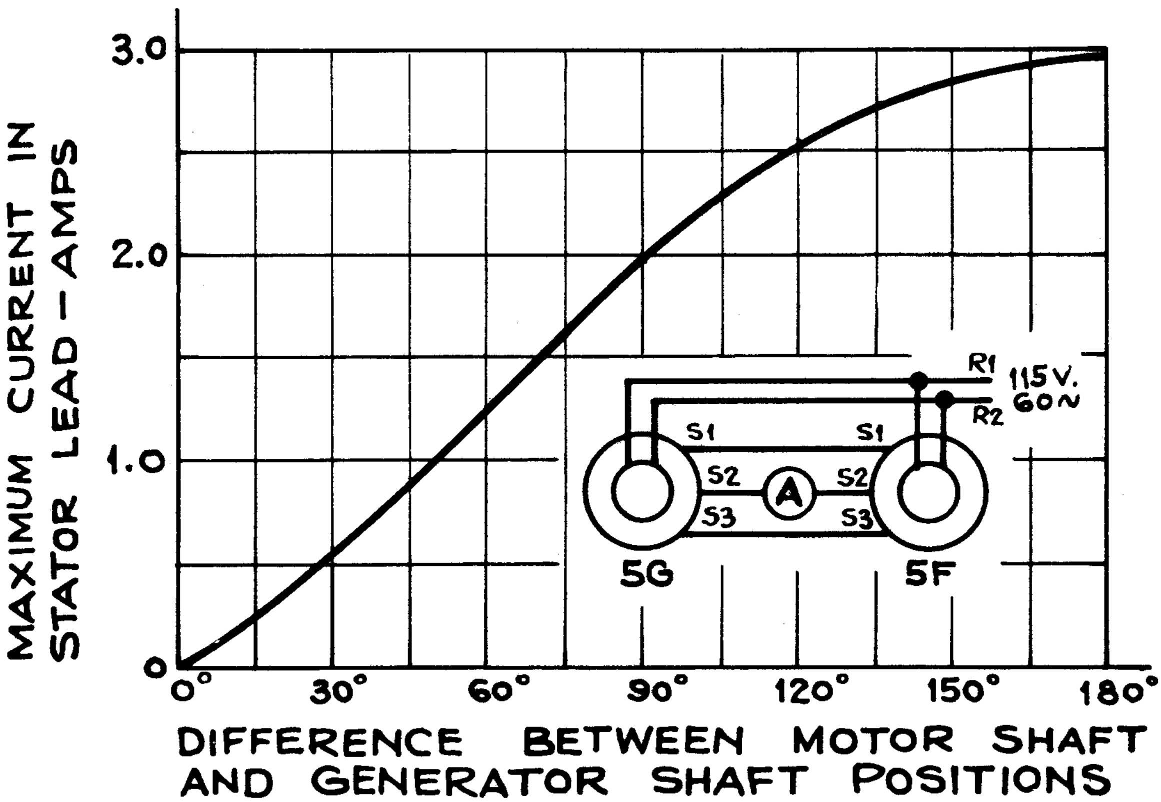
A "snapshot" of the conditions in the two Synchros at a particular instant of time now looks like this:



The magnetic forces in each Synchro act to turn them towards the same position.

HOW THE CURRENTS IN A SYNCHRO SYSTEM DEPEND ON SHAFT POSITIONS

The Stator Currents: Whenever the shafts of two Synchros are in different positions, current flows in the stator circuit. The strength of the current flowing in each stator lead depends on the difference between the voltages induced in the two coils to which that lead connects. Suppose that the current in any one stator lead between two Synchros (the S2 lead for example) is measured, and the actual shaft positions are adjusted so that this current is maximum for each *difference* between shaft positions. A graph showing how this maximum current depends on the difference between shaft positions looks like this in a typical case:



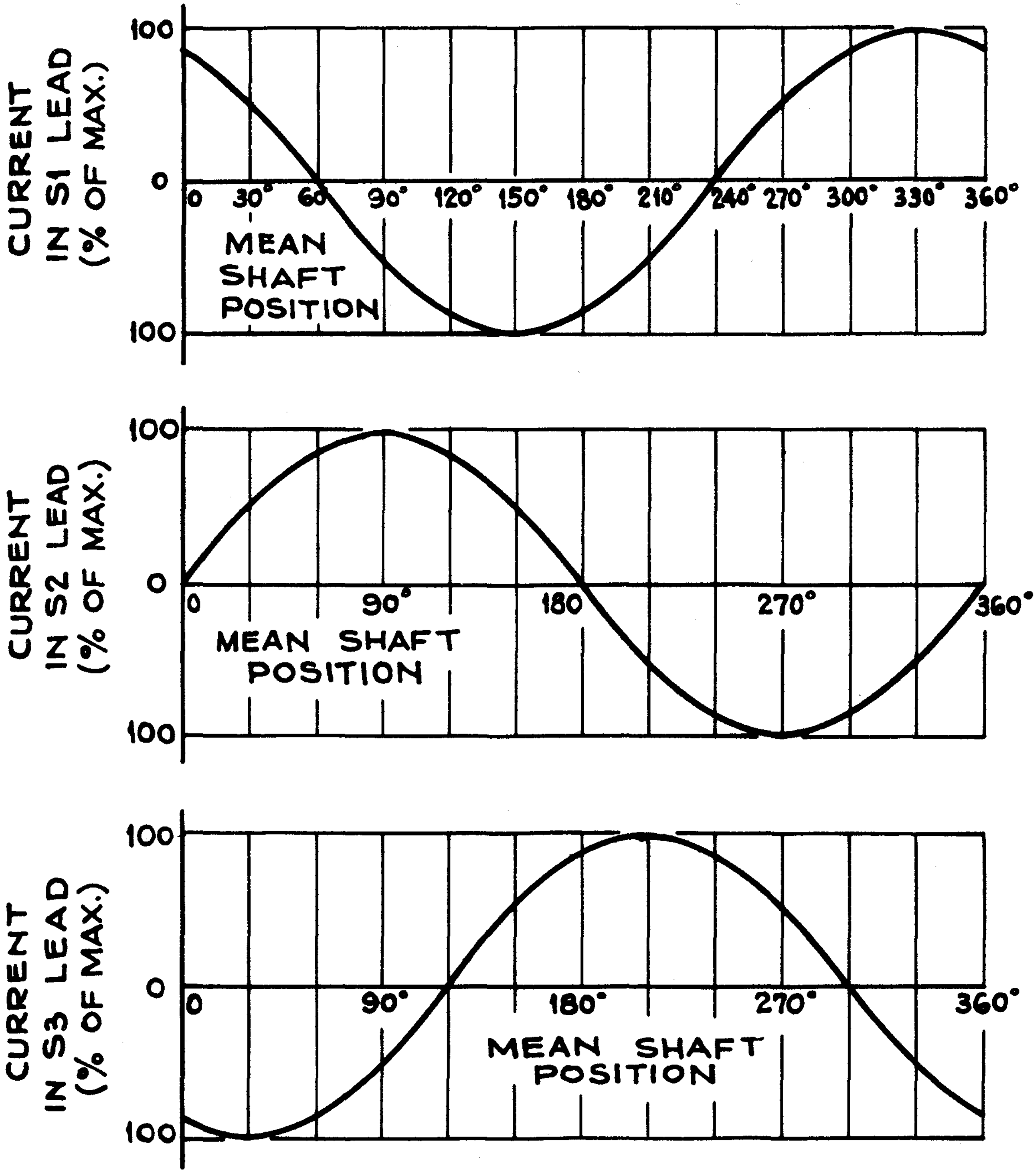
Note that, in practical operation, the position of the Motor's shaft would never be more than a degree or so away from the Generator's, so that the maximum stator current under normal conditions would be less than a tenth of an amp. (in this case).

The current that flows in *any one* stator lead depends not only on the *difference* between shaft positions, but on the *actual positions* as well. For example, the current in the S2 lead in the last example of the previous section was 1.5 amps., the maximum in any one lead with these two shafts 60° apart. The current in the other two leads was only .75 amps. If the shafts had been turned to 120° and 180° respectively the current in the S2 lead wculd have dropped to .75 amps., while the current in the S1 lead would have risen to 1.5 amps.

The following graphs show how the current in each of the three stator leads depends on the mean shaft position (the position that is half-way between the actual positions of the Motor's shaft and that of the Generator).

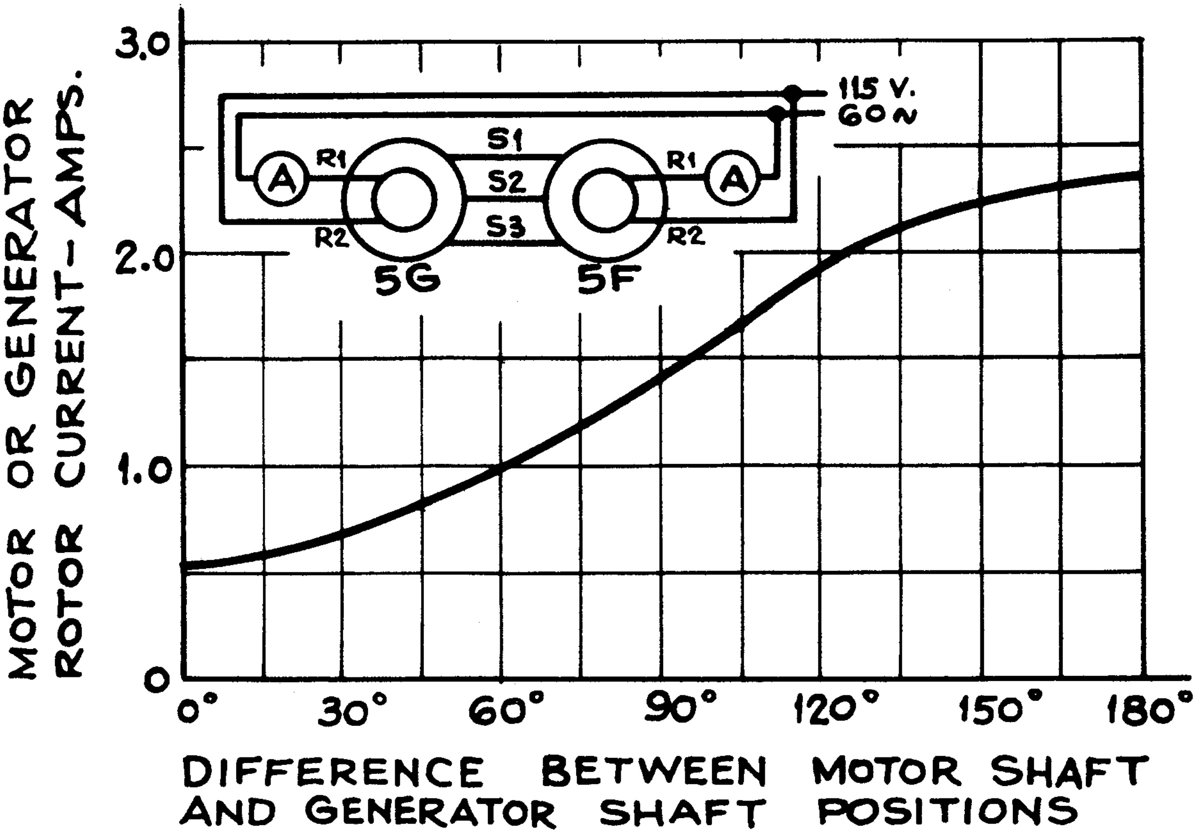
 Table of Contents

How the Currents in Each Stator Lead Depend on the Position of the Motor and Generator Shafts



NOTE: ALL CURRENTS ARE AC. EFFECTIVE VALUE.
CURRENTS SHOWN ABOVE THE O LINE ARE IN PHASE WITH S1 CURRENT AT 0°.
CURRENTS SHOWN BELOW THE O LINE ARE 180° OUT OF PHASE WITH S1 CURRENT AT 0°.

The Rotor Currents: A Synchro Generator or Motor acts like a transformer, so an increase in the stator (secondary) current results in a corresponding increase in the rotor (primary) current. When the rotor current of either of the units is plotted on a graph for the same conditions described above, it looks like this:

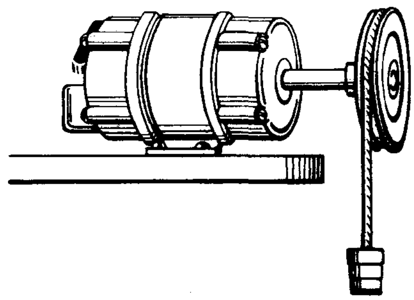


Although all three stator currents are zero when the shafts are in the same positions, the rotor current is not. As in any transformer, the primary draws some current with no load on the secondary. This current produces magnetization of the rotor and supplies its losses.

THE TORQUE PRODUCED BY A SYNCHRO MOTOR

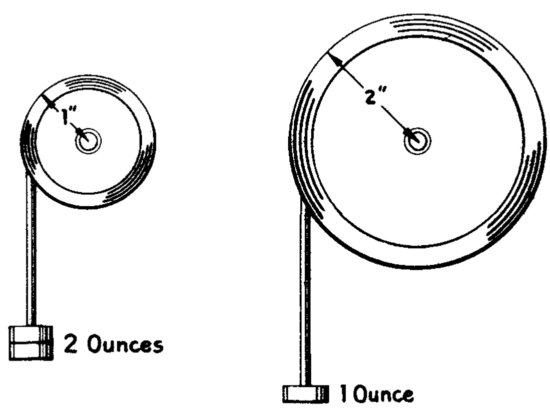
How Torque is Measured: Before discussing the torque characteristics of a Synchro Motor, it is necessary to understand just what is meant by torque, and how it is measured.

Torque is simply a measure of how much load a Motor can turn. One way of measuring it is to wrap a cord around a pulley attached to the shaft of the Motor, and to hang weights on the cord, like this:



The amount of torque required to turn the shaft depends on the size of the pulley, and on the weight attached:

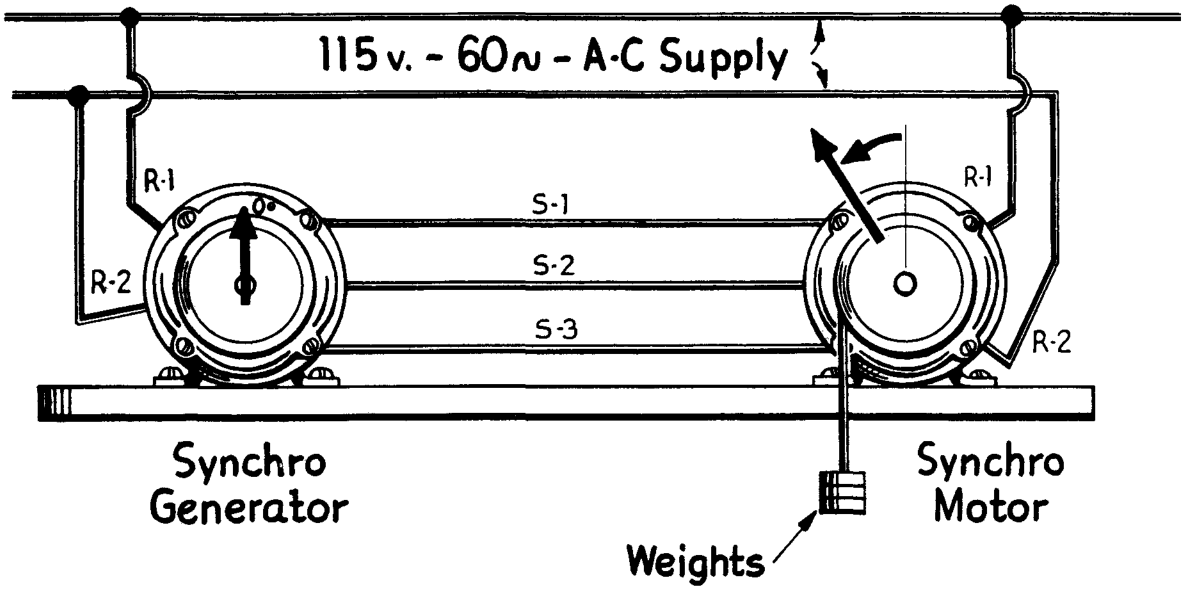
It would be just as hard for a Motor to turn the pulley shown on the left as it would be to turn the other one. The torque required is measured by multiplying the radius of the pulley by the attached weight. In each case shown, for example, the torque required is 2 inch-ounces. ("Inch-ounces" means "Inches times Ounces.")



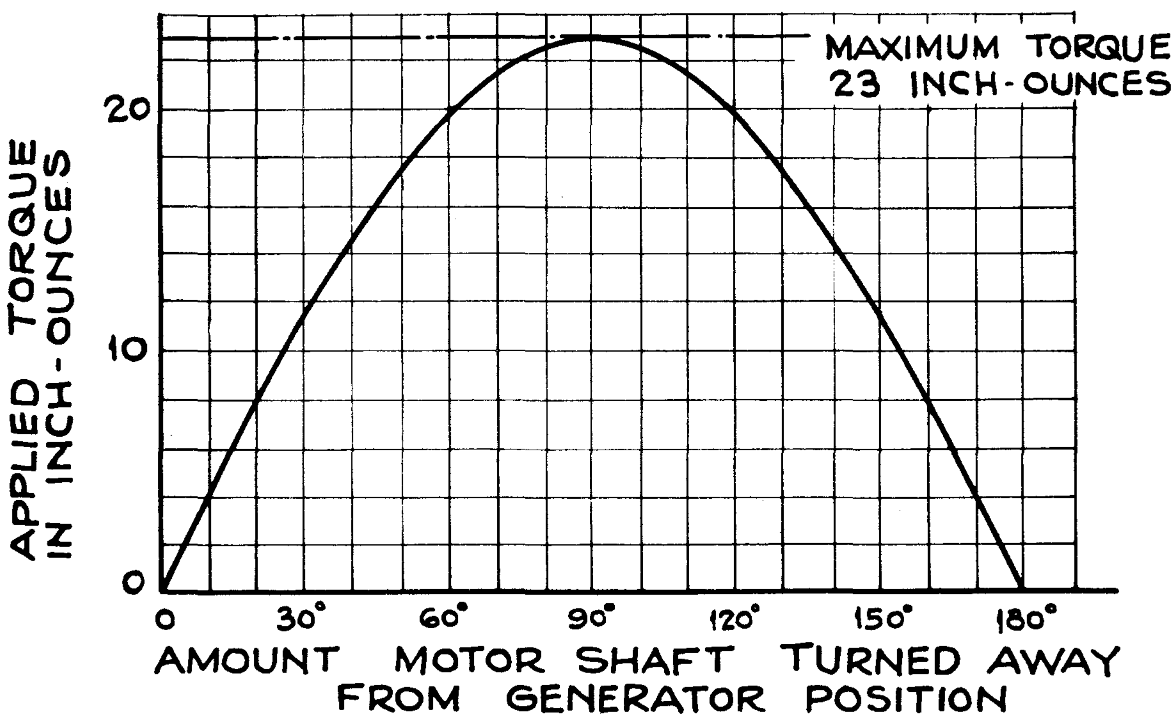
Torque on shaft in each case is 2 *inch-ounces

The Torque of a Typical Motor: When a Synchro Motor is connected electrically to a Generator which is held on 0°, its shaft turns to 0° if it is free to turn. If a pulley is mounted on the Motor's shaft, and weights hung on it, as shown on the next page, the shaft will be turned away from the 0° position. How far it is turned depends on how much torque is applied, and on how "stiff" the system is (that is, how fast the Motor's torque increases as it is turned away from 0°).

A COMPLETE SYSTEM



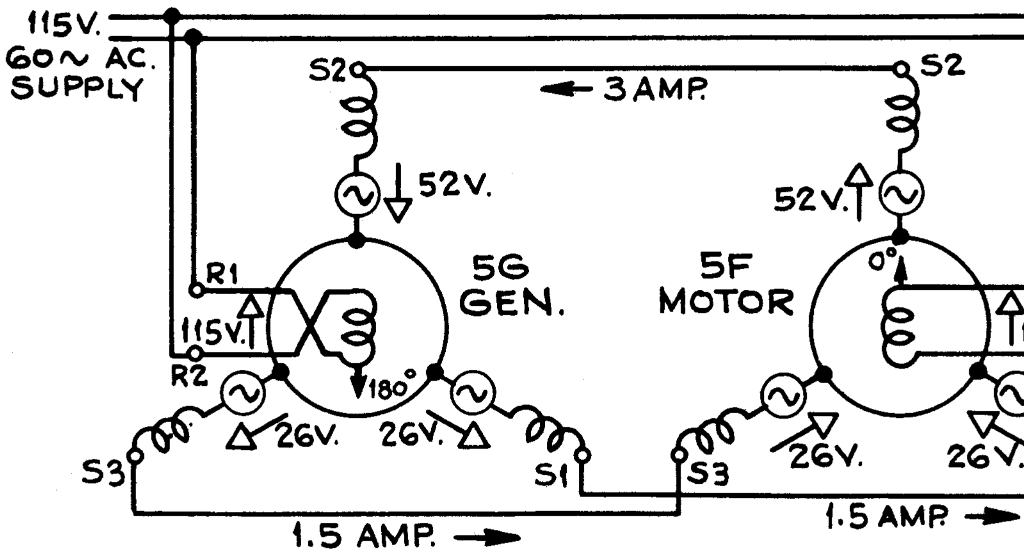
A typical Synchro Motor was connected to a Generator of the same size, and weights hung on a cord attached to a pulley on its shaft. The torque required to hold its shaft in various positions is shown on this graph:



With no load the two shafts were in the same positions. As more and more weights were hung on, the Motor's shaft turned away from 0°. Notice that the curve reaches a peak at 90°. This means that the Motor produced its greatest torque when its shaft was 90° away from the Generator. If more weights were hung on, the shaft simply turned around and around until the string came off. This Motor simply couldn't supply more than 23 in.-oz. of torque.

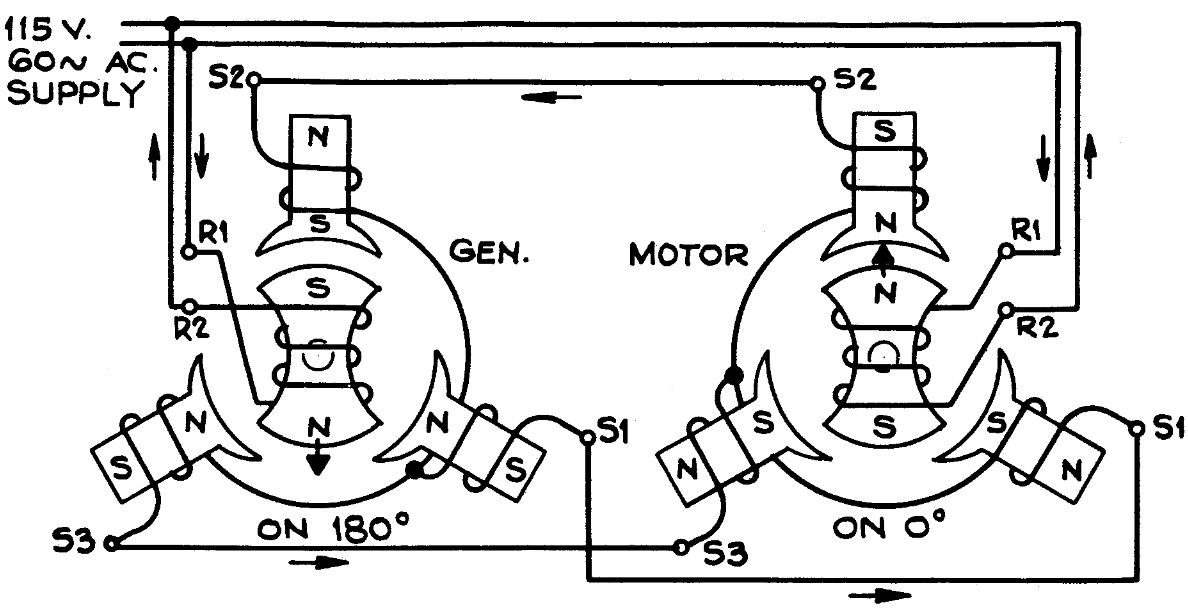
Notice also that the curve goes down again beyond 90°. This means that, if enough torque was applied to turn the shaft past 90° originally, less torque would be required to hold it in any position between there and 180°. For example, 10 in.-oz. would *turn* the Motor's shaft to about 25°, but if the shaft were first turned by hand to 155°, 10 in.-oz. would *hold* it there.

Why There is No Torque at 180° Difference: Since the stator and rotor currents are both *maximum* when the shafts are 180° apart, it doesn't seem to make sense that the torque is *zero* there. To understand this, consider the current conditions in the two Synchros when their shafts are 180° apart:



Since all the voltages aid each other, strong currents flow in all three stator leads. (If the two units are the same size, the currents are the same as if all three stator leads were shorted together.)

To see why no torque results from these strong currents, consider a "snapshot" showing currents and magnetic polarities in the two units at a particular instant in time:



Powerful magnetic forces are acting on each rotor, but they all balance each other out, so that the resulting torque is zero. The two shafts would never stay in these positions practically (unless held there) because the slightest displacement of either one produces a torque which rapidly pulls them back to the same positions.

The Torque Gradient: In practical operation the shaft of a Synchro Motor is never more than a degree or so away from its Generator's shaft. This means that practically it isn't necessary to consider the torque curve shown above to find the operating torque. For small angles the torque produced depends directly on the difference in shaft position. For example, if a torque of 0.4 in.-oz. pulls the shafts 1° apart, 0.8 in.-oz. will pull them 2° apart, 4 in.-oz. will pull them 10° apart, and so on.

Because the torque required to pull a Synchro 1° off is such a convenient measure of the Synchro's torque, it is given a special name: the "Torque Gradient." As soon as the Torque Gradient is known for a Synchro Motor operating under certain conditions, the actual torque it will produce for any normal difference in shaft positions can be found easily by multiplying the Torque Gradient by the number of degrees of difference.

As an example the Torque Gradient of the Motor for which the above graph was drawn is .4 in.-oz. per degree, when connected to a Generator of the same size. Thus the torque for 5° difference is 5 x .4 or 2 in.-oz., which agrees with the graph.

The Unit Torque Gradient: A Motor is not always connected to a Generator of the same size. There are many other possibilities, as will be described later. To provide a measure of a Synchro's performance which doesn't depend on where it is used, the "Unit Torque Gradient" is usually given. This is simply the torque gradient which is measured when that Synchro is connected to another of the same size and construction. In the case above, for example, the figure of .4 in.-oz. per degree would be the Unit Torque Gradient of either the Motor or the Generator, since that was the Torque Gradient measured when they were connected together, and they were the same size.

Unit Torque Gradient Depends on Internal Impedance: When a Motor is connected to a Generator of the same size, the amount of torque that is produced for a 1° difference in shaft positions depends directly on the strength of the currents that flows in the stator coils. The strength of these currents is determined by the amount of unbalanced voltage in each coil circuit, and by the internal impedance of each Synchro.

The unbalanced stator voltages will be the same for any standard Synchro Motor or Generator, regardless of size. The only thing that varies with the size of the Synchro is the internal impedance. This brings out an important point: The thing that determines how much current flows, and how much torque is produced when two standard Synchros of the same size are connected together, is simply the internal impedance of the stator circuits. Since the Unit Torque Gradient determines the same thing, it follows that the **Unit Torque Gradient of a Synchro is inversely proportional to the internal impedance of its stator coils.**

A small Synchro Motor or Generator has a low value of Unit Torque Gradient, and a high internal impedance. A large one has a high Unit Torque Gradient, and a low internal impedance.

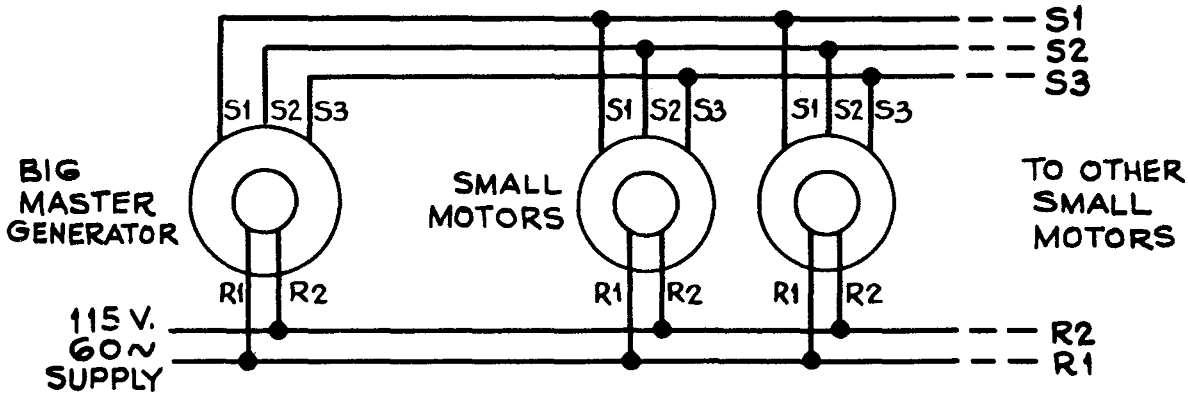
USING ONE GENERATOR TO DRIVE A NUMBER OF MOTORS

One large Generator may be used to drive a number of smaller Motors by connecting them in parallel as shown at the top of the next page.

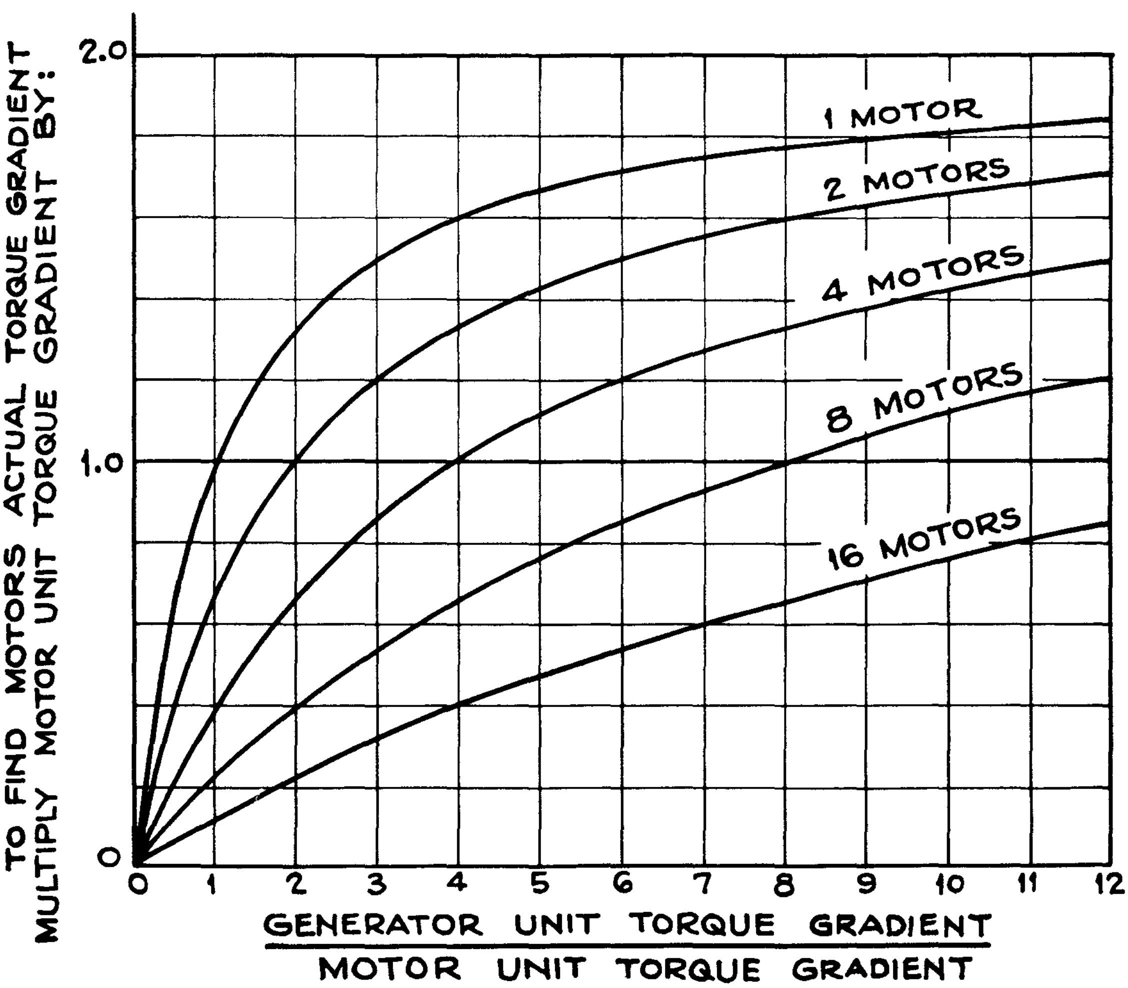
With this arrangement the impedance of the Generator's stator windings must be low enough so that it can supply the necessary current to turn all the Motors without excessive voltage drop.

If any one Motor in a system like this has to supply more torque than the others, its shaft will lag further behind the Generator's, producing less opposing voltage in its stator coils, so it will draw a larger current than the others. This increased current will lower the Generator's output voltage, and cause all the rest of the Motors on the system to lag more than before. For accuracy it is essential that the Generator have low impedance (high Unit Torque Gradient) and that the load on each Motor be as low as possible.

An extremely important fact concerning a multiple-Motor system is that **any unnecessary load on the shaft of any one Motor in the system hurts the accuracy of the whole system.**



When a Generator is driving a number of Motors, and all the Motors are the same size and loaded equally, the actual Torque Gradient of each Motor under this condition can be found from this graph:



This graph is a plot of the mathematical formula:

$$T'_m = \frac{(2R)}{(N+R)}$$

where
- T'_m represents the **actual** torque gradient of each Motor.
- T_m represents the **unit** torque gradient of each Motor.
- **N** represents the number of identical Motors.
- **R** is the ratio $\frac{T_g}{T_m}$
- T_g represents the unit torque gradient of the Generator.

This graph does not apply to systems using Differentials or Control Transformers, nor to systems in which the Motors are loaded unequally.

FACTORS THAT AFFECT THE ACCURACY OF A SYNCHRO SYSTEM

The accuracy of a Synchro system is probably its most important characteristic. The accuracy is determined by how closely the shaft of any Motor in the system approaches the position to which the Generator is turned.

In a Simple System: Consider first a system which consists simply of one Motor connected to one Generator. Regardless of how carefully the Motor is constructed, *some* friction is always present. To overcome the drag of this friction, the Motor must always produce some torque. Since no torque is produced when the Motor is in the same position as the Generator, it must lag slightly, and thus the **accuracy can never be perfect.**

For maximum accuracy:

1. **The friction on the shaft of the Motor must be reduced to an absolute minimum.**

2. **The Torque Gradient of the Motor must be high so that a very small lag produces enough torque to overcome the friction.**

To satisfy the first requirement, the ball bearings used on Synchro Motors are selected with extreme care, and they are lubricated only with the highest grade of light oil. It is interesting to note that friction on the shaft of the *Generator* does *not* affect the system's accuracy, but only increases the power required to turn the large unit to which it is geared. As a result the requirements concerning mechanical tolerances and lubrication of a Generator are less severe. Grease-lubricated bearings are often used. It is common practice, in the manufacture of Synchros, to make a number of units, select those which make satisfactory Motors and equip them with dampers. Many units which are not satisfactory as Motors can still be used as Generators with no sacrifice in performance.

To satisfy the second requirement, both the Generator and the Motor must be large enough. If either or both is too small, the high impedance of its stator windings will reduce the current for small unbalanced voltages, and thus reduce the Motor's Torque Gradient.

Practically, only two sizes of Synchro Motors are used in the Navy: (Note: An intermediate size is shortly to be introduced.)

The smaller Motor (size 1) is used where accuracy is less important.

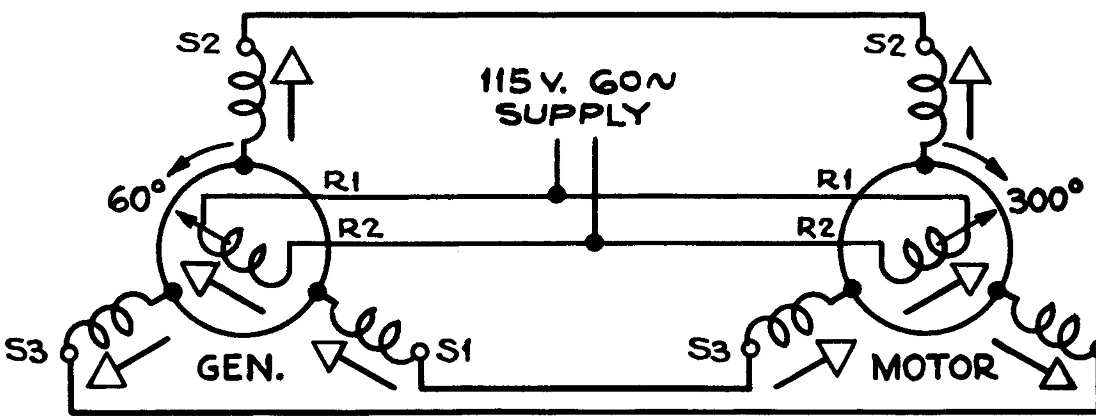
The larger Motor (size 5) is used in all positions where accuracy is required. When properly used a 5 size Motor is accurate within a half a degree or better, and a 1 size Motor within two degrees or so.

In a System Involving a Number of Motors: In such a system the accuracy with which each Motor follows the master Generator is determined by the following factors:

1. The friction or other load on the shaft of that Motor.
2. The friction or other load on the shafts of all the other Motors. If any one Motor turns hard, or becomes jammed, the accuracy of the whole system is affected.
3. The size of the Generator (its Unit Torque Gradient) as related to the number and size of the Motors in the system. If too many Motors are connected to a Generator its output voltages are reduced and excessive lag is produced in all the Motors in the system.

MAKING A SYNCHRO MOTOR TURN BACKWARDS

If it is desired to make the shaft of a Synchro Motor turn in the opposite direction from that in which the Generator shaft is turned, it can be done by connecting S1 on the Motor to S3 on the Generator, and S3 to S1 like this:



Suppose that both Motor and Generator are initially at 0°, and that the Generator is then turned *counter-clockwise* to 60°. In this position maximum voltage will be induced in coil 1 on the Generator. This will cause maximum current to flow in coil 3 on the Motor, and its shaft will turn *clockwise* until the rotor lines up with coil 3. This occurs at 300° (which is the same as *minus* 60°).

With this connection the Motor's shaft will always turn opposite to the Generator's shaft, and the position of the Motor's shaft at any time can be found by subtracting the Generator's position from 360°.

IMPORTANT

This connection (S1-S3) is the only one that is ever interchanged in a standard Synchro system. Interchanging other pairs of S leads introduces 120° errors in reading.

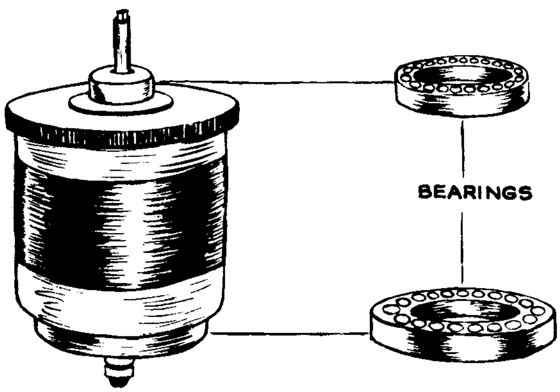
THE BEARING-MOUNTED MOTOR

THE BEARING-MOUNTED SYNCHRO MOTOR

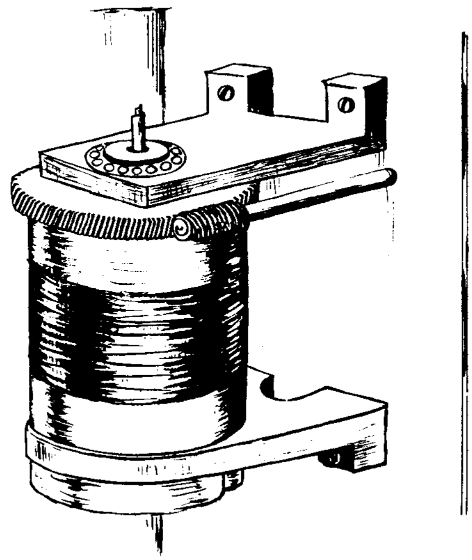
This type of Synchro is widely used in the Navy. Electrically its construction and operation are identical with that of a Synchro Motor. The difference is in the mechanical construction.

The stator of a bearing mounted Synchro is mounted on two sets of ball bearings so that it is free to rotate, as well as the rotor. It is usually mounted something like this:

Ball races are fitted over shoulders provided on each end of the stator.



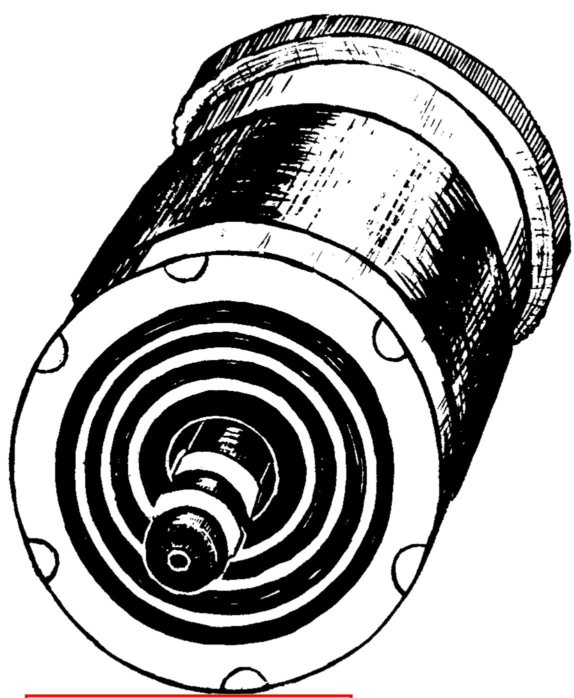
And the whole business is supported on hangers.



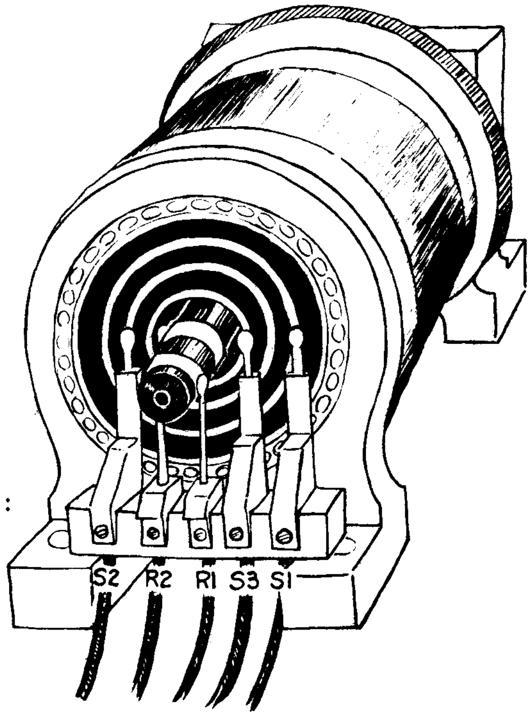
With this arrangement the position of the rotor with respect to the stator is determined by the voltages applied to the five leads, as with any Synchro Motor. The position of the stator with respect to its mounting is usually set by means of a worm which drives a big gear mounted on the stator.

To allow connections to the three stator leads, three additional slip rings are provided on a Bearing Mounted Synchro. They are mounted on the end of the stator opposite the shaft end like this:

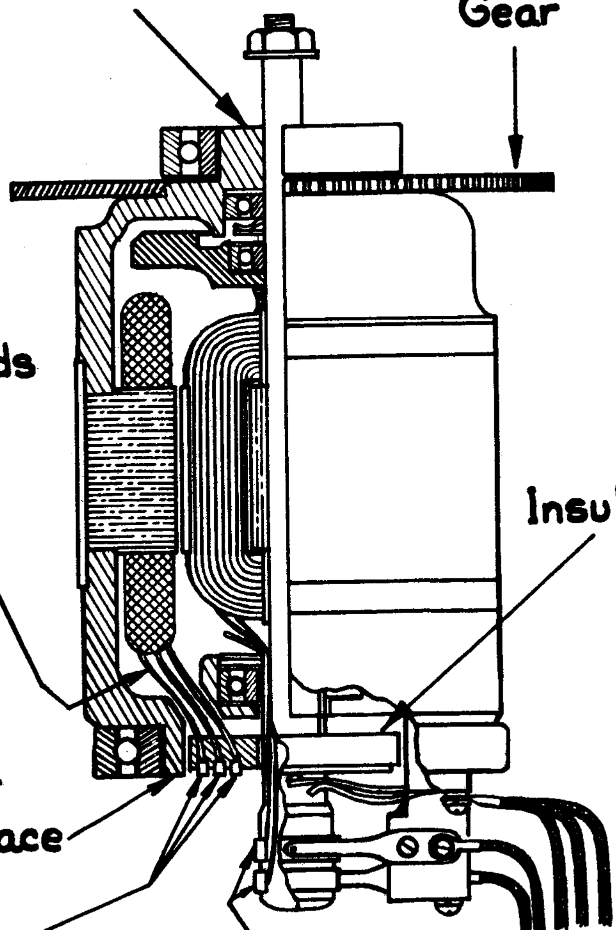
The three stator slip rings are mounted in an insulating plate.



Three stator brushes ride on these slip rings in addition to the two that make contact with the rotor's slip rings.



A cut-away view shows the construction a little better:



THE DIFFERENTIAL

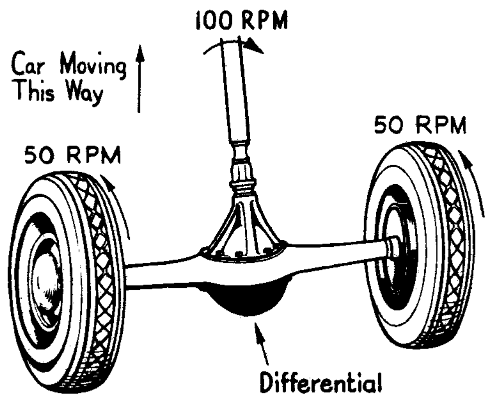
HOW A SYNCHRO DIFFERENTIAL WORKS

The usefulness of a Synchro system in many applications is greatly increased by the addition of another member of the Synchro family, the Synchro Differential. This unit does, in a Synchro system, very much the same job as a mechanical differential does in a mechanical system.

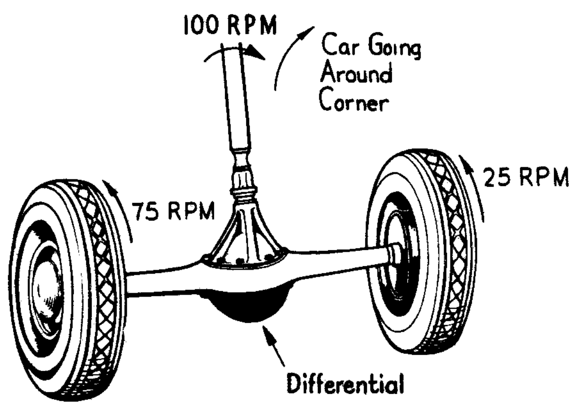
A MECHANICAL DIFFERENTIAL

Consider the differential on a car. It works something like this:

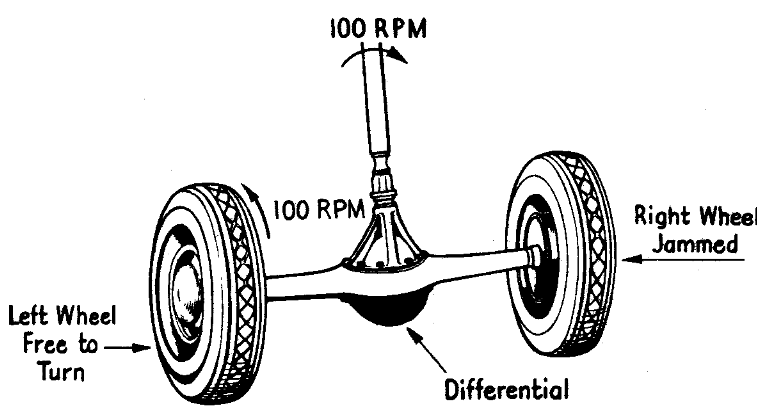
When the car is moving along a straight road, both rear wheels turn at the same speed. For example, with the drive shaft turning 100 RPM, each wheel might turn, as shown, at 50 RPM.



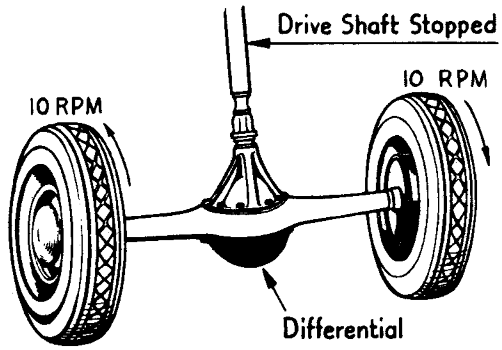
If the car goes around a sharp corner to the right, so that the right wheel has a shorter distance to travel than the left wheel, the left wheel goes faster, and the right one slower, like this:



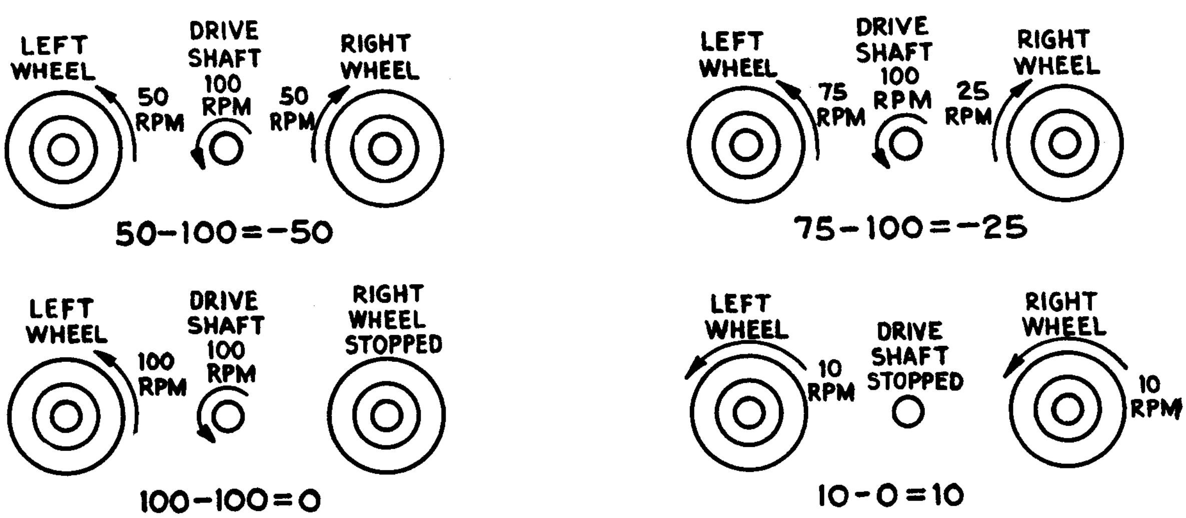
Suppose the car gets down in the ditch so that the left wheel is off the ground. If the drive shaft still turns at 100 RPM, the right wheel doesn't turn at all, and the left wheel spins around twice as fast as before, like this:



Now suppose the motor is stalled so that the drive shaft is stopped entirely and both wheels are lifted off the ground. If the left wheel is turned by hand, the right wheel turns *in the opposite direction* and at the same speed like this:



Consider how the rotations of these three shafts would look if, in each case, you looked at the *end* of the shaft. When thinking of a wheel, you are looking at the *hub* of the wheel, and when thinking of the drive shaft you are looking at the end that connects to the motor. The rotations of these shafts under the various conditions pictured above would then look like this:



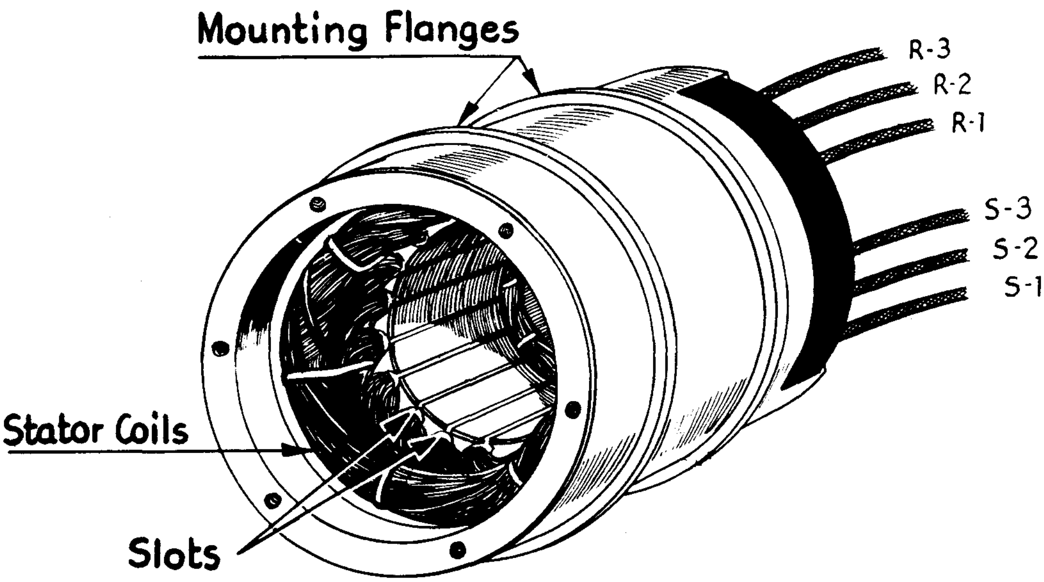
The important thing to notice is this: In each case the total number of revolutions through which the right wheel turns each minute is equal to the difference between the revolutions of the other two shafts.

This is where a *differential* gets its name: it connects three shafts together in such a way that the amount one of them turns is the *difference* between the amounts the other two turn.

The next step is to find out how a Synchro Differential does this job in a Synchro system.

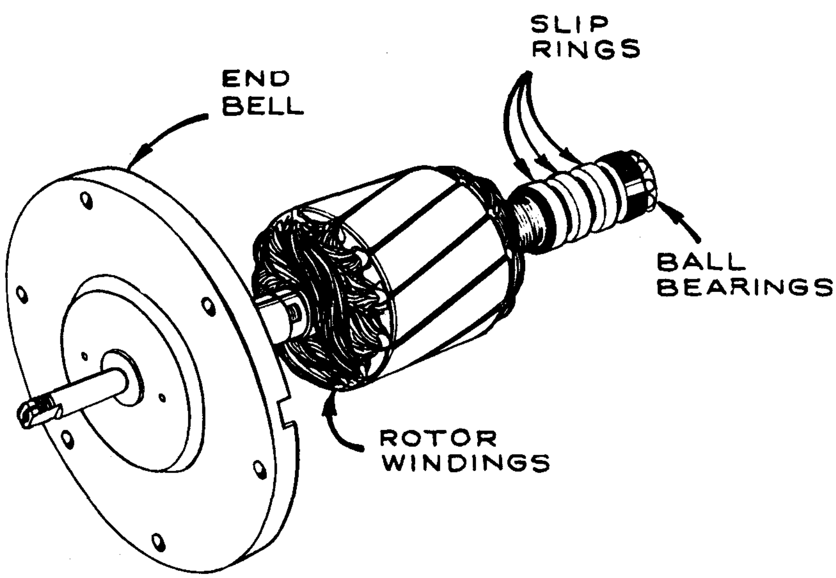
THE CONSTRUCTION OF A SYNCHRO DIFFERENTIAL

The stator of a Synchro Differential is similar to the stator of a Motor or a Generator, consisting of three sets of coils wound in slots and spaced equally around the inside of the field structure.



The Stator of a Typical Synchro Differential

The rotor of a Differential is entirely different from that of a Motor or Generator. It is cylindrical in shape and is similar to the stator, having *three* sets of coils wound in slots and spaced equally around the circumference like this:



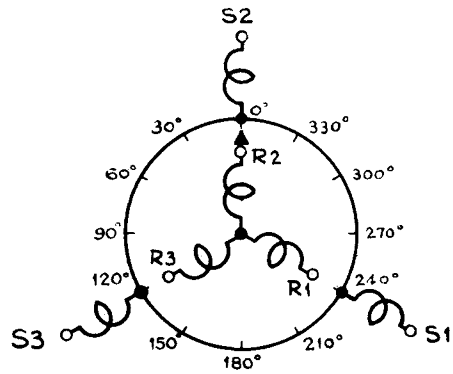
The Rotor of a Typical Synchro Differential

Three slip rings are mounted on the end of the rotor and three brushes are used to allow connection to the three free ends of the rotor coils.

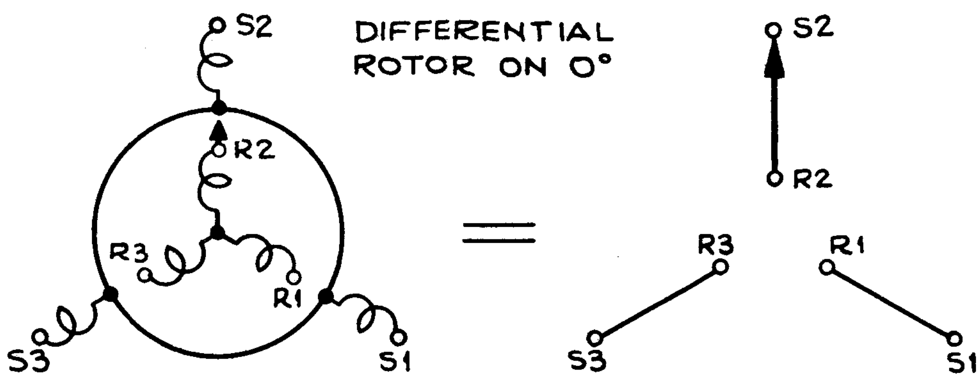
HOW A SYNCHRO DIFFERENTIAL WORKS

The operation of a Synchro Differential can best be understood by means of a diagram similar to the one used to explain the operation of the Motor and the Generator.

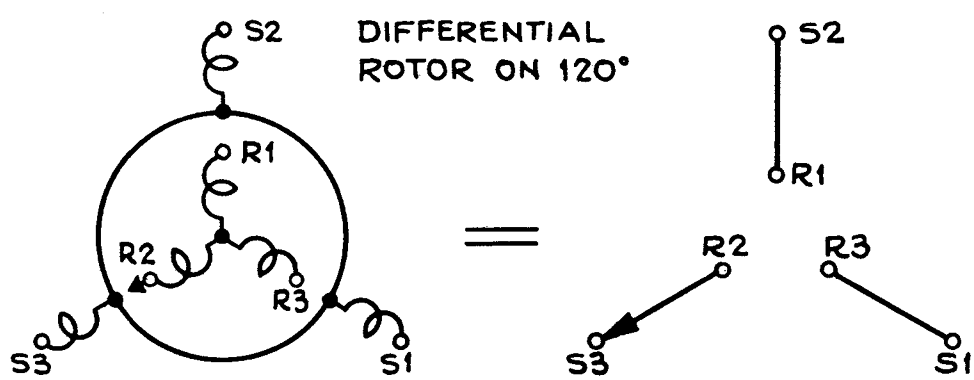
To use this diagram, assume that the three rotor coils turn around an axis in the center of the diagram, the electrical position of the rotor being shown by the arrow on the R2 lead.



When voltages are applied to the stator windings, each of the three coils on the rotor has a voltage induced in it which depends on its position and on the stator voltages. The turns ratio between any one stator coil and a rotor coil is one-to-one. Thus, when the Differential is on "electrical zero" with its rotor coils lined up with the corresponding stator coils, the voltage induced in each rotor coil is equal to the voltage applied to the corresponding stator coil. The effect on a Synchro Motor connected to the rotor leads is just as if these leads were connected directly to the corresponding stator leads, like this:

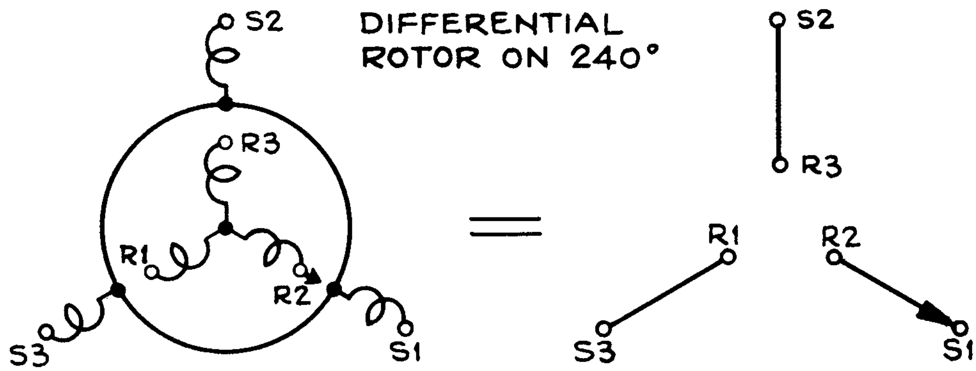


As the rotor is turned away from this position, the voltages induced in the stator coils will gradually change, until, when rotor coil 2 is in line with stator coil 3, the voltage induced in S3 will equal that across R2; the voltage induced in S1 will equal that across R3, and so on. The effect will be as if connections were made like this:



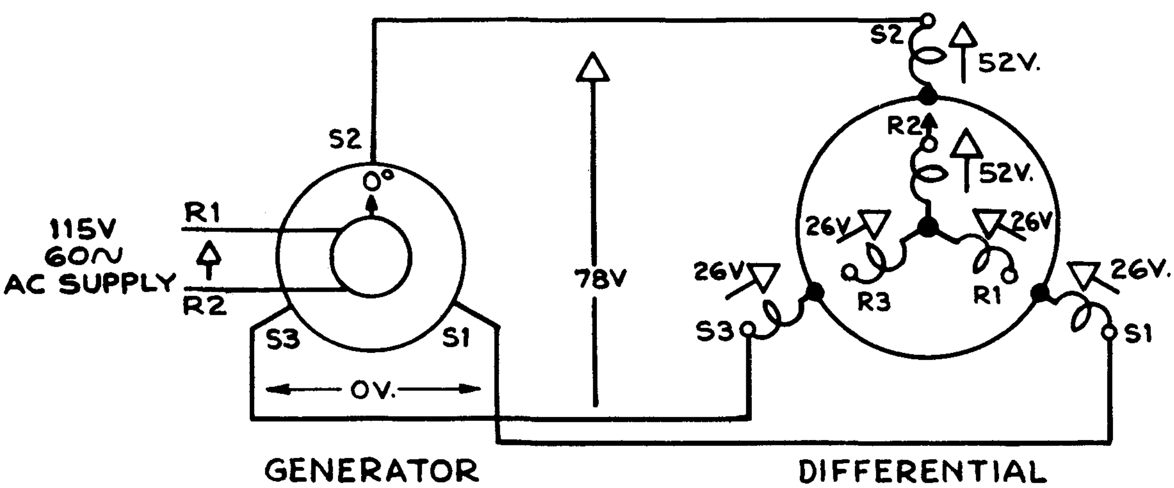
THE DIFFERENTIAL

If the rotor is turned to the position where R2 is in line with S1, the effect will be as if connections were made like this:



In other words the Synchro Differential acts as a sort of "continuous switch," "connecting" its rotor leads to its stator leads in various ways depending entirely on the position of its rotor.

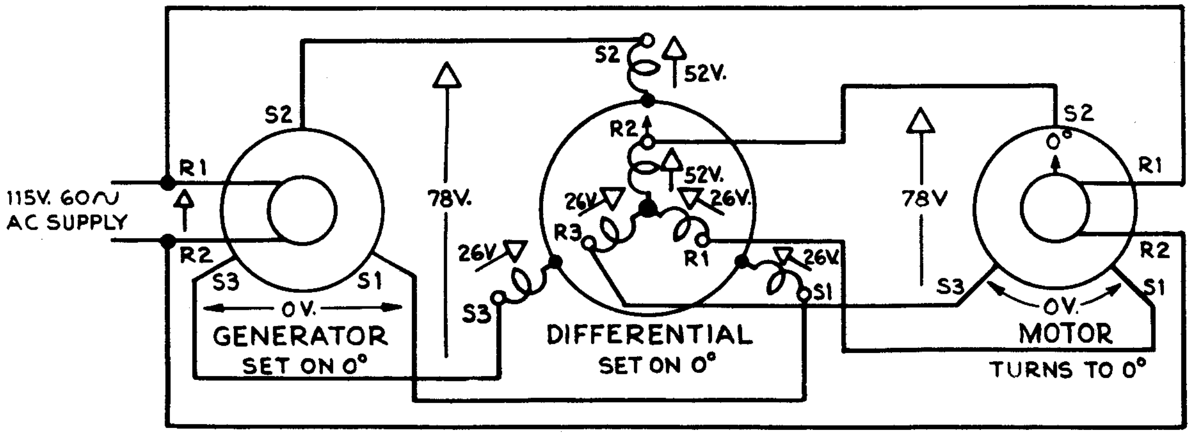
As an example of how this works out, suppose that the stator leads of a Synchro Generator are connected to the corresponding stator leads of a Synchro Differential, and that both shafts are turned to electrical zero, like this:



In this condition, coil 2 on the Differential's rotor is in line with stator coil 2, and the induced voltage is equal to the stator coil voltage (52 volts). Similarly a voltage is induced in each of the other rotor coils which is equal to the voltage across the corresponding stator coil (26 volts).

If the rotor coil voltages are added together, it can be seen that the voltage between R2 and R3 is 78 volts, just like the voltage applied between S2 and S3. Also the voltage between R3 and R1 is zero, just like that applied between S3 and S1. In short, the output voltages from the Differential's rotor leads are identical with the voltages applied to its stator.

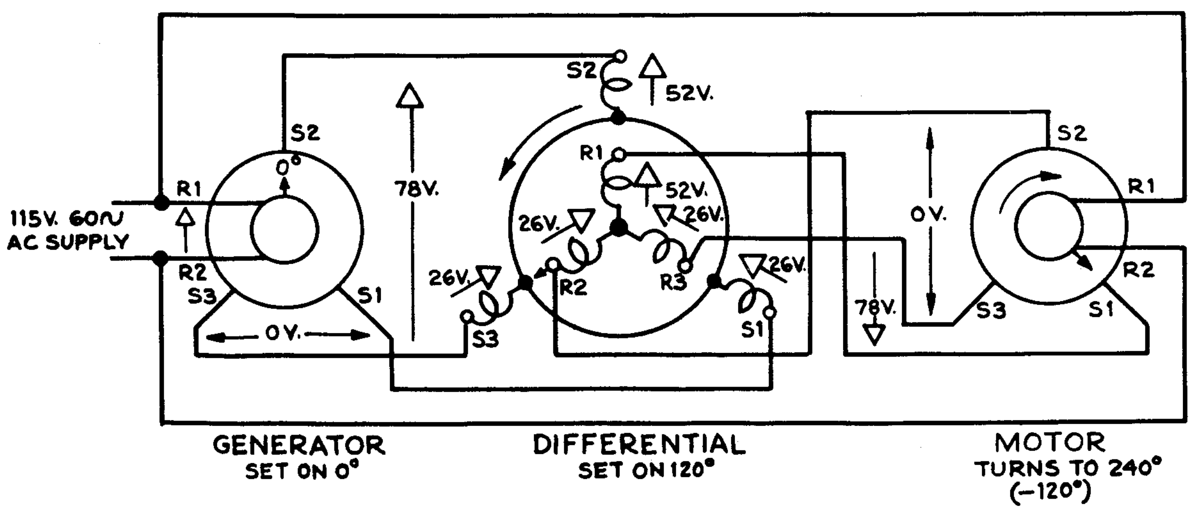
A Motor connected to the Differential's rotor leads under this conditions turns to 0°, like this:



Now consider what happens if the shaft of the Generator is turned to any other position. The voltages applied to the stator coils of the Differential change, and the voltages induced in its rotor coils change in exactly the same way, so that the net effect is as if the Differential were not in the circuit.

When the shaft of a Differential is set on 0° its output voltages are equal to its input voltages at all times. If the shaft of the Generator connected to its input leads is turned, the shaft of the Motor connected to its output leads will turn to the same position.

Now consider what happens when the shaft of the Differential is turned to 120°, with the Generator set on 0°, like this:



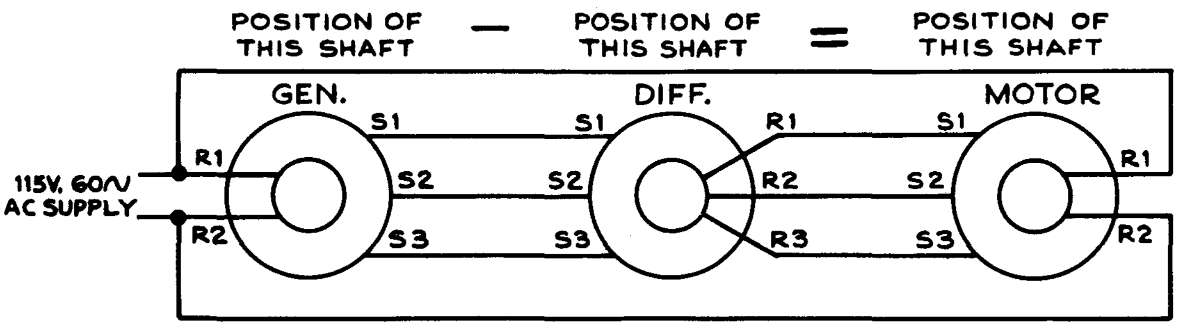
The voltage across S2 is now induced in R1, the voltage across S3 is induced in R2 and the voltage across S1 is induced in R3. In other words the Differential effectively connects S2 to R1, S3 to R2 and S1 to R3. As a result 78 volts is produced between S1 and S2 or S3 on the Motor, with 0 volts between S2 and S3, and the Motor turns to 240°, since these are the same voltages that would come out of a Generator which was set on 240°.

If the Generator were turned to any other position, with the Differential set at 120°, the Motor would turn to a position equal to the Generator's position *minus* 120°.

THE DIFFERENTIAL

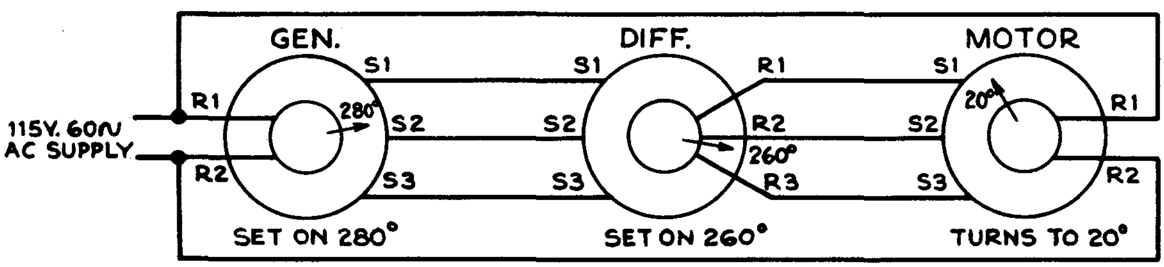
To make a long story short, the rotations of the shafts of the Generator, the Differential, and the Motor are related in the same way as the rotations of the three shafts in a mechanical differential. Here is a simple rule:

> **When a Differential is connected directly between two Synchros (as shown below), the shaft position of the unit connected to the Differential's rotor leads is equal to the position of the other unit *minus* the Differential's position.**



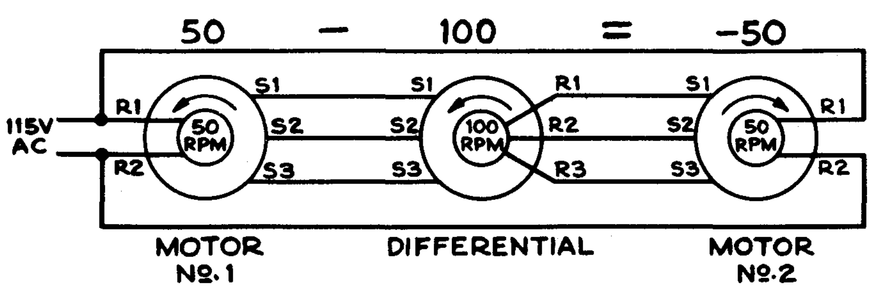
A good way to think of this is that the Differential subtracts a correction equal to the position of its shaft from the order transmitted by the Generator.

A few examples may help to make this clear:



When the Generator is turned to 280° and the Differential to 260°, the Motor turns to 20°, because 280° minus 260° is 20°.

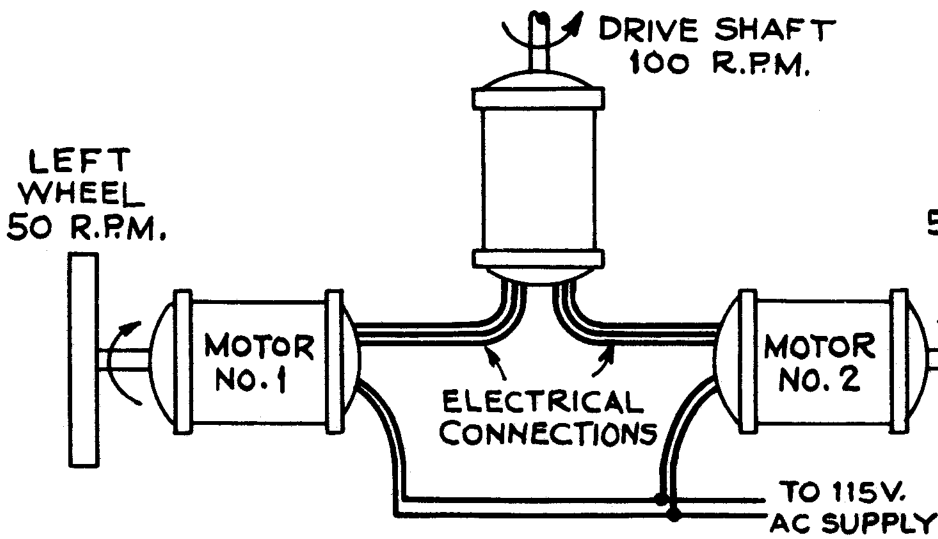
Consider a Differential connected between two Motors, like this:



When the shaft of the Differential is turned one way at a speed of 100 RPM, and the Motors are equally loaded, Motor No. 1 turns the same way at 50 RPM, and Motor No. 2 turns the other way at 50 RPM. This satisfies the rule given above, since the total number of revolutions through which Motor No. 2 turns each minute is equal to No. 1's revolutions minus the Differential's revolutions. (50–100 = –50.)

With these connections, if No. 2's shaft is stopped, No. 1's turns twice as fast; if the Differential is stopped and No. 1 is turned one way at 10 RPM, No. 2 turns the same way at 10 RPM.

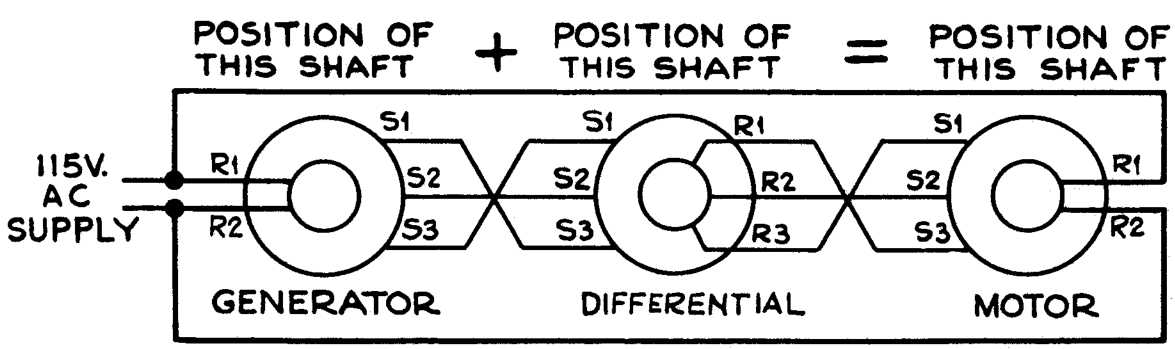
Suppose these three units were connected electrically as shown above, and mounted mechanically like this:



It is easy to see that they would give the same results as the *mechanical* differential that was described before. This would not be a very practical way to drive a car, however, because of the large units required, and the need for an AC supply. The advantage of the Synchro differential system over the mechanical one is the fact that the units can be widely separated from each other without any mechanical connection.

TO REVERSE THE EFFECT OF A DIFFERENTIAL'S SHAFT

The effect of the Differential's shaft position on the associated units can be reversed, by interchanging *both* the S1-S3 connections and the R1-R3 connections like this:



With reversed connection the rule given above is modified as follows:

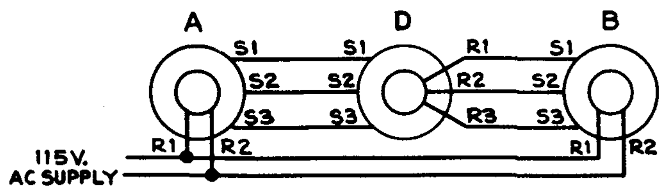
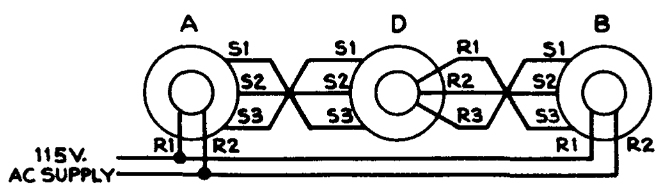
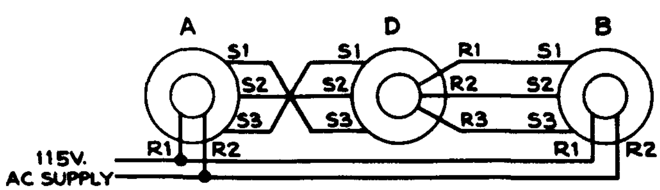
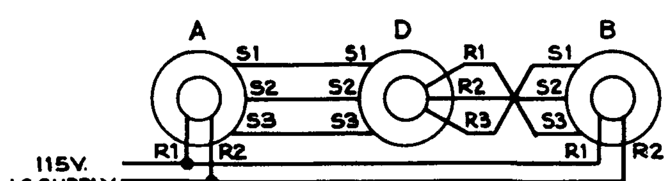
> **If both the S1-S3 and the R1-R3 connections to a Differential are interchanged, the shaft position of the unit connected to the Differential's rotor leads is equal to the position of the other unit *plus* the Differential's position.**

In other words, the Differential now *adds* a correction equal to its position to the order transmitted by the Generator.

THE DIFFERENTIAL

RULES FOR A DIFFERENTIAL WITH VARIOUS CONNECTIONS

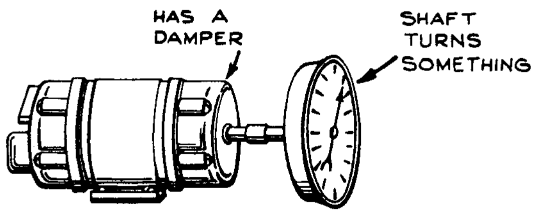
By interchanging various combinations of S1-S3 leads it is possible to get any desired relationship between the units connected to a Differential. All the connections which may be used in a standard Synchro system are shown below, with the corresponding relationship between shaft positions.

CONNECTIONS	OPERATION ("A°" INDICATES POSITION OF A's SHAFT IN DEGREES ETC.)
 DIRECT CONNECTIONS	$A^\circ - D^\circ = B^\circ$
 DIFFERENTIAL REVERSED	$A^\circ + D^\circ = B^\circ$
 "A" REVERSED	$-A^\circ - D^\circ = B^\circ$
 "B" REVERSED	$A^\circ - D^\circ = -B^\circ$

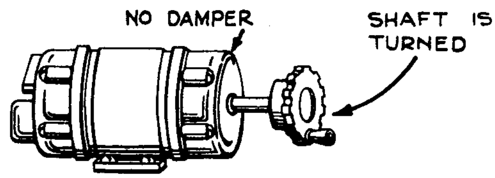
A SYNCHRO DIFFERENTIAL MAY BE USED EITHER AS A GENERATOR OR A MOTOR

In any Synchro system, the only thing that determines whether a given unit acts as a Motor or as a Generator is whether its shaft turns something, or whether it is turned by something. In any of the systems that have been described, if the Generator shaft is made *free to turn,* and the Motor shaft is *turned,* the system works "backwards" and the Generator's shaft follows the Motor's shaft. Of course, if spinning is to be avoided, all units working in "Motor" positions must have inertia dampers.

Up to this point the Differential has been described as if it were a Generator, that is, as if its shaft were always turned. Actually two types of Differential units are made. One type has an inertia damper mounted on its shaft, and is called a Differential Motor. The other type, without a damper, is called a Differential Generator. The difference between these two units is essentially the same as the difference between a Motor and a Generator.



Differential Motor



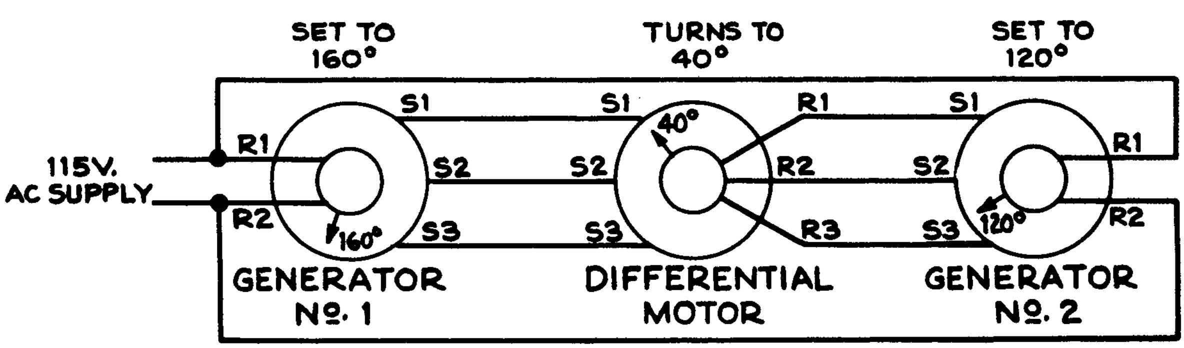
Differential Generator

A Differential Generator is always used in a position where its shaft is driven by some large unit, so no damper is needed. Friction is not critically important, so the bearings are often lubricated with grease.

A Differential Motor is used in a position where its shaft drives a small dial or a switch, so a damper is needed. Friction is critically important if accuracy is to be maintained, so the bearings are selected with extreme care and lubricated only with the finest grade of light oil.

If the rotor of a Differential Motor is free to turn, and two sets of voltages are applied to its stator and rotor windings, currents will flow in these windings which will cause the rotor to turn. It will turn to the position where the voltages induced in its windings balance the applied voltages, and the currents are reduced to zero (almost, they don't quite fall to zero practically).

Consider, for example, what happens when a Differential Motor is connected between two Generators like this:



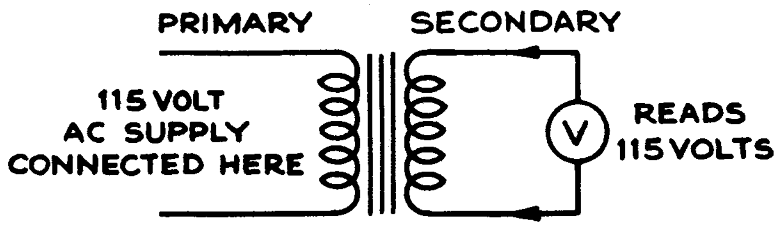
The rule given above for direct connections applies to this case. It indicates that Generator No. 1's setting minus that of the Differential must equal Generator No. 2's setting. It means the same thing, and its easier to remember that the Differential Motor reads the difference between the settings of the two Generator's (for direct connections).

THE DIFFERENTIAL

A DIFFERENTIAL'S ROTOR AND STATOR LEADS AREN'T INTERCHANGEABLE

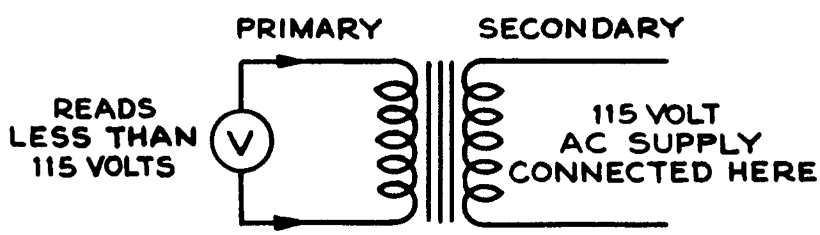
At first glance it looks as if it wouldn't make much difference (except for the directions of rotation) which way around a Differential is connected. Since voltages applied to the rotor coils will induce voltages in the stator coils, as well as the other way around, it wouldn't seem to matter which is called the primary, and which the secondary. Actually it makes a considerable difference.

To understand this, consider the operation of a simple one-to-one transformer:



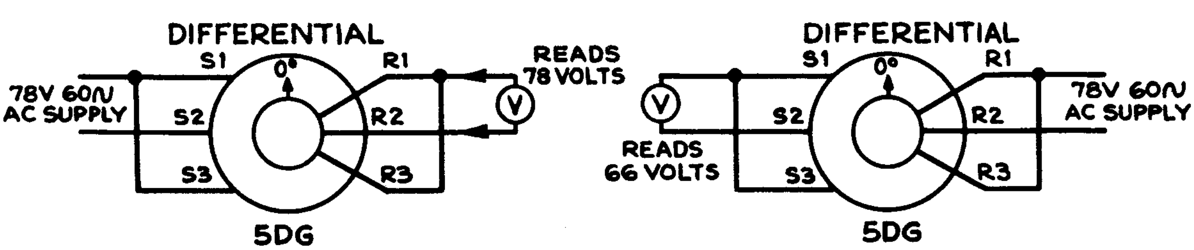
If this transformer is designed to give a one-to-one voltage ratio, a voltmeter connected across the secondary will read the same voltage that is applied to the primary. There has to be a few extra turns on the secondary to give this effect, since the coupling between primary and secondary is never perfect.

As a result, this transformer does not act the same if the primary and secondary are interchanged.



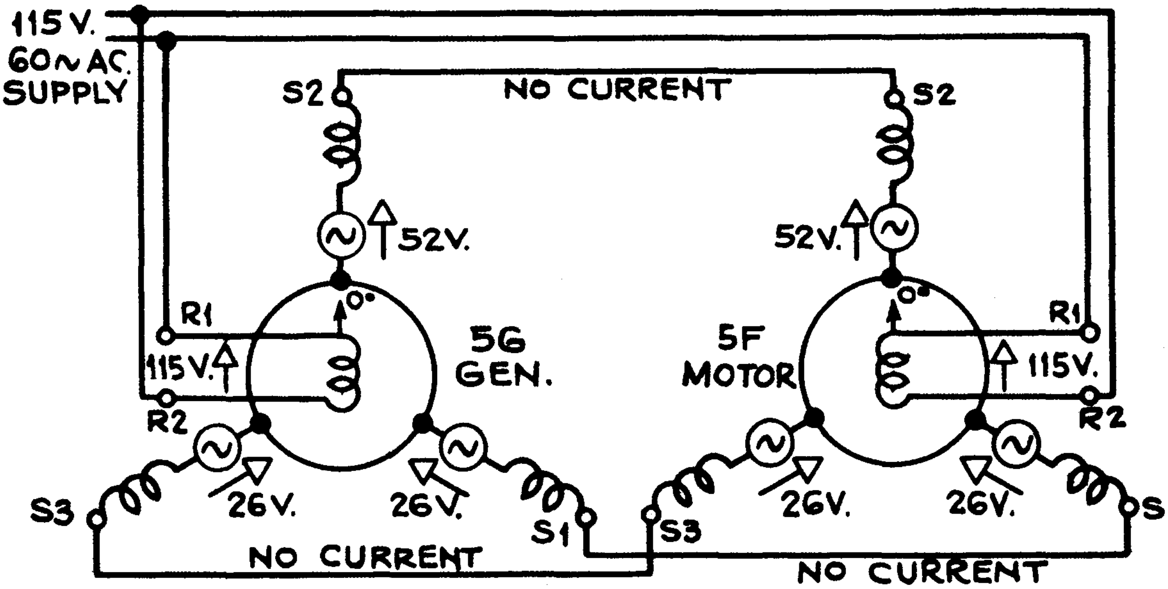
Since there are more turns on the secondary than on the primary, it acts as a step-down transformer when connected this way and the voltmeter reads less than the applied voltage.

Since the secondary (rotor) of a Differential has to turn, there is a small air gap between it and the primary, so the coupling is somewhat less than it would be in a well-designed transformer. As a result the effect mentioned above is more noticeable. The voltage ratio of a typical Differential was measured in the two directions, like this:



Notice that there are effectively more turns on the secondary (rotor) so that it acts like a one-to-one transformer when fed from the primary (stator). When fed from the rotor, the voltages induced in the stator windings are considerably lower than the applied voltages.

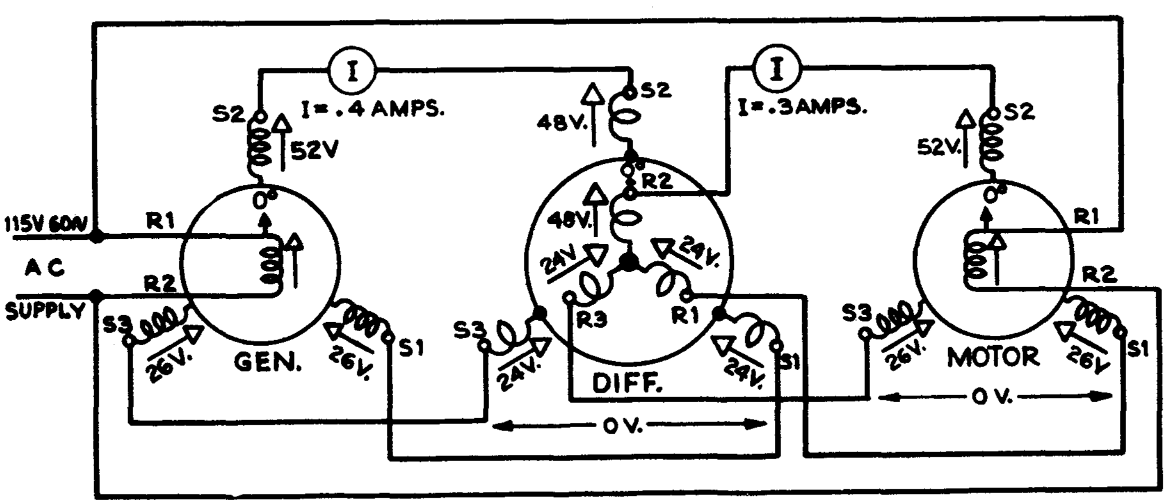
To understand what effect this has on the operation of a Synchro system, consider again what happens when a Synchro Motor is connected to a Synchro Generator:



When both are in the same position, the voltages induced in the Motor windings almost exactly balance those induced in the Generator windings, so practically no current flows in the stator leads. As a result the Motor is very sensitive to small changes in Generator position, and gives high accuracy.

Now consider what happens when a Differential is connected between the Generator and the Motor. The Differential could be designed so that, with all shafts in the balanced position, the voltages induced in its *rotor* windings balanced the *Motor* voltages, or so that its *stator* voltages balanced the *Generator* voltages, but it could not be designed to do both things at the same time, since it can't be made one-to-one in both directions.

Actually, standard Synchro Differentials are designed so that the voltages induced in the rotor windings are equal to the voltages applied to stator windings. When a Differential is connected between a Generator and a Motor, some current flows in the Generator's stator circuit, and so the Generator's output voltages are reduced below normal. These lower-than-normal voltages are induced in the rotor windings of the Differential, and they are not high enough to buck out the Motor voltages. As a result current flows in both stator circuits, although the current in the Generator circuit is usually higher:



The effect of these currents is to reduce the accuracy of the system. Since the current in the Differential's stator circuit is greater, it is important that this side of the Differential be connected to the Generator, which is often larger than the Motor, and better able to supply this current. Synchro Capacitors should always be used to reduce this current to a minimum (see section on Capacitors).

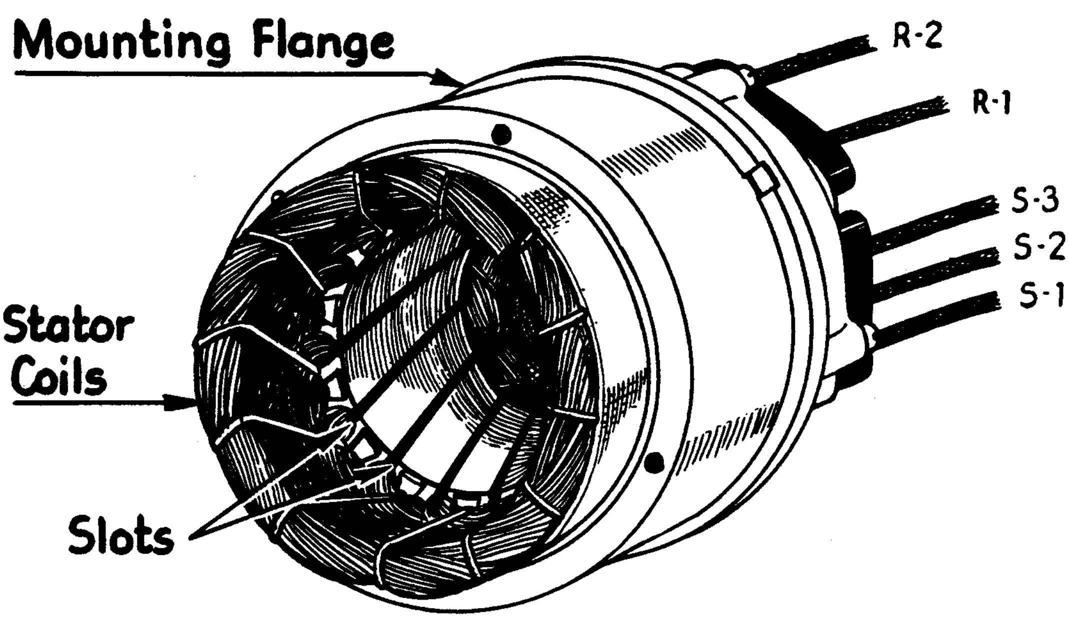
It is well to remember that the accuracy of a Synchro system may be reduced when a Differential is connected into the system. Where extreme accuracy is essential, the use of a Differential should be avoided, if possible. On the other hand Differentials are manufactured under rigid specifications that hold the error which it introduces to a value that is low enough for most purposes.

HOW A SYNCHRO CONTROL TRANSFORMER WORKS

Another type of Synchro unit, widely used in Automatic Control Systems, is the Control Transformer. The purpose of this unit is to supply, from its rotor terminals, an AC voltage whose magnitude and phase polarity depends on the position of its rotor, and on the voltages applied to its three stator windings. It is designed with high impedance stator coils which draw relatively little current, and its output is usually connected to a high impedance load (10,000 ohms or more) such as the grid circuit of a vacuum tube.

THE CONSTRUCTION OF A SYNCHRO CONTROL TRANSFORMER

The stator of a Control Transformer looks just about the same as the stators of the other units:



The Stator of a Typical Synchro Control Transformer

The coils are wound with more turns and finer wire so that their impedance is higher than the coils in the other units.

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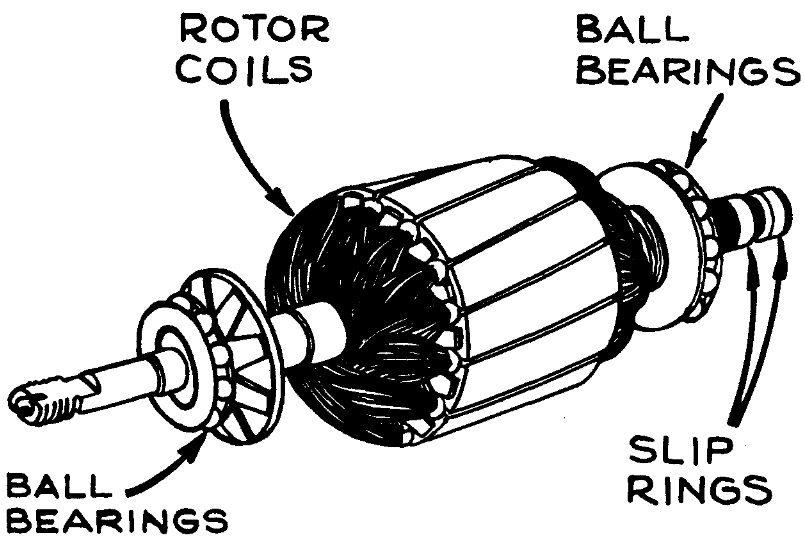
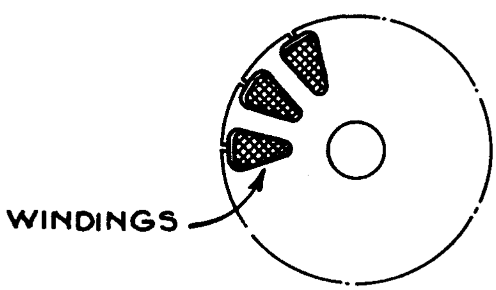
There are several important differences between the Control Transformer and the other Synchro units. Since the rotor winding is never connected to the AC supply, it induces no voltage in the stator coils. As a result the stator current is determined only by the impedance of the windings, which is high, and it is not affected appreciably by the rotor's position. Also there is no appreciable current in the rotor, and it does not tend to turn to any particular position when voltages are applied to the stator. The shaft of a Control Transformer is always turned by something, and it produces varying output voltages from its rotor winding. Thus it is some respects like a Generator or a DG, requiring no inertia damper.

To keep the position of the Control Transformer's rotor from affecting the stator currents, it is built like this:



The Rotor of a Typical Synchro Control Transformer

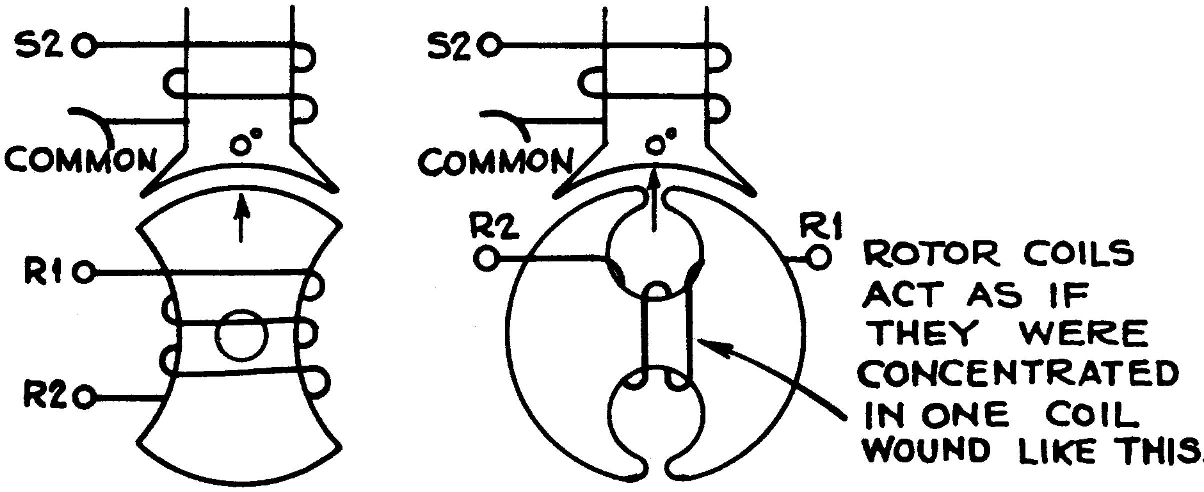


Cross Section of Rotor

This looks very much like the rotor on the Synchro Differential, but it is actually quite different. Instead of being connected in three groups, all of the coils on the C.T.'s rotor are connected in series, and the two ends are connected to two slip rings. These coils are wound with many turns of fine wire, the turns ratio being such that a maximum of 55 volts is induced in the rotor with normal stator voltages.

THE CONTROL TRANSFORMER

The comparison between a C.T. and a Motor or Generator can be seen more clearly from this diagram:



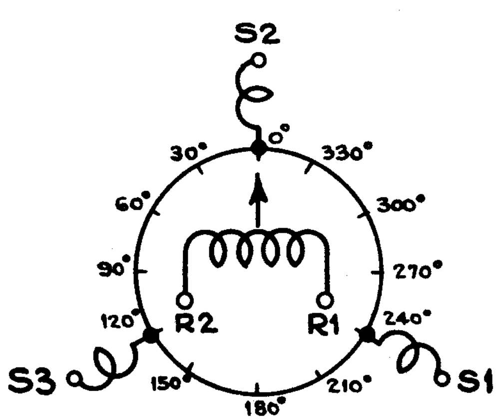
Synchro Motor or Generator Rotor Shown in the 0° Position

Control Transformer Rotor Shown in the 0° Position

Notice that the "Electrical Zero" position for a C.T. is different from that for a Motor or Generator. On a C.T. the position where *minimum* voltage is induced in the rotor by coil 2 is chosen as the electrical zero position.

THE OPERATION OF A CONTROL TRANSFORMER

The detailed operation of a Control Transformer can be described with a diagram similar to the one that was used for the Motor and the Generator, except that the coil is in a different position with respect to the arrow:



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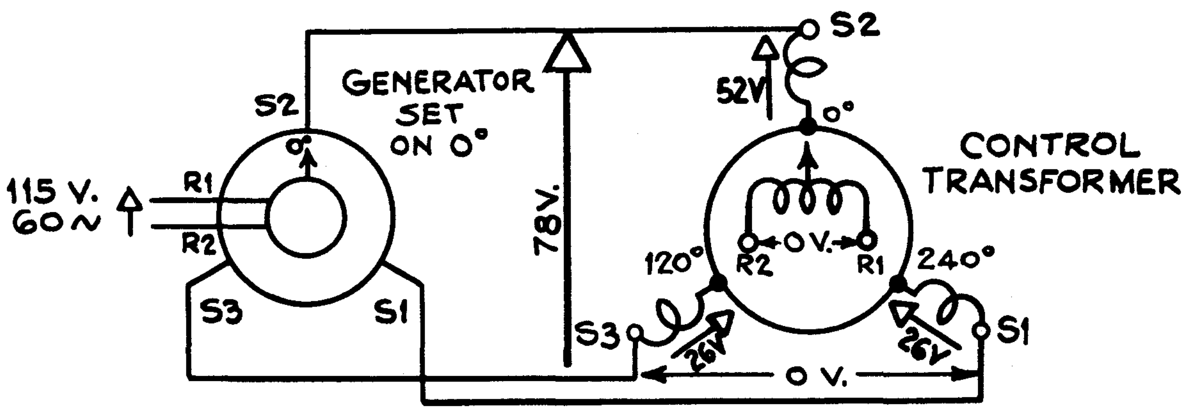
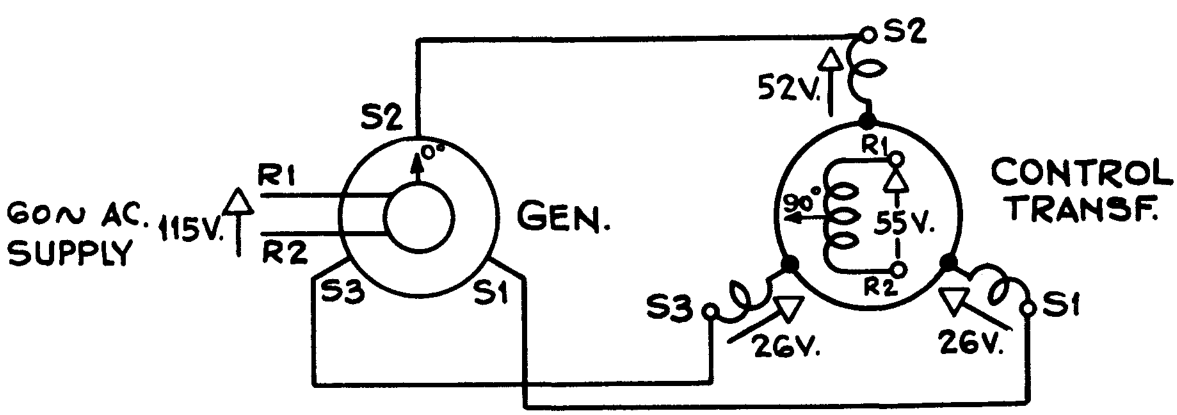
With Generator on 0°: Suppose that a Control Transformer is connected to the stator leads of a Generator that is set on 0°. The stator voltages of the Generator will cause current to flow through the stator windings of the C.T., producing voltages across the three windings like this:



When the shaft of the Control Transformer is in the Electrical Zero position, as shown, no voltage is induced in the rotor by coil 2, since they are perpendicular to each other. Since equal currents are flowing in coils 1 and 3, they induce equal and opposite voltages in the rotor. Thus the net induced voltage is zero, and no voltage appears between R1 and R2.

Now consider what happens when the shaft of the C.T. is turned to the 90° position, with the Generator still on 0° like this:

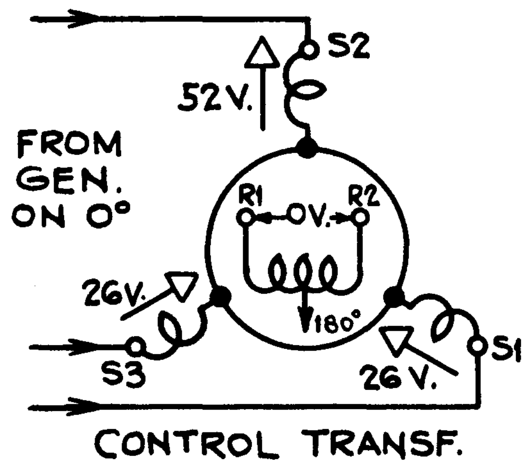


Now the rotor coil is in line with coil 2, so coil 2 induces a maximum voltage in it. At the same time the voltages induced by coils 1 and 3 add together and to the voltage from coil 2, producing a total induced voltage of 55 volts. Thus, with no load, 55 volts appears between R1 and R2. Since the rotor coil is wound in the same direction going from R1 to R2 as is coil 2 going from S2 to common, the voltage from R1 to R2 is in phase with the voltage from S2 to common. In other words it is in phase with the voltage from R1 to R2 on the Generator.

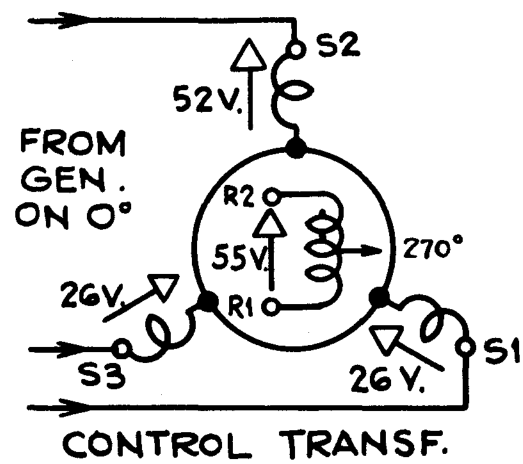
THE CONTROL TRANSFORMER

Consider two other positions of the C.T.'s rotor with the Generator still on 0°:

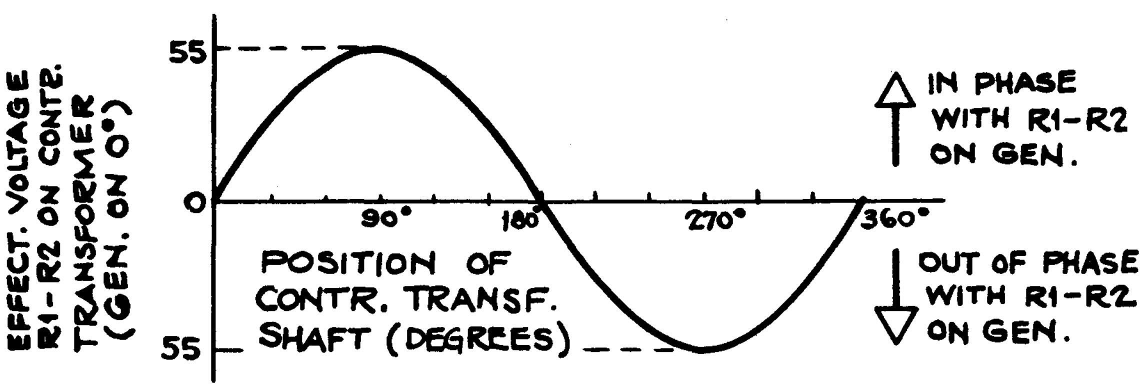
When the C.T.'s rotor is at 180° coil 2 induces no voltage, and the voltages induced by coils 1 and 3 cancel again, so no voltage appears between R1 and R2.



When the C.T. is turned to 270° the rotor is again lined up where all three induced voltages add up, so 55 volts appears again between R1 and R2. In this case, however, the coil is turned the other way up, so now the voltage from R1 to R2 is 180° out of phase with the voltage from R1 to R2 on the Generator.

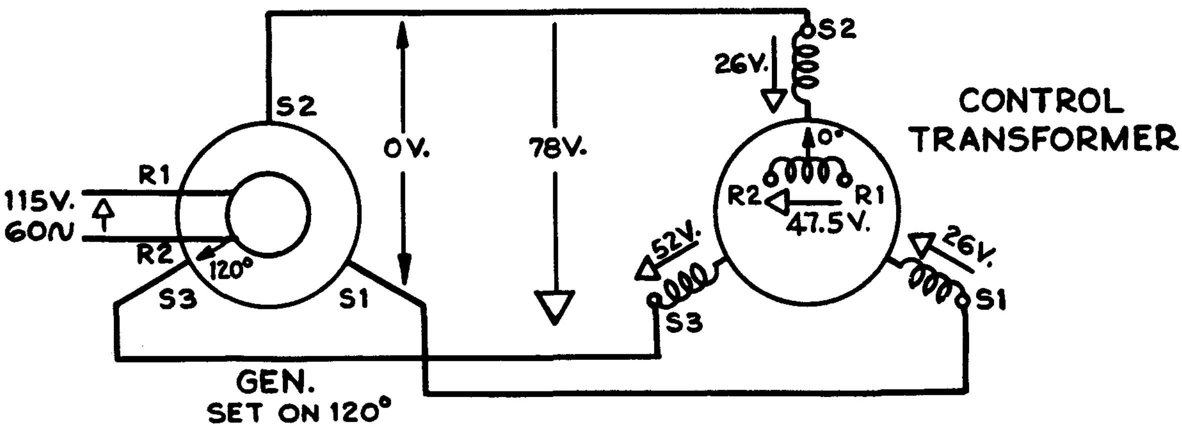


A graph showing how the output voltage of a Control Transformer connected to a Generator on 0° varies when the shaft is turned, looks like this:



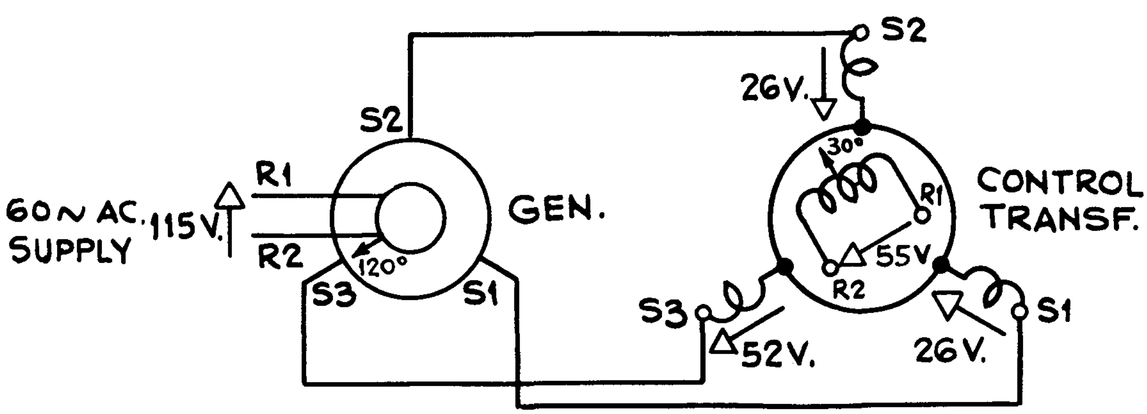
Since the operation of a Control Transformer is almost the reverse of the operation of a Generator or Motor, this graph has the shape of a sine-curve just like the graph of the voltage induced in a Motor's stator coil.

With Generator on 120°: Now consider what happens when the Generator's shaft is turned to another position, 120° for example, producing a different voltage distribution on the C.T.'s stator coils:



When the C.T.'s shaft is on 0° there is no voltage induced in the rotor due to coil 2. The voltages induced by coils 1 and 3 now add together, producing a voltage between R1 and R2 which is 180° out of phase with the voltage from R1 to R2 on the Generator. It is a little lower than 55 volts because the rotor is not quite in line with coil 3 which now has the highest voltage across it.

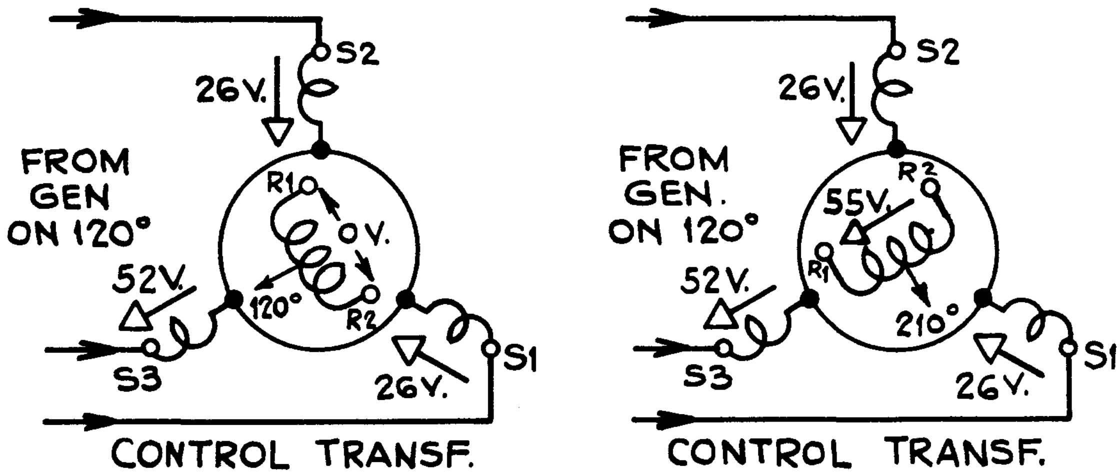
When the shaft is turned to the 30° position, a maximum of 55 volts is induced in the rotor coil, like this:



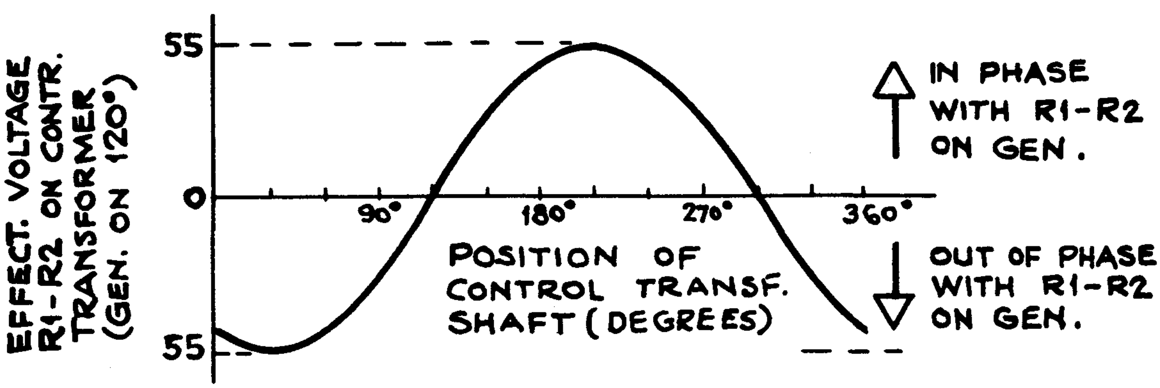
Now the rotor coil is lined up with stator coil 3, and also the voltages induced by coils 1 and 3 add together, so the maximum voltage is induced.

THE CONTROL TRANSFORMER

The rotor voltage falls to zero when the C.T.'s shaft is turned to 120°, and rises to 55 volts with the opposite polarity when it is turned to 210°, like this:



A graph of the C.T.'s output voltages for various shaft positions now looks like this:



The important point about the operation of a Control Transformer is this:

When the position of the C.T.'s shaft is the same as that of the Generator to which it is connected, its output voltage is zero. Since there are *two* points in the rotation of the shaft at which this occurs, there must be some way of telling the difference between them. This is done by the phase of the voltage that is produced when the shaft is turned slightly from the "0 volts" position.

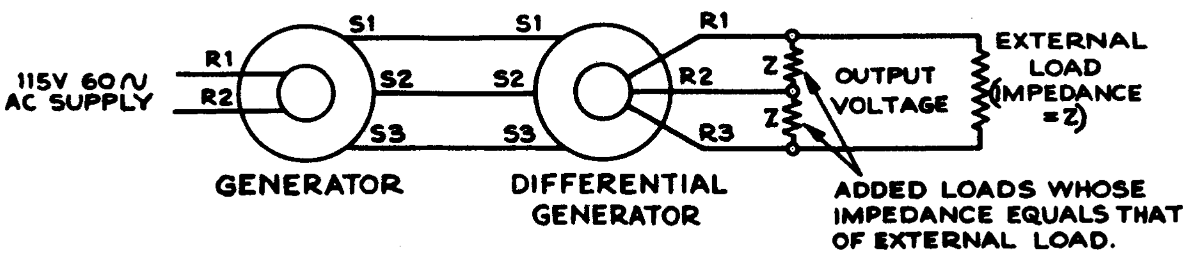
> ***General Rule:* When the shaft of a Control Transformer is in the same electrical position as the shaft of the Generator to which its stator leads are connected, its output voltage is zero, and turning its shaft slightly counter-clockwise from this position produces a voltage from R1 to R2 on the C.T. which is *in phase* with the voltage from R1 to R2 on the Generator.**

USING A DIFFERENTIAL GENERATOR AS A CONTROL TRANSFORMER

The accuracy of any Synchro system depends, among other things, on how closely the Generator's output voltages follow the normal sine-curve variation as its rotor is turned. When the stator leads of a Control Transformer are connected across the output of a Generator the balance between these three voltages is not seriously affected, provided the currents drawn by the three windings of the Control Transformer are balanced.

As long as the load impedance across the rotor leads of the Control Transformer is fairly high (10,000 ohms or more) the position of the rotor has no effect on the balance of the stator currents. If an attempt is made to supply a lower impedance load the current in the rotor circuit reacts on the stator currents, and may seriously unbalance the system.

Much the best answer to this problem is to arrange things so that the Control Transformer works into a high-impedance load. In some cases where this was impossible, a Differential Generator has been used in place of a Control Transformer like this:



With this connection the voltage between R1 and R3 on the DG varies in the same way as does the voltage between R1 and R2 on a Control Transformer. Due to the balanced load on the DG's rotor, the currents that flow in the rotor windings do not unbalance the stator currents as the rotor is turned.

This arrangement has the severe disadvantage that the DG requires a great deal more exciting current than does a CT. For example, a 5DG with this connection might draw as much as 0.6 amps. from the Generator, as compared with perhaps 0.04 amps. for a CT.

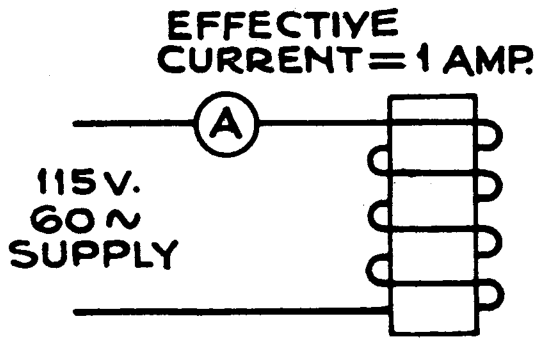
HOW SYNCHRO CAPACITORS (SYNCHRO "EXCITERS") ARE USED

In early Synchro systems these currents were reduced by connecting a free-running Motor, called an "Induction Exciter" into the system. This supplied some of the current and reduced the load on the Generator.

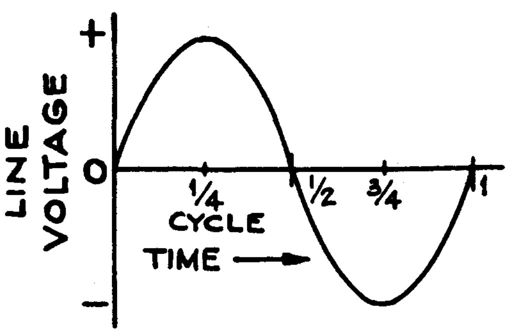
In all present Synchro systems this job is done by Synchro Capacitors (which are sometimes called "Capacitor Exciters" or simply "Exciters"). A Synchro Capacitor of the proper size is connected to the stator leads of every Differential or Control Transformer in the system, reducing its current drain and improving the performance. It is important to understand the effect of these capacitors.

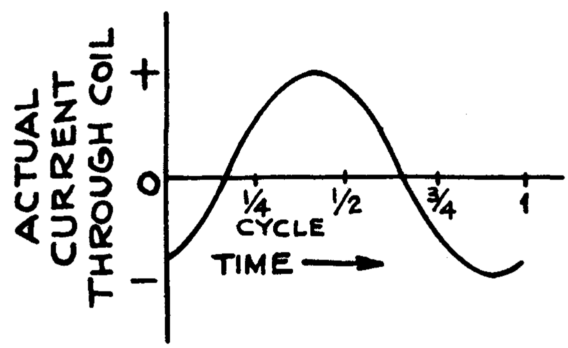
THE AC CURRENT DRAWN BY A COIL

Consider first what happens when an AC voltage is applied to a coil of wire wound on an iron core:



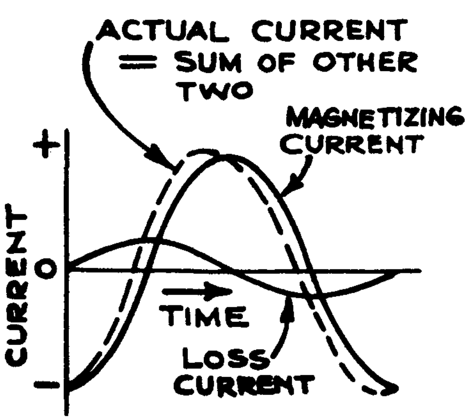
The AC current that flows in this coil has a certain magnitude which depends on how the coil is made (in this example it is 1 amp.). If the instantaneous values of this current were measured with an oscilloscope, and compared with the line voltage the graphs that would be seen would look like this:

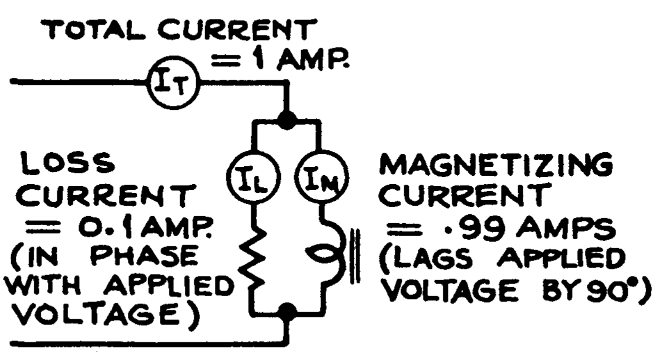




Because such a coil is highly inductive, its current reaches each point in the cycle almost 1/4 cycle later than the applied voltage. In other words, the current lags the applied voltage by almost 90°.

It is convenient to think of this current as being made up of two parts: one part, called the "loss current," which is in phase with the applied voltage, and another part, called the "magnetizing current," which lags that voltage by exactly 90°. The actual coil is equivalent to a high resistance in parallel with a pure inductance:



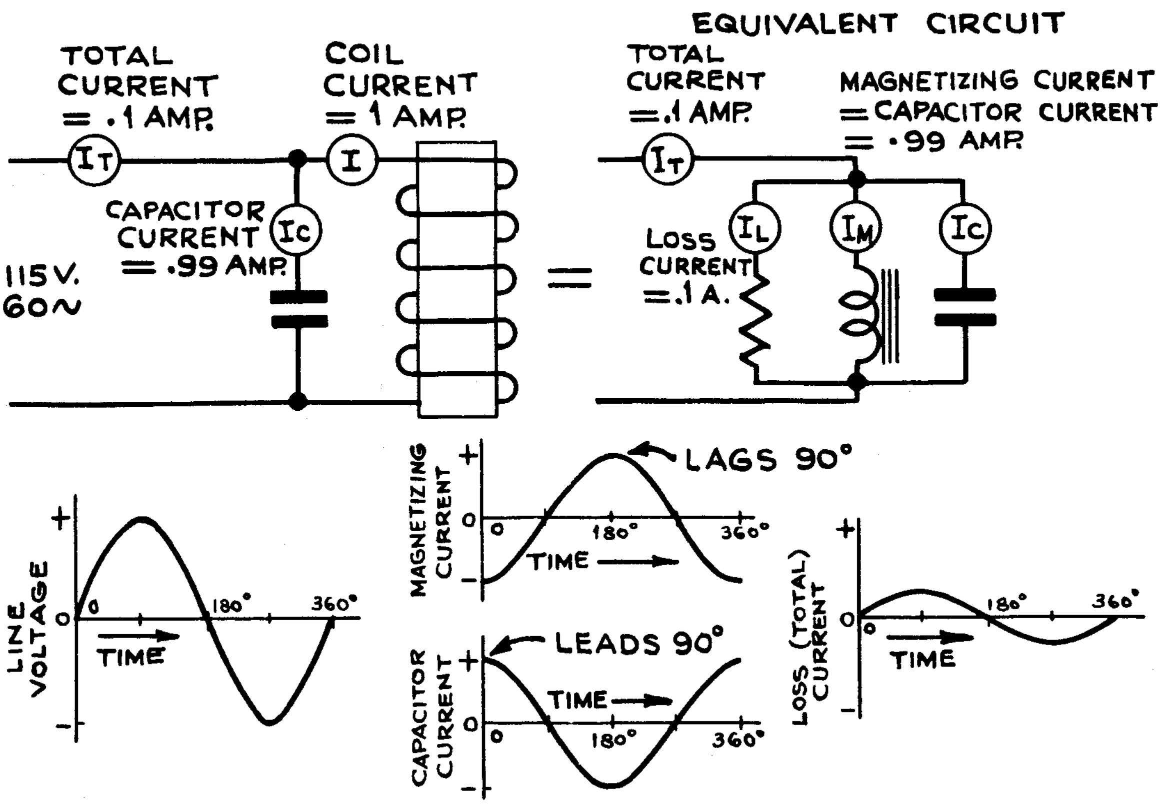


THIS CIRCUIT IS EQUIVALENT TO ACTUAL COIL

The loss current supplies the losses of the coil and core (in this example the loss is 0.1 times 115 volts or 11.5 watts), and the magnetizing current produces the magnetic field around the coil. Since these two parts of the total current are not in phase, the effective value of the total current is somewhat less than the sum of their effective values.

THE USE OF A CAPACITOR TO CANCEL THE MAGNETIZING CURRENT

The current drawn from the line by such a coil can be greatly reduced by connecting a capacitor across it. If the capacitor is selected so that it draws a current equal to the magnetizing current of the coil, it will cancel this current, and the line current will simply be the loss current of the coil, like this:

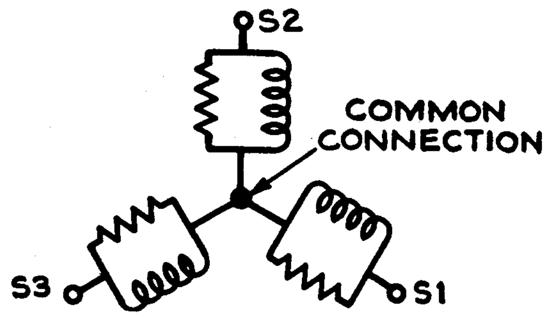


Since the magnetizing current *lags* the applied voltage by 90°, and the capacitor current *leads* it by 90°, the two currents are 180° out of phase with each other, so they add to zero, leaving only the loss current.

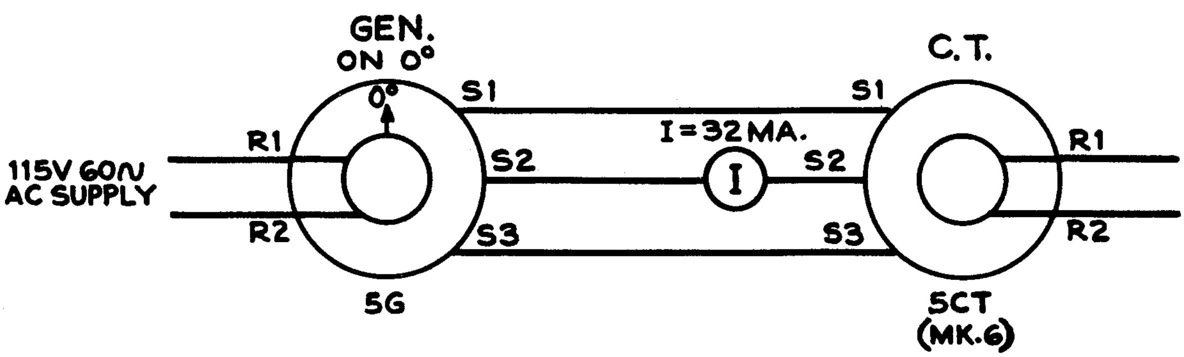
Another way of saying this, which means the same thing, is to say that the capacitor compensates the lagging power factor of the coil and reduces the wattless current drawn from the line.

THE USE OF CAPACITORS WITH A CONTROL TRANSFORMER

The simplest case in which capacitors are used is across the stator leads of a Control Transformer. Each of the three stator windings of a C.T. can be thought of as consisting of a high resistance (which draws the loss current) in parallel with an inductance (which draws the magnetizing current) like this:

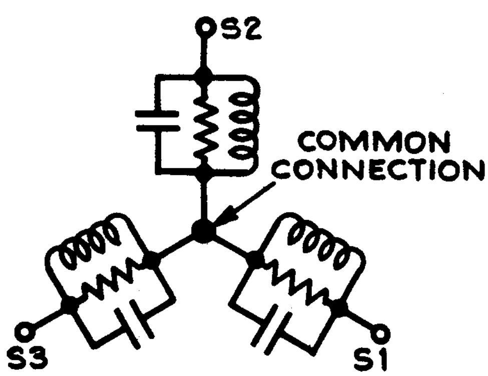


When a Control Transformer is connected to a Generator, the current in each stator lead depends on the position of the Generator's rotor and on the construction of the C.T. The current in the S2 lead (for example) reaches its highest value when the Generator is on 0° (or 180°). The current in the S2 lead of a typical C.T. measures about .032 amps. (32 milliamps.) under this condition:



This current consists of about 10 milliamps. loss current, and about 30 milliamps. magnetizing current.

The magnetizing current of each coil in the C.T. could be cancelled by connecting across it a capacitor which drew an equal and opposite current, like this:



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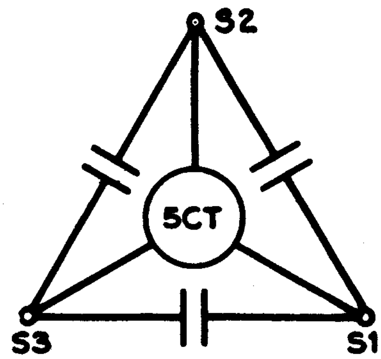
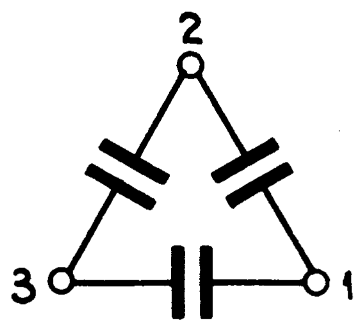
Practically this wouldn't work very well, since there is no connection to the common lead available outside the case of the unit. Besides the same effect can be obtained with smaller capacitors by connecting them between stator leads, like this:



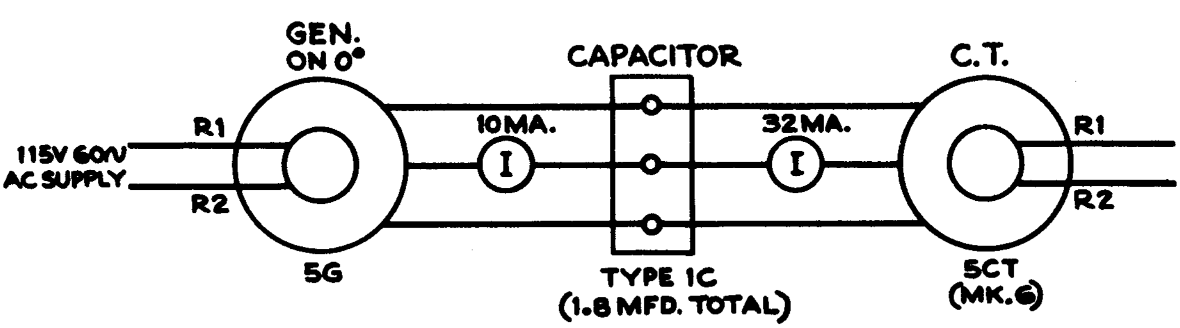
Navy Standard Synchro Capacitors are made up in sets of three units mounted in a case and connected to three terminals, like this:



These are made in a variety of sizes for all standard Differentials and Control Transformers. They are usually rated according to the "total capacitance" which is the sum of the three capacitances. The whole unit is called a "Synchro Capacitor."

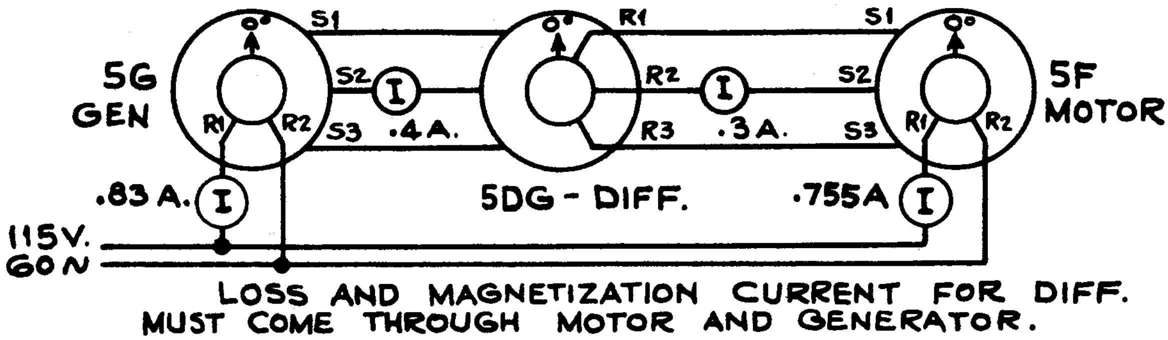
When the three terminals of a capacitor are connected to the stator leads of the unit for which it was designed, the magnetizing current of that unit is practically cancelled by the capacitor current, regardless of the Generator's shaft position.

For example, the current drawn by the Control Transformer previously mentioned is reduced from about 32 milliamps. to about 10 milliamps. when the right capacitor is added:



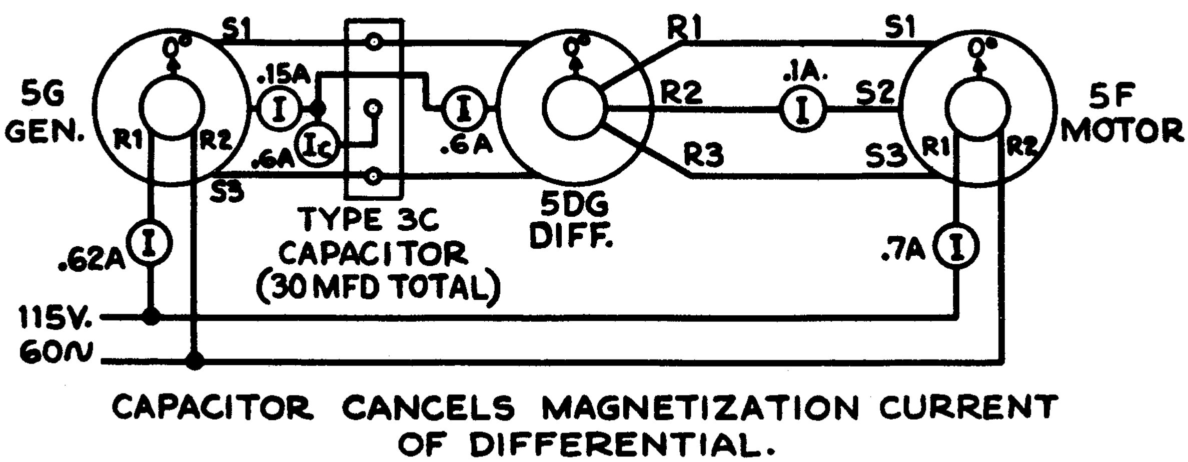
THE USE OF CAPACITORS WITH A SYNCHRO DIFFERENTIAL

When a Synchro Differential is connected between a Generator and a Motor, the stator currents are no longer zero when the shafts are lined up, as was explained in the section on Differentials. Also, because current is being drawn from the Generator and Motor stators, their rotor currents are higher than normal. In a typical case the currents have these values:



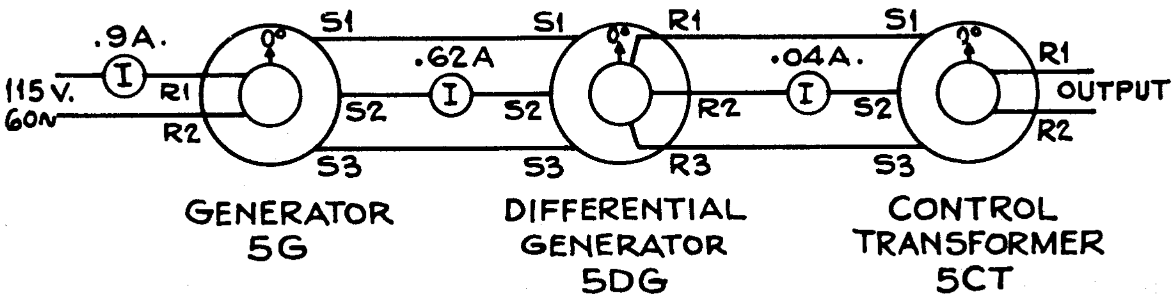
(Note: The normal rotor current for a 5G or a 5F is about 0.6 amps.)

Since the current drawn by the Differential is largely magnetizing current, it can be greatly reduced by connecting the proper Synchro capacitor across the Differential's stator leads. This decreases the current drawn from the Generator, increasing the Generator's output voltage, thus giving a better balance and decreasing the current from the Motor. In the case shown above the addition of a capacitor changes the currents as shown here:



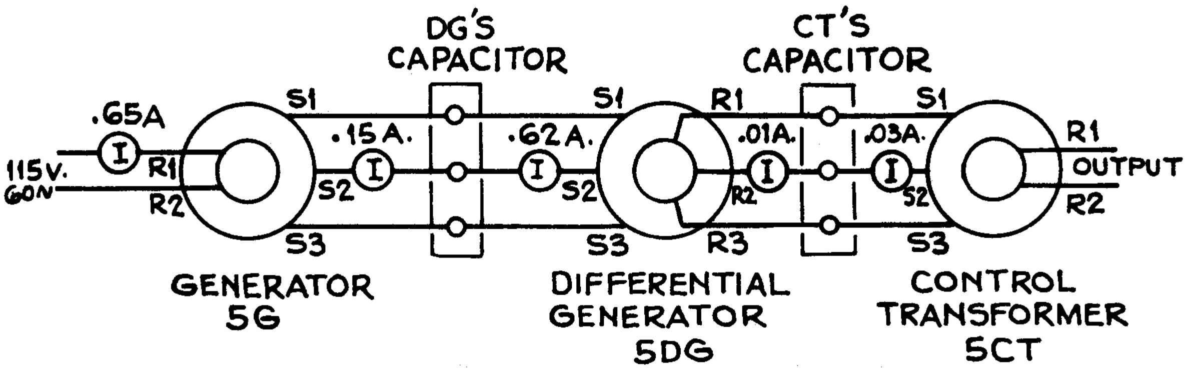
A considerable improvement in system accuracy results from the addition of a capacitor in a situation like this. In a particular case, for example, the error in Motor position was reduced 10%.

A situation in which the use of Synchro Capacitors is even more essential than that described above, is where a Generator feeds a Differential whose rotor leads are connected only to a Control Transformer. In this case the Generator must supply all of the losses and magnetizing current for both of the other units, so the current drawn from the Generator's stator leads is very high. The values measured in a typical case are like this:



GENERATOR MUST SUPPLY EXCITING CURRENTS TO BOTH UNITS.

The load on the Generator is greatly reduced by connecting the right size Synchro Capacitor across the Differential's stator leads and another across the Control Transformer's stator like this:



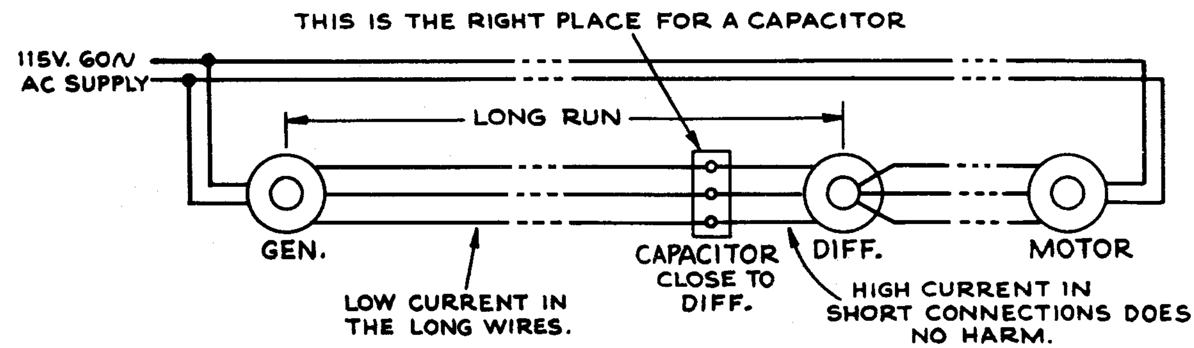
CAPACITORS REDUCE LOAD ON GENERATOR.

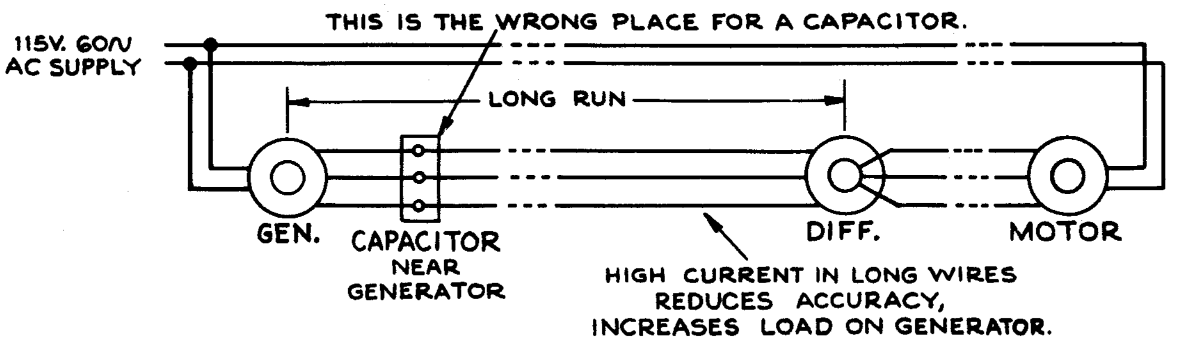
GENERAL NOTES CONCERNING SYNCHRO CAPACITORS

Synchro capacitors are specially constructed to do the job for which they are intended, do not try to use substitutes. **Never use Electrolytics** even for temporary replacement. Due to the AC voltage applied they would immediately short and burn out the connected units. Do not try to use ordinary paper filter capacitors, they will cause high losses and unbalanced currents which will ruin the accuracy of the system.

Always use standard Synchro Capacitors with Synchros. These are made up of very high grade paper-foil units. The capacity values of the individual capacitors in each group of three are matched within less than 1%. This matching is particularly important because it affects the current balance between the three wires, which must be correct to keep the system accurate. Of less importance is the actual value of total capacity, which is held to within 10% of the rated value.

A Capacitor should always be mounted close to the Differential or Control Transformer whose current it corrects. A great deal of the benefit of a Capacitor is lost if the high magnetizing current of the unit has to flow through a long run of wire before it is cancelled by the Capacitor.

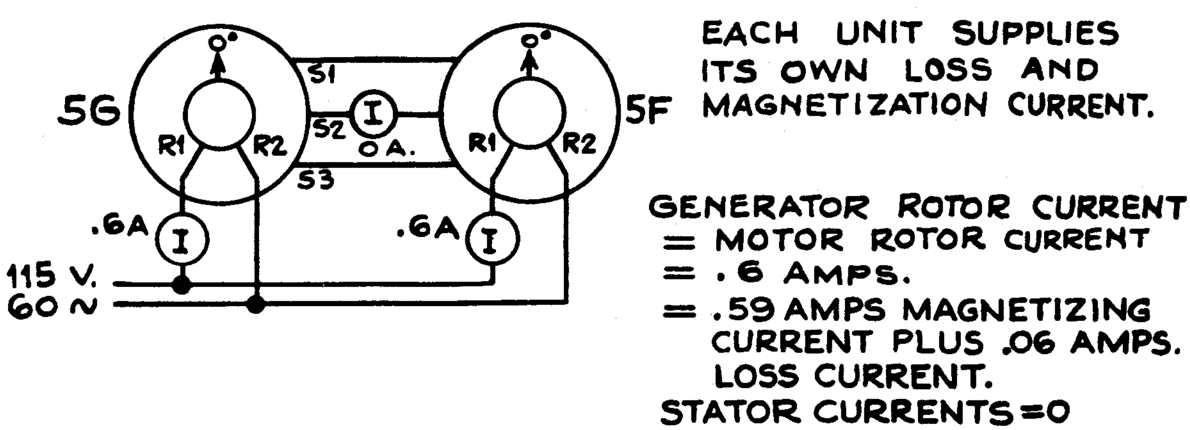




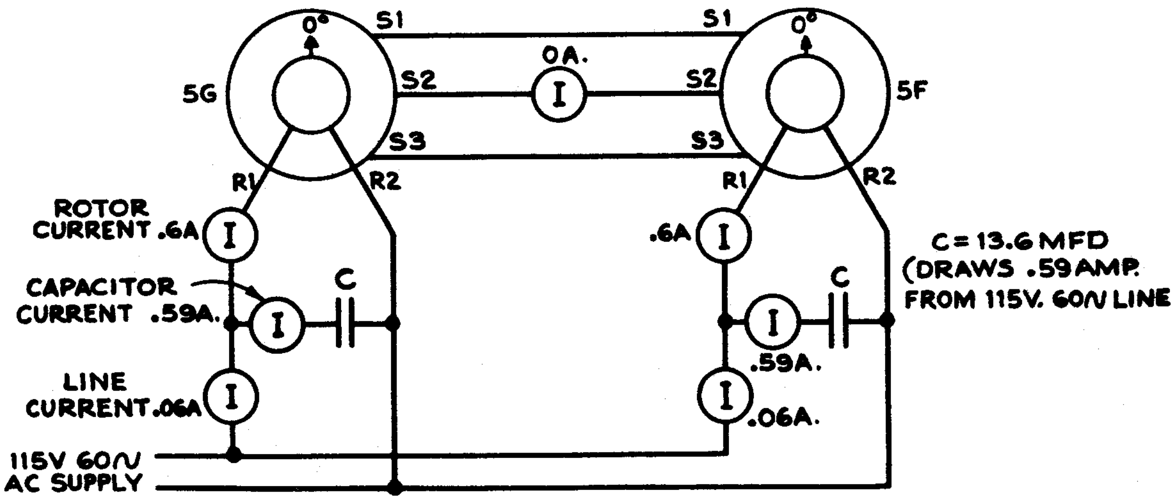
USING A CAPACITOR TO REDUCE THE LINE CURRENT OF A GENERATOR OR MOTOR

In most cases the rotor leads of a Motor or a Generator are connected to a 115 volt AC supply line which is fed from a great big AC generator, so that the current drawn by these units is of no importance. Under very unusual conditions, as for example where the AC supply comes from a motor-generator set which is operating near its maximum load, it might be worthwhile to use a capacitor to cancel the magnetizing current of these units.

When the rotor leads of a Synchro Motor or a Generator are connected to the AC supply, and no current flows in the stator circuit (as is normally the case) the current drawn by the rotor is largely magnetizing current. In a typical case the currents in a simple system measure as shown:



By connecting capacitors across the rotor leads of each unit the current drawn from the line can be greatly reduced:



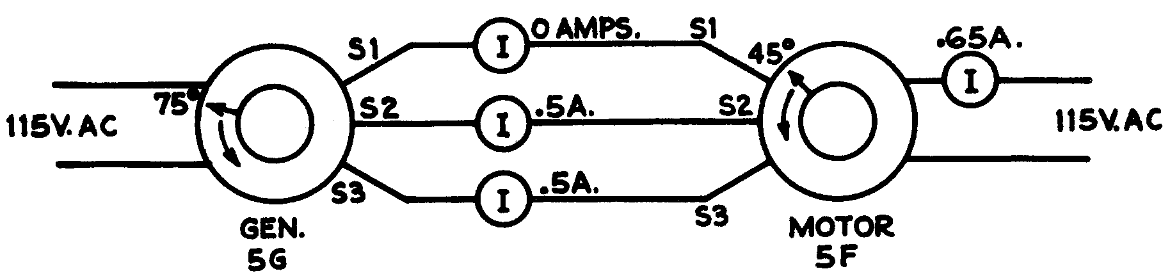
Never connect capacitors in the stator circuit between a Motor and a Generator. Since the current in this circuit is already zero, the addition of capacitors will *increase* the current and seriously reduce the accuracy of the system.

"OVERLOAD" AND "BLOWN FUSE" INDICATORS

Many practical installations involve a great many Synchro units, located in widely separated positions. When trouble occurs in such a system, it may be quite difficult to find out which unit is faulty. The use of Overload and Blown Fuse indicators makes signal lights on a central control board light up when trouble occurs on any one of the units in the system. These lights are marked to show which unit each is connected to, making it easy to find the faulty unit.

OVERLOAD INDICATORS

The current in the *stator* circuit of a Synchro unit gives a much more sensitive indication of mechanical loading than does the current in the *rotor* circuit. For example, consider the current drawn by a Motor whose bearings are rusted so badly that its shaft lags 30° behind the Generator shaft:



MOTOR READS 30° BEHIND GENERATOR

The current in the rotor circuit, which is normally .6 amps., has increased only slightly; but the stator current, which is normally zero, has increased a great deal.

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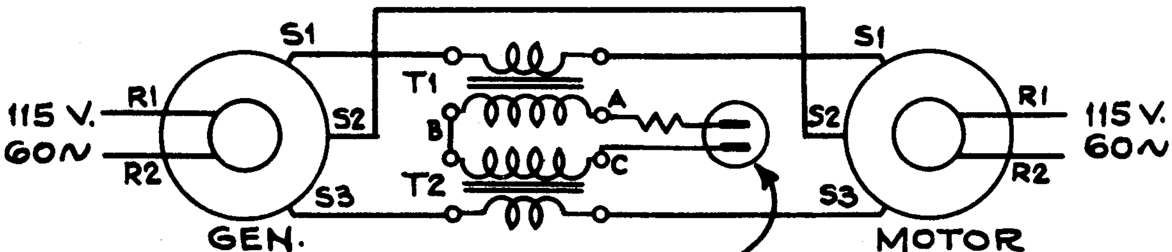
OVERLOAD AND BLOWN FUSE INDICATORS

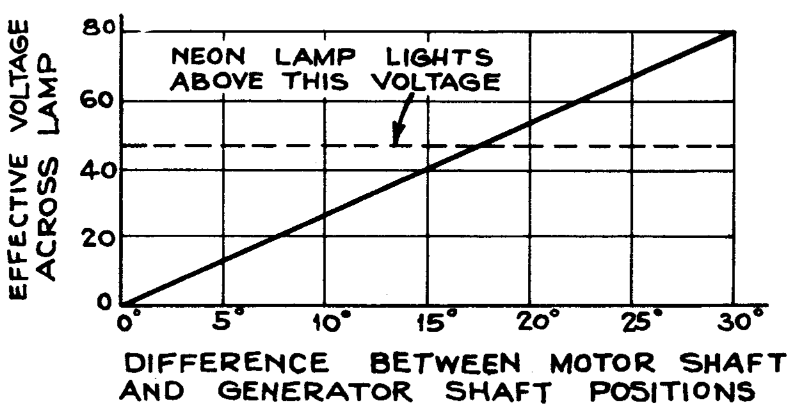
Because of this fact, Overload Indicators are usually connected so they respond to the current in the stator circuit of a Synchro unit. This introduces another complication, since the current in *any one lead* may be zero, regardless of the overload, if the mean shaft position is just right. In the above case, for example, there is no current in the S1 lead, although an overload exists. For this reason, it is necessary to connect the Overload Indicator so that it responds to the currents in at least *two* of the stator leads.

One form of overload indicator is connected like this:



Two transformers, each of which has a few turns of heavy wire on the primary and a great many turns of fine wire on the secondary, are connected as shown. With this connection the voltage across the secondary of each transformer depends directly on how much current is flowing in its primary. The voltage from A to B is a measure of the current in the S1 lead of the Synchro units, and the voltage from B to C is a measure of the current in the S3 lead. Thus the voltage applied to the lamp depends on the *difference* between these two currents.

It works out that the difference between these currents depends almost entirely on the *difference* between the electrical positions of the two rotors, regardless of what their *actual* positions are. The voltage applied to the lamp in a particular case varied like this when the Motor was held and the Generator turned:



Since the lamp lights whenever the applied voltage exceeds 45 volts, it will light when the difference between the two rotor positions (in this particular case) exceeds about 18°, thus indicating the presence of a mechanical overload.

The two transformers of this Indicator are usually mounted in the same case. These units are supplied in several sizes, with a variety of primary taps to give correct indications with different types of Synchro units.

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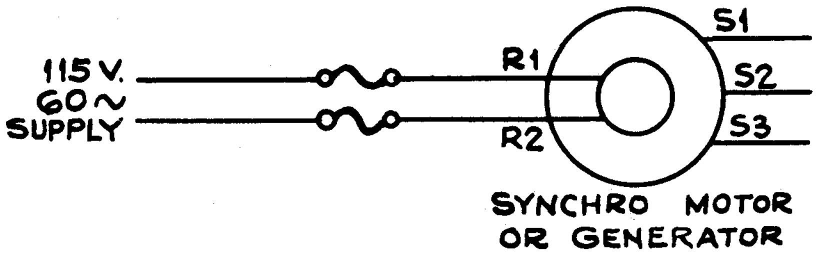
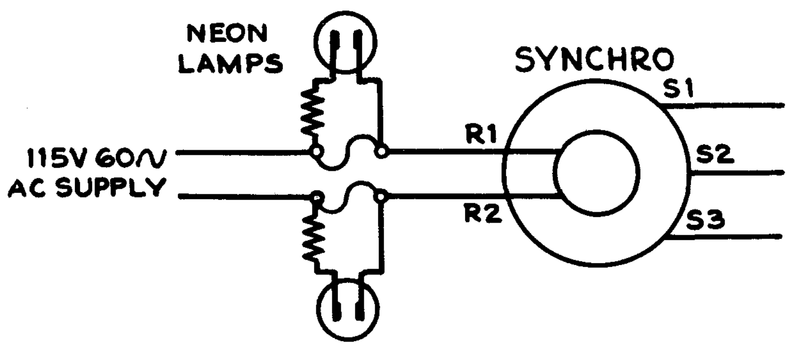
BLOWN FUSE INDICATORS

In addition to the Overload Indicators described above, it is customary to protect a Synchro Motor or Generator with fuses connected like this:



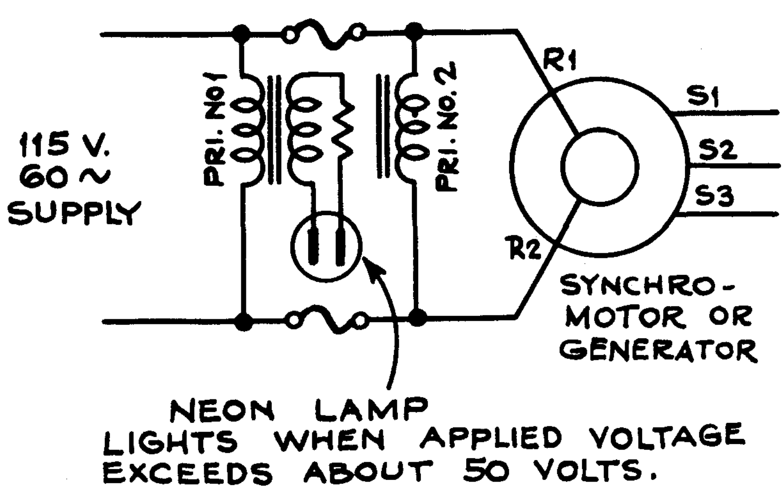
These fuses are the right size so that they will blow out and open the circuit if excessive current flows in the rotor circuit due to a short in the windings or a severe mechanical overload. When this happens, the Overload Indicator may not give any indication of trouble, since the rotor circuit is no longer excited, and a second type of indicator is needed which lights up when a fuse blows out.

A simple type of Blown Fuse Indicator is obtained by simply connecting small neon lamps across the fuses like this:



If either fuse blows, the voltage that appears across it will light the corresponding lamp, giving indication of the failure.

One disadvantage of this simple type of Blown Fuse Indicator is that the leads that connect to the lamps on the central panel (which may be some distance away from the Synchro) are connected directly across the rotor. Any short circuit in these leads will put the Synchro out of commission. Another type of Blown Fuse Indicator that gets away from this trouble, is connected like this:



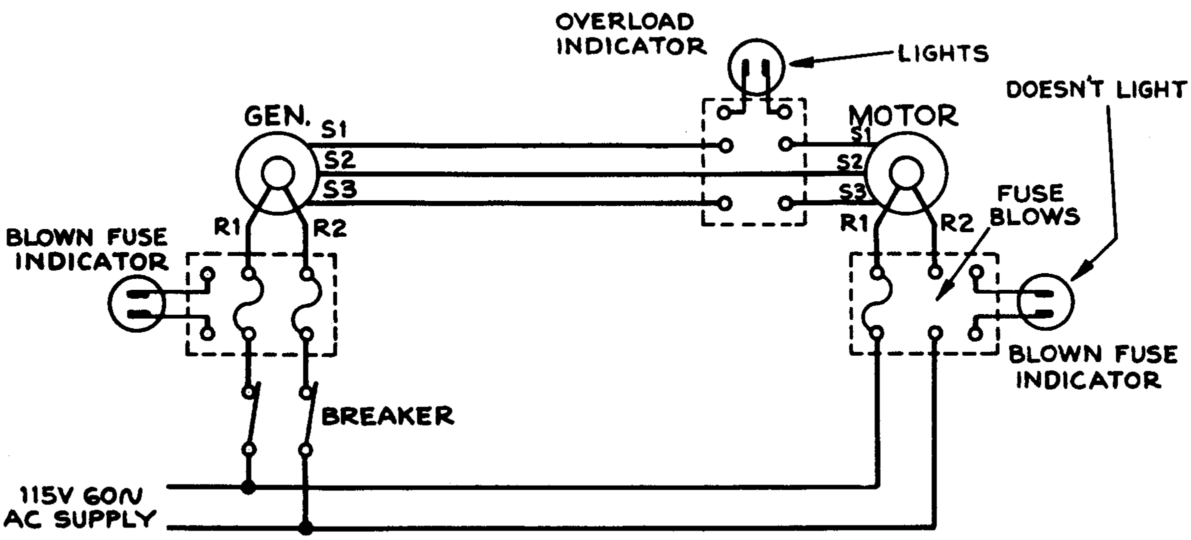
OVERLOAD AND BLOWN FUSE INDICATORS

A small transformer having two identical primaries and a secondary is connected as shown. When both fuses are closed, equal currents flow in the two primaries, inducing equal and opposite voltages in the secondary. Since these two voltages cancel each other there is no voltage applied to the lamp, and it does not light.

If either fuse blows out, the current in Primary No. 2 is interrupted, and the voltage induced in the secondary by Primary No. 1 appears across the lamp, causing it to light.

This type of indicator has the additional advantage of requiring only one lamp, and it gives an indication if either primary, or the leads connecting to it, opens up.

One trouble that is common to all types of Blown Fuse Indicators should be mentioned. Suppose a fuse blows in a Synchro system that is connected like this:



When the Motor's rotor circuit is opened up by the fuse blowing, the voltages in the stator circuit are no longer balanced, and current flows. These currents induce a voltage of 85 or 90 volts in the Motor's rotor winding. As a result there is only 15 or 20 volts across the open fuse, and the Blown Fuse Indicator may not light. At the same time the currents flowing in the stator circuit cause the Overload Indicator to light. Thus a blown fuse causes an Overload indication.

If the Generator circuit breaker is opened to clear the circuit, the Blown Fuse Indicator will then light and show the true location of the trouble.

THE CHARACTERISTICS OF STANDARD SYNCHROS

All Standard Navy Synchros are manufactured for the Navy in accordance with the latest revision of the Bureau of Ordnance specification O.S. 671.

THE MEANING OF SYNCHRO NAMEPLATE MARKINGS

THE MOD. NUMBER

The Mod. (Modification) number that appears on a Synchro's nameplate indicates by whom it was manufactured, according to the following code:

Mod. No.	Manufacturer
1	The Arma Corporation.
2	The General Electric Company.
3	The Ford Instrument Company.
4	The Bendix Aviation Corp., Marine Division.
5	The Control Instrument Company.
6	The Diehl Manufacturing Co.
7	The Bennel Machine Company.

When a manufacturer makes an improved design of a given type unit, this is shown by a letter following the Mod. number. For example: A 5G Mod. 2A would be a 5G manufactured by G.E. and improved in some way as compared with a 5G Mod. 2.

THE MARK NO.

Standard Synchros carry a Mark number. A Synchro of a given type and Mark number can be replaced by any other unit of that type having the same Mark number. In addition the replaceable parts of a Synchro of a given type, Mark *and* Mod. can be interchanged with those of another unit of the same type which has the same Mark and Mod. numbers.

In general, Special ("S") units do not have a Mark number, being designated merely by type and Mod. number. A 5SB Mod. 1 might have (and probably has) entirely different characteristics from a 5SB Mod. 2. The one exception to this rule is certain Control Transformers made prior to Nov. 1943. These units (5CT Mk. 3, 5CT Mk. 1) were classed as special units, but carried Mark numbers.

DESIGNATIONS

The general characteristics of a Synchro are indicated by its designation. The number preceding the letters gives the approximate size and weight as follows:

Designation Number	Approx. Weight	Approx. Length	Approx. Diameter
1	2 lbs.	3.9 in.	2.95 in.
3	3 lbs.	5.2 in.	3.10 in.
5	5 lbs.	6.0 to 6.8 in.	3.39 to 3.625 in.
6	8 lbs.	6.4 to 7.5 in.	4.5 in.
7	18 lbs.	8.9 to 9.2 in.	5.75 in.
8	60 lbs.	13.13 in.	8.625 in.

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The letters give additional information as follows:

Synchros are supplied in three types of cases to permit mounting in three different ways as shown on the opposite page. The mounting is indicated by a letter as follows:

Letter	Means
F	Flange mounted (the most common type).
B	Bearing mounted (stator can be turned, as well as rotor).
N	Nozzle mounted (provision made for mounting a ball race on shaft end).

On standard Synchro Motors no other letters are added. On other units the type is indicated by an additional letter as follows:

Letter	Type
G	Generator.
D	Differential Motor.
DG	Differential Generator.
CT	Control Transformer.

Units other than Motors are flange-mounted unless a "B" or an "N" occurs in the designation.

Two other letters are used:

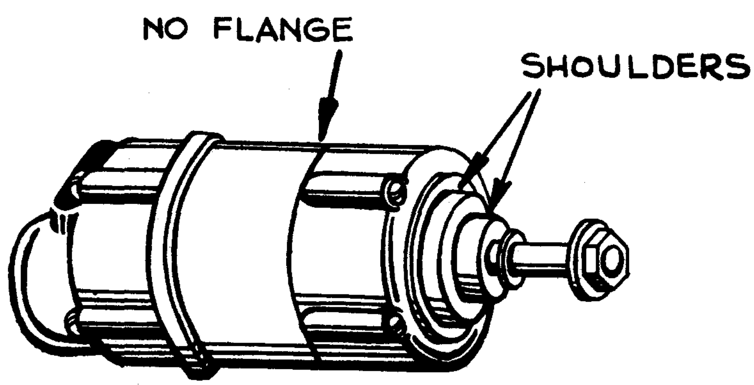
H occurring before the other letters indicates a **H**igh Speed unit, one that is designed with grease-lubricated bearings and long-life brushes so that it will stand continuous or high-speed rotation. (High speed Synchros should be used where the speed of rotation exceeds 300 R.P.M., or rotation is continuous.)

S occurring before the other letters indicates a **S**pecial unit, one which does not agree with the standard specifications in some way. "S" units made by two different manufacturers may be entirely different, even though their designations are the same.

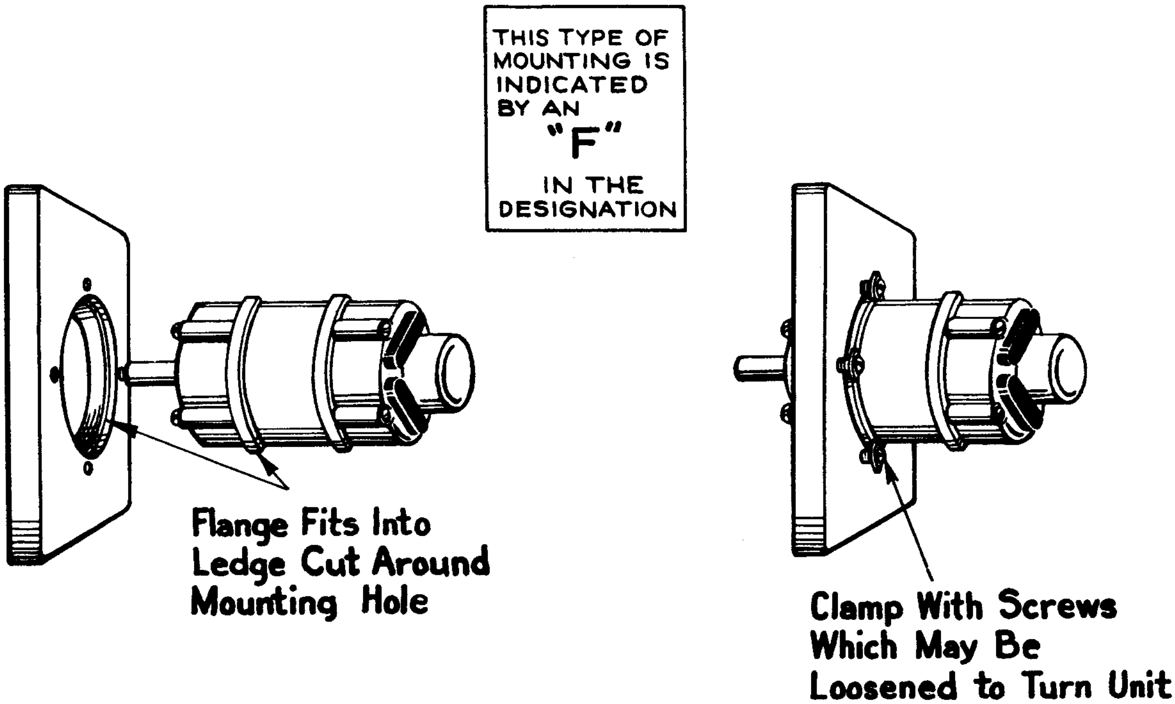
A few examples will help to show how these designations are used:

A 6G is a 6-size, Flange-mounted Generator. A 1DG is a 1-size, Flange-mounted Differential Generator. A 5B is a 5-size, Bearing-mounted Motor. A 5SN is a special, 5-size, Nozzle-mounted Motor. A 5HCT is a 5-size, Flange-mounted Control Transformer designed for high-speed operation.

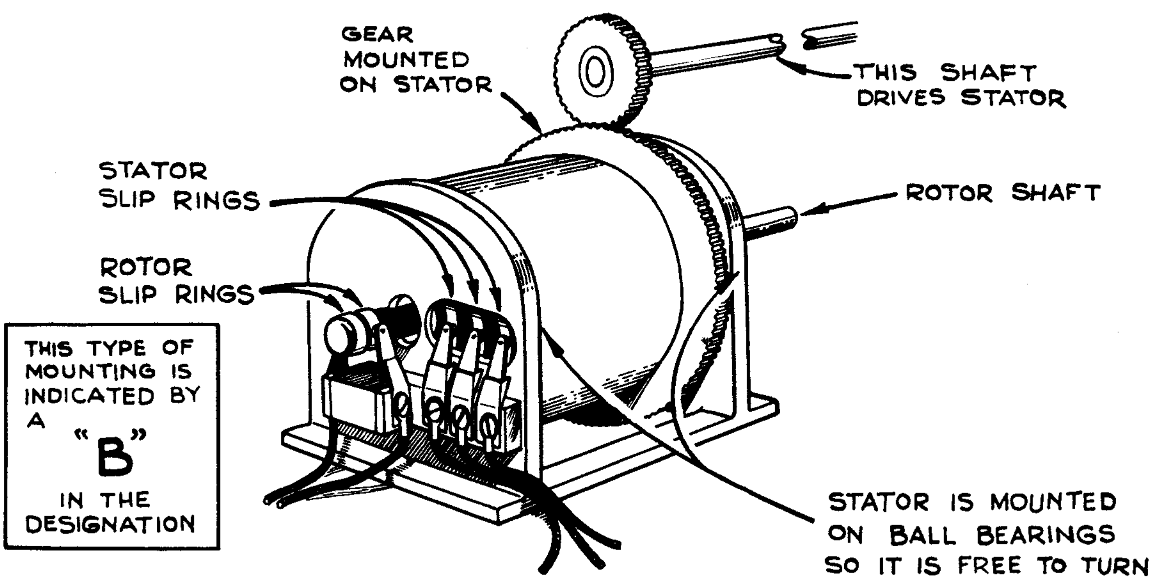
THIS TYPE OF MOUNTING IS INDICATED BY AN "N" IN THE DESIGNATION



A "NOZZLE MOUNTED" SYNCHRO



TYPICAL MOUNTING OF A "FLANGE MOUNTED" SYNCHRO



Typical Mounting of a "Bearing Mounted" Synchro

AVAILABLE TYPES OF SYNCHROS

The situation with regard to Standard Navy Synchros at the time of printing of this booklet is as follows:

THESE ARE CURRENT TYPES OF SYNCHRO UNITS

Generators	Motors	Differential Generators	Differential Motors	Control Transformers
5G Mk. 1	1F Mk. 8	5DG Mk. 4	5D Mk. 7	1CT Mk. 5
6G Mk. 2	5F Mk. 4	6DG Mk. 5		5CT Mk. 3
7G Mk. 3	5B Mk. 5	7DG Mk. 6		
	5N Mk. 6			

THESE ARE NEW TYPES OF SYNCHRO UNITS TO BE PRODUCED IN THE FUTURE

Generators	Motors	Differential Generators	Differential Motors	Control Transformers
5HG Mk. 6	3F Mk. 9	3HDG Mk. 8	3D Mk. 3	3HCT Mk. 7
6HG Mk. 7	5HF Mk. 11	5HDG Mk. 9		5HCT Mk. 6
7HG Mk. 9		6HDG Mk. 10		
		7HDG Mk. 11		

THESE TYPES OF SYNCHRO UNITS SHOULD NOT BE USED EXCEPT AS REPLACEMENTS OR UPON APPROVAL BY THE BUREAU OF ORDNANCE FOR EACH SPECIFIC APPLICATION

Generators	Motors	Differential Generators	Control Transformers
7SG Mk. 8	5SB1 Mod. 2	8DG Mk. 7	5CT Mk. 1
8G Mk. 4	5SB Mod. 1	5SDG Mod. 1	5CT Mk. 4
1G Mk. 5	5SB Mod. 2	7SDG Mod. 2	5CTB Mk. 8
3HG Mk. 10	5SF Mod. 3	1DG Mk. 1	6CT Mk. 2
	5SF Mod. 4		1CT Mod. 2
	5SN Mod. 1		1CT Mod. 3
			5CTB Mod. 1
			5SCT Mod. 2
			5SCT Mod. 4

THESE TYPES OF SYNCHRO UNITS ARE LISTED IN THE SPECIFICATIONS, BUT HAVE NEVER BEEN DESIGNED OR BUILT SINCE THERE ARE NO REQUIREMENTS FOR THEM

Motors	Differential Generators	Differential Motors
1B Mk. 1	1DGB Mk. 2	1D Mk. 1
	5DGB Mk. 3	1DB Mk. 2
		5DB Mk. 9

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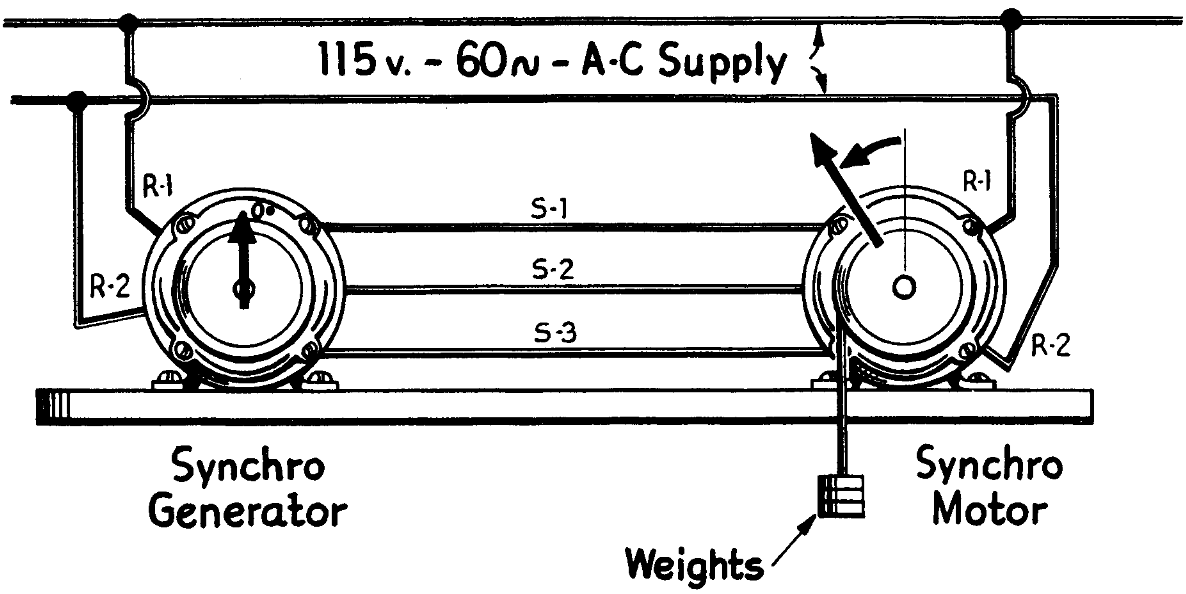
TABLES OF SYNCHRO CHARACTERISTICS

The following tables show information which is thought to be most useful to those who work with Synchros. Some of the values shown are covered by Bureau of Ordnance specification and are sure to be correct for any Standard Synchro. Others of the values shown are not specified, but are based on measurements made on a number of representative units and are believed to be reasonably accurate.

VALUES HELD BY SPECIFICATION

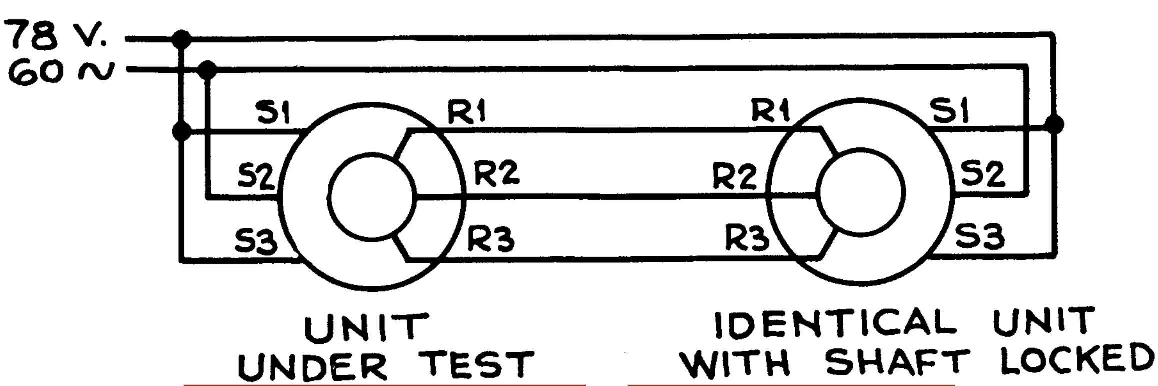
The **Unit Torque** values shown are *minimum* permissible values, the torque of any actual unit will be somewhat higher than this.

The torque figures usually given for a Synchro unit are measured with the unit connected electrically to another identical unit. When tested in this way the torque is called the "Unit Torque"; and the torque gradient measured under this condition is called the "Unit Torque Gradient."



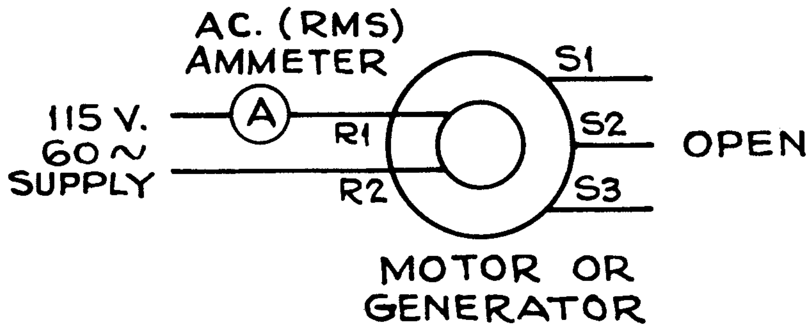
The torque developed by a given Synchro Motor in an actual installation depends on what is driving it, and on how many other Motors there are in the system, as well as on the characteristics of the particular Motor.

Differential units are connected like this for Unit Torque measurements:



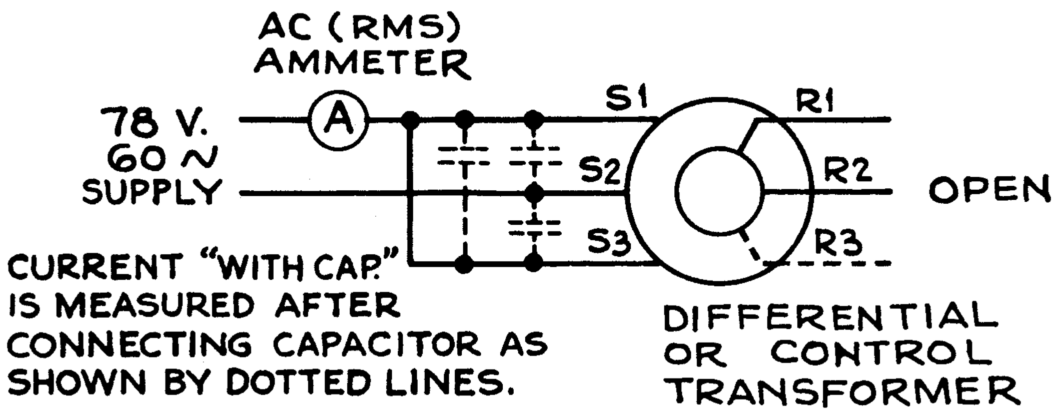
The **Exciting Current** (less capacitor) values shown are the *maximum* permissible values, these will be somewhat lower on any actual unit.

The exciting current of a Motor or Generator is the current that is measured when normal voltage is applied to R1 and R2 with no connection to the stator:



The actual current drawn by the rotor under operating conditions may be slightly higher than this if any current flows in the stator circuit.

The exciting current of a Differential unit or a Control Transformer is measured by connecting S1 to S3 and applying normal voltage like this:



The actual maximum current in any one stator lead of a Differential will be *lower* than this when its rotor leads are connected to another Generator or Motor, and slightly *higher* when they are connected to a Control Transformer.

The actual maximum current in any one stator lead of a Control Transformer is equal to the current measured in this way.

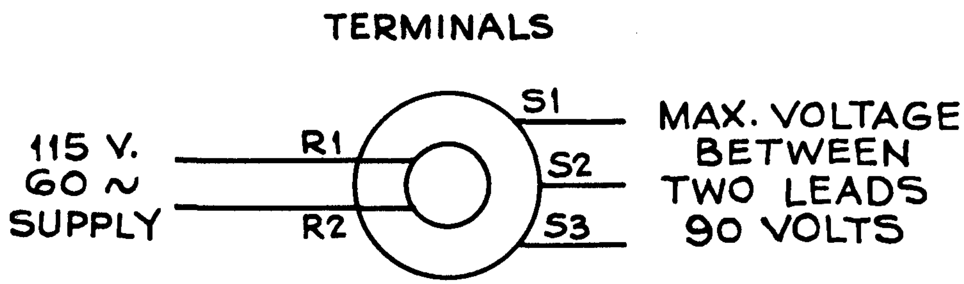
VALUES DETERMINED BY MEASUREMENTS ON REPRESENTATIVE UNITS

The **Exciting Current** (with capacitor) values shown for Differential Units and CT's and the **Exciting Power** values for all units are maximum values found by measuring a number of typical units.

The **DC Resistance** values are shown in each case as a *range* of values which includes all units for which information could be obtained. Since the resistances depend critically on the design they may be expected to differ considerably between units of the same type built by different manufacturers.

CHARACTERISTICS OF NAVY STANDARD

SYNCHRO MOTORS

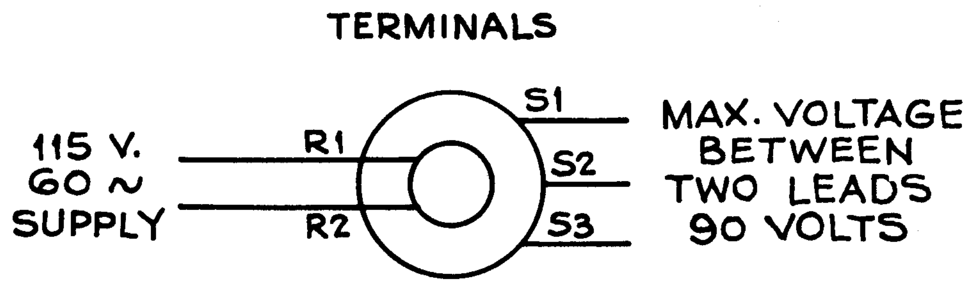


Designation	Unit Torque Grad. (in. oz. per deg.) (min.)	Exciting Current (amps) (max.)	Exciting Power (watts) (max.)	Approximate DC Resistance (ohms) between:	
				R1—R2	Any 2 S leads
*1F	.06	.3	6.0	60 to 140	140 to 220
*5F, 5B, 5N	.4	.6	8.0	12 to 15	15 to 30

* Indicates preferred types.

CHARACTERISTICS OF NAVY STANDARD

SYNCHRO GENERATORS

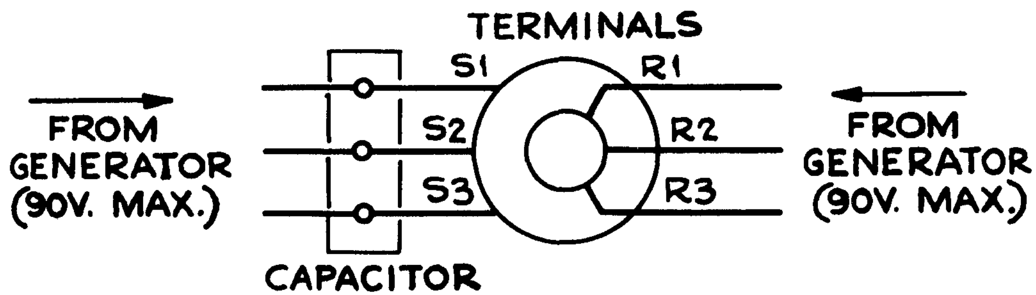


Designation	Drives with Normal Accuracy	Unit Torque Gradient (in.-oz. per °) (min.)	Exciting Current (amps) (max.)	Exciting Power (watts) (max.)	Approximate DC Resistance (ohms) Between:	
					R1—R2	Any 2 S leads
1G	One 1F	.06	.3	6.0	60 to 140	140 to 220
*5G	Four 5F's or nine 1F's	.4	.6	8.0	12 to 15	15 to 30
*6G	Nine 5F's or eighteen 1F's	1.2	1.3	14.0	2.5 to 6.0	4.5 to 6.5
*7G	Eighteen 5F's or thirty-six 1F's	3.4	3.0	24.0	.60 to 1.5	1.2 to 2.4

* Indicates preferred types.

CHARACTERISTICS OF NAVY STANDARD

SYNCHRO DIFFERENTIAL MOTORS

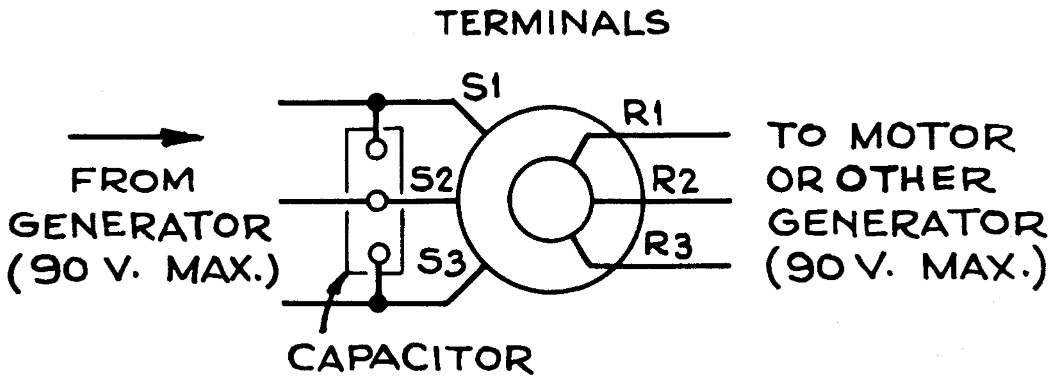


Designation	Unit Torque Gradient (in.-oz. per °) (min.)	Use with Capacitor		Exciting Current (amps)		Exciting Power (watts) (max.)	DC Resistance Between: (ohms)	
		Type	Total Cap. Mfd.	With Cap. (approx.)	Less Cap. (max.)		R leads	S leads
*5D	.3	3C Mk. 1	30	.3	1.0	12.0	18 to 20	13 to 18

* Indicates preferred types.

CHARACTERISTICS OF NAVY STANDARD

SYNCHRO DIFFERENTIAL GENERATORS

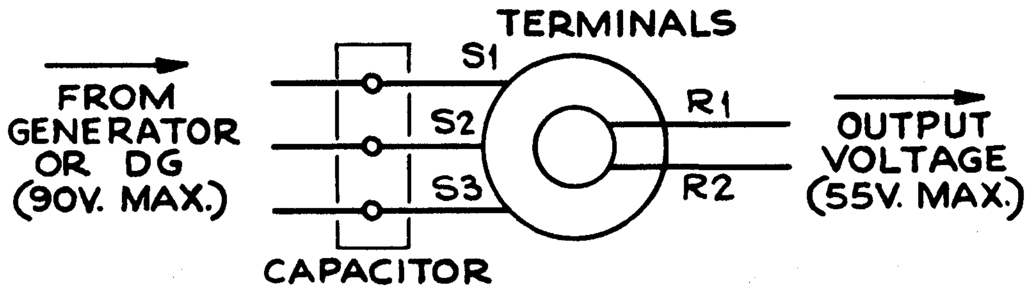


Designation	Unit Torque Gradient (in.-oz. per °) (min.)	Drives with Normal Accuracy	Use with Capacitor:		Exciting Current (amps)		Exciting Power (watts) (max.)	DC Resistance (ohms) between:	
			Type	Total Cap. (mfd.)	with Cap. (approx.)	less Cap. (max.)		R leads	S leads
1DG	.04	One 1F	4C Mk 14	9	.14	.3	5.0	—	—
*5DG	.3	Two 5F's or five 1F's	3C Mk 1	30	.30	1.0	12.0	18 to 20	13 to 18
*6DG	1.4	Six 5F's or twelve 1F's	9C Mk 3	90	.90	2.0	20.	4.6 to 5.2	3.3 to 4.3
*7DG	4.0	Twelve 5F's or twenty-four 1F's	15C Mk 4	150	0.9	3.0	29.	1.3 to 1.8	1.0 to 1.5

* Indicates preferred types.

CHARACTERISTICS OF NAVY STANDARD

SYNCHRO CONTROL TRANSFORMERS



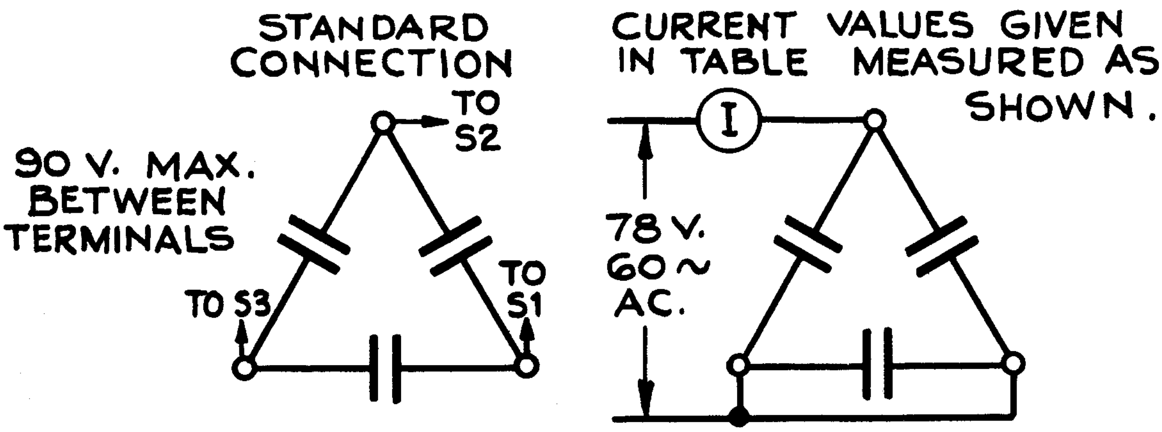
Designation	Mark	Mod.	Use with Capacitor		Exciting current (amps)		Exciting Power (watts) (max.)	Minimum Load Impedance (ohms)	DC Resistance (ohms) between	
			Type	Total Cap. (mfd.)	With Cap. (approx.)	Less Cap. (max.)			R leads	S leads
*1CT	5	New Std.	1C Mk. 12	1.8	.020	.045	1.5	15,000	200 to 500	700 to 850
1CT	—	2								
1CT	—	3A								
1CT	—	3	4C Mk. 14	9	.125	.250	5.0	——	——	——
*5CT	3	New Std.	1C Mk. 12	1.8	.015	.045	1.0	10,000	75 to 160	175 to 275
*5HCT	6									
5CT	4	4								
5CT	1	4								
5CT	1	3	2C Mk. 13	4.2	.025	.125	2.0	10,000	55.5	124.6

*** Indicates preferred types.**

Note: Until November, 1943 Control Transformers were classed as Special units. Those types indicated as (*) preferred have now been classed as Standard types.

CHARACTERISTICS OF NAVY STANDARD

SYNCHRO CAPACITORS



Type	Mark	For Use With	Total Cap.	Cap. per Leg	Cap. between Terminals	Current amps. (see above)	Weight (Lbs.)
1C	12	1CT Mod. 3A 1CT Mod. 2 1CT Mk. 5 std. 5CT Mk. 3 std. 5HCT Mk. 6 std. 5CT Mk. 1, Mod. 4 5CT Mk. 4, Mod. 4	1.8	.6	.9	.035	1
2C	13	5CT Mk. 1, Mod. 3	4.2	1.4	2.1	.082	2
3C	1	5D, 5DG	30.	10.	15.	.59	6
4C	14	1DG Mk. 1, Mod. 1 1CT Mod. 3	9.	3.	4.5	.176	
9C	3	6DG	90.	30.	45.	1.76	16
15C	4	7DG	150.	50.	75.	2.94	25

THE FOLLOWING TYPES OF CAPACITORS SHOULD BE USED ONLY AS REPLACEMENTS

Type	Mark	Superseded By Type	Total Cap.	Cap. per Leg.	Cap. between Terminals	Weight (Lbs.)
3CE	5	3C	30	10	15	7
6CE	6	6C	60	20	30	14
9CE	7	9C	90	30	45	21
15CE	8	15C	150	50	75	33
30C	9	—	—	—	—	—
9CX	10	—	90	30	45	19
2.25CX	11	—	—	—	—	6.25
6C	2	—	60	20	30	11

SYNCHRO CAPACITOR BOXES

It is a necessary requirement that a Synchro Capacitor should be mounted as close as is practical to the unit whose current it corrects. In some cases this means that the Capacitor must be mounted in an exposed location. Capacitor boxes are designed to protect the Capacitor in such a case.

STANDARD CAPACITOR BOXES

Mark	Mod.	Holds the following Capacitors:
1	0	2 type 1C, Mk. 12.
2	0	2 type 2C, Mk. 13.
3	0	2 type 3C, Mk. 1.
4	0	2 type 9C, Mk. 3.
5	0	2 type 15C, Mk. 4.
2	1	2 type 4C, Mk. 14.

SPECIAL TYPES OF CAPACITOR BOXES (CALLED "SYNCHRO EXCITER ASSEMBLIES")

Mark	Mod.	Holds the following Capacitors:
14	0	4 type 9C, Mk. 3.
15	0	1 type 3C, Mk. 1.
16	0	2 type 3C, Mk. 1.
18	0	3 type 3C, Mk. 1.
19	0	1 type 3C, Mk. 1, and 1 type 9C, Mk. 3.
24	0	2 type 3C, Mk. 1.
25	0	3 type 9C, Mk. 3.
26	0	2 type 9C, Mk. 3.
27	0	4 type 9C, Mk. 3.
28	0	1 type 3C, Mk. 1, and 1 type 9C, Mk. 3.

NOTES ON NAVY STANDARD SYNCHRO UNITS

In considering Navy Standard units, it should be kept in mind that the specifications for these units were aimed at producing instruments to be used primarily for Position Indicators. (As Gun Train Indicators, for example.) For this reason all data given with regard to the capacity of Generators, etc., refers to capacity *with normal accuracy.* Where accuracy throughout the entire system is less important, the loading may be increased considerably (with the approval of the Bureau of Ordnance) before overheating of the units is incurred.

THINGS TO AVOID

The Navy does not consider the following to be good practice:

1. Using a 1F, 5D, or 5F to drive anything more than a simple dial (made of thin aluminum 3 inches or less in diameter, with a small hub).
2. Paralleling a Control Transformer with a Motor or Differential Motor.
3. Connecting more than two Differentials in series.
4. Using Differential units in place of Control Transformers.

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5. Operating 1CT, 1F, 5D or 5F units faster than 300 RPM, or other units faster than 1,200 RPM.

6. Using a grease-lubricated Motor for highly accurate work.

7. Using a Motor to control a Servo system in any case where it is possible to use a Control Transformer.

MAXIMUM ALLOWABLE LOADING ON GENERATORS AND DIFFERENTIAL GENERATORS

(Differential Generators driven by Generator of same size or larger.)

Type	5F's	1F's	5CT's (Mk. 3 or Mk. 6 with cap.)	1CT's (Mk. 5 with cap.)
1G	None	1	1	1
5G	4	9	14	14
5DG	2	5	12	12
6G	9	18	30	30
6DG	6	12	24	24
7G	18	36	60	60
7DG	12	24	48	48

THE CURRENT DRAWN BY A DIFFERENTIAL GENERATOR UNDER OPERATING CONDITIONS

A Differential Generator differs from a Motor, Generator, or Control Transformer in that the Exciting Current, measured by applying 78 volts between S2 and S1-S3 with the R leads open, is not the same as the current that flows under operating conditions.

When a Differential Generator is connected between a Generator and a standard Control Transformer which is corrected with the right Capacitor, the additional current in the Rotor circuit due to the C.T. is usually small enough so that it can be overlooked, and in this case the Exciting Current values in the table are close enough for most purposes.

However, when a Differential Generator is connected between a Generator and a Motor, or a number of Motors, the Motors supply a considerable part of the Differential's excitation, and the stator current is reduced accordingly. The current values shown in the following table are based on measurements of a number of standard Synchros under the indicated conditions. The current values with other normal combinations of Generators and Motors would not differ very greatly from those shown.

Designation	Connected Between	Max. Current in any one lead (amps.)			
		with correct Capacitor		Less Cap.	
		S lead	R lead	S lead	R lead
1DG	a 5G and a 1F	.072	——	.174	——
5DG	a 5G and a 5F	.15	.15	.40	.30
6DG	a 6G and six 5Fs	.50	.25	.90	.70

THE PREFERRED WAY OF MOUNTING A DIAL OR GEAR ON A SYNCHRO'S SHAFT

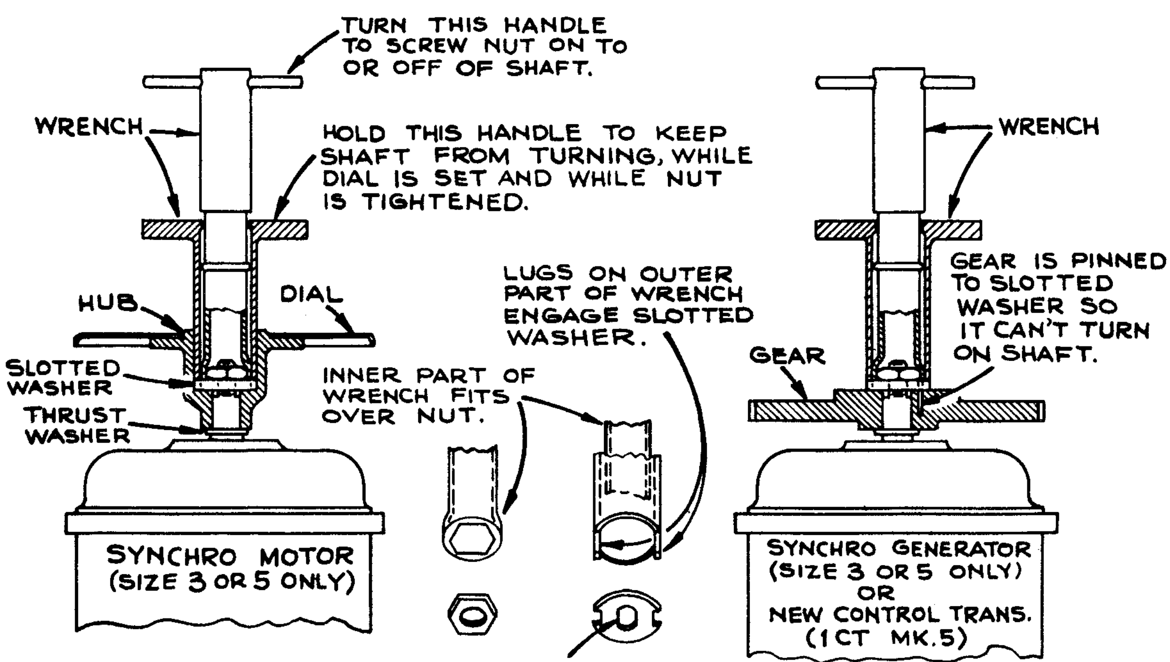
The shaft of the most commonly used sizes of Synchro Motors and Generators is built so that a dial may be clamped to the Motor's shaft, or a gear to the Generator's shaft without using set screws or pins through the shaft.

A special wrench, which is supplied on all Allowance Lists and will be found in spare parts boxes, is used to remove, install, or adjust dials or gears which are mounted in this way.

The drawings below show typical mountings.

On a Motor the nut is tightened down, holding the hub of the dial tightly clamped between the slotted washer on top and the thrust washer (which rests on a step in the shaft) at the bottom. To adjust the dial's position (when setting zero, for example), the nut is loosened, the outer part of the wrench is held to keep the shaft from turning, and the dial is turned.

On a Generator or C.T. where the gear has to drive the shaft, a pin may be used to keep the gear and the slotted washer turning together. Effectively this locks the gear to the shaft, since the slotted washer can't turn.



MOUNTING A TYPICAL DIAL

MOUNTING A TYPICAL GEAR

STANDARD CONNECTIONS FOR NAVY SYNCHROS

In systems in which a great many Synchro units are used, it is necessary to have a clearly defined set of standard connections if confusion is to be avoided. The following conventions are usually followed unless there is good reason for doing otherwise:

NOTES:

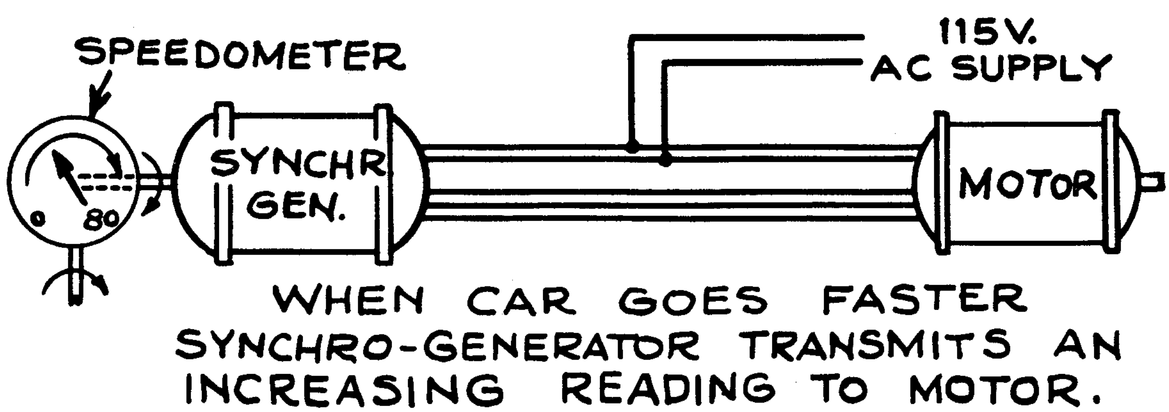
1. All diagrams are shaft-end views.

2. In practice any letter may be used in place of those shown. "B" indicates any single-letter bus, "BB" any double-letter bus, etc.

DEFINITION OF AN "INCREASING READING."

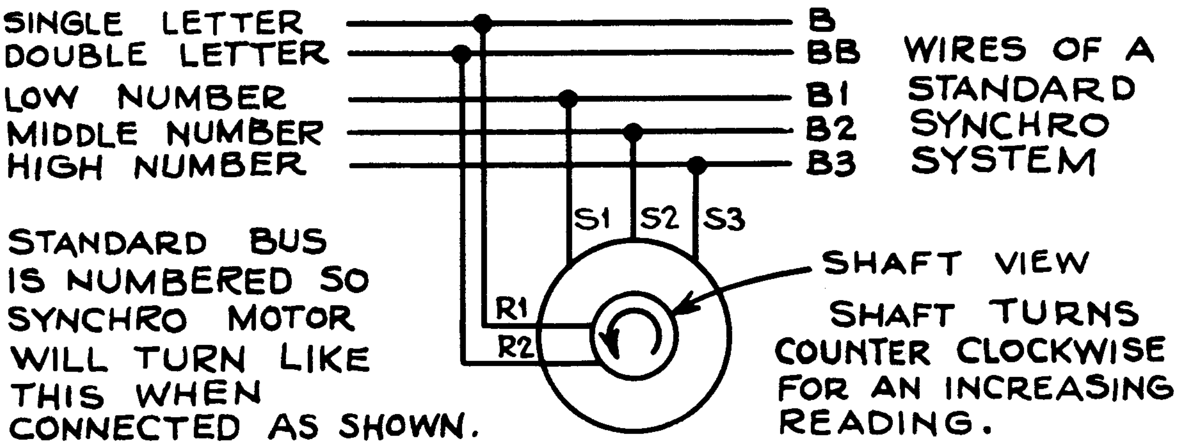
1. **An INCREASING READING is being sent over the wires of a Synchro system when the numbers associated with the thing being measured are increasing.**

   For example, if a Synchro Generator were connected to the needle on the speedometer of a car, as shown, it would send out an *increasing reading* when the car went faster, and a *decreasing reading* when it went slower.



STANDARD WIRE DESIGNATIONS

2. The five wires of a Synchro system are numbered in such a way that the shaft of a normal Motor will turn counter-clockwise when an increasing reading is sent over these wires, provided it is connected directly like this:

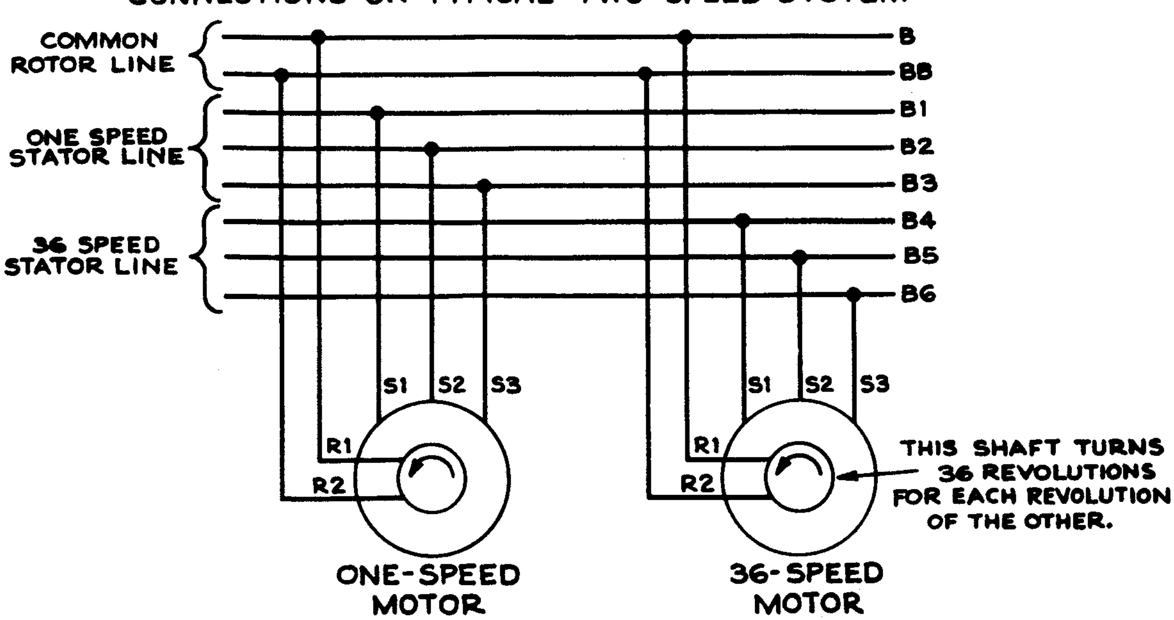


A direct connection is obtained by connecting R1 to the single letter bus, R2 to the double letter bus, S1 to the low-numbered bus, S2 to the middle, and S3 to the high-numbered bus.

TWO SPEED SYSTEMS

3. In a Synchro system where similar information is transmitted at several different speeds, the numbered wires are marked 1, 2, and 3 for the lowest speed; 4, 5, and 6 for the next higher speed, and so on. For example:

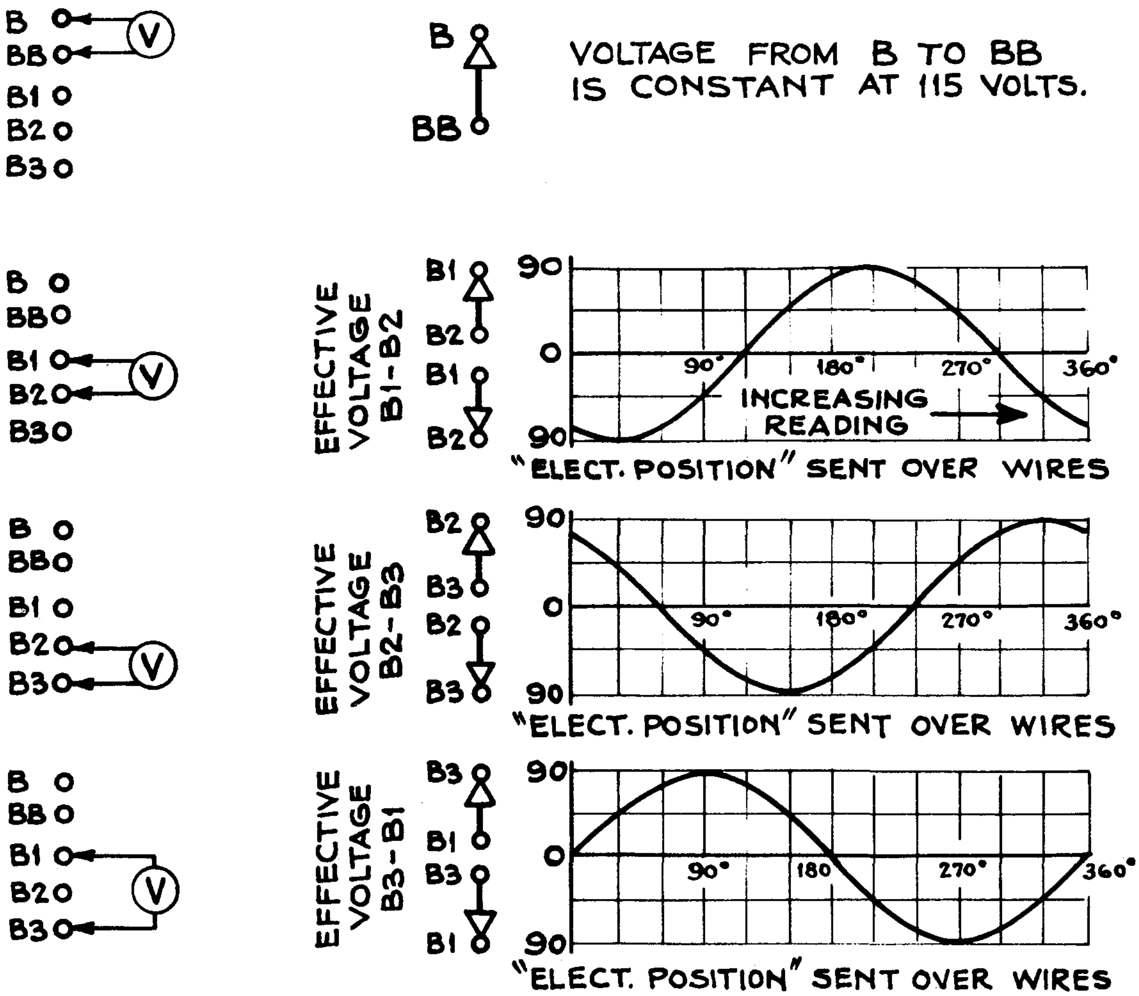
CONNECTIONS ON TYPICAL TWO-SPEED SYSTEM



STANDARD CONNECTIONS

STANDARD VOLTAGES

4. When an increasing reading is sent over the five wires of a Synchro system the voltages between the five wires change like this:

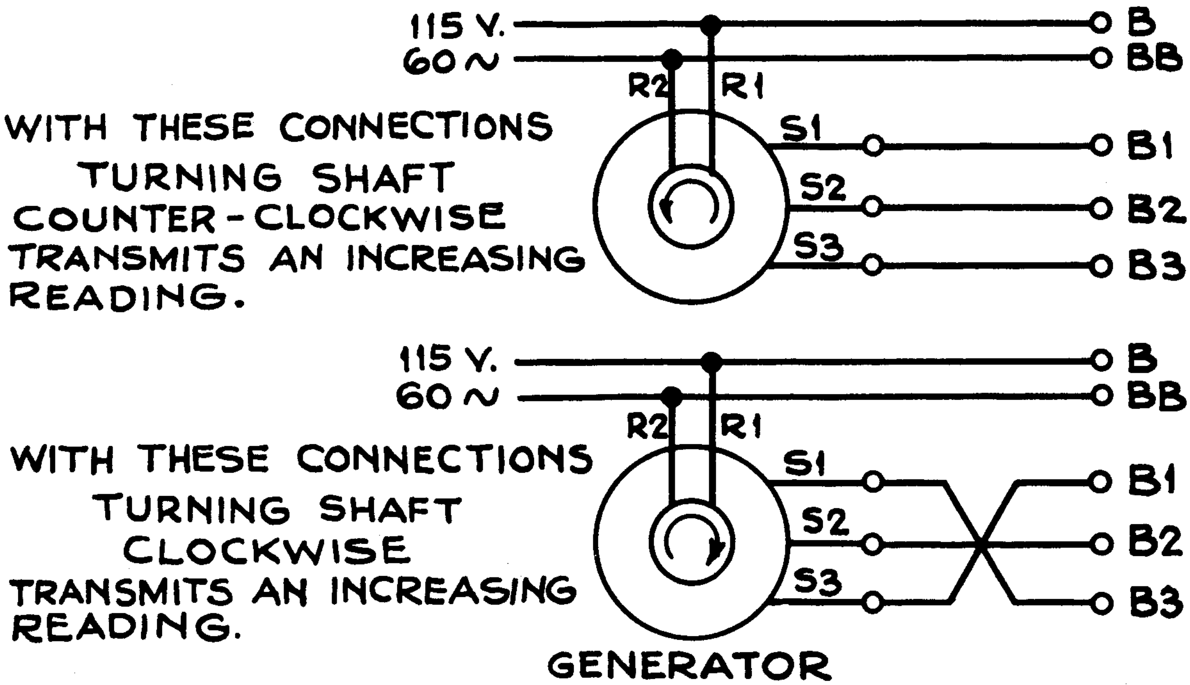


NOTE: ALL VOLTAGES ARE 60 CYCLES AC. EFFECTIVE VALUE.
↑ INDICATES THAT VOLTAGE IS IN PHASE WITH B-BB
↓ INDICATES THAT VOLTAGE IS 180° OUT WITH B-BB

(Note: The actual numbers and letters used on a particular system may not agree with those used here. In any case, B represents the single-lettered bus, BB the double-lettered bus, B1 the low-numbered bus, and so on.)

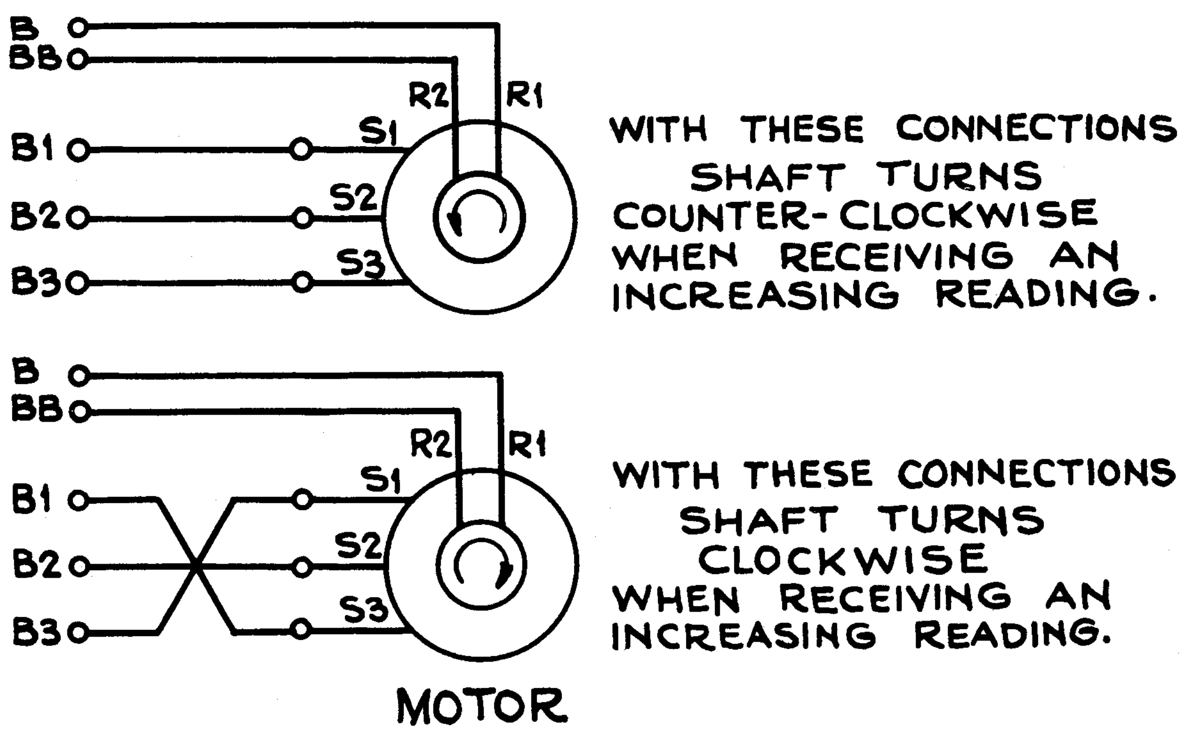
STANDARD GENERATOR CONNECTIONS

5. Connect a Generator to the bus as shown in each case if it is to transmit an increasing reading when its shaft is turned in the indicated direction.



STANDARD MOTOR CONNECTIONS

6. Connect a Motor to the bus as shown in each case if its shaft is to turn in the indicated direction when it receives an increasing reading.

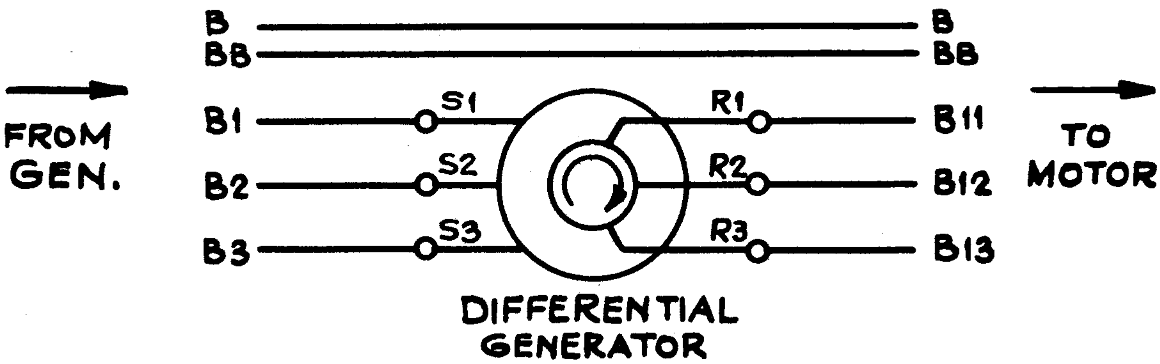


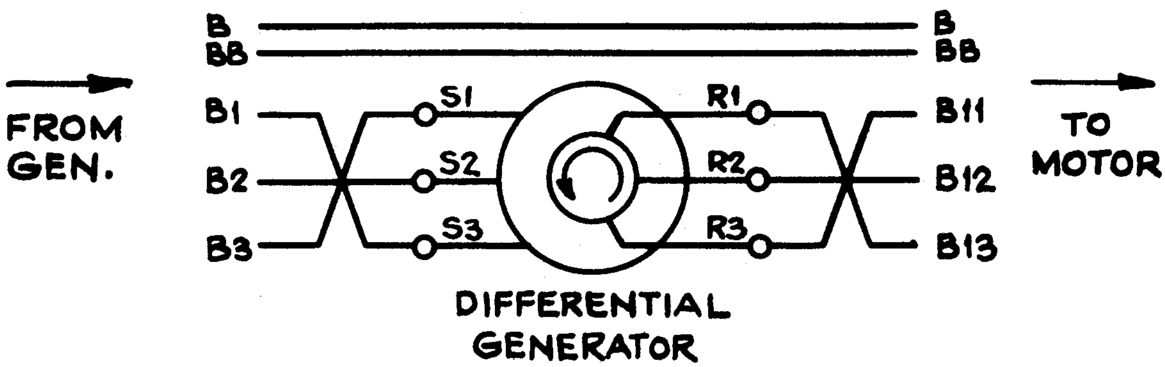
STANDARD CONNECTIONS

STANDARD CONNECTIONS FOR DIFFERENTIAL GENERATORS

7. Connect the stator leads of a Differential to the Generator circuit, and its rotor leads to the Motor or Control Transformer circuit.

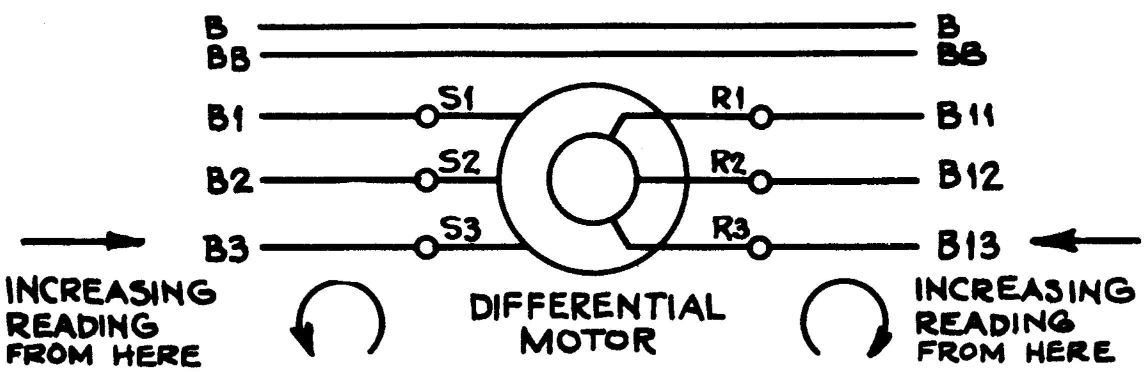
8. Connect a Differential Generator to the busses as shown in each case if, with constant stator voltages, it is to transmit an increasing reading from its rotor leads when its shaft is turned in the indicated direction. In either case it will transmit an increasing reading from its rotor leads when it receives one on its stator leads with its shaft stationary.





STANDARD CONNECTIONS FOR DIFFERENTIAL MOTORS

9. Connect a Differential Motor to the busses as shown in each case if, with constant voltages on one side, its shaft is to turn as indicated when it receives an increasing reading from the other side.



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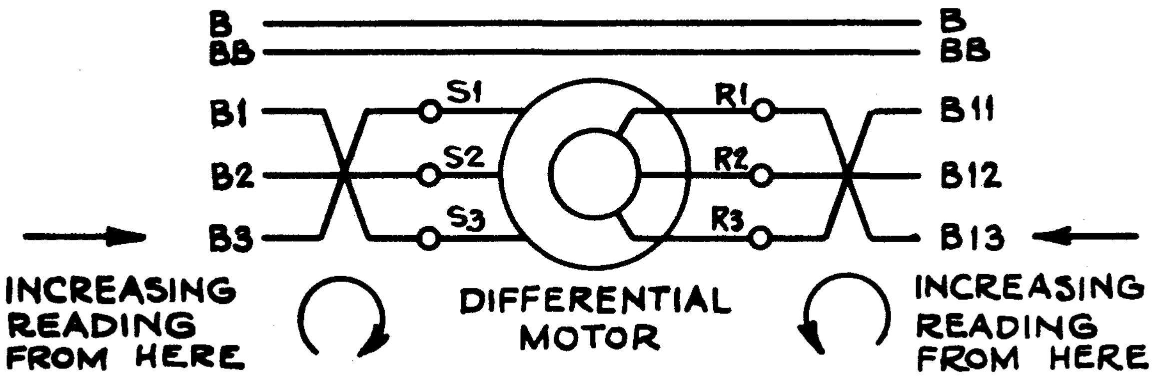
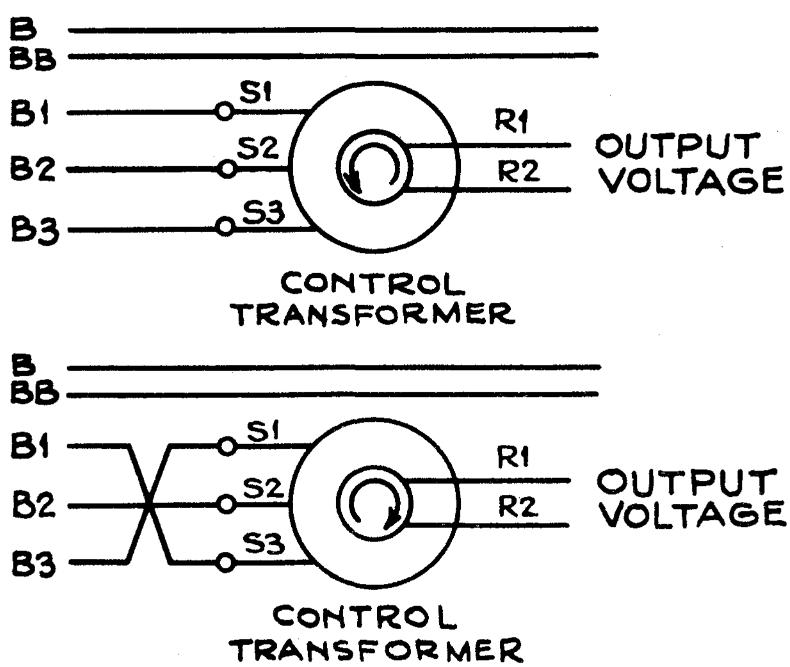
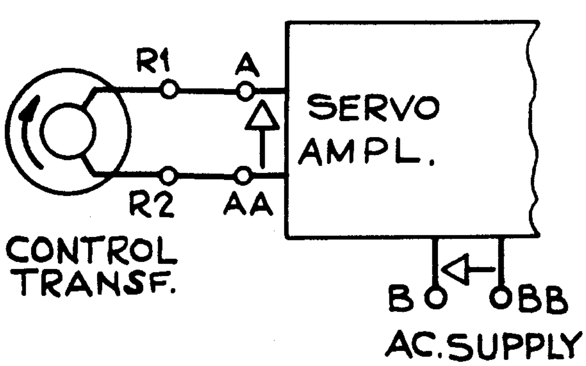


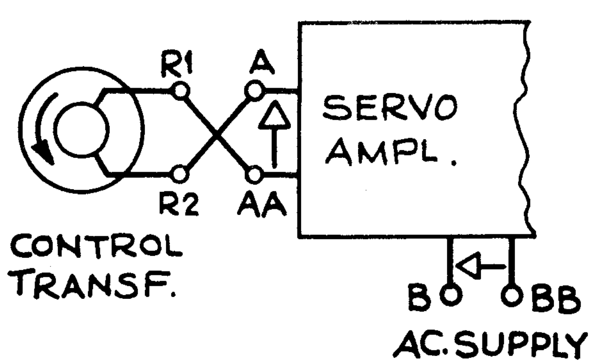
STANDARD CONNECTIONS FOR CONTROL TRANSFORMERS

10. Connect the stator leads of a Control Transformer to the bus as shown in each case if its shaft is to turn as indicated when following an increasing reading.



11. Connect the rotor leads of a Control Transformer to the Signal Input terminals of the Servo Amplifier as shown in each case if its shaft is to turn as indicated when following an increasing reading.

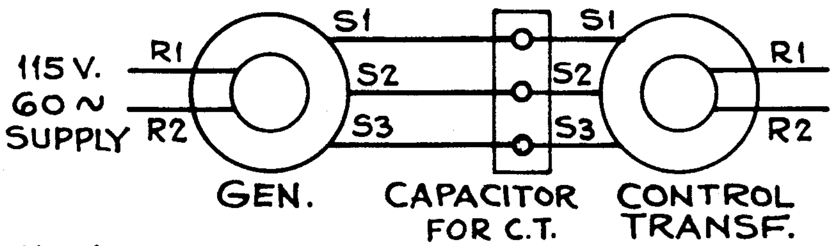


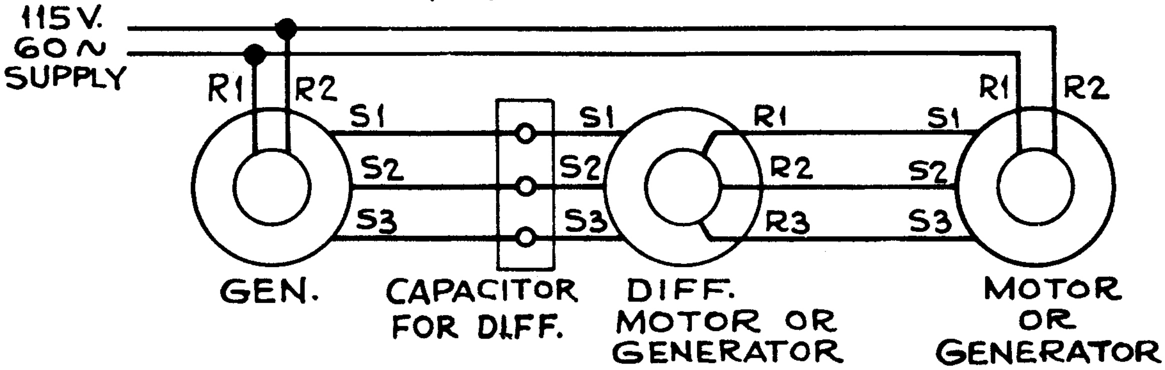


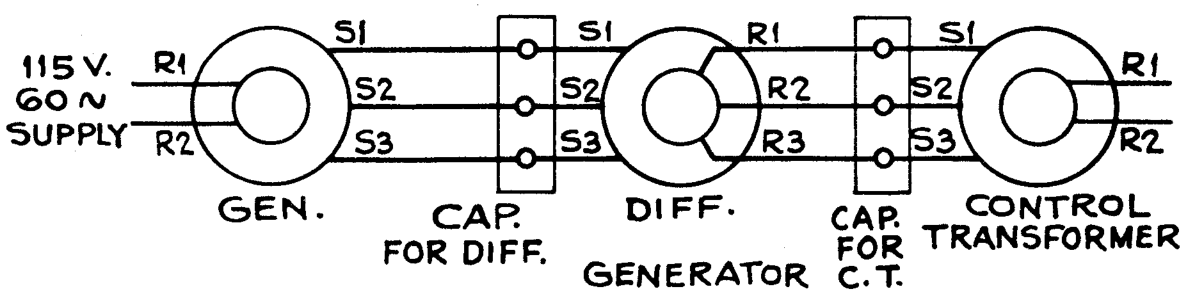
STANDARD CONNECTIONS

STANDARD CONNECTIONS FOR SYNCHRO CAPACITORS

12. Whenever a Differential or Control Transformer is used, mount a Synchro Capacitor of the proper size as close to it as possible, and connect as shown below:

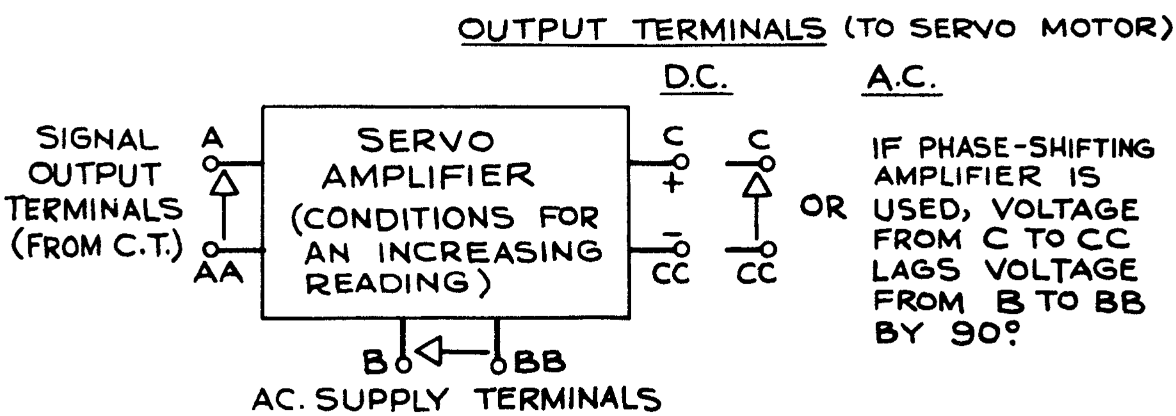






STANDARD CONNECTIONS FOR SERVO AMPLIFIERS

13. When a Servo System is following an increasing reading, the Signal Input voltage is in phase with the AC Supply voltage, and the Output voltage is either *positive* (for a DC output), *in phase* with the supply (for a straight AC amplifier), or *lags* the supply by 90° (when there is a 90° shift in the amplifier). (In each case the voltage is measured at the single-letter terminal on the Servo Amplifier with respect to the corresponding double-letter terminal.)

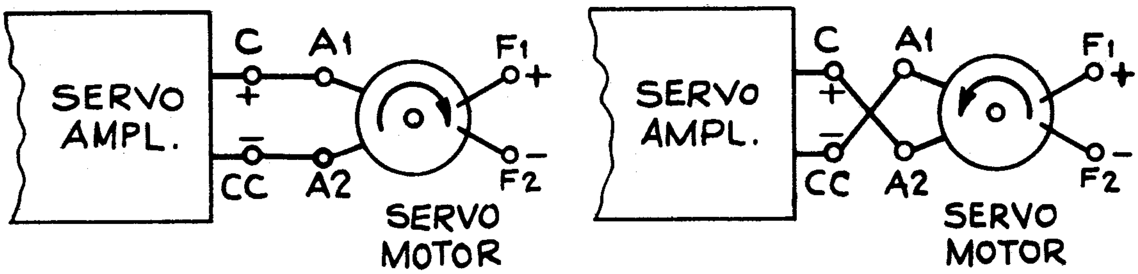


STANDARD CONNECTIONS FOR SERVO MOTORS

NOTE: On commutator type motors with a double-ended shaft, rotation is observed when looking at the shaft end opposite the commutator.

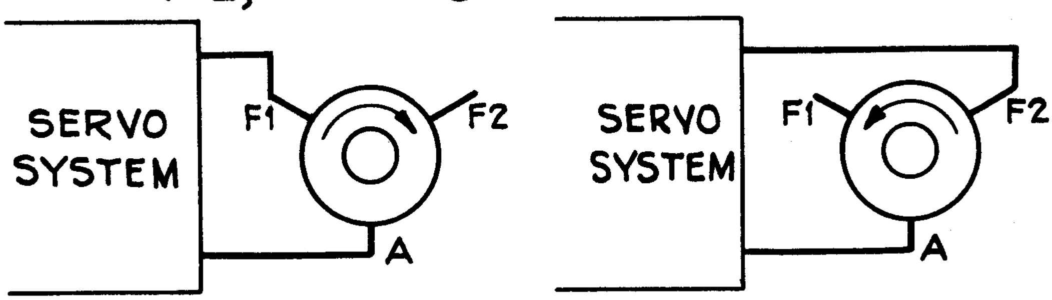
14. When a Shunt Field D.C. Servo Motor is used connect it as shown in each case if its shaft is to turn in the indicated direction when following an increasing reading.

SHUNT FIELD D.C. SERVO MOTOR



15. When a Split Series Field Servo Motor is used connect it as shown in each case if its shaft is to turn in the indicated direction when following an increasing reading.

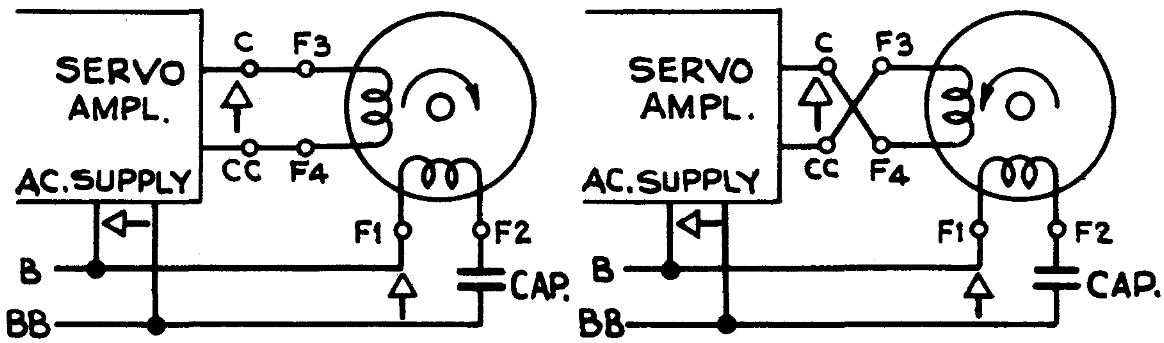
SPLIT SERIES FIELD, COMMUTATOR TYPE, AC. OR DC. SERVO MOTOR



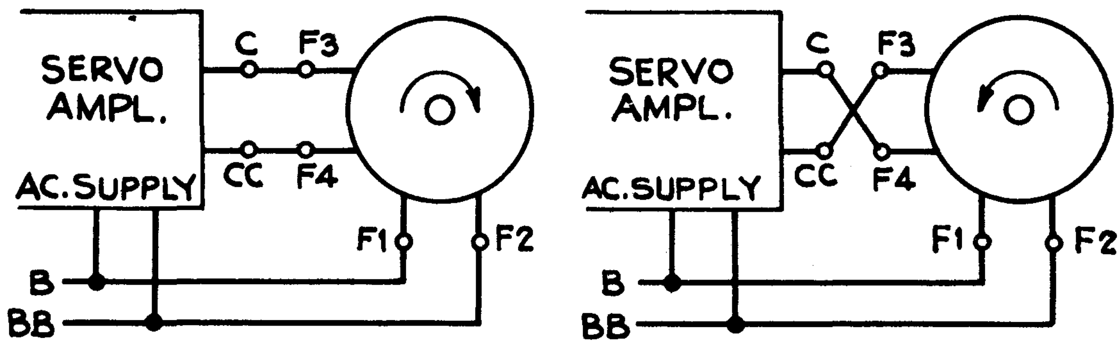
STANDARD CONNECTIONS

16. When a Two Field Induction Motor is used, one field being excited from the line and one through the Servo Amplifier, connect it as shown in each case if its shaft is to turn in the indicated direction when following an increasing reading.

TWO FIELD INDUCTION TYPE AC. SERVO MOTOR WITH CAPACITOR



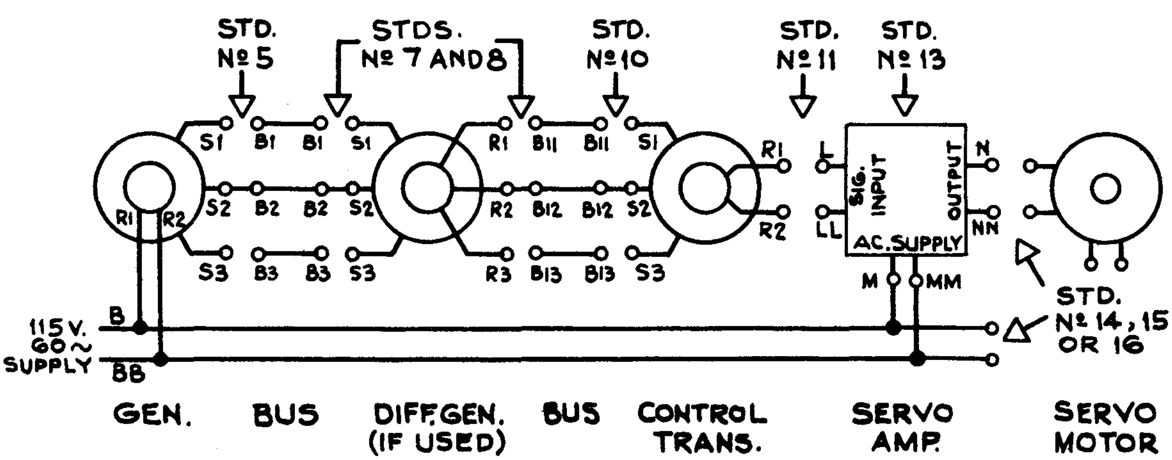
TWO FIELD INDUCTION TYPE AC. SERVO MOTOR WITH 90° PHASE SHIFT IN SERVO AMPLIFIER



THE STANDARD CONNECTIONS THAT APPLY TO A TYPICAL SERVO SYSTEM

17. There are two possible connections for each unit in a Servo System which has a shaft. The one to use is determined by the direction in which that shaft turns when the system is following an increasing reading. The indicated standard connections in this section determine connections at each point.

MAKE CONNECTIONS ACCORDING TO:



ZEROING SYNCHROS

INTRODUCTION

THE ADVANTAGE OF USING ELECTRICAL ZERO AS A REFERENCE

The use of Electrical Zero provides a standard way of aligning Synchro units so that they all work right when connected together in a Synchro system. Consider, for example, a Gun Director Train Indicator system. Such a system is used to show, on a dial at each gun station, the position of the Director, so that the guns may be trained accordingly. If the Indicator dials were mounted on the shafts of all the Motors, and the Generator shaft was geared to the Gun Director in any convenient position, then, when the system was first turned on, all of the dials would read differently, and none of them would show the position of the Gun Director correctly. Before the system could be used it would be necessary to set the dials so that they all read the true position of the Director. Once this was done they would continue to read correctly, due to the self-aligning feature of a Synchro.

There are two ways in which this initial adjustment could be made. One way would be to have two men, one at the Director, and the other at each gun station in turn. They could talk over a phone, and change the setting of the dial on each Motor until it showed the position of the Director correctly.

A much better way would be this: First: unclamp the Generator and turn it until the shaft of the Generator is exactly in the Electrical Zero position when the Director is trained on 0°. Second: set the dial on each Motor in the system so that, when the Motor's shaft is exactly in the Electrical Zero position, the dial reads 0°.

The second method has the very important advantage that the mechanical position of the dial on each Motor's shaft is the same for any system. The dial could, for example, be locked to the shaft in the correct position at the factory, and it would read correctly when installed on a ship, without any further adjustment.

This method has the further advantage that trouble in the system always shows up the same way on the Indicator dials. For example, a short circuit from S2 to S3 causes all the dials to stop at 60° or 240°.

This method, called "Zeroing" each Synchro, is universally used on Synchro systems.

THE DIAL READING AT ELECTRICAL ZERO (THE "ZERO" READING)

The reading to which the Motor's dial is set when the shaft is at Electrical Zero depends on the type of Synchro system. On a Gun Director Train Indicator system, and any other system which has a "0°" on its dial, the dial is set to 0° at Electrical Zero. On a Range Transmission system, 1,000 yards is often used. On a fuze time transmission system 10 seconds is used. On an Engine Room Telegraph, STOP is used. Before making this adjustment on any system, it is necessary to know what dial reading to use. In what follows this reading is called the "Zero reading," and the corresponding position of the Generator is called the "Zero position."

WHAT IS MEANT BY "ZEROING" A SYNCHRO

"Zeroing" a Synchro means, in general, adjusting it, mechanically, so it will work properly in a system in which all the other Synchros are zeroed. This mechanical adjustment is usually made by loosening the lugs that clamp the flange and turning the whole case. In some cases it may be better to loosen the shaft coupling or some intermediate gear, and to turn the shaft.

(In what follows "Electrical Zero" Voltages means the voltages required to make a Motor turn to Electrical Zero, that is, 115 volts between R1 and R2, 78 volts in phase with R1-R2 between S2-S1 and S2-S3, and 0 volts between S1 and S3.)

A Synchro Motor is zeroed if its dial shows the Zero reading when Electrical Zero voltages are applied.

A Synchro Generator is zeroed if it produces Electrical Zero voltages when the unit whose position it transmits is set in Zero position.

A Bearing-Mounted Synchro Motor is zeroed if, when Electrical Zero voltages are applied, and the unit to which its stator is geared is set in its Zero position, its dial reads zero (or its switch is centered between contacts).

A Synchro Differential Motor is zeroed if its dial shows the Zero reading when Electrical Zero voltages are applied to both its sets of windings.

A Synchro Differential Generator is zeroed if its secondary (rotor) produces Electrical Zero voltages when Electrical Zero voltages are applied to its primary (stator) and the unit whose position it transmits is set in Zero position.

A Synchro Control Transformer is zeroed if its secondary (rotor) voltage is zero when Electrical Zero voltages are applied to its primary (stator) and the unit whose position it transmits is set in Zero position; and if turning the C.T.'s shaft slightly counter-clockwise produces a voltage from R1 to R2 which is in phase with the voltage from R1 to R2 on the Generator supplying its stator.

TO AVOID TROUBLE:

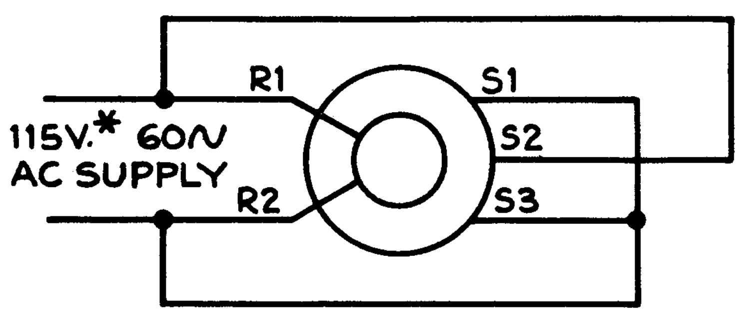
1. Be sure that all units that should be zeroed *are* zeroed before testing a new installation, and before hunting trouble on an old one.
2. Be sure you know what Zero reading to use before you try to zero a Synchro.
3. These instructions apply directly to standard Navy Synchros. The same general methods may be applied to other similar units (Selsyns, Autosyns, Teleindicators, Army Synchros, etc.) provided the connections are changed where necessary to agree *electrically* with those shown here, and voltages are changed where necessary to match the characteristics of the unit zeroed.

TO ZERO A SYNCHRO MOTOR

The shaft of a Motor is usually free to turn. The way to zero such a Synchro is to apply the right voltages to hold it on electrical zero while its dial is adjusted to the Zero reading.

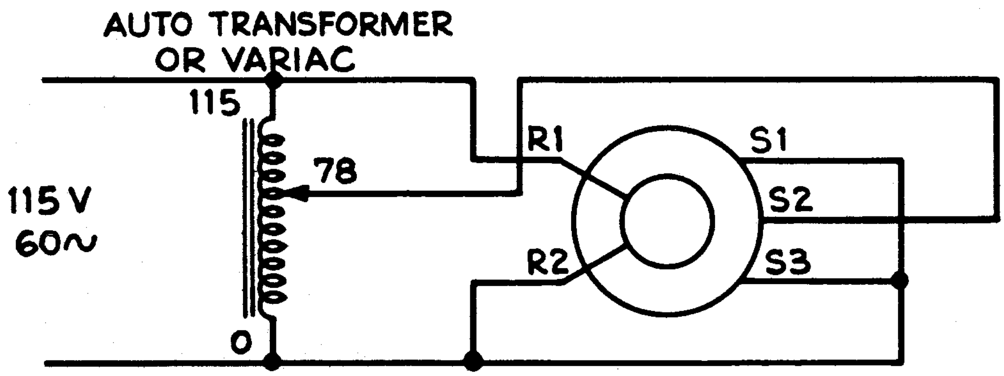
METHOD A:

If the lead connections can be readily changed, remove all stator connections and re-connect like this:



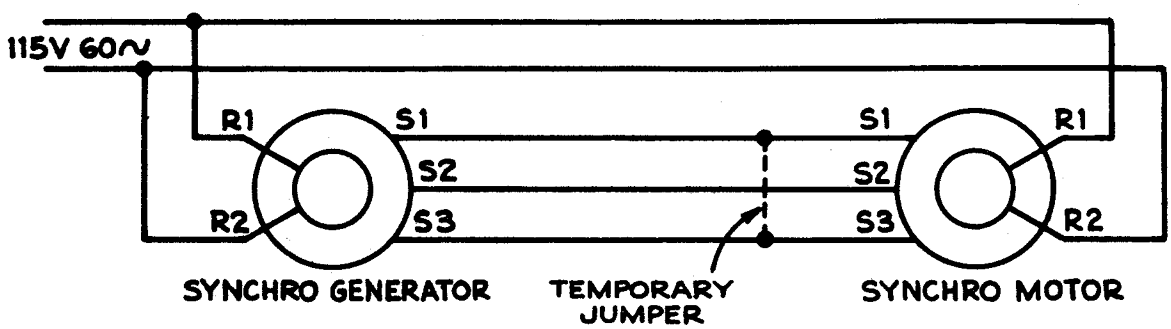
The shaft will turn definitely to 0°. Set the dial to its Zero reading while the Motor is connected this way.

**DON'T leave a Motor connected this way longer than is necessary to zero it.* 115 volts is applied between S2 and S1-S3 instead of the normal 78 volts, and the Motor will overheat. If a Motor has to be held on zero for more than a few minutes, connect like this:



METHOD B:

Method A is better, but when the Motor is installed in an equipment and it's connections can't be changed easily, proceed as follows: Leave the normal circuit connected, like this: (If S1 and S3 are reversed, don't bother changing them, this won't affect the results).



First make sure that the Generator has been correctly zeroed, and that the connecting wires are properly installed. (Ring them out with a battery and buzzer.) Then set the Generator in the Zero position and make sure that it stays there while you are adjusting the Motor. Connect a temporary jumper from S1 to S3 (as shown by the dotted line). This holds the Motor more definitely on 0°, so its dial can be set more easily. *Caution: If the Motor shaft moves more than a fraction of a degree when this jumper is connected, the Generator is not set on 0°, recheck it.*

Unclamp the case of the Motor and turn it (or loosen the dial and turn *it*) until the dial reads zero while the Motor is connected this way. (It sometimes helps to get the dial set more accurately if the jumper is connected and disconnected several times so the dial moves very slightly.) Clamp the Motor in position when finished, and remove the jumper.

TO ZERO A BEARING-MOUNTED SYNCHRO MOTOR

Both the rotor and the stator of a Bearing-Mounted Motor are free to turn. The stator is usually geared to some large unit, and there is a shaft coupling or a gear in this connection which may be loosened to set zero. A dial or a switch is usually mounted on the shaft.

1. Set the unit to which the stator is geared in its Zero position.

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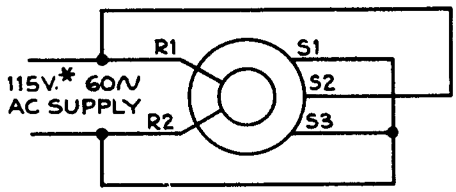
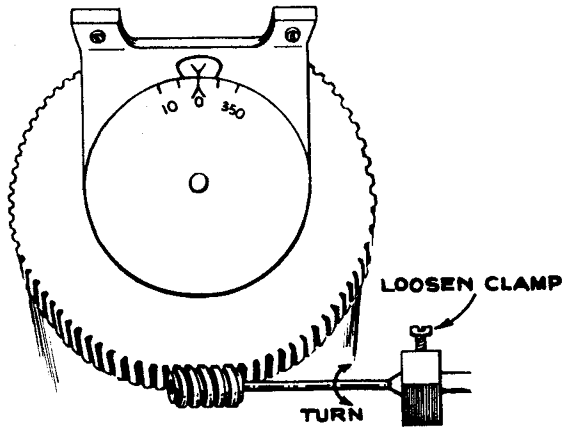
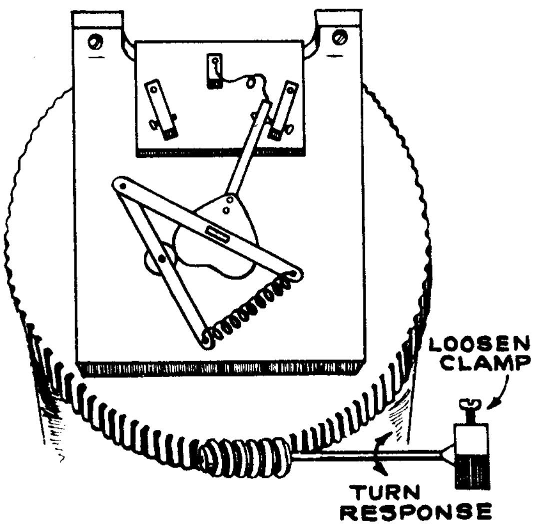
2. Remove all stator connections and reconnect like this: (This turns the shaft to the 0° position with respect to the stator.)



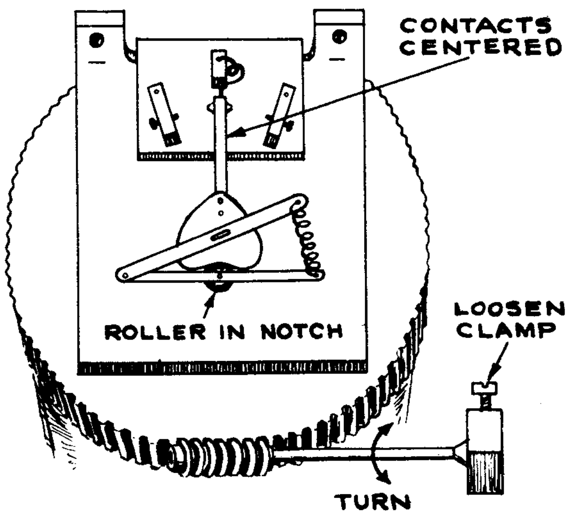
3. If a dial is used, loosen the mechanical connection to the stator and turn by hand until the dial reads 0° like this:



4. If a switch is used, the roller will probably be turned out of the notch when Zero voltages are applied, like this:



Loosen the mechanical connection to the stator and turn by hand until the roller is in the notch and the contacts are centralized, like this:



5. Tighten the mechanical connection again, and reconnect the stator leads normally.

**DON'T* leave a Motor connected this way longer than is necessary to zero it. 115 volts is applied instead of the normal 78 volts and it will overheat.

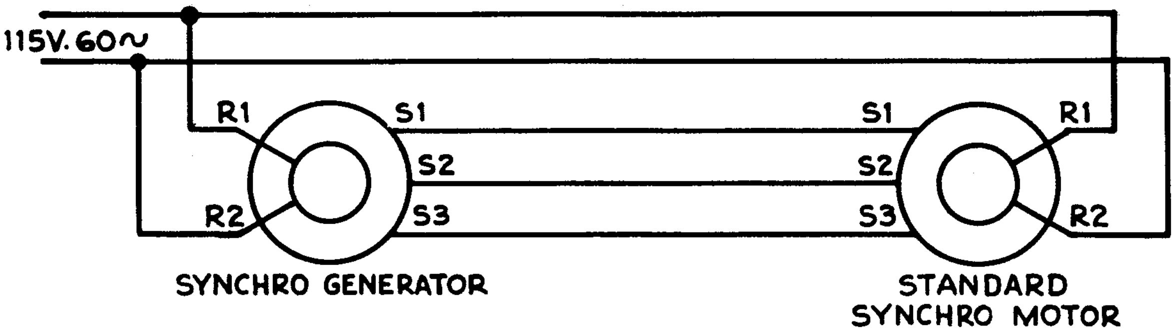
TO ZERO A SYNCHRO GENERATOR

The shaft of a Synchro Generator is usually connected directly or through a gear train to some large unit whose position it transmits. The way to zero such a Synchro is to set the large unit in its Zero position, then to adjust the Synchro mechanically until its output voltages indicate electrical zero.

ZEROING A GENERATOR

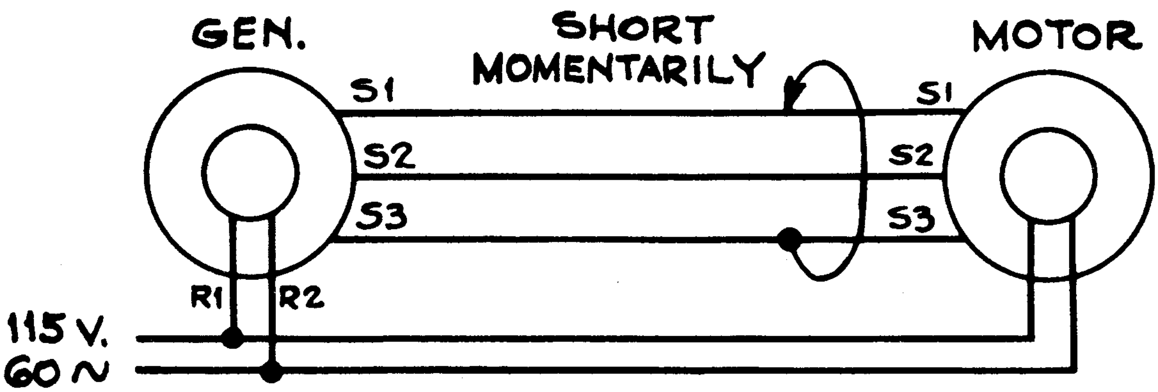
USING A STANDARD MOTOR TO ZERO A GENERATOR

The easiest way to zero a Generator is to use a Synchro Motor equipped with a dial which shows when its shaft is in the electrical zero position. (This can be a Motor that is already in the system, or a separate portable unit. In any case it must be correctly zeroed before being used for this purpose.) Connect like this:



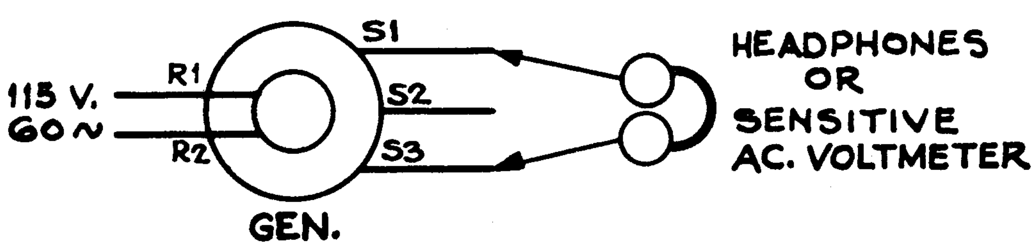
1. Set the unit whose position the Generator transmits, accurately in its Zero position. Unclamp the Generator and turn it until the Motor reads 0°. The Generator is now *approximately* on 0°.

2. Check like this:



If the Motor's shaft moves at all when S1 is shorted to S3, the Generator is not zeroed, shift slightly and try again. When it is accurately zeroed clamp it and remove any added connections.

Another way to check the Generator's zero position accurately is, first set the Generator to zero with a Motor, then remove all connections from the Generator's stator leads and connect a sensitive AC voltmeter (capable of indicating 0.1 volt) or a pair of headphones like this:



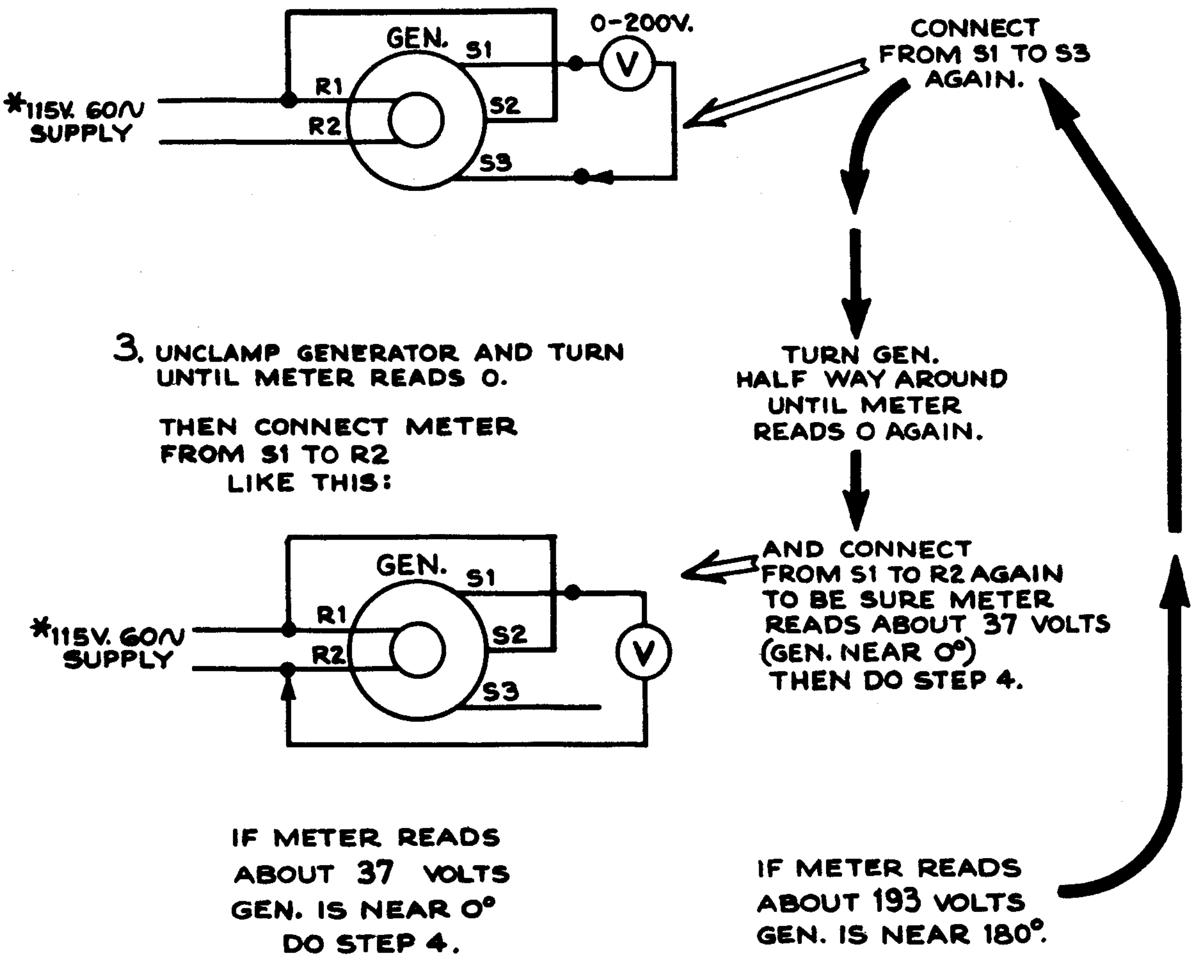
Turn the Generator carefully until you get minimum sound (or voltage). Clamp it in this position and reconnect the stator leads normally.

Note: Do not try to use the voltmeter or headphones in this way without first setting the Generator approximately right in some other way. The voltage from S1 to S3 falls to zero at both 0° and 180°, and this check doesn't give any way of telling the difference.

USING AN AC VOLTMETER TO ZERO A SYNCHRO GENERATOR

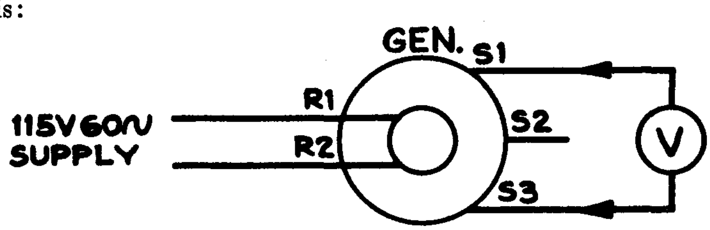
When no Synchro Motor is available, a Generator can be zeroed just as accurately with an AC voltmeter. Use a meter which has one scale reading up to 200 volts or higher, and another scale which reads down to 0.1 volt or less. (A 0-5 volt scale is O.K.). Proceed as follows:

1. Set the unit whose position the Generator transmits, accurately in its zero position.
2. Remove all other connections from the stator leads, set the voltmeter on its 200 volt scale, and connect like this:



**DON'T* leave a Generator connected this way longer than is necessary to zero it. 115 volts is applied instead of the normal 78 volts and it will overheat.

4. Connect like this:



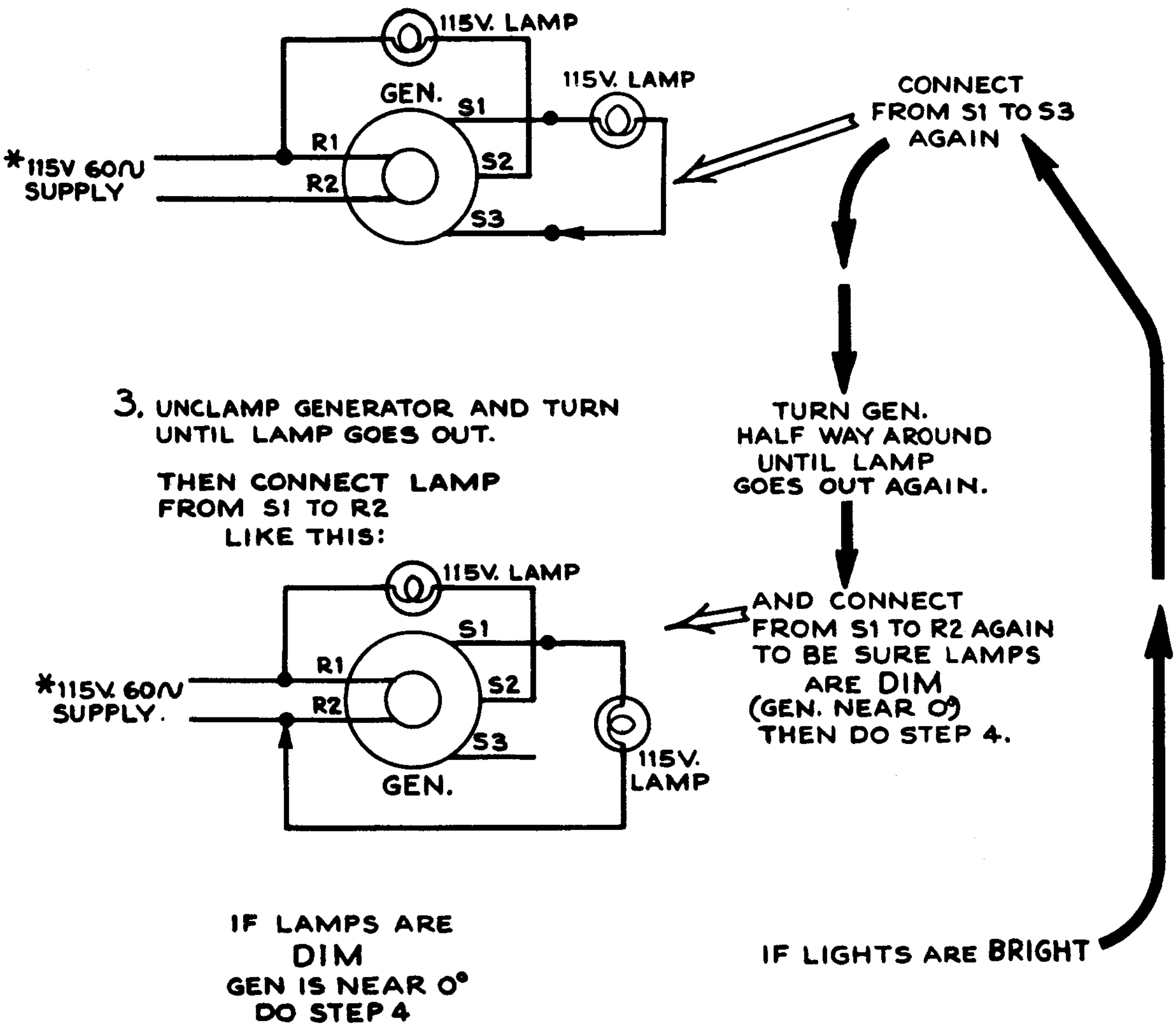
Set the voltmeter on its lowest scale and turn the Generator carefully for minimum reading. Clamp the Generator in this position and reconnect the stator leads normally.

ZEROING A GENERATOR

USING TWO LAMPS AND A PAIR OF HEADPHONES TO ZERO A SYNCHRO GENERATOR

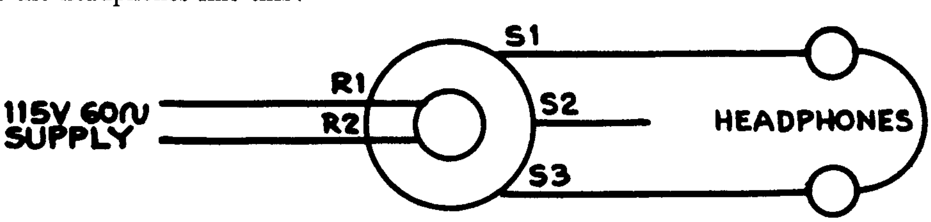
Another accurate way to zero a Generator is to use two 115 volt lamps (the small 6 watt size is convenient, although any low-power lamp is OK) and a pair of headphones. Proceed as follows:

1. Set the unit whose position the Generator transmits, accurately in its zero position.
2. Remove all other connections from the stator leads, and connect like this:



**DON'T* leave a Generator connected this way longer than is necessary to zero it. 115 volts is applied instead of the normal 78 volts and it will overheat.

4. Connect the headphones like this:



Turn the Generator carefully until you get minimum sound and clamp it in this position. Then reconnect the stator leads normally.

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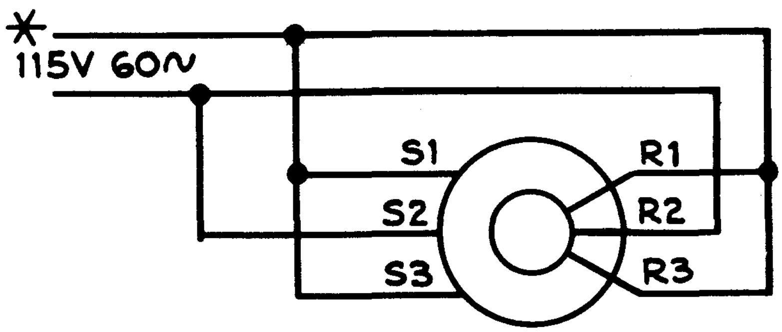
TO ZERO A DIFFERENTIAL MOTOR

The shaft of a Differential Motor is usually free to turn, and it is zeroed very much like an ordinary Motor.

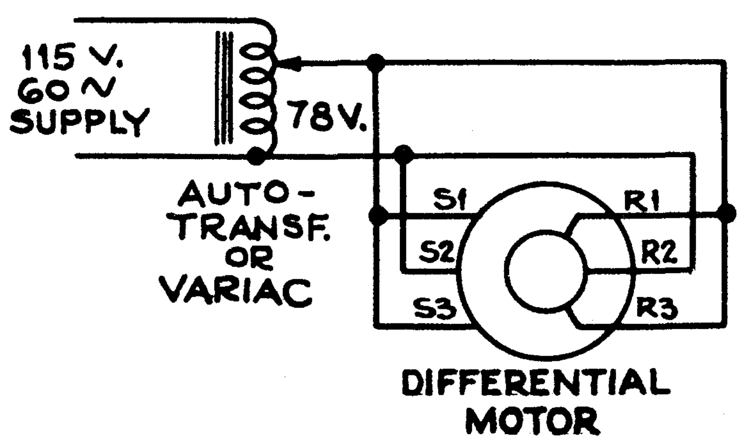
METHOD A:

If the lead connections can be readily changed, re-connect like this:



The shaft will definitely turn to 0°. Set the dial to its Zero reading while the Motor is connected this way.

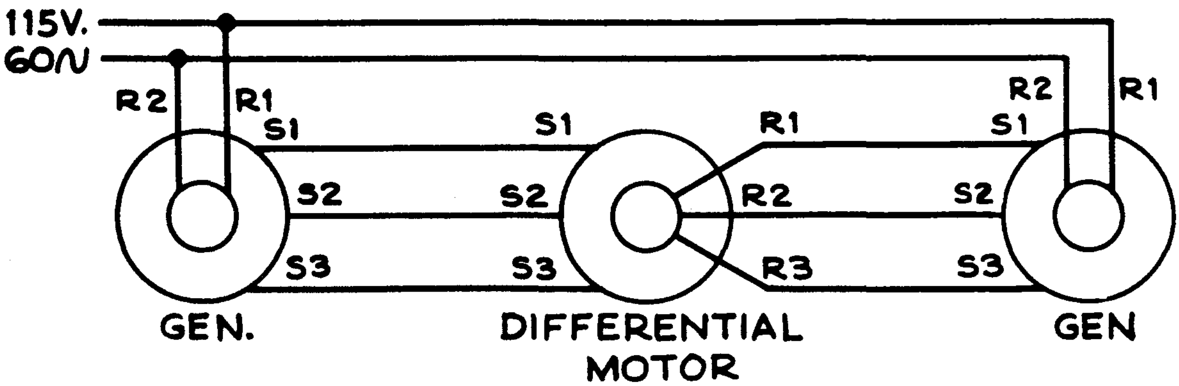
******DON'T leave a Motor connected this way longer than is necessary to zero it.* 115 volts is applied between S2 and S1-S3, and between R2 and R1-R3. Since the normal voltages are 78 volts, the Motor will overheat. If a Differential Motor has to be held on 0° for more than a few minutes, connect like this:



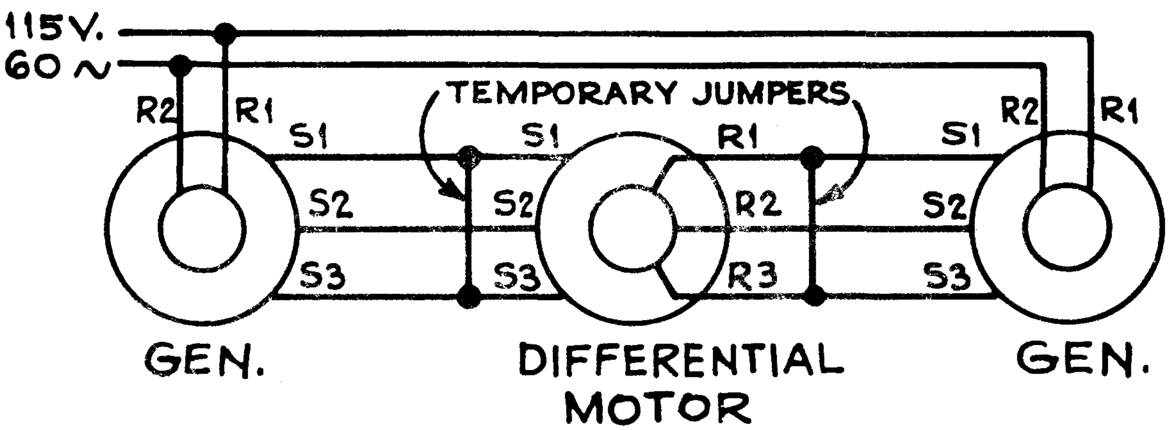
ZEROING A DIFFERENTIAL MOTOR

METHOD B:

Method A is better, but when the Differential Motor is installed in an equipment and it's connections can't be changed easily, proceed as follows: Leave the normal circuit connected like this: (If R1-R3 or S1-S3 are reversed, don't bother changing them, this won't affect the results.)



First make sure that both Generators have been correctly zeroed, and that the connecting wires are properly installed. (Ring them out with a battery and a buzzer.) Then set both Generators on 0° and make sure they stay there while you are adjusting the Motor. Connect Temporary jumpers like this:



These jumpers hold the Motor definitely on 0° so the scale may be set more easily.

Caution: If the Motor shaft moves more than a fraction of a degree when either jumper is connected, the Generator on that side is not on 0°, recheck.

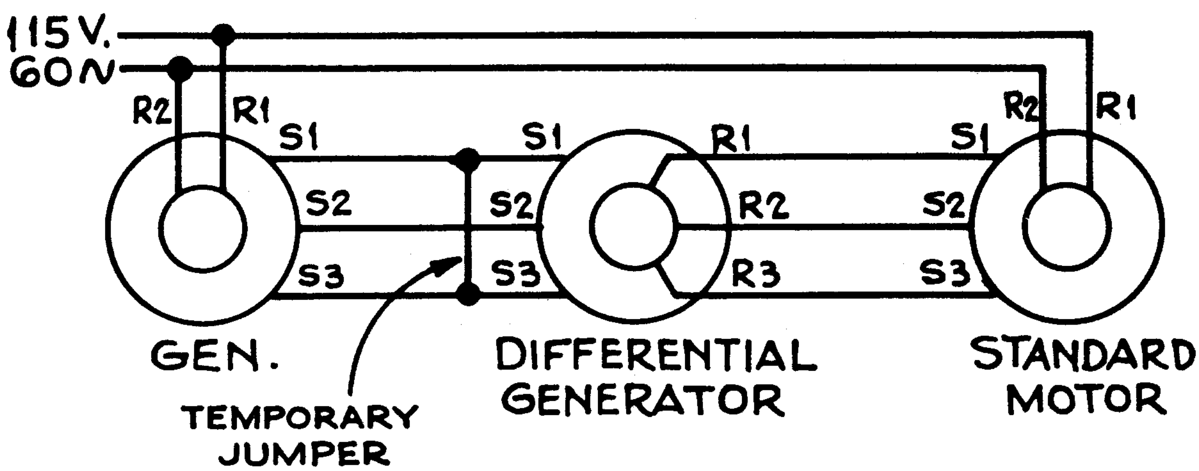
Set the dial on the Differential Motor to its Zero reading while the Motor is connected this way Clamp it there and remove the jumpers.

TO ZERO A DIFFERENTIAL GENERATOR

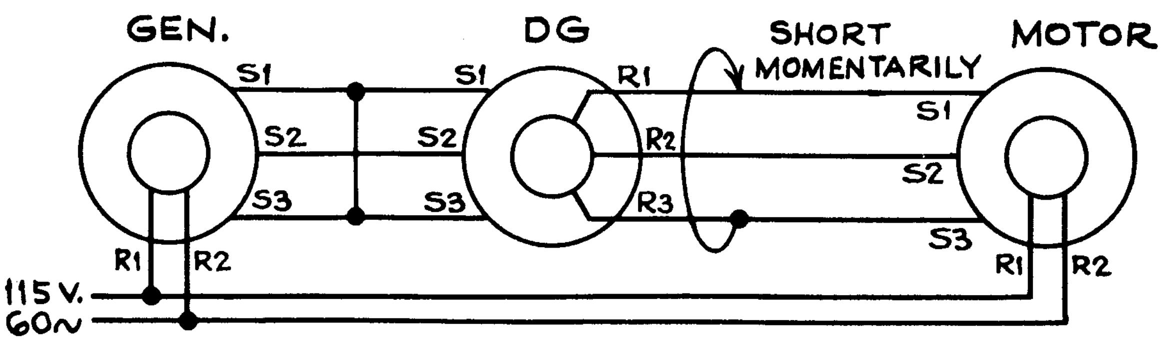
The shaft of a Differential Generator is usually connected to some large unit whose position it transmits. It is zeroed in very much the same way as a Generator.

USING A STANDARD MOTOR AND A GENERATOR TO ZERO A DIFFERENTIAL GENERATOR:

These can be units already in the system, or either one may be a separate portable unit. Make sure that both of them are correctly zeroed before starting, and that the Generator is held on 0° during the adjustment. Connect as shown below. *If the Motor shaft moves at all when the jumper is connected from S1 to S3, the Generator is not on 0°, recheck.*



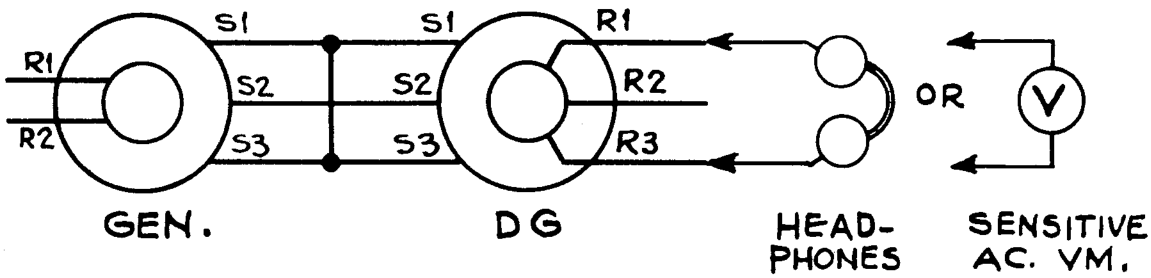
1. Set the unit whose position the DG transmits, accurately in its Zero position. Unclamp the DG and turn it until the Motor reads 0°. The DG is now approximately on 0°.
2. Check like this:



If the Motor shaft moves at all when R1-R3 is shorted, the DG is not on 0°, shift slightly and try again. When it is accurately on 0° clamp it and remove the jumpers.

ZEROING A DIFFERENTIAL GENERATOR

Another way to check the DG accurately is to set for 0° reading on the Motor, then disconnect the Motor completely and connect a pair of headphones or a sensitive AC voltmeter, like this:

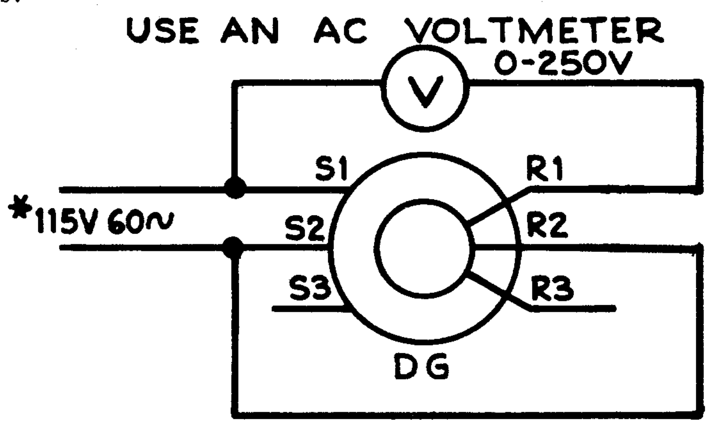


Turn the DG carefully until you get minimum sound (or voltage). Clamp it in this position, and remove the jumper.

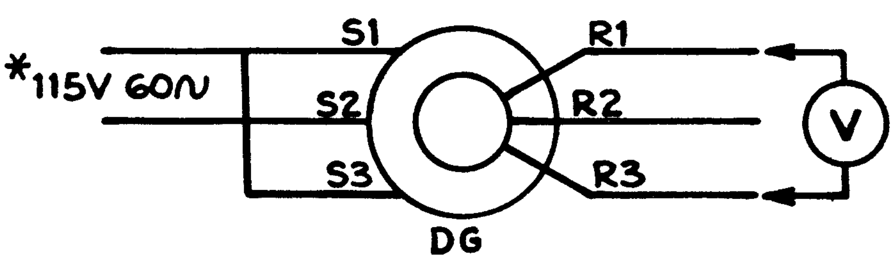
USING AN AC VOLTMETER TO ZERO A DIFFERENTIAL GENERATOR

A DG may be zeroed accurately with an AC voltmeter. Use one that reads up to 250 volts on one scale and down to 0.1 volt on another (a 0-5 volt scale is O.K.).

1. Set the unit whose position the DG transmits, accurately in its Zero position.
2. Remove all other connections from the DG's leads, set the voltmeter on its 250 volt scale and connect like this:



3. Unclamp the DG and turn it until the meter reads minimum. The DG is now approximately on 0°. Reconnect like this:



4. Set the voltmeter on its lowest scale and turn the DG carefully until you get minimum reading. Clamp the DG in this position and reconnect all leads normally.

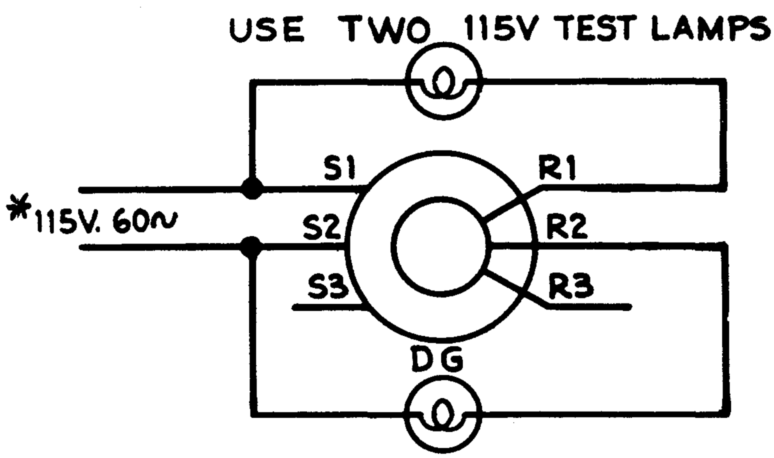
******DON'T leave a DG connected this way any longer than is necessary to zero it.* 115 volts is applied where the voltage is normally lower, and the DG will overheat.

USING TWO LAMPS AND A PAIR OF HEADPHONES TO ZERO A DIFFERENTIAL GENERATOR

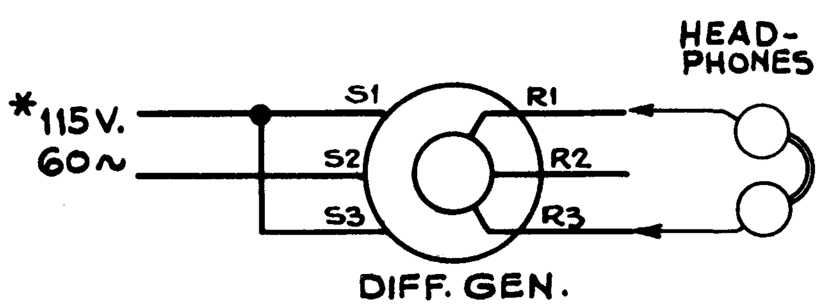
Another accurate way to zero a DG is to use two small 115 volt lamps (the 6 watt size is convenient) and a pair of headphones.

1. Set the unit whose position the DG transmits, accurately in its Zero position.

2. Remove all other connections from the DG's leads and connect like this:



3. Unclamp the DG and turn it until the lamps are dimmest. The DG is now approximately on 0°. Reconnect like this:



4. Turn the DG until you get minimum sound in the phones. Clamp it in this position and reconnect all leads normally.

**DON'T leave a DG connected this way any longer than is necessary to zero it.* 115 volts is applied where the voltage is normally lower, and the DG will overheat.

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ZEROING A CONTROL TRANSFORMER

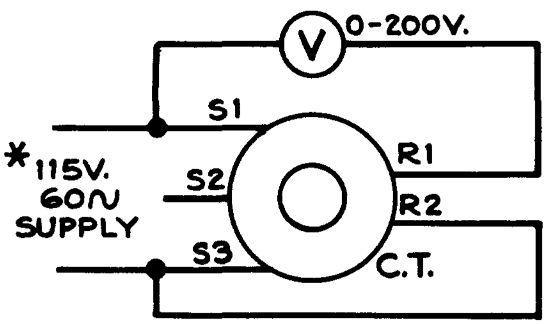
TO ZERO A CONTROL TRANSFORMER

USING AN AC VOLTMETER TO ZERO A CONTROL TRANSFORMER

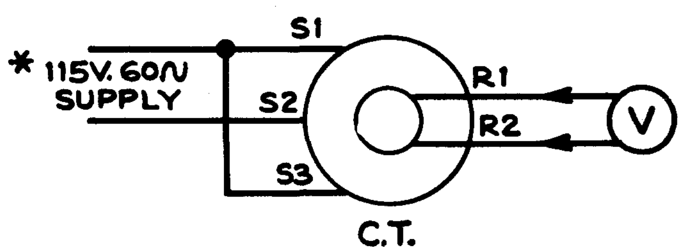
Use a voltmeter that reads up to 200 volts on one scale, and down to 0.1 volt on another.

1. Set the unit whose position the CT transmits, accurately in its Zero position.

2. Remove all other connections from the CT's leads, set the voltmeter on its 200 volt scale and connect like this:



3. Unclamp the CT and turn it until the meter reads minimum (about 40 volts). The CT is now approximately on 0°. Reconnect like this:



4. Set the voltmeter on its lowest scale and turn the CT until you get minimum reading. Clamp the CT in this position and reconnect all leads normally.

**DON'T leave a CT connected this way any longer than is necessary to zero it.* 115 volts is applied where the voltage is normally lower, and the CT will overheat.

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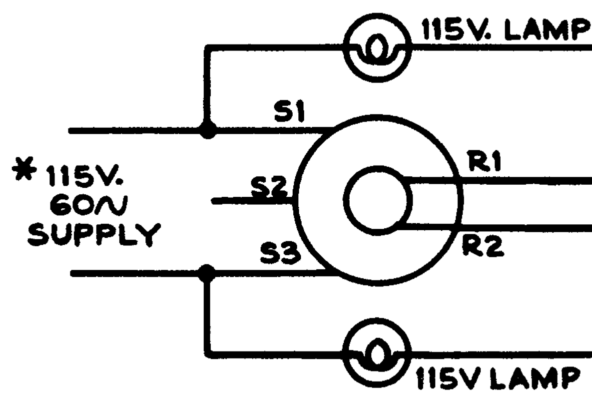
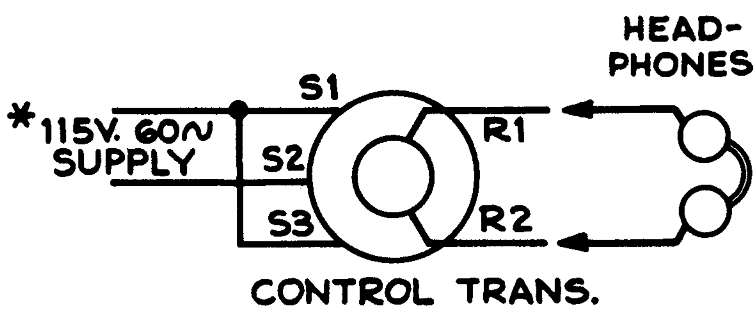
USING TWO LAMPS AND A PAIR OF HEADPHONES TO ZERO A CONTROL TRANSFORMER

Use two small 115 volt lamps (the 6 watt size is convenient) and a pair of headphones.

1. Set the unit whose position the CT transmits, accurately in its Zero position.
2. Remove all other connections from the CT's leads, and connect like this:



3. Unclamp the CT and turn it until the lamps are dimmest. The CT is now approximately on 0°. Reconnect like this:



4. Turn the CT for minimum sound in the phones. Clamp the CT in this position and reconnect all leads normally.

**DON'T leave a CT connected this way any longer than is necessary to zero it.* 115 volts is applied where the voltage is normally lower, and the CT will overheat.

THE MAINTENANCE OF SYNCHROS

The proper attitude toward Synchros can be stated in two sentences—remember them!

If A Synchro Works OK—Leave It Alone! **If It Goes Bad—Replace It!**

A Synchro is not just another kind of electric motor. It is a highly precise instrument. Handle it like you would a watch or an electric meter.

When you install or remove a Synchro from a piece of equipment, do it carefully. Don't hammer the case, or force it into place. Be sure the shaft is lined up before tightening couplings. Don't drop it!

NEVER NEVER take a Synchro apart to see what makes it work so well! Synchros are sealed. These seals should be broken only by technicians in authorized repair shops.

DON'T try to lubricate a Synchro. When is was manufactured it was lubricated sufficiently to last a long, long time. Incorrect lubrication will just cause trouble.

If It's OK—Don't Mess With It! **If It's Shot—Get A New One!**

REPAIRING DEFECTIVE SYNCHROS

This section is written for technicians in authorized Synchro repair shops.

Nobody else has any business trying to repair a Synchro!

GENERAL RULES

1. Dirt and dust are death on Synchros. Before taking one apart: Get a clean, dry place to work. Spread a large sheet of paper over your bench. Don't work where it's dusty.

   Clean off the outside of the Synchro. Dirt from the outside may easily fall *inside* when you take it apart.

2. Handle with care. Don't force any parts. If they don't come apart or go together easily, find out what's wrong. A precision-built instrument like a Synchro can easily be ruined by rough handling.

3. Don't touch the ball races or the balls with bare hands. Wear gloves or handle with a clean, lint-free cloth such as viscose rayon twill Spec. C-7-8271 dyed white. A little sweat may rust the surface of the steel balls and ruin them.

LUBRICATING A SYNCHRO

A Synchro should be taken apart for lubrication only if it squeaks or sticks. The routine lubrication of these units will generally cause more trouble than it will prevent.

Before applying lubricant **be sure:**

(a) The Synchro needs it.

(b) You know how to apply it.

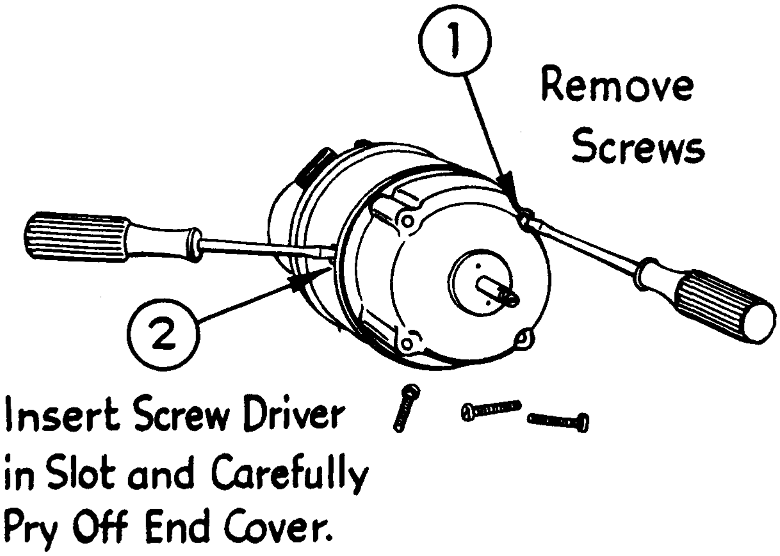
(c) It is the right lubricant for the job.

OIL is used on *all* Synchro Motors, and on most other units.

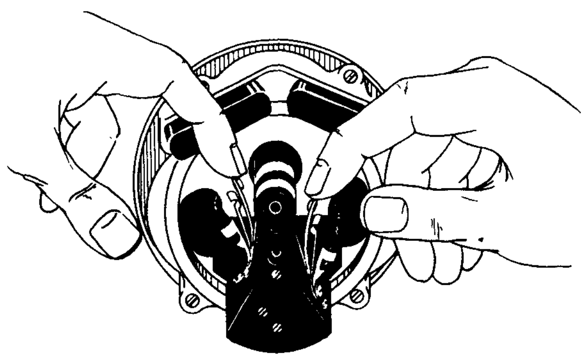
GREASE is used only on Generators, Differential Generators, or Control Transformers that run frequently at high speeds (over 100 RPM), or that run *continuously* at any speed. It is also used on all units which have an "H" (high speed) in their designation, as for example, on a 5HG.

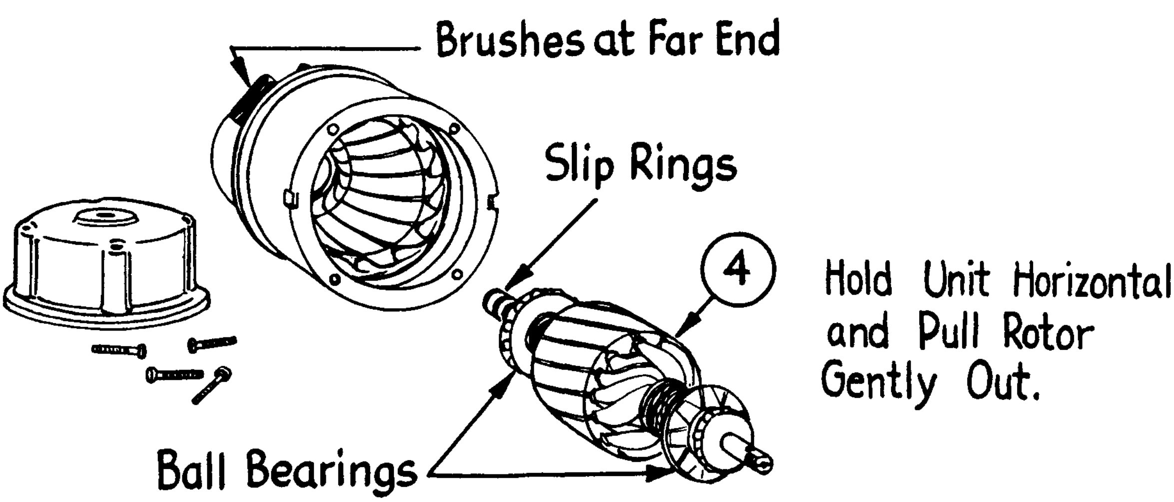
TO TAKE THE ROTOR OUT

First break the seal, then hold the unit horizontally and take it apart like this: (Note: These illustrations apply directly only to one type of Synchro, the same general idea can be applied to any type.)



3 Take Off Cover Over Brushes and Hold Them Clear of Slip Rings While Rotor Is Being Removed.





If you have to take any parts off of the shaft, notice exactly how they were on there and put them back exactly the same way.

TO LUBRICATE A SYNCHRO

1. Take out the rotor as shown above.

2. If the balls or races are dirty or gummy, wash thoroughly in solvent dry-cleaning fluid, Federal Specification PS661 (this doesn't leave any deposit) and wipe dry on a clean lint-free cloth such as viscose rayon twill Spec. C-7-8271, dyed white.

3. Inspect the slip rings. If they are oily or dirty, wipe them clean with a lint-free cloth such as viscose rayon twill Spec. C-7-8271, dyed white.

4. **On Units Requiring OIL**

Use the special oil specified by the manufacturer of the Synchro you are working on if you know what it is and can get some. (Most manufacturers are now using Standard Oil Company of New Jersey "Univis No. 48" or equivalent.)

Otherwise use O.S. 1362 oil, lubricating preservative, light, or instead you may use Navy symbol 1042 oil, extra light, or Navy symbol 2075 oil, ice machine.

Place one drop of oil at the top of each ball. If balls appear oily, *use less oil.* Wipe off any excess oil.

5. **On Units Requiring GREASE**

Use the special grease specified by the manufacturer of the Synchro you are working on if you know what it is and can get some. (Most manufacturers are now using Standard Oil Company of New Jersey "Andock C," Navy M-285 or equivalent.)

Otherwise use O.S. 1350 Bearing grease; or instead you may use AN-G-3 grease, low temperature lubricating.

With a screwdriver, pack just enough grease into the spaces between the balls to bring the grease up flush with the top of the ball race.

6. Replace the rotor, holding the brushes clear of the slip rings until it is in place. Reassemble the Synchro carefully.

7. Reseal the Synchro and test it for accuracy by the standard method before releasing. *A Synchro must be accurate or its no good.*

   CAUTION: Never use EMERY CLOTH on any part of a Synchro. Small particles of the emery stick in the metal and promote rapid wear.

FINDING TROUBLE IN A SYNCHRO SYSTEM

GENERAL HINTS

There are two important kinds of trouble that occur in Synchro systems:

Troubles That Occur in a New Installation or After Changes Have Been Made in an Old One:

These are almost always due to wrong wiring or to failure to set zero properly.

When trouble occurs on a new job:

1. Check all wiring to be sure it's right. Don't trust color coding, ring out all circuits with a battery and buzzer or a low-resistance ohmmeter. Tighten all terminals.

2. Set all units on electrical zero.

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Troubles That Occur After a System Has Been in Service for a While:

Study of a number of reports on troubles indicates that the following are most common:

1. Most Synchro wiring aboard ship passes through many switches. Opens, shorts, grounds, and all kinds of misconnections at these switches are a common source of trouble.

2. Heavy oil or water may leak into the Synchro housing from nearby equipment causing overheating, sluggish action and shorted windings.

3. Lugs on terminal boards often loosen up due to vibration, and cause intermittent open circuits.

4. Bearings sometimes rust due to inadequate rust-preventing lubrication. This usually causes jerky operation, overheating, and possibly a burnt out unit.

5. Windings occasionally become open or shorted due to vibration or corrosion.

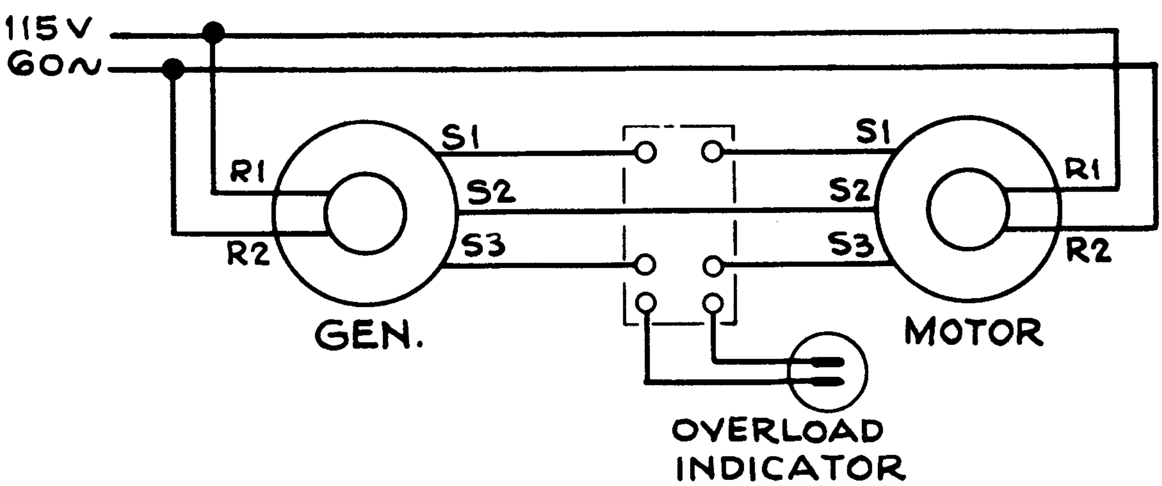
6. Laminations or windings occasionally get loose, causing mechanical hum and vibration.

7. Slip rings get worn and dirty and brushes don't make good contact, causing intermittent operation.

8. Synchro Motors sometimes oscillate or spin due to defective dampers or to short circuits.

SOME SYMPTOMS AND THEIR PROBABLE CAUSES

In many Synchro systems trouble can be most easily located by watching the action of the Motors, and checking a few other simple symptoms. The following tables apply specifically to one Synchro Generator connected directly to one Synchro Motor like this:



Similar symptoms will occur on a system involving a master Generator feeding a *number* of Motors. If the symptoms appear on *all of the Motors*, the trouble is in the Generator or main bus. If they appear on one Motor only, the trouble is in that Motor.

The particular angles mentioned in the tables will not apply to a system using Differentials, nor to a system on which the Motors are not correctly zeroed.

TROUBLE SHOOTING

IF UNITS HUM AND GET HOT, OVERLOAD INDICATOR LIGHTS, OR FUSES BLOW

First: Be sure the Motor is not jammed mechanically.

Then turn the Generator smoothly in one direction and see how the Motor acts:

IF:	IF:	IF:
Overload Indicator lights, and units hum *at all Generator Settings:*	Overload Indicator lights, and units hum at all Generator settings *except two opposite ones:*	Overload Indicator lights, and units hum only occasionally, at two opposite Generator settings.
One unit gets hot.	Both units get hot.	Both units get warm.
Motor follows smoothly in the right direction, but reads wrong.	Motor stays on one reading half the time, then swings abruptly to the opposite one. May oscillate or spin.	Motor turns smoothly in one direction, then reverses and turns the other way.
ROTOR CIRCUIT IS OPEN OR SHORTED.	STATOR CIRCUIT IS SHORTED.	STATOR CIRCUIT IS OPEN.
See Table A	See Table B	See Table C

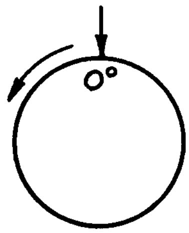
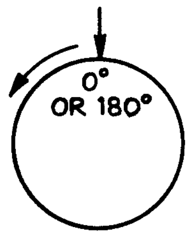
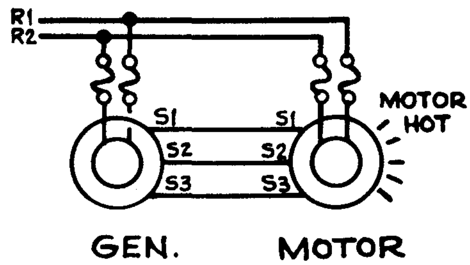
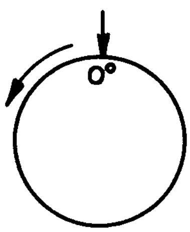
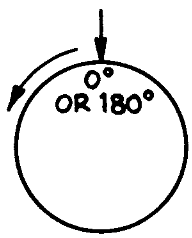
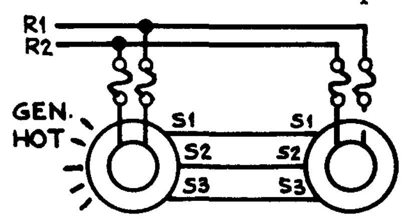
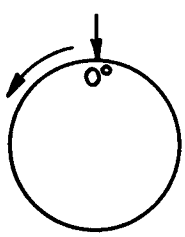
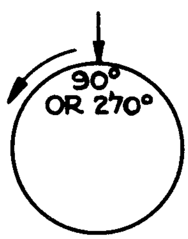
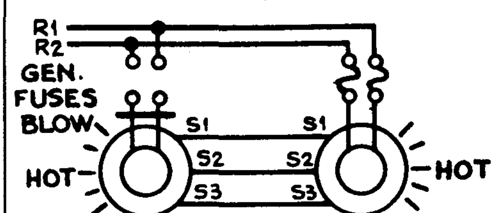
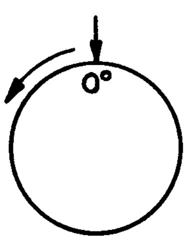
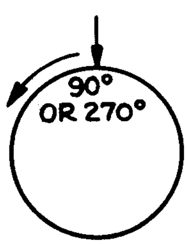
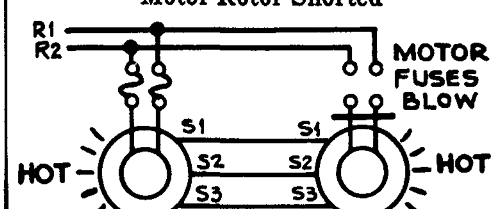
IF UNITS DO NOT OVERLOAD OR GET HOT, BUT MOTOR READS WRONG OR TURNS BACKWARD, FOLLOWING THE GENERATOR SMOOTHLY:

THE WIRING BETWEEN THE ROTORS OR THE STATORS IS MIXED UP, OR UNITS ARE NOT ZEROED.

See Tables D and E

TABLE A
ROTORS OPEN OR SHORTED

GENERAL SYMPTOMS: Overload Indicator lights and units hum at all Generator settings. One gets hotter. Motor follows OK, but may read wrong.

PARTICULAR SYMPTOMS		TROUBLE
When Generator is set on 0° and then turned as shown:	*Motor acts like this:*	
	 Sloppy	Generator Rotor Circuit Open 
	 Sloppy	Motor Rotor Circuit Open 
	 Torque about normal	Generator Rotor Shorted 
	 Torque about normal	Motor Rotor Shorted 

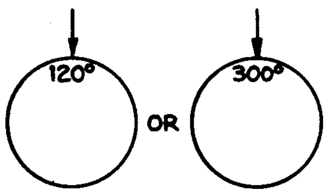
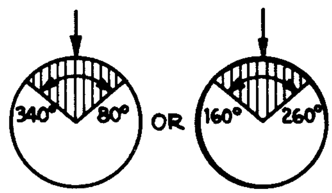
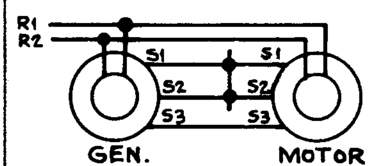
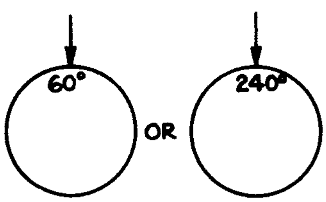
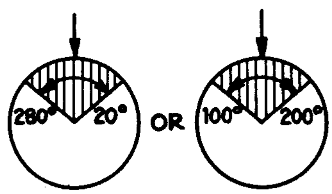
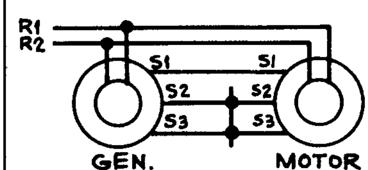
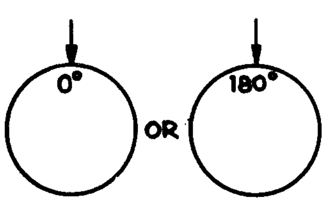
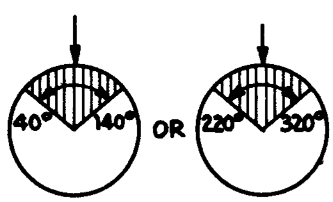
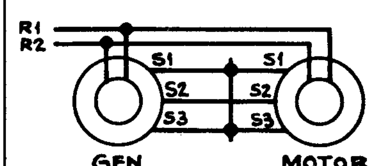
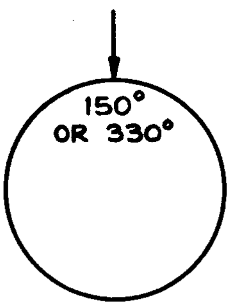
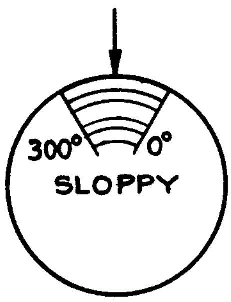
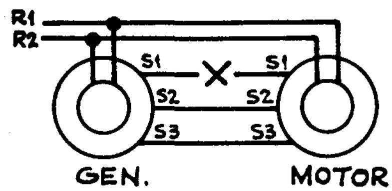
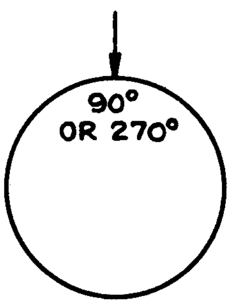
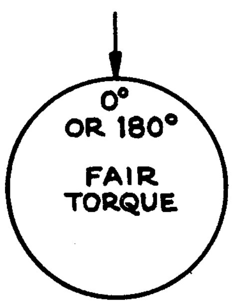
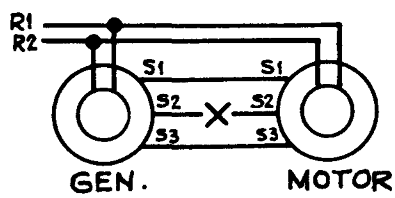
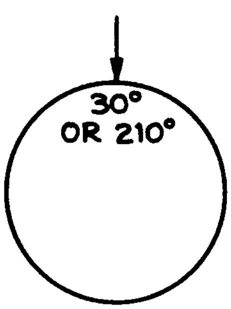
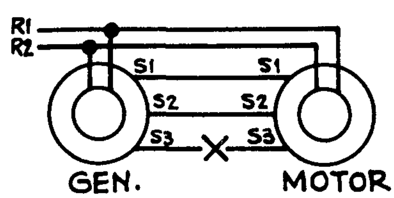
<table>
<tr><th colspan="3">TABLE B
STATOR CIRCUIT SHORTED</th></tr>
<tr><td colspan="3">GENERAL SYMPTOMS: Overload Indicator lights, units hum and get hot at all Generator settings except two opposite ones. Motor stays at one reading all the time, or flops between two opposite readings. It may oscillate violently or spin.</td></tr>
<tr><th colspan="2">PARTICULAR SYMPTOMS</th><th rowspan="2">TROUBLE</th></tr>
<tr><th>Overload goes out and Motor reads right when Generator is on:</th><th>Overload lights, units hum and get hot when Generator is between:</th></tr>
<tr><td>
</td><td>
</td><td rowspan="2">Shorted from S1 to S2

</td></tr>
<tr><td colspan="2">Motor stays on 120° or 300°, may flop suddenly from one to the other.</td></tr>
<tr><td>
</td><td>
</td><td rowspan="2">Shorted from S2 to S3

</td></tr>
<tr><td colspan="2">Motor stays on 60° or 240°, may flop suddenly from one to the other.</td></tr>
<tr><td>
</td><td>
</td><td rowspan="2">Shorted from S1 to S3

</td></tr>
<tr><td colspan="2">Motor stays on 0° or 180°, may flop suddenly from one to the other.</td></tr>
<tr><td colspan="2">Both units get very hot and hum. Indicator lights all the time. Motor doesn't follow at all or spins.</td><td>ALL THREE STATOR LEADS SHORTED TOGETHER</td></tr>
</table>

TABLE C
STATOR CIRCUIT OPEN

GENERAL SYMPTOMS: Overload Indicator lights and units hum only occasionally, at two opposite Generator settings. Motor follows fairly well in one direction, then stalls at a particular reading, or reverses and turns fairly well the other way.

PARTICULAR SYMPTOMS		TROUBLE
Motor reverses or stalls, lighting Indicator, when Generator is on:	*Motor acts like this when Generator is held on 0°:*	
		Open S1 
		Open S2 
		Open S3 
Motor doesn't follow. There is no overload. Nothing gets hot or hums.		TWO OR THREE STATOR LEADS ARE OPEN (or both Rotor circuits are open)

TROUBLE SHOOTING

TABLE D
STATOR WIRING MIXED UP. ROTOR WIRING OK.

GENERAL SYMPTOMS: Motor reads wrong or turns backward, but has normal torque. There is no overload. Nothing gets hot.

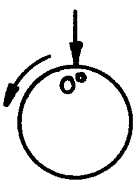
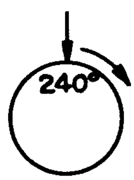
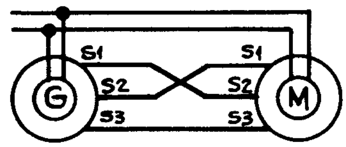
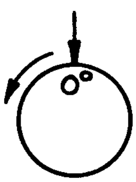
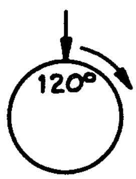
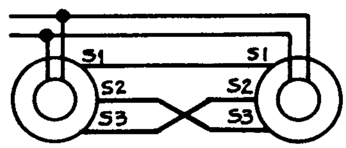
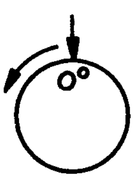
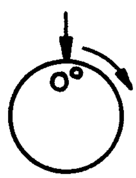
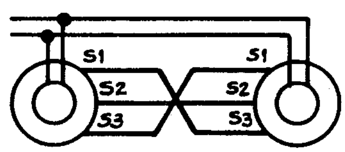
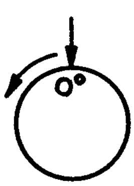
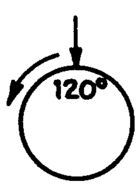
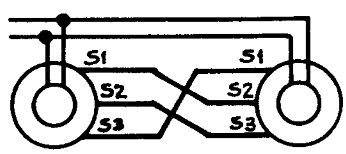
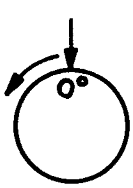
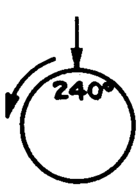
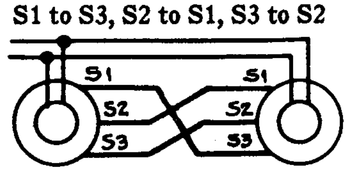
PARTICULAR SYMPTOMS		TROUBLE
When Generator is set on 0° and turned like this:	*Motor reads wrong and turns like this:*	
		S1-S2 Reversed 
		S2-S3 Reversed 
		S1-S3 Reversed 
		S1 to S2, S2 to S3, S3 to S1 
		S1 to S3, S2 to S1, S3 to S2 

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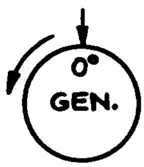
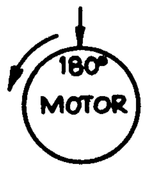
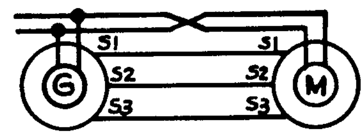
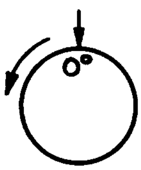
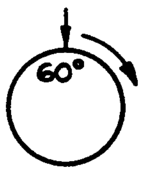
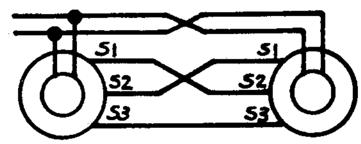
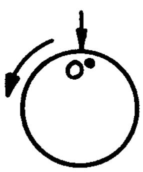
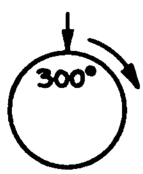
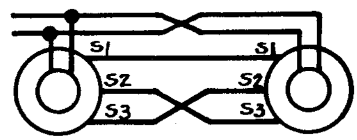
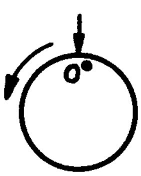
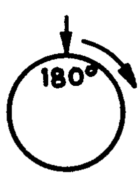
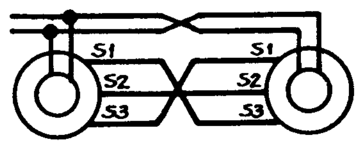
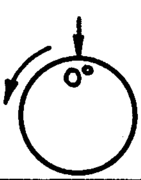
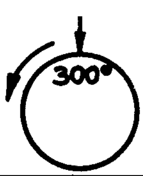
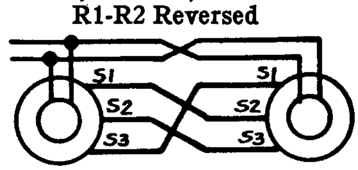
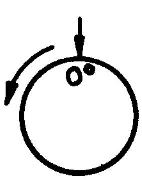
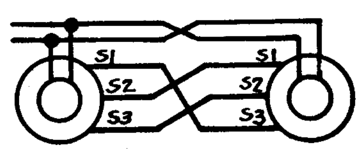
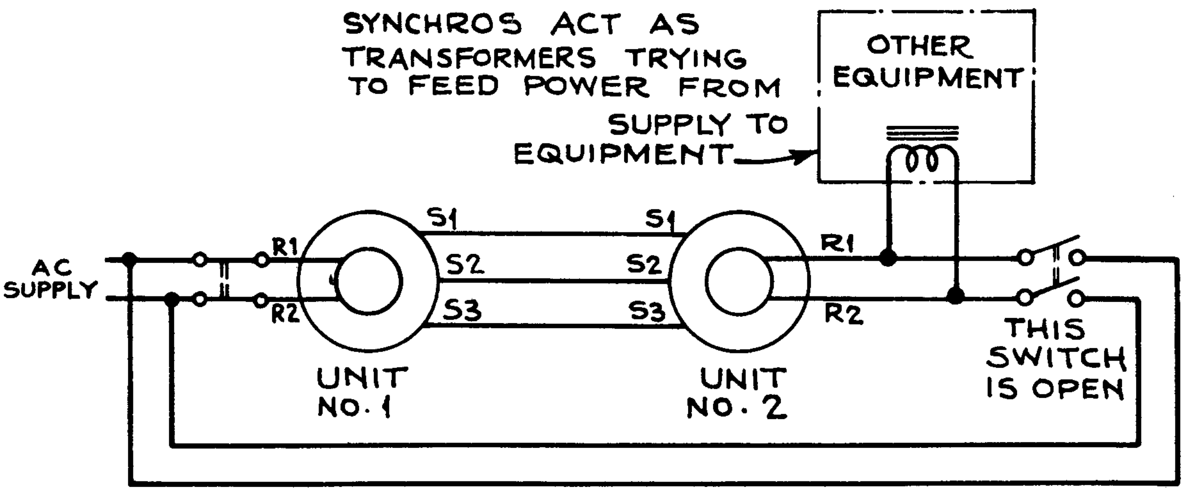
TABLE E
STATOR WIRING MIXED UP AND ROTOR WIRING REVERSED

GENERAL SYMPTOMS: Motor reads wrong or turns backward, but has normal torque. There is no overload. Nothing gets hot.

PARTICULAR SYMPTOMS:		TROUBLE
When Generator is set on 0° and turned like this:	*Motor reads wrong and turns like this:*	
		S leads OK. R1-R2 Reversed 
		S1-S2 Reversed and R1-R2 Reversed 
		S2-S3 Reversed and R1-R2 Reversed 
		S1-S3 Reversed and R1-R2 Reversed 
		S1 to S2, S2 to S3, S3 to S1 and R1-R2 Reversed 
		S1 to S3, S2 to S1, S3 to S2 and R1-R2 Reversed 

MISCELLANEOUS SYMPTOMS

1. If a Synchro system shows all the symptoms of a shorted rotor when it is turned ON, but everything checks OK when it is turned OFF: Suspect this trouble:

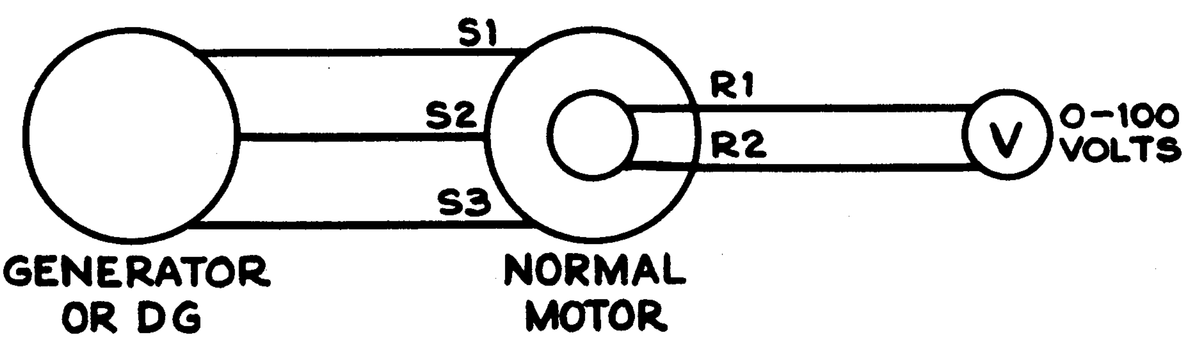


The rotor of unit No. 2 is connected in parallel with other electrical equipment (power supplies, etc.) and both are normally fed from the AC supply through switch No. 2. If this switch is opened while switch No. 1 is still closed, the equipment connected across No. 2 rotor acts as a partial short, causing overheating of both units.

2. If a Synchro shows all the symptoms of an open rotor at some settings, but is normal at others, suspect bad slip rings.

TO CHECK THE VOLTAGE BALANCE ON THE OUTPUT OF A GENERATOR OR DG:

Connect a good Motor whose shaft is free to turn, like this:



If the output voltages are correctly balanced the voltmeter will read a constant voltage which won't vary more than a volt or so as the shaft of the Generator (or DG) is turned all the way around. Any variation in the voltmeter reading indicates an unbalance due possibly to a defective Synchro Capacitor, or to leakage between two of the three wires.

CAUTION: This connection causes excessive currents to flow in this Motor and in the circuit to which it is connected. Do not leave it connected any longer than is necessary to complete the test.

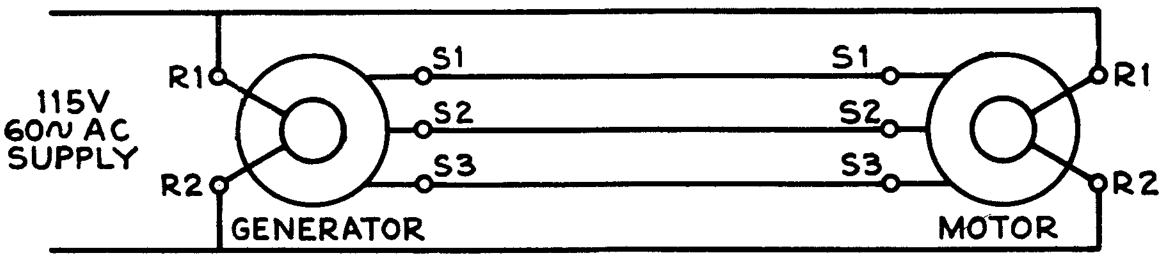
TROUBLE SHOOTING WITH AN AC VOLTMETER

In many Synchro systems it is difficult or impossible to observe the behavior of the Motor's shaft when the Generator turns. A good way to shoot trouble on such a system is to measure the stator and rotor voltages. Since the proper operation of the system depends on the proper variation of these voltages, any unusual voltage condition indicates trouble.

As an aid in learning to apply this method of trouble-shooting the following table has been made up for a simple combination of Synchro units. The exact voltage values indicated hold only for the particular combination and unit sizes shown, but will serve to show the effects to be expected.

TROUBLE SHOOTING WITH AN AC VOLTMETER

In a system consisting of a Generator connected to a Motor like this:



The voltages at various points should read as follows: (numbers in parentheses refer to Generator settings at which these voltages occur.)

Voltage Between:	*Under Normal Conditions*
S1 — S2	Varies from 0 (at 120° and 300°) to 90 volts (at 30° and 210°).
S2 — S3	Varies from 0 (at 60° and 240°) to 90 volts (at 150° and 330°).
S1 — S3	Varies from 0 (at 0° and 180°) to 90 volts (at 90° and 270°).
R1 — R2	On both Generator and Motor, is constant at 115 volts.

Any trouble except an open in the stator circuit will cause one or more of the voltages to be wrong, as follows:

Symptoms	*Trouble*
IF: Voltage between one pair of S leads is 0 for all Gen. positions. Voltage between other pairs of S leads varies from 0 to 78 volts. R1—R2 voltages are both 115 volts.	**S LEADS ARE SHORTED** (where 0 volts is read at all positions)
IF: S voltages vary from 0 to 55 volts, R1—R2 voltage on one unit is 115 volts, on the other unit is 0 volts.	**R LEADS ARE SHORTED** (on unit where 0 volts is read)
IF: S voltages vary from 0 to 75 volts, R voltage is 115 volts on both units.	**ONE ROTOR IS OPEN INTERNALLY** (see below)
IF: S voltages vary from 0 to 80 volts, R voltage is 115 volts on one unit and 90 volts on the other.	**ROTOR SUPPLY LEADS ARE OPEN** (on unit reading 90 volts)

To Check for Open Windings: Disconnect Stator Leads on suspected unit and read the voltage between them:	
IF: **All** Stator voltages are 0, and Rotor voltage is 115 volts.	**ROTOR IS OPEN**
IF: One S voltage is normal, other two are 0. (The lead that is common to the two connections that read 0 is open.)	**STATOR IS OPEN**

OSCILLATION AND SPINNING IN SYNCHRO SYSTEMS

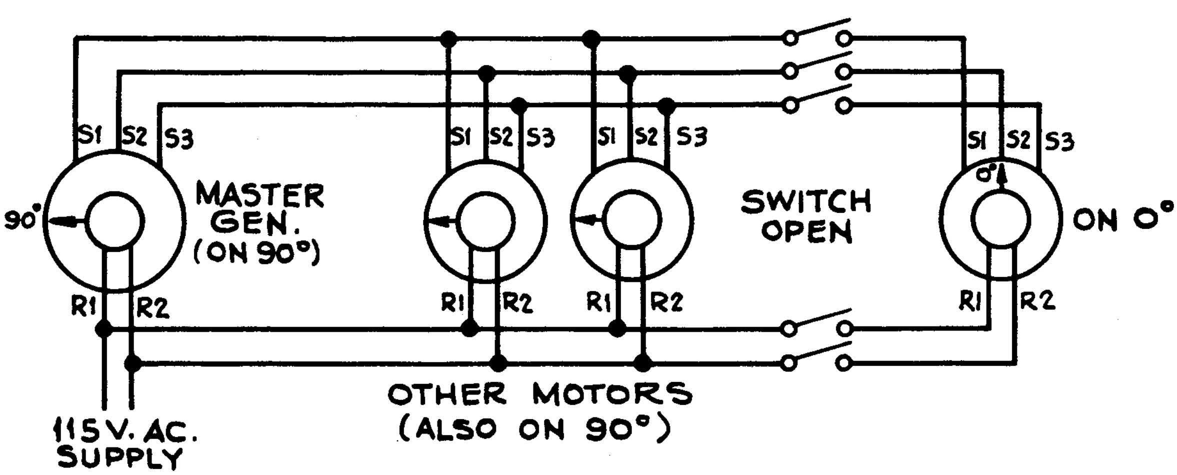
Oscillation (rapid swinging back and forth) and spinning of Synchro Motors is a fairly common type of trouble, particularly on systems involving a great many Motors. There are two important causes for this trouble, with decidedly different symptoms:

1. **Oscillations Caused by Switching** show up as small, rapid variations in position which last for a few seconds, then die away. This effect shows up on all the Motors in a system whenever a switch is thrown connecting to the system a Motor which is far off position. This type of oscillation is normal, that is, there isn't much that can be done about it in most cases.

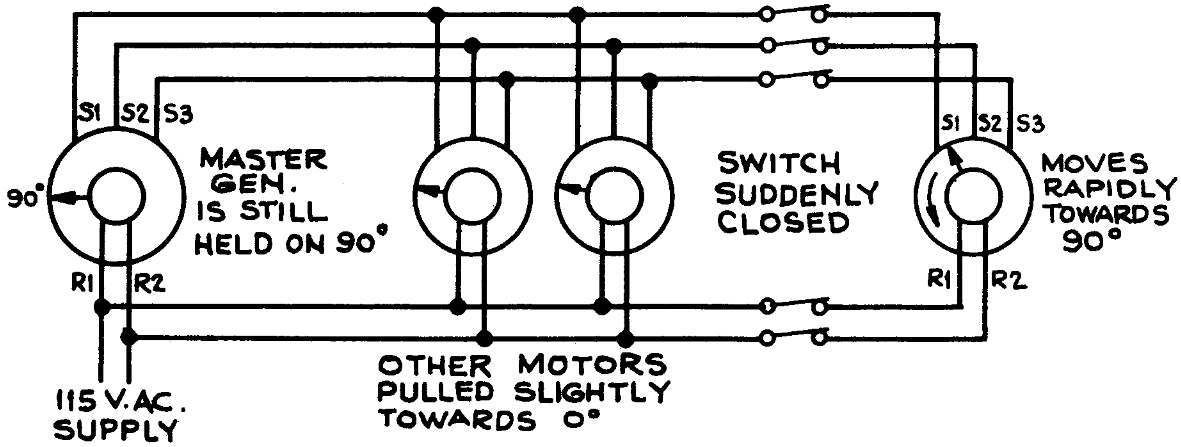
2. **Oscillations or Spinning Caused by a Defective Synchro or Short Circuits** show up as a very violent effect which may be started by a switching operation, but which does not die away. If one unit is defective, the effect will generally be much more pronounced on that unit. This type of oscillation indicates serious trouble.

OSCILLATIONS CAUSED BY SWITCHING

The Cause of Switching Oscillations: To understand why these occur, consider what happens when a Synchro Motor is suddenly connected to a system consisting of a Generator and a number of other Motors. Suppose for example, that before the switch is closed, the one Motor is at 0° while the rest of the system is at 90°, like this:

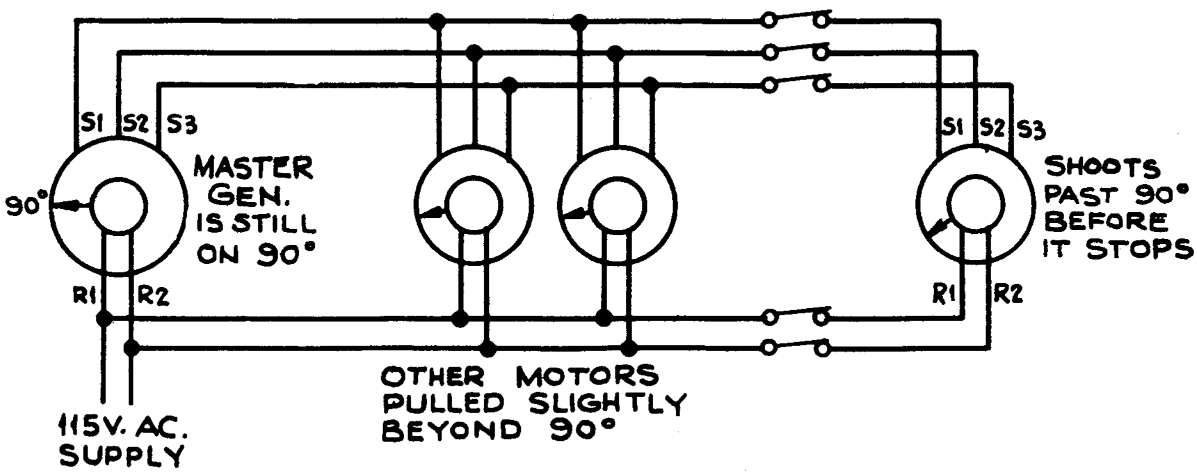


At the instant the switch is thrown the voltages induced in the Motor's stator coils are very different from the applied voltages, so strong currents flow in these coils. These strong currents produce a strong torque, turning the Motor's shaft suddenly towards 90°.



At the same time these currents change the voltages on the stator wires in such a way that all the other Motors turn slightly towards 0°. (How far they turn depends on the size of the Generator and how many Motors there are.)

When the Motor that was switched in gets to 90°, the voltages are balanced and the stator currents are reduced to zero. At this time there is no torque acting on this Motor's shaft. However, it has gotten up some speed and it keeps on going, shooting past 90° to some position beyond it. This pulls all the rest of the Motors slightly out of position in that direction, like this:



When enough torque builds up to stop the Motor, it turns around and comes back toward 90° again, shooting past a little slower this time. This operation is repeated several times, the whole system settling down on 90° again two or three seconds after the switch was closed.

The fact that the torque on the Motor is always reduced to zero just as it gets to the correct position tends to make the whole situation worse, since the Motor has to go *past* the right point before forces act to slow it down. This is a weakness of the Synchro type of machine.

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OSCILLATIONS AND SPINNING

The Correction of Switching Oscillations: Although nothing much can be done about it when this trouble shows up *after* installation, care in planning *before* installation will minimize it. The following factors should be considered:

1. Any Motor which is normally switched into a system should be the smallest size unit that will operate with sufficient accuracy in that position. A smaller Motor draws less current and causes less disturbance when switched in.

2. Anything mounted on the shaft of such a Motor should be as light and as small in diameter as is possible. Anything that increases the inertia of the rotor makes the oscillation worse.

3. The Generator should be plenty big enough to handle the number of Motors attached to it so that these disturbances do not change its output voltages too much. For the same reason long runs of small wire should be avoided.

4. Overload Indicators or other devices that are connected in series with the Generator's stator leads will tend to make these effects worse.

5. In cases where a Differential unit with a Capacitor across it stator leads is switched into the system, the Capacitor may aggravate the disturbance caused, since it draws a heavy initial charging current if the switch is closed at just the wrong point in the cycle of the AC voltage.

OSCILLATIONS OR SPINNING CAUSED BY A DEFECTIVE SYNCHRO OR SHORT CIRCUIT

IF: **Switching or sudden changes in position start spinning or oscillations that don't die away,** and the trouble shows up much more on one Motor in the system than it does on the others:

THE DAMPER ON THAT MOTOR IS BAD (or a Generator was installed by mistake). Replace the Motor with one from spares, and send it in for repair.

IF: **All the Motors on the system oscillate or spin equally hard.**

TWO OR POSSIBLY ALL THREE STATOR LEADS ARE SHORTED TOGETHER.

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INTERIOR COMMUNICATION SELF-SYNCHRONOUS TRANSMITTER-GENERATORS AND INDICATOR MOTORS

The following section is concerned with another type of self-synchronous unit which is widely used on Naval vessels for Interior Communications (Engine Order Telegraph, Steering Telegraph, Rudder Indicator, and so on).

Although these units operate on the same general principles as Synchros, and while they are not the same, they are similar, and their differences should be understood before any of the preceding information in this book is applied to them.

GENERAL DESCRIPTION

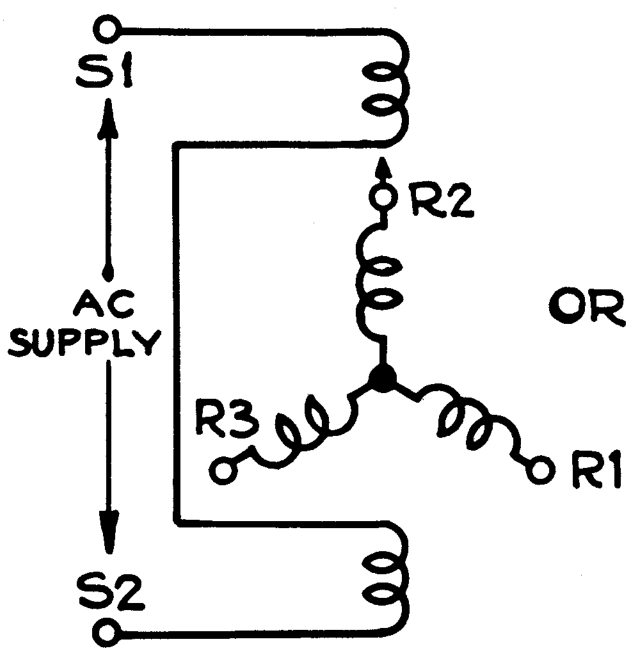
These units are manufactured for the Bureau of Ships according to the Supplementary General Specifications for Machinery — SGS(65)-42a dated 15 February 1937, by two concerns: The Henschel Corporation, and the Bendix Aviation Corporation. Henschel's trade name for the units is "Teleindicators" and Bendix's is "Autosyns."

These units come in the following types and sizes:

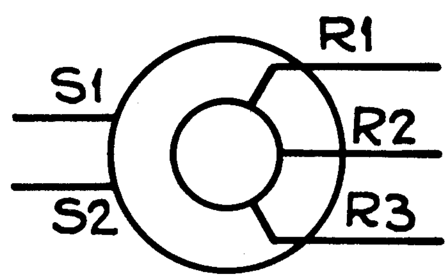
Type	Capacity	Approximate Synchro Equivalent
Type "A" Transmitter Generator	6 Type "M"s	5G Generator
Type "B" Transmitter Generator	12 Type "M"s	6G Generator
Type "M" Indicator Motor		5F Motor
Type "N" Indicator Motor		1F Motor

ELECTRICAL CONSTRUCTION

The *primary* (two-wire winding) of I.C. Generators and Motors is mounted physically on the *stator,* and the *secondary* (three-wire winding) is mounted on the *rotor.* Thus a diagram for these units similar to the one that was used to explain the operation of Synchro units, looks like this:



OR

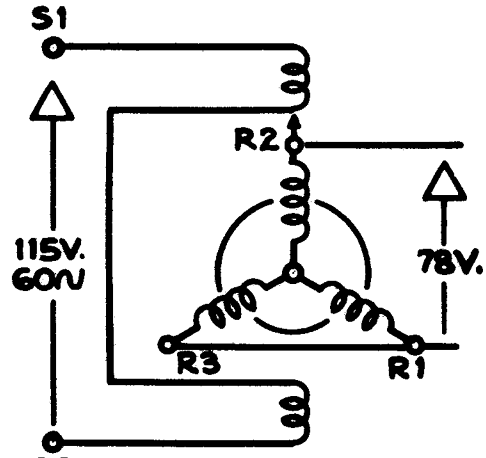


VOLTAGE RATINGS

The voltage ratings on the IC units are the same as on Synchros, that is, with 115 volts, 60 cycles AC applied to the two stator leads, a maximum of 90 volts is produced between any two rotor leads.

DIRECTION OF ROTATION

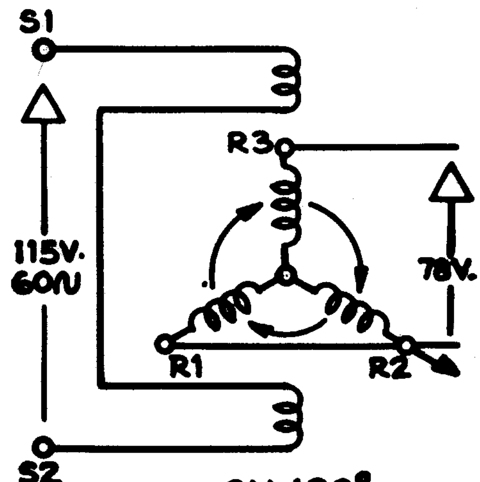
The "Electrical Zero" position on these units is defined (very much like the Synchro) as the position where rotor coil 2 lines up with the stator coils. To turn an Indicator Motor to Electrical Zero, 115 volts is applied to the stator, and 78 volts to the rotor as shown:



ON 0°

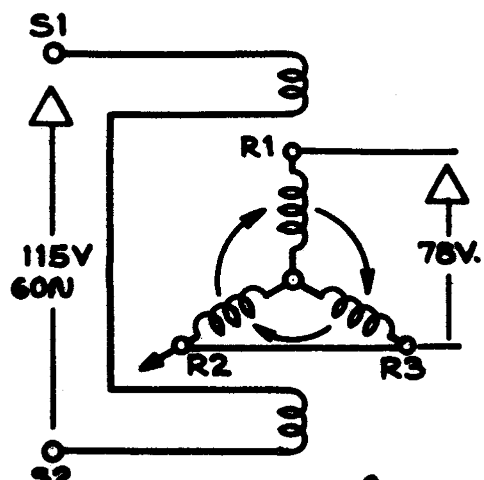
Now if R1 and R2 are shorted together, and 78 volts applied between them and R3, the rotor turns *clockwise* 120° like this:

(If 78 volts is applied in a similar manner between S1-S2 and S3 on a *Synchro,* the rotor would turn *counter-clockwise* 120°.)



ON 120°

If R2 and R3 are shorted and 78 volts applied like this the rotor turns another 120°:



ON 240°

Gene Slover's US Navy Pages
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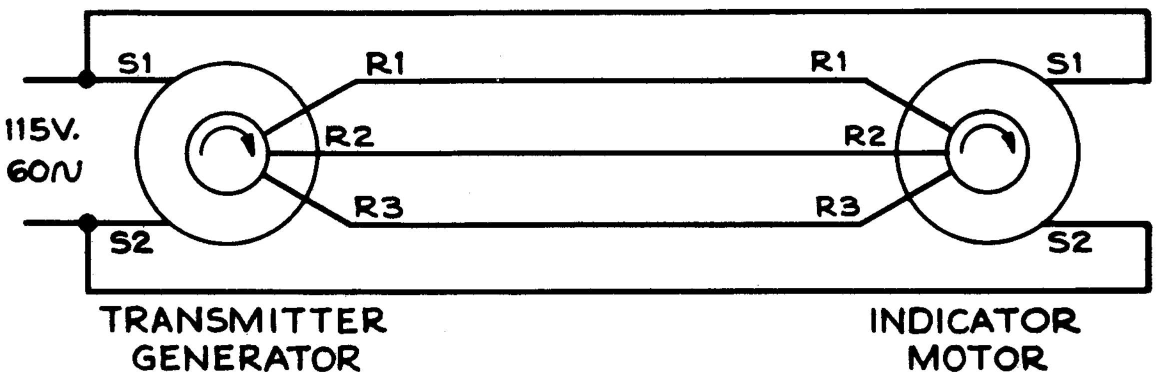
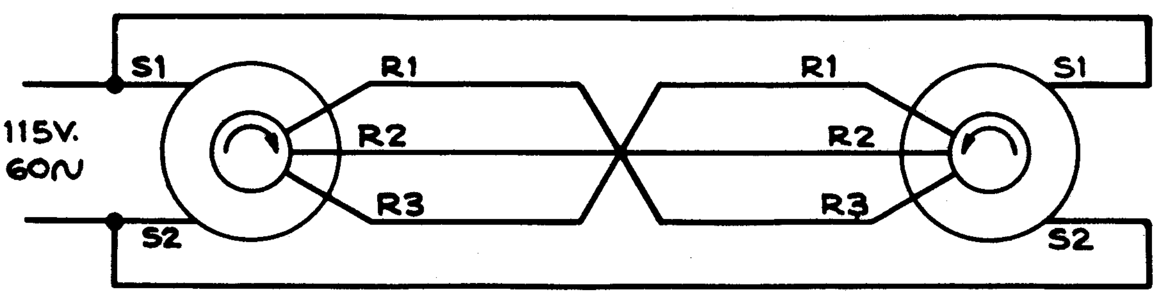
If three voltages which vary in a manner corresponding to an increasing reading in a Synchro system are applied to the R leads of an IC Motor, the shaft turns *clockwise* (looking at the projecting end), instead of counter-clockwise (as a Synchro's shaft does).

This isn't of much importance in connection with a normally-operating system. When a Transmitter Generator is connected directly to an Indicator Motor like this:



The shaft of the Motor will turn in the same direction when the shaft of the Generator is turned. To reverse the rotation of the Motor, cross the R1 and R3 leads like this:



(Note: There is one exception to this: The internal connections of the Bendix type "N" unit [CAL-4400-1] are so arranged that, when used with a type "A" or "B" Transmitter Generator, S1-S3 must be *crossed* for the *same* rotation, and *connected directly* for the *opposite* rotation.)

ELECTRICAL ZERO SETTING

(Read through the section on "Zeroing Synchros" (pp 111-117) for additional information.)

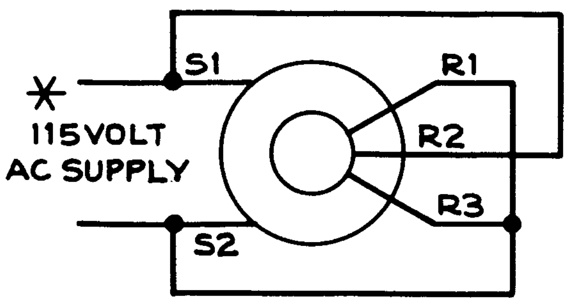
When an Indicator Motor or a Transmitter is removed from an instrument and then replaced, it must be zeroed as described below.

The "zero reading" (scale reading when the shaft is at electrical zero) for various instruments which use these units is as follows: (These apply in most cases, but there may be exceptions. See the Instruction Book for the particular equipment to be sure.)

Application	Zero Reading or Position
Engine Order Telegraph	Center of STOP Order
Steering Telegraph	0
Rudder Indicator	0
Propeller Revolution Telegraph	0
Propeller Revolution Indicator	See I.B. Not at 0 because of limit switch.
Underwater Log	0
Wind Direction and Intensity	0

TO ZERO AN INDICATOR MOTOR

After the unit has been mounted in place, disconnect all external connections from its leads, and connect like this:



The shaft will turn definitely to the electrical zero position. Loosen the shaft coupling (or the clamps on the stator) and turn one or the other until the pointer shows the "Zero reading" (see above). Tighten in this position, and reconnect normally.

*DON'T leave a Motor connected this way any longer than is necessary to zero it, as it will eventually overheat and perhaps burn out.

TO ZERO A TRANSMITTER GENERATOR

Mount the Generator in place and set the unit whose position it transmits, in the Zero position (see above), then proceed as follows:

If the Generator's Shaft Coupling can be Loosened:

Loosen it, disconnect all external leads, and connect the Generator as shown for zeroing a Motor. While the shaft is held in the zero position, tighten the shaft coupling again, then reconnect normally.

If the Generator's Shaft Coupling cannot be Loosened:

Method A:

The simplest procedure is First: Accurately Zero some Motor in the system as described above. Second: Adjust the position of the Generator's stator (or the linkage connecting its shaft to the associated equipment) until that Motor shows the Zero reading.

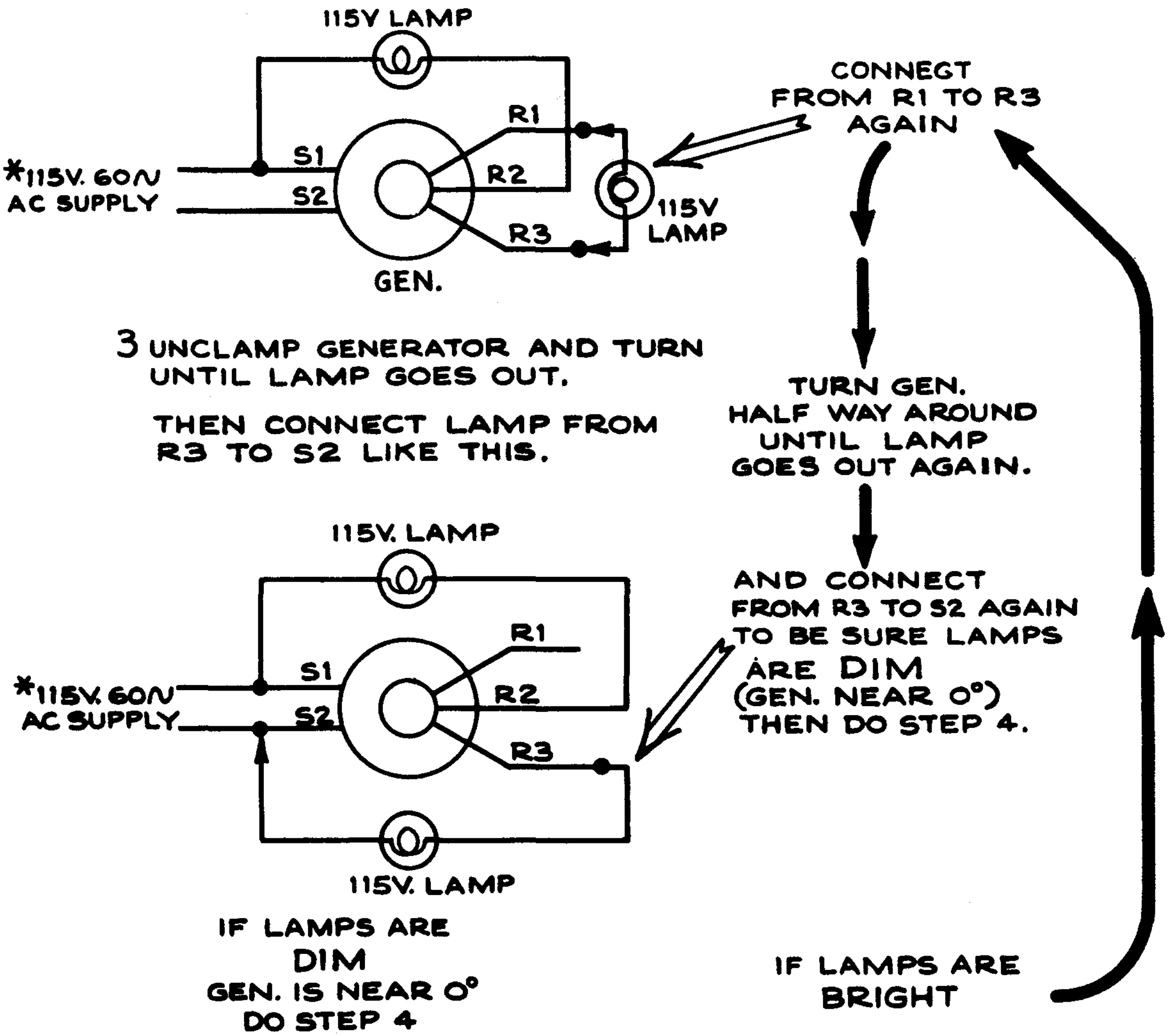
I. C. UNITS—ZEROING

Method B:

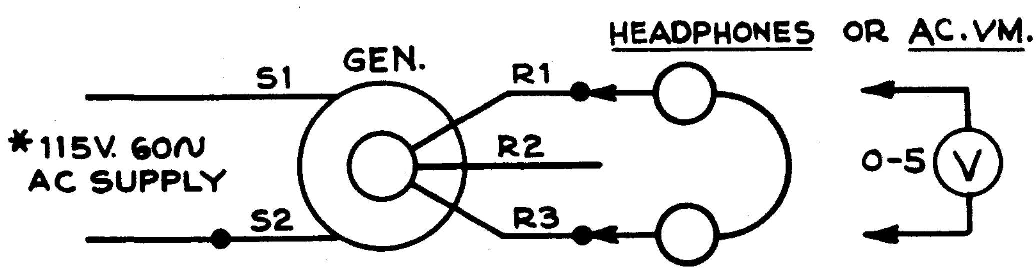
If Method A isn't practical, proceed as follows, using a couple of small 115 volt lamps (the 6 watt size is convenient) and a pair of headphones (or a low scale AC voltmeter):

1. Set the unit whose position the Transmitter Generator transmits, accurately in its Zero position.

2. Remove all connections from the rotor leads, and connect like this:



4. Connect the headphones or voltmeter like this:



Turn the Generator carefully until you get minimum sound or voltage and clamp it in this position. Reconnect the rotor leads normally.

TROUBLE SHOOTING

The Trouble-shooting information for Synchros (see pages 127 to 137) may be applied to IC systems if the following changes are made:

Where	the	book	shows	"rotor"	substitute	"stator."
"	"	"	"	"stator"	"	"rotor."
"	"	"	"	R1	"	S1.
"	"	"	"	R2	"	S2.
"	"	"	"	S1	"	R3.
"	"	"	"	S2	"	R2.
"	"	"	"	S3	"	R1.

In addition the following hints may be helpful:

IF INDICATOR FOLLOWS BUT READS WRONG

1. Be sure all units are correctly zeroed.
2. Ring out inter-connections to be sure they're O.K.
3. If it is sometimes correct, sometimes 180° out, suspect an open in the Motor's or Generator's stator circuit.
4. If Indicator follows correctly for certain Generator positions, but is sloppy and oscillates around for other positions, suspect an open in the rotor circuit.
5. If fuses are blown and Indicator reads 90° off, suspect a shorted stator circuit.
6. If one unit of a multiple system is jammed, the rest read wrong.

IF INDICATOR DOESN'T FOLLOW WHEN GENERATOR IS TURNED

1. Turn the Indicator by hand to be sure it isn't jammed. (Other Indicators on the same system will read wrong if it is.)
2. 115 volt supply on *both* stators may be open.
3. Two rotor connections may be open.
4. There may be a short between two rotor leads. In this case all the Indicators in the system are held on some multiple of 60° (60°, 180°, 240°, etc.)

IF INDICATOR SWINGS VIOLENTLY BACK AND FORTH OR SPINS

(This is usually started by sudden position changes or switching operations, see pp. 137 to 139, inc.)

Stop it by hand:

1. If it then follows correctly and reads right until it gets a sudden shock which starts it spinning or oscillating again, the damper mounted on its shaft is not working properly, remove and repair.
2. If it then locks in at a certain position and holds there regardless of Generator position, two rotor leads are shorted together (damper is probably bad too).
3. If it shows no tendency to lock in nor to follow, just spins again, all three rotor leads are probably shorted together.

MAINTENANCE

The maintenance procedure on these units is quite different from that followed on Synchros. They may be taken apart, if necessary, by a qualified technician on shipboard. Rotor assemblies are carried in spares if needed. Before taking a unit apart, read through the instructions for Synchro repairmen (page 125), the same care should be exercised with these units.

CLEANING BRUSHES OR SLIP RINGS

When there is trouble in the rotor circuit remove the cover over the brushes (the *nameplate* on Henschel machines) and inspect the brushes and slip rings. If they are corroded or dirty, remove the brushes and clean off brushes and slip rings. Use a clean, lint-free cloth or chamois. In bad cases of corrosion or pitting, very fine sandpaper may be used lightly on the slip rings.

OILING OR REPLACING A ROTOR

If a unit needs oiling, or a new rotor, it is necessary to take it apart. First remove the brushes, and the screws that hold the unit together. Then pull it apart carefully and remove the rotor. Inspect the ball bearings to be sure they are in good condition, and replace them from spares if necessary. If new bearings are used clean off the thick vaseline used to prevent rust before installing them.

If oil is needed, apply one drop at the top of each ball, (or less if balls are oily). Use a high grade light oil as recommended by the manufacturer, or, if you can't get this use Standard Oil Company of New Jersey "Univis No. 48," or watch oil.

When replacing a bearing in the front end frame, don't disturb the shims. Four shims are usually needed, allowing an end play of .01 to .015 inches.

Inspect the oscillation damper. Clean it thoroughly and cover the rubbing surfaces with a light film of vaseline before assembling the unit.

CHARACTERISTICS OF BUREAU OF SHIPS SELF-SYNCHRONOUS UNITS

The following tables show the important characteristics of current types of these units, and, for comparison, of the equivalent Synchros.

5 SIZE UNITS

Characteristics (Dimensions are in inches)	Requirements of BuShips specifications Types "A" and "M"①	Bendix CAL-3075, CAL-3076	Bendix CAL-3075-1, 3075-2, 3076-1, 3076-2	Henschel 15-001, 15-002, 15-014, 15-015, 15-030③	Henschel 15-021	Requirement of Bu-ORD specifications, types 5F and 5G②
Diameter of mounting:						
Face-shaft end		1.500	1.500	1.875	1.875	1.63
Outside flange diameter	3.625	3.625	3.625	3.625	3.625	3.625
Outside shell diameter	3.39	3.375	3.375	3.39	3.23	3.39
Shaft diameter and description	0.25	0.25	0.3125	0.25 No. 4-48 tap through 1/4" from end.	0.3125 No. 6-40 tap through 1/4" from end and keyway 3/8 x 1/16 x 1/32.	0.25, threaded on end-1/4"-28-NF3 .247 diameter.
Over-all length to end of shaft	6.05	6.04	6.04	6.05	6.05	6.05
End of shaft to first flange	2.02	2.03	2.03	2.02	2.02	2.02
Width of flange	0.25	0.25	0.25	0.25	0.25	0.25
Distance between flanges (center to center)	2.06	2.06	2.06	2.06	2.06	2.07
Secondary voltage	None	90	90	90	90	90
Rotation for 1-2-3 connection-shaft end	None	CW	CW	CW	CW	CCW
Primary supply	115 volts, 60 cycles	115 volts, 60 cycles	115 volts, 60 cycles	115 volts, 60 cycles	115 volts, 60 cycles	115 volts, 60 cycles

Notes: ① Supplementary General Specifications for Machinery (BuEng) SGS/(65) 42a dated 15 Feb. 1937.

② Specifications for Synchro Transmitter Units and Systems. (BuOrd) O.S. No. 671 (Revision D) dated 1 Feb. 1941.

③ The Henschel 15-030 and 15-021 are the only units of this size currently being supplied. The 15-030 is labeled type A-SR (Transmitter Generator) or type M-SR (Indicator Motor). (The "SR" stands for "Special Replacement.") It is essentially a type 15-021 unit with a small shaft and a shim fitted between flanges to make it suitable for use as a replacement for the older type Henschel units (15-001, 15-002, 15-014, and 15-015).

Henschel 15-011 units are found on many converted vessels and are somewhat shorter than the 15-030 units, distances between mounting flanges being 1.750 inches and 2.060 inches. However, a complete 15-030 unit can always be used to replace a complete 15-011 unit.

Spare part items for special replacement units will be the same as for current Type A and Type M units and will not be interchangeable with spare parts originally furnished. This is illustrated by the summary of spare part numbers contained in Table on page 151.

1 SIZE GENERATORS

Characteristics (Dimensions are in inches)	Requirement of BuShips Specifications Type N①	Bendix CAL-4400-1③	Henschel 15-023	Requirement of BuOrd Specifications Type 1F②
Diameter of mounting:				
Face-shaft end.		{1.0625 / 1.250} 2 steps.	1.000	{1.0625 / 1.250} 2 steps
Outside flange diameter.	2.375	2.250	2.375	2.25
Outside shell diameter.	2.188	1.950	{2.188, 2.268 / two sec. of shell}	1.950
Shaft diameter and description.	0.125	0.156	0.1251	0.182 shaft tapered threaded on end No. 2-64 NF3 0.086 diameter.
Over-all length to end of shaft.	3.969	3.938	3.969	3.90
End of shaft to first flange.	1.063	2.192	1.063	2.14
Width of flange.	0.25	0.25	0.25	0.25
Distance between flanges (center to center).	1.196	Only one flange.	1.196	Only one flange.
Secondary voltage.	None	90	90	90
Rotation for 1-2-3 connection-shaft end.	None	CCW	CW	CCW
Primary supply.	115 volts, 60 cycles.	115 volts, 60 cycles.	115 volts, 60 cycles.	115 volts, 60 cycles.

Notes: ① Supplementary General Specifications for Machinery (BuEng) SGS/(65) 42a dated 15 Feb. 1937.

② Specifications for Synchro Transmitter Units and Systems. (BuOrd) O.S. No. 671 (Revision D) dated 1 Feb. 1941.

③ Notice that the Bendix Cal-4400-1 is identical, except for shaft size with a type 1F Synchro. When used with a type A or B Transmitter Generator S1 and S3 must be reversed for normal rotation.

6 SIZE GENERATORS

Characteristics (Dimensions are in inches)	Requirement of BuShips Specifications Type B①	Bendix CAL-3482	Henschel 15-022③	Requirement of BuOrd Specifications Type 6G②
Diameter of mounting:				
Face-shaft end	....	1.625	2.000	1.625
Outside flange diameter	4.50	4.50	4.50	4.50
Outside shell diameter	4.00	Approx. 4 (4.25 to step on flange)	4.00	4.08
Shaft diameter and description	0.35	0.350	0.350	0.35 shaft tapered threaded on end 1/4"-28 NF3 key-way 5/16 x 0.0937 x 3/32.
Over-all length to end of shaft	7.22	7.167	7.094	7.22
End of shaft to first flange	2.22	2.22	2.22	2.22
Width of flange	0.25	0.25	0.25	0.25
Distance between flanges (center to center)	2.50	2.50	2.50	2.50
Secondary voltage	None	90	90	90
Rotation for 1-2-3 connection-shaft end	None	CW	CW	CCW
Primary supply	115 volts, 60 cycles	115 volts, 60 cycles	115 volts, 60 cycles	115 volts, 60 cycles

Notes: ① Supplementary General Specifications for Machinery (BuEng) SGS/(65) 42a dated 15 Feb. 1937.

② Specifications for Synchro Transmitter Units and Systems. (BuOrd) O.S. No. 671 (Revision D) dated 1 Feb. 1941.

③ Will handle up to 18 Type "M" Indicator Motors without overload.

SUMMARY OF HENSCHEL SELF-SYNCHRONOUS UNIT SPARE PART NUMBERS

SPARE PART ITEMS	PART NO. FOR HENSCHEL 15-001 and 15-002	PART NO. FOR HENSCHEL 15-014 and 15-015	PART NO. FOR HENSCHEL 15-011	PART NO. FOR HENSCHEL 15-021 and SPECIAL REPLACEMENT UNITS—TYPE A-SR and M-SR (HENSCHEL 15-030)
Brushes	A-946	A-2495	A-2927	A-3817
Ball Bearings	New Departure No. 37	SAE No. 37 New Departure No. 37	Front—New Departure No. 37 Rear—New Departure—Cat. No. R-6	SAE No. 38 New Departure No. 38
Stator Coils	A-1343	A-2882	C-854	C-842
Rotor Assembly (Transmitter Generator)	C-191	C-671	C-813	A-3962
Rotor Assembly (Indicator Motor)	C-191 with Damper and Spring	C-671 with Damper and Spring	C-813 with Damper and Spring	A-3962 with Damper and Spring

THE INTERCHANGEABILITY OF BUSHIPS UNITS

REPLACING A BUSHIPS UNIT WITH ANOTHER TYPE BUSHIPS UNIT

Study of these tables will show that Bureau of Ships self-synchronous units of any given type are interchangeable for most applications as complete units mechanically and electrically regardless of manufacturer or date of manufacture with the following exceptions:

1. Henschel and Bendix Type N units are electrically interchangeable, but considerably different as to mounting dimensions.

2. Type A and M units are now supplied with 0.3125 inch diameter shafts instead of 0.250 inch diameter shafts. When adapting the new type units to instruments formerly equipped with the older type, the following should be noted:

3. Where a unit with a 0.250 inch diameter shaft was used in connection with a shaft extension or coupling with *thin cross section,* the best thing to do is to make a new extension or coupling to fit the new 0.3125 inch diameter shaft.

4. Where a unit with a 0.250 inch diameter shaft was used in connection with gears, hubs, clamping nuts, shaft extensions, couplings, pointer hubs, or arrow collars having *adequate cross section,* the simplest thing to do is to ream a larger hole to fit the larger shaft. Grinding the 0.3125 inch diameter shaft to 0.250 inch diameter is not recommended.

5. Some applications of Henschel 15-001 units require a 4-48 screw through the end of the shaft. Newer Henschel 15-021 units use a 6-40 screw. This applies particularly to the type A unit used in Pitometer Log Corporation, type B shaft revolution transmitters.

6. The variation in outside shell diameter for type A and M units as listed in the tables is not serious and does not affect interchangeability for most applications.

7. Adequate spares are normally provided for all Interior Communication units installed on naval vessels. It is good to know, however, that in an emergency Bureau of Ships units may be interchanged to the extent indicated in the table. Normally, Bureau of Ordnance Synchros should never be used to replace Bureau of Ships units.

REPLACING A BUSHIPS UNIT WITH A SYNCHRO

The possibilities of emergency replacement of a Bureau of Ships unit with the corresponding Bureau of Ordnance Synchro will be made clearer by noting the following differences:

1. Mounting dimensions as shown by the tables are essentially the same for Bureau of Ships units and corresponding Bureau of Ordnance Synchros, except for Henschel type N units.

2. Shaft diameters and methods of shaft coupling differ considerably as shown. Some form of adapter must be used in practically all cases.

3. Shaft rotation is opposite for Bureau of Ships units and Bureau of Ordnance Synchros. Also the primary is on the stator for Bureau of Ships units and on the rotor for Bureau of Ordnance Synchros. Bureau of Ships units and corresponding Bureau of Ordnance Synchros are electrically interchangeable provided terminals R1, R2, S1, S2, S3, respectively, of Bureau of Ordnance Synchros, are connected where terminals S1, S2, R3, R2, R1, respectively of Bureau of Ships units were.

4. Accuracy of Bureau of Ordnance Synchros is higher than for corresponding Bureau of Ships units.

5. Bureau of Ships units are equipped with terminal blocks and Bureau of Ordnance Synchros are not, but this does not affect interchangeability.

OBSOLETE TYPES

Obsolete types of Bureau of Ships units not covered by the tables are in general not interchangeable. Some of the more important variations include the following:

1. Bureau of Ships, types A, B, and M units furnished by Arma Corporation have a higher maximum secondary voltage (approximately 103 volts) and are, therefore, noninterchangeable electrically with other makes. A few special replacement units have been made up for specific vessels, but in most cases the original equipment has been completely replaced by new equipment.

2. General Electric units furnished to the Bureau of Ships are not interchangeable mechanically with other makes. A special stock has been set up at Navy Yard, Mare Island, to cover possible need for G.E. Model T-3637297 (Type A). G.E. Model T-51E130, T-51E130 (Type B), and G.E. Model T-3637295 (Type M).

3. Henschel units furnished prior to 1936 have a lower maximum secondary voltage (approximately 80 volts). They are interchangeable electrically with other makes, although some circulating current is produced by interconnection with units having 90-volt secondaries. Mounting dimensions are also different as illustrated by the following data:

Type	Henschel Plan	Shaft Diameter Inch	Flange Diameter Inches	Shell Diameter Inches	End of Shaft to 1st Flange Inches	Distance Between Flanges Inches
A	10-548-1	0.218	3.625	3.344	1.812	1.544
B	10-589	.312	4.500	4.000	2.188	1.969
M	10-548	.218	3.625	3.344	1.812	1.594

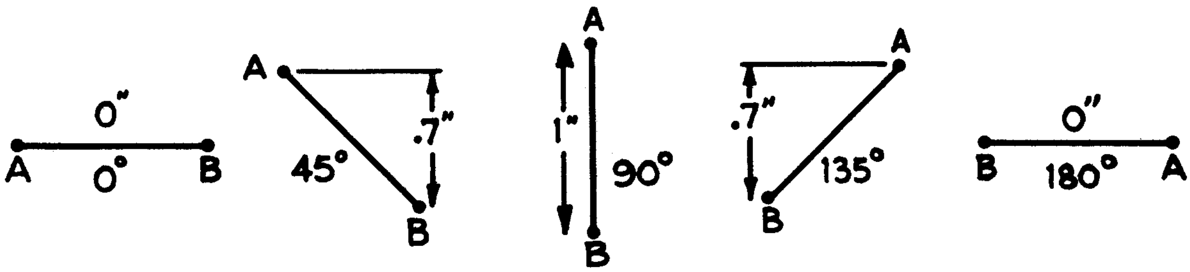
Diameter of mounting face on the shaft end (types A, B, and M) is 1.875 inches.

APPENDIX

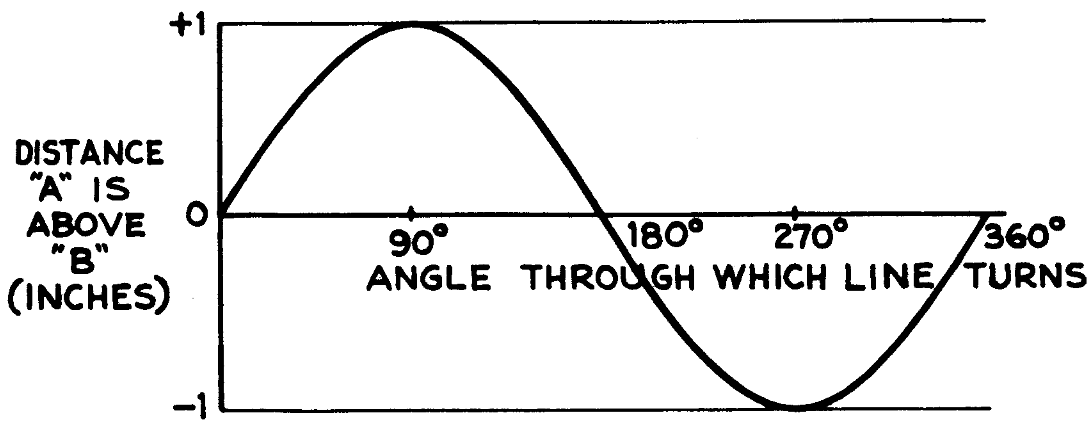
A GEOMETRICAL WAY OF SHOWING THE VOLTAGE RELATIONSHIPS IN A SYNCHRO SYSTEM

Here is a horizontal line one inch long printed on this paper: A ——— B

Consider what happens to the *vertical* distance between the ends of this line if it is turned around its center point like this:



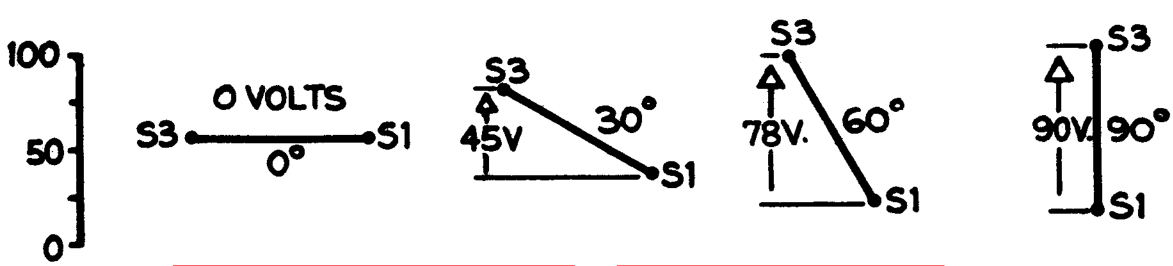
When the line is horizontal, point A is on the same level as point B, so the vertical distance between them is 0 inches. When the line turns 45°, A is about .7 inches above B. When the line is vertical, A is 1 inch above B, and so on. If this distance is plotted out on a graph against the angle through which the line turns, it looks like this:



(When B is 1 inch above A, A is *minus* 1 inch above B.)

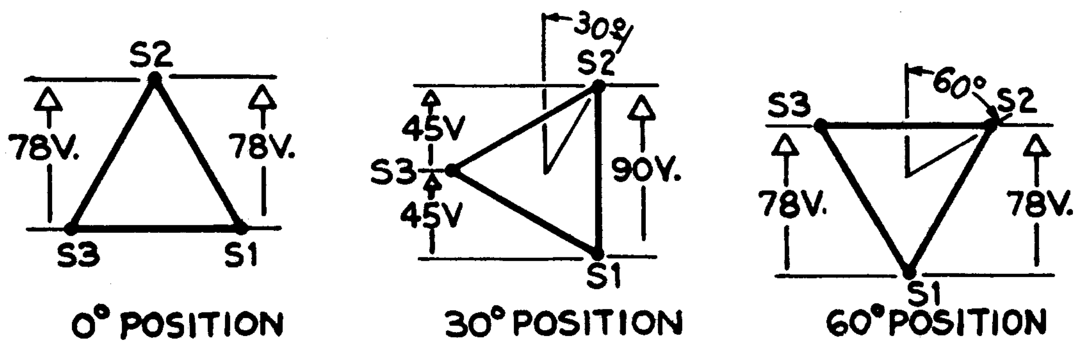
Notice that this curve is a sine curve, just like the curve that showed the relation between the voltage measured between two stator leads on a Synchro Motor, and the electrical position of the rotor. Since this vertical distance changes in the same way as that voltage, we can use it to represent the voltage.

For example, suppose a line is used to show how the effective value of the AC voltage between S1 and S3 on a Synchro Generator changes when the rotor is turned. A vertical distance of 1 inch represents an effective voltage of 100 volts:



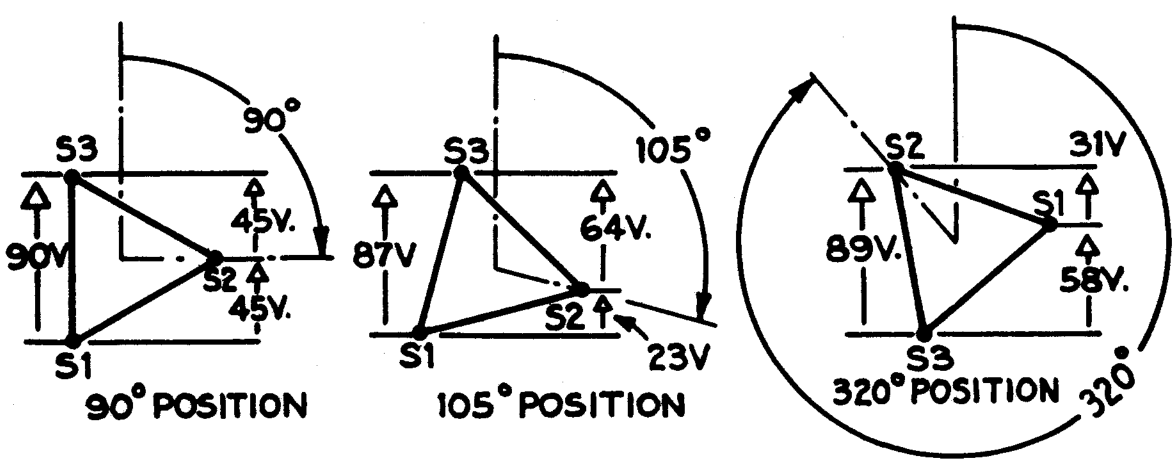
By making the line 90 volts (.9 inches) long, the vertical distance between S1 and S3 on the diagram is made to represent, for each position of the line, the voltage between S1 and S3 on a Synchro for the corresponding positions of the rotor. In addition, by making the line turn clockwise, S3 goes *above* S1 on the diagram when the line is between 0° and 180°, and *below* S1 between 180° and 360°. This agrees with the voltage between S3 and S1, which is *in phase* with the voltage from R1 to R2 for electrical positions between 0° and 180° and *out of phase* for electrical positions between 180° and 360°. In other words, when one terminal appears *above* the other on a diagram like this, it indicates that the voltage measured at that terminal with respect to the other is *in phase* with the voltage from R1 to R2.

All three voltages between stator terminals of a Synchro Generator can be shown at once on diagrams like these:



Here three lines are put together to form a triangle, and the whole triangle is turned clockwise from the 0° position, by the number of degrees corresponding to the electrical position represented. Notice that the voltage values and phase conditions which appear on the diagram agree with those that occur on an actual Synchro for the corresponding rotor positions.

A few more examples may make the operation of the diagram clearer:



These diagrams are simply a geometrical way of showing the effective voltages between the stator terminals of a Synchro Motor or Generator, and how their magnitude and phase polarity change as the rotor turns. They are *not* vector diagrams, and should not be confused with them.

THE STEP-BY-STEP MOTOR

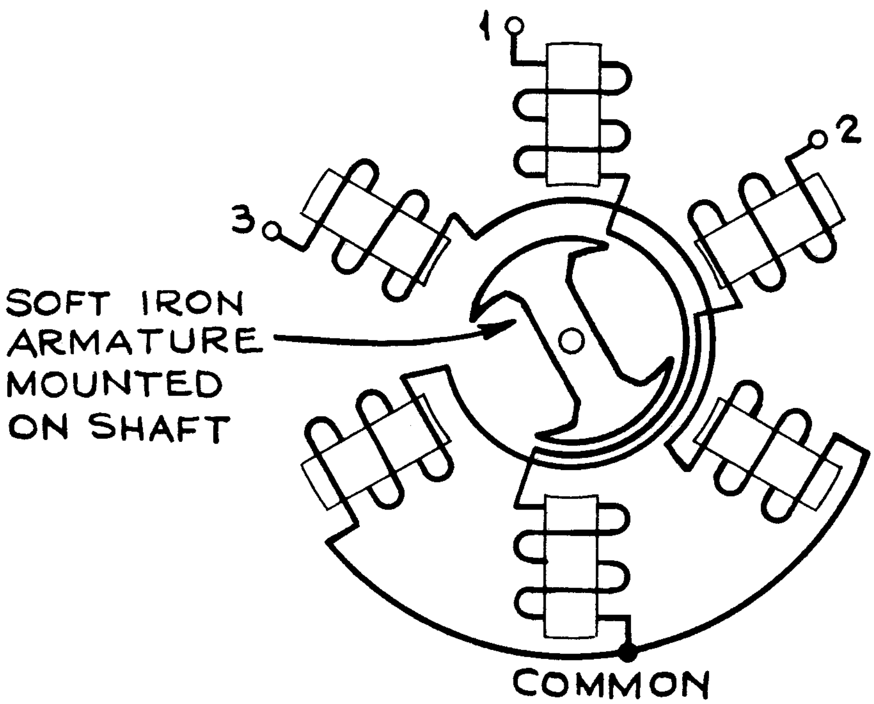
THE STEP-BY-STEP SYSTEM

On modern ship installations, where it is desired to have a number of compass repeaters located at various points on the ship, these repeaters are usually Synchro Motors which are driven by a master Synchro Generator. The master Synchro Generator is controlled by a Gyro compass so that the card on each of the remote Synchro Motors turns to show the True bearing of the ship at any time.

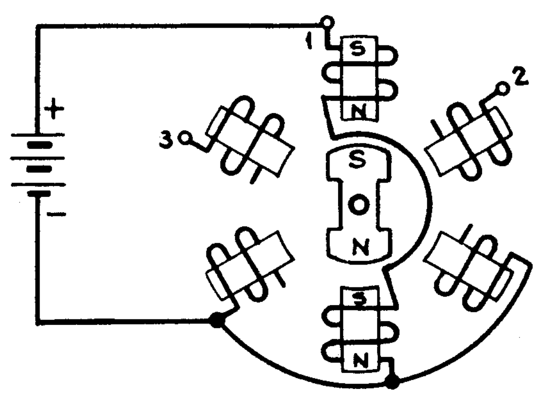
On older ships a different system known as the "Step-by-Step" system is sometimes used to drive the compass repeaters. This system operates directly from the DC supply normally available on these ships, requiring no AC excitation.

HOW A STEP-BY-STEP MOTOR WORKS

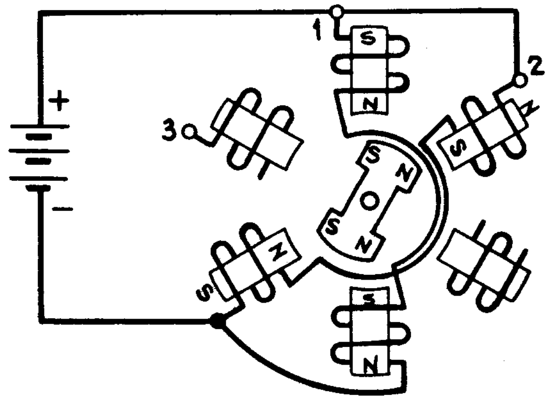
The Step-by-Step motor operates on a principal very much the same as that of the DC machine that was described at the beginning of this booklet. Six electro-magnets are mounted around a soft iron armature and connected like this: (Notice that each pair of coils is wound in a direction opposite to the adjacent pair.)



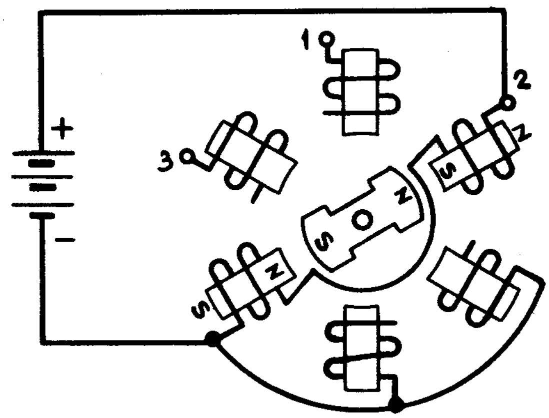
When a DC voltage is applied across the number 1 coils, the armature turns to this position. (Since the armature is soft iron, it does not retain magnetism and either end may turn up, depending on where it is when the voltage is applied.)



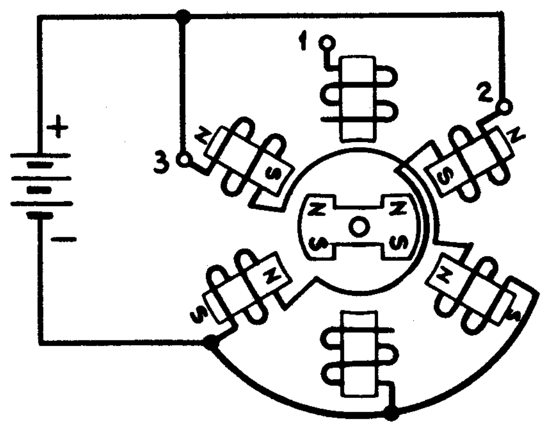
If this voltage is applied *also* to the number 2 coils, the armature turns to a position midway between the two sets of coils, since it is attracted equally by each of them.



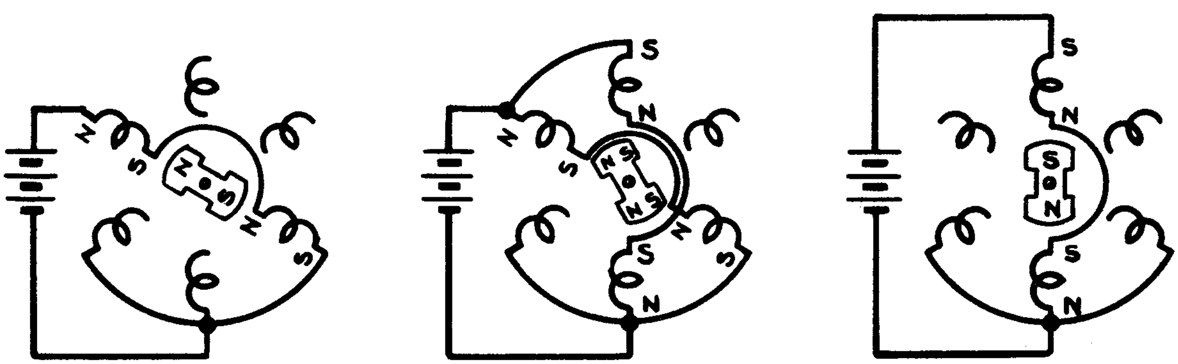
If the number 1 coils are now disconnected, the armature turns until it lines up with the number 2 coils like this:



If the number 3 coils are now connected, the armature moves another step like this:



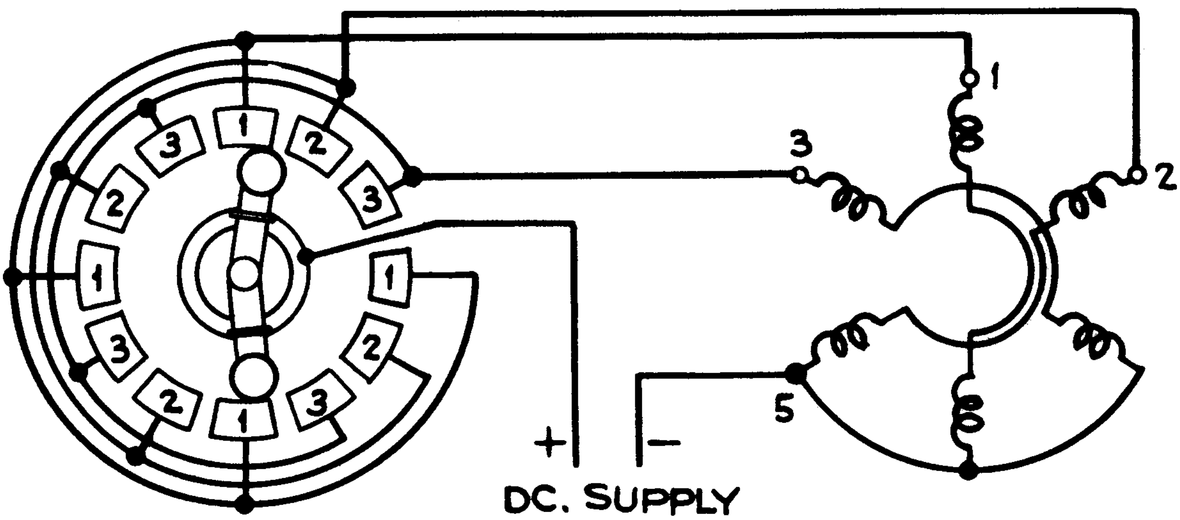
By continuing the process, the armature can be moved around until it is in the same condition as when it started:



THE STEP-BY-STEP SYSTEM

HOW A STEP-BY-STEP SYSTEM WORKS

In an actual step-by-step system this motor is driven by a rotary switch which is connected like this:



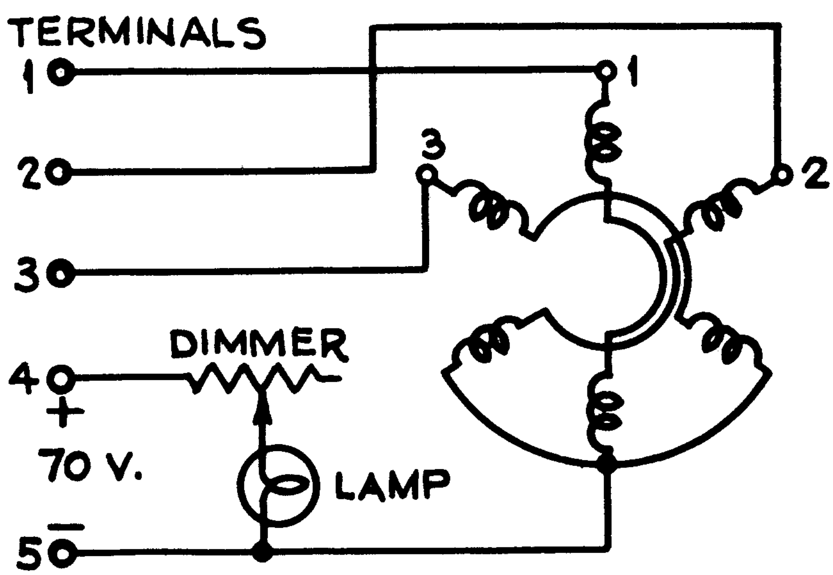
As the switch turns around it applies voltage, first to coils 1, then to 1 and 2 together, then to coils 2, then 2 and 3 together, and so on. As a result, the armature, and the shaft on which it is mounted, turn in 30° jumps following the rotation of the switch.

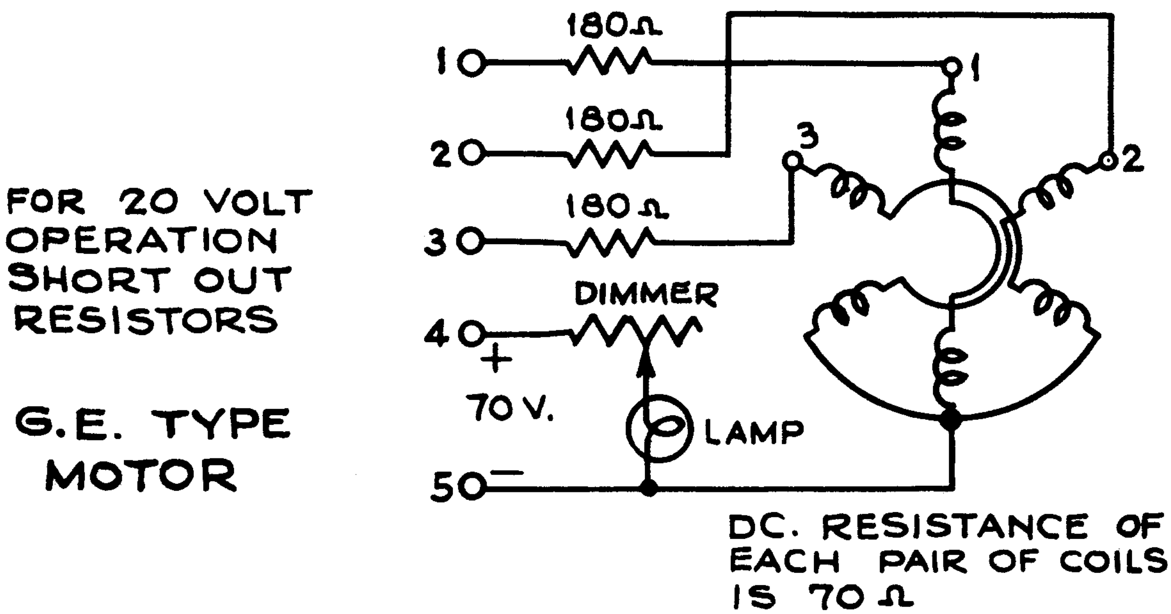
The rotary switch is geared to the Gyro compass in such a way that it turns from one No. 1 contact to the next No. 1 contact when the compass turns through 1°.

The step-by-step motor is geared correspondingly to its compass card so that the card is moved 1° for each six steps. Thus the compass card actually turns in one-sixth degree steps.

Practically there are two kinds of step-by-step system, the only difference being the voltage applied to the motor coils. The older system used 20 volts, the later one 70 volts. Here are diagrams of two typical repeaters:

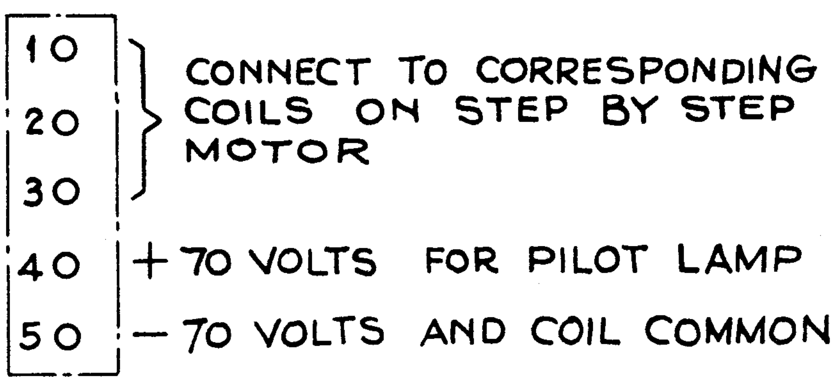
THE SPERRY M-64024 STEP BY STEP REPEATER





STANDARD CONNECTIONS IN A STEP-BY-STEP SYSTEM

There are five wires in the standard step-by-step system, numbered like this:



"SETTING ZERO" ON A STEP-BY-STEP REPEATER

If the power supply to a *Synchro system* is interrupted, and reconnected at a later time, the repeaters will always turn automatically when power is reconnected to show the same reading as the master Synchro. If the DC supply is disconnected from a *step-by-step system* when the master compass reads 160° and reconnected after it has changed to 140°, all of the repeaters will still read 160°, and will read 20° high from then on, until they are corrected.

A hand reset knob is provided on step-by-step repeaters so that the motor may be turned by hand to agree with the reading on the Master Compass each time the power supply is reconnected.

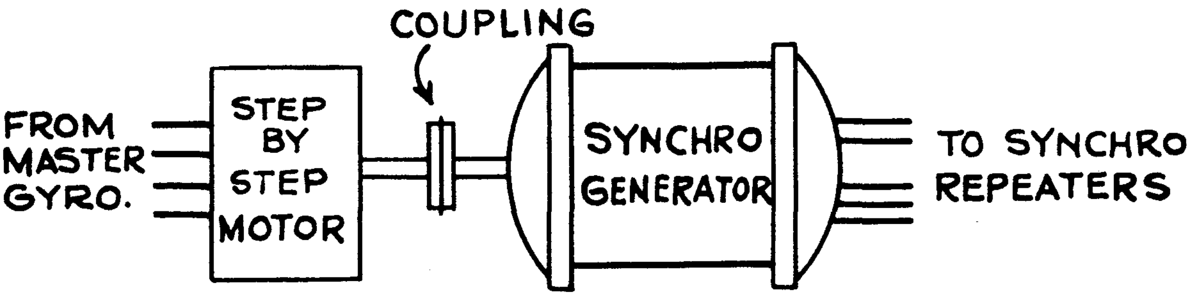
CONVERTERS

STEP-BY-STEP TO SYNCHRO CONVERTERS

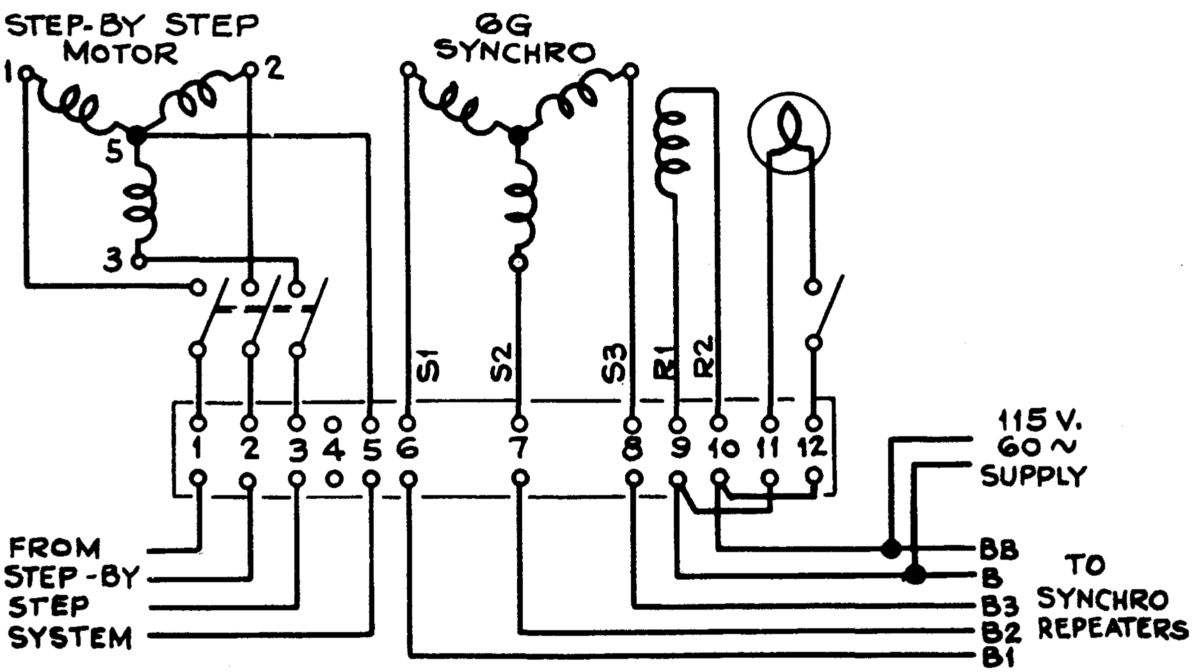
A SIMPLE CONVERTER

When Synchro repeaters must be used on a vessel which has a step-by-step system, a Converter is necessary to change from one to the other.

The simplest kind of Converter consists of a step-by-step motor directly connected to the shaft of a Synchro Generator like this:



This converter receives step-by-step transmission from the Gyro Compass system and transmits Synchro signals to Synchro systems requiring Compass information. The wiring diagram of a particular converter looks like this:

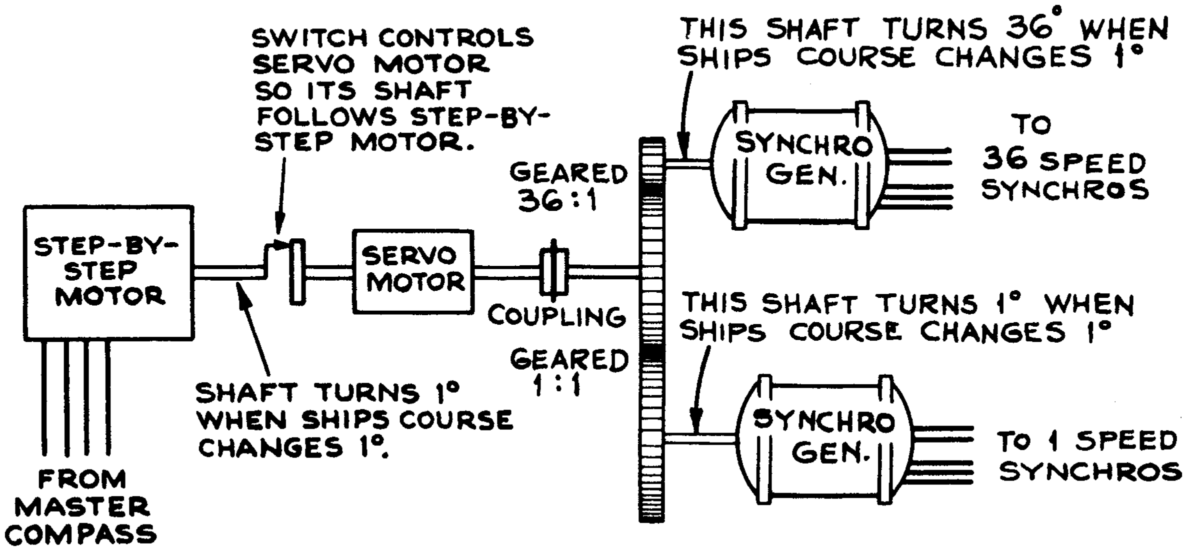


TO ZERO A CONVERTER

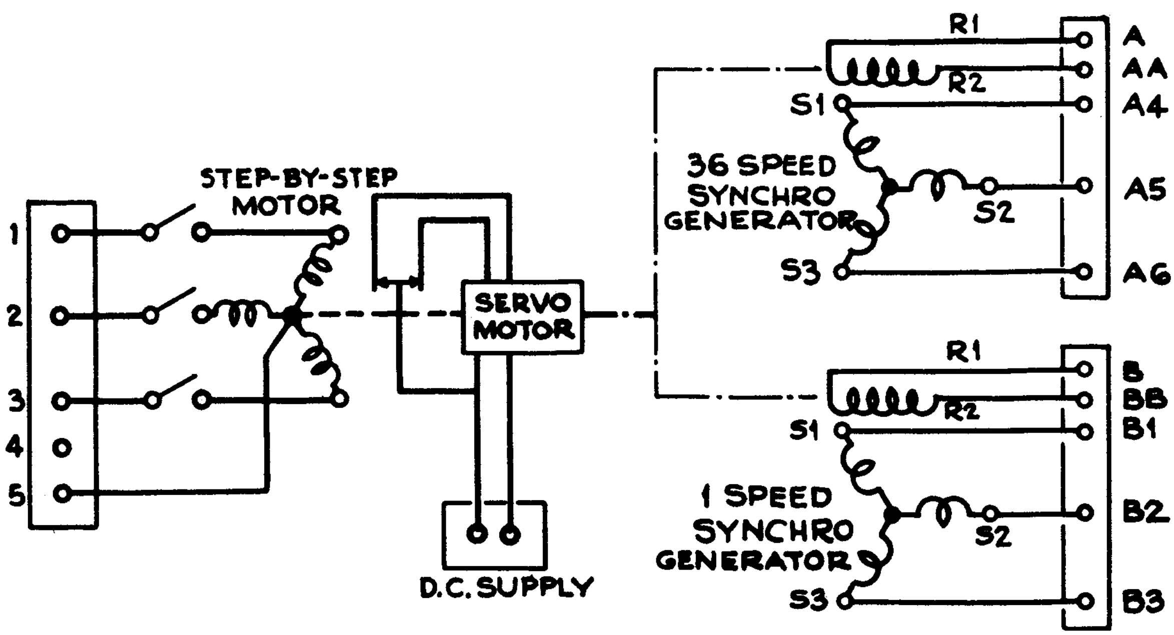
1. Make sure the associated Synchro repeaters are all properly zeroed.
2. Remove excitation from the step-by-step motor.
3. Set the Synchro Generator on electrical zero, and adjust the attached scale so it reads zero.
4. Set the shaft of the step-by-step motor by hand so that the scale reading agrees with the reading of the master compass, and reconnect the step-by-step motor to the system.

A MORE COMPLICATED TYPE OF CONVERTER

When it is desired to have Synchro busses which provide compass information at "1 speed" and also "36 speed" on a ship equipped with a step-by-step system, a more complicated type of Converter is required. Because gearing is required to operate the 36 speed Synchro Generator, it is necessary to add a Servo motor to the system to supply the necessary torque. This makes it so that the Step-by-Step motor has only to supply enough power to operate a switch. The power to run the gears and the Synchro Generators comes from the Servo motor.



The step-by-step motor is driven by the master compass as usual. Its shaft operates a switch which makes the Servo motor's shaft follow its rotation accurately. The shaft of the Servo motor is geared to two Synchro Generators, one of which simply repeats the compass information, and the other turns 36 times as fast. The wiring diagram of such a converter would look something like this:



Another advantage of this type of Converter is that the number of repeaters that can be operated from one step-by-step transmitter is greatly increased. Since the step-by-step motor merely operates a switch, the capacity of the Synchro output is limited only by the size of the Servo Motor and the Synchro Generators.

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