CHAPTER 1

SYNCHROS

LEARNING OBJECTIVES

Learning objectives are stated at the beginning of each chapter. These learning objectives serve as a preview of the information you are expected to learn in the chapter. The comprehensive check questions placed throughout the chapters are based on the objectives. By successfully completing the Nonresident Training Course (NRTC), you indicate that you have met the objectives and have learned the information. The learning objectives for this chapter are listed below.

Upon completing this chapter, you will be able to:

1. Define the term "synchro."
2. State the primary purpose of a synchro.
3. Explain the importance of synchros in naval equipment.
4. Name the two general classifications of synchros.
5. Explain the differences between torque and control synchros.
6. Name the seven functional classes of synchros and list all inputs and outputs.
7. Name the two types of synchro identification codes.
8. Interpret all synchro markings and identify the particular codes used.
9. Draw the five standard schematic symbols for synchros and identify all connections.
10. Describe the general construction and physical appearance of synchro rotors and stators.
11. Name the two common types of synchro rotors, giving an application of each.
12. List the different synchro characteristics and give a brief explanation of each.
13. State the advantage of using 400-Hz synchros over 60-Hz synchros.
14. Explain the operation of a basic synchro transmitter and receiver.
15. State the difference between a synchro transmitter and a synchro receiver.
16. List the basic components that compose a torque synchro system.
17. Explain the operation of a simple synchro transmission system.
18. Define the term "correspondence" and explain how it is used in a simple synchro system.
19. Explain the principle behind reversing the S1 and S3 leads on a synchro receiver and how this action affects receiver operation.

20. Explain what happens when the rotor leads on a synchro transmitter or receiver are reversed.
21. State the purposes of differential synchros.
22. Name the two types of differential synchros and give a brief explanation of each.
23. Explain the difference between the torque differential transmitter and the torque differential receiver.
24. Name the components that make up the TDX and the TDR synchro systems.
25. Explain how the two differential synchro systems add and subtract.
26. State the wiring changes required to convert the differential synchro systems from subtraction to addition.
27. State the purposes and functions of control synchros.
28. Name the different types of control synchros.
29. Explain how the CX and CDX differ from the TX and TDX.
30. Explain the theory and operation of a control transformer.
31. List the basic components that compose a control synchro system.
32. Explain the operation of a control synchro system and how it is used to control a servo system.
33. State the purpose and function of the synchro capacitor.
34. Explain how synchro capacitors improve the accuracy of synchro systems.
35. Explain the method used to connect synchro capacitors in a circuit.
36. Define single and multispeed synchro systems.
37. State the purposes and functions of multispeed synchro systems.
38. Stale the purposes for zeroing synchros.
39. Name three common synchro zeroing methods and give a brief explanation of each.
40. Explain the different troubleshooting techniques used in isolating synchro malfunctions and breakdowns.

SYNCHRO FUNDAMENTALS

Synchros play a very important role in the operation of Navy equipment. Synchros are found in just about every weapon system, communication system, underwater detection system, and navigation system used in the Navy. The importance of synchros is sometimes taken lightly because of their low failure rate. However, the technician who understands the theory of operation and the alignment procedures for synchros is well ahead of the problem when a malfunction does occur. The term "synchro" is an abbreviation of the word "synchronous." It is the name given to a variety of rotary, electromechanical, position-sensing devices. Figure 1-1 shows a phantom view of typical synchro. A synchro resembles a small electrical motor in size and appearance and operates like a variable transformer. The synchro, like the transformer, uses the principle of electromagnetic induction.

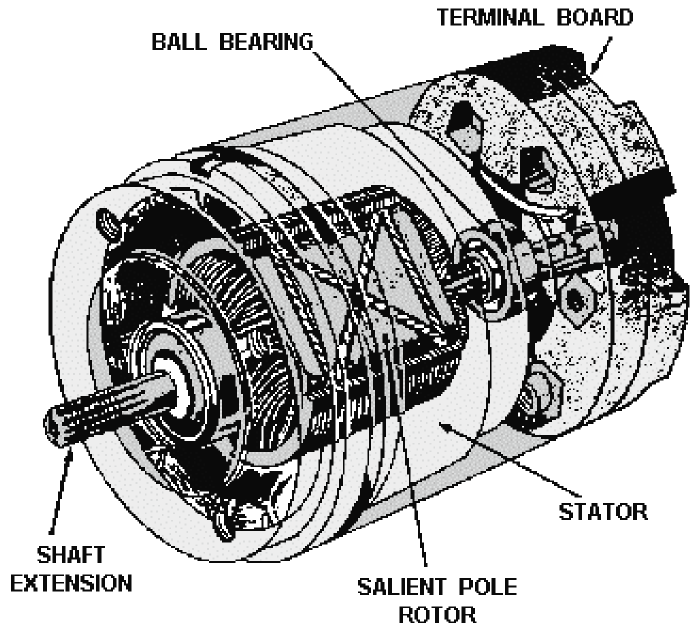


Figure 1-1.—Phantom view of a synchro.

Synchros are used primarily for the rapid and accurate transmission of information between equipment and stations. Examples of such information are changes in course, speed, and range of targets or missiles; angular displacement (position) of the ship's rudder; and changes in the speed and depth of torpedoes. This information must be transmitted quickly and accurately. Synchros can provide this speed and accuracy. They are reliable, adaptable, and compact. Figure 1-2 shows a simple synchro system that can be used to transmit different as of data or information In this system, a single synchro transmitter furnishes information to two synchro receivers located in distant spaces. Operators put information into the system by turning the handwheel. As the handwheel turns, its attached gear rotates the transmitter shaft (which has a dial attached to indicate the value of the transmitted information). As the synchro transmitter shaft turns, it converts the mechanical input into an electrical signal, which is sent through interconnecting wiring to the two synchro receivers. The receiver shafts rotate in response to the electrical signal from the transmitter. When these shafts turn, the dials attached to the shafts indicate the transmitted information.

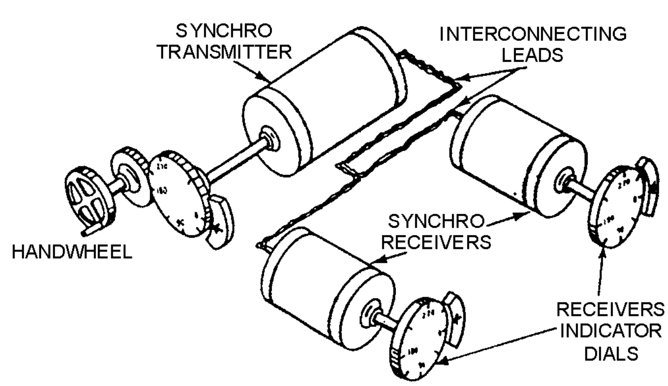


Figure 1-2.—Data transfer with synchros.

By studying the simple synchro system, you can see that information can be transmitted over long distances, from space to space, and from equipment to equipment.

In addition to supplying data by positioning dials and pointers, synchros are also used as control devices in servo systems. When the synchro and the servo are combined, they work as a team to move and position heavy loads. The methods used to accomplish this are covered in detail in the next chapter.

Q-1. What is the name given to a variety of rotary electromechanical, position sensing devices?

Q-2. What is the primary purpose of a synchro system?

SYNCHRO CLASSIFICATION

Synchros work in teams. Two or more synchros interconnected electrically form a synchro system. There are two general classifications of synchro systems—TORQUE SYSTEMS AND CONTROL SYSTEMS. Torque-synchro systems use torque synchros and control-synchro systems use control synchros. The load dictates the type of synchro system, and thus the type of synchro.

Torque-synchro systems are classified "torque" because they are mainly concerned with the torque or turning force required to move light loads such as dials, pointers, or similar indicators. The positioning of these devices requires a relatively low amount of torque. Control synchros are used in systems that are designed to move heavy loads such as gun directors, radar antennas, and missile launchers.

In addition to the two general classifications, synchros are grouped into seven basic functional classes as shown in table 1-1. Four of these are the torque type and three are the control type. Each synchro is described in the table by name, abbreviation, input, output, and the other synchro units that may be connected to it. Generally, torque and control synchros may not be interchanged. The functional operation of each of these seven synchros is covered later in this text.

Table 1-1.—Synchro Information

FUNCTIONAL CLASSIFICATION	ABBREVIATION	INPUT	OUTPUT
Torque transmitter	TX	Mechanical input to rotor (rotor energized from AC source)	Electrical output from stator representing angular position of rotor to TDX, TDR, or TR.
Control transmitter	CX	Same as TX	Same as TX except it is supplied to CDX or CT
Torque differential transmitter	TDX	Mechanical input to rotor, electrical input to stator from TX or another TDX.	Electric output from rotor representing algebraic sum or difference between rotor angle and angle represented by electrical input to TR, TDR, or another TDX.
Control differential transmitter	CDX	Same as TDX except electrical input is from CX or another CDX.	Same as TDX except output to CT or another CDX.
Torque receiver	TR	Electrical input to stator from TX or TDX. (Rotor energized from AC source)	Mechanical output from rotor. Note: Rotor has mechanical inertia damper.
Torque differential receiver	TDR	Electrical input to stator from TX or TDX, another electrical input to rotor from TX or TDX.	Mechanical output from rotor representing algebraic sum or difference between angles represented by electrical inputs. Has inertia damper.
Control transformer	CT	Electric input to stator from CX or CDX, mechanical input to rotor.	Electrical output from rotor proportional to the sine of the angle between rotor position and angle represented by electrical input to stator. Called error signal.
Torque receiver	TRX	Depending on application, same as TX.	Depending on application, same as TX or TR.

Synchros are also classified according to their operating frequency. This classification was brought about by the development of the 400-Hz synchro. Prior to this time, the 60-Hz synchro was the only one in use. Synchro operating frequencies are covered in detail in the section on synchro characteristics.

Q-3. Name the two general classifications of synchro systems.

Q-4. What is the difference between a torque synchro and a control synchro?

Q-5. Using table 1-1, name two synchros that provide a mechanical output.

STANDARD MARKINGS AND SYMBOLS

Synchros used in the Navy can be grouped into two broad categories: MILITARY STANDARD SYNCHROS and PRESTANDARD NAVY SYNCHROS. Military standard synchros conform to specifications that are uniform throughout the armed services. New varieties of equipment use synchros of this type. Prestandard synchros were designed to meet Navy, rather than servicewide, specifications. Each category has its own designation code for identification.

Military Standard Synchro Code

The military standard designation code identifies standard synchros by their physical size, functional purpose, and supply voltage characteristics. The code is alphanumerical and is broken down in the following manner. The first two digits indicate the diameter of the synchro in tenths of an inch, to the next higher tenth. For example, a synchro with a diameter of 1.75 inches has the numeral 18 as its first two digits. The first letter indicates the general function of the synchro and of the synchro system-C for control or T for torque. The next letter indicates the specific function of the synchro, as follows:

LETTER	DEFINITION
D	Differential
R	Receiver
T	Transformer
X	Transmitter

If the letter B follows the specific function designation, the synchro has a rotatable stator. The last number in the designation indicates the operating frequency-6 for 60 Hz and 4 for 400 Hz. The upper-case letter following the frequency indicator is the modification designation. The letter "A" indicates that the synchro design is original. The first modification is indicated by the letter "B." Succeeding modifications are indicated by the letters "C," "D," and so on, except for the unused letters "I," "L," "O," and "Q."

For example, an 18TR6A synchro is an original design, 60-Hz torque receiver with a diameter of between 1.71 and 1.80 inches.

A synchro designated 16CTB4B is the first modification of a 400-Hz control transformer with a rotatable stator and a diameter of between 1.51 and 1.60 inches.

All standard synchros are labeled with such a code. Synchros used in circuits supplied by 26 volts are classified in the same way, except that the symbol 26V is prefixed to the designator (for example, 26V-16CTB4A). Otherwise, a 115 volts source is assumed for the synchro system.

Navy Prestandard Synchro Code

The Navy prestandard designation code identifies prestandard synchros by size and function, using a number and letter combination. Unlike the standard code, the number does not indicate directly the diameter of the synchro. The number merely represents the approximate size of the synchro, increasing as the size increases. The approximate size and weight of the five most common sizes are shown in the following table.

SIZE	APPROX. DIAMETER	APPROX. LENGTH	APPROX WEIGHT
1	2 1/4 in	4 in	2 lb
3	3 1/10 in	5 3/8 in	3 lb
5	3 3/8 to 3 5/8 in	6 1/2 in	5 lb
6	4 1/2 in	7 in	8 lb
7	5 3/4 in	9 in	18 lb

Note that prestandard size 1 is approximately the same size as standard size 23 (2.21 to 2.30 inches in diameter). Prestandard size 3 is approximately the same size as standard size 31. Prestandard size 5 is approximately the same size as standard size 37.

The letters used in the prestandard coding system indicate the function, mounting, or special characteristics of the synchro as shown in the following chart.

LETTER	DEFINITION
G	Transmitter
F	Flange Mounted Receiver (this letter is normally omitted if letters other than H or S occur in type designation)
D	Differential Receiver
DG	Differential Transmitter
CT	Control Transformer
H	High-Speed Unit
B	Bearing Mounted Unit
N	Nozzle Mounted Unit
S	Special Unit

Navy prestandard synchros are rarely used today. They have been replaced by the standard synchro. However, by being familiar with the prestandard coding system, you will be able to identify the older synchros and make correct replacements if necessary.

Q-6. What does the code 26V-11TX4D mean on a synchro nameplate?

Q-7. Which of the two synchro designation codes is indicated by 5DG on a synchro nameplate?

Schematic Symbols

Schematic symbols for synchros are drawn by various manufacturers in many different ways. Only five symbols (as shown in figure 1-3), however, meet the standard military specifications for schematic diagrams of synchros and synchro connections. When a symbol is used on a schematic, it will be accompanied by the military abbreviation of one of the eight synchro functional classifications (TR, TX, TDX, etc.).

The symbols shown in views A and B of figure 1-3 are used when it is necessary to show only the external connections to a synchro, while those shown in views C, D, and E are used when it is important to see the positional relationship between the rotor and stator. The letters R and S, in conjunction with an Arabic number, are used to identify the rotor and stator connections; for example, R1, R2, S1, S2, and S3. The small arrow on the rotor symbol indicates the angular displacement of the rotor; in figure 1-3 the displacement is zero degrees.

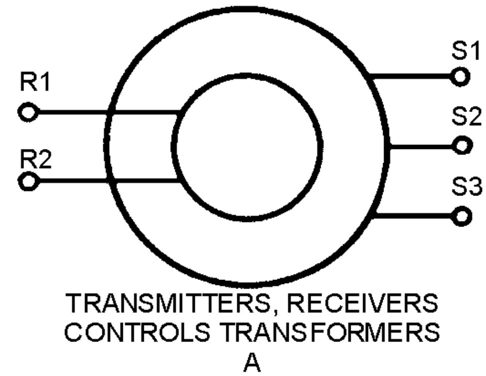


Figure 1-3A.—Schematic symbols for synchros.

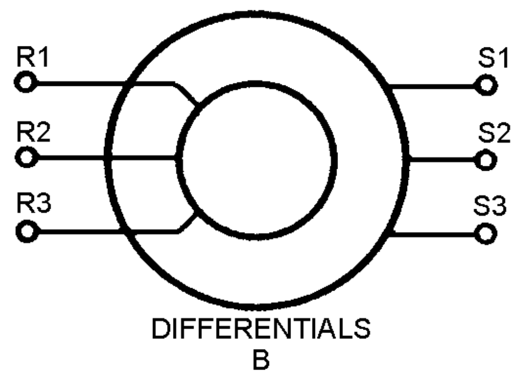


Figure 1-3B.—Schematic symbols for synchros.

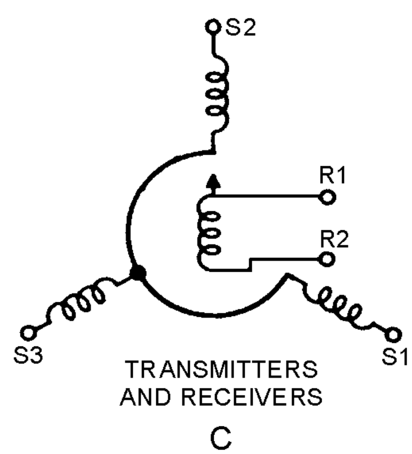


Figure 1-3C.—Schematic symbols for synchros.

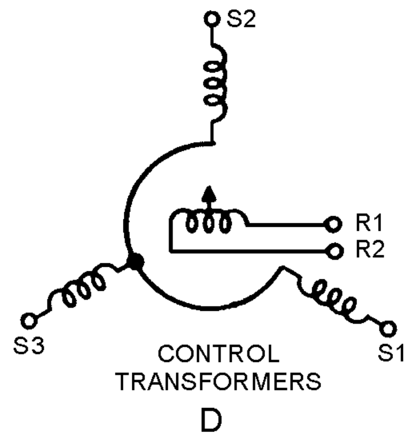


Figure 1-3D.—Schematic symbols for synchros.

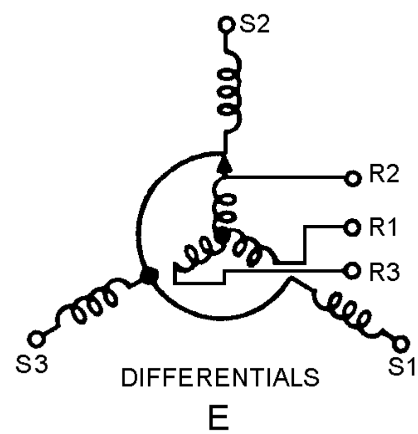


Figure 1-3E.—Schematic symbols for synchros.

Q8. On the synchro schematic symbol, what indicates the angular displacement of the rotor?

SYNCHRO CONSTRUCTION

Figure 1-4 shows a cutaway view of a typical synchro. Having the knowledge of how a synchro is constructed should enable you to better understand how synchros operate.

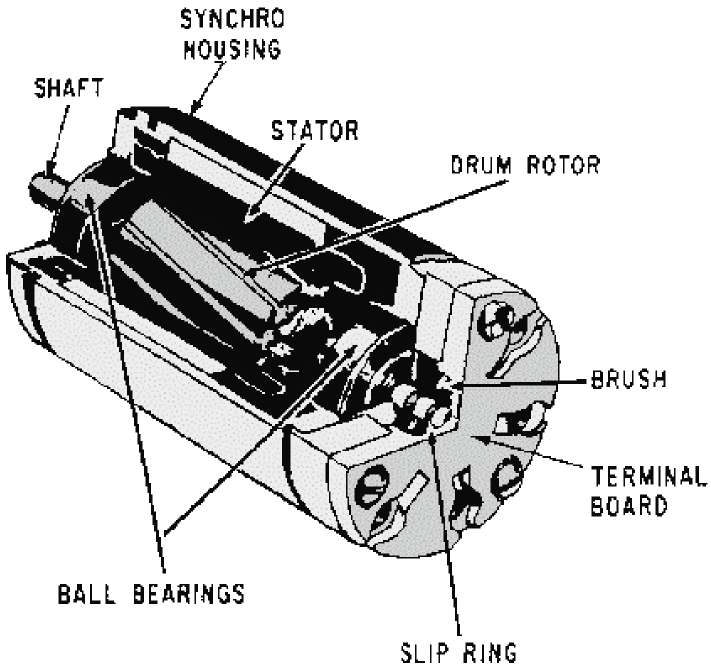


Figure 1-4.—Typical synchro assembly.

In this section we will discuss how rotors and stators are constructed and how the synchro is assembled. Each synchro contains a rotor, similar in appearance to the armature in a motor, and a stator, which corresponds to the field in a motor. The synchro stator is composed of three Y-connected windings (S1, S2, and S3). The rotor is composed of one single winding (R1 and R2). As you can see in the figure, the rotor winding is free to turn inside the stator. The rotor is usually the primary winding and receives its voltage (excitation) from an external voltage source. The stator receives its voltage from the rotor by magnetic coupling.

ROTOR CONSTRUCTION

There are two common types of synchro rotors in use-the SALIENT-POLE ROTOR and the DRUM or WOUND ROTOR. The salient-pole rotor shown in figure 1-5 has a single coil wound on a laminated core. The core is shaped like a "dumb-bell" or the letter "H."

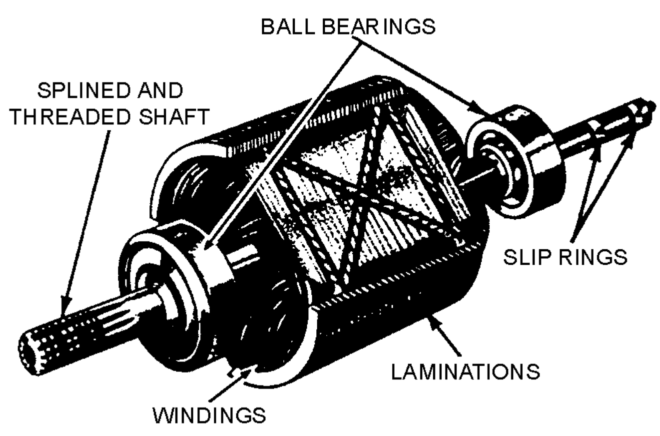


Figure 1-5.—Salient-pole rotor.

This type of winding is frequently used in both transmitters and receivers.

The drum or wound rotor has coils wound in slots in a laminated core as shown in figure 1-6. This type of rotor is used in most synchro control transformers and differential units, and occasionally in torque transmitters. It may be wound continuously with a single length of wire or may have a group of coils connected in series. The single continuous winding provides a distributed winding effect for use in transmitters. When the rotor is wound with a group of coils connected in series, a concentrated winding effect is provided for use in control transformers. When used in differential units, the rotor is wound with three coils so their magnetic axes are 120º apart.

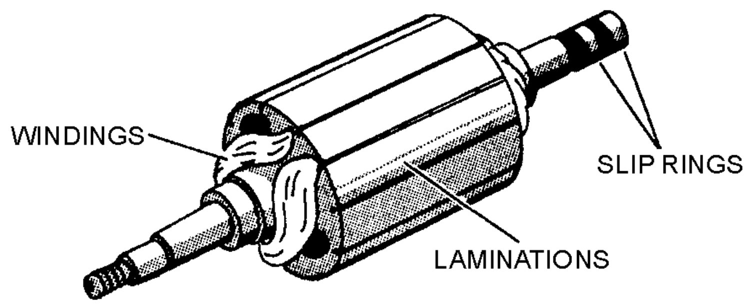


Figure 1-6.—Drum or wound rotor.

Both types of synchro rotors have their coils wound on laminated cores that are rigidly mounted on a shaft. To enable the excitation voltage to be applied to the rotor winding, two slip rings are mounted on one end of the shaft and insulated from the shaft to prevent shorting. An insulated terminal board, mounted on the end of the cylindrical frame, houses the brushes, which ride on the slip rings. These brushes provide continuous electrical contact to the rotor during its rotation. Also mounted on the rotor shaft are low-friction ball bearings, which permit the rotor to turn easily.

STATOR CONSTRUCTION

The stator of a synchro is a cylindrical structure of slotted laminations on which three Y-connected coils are wound with their axes 120º apart. In figure 1-7, view A shows a typical stator assembly consisting of the laminated stator, stator windings, and cylindrical frame; view B shows the stator lamination and the slots in which the windings are placed. Some synchros are constructed so both the stator and the rotor may be turned. Electrical connections to this type of stator are made through slip rings and brushes.

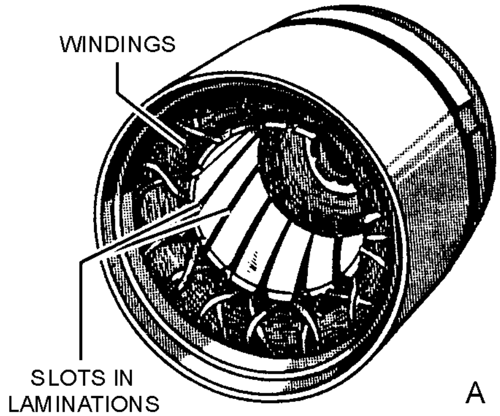


Figure 1-7A.—Typical stator.

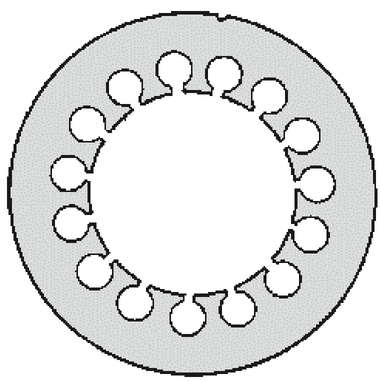


Figure 1-7B.—Stator lamination.

Now, refer to figure 1-4 for a view of a completed synchro assembly. The rotor has been placed in the stator assembly, and a terminal board has been added to provide a point at which internal and external connections can be made.

Q-9. What are the two major components of a synchro?

Q-10. Which of the two main types of rotors can have either a single winding or three Y-connected windings?

Q-11. How does the stator receive its voltage?

Q-12. Where are the external connections made on standard synchros?

SYNCHRO CHARACTERISTICS

Synchro characteristics play a very important part in synchro troubleshooting and maintenance. By closely observing these characteristics, you can generally tell if a synchro or synchro system is working properly. Low torque, overheating, and improper operating voltages are just a few of the abnormal characteristics found in synchro systems. In general, the load capacity of a synchro system is limited by the number and types of receiver units loading the transmitter, the loads on these receiver units, and the operating temperature.

TORQUE

Torque is simply a measure of how much load a machine can turn. In torque synchros, only small loads are turned; therefore, only a small amount of torque is required. The measure of torque is the product of the applied force and the distance between the point of application and the center of rotation. For instance, if a 3 ounce weight is suspended from a synchro pulley having a radius of 2 inches, the torque required to move the weight is 6 ounce-inches. In heavy machinery, torque may be expressed in pound-feet, but torque synchro measurements are in ounce-inches.

NOTE: The unit of torque is the pound-foot or ounce-inch. Do not confuse this with foot-pounds, which is the measurement of work. Many times in referring to torque, tools are marked in foot-pounds. While this use of foot-pounds is technically incorrect, common usage has made it acceptable.

The torque developed in a synchro receiver results from the tendency of two electromagnets to align themselves. Since the rotor can be turned and the stator usually cannot, the stator must exert a force (torque) tending to pull the rotor into a position where the primary and secondary magnetic fields are in line. The strength of the magnetic field produced by the stator determines the torque. The field strength depends on the current through the stator coils. As the current through the stator is increased, the field strength increases and more torque is developed.

Q-13. What major factors determine the load capacity of a torque-synchro transmitter?

Q-14. Define the term "torque."

Q-15. What unit of measurement refers to the torque of a synchro transmitter?

OPERATING VOLTAGES AND FREQUENCIES

Military standard and Navy prestandard synchros are designed to operate on either 115 volts or 26 volts. Synchros used in shipboard equipment are designed predominately for 115 volts, while most aircraft synchros operate on 26 volts.

Synchros are also designed to operate on a 60- or 400-Hz frequency. But like transformers, they are more efficient at the higher frequency. Operating a synchro at a higher frequency also permits it to be made physically smaller. This is because the lines of flux produced by the 400-Hz excitation voltage are much more concentrated than those produced by the 60-Hz excitation voltage. Hence, the core of the 400-Hz synchro can be made smaller than the core of the 60-Hz synchro. However, some 400-Hz synchro units are identical in size to their 60-Hz counterparts. This is done so that 60- and 400-Hz units can be physically interchanged without special mounting provisions. The operating voltage and frequency of each synchro is marked on its nameplate.

The use of the smaller size synchro permits the construction of smaller and more compact equipment. The most widely used frequency for airborne equipment is 400 Hz. It is being used increasingly in shipboard equipment as well. The newer gun and missile fire-control systems use 400-Hz synchros almost exclusively.

A synchro designed for 60-Hz operation may occasionally be used with a 400-Hz supply. There may be considerable loss of accuracy, but the synchro will not be damaged. This should be done only in the case of an emergency when the specified replacement is not available, and system accuracy is not critical.

CAUTION

NEVER connect a 400-Hz synchro to 60-Hz voltage. The reduced impedance results in excessive current flow and the windings quickly burn out.

Q-16. What type of equipment normally uses 26-volt 400-hertz synchros?

OPERATING TEMPERATURES AND SPEEDS

Standard synchros are designed to withstand surrounding temperatures ranging from −67º F to +257º F (-55º C to +125º C) at the terminal board. Prestandard synchros operate in a range of −13º F to +185º F (-25º C to +85º C). When a synchro is energized and not loaded, its temperature should stay within prescribed limits. Loading an energized synchro causes it to generate more heat. Similarly, overloading causes a synchro to generate much more heat than it would under normal loading conditions and could possibly result in permanent synchro damage. To meet military specifications, all standard synchros must be capable of continuous operation for 1,000 hours at 1,200 revolutions per minute (rpm) without a load.

A prestandard synchro has one of two specifications, depending upon its use in a data transmission system. Low-speed prestandard synchros must be capable of continuous operation for 500 hours at 300 rpm without a load. Low-speed prestandard synchros must be capable of continuous operation for 1,500 hours at 1200 rpm without a load.

Q-17. When will a synchro generate more heat than it is designed to handle?

THEORY OF OPERATION

Synchros, as stated earlier, are simply variable transformers. They differ from conventional transformers by having one primary winding (the rotor), which may be rotated through 360º and three stationary secondary windings (the stator) spaced 120º apart. It follows that the magnetic field within the synchro may also be rotated through 360º. If an iron bar or an electromagnet were placed in this field and allowed to turn freely, it would always tend to line up in the direction of the magnetic field. This is the basic principle underlying all synchro operations.

We will begin the discussion of synchro operation with a few basic points on electromagnets. Look at figure 1-8. In this figure, a simple electromagnet is shown with a bar magnet pivoted in the electromagnet's field. In view A, the bar is forced to assume the position shown, since the basic law of magnetism states that like poles of magnets repel and unlike poles attract. Also notice that when the bar is aligned with the field, the magnetic lines of force are shortest. If the bar magnet is turned from this position and held as shown in view B, the flux is distorted and the magnetic lines of force are lengthened. In this condition, a force (torque) is exerted on the bar magnet. When the bar magnet is released, it snaps back to its original position. When the polarity of the electromagnet is reversed, as shown in view C, the field reverses and the bar magnet is rotated 180º from its original position.

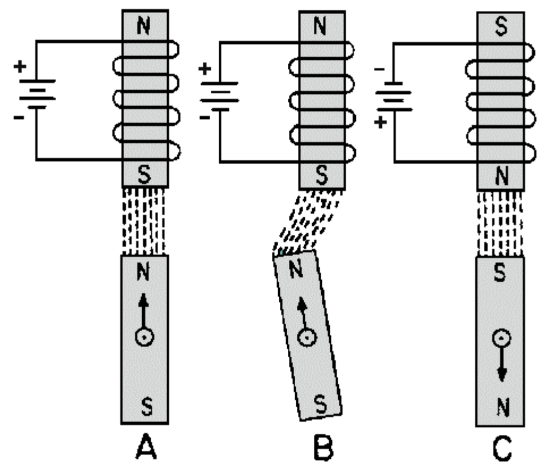


Figure 1-8.—Operation of an electromagnet with a bar-magnet rotor.

Keeping in mind these basic points, consider how the bar magnet reacts to three electromagnets spaced 120º apart as illustrated in figure 1-9. In this figure, stator coils S1 and S3, connected in parallel, together have the same field strength as stator coil S2. The magnetic field is determined by current flow through the coils. The strongest magnetic field is set up by stator coil S2, since it has twice the current and field strength as either S1 or S3 alone. A resultant magnetic field is developed by the combined effects of the three stator fields. Coil S2 has the strongest field, and thus, the greatest effect on the resultant field, causing the field to align in the direction shown by the vector in view B of the figure. The iron-bar rotor aligns itself within the resultant field at the point of greatest flux density. By convention, this position is known as the zero-degree position. The rotor can be turned from this position to any number of positions by applying the proper combination of voltages to the three coils, as illustrated in figure 1-10, view (A), view (B), view (C), view (D), view (E), view (F).

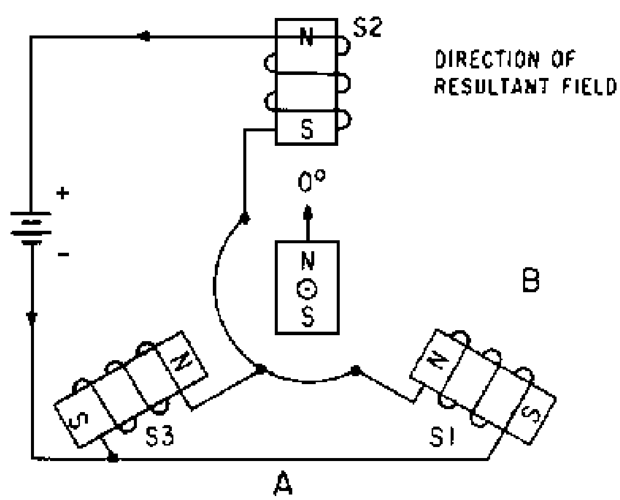


Figure 1-9.—Operation of three electromagnets spaced 120º apart.

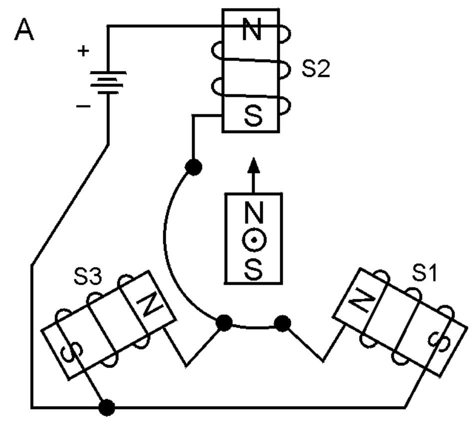


Figure 1-10A.—Positioning of a bar magnet with three electromagnets.

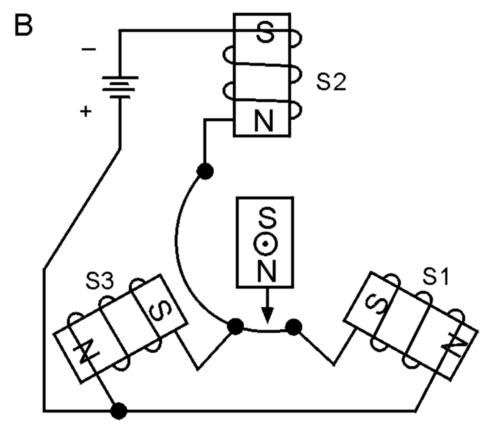


Figure 1-10B.—Positioning of a bar magnet with three electromagnets.

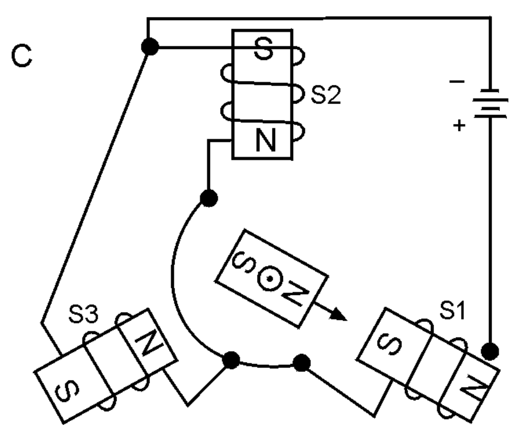


Figure 1-10C.—Positioning of a bar magnet with three electromagnets.

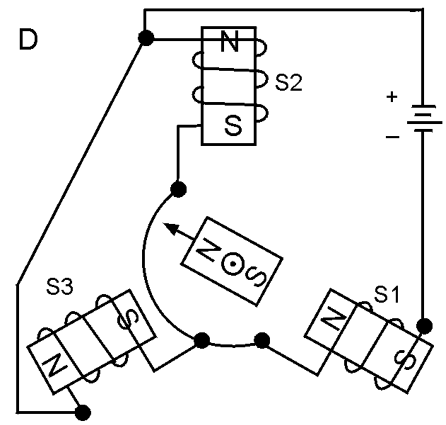


Figure 1-10D.—Positioning of a bar magnet with three electromagnets.

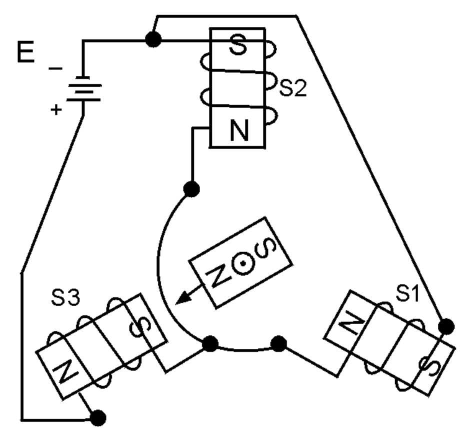


Figure 1-10E.—Positioning of a bar magnet with three electromagnets.

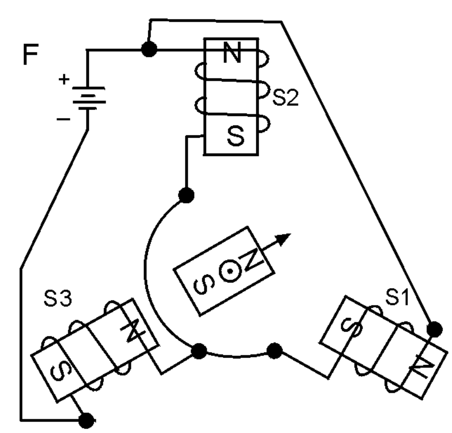


Figure 1-10F.—Positioning of a bar magnet with three electromagnets.

Notice in figure 1-10, in views A C, and E, that the rotor positions are achieved by shifting the total current through different stator windings (S1, S2, and S3). This causes the rotor to move toward the coil with the strongest magnetic field. To obtain the rotor positions in views B, D, and F, it was necessary only to reverse the battery connections. This causes the direction of current flow to reverse and in turn reverses the direction of the magnetic field. Since the rotor follows the magnetic field the rotor also changes direction. By looking closely at these last three rotor positions, you will notice that they are exactly opposite the first three positions we discussed. This is caused by the change in the direction of current flow. You can now see that by varying the voltages to the three stator coils, we can change the current in these coils and cause the rotor to assume any position we desire.

In the previous examples, dc voltages were applied to the coils. Since synchros operate on ac rather than dc, consider what happens when ac is applied to the electromagnet in figure 1-11. During one complete cycle of the alternating current, the polarity reverses twice.

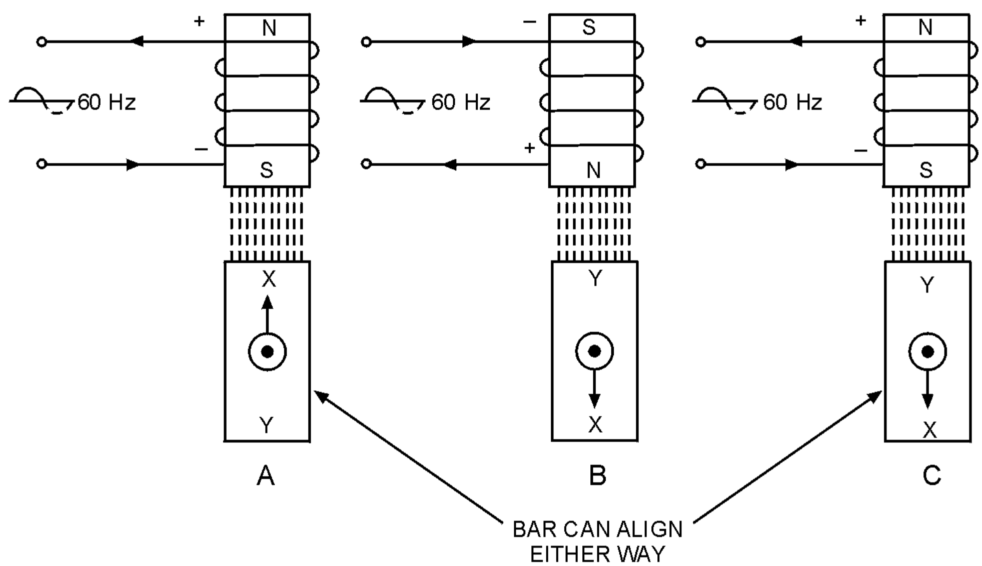


Figure 1-11.—Operation of an electromagnet with ac voltage.

Therefore, the number of times the polarity reverses each second is twice the excitation frequency, or 120 times a second when a 60-Hz frequency is applied. Since the magnetic field of the electromagnet follows this alternating current, the bar magnet is attracted in one direction during one-half cycle (view A) and in the other direction during the next half cycle (view B). Because of its inertia, the bar magnet cannot turn rapidly enough to follow the changing magnetic field and may line up with either end toward the coil (view C). This condition also causes weak rotor torque. For these reasons, the iron-bar rotor is not practical for ac applications. Therefore, it must be replaced by an electromagnetic rotor as illustrated in figure 1-12.

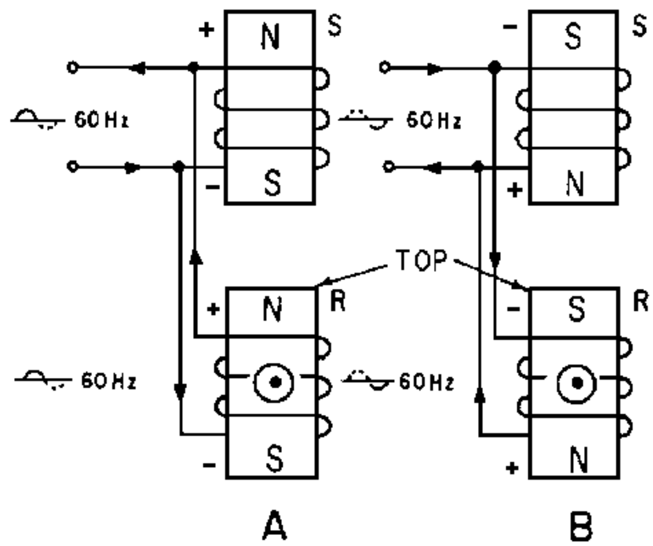


Figure 1-12.—Operation of fixed and moveable electromagnets with ac voltage.

In this figure, both stationary and rotating coils are connected to the same 60-Hz source. During the positive alternation (view A), the polarities are as shown and the top of the rotor is attracted to the bottom of the stationary coil. During the negative alternation (view B), the polarities of both coils reverse, thus keeping the rotor aligned in the same position. In summary, since both magnetic fields change direction at the same time when following the 60-Hz ac supply voltage, the electromagnetic rotor does not change position because it is always aligned with the stationary magnetic field.

Q-18. How do synchros differ from conventional transformers?

Q-19. Describe the zero-position of a synchro transmitter.

SYNCHRO TORQUE TRANSMITTER

The synchro transmitter converts the angular position of its rotor (mechanical input) into an electrical output signal.

When a 115-volt ac excitation voltage is applied to the rotor of a synchro transmitter, such as the one shown in figure 1-13, the resultant current produces an ac magnetic field around the rotor winding. The lines of force cut through the turns of the three stator windings and, by transformer action, induce voltage into the stator coils. The effective voltage induced in any stator coil depends upon the angular position of that coil's axis with respect to the rotor axis. When the maximum effective coil voltage is known, the effective voltage induced into a stator coil at any angular displacement can be determined.

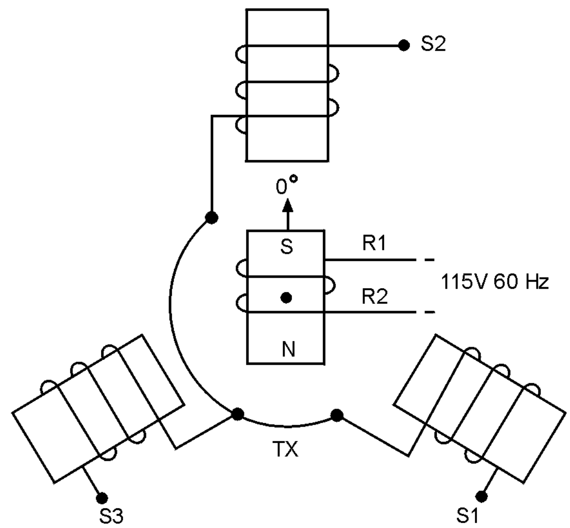


Figure 1-13.—Synchro transmitter.

Figure 1-14 illustrates a cross section of a synchro transmitter and shows the effective voltage induced in one stator coil as the rotor is turned to different positions. The turns ratios in synchros may vary widely, depending upon design and application, but there is commonly a 2.2:1 stepdown between the rotor and a single coil. Thus, when 115 volts is applied to the rotor, the highest value of effective voltage induced in any one stator coil is 52 volts. The maximum induced voltage occurs each time there is maximum magnetic coupling between the rotor and the stator coil (views A, C, and E). The effective voltage induced in the secondary winding is approximately equal to the product of the effective voltage on the primary, the secondary-to-primary turns ratio, and the magnetic coupling between primary and secondary. Therefore, because the primary voltage and the turns ratio are constant, it is commonly said that the secondary voltage varies with the angle between the rotor and the stator.

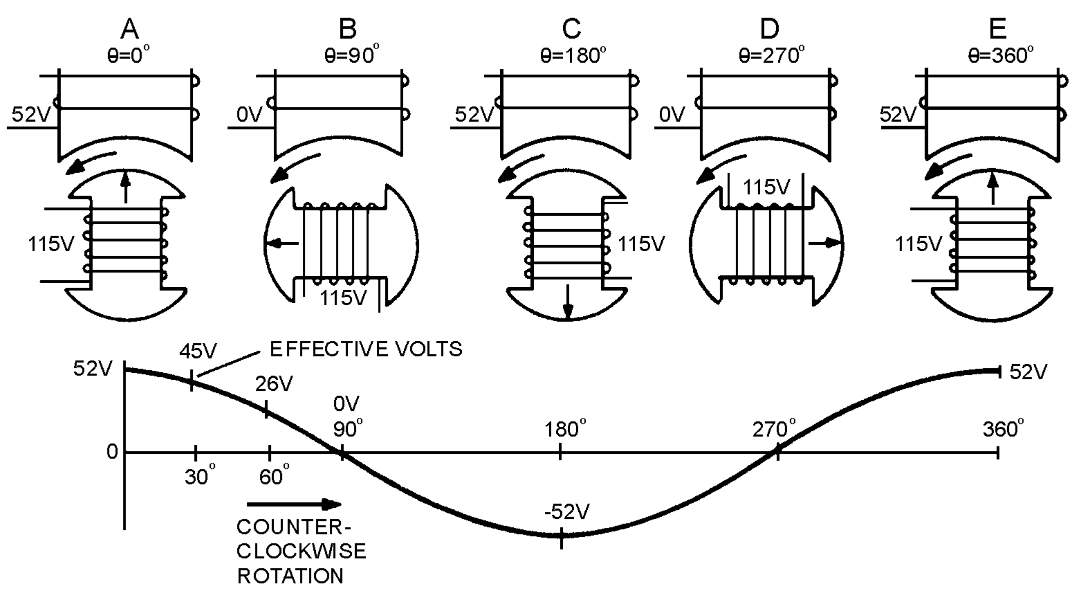


Figure 1-14.—Stator voltage vs rotor position.

When stator voltages are measured, reference is always made to terminal-to-terminal voltages (voltage induced between two stator terminals) instead of to a single coil's voltage. This is because the voltage induced in one stator winding cannot be measured because the common connection between the stator coils is not physically accessible.

In summary, the synchro transmitter converts the angular position of its rotor into electrical stator signals, which are sent through interconnecting wires to other synchro devices.

Q-20. When is the maximum voltage induced into a stator coil?

Q-21. What three factors determine the amplitude of the voltage induced into a stator winding?

SYNCHRO TORQUE RECEIVER

Synchro torque receivers, commonly called synchro receivers, are electrically identical to torque transmitters of the same size except for the addition of some form of damping. In some sizes of 400-Hz synchros, units are designated as torque receivers but may be used as either transmitters or receivers.

Unlike the transmitter, the receiver has an electrical input to its stator and a mechanical output from its rotor. The synchro receiver's function is to convert the electrical data supplied to its stator from the transmitter, back to a mechanical angular position through the movement of its rotor. This function is accomplished when the rotor is connected to the same ac source as the transmitter and assumes a position determined by the interaction of its magnetic field with the magnetic field of the stator. If you recall, this is the same concept discussed earlier under the operation of electromagnets.

Normally, the receiver rotor is unrestrained in movement except for brush and bearing friction. When power is first applied to a system, the transmitter position changes quickly; or if the receiver is switched into the system, the receiver rotor turns to correspond to the position of the transmitter rotor. This sudden motion can cause the rotor to oscillate (swing back and forth) around the synchronous position If the movement of the rotor is great enough, it may even spin. Some method of preventing oscillations or spinning must be used. Any method that accomplishes this task is termed DAMPING.

There are two types of damping methods ELECTRICAL and MECHANICAL. In small synchros the electrical method is used more frequently than the mechanical method. This method uses an additional winding placed in the synchro to retard oscillations. In larger units, a mechanical device, known as an inertia damper, is more effective. Several variations of the inertia damper are in use. One of the more common types consists of a heavy brass flywheel (inertia damper), which is free to rotate around a bushing that is attached to the rotor shaft (fig. 1-15). A tension spring on the bushing rubs against the flywheel so that the bushing and flywheel turn together during normal operation. If the rotor shaft turns or tends to change its speed or direction of rotation suddenly, the inertia of the damper opposes the changing condition.

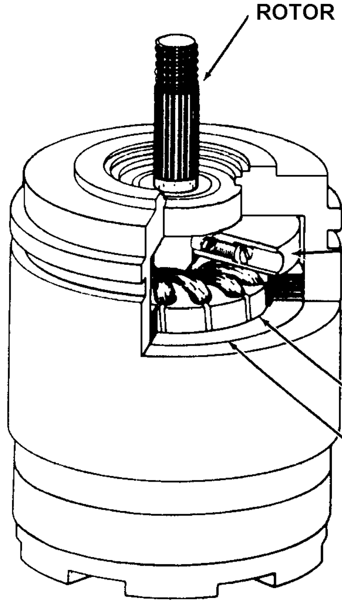


Figure 1-15.—Cutaway view of torque receiver with inertia damper.

Q-22. What is the physical difference between a synchro transmitter and a synchro receiver?

Q-23. What method is used to prevent oscillations in large synchro units?

TORQUE SYNCHRO SYSTEM

A torque transmitter (TX) and a torque receiver (TR) make up a simple torque-synchro system. Basically, the electrical construction of synchro transmitters and receivers is similar, but their intended functions are different. The rotor of a synchro transmitter is usually geared to a manual or mechanical input. This gearing may drive a visual indicator showing the value or quantity being transmitted. The rotor of the receiver synchronizes itself electrically with the position of the rotor of the transmitter and thus responds to the quantity being transmitted.

BASIC SYNCHRO SYSTEM OPERATION

A simple synchro transmission system consisting of a torque transmitter connected to a torque receiver (TX-TR) is illustrated in figure 1-16. As you can see, in this system the rotors are connected in parallel across the ac line. The stators of both synchros have their leads connected S1 to S1, S2 to S2, and S3 to S3, so the voltage in each of the transmitter stator coils opposes the voltage in the corresponding coils of the receiver. The voltage directions are indicated by arrows for the instant of time shown by the dot on the ac line voltage.

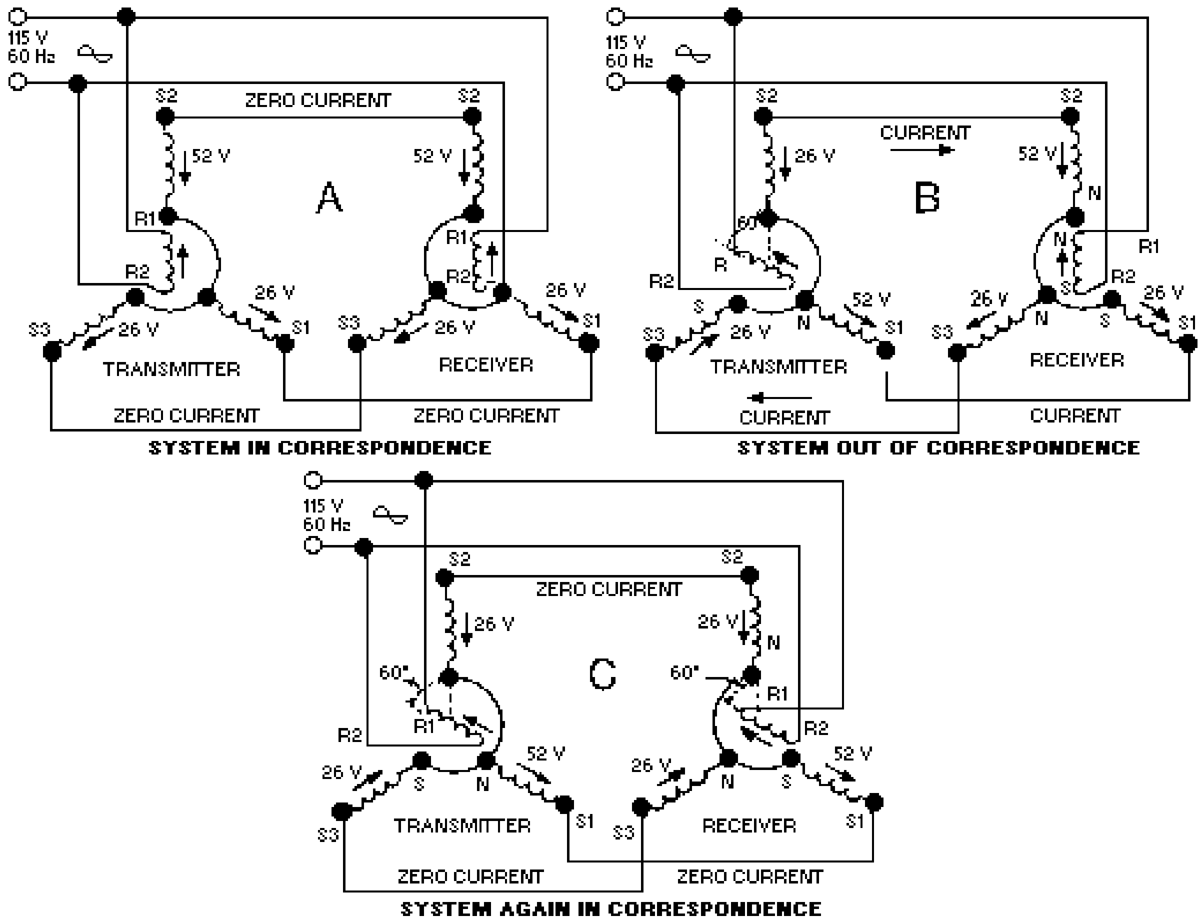


Figure 1-16.—A simple synchro transmission system.

When both transmitter and receiver rotors in a synchro system are on zero or displaced from zero by the same angle, a condition known as CORRESPONDENCE exists. In view A of figure 1-16, the transmitter and receiver are shown in correspondence. In this condition, the rotor of the TR induces voltages in its stator coils (S2 = 52V; S1 and S3 = 26V) that are equal to and opposite the voltages induced into the TX stator coils (S2 = 52V; S1 and S3 = 26V). This causes the voltages to cancel and reduces the stator currents to zero. With zero current through the coils, the receiver torque is zero and the system remains in correspondence.

The angle through which a transmitter rotor is mechanically rotated is called a SIGNAL. In view B of figure 1-16, the signal is 60º. Now, consider what happens to the two synchros in correspondence when this signal is generated

When the transmitter rotor is turned, the rotor field follows and the magnetic coupling between the rotor and stator windings changes. This results in the transmitter S2 coil voltage decreasing to 26 volts, the S3 coil voltage reversing direction, and the S1 coil voltage increasing to 52 volts. This imbalance in voltages, between the transmitter and receiver, causes current to flow in the stator coils in the direction of the stronger voltages. The current flow in the receiver produces a resultant magnetic field in the receiver stator in the same direction as the rotor field in the transmitter. A force (torque) is now exerted on the receiver rotor by the interaction between its resultant stator field and the magnetic field around its rotor. This force causes the rotor to turn through the same angle as the rotor of the transmitter. As the receiver approaches correspondence, the stator voltages of the transmitter and receiver approach equality. This action decreases the stator currents and produces a decreasing torque on the receiver. When the receiver and the transmitter are again in correspondence, as shown in view C, the stator voltages between the two synchros are equal and opposite (S1 = 52V; S2 and S3 = 26V), the rotor torque is zero, and the rotors are displaced from zero by the same angle (60º). This sequence of events causes the transmitter and receiver to stay in correspondence.

In the system we just explained, the receiver reproduced the signal from the transmitter. As you can see, a synchro system such as this could provide a continuous, accurate, visual reproduction of important information to remote locations.

Q-24. What two components make up a simple synchro transmission system?

Q-25. What leads in a simple synchro system are connected to the ac power line?

Q-26. What is the relationship between the transmitter and receiver stator voltages when their rotors are in correspondence?

Q-27. What is the name given to the angle through which a transmitters rotor is mechanically rotated?

Receiver Rotation

When the teeth of two mechanical gears are meshed and a turning force is applied, the gears turn in opposite directions. If a third gear is added, the original second gear turns in the same direction as the first. This is an important concept, because the output of a synchro receiver is often connected to the device it operates through a train of mechanical gears. Whether or not the direction of the force applied to the device and the direction in which the receiver rotor turns are the same depends on whether the number of gears in the train is odd or even. The important thing, of course, is to move the dial or other device in the proper direction. Even when there are no gears involved, the receiver rotor may turn in the direction opposite to the direction you desire. To correct this problem, some method must be used to reverse the receiver's direction of rotation. In the transmitter-receiver system, this is done by reversing the S1 and S3 connections so that SI of the transmitter is connected to S3 of the receiver and vice versa (fig. 1-17), view (A) and view (B).

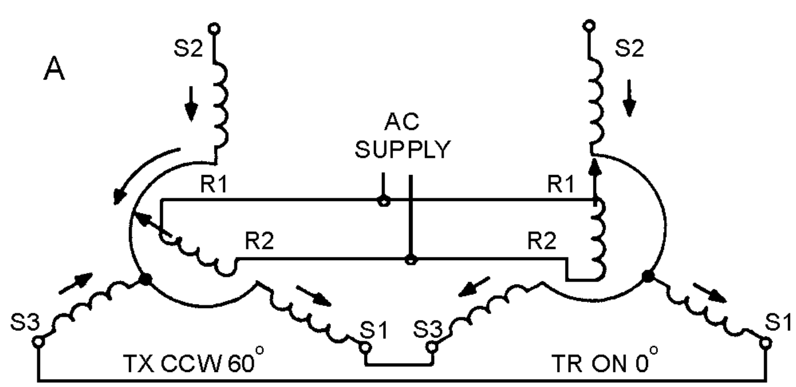


Figure 1-17A.—Effect of reversing the S1 and S3 connections between the transmitter and the receiver.

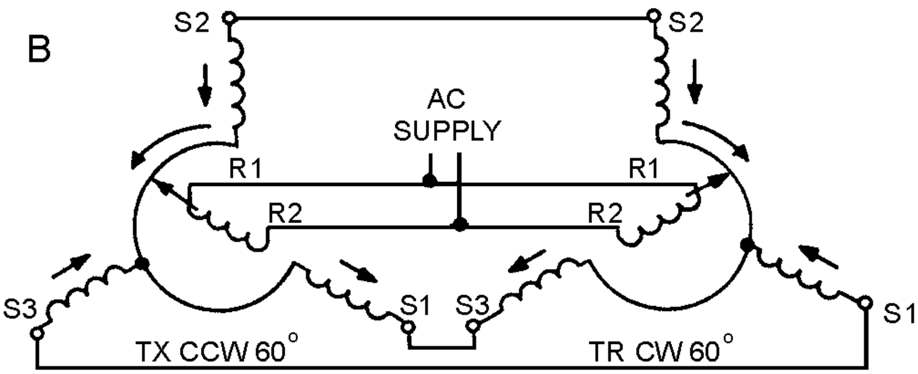


Figure 1-17B.—Effect of reversing the S1 and S3 connections between the transmitter and the receiver.

Even when the S1 and S3 connections are reversed, the system at 0º acts the same as the basic synchro system we previously described at 0º. This is because the voltages induced in the S1 and S3 stator windings are still equal and oppose each other. This causes a canceling effect, which results in zero stator current and no torque. Without the torque required to move the receiver rotor, the system remains in correspondence and the reversing of the stator connections has no noticeable effect on the system at 0º.

Suppose the transmitter rotor is turned counterclockwise 60º, as shown in view A of figure 1-17. The TX rotor is now aligned with S1. This results in maximum magnetic coupling between the TX rotor and the S1 winding. This maximum coupling induces maximum voltage in S1. Because S1 is connected to S3 of the TR, a voltage imbalance occurs between them. As a result of this voltage imbalance, maximum current flows through the S3 winding of the TR causing it to have the strongest magnetic field. Because the other two fields around S2 and S1 decrease proportionately, the S3 field has the greatest effect on the resultant TR stator field. The strong S3 stator field forces the rotor to turn 60º clockwise into alignment with itself, as shown in view B. At this point, the rotor of the TR induces canceling voltages in its own stator coils and causes the rotor to stop. The system is now in correspondence. Notice that by reversing S1 and S3, both synchro rotors turn the same amount, but in OPPOSITE DIRECTIONS.

We must emphasize that the only stator leads ever interchanged, for the purpose of reversing receiver rotation, are S1 and S3. S2 cannot be reversed with any other lead since it represents the electrical zero position of the synchro. As you know, the stator leads in a synchro are 120º apart. Therefore, any change in the S2 lead causes a 120º error in the synchro system and also reverses the direction of rotation.

In new or modified synchro systems, a common problem is the accidental reversal of the R1 and R2 leads on either the transmitter or receiver. This causes a 180º error between the two synchros, but the direction of rotation remains the same.

Q-28. What two receiver leads are reversed to reverse the rotor's direction of rotation?

Q-29. What is the most likely problem if the transmitter shaft reads 0º when the receiver shaft indicates 180º?

TORQUE DIFFERENTIAL SYNCHRO SYSTEMS

The demands on a synchro system are not always as simple as positioning an indicating device in response to information received from a single source (transmitter). For example, an error detector used in checking weapons equipment uses a synchro system to determine the error in a gun's position with respect to the positioning order. To do this, the synchro system must accept two signals, one containing the positioning order and the other corresponding to the actual position of the gun. The system must then compare the two signals and position an indicating dial to show the difference between them, which is the error.

Obviously, the simple synchro transmitter-receiver system discussed so far could not handle a job of this sort. A different type of synchro is needed, one which can accept two signals simultaneously, add or subtract the signals, and furnish an output proportional to their sum or difference. This is where the SYNCHRO DIFFERENTIAL enters the picture. A differential can perform all of these functions.

There are two types of differential units - differential transmitters and differential receivers. The differential transmitter (TDX) accepts one electrical input and one mechanical input and produces one electrical output. The differential receiver (TDR) accepts two electrical inputs and produces one mechanical output. A comparison of the TDX and TDR is shown in figure 1-18. The torque differential transmitter and the torque differential receiver can be used to form a DIFFERENTIAL SYNCHRO SYSTEM. The system can consist either of a torque transmitter (TX), a torque differential transmitter (TDX), and a torque receiver (TR), (TX-TDX-TR); or two torque transmitters (TXs) and one torque differential receiver (TDR), (TX-TDR-TX). Before beginning a discussion of the systems using differentials, we need to provide a brief explanation on the newly introduced synchros, the TDX and the TDR.

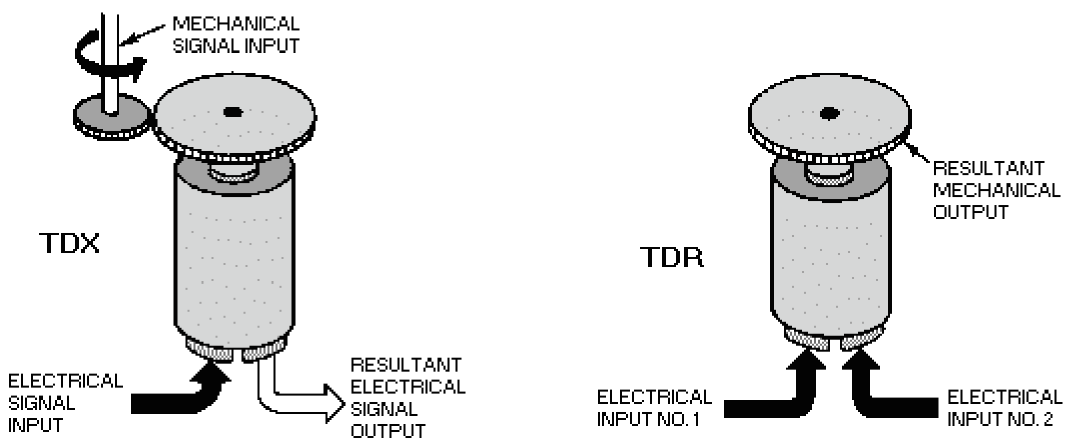


Figure 1-18.—Torque differentials.

Torque Differential Transmitter

In the torque differential transmitter, BOTH the rotor and stator windings consist of three Y-connected coils, as illustrated in view A of figure 1-19. The stator is normally the primary, and receives its input signal from a synchro transmitter. The voltages appearing across the differential's rotor terminals (R1, R2, and R3) are determined by the magnetic field produced by the stator currents, the physical positioning of the rotor, and the step-up turns ratio between the stator and the rotor. The magnetic field, created by the stator currents, assumes an angle corresponding to that of the magnetic field in the transmitter supplying the signal. The position of the rotor controls the amount of magnetic coupling that takes place between the stator magnetic field and the rotor, and therefore, the amount of voltage induced into the rotor windings. If the rotor position changes in response to a mechanical input, then the voltages induced into its windings also change. Therefore, the output voltage of the TDX varies as a result of either a change in the input stator voltage or a change in the mechanical input to the rotor. This electrical output of the TDX may be either the SUM or the DIFFERENCE of the two inputs depending upon how the three units (the TX, the TDX, and the TR) are connected.

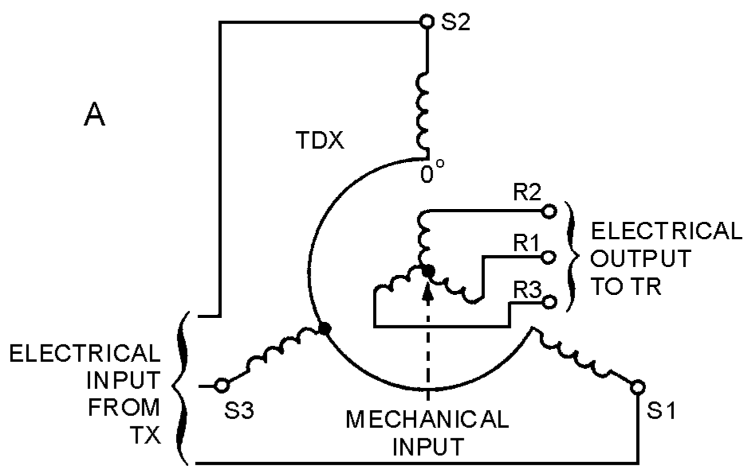


Figure 1-19A.—Torque differential transmitter.

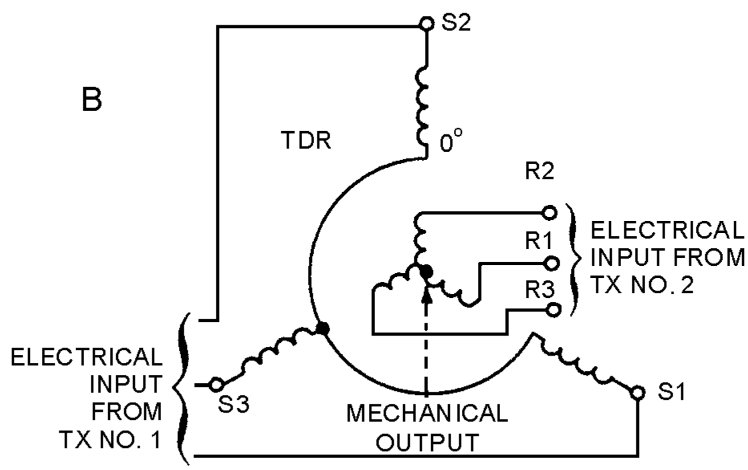


Figure 1-19B.—Torque differential receiver.

Torque Differential Receiver

The torque differential transmitter (TDX) and the torque differential receiver (TDR) are ELECTRICALLY IDENTICAL. The only difference in their construction is that the receiver (TDR) has a damper, which serves the same purposes as the damper in the TR — it prevents the rotor from oscillating. The real difference in the receiver lies in its application. It provides the mechanical output for a differential synchro system usually as the sum or difference of two electrical inputs from synchro transmitters. As in the case with the TDX, the TDR addition or subtraction function depends upon how the units in the system are connected.

Basically, the torque differential receiver operates like the electromagnets we discussed earlier in this chapter. In view B, the rotor and stator of the torque differential receiver receive energizing currents from two torque transmitters. These currents produce two resultant magnetic fields, one in the rotor and the other in the stator. Each magnetic field assumes an angle corresponding to that of the magnetic field in the transmitter supplying the signal. It is the interaction of these two resultant magnetic fields that causes the rotor in the TDR to turn.

Q-30. What is the purpose of using differential synchros instead of regular synchros?

Q-31. What are the two types of differential synchros?

Q-32. Other than their physical differences, what is the major difference between a TDX and a TDR?

Q-33. What determines whether a differential synchro adds or subtracts?

TX-TDX-TR System Operation (Subtraction)

Now that you know how the individual units work, we can continue our discussion with their application in different systems. The following sections explain how the TDX and TDR are used with other synchros to add and subtract.

To understand how a TDX subtracts one input from another, first consider the conditions in a TX-TDX-TR system when all the rotors are on 0º, as in view A of figure 1-20. In this case, the TDX is on electrical zero and merely passes along the voltages applied to its windings without any change. Therefore, the TX stator voltages are felt at the TDX rotor. With the system in perfect balance, the TDX rotor voltages equal and oppose the TR stator voltages so that no current flows in the circuit. Since there is no current to produce the torque required to move the TR rotor, the system will remain in this condition, thus solving the equation 0º – 0º = 0º.

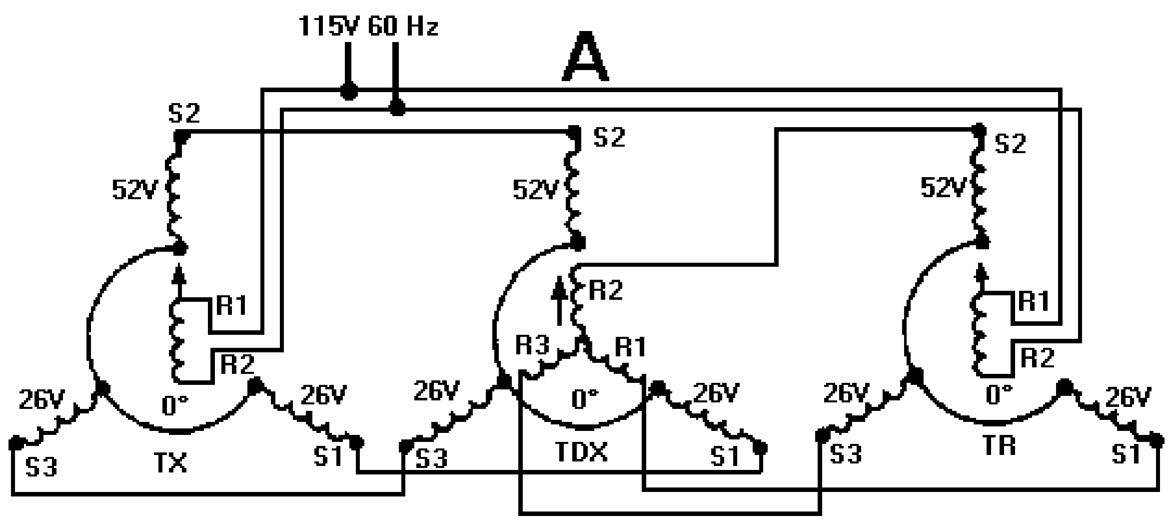


Figure 1-20A.—TX-TDX-TR system operation (subtraction).

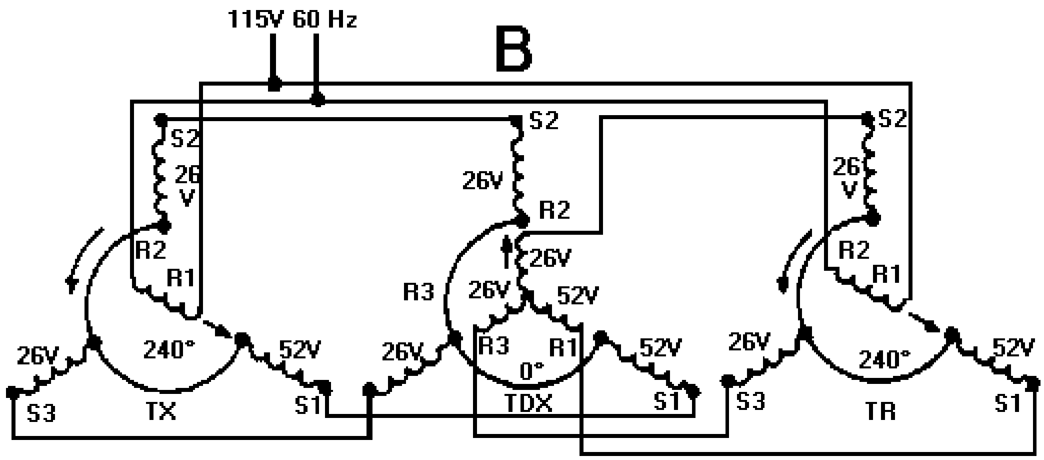


Figure 1-20B.—TX-TDX-TR system operation (subtraction).

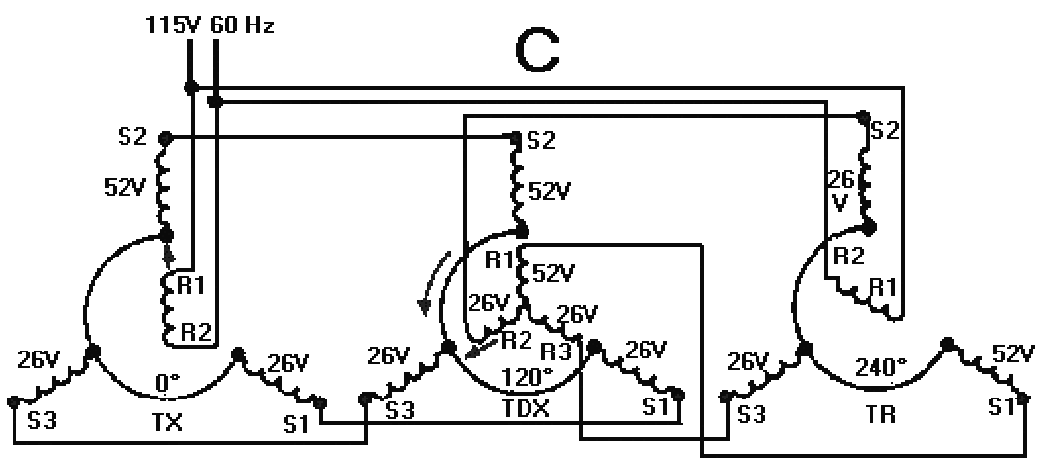


Figure 1-20C.—TX-TDX-TR system operation (subtraction).

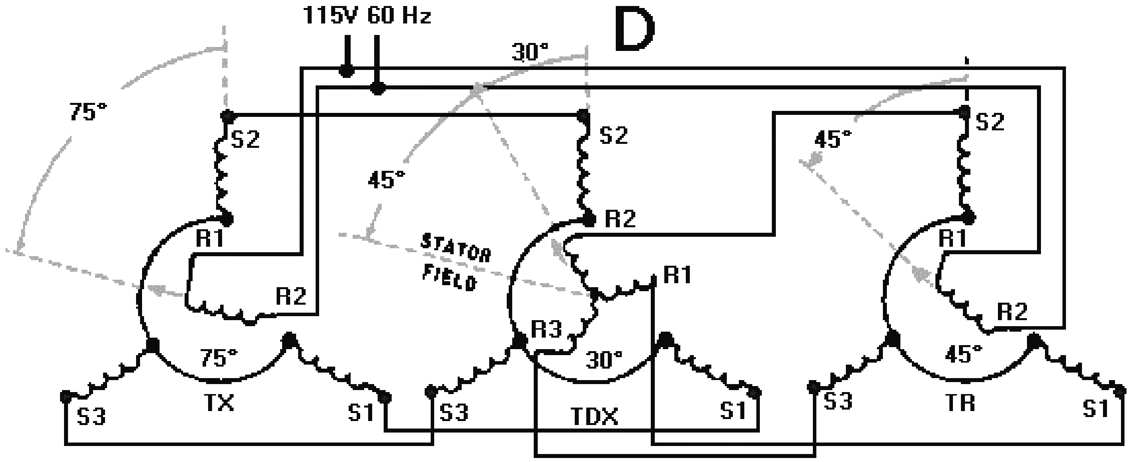


Figure 1-20D.—TX-TDX-TR system operation (subtraction).

Up to this point, we have discussed the number of degrees a rotor is turned. Now, it is important to point out the labeling of synchro positions. Labeling is necessary to determine the actual position of the synchro's rotor. Notice that synchro rotor positions are labeled from 0º, increasing in a counterclockwise direction. It is common practice to refer to a synchro transmitter as being on 120º when its rotor is pointing toward the S3 winding. Do not confuse these positions with the number of degrees a rotor is turned.

Assume that a 240º input is applied to the system, as indicated in view B, by turning the TX rotor to its 240º position. At this position maximum voltage is induced into the S1 winding of the TX and coupled to S1 of the TDX. Since the TDX rotor is on 0º, it passes this maximum voltage (via R1) along to the S1 winding of the TR. The stator magnetic field in the receiver now lines up in the direction of the S1 winding and causes the rotor to turn counterclockwise to the 240º position. This illustrates an important point:

Whenever the TDX rotor is at 0º, the TR rotor follows the TX rotor exactly. In the present case, the system has just solved the equation 240º – 0º = 240º.

Before we go to another example, you need to understand that when you subtract a higher value of degrees from a lower value of degrees, you add 360º to the lower value and subtract directly.

For example: 10º - 260º

Add 360º to lower value: 10º + 360º = 370º

Subtract: 370º – 260º = 110º

In the next example, hold the TX rotor on 0º and turn the TDX rotor to 120º, as illustrated in view C of figure 1-20. In this situation, R1 of the TDX has maximum voltage induced in its winding since it is in line with S2. With R1 of the TDX connected to S1 of the TR, the TR stator magnetic field lines up in the direction of S1 and causes the TR rotor to turn clockwise to the 240º position. Given, then, that the TX is on 360º (or the 0º position), and subtracting the 120º displacement of the TDX rotor, the difference is 240º. This is the position at which the TR rotor comes to rest. Therefore, the system has solved the equation 360º – 120º = 240º. The actual subtraction operation of the TDX is a little more apparent in the next example.

Now, consider what happens in view D when the TX rotor is turned manually to 75º and the TDX rotor is set manually on 30º. When the TX rotor is turned to 75º, magnetic coupling increases between the rotor and S1. This, in turn, increases the voltage in S1 and, therefore, the magnetic field surrounding it. At the same time, the field in S2 and S3 decreases proportionately. This causes the resultant TX stator field to line up in the direction of its rotor. The increased voltage in S1 of the TX also causes an increase in current flow through S1 in the TDX, while decreased currents flow through S2 and S3. Therefore, a strong magnetic field is established around the S1 winding in the TDX. This field has the greatest effect on the resultant TDX stator field and causes it to line up in the same relative direction as the TX stator field (75º). The TDX stator field does not move from this 75º position because it is controlled by the position of the TX rotor. However, its angular position with respect to the R2 winding decreases by 30 when the TDX rotor is turned. Therefore, the signal induced into the TDX rotor and transmitted to the TR is 45º. The TR rotor responds to the transmitted signal and turns counterclockwise to 45º. This system has just solved the equation 75º – 30º = 45º.

TX-TDX-TR System Operation (Addition)

Frequently it is necessary to set up a TX-TDX-TR system for addition. This is done by reversing the S1 and S3 leads between the TX and the TDX, and the R1 and R3 leads between the TDX and the TR. With these connections, the system behaves as illustrated in figure 1-21. Consider what happens when the TX rotor is turned to 75º, while the TDX is set at 0º view A. In the TX, with the rotor at 75º, increased coupling between the rotor and S1 increases the current in, and consequently the magnetic field around, that coil. At the same time, the field strengths of S2 and S3 decrease proportionately. This causes the resultant field of the TX stator to rotate counterclockwise and align itself with its rotor field. The system is now connected so the increased current in S1 of the TX flows through S3 of the TDX, while decreased currents flow through S1 and S2. Therefore, in the TDX, the resultant stator field is shifted 75º clockwise because of the stronger field around S3. Since the rotor of the TDX is on 0º, the voltage in the rotor is not changed but simply passed on to the TR. Remember, the R1 and R3 leads between the TDX and the TR have also been reversed. Just as in the simple TX-TR system with S1 and S3 leads interchanged, torque is developed in the TR, which turns the rotor in a direction opposite to the rotation of the TDX stator field. Therefore, the TR rotor rotates 75º counterclockwise and aligns itself with the TX rotor. Thus, the TX-TDX-TR system connected for addition behaves in the same way as the system connected for subtraction as long as the TDX rotor remains on 0º. When this condition exists, the TR rotor follows the TX rotor exactly. As you can see, the system in view. A just solved the equation 75º + 0º = 75º.

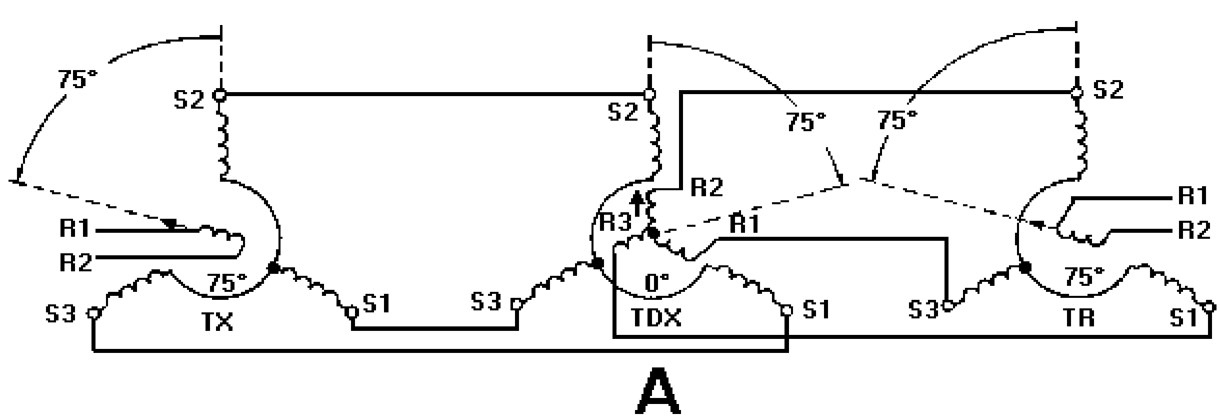


Figure 1-21A.—TX-TR system operation (addition).

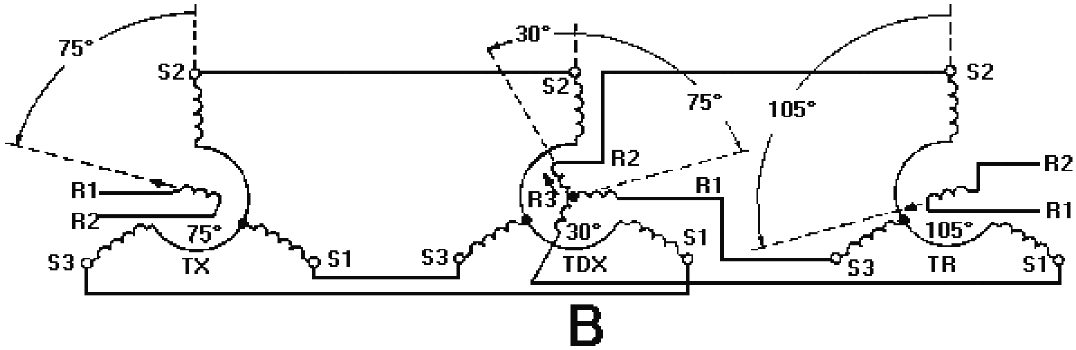


Figure 1-21B.—TX-TR system operation (addition).

Now, with the TX in the same position (75º), the TDX rotor is turned to 30º (view B). The angle between the TDX stator field and R2 is then increased by 30º. This appears to the TR as an additional rotation of the TDX stator field. In transmitting the TX signal to the TR, the TDX adds the amount its own rotor has turned. The TR rotor now turns to 105º. Thus, the equation 75º + 30º = 105º is solved.

Q-34. In a TDX system when does the TR rotor follow the TX rotor exactly?

Q-35. What is the angular position of a TX rotor when it is pointing toward the S1 winding? (Hint. Remember synchros are labeled counter clockwise from 0º.)

Q-36. In a TDX system with standard synchro connections, the TX rotor is at 120º and the TDX rotor is at 40º. What position will the TR indicate?

Q-37. What connections in a TDX system are reversed to set up the system for addition?

TX-TDR-TX System Operation (Subtraction)

As we previously explained, the differential receiver differs chiefly from the differential transmitter in its application. The TDX in each of the previous examples combined its own input with the signal from a synchro transmitter (TX) and transmitted the sum or difference to a synchro receiver (TR). The synchro receiver then provided the system's mechanical output. When the differential receiver (TDR) is used, the TDR itself provides the system's mechanical output. This output is usually the sum or difference of the electrical signals received from two synchro transmitters. Figure 1-22 shows a system consisting of two TXs (No. 1 and No. 2) and a TDR connected for subtraction.

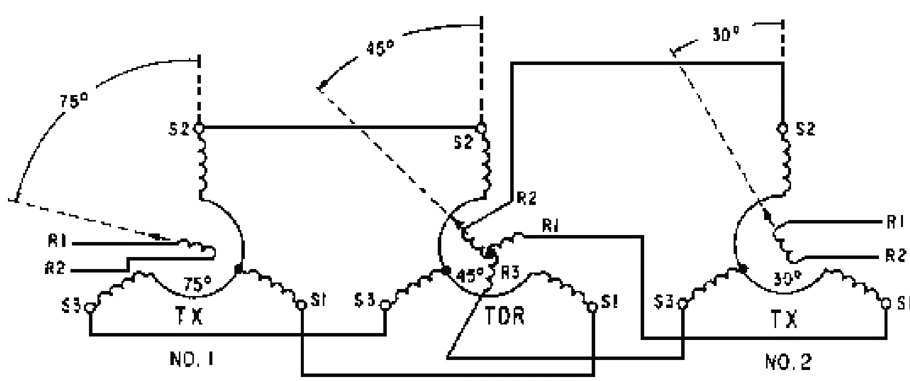


Figure 1-22.—TX-TDR-TX system operation (subtraction).

In this figure the signal from TX No. 1 rotates the resultant TDR stator field 75º counterclockwise. In a similar manner, the signal from TX No. 2 rotates the resultant TDR rotor field counterclockwise 30º. Since the two resultant fields are not rotated by equal amounts, a torque is exerted on the rotor to bring the two fields into alignment. This torque causes the rotor to turn to 45º, the point at which the two fields are aligned. To bring the two fields into alignment, the TDR rotor need turn only through an angle equal to the difference between the signals supplied by the two TXs.

TX-TDR-TX System Operation (Addition)

To set up the previous system for addition, it is necessary to reverse only the R1 and R3 leads between the TDR rotor and TX No. 2. With these connections reversed, the system operates as shown in figure 1-23.

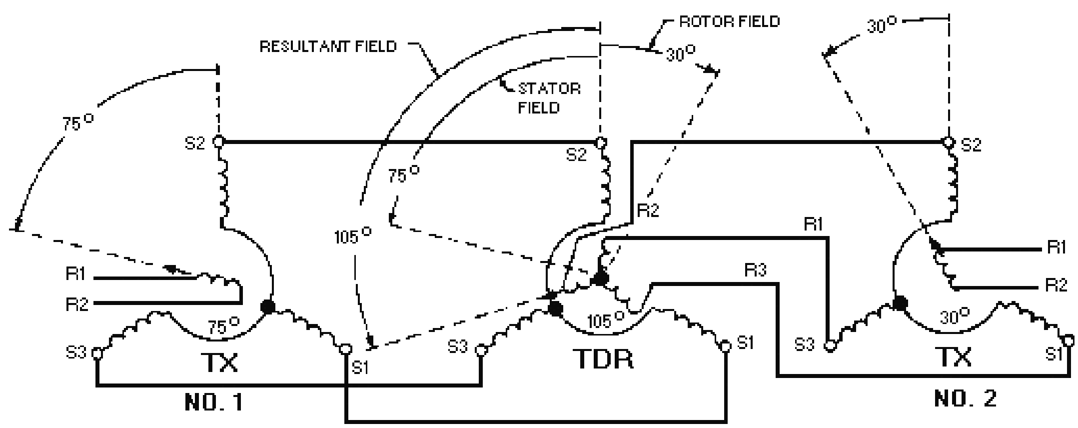


Figure 1-23.—TX-TDR-TX system operation (addition).

Assume the TDR rotor is initially at 0º. TX No. 1 is turned to 75º, and TX rotor No. 2 is turned to 30º. The TDR stator field still rotates counterclockwise 75º, but because R1 and R3 on the TDR rotor are reversed, its rotor field rotates 30º clockwise. The angular displacement of the two fields then, with respect to each other, is the sum of the signals transmitted by the two TXs. The magnetic force pulling the TDR rotor field into alignment with that of the stator turns the TDR rotor to 105º. Therefore, the system solves the equation 75º + 30º = 105º.

Q-38. What connections in a TDR system are reversed to set up the system for addition?

Q-39. In a TDR system connected for addition in what direction will the TDR rotor field turn when the TX rotor to which it is connected turns counterclockwise?

CONTROL SYNCHRO SYSTEMS

It should be clear to you from our discussion of torque synchro systems that, since they produce a relatively small mechanical output, they are suitable only for very light loads. Even when the torque system is moderately loaded, it is never entirely accurate because the receiver rotor requires a slight amount of torque to overcome its static friction.

When large amounts of power and a higher degree of accuracy are required, as in the movement of heavy radar antennas and gun turrets, torque synchro systems give way to the use of CONTROL

SYNCHROS. Control synchros by themselves cannot move heavy loads. However, they are used to "control" servo systems, which in turn do the actual movement. Servo systems are covered in depth in the next chapter in this module.

There are three types of control synchros: the CONTROL TRANSMITTER (CX), the CONTROL TRANSFORMER (CT), and the CONTROL DIFFERENTIAL TRANSMITTER (CDX). The control transmitter (CX) and the control differential transmitter (CDX) are identical to the TX and the TDX we discussed previously except for higher impedance windings in the CX and CDX. The higher impedance windings are necessary because control systems are based on having an internal voltage provide an output voltage to drive a large load. Torque systems, on the other hand, are based on having an internal current provide the driving torque needed to position an indicator. Since we discussed the theory and operation of the TX and the TDX earlier, we will not discuss their counterparts, the CX and CDX. However, we will cover the third control synchro, the CT, in depth during this discussion.

CONTROL TRANSFORMERS

A control transformer is just what its name implies-a control synchro device accurately governing some type of power amplifying device used for moving heavy equipment. Figure 1-24 shows a phantom view of a typical CT and its schematic symbols.

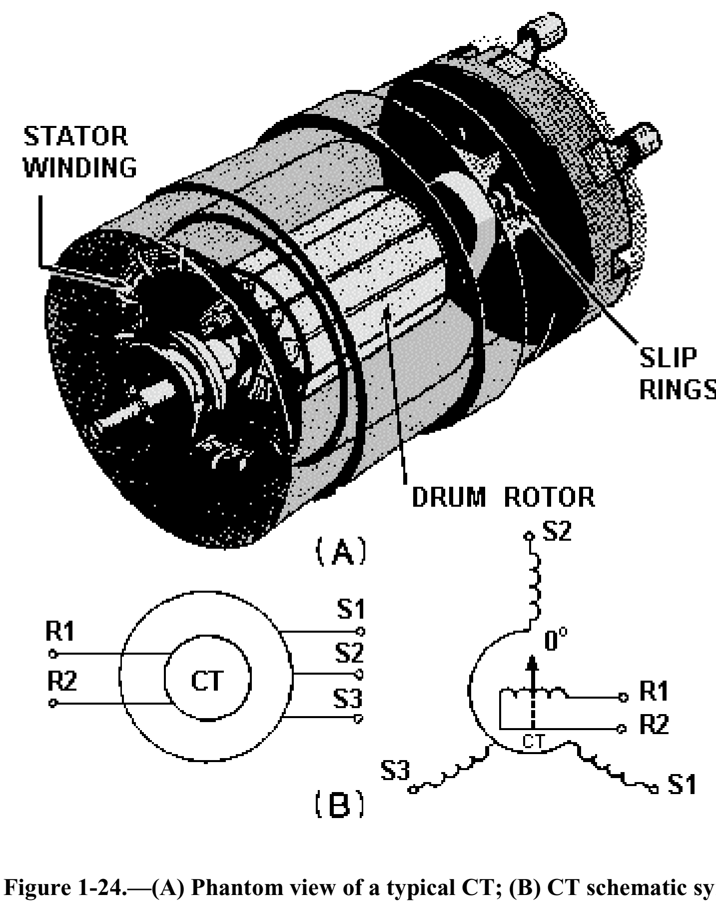


Figure 1-24.—(A) Phantom view of a typical CT; (B) CT schematic symbols.

The CT compares two signals, the electrical signal applied to its stator and the mechanical signal applied to its rotor. Its output is a difference signal that controls a power amplifying device and thus the movement of heavy equipment.

The unit construction and physical characteristics of a control transformer are similar to those of a control transmitter or torque receiver, except that there is no damper and the rotor is a drum or wound rotor rather than a salient-pole rotor.

An interesting point about the rotor is that it is never connected to an ac supply and, therefore, induces no voltages in the stator coils. As a result, the CT stator currents are determined solely by the voltages applied to the high-impedance stator windings. The rotor itself is wound so that its position has very little effect on the stator currents. Also, there is never any appreciable current flowing in the rotor because its output voltage is always applied to a high-impedance load. As a result, the CT rotor does not try to follow the magnetic field of its stator and must be turned by some external force.

The stator windings of the CT are considered to be the primary windings, and the rotor windings the secondary windings. The output, which is taken off the R1 and R2 rotor leads, is the voltage induced in the rotor windings. The phase and amplitude of the output voltage depend on the angular position of the rotor with respect to the magnetic field of the stator.

Q-40. What type of synchro is used in systems requiring large amounts of power and a high degree of accuracy?

Q-41. What are the three types of control synchros?

Q-42. How do the CX and CDX differ from the TX and TDX?

Q-43. What three things prevent a CT rotor from turning when voltages are applied to its stator windings?

CONTROL SYNCHRO SYSTEM OPERATION

A control synchro system consisting of a control transmitter and a control transformer is illustrated in figure 1-25. The stator windings of the CX are connected to the stator windings of the CT and both synchros are shown on 0º. Notice, that at 0º, the CT rotor is perpendicular to its S2 winding. This is contrary to what we have learned so far about synchros, but it is just another peculiarity of the CT. When the rotor of the CX is on 0º, the rotor's magnetic field points straight up as shown (the black arrow). The voltages induced in the CX stator windings, as a result of this field, are impressed on the CT stator windings through the three leads connecting the S1, S2, and S3 terminals. Exciting currents proportional to these voltages flow in the CT stator windings and establish a magnetic field in the CT in the same direction (white arrow) as the magnetic field (black arrow) in the CX. Observe that the rotor of the CT is perpendicular to the stator magnetic field and, therefore, the induced voltage in the rotor is zero, as indicated by the straight line on the oscilloscope presentation.

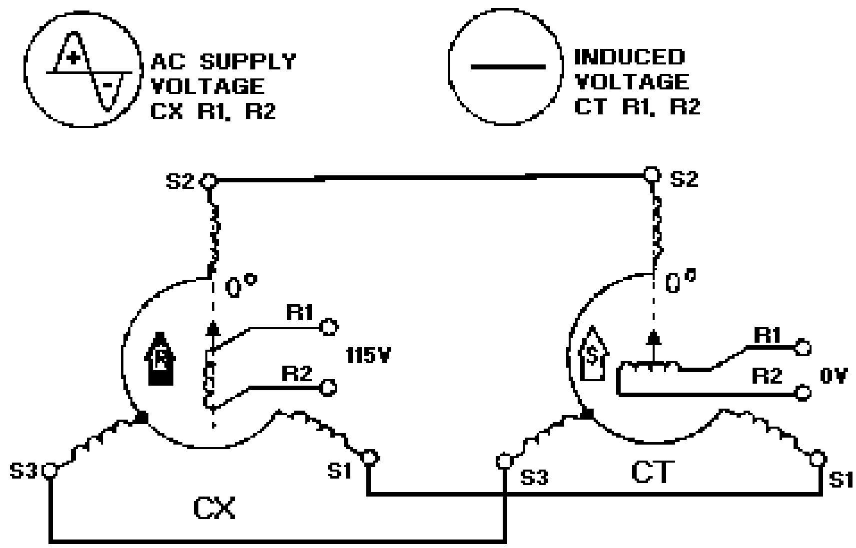


Figure 1-25.—CX-CT system operation with rotor in correspondence.

When the CT rotor is rotated 90º, as shown in figure 1-26, the rotor is parallel to the resultant stator field Maximum magnetic coupling occurs between the rotor and stator fields at this point. As a result of this coupling, the stator windings induce a maximum of 55 volts into the rotor winding. The phase of this voltage depends upon the direction in which the CT rotor is turned. The rotor of the CT is wound so that clockwise rotation of the stator magnetic field induces a voltage across the rotor which is proportional to the amount of rotation and in phase with the ac supply voltage. Counterclockwise rotation of the stator magnetic field produces a voltage that is still proportional to the amount of rotation, but 180º out of phase with the supply voltage. Keep in mind that the clockwise rotation of the CT stator magnetic field is the same as the counterclockwise rotation of the CT rotor. This phase relationship between the ac supply voltage and the CT output voltage becomes more apparent in figure 1-27.

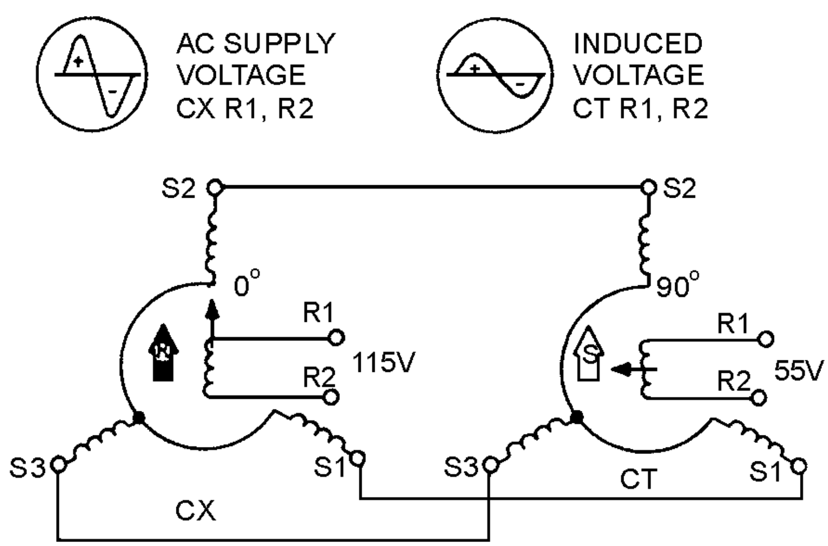


Figure 1-26.—CX-CT system operation with the CX rotor at 0º and the CT rotor at 90º.

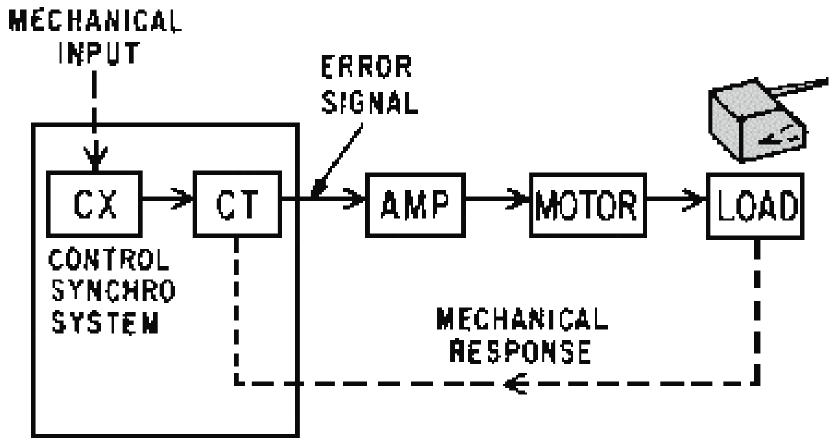


Figure 1-27A.—Control synchro system operation.

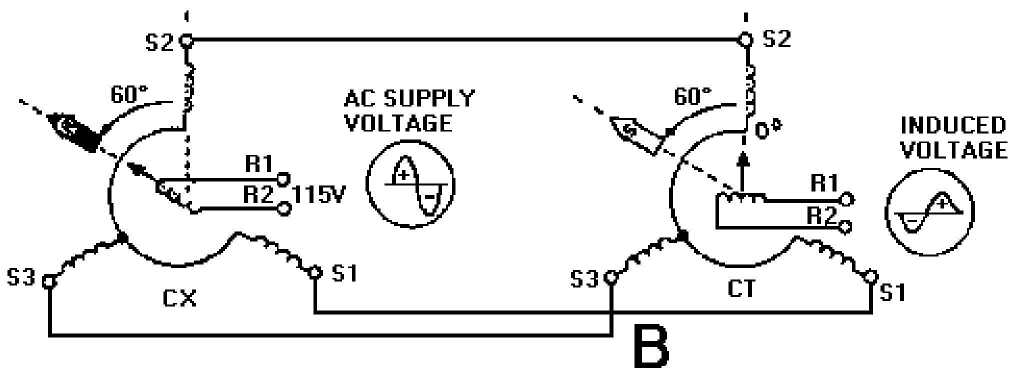


Figure 1-27B.—Control synchro system operation.

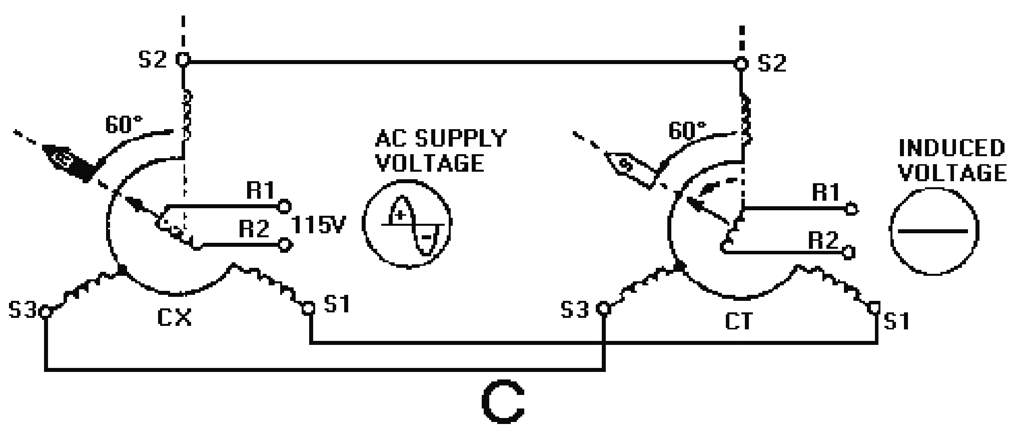


Figure 1-27C.—Control synchro system operation.

When the rotor of the CX in view A of figure 1-27 is turned 60º clockwise, the magnetic field in the CX (black arrow) and the magnetic field in the CT (white arrow) also rotate 60º clockwise. This action induces a voltage in the CT rotor that is in phase with the ac supply, as indicated by the oscilloscope presentation. If the rotor of the CX in view B is turned 60º in a counterclockwise direction from its 0º position, the magnetic field (white arrow) in the CT also rotates counterclockwise through the same number of degrees as the CX. Since the magnetic field in the stator of the CT cuts through the rotor in the opposite direction, the induced voltage in the rotor is now out of phase with the ac supply to the CX, as shown in the oscilloscope presentation.

At times it is necessary, because the CT is used to control servo systems, to have the CT output reduced to zero volts to prevent any further movement of a load. To accomplish this, it is necessary to turn the rotor of the CT through the same number of degrees and in the same direction as the rotor of the CX. This places the CT rotor perpendicular to its own stator field and reduces its output to zero volts as illustrated in view C.

The CT output voltage discussed throughout this section is commonly referred to as an ERROR SIGNAL. This is because the voltage represents the amount and direction that the CX and CT rotors are out of correspondence. It is this error signal that eventually is used in moving the load in a typical servo system.

Now that we have covered the basic operation of the control synchro system, let us see how this system works with a servo system to move heavy equipment. Figure 1-28 shows a block diagram of a typical servo system that uses a control synchro system. Assume the shaft of the CX in this system is turned by some mechanical input. This causes an error signal to be generated by the CT because the CX and the CT rotors are now out of correspondence. The error signal is amplified by the servoamplifier and applied to the servomotor. The servomotor turns the load, and through a mechanical linkage called RESPONSE, also turns the rotor of the CT. The servomotor turns the rotor of the CT so that it is once again in correspondence with the rotor of the CX, the error signal drops to zero volts, and the system comes to a stop.

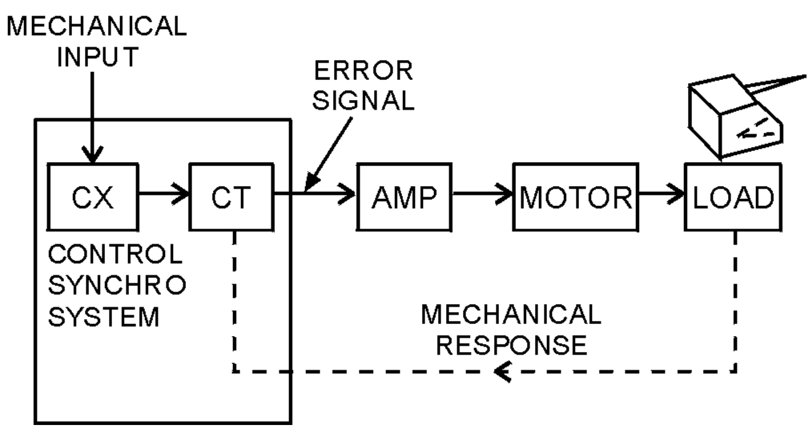


Figure 1-28.—A positioning servo system using a control synchro system.

Q-44. When a CT is on electrical zero, what is the relationship between its rotor and the S2 winding?

Q-45. What is the amplitude and voltage induced into the rotor when the CX is turned 90º while the CT remains on electrical zero?

Q-46. What is the name given to the electrical output of a CT?

Q-47. In a control synchro system, when is the output of the CT reduced to zero?

SYNCHRO CAPACITORS

As we stated earlier, the speed and accuracy of data transmission are most important. With the use of more complex synchros, like the differential and the control transformer, the accuracy of the synchro systems may be affected. The following discussion will deal with how complex synchros affect the accuracy of synchro systems and what can be done to keep this accuracy as high as possible. Synchro capacitors play a major role in maintaining a high degree of accuracy in synchro systems.

When a torque transmitter is connected to a torque receiver (TX-TR), very little, if any, current flows in the stators when the rotors are in correspondence. This is because the voltages induced in the TR windings almost exactly balance out the voltages induced in the TX windings. As a result, the TR is very sensitive to small changes in the position of the TX rotor, causing the TR to follow the TX with a high degree of accuracy.

When a synchro system contains differential synchros (TDX or CDX), the stator currents at correspondence are greater than they are in a single TX-TR system. The reason is the step-up turns ratio between the stator and rotor in the differential synchro.

In a synchro system that uses a CT, stator current at correspondence is also greater than in a TX-TR system. In this case, however, this reason is that the CT rotor is not energized and as a result no voltage is induced in the stator to oppose the voltage in the transmitter stator. The overall effect of this increase in stator current is to reduce the accuracy of the system. To maintain high accuracy in a synchro system containing either differential units or CTs, the stator currents must be kept to a minimum. This is done by connecting synchro capacitors in the circuit.

To understand the operation of a synchro capacitor and how it reduces current drain on the transmitter requires a recollection of the voltage and current relationships in inductive and capacitive circuits. As you learned in module 2 of this series, current lags voltage by 90º in a purely inductive circuit. You also know that an ideal inductor is impossible to make because there is always resistance present. Therefore, an inductor has a combination of inductive reactance and resistance. Since current and voltage are always in phase in a resistive circuit and 90º out of phase in an inductive circuit, we can say that there are two currents in an inductor-the loss current, which is the resistive (in-phase) current, and the magnetizing current, which is the inductive (out-of-phase) current. It is this magnetizing current that we would like to eliminate in the stator coils of the TDX, CDX, and CT because it makes up most of the line current.

Keeping in mind that current leads voltage by 90º in a capacitive circuit, let's see what happens to magnetizing current when a capacitor is added to the circuit.

Suppose a capacitor is hooked up across one of the stator coils of a TDX and its capacitance is adjusted so that its reactance equals the reactance of the coil. Since the two reactances are equal, the current they draw from the line must also be equal. However, these currents are going to be 180º out of phase, because the current in the coil lags the line voltage, while the capacitor's current leads it. Since the two currents are equal in magnitude but opposite in phase, they cancel. The total line current is reduced by this effect and, if a capacitor is placed across each coil in the TDX, the line current decreases even further. This, in effect, increases torque in synchro systems near the point of correspondence and, therefore, increases overall system accuracy.

Connecting capacitors across individual stator windings is impractical because it requires that the stator winding's common connection be outside the synchro. Since this is not done with synchros, another method has been devised to connect up the capacitors which works just as well. This method is shown in figure 1-29.

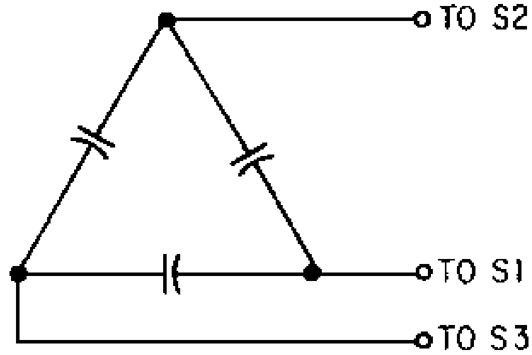


Figure 1-29.—The synchro capacitor.

The three delta-connected capacitors, shown in figure 1-29, usually come as a unit mounted in a case with three external connections. The entire unit is called a SYNCHRO CAPACITOR. The synchro capacitor is made in many sizes to meet the requirements of all sizes of standard differentials and control transformers. The synchro capacitor is rated by its total capacity, which is the sum of the individual capacities in the unit.

Figure 1-30 shows how a synchro capacitor affects the operation of a control synchro system. In this figure, the capacitor is placed between the CX and the CT. Two current meters are also placed in the circuit to show the effect the capacitor has on stator current. The meter connected between the capacitor and the CT reads normal stator current, 32 milliamperes (mA). This current would normally flow in the stator of the CX if the synchro capacitor were not connected. The other meter reads 10 mA, which is what is left of the original stator current after the magnetizing current has been canceled by the synchro capacitor. By reducing the current drain on the transmitter, the sensitivity and accuracy of the system increase.

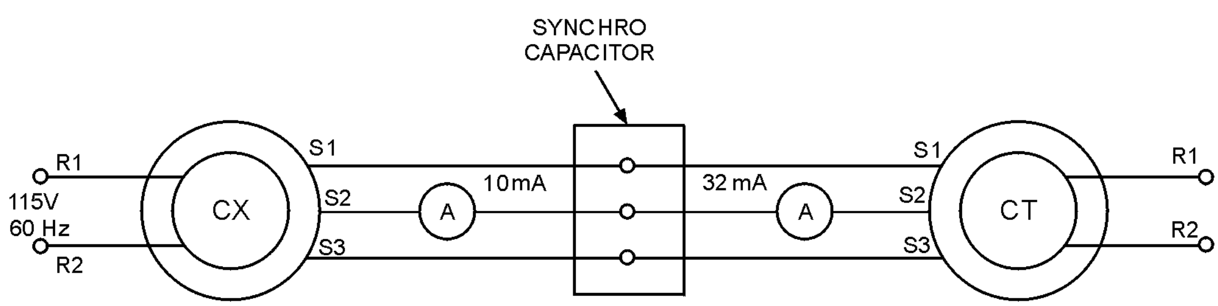


Figure 1-30.—The use of a synchro capacitor with a CT.

Figure 1-31 shows another application of a synchro capacitor; this time in a differential system in this circuit the capacitor is placed between a TX and a TDX. The meter readings show the same comparison between currents as in the previous paragraph. The only significant difference between this circuit and the one in figure 1-30 is that the differential draws more stator current than the CT.

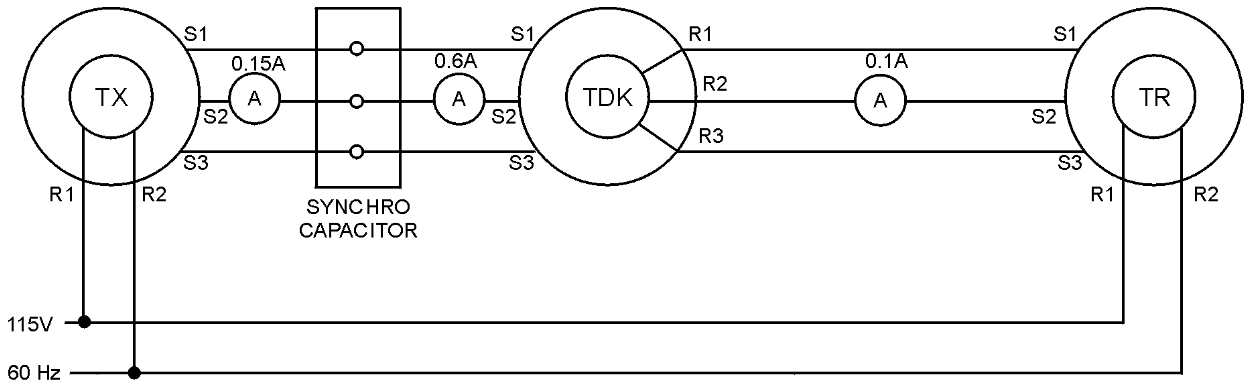


Figure 1-31.—The use of a synchro capacitor with a TDX.

Some synchro systems contain a differential and a control transformer, as illustrated in figure 1-32. In this figure, there are large stator currents flowing in the CX, since it supplies all the losses as well as the magnetizing current for both synchros. Two meters are placed in the circuit to show the value of stator current for the CDX and CT. Another meter is placed in series with the ac excitation voltage to show the amount of current being drawn from the ac line is 0.9 ampere.

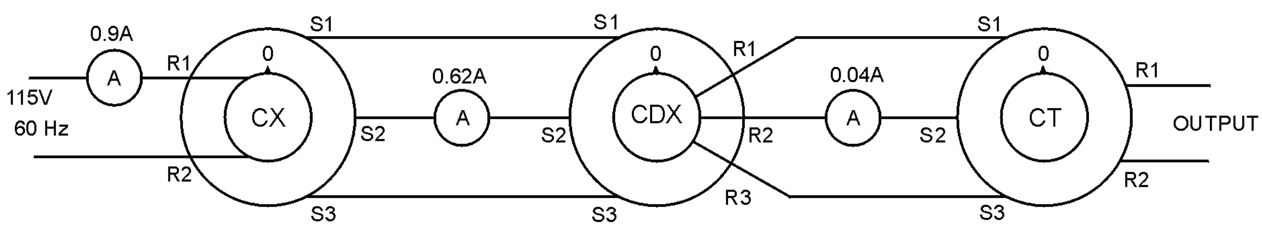


Figure 1-32.—Synchro current in a control synchro system using a CDX and a CT.

Adding synchro capacitors to this system, as shown in figure 1-33, greatly reduces the stator currents and improves the efficiency of the system. Also, notice that the line current is reduced from 0.9 ampere in figure 1-32 to 0.65 ampere in figure 1-33.

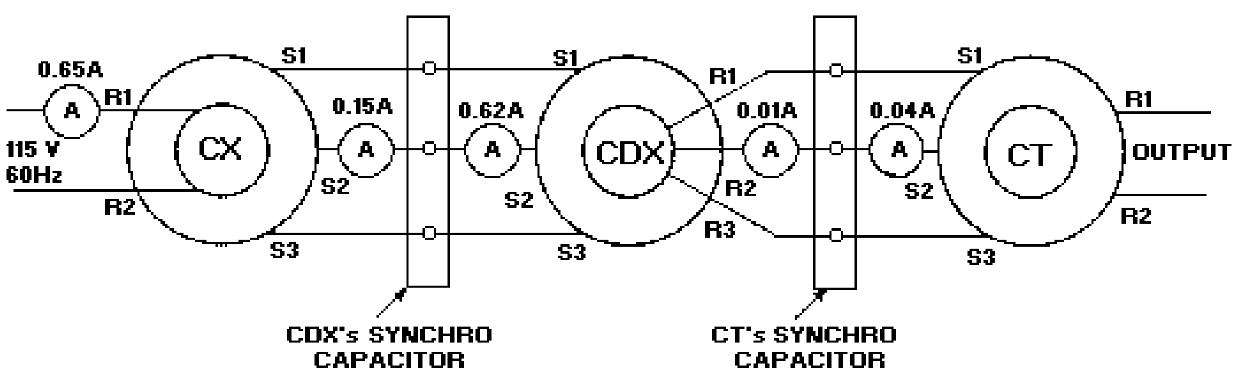


Figure 1-33.—The effects of synchro capacitors in a control synchro system using a CDX and a CT.

When a synchro capacitor is used, it is always placed physically close to the differential or control transformer whose current it corrects. This is done to keep the connections as short as possible, because high currents in long leads increase the transmitter load and reduce the accuracy of the system.

We must stress that the synchro capacitor should never be used in a simple transmitter-receiver system. This is because stator currents in this system are zero at correspondence and the addition of a synchro capacitor would only increase the stator current and throw the system out of balance.

Q-48. What is the purpose of the synchro capacitor?

Q-49. What type of synchros usually require the use of synchro capacitors?

Q-50. What type of current is eliminated by synchro capacitors?

Q-51. How are synchro capacitors connected in a circuit?

Q-52. Why are synchro capacitors placed physically close to differentials transmitters and CTs?

MULTISPEED SYNCHRO SYSTEMS

The data to be transmitted is another important factor that we must consider when we discuss the accuracy of a synchro system. If this data covers a wide range of values, the basic synchro system is unable to detect any small changes in the data. When this happens, the accuracy of the system decreases. Because of this difficulty, multispeed synchro systems were developed. They handle this type of data very effectively and still maintain a high degree of accuracy.

Multispeed synchro systems use more than one speed of data transmission. The speed of data transmission is, simply, the number of times a synchro transmitter rotor must turn to transmit a full range of values. For example, a system in which the rotors of synchro devices turn in unison with their input and output shafts is commonly called a 1-speed data transmission system. In this system, the transmitter's rotor is geared so that 1 revolution of the rotor corresponds to 1 revolution of the input. Until now, the discussion of synchro systems has dealt exclusively with this 1-speed system.

In a 36-speed data transmission system, the rotor of the synchro transmitter is geared to turn through 36 revolutions for 1 revolution of its input. Units transmitting data at one speed are frequently called 1-speed synchros; a unit transmitting data at 36-speed would be a 36-speed synchro, and so forth.

It is quite common in synchro systems to transmit the same data at two different speeds. For example, ship's course information is usually transmitted to other locations on a ship at 1-speed and 36-speed. A system in which data is transmitted at two different speeds is called a dual- or double-speed system. Sometimes a dual-speed system will be referred to by the speeds involved, for example a 1- and 36-speed system.

In summary, the speed of data transmission is referred to as 1-speed, 2-speed, 36-speed, or some other definite numerical ratio. To indicate the number of different speeds at which data is transmitted, refer to the system as being a single-speed, dual-speed, or tri-speed synchro system.

SINGLE-SPEED SYNCHRO SYSTEM

If the data to be transmitted covers only a small range of values, a single-speed system is normally accurate enough. However, in applications where the data covers a wide range of values and the accuracy of the system is most important, the 1-speed system is not adequate enough and must be replaced by a more suitable system. Increasing the speed of a single-speed system from 1-speed to 36-speed provides greater accuracy, but the self-synchronous feature of the 1-speed system is lost. If primary power is interrupted in a 36-speed system and the transmitter is turned before power is reapplied, the synchros could realign themselves in an erroneous position. The number of positions in which the transmitter and receiver rotors can correspond is the same as the transmission speed. Thus, in the 36-speed system, there are 35 incorrect positions and only 1 correct position of correspondence.

For accurate transmission of data over a wide range of values without the loss of self-synchronous operation, multispeed synchro systems must be used. Multispeed synchro systems use more than one speed of data transmission and, therefore, require more than one output shaft.

DUAL-SPEED SYNCHRO SYSTEM

A basic dual-speed synchro system consists of two transmitters and two receivers, as shown in figure 1-34. One transmitter receives the external input to the system and, through a network of gears, passes the effects of the external input to the second transmitter. The gear ratio between these two transmitters determines the two specific speeds the system will use to transmit the input data. The two speeds of this system are often referred to as fast and slow, high and low, or more often as fine and coarse.

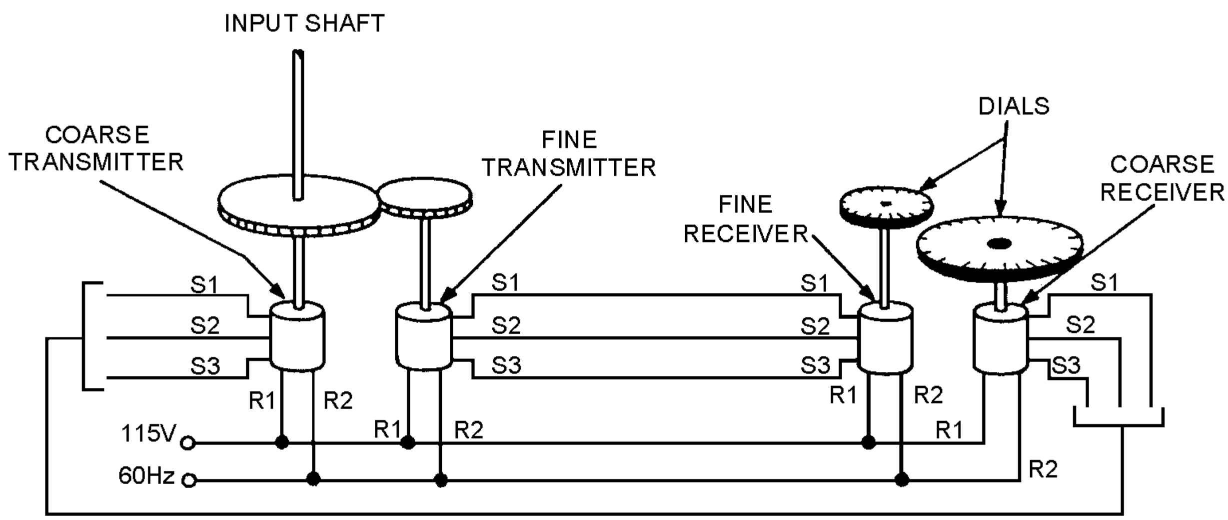


Figure 1-34.—Dual-speed synchro system.

If, for example, the gear ratio between the two transmitters is 36 to 1, 1 revolution of the rotor of the first transmitter causes 36 revolutions of the rotor of the second transmitter. The first transmitter-the one that accepts the external input-can be called the coarse transmitter, and the second one can be called the fine transmitter. Representative speeds include 1 and 36, 2 and 36, and 2 and 72.

The output of each transmitter is passed through standard synchro connections to a receiver. One receiver receives the coarse signal and the other one receives the fine signal. The two receivers may or may not be connected by a network of gears similar to the network between the two transmitters. In some dual-speed applications, a double receiver is used instead of two individual receivers.

The double receiver (fig. 1-35) consists of a coarse and a fine receiver enclosed in a common housing. It has a two-shaft output one inside the other. The coarse and fine receivers may be likened to the hour and minute hands of a clock. The coarse receiver corresponds to the hour hand, and the fine receiver corresponds to the minute hand. This double receiver has the advantage of requiring less space than two single receivers. However, it also has a disadvantage — when one receiver goes bad, both must be replaced.

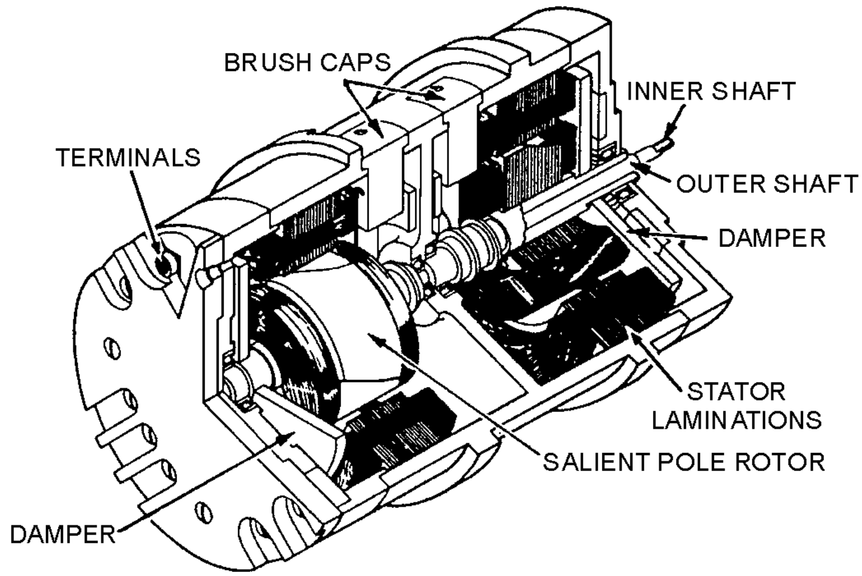


Figure 1-35.—Cutaway view of a double receiver.

In the dual-speed synchro system, data is transmitted by the coarse transmitter, while the system is far out of correspondence and then is shifted to the fine transmitter as the system approaches correspondence. This shifting from coarse to fine control is done automatically when the fine error signal exceeds the coarse error signal. The fine synchro transmitter then drives the system to the point of correspondence.

When the dual-speed synchro system includes control transformers, there is always the possibility of a 180º error being present in the system. The reason is the rotor of the CT is not energized and its error-voltage output is zero both at its proper position and also at a point 180º away from that position. To prevent the CT from locking 180º out of phase with the rest of the system, a low voltage is applied across the rotor terminals of the coarse CT as shown in figure 1-36.

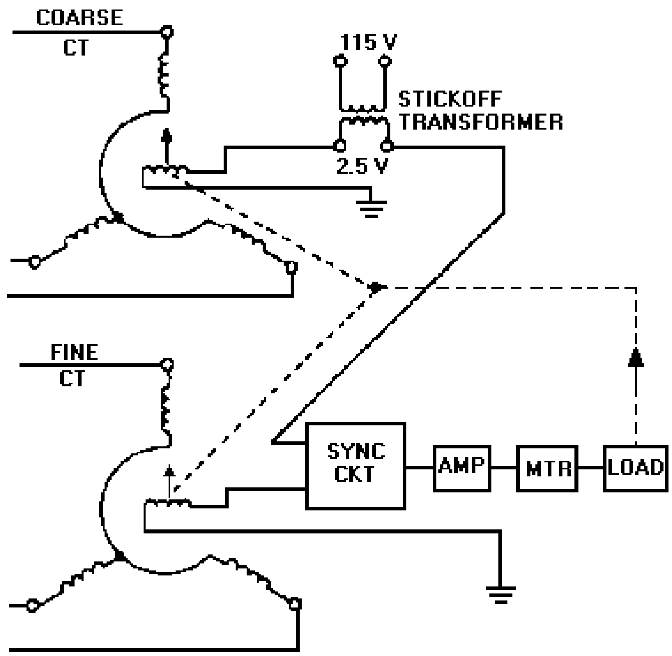


Figure 1-36.—Dual-speed synchro system using a stickoff transformer.

This voltage is normally about 2.5 volts and is commonly termed "stickoff" voltage. It is obtained from the secondary of a small transformer. The voltage induced in the secondary of the transformer shifts the 0º position of the coarse CT To reestablish a new 0º position, the stator of the coarse CT must be turned through an angle that induces an opposing 2.5 volts in the rotor to cancel the stickoff voltage. Therefore, at 0º the two voltages cancel and no input exists to drive the servo amplifier. Should the rotor of the CT stop at 180º, the same 2.5 volts would be induced in the rotor. However, it would be in phase with the stickoff voltage and no cancellation would occur. The end result is an error signal at 180º that drives the dual-speed synchro system out of any false synchronizations.

TRI-SPEED SYNCHRO SYSTEM

The advent of long-range missiles and high-speed aircraft has brought about the need for accurately transmitting very large quantities. This is best done by a tri-speed synchro system, which transmits data at three different speeds. These speeds are sometimes referred to as coarse, medium or intermediate, and fine. A typical weapons systems, for example, might transmit range in miles, thousands of yards, and hundreds of yards. By providing this range in three different scales, greater accuracy is obtained than would be possible with a dual-speed system. Representative speeds for tri-speed systems include 1, 36, and 180; 1, 36, and 360; and 1, 18, and 648.

Q-53. What is the name given to the synchro system that transmits data at two different speeds?

Q-54. What is the main reason for using a multispeed synchro system instead of a single-speed synchro system?

Q-55. In a dual-speed synchro system what determines the two specific speeds at which the data will be transmitted?

Q-56. What type of synchro system is used to transmit very large quantities?

Q-57. What is the disadvantage of using a double receiver instead of two individual receivers?

Q-58. What is the purpose of "stickoff voltage"?

ZEROING SYNCHROS

If synchros are to work properly in a system, they must be connected and aligned correctly with respect to each other and to the other devices with which they are used. The reference point for alignment of all synchro units is ELECTRICAL ZERO. The mechanical reference point for the units connected to the synchros depends upon the particular application of the synchro system. Whatever the application, the electrical and mechanical reference points must be aligned with each other. The mechanical position is usually set first, and then the synchro device is aligned to electrical zero.

There are various methods for zeroing synchros. Some of the more common zeroing methods are the voltmeter, the electrical-lock, and the synchro-tester methods. The method used depends upon the facilities and tools available and how the synchros are connected in the system. Also, the method for zeroing a unit whose rotor or stator is not free to turn may differ from the procedure for zeroing a similar unit whose rotor or stator is free to turn.

VOLTMETER METHOD

The most accurate method of zeroing a synchro is the ac voltmeter method. The procedure and the test circuit configuration for this method vary somewhat, depending upon which type of synchro is to be zeroed. Transmitters and receivers, differentials, and control transformers each require different test circuit configurations.

Regardless of the synchro to be zeroed, there are two major steps in each procedure. The first step is the coarse or approximate setting. The second step is the fine setting. The coarse setting ensures the device is zeroed on the 0º position rather than the 180º position. Many synchro units are marked in such a manner that the coarse setting may be approximated physically by aligning two marks on the synchro. On standard synchros, this setting is indicated by an arrow stamped on the frame and a line marked on the shaft, as shown in figure 1-37. The fine setting is where the synchro is precisely set on 0º.

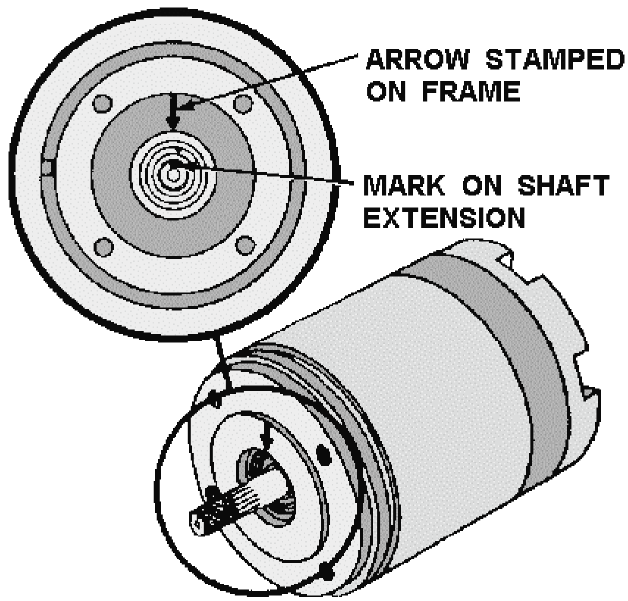


Figure 1-37.—Coarse electrical zero markings.

For the ac voltmeter method to be as accurate as possible, an electronic or precision voltmeter having 0- to 250-volt and a 0- to 5-volt ranges should be used. On the low scale this meter should also be able to measure voltages as low as 0.1 volt.

Q-59. What is the reference point for alignment of all synchro units?

Q-60. What is the most accurate method of zeroing a synchro?

Q-61. What is the purpose of the coarse setting of a synchro?

Zeroing Transmitters and Receivers (Voltmeter Method)

Since the TX, CX, and TR are functionally and physically similar, they can be zeroed in the same manner. For the TX and CX to be properly zeroed, electrical zero voltages (S2 = 52V; S1 and S3 = 26V) must exist across the stator winding when the rotor of the transmitter is set to 0º or its mechanical reference position. The synchro receiver (TR) is properly zeroed when the device it actuates assumes its zero or mechanical reference position while electrical zero voltages (S2 = 52V; S1 and S3 = 26V) exist across its stator windings. The following is a step-by-step procedure used to zero the TX, CX, and TR.

1. Carefully set the unit (antenna, gun mount, director, etc.) whose position the CX or TX transmits, accurately on 0º or on its reference position. In the case of the TR, deenergize the circuit and disconnect the stator leads before setting its rotor on zero or to its reference position. The rotor may need to be secured in this position; taping the dial to the frame is usually sufficient.

2. Deenergize the synchro circuit and disconnect the stator leads. NOTE: Many synchro systems are energized by individual switches. Therefore, be sure that the synchro power is off before working on the connections.Set the voltmeter to its 0- to 250-volt scale and connect it into the circuit as shown in view A of figure 1-38.

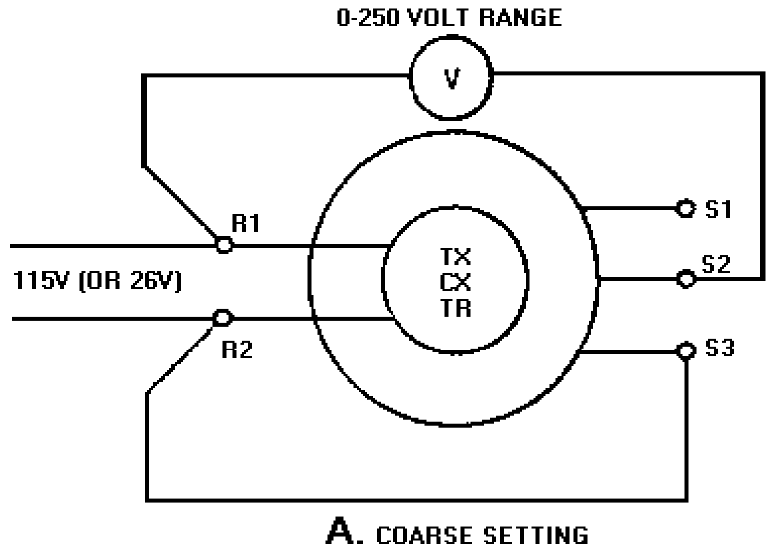


Figure 1-38A.—Zeroing a transmitter or receiver by the voltmeter method.

3. Energize the synchro circuit and turn the stator until the meter reads about 37 volts (15 volts for a 26-volt synchro). Should the voltmeter read approximately 193 volts (115 volts + 78 volts = 193 volts), the rotor is at 180º. Turn it through a half revolution to bring it back to 0º. If you cannot obtain the desired 37 (or 15) volts, use the lowest reading you can take with the meter. This is the coarse setting and places the synchro approximately on electrical zero.

4. Deenergize the synchro circuit and connect the meter as shown in view B. Start with a high scale on the meter and work down to the 0- to 5-volt scale to protect the meter movement.

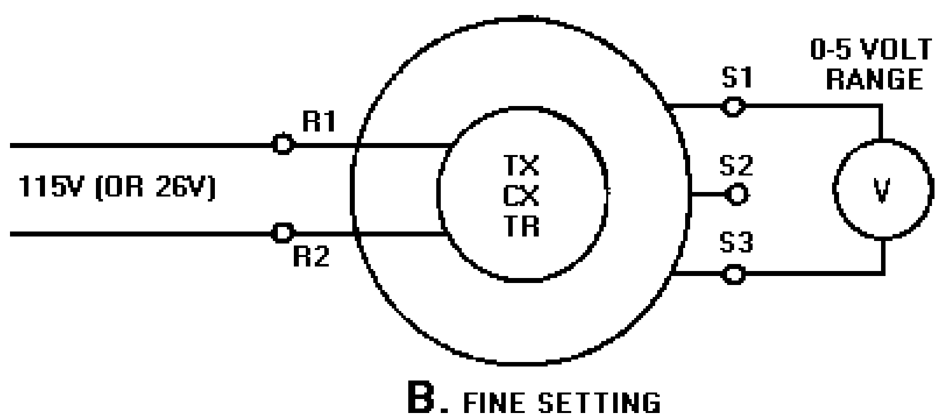


Figure 1-38B.—Zeroing a transmitter or receiver by the voltmeter method.

5. Reenergize the synchro circuit and adjust the stator for a zero or minimum voltage reading. This is the fine electrical zero position of the synchro.

When you have reconnected a TX and a TR into a system after zeroing them, you can perform a simple check on the system to see if they are accurately on electrical zero. First, place the transmitter on 0º. When the system reaches the point of correspondence, the induced voltages in the S1 and S3 stator windings of both synchros should be equal. Since the terminals of S1 and S3 are at equal potential, a jumper between these terminals at the TR should not affect the circuit. If, however, the TR rotor moves when you connect a jumper, there is a slight voltage difference between S1 and S3. This voltage difference indicates that the transmitter is not on electrical zero. If this is the case, recheck the transmitter for electrical zero.

Zeroing Differential Synchros (Voltmeter Method)

A differential synchro is zeroed when it can be inserted into a system without introducing any change. If a differential synchro requires zeroing, use the following voltmeter method:

1. Carefully and accurately set the unit whose position the CDX or TDX transmits on zero or on its reference position. In the case of the TDR, deenergize the circuit and disconnect all leads before setting its rotor to 0º or to its reference position. You may need to secure the rotor in this position; taping the dial to the frame is usually sufficient.

2. Deenergize the circuit and disconnect all leads on the differential except leads S2 and S3 when you use the 78-volt (10.2 volts for 26-volt units) supply from the transmitting unit to zero the differential. Set the voltmeter to its 0- to 250-volt scale and connect it as shown in view A of figure 1-39. If the 78-volts is not available from the transmitter or from an auto transformer, you may use a 115-volt source instead. If you use 115 volts instead of 78 volts, do not leave the synchro connected for more than 2 minutes or it will overheat and may become permanently damaged.

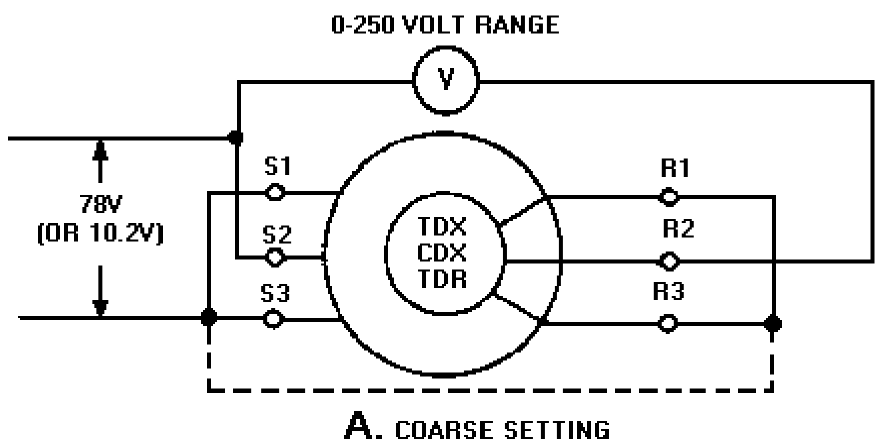


Figure 1-39A.—Zeroing differential synchros by the voltmeter method.

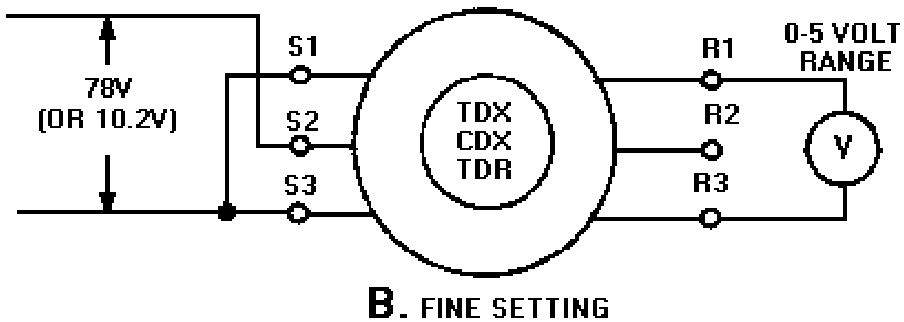


Figure 1-39B.—Zeroing differential synchros by the voltmeter method.

3. Energize the circuit, unclamp the differential's stator, and turn it until the meter reads minimum. The differential is now approximately on electrical zero. Deenergize the circuit and reconnect it as shown in view B.

4. Reenergize the circuit. Start with a high scale on the meter and work down to the 0- to 5-volt scale to protect the meter movement. At the same time, turn the differential's stator until you obtain a zero or minimum voltage reading. Clamp the differential stator in position, ensuring the voltage reading does not change. This is the fine electrical zero position of the differential.

Zeroing a Control Transformer (Voltmeter Method)

Two conditions must exist for a control transformer (CT) to be on electrical zero. First, its rotor voltage must be minimum when electrical zero voltages (S2 = 52 volts; S1 and S3 = 26 volts) are applied to its stator. Second, turning the shaft of the CT slightly counterclockwise should produce a voltage across its rotor in phase with the rotor voltage of the CX or TX supplying excitation to its stator. To zero a CT (using 78 volts from its transmitter) by the voltmeter method, use the following procedure:

1. Set the mechanism that drives the CT rotor to zero or to its reference position. Also, set the transmitter (CX or TX) that is connected to the CT to zero or its reference position.

2. Check to ensure there is zero volts between S1 and S3 and 78 volts between S2 and S3. If you cannot obtain these voltages, you will need to rezero the transmitter. NOTE: If you cannot use the 78 volts from the transmitter circuit and, an auto transformer is not available, you may use a 115-volt source. <u>If you use 115 volts instead of 78 volts, do not energize the CT for more than 2 minutes because it will overheat and may become permanently damaged.</u>

3. Deenergize the circuit and connect the circuit as shown in view A of figure 1-40. To obtain the 78 volts required to zero the CT, leave the S1 lead on, disconnect the S3 lead on the CT, and put the S2 lead (from the CX) on S3. This is necessary since 78 volts exists only between S1 and S2 or S2 and S3 on a properly zeroed CX. Now energize the circuit and turn the stator of the CT to obtain a minimum reading on the 250-volt scale. This is the coarse or approximate zero setting of the CT.

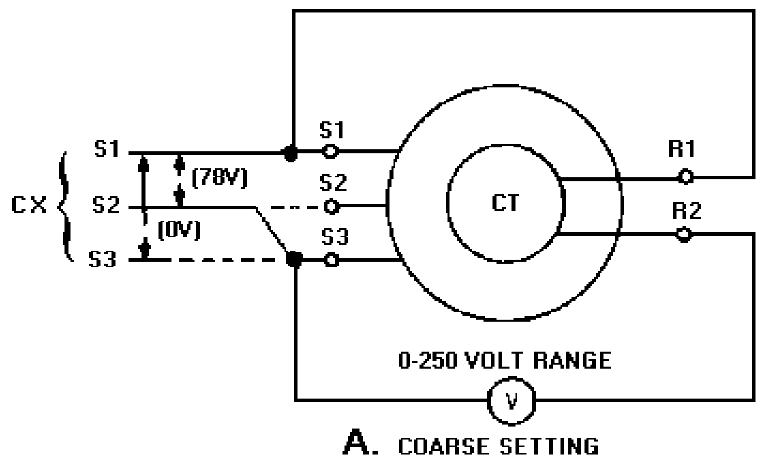


Figure 1-40A.—Zeroing a control transformer by the voltmeter method.

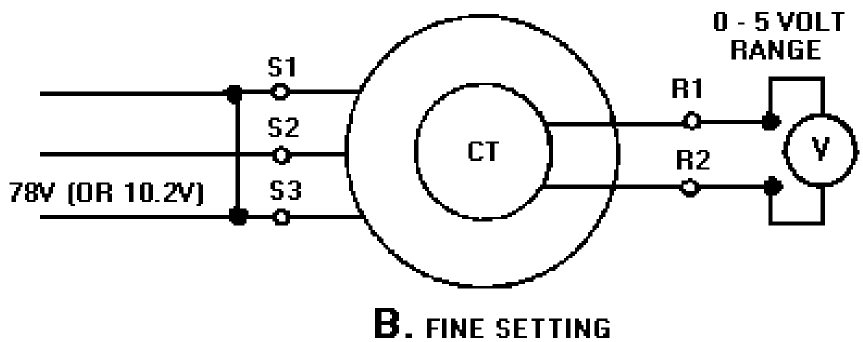


Figure 1-40B.—Zeroing a control transformer by the voltmeter method.

4. Deenergize the circuit, reconnect the S1, S2, and S3 leads back to their original positions, and then connect the circuit as shown in view B.

5. Reenergize the circuit. Start with a high scale on the meter and work down to the 0- to 5-volts scale to protect the meter movement. At the same time, turn the stator of the CT to obtain a zero or minimum reading on the meter. Clamp down the CT stator, ensuring the reading does not change. This is the fine electrical zero position of the CT.

Zeroing Multispeed Synchro Systems.

If multispeed synchro systems are used to accurately transmit data, the synchros within the systems must be zeroed together. This is necessary because these synchros require a common electrical zero to function properly in the system.

First, establish the zero or reference position for the unit whose position the system transmits. Then, zero the most significant synchro in the system first, working down to the least significant. For example, zero the coarse synchro, then the medium synchro, and finally the fine synchro. When you zero those synchros, consider each synchro as an individual unit and zero it accordingly.

Q-62. When is a synchro receiver (TR) properly zeroed?

Q-63. What should a voltmeter read when a TX is set on coarse zero?

Q-64. What precaution should you take when you use 115 volts to zero a differential?

Q-65. Why should a synchro be rechecked for zero after it is clamped down?

Q-66. What is the output voltage of a CT when it is set on electrical zero?

Q-67. When you zero a multispeed synchro system which synchro should you zero first?

ELECTRICAL LOCK METHOD

The electrical lock method, although not as accurate as the voltmeter method, is perhaps tile fastest method of zeroing synchros. However, this method can be used only if the rotors of the units to be zeroed are free to turn and the lead connections are accessible. For this reason, this method is usually used on the TR because, unlike transmitters, the TR shaft is free to turn.

To zero a synchro by the electrical lock method, deenergize the unit, connect the leads as shown in figure 1-41, and apply power. The synchro rotor will then quickly snap to the electrical zero position and lock. If the indicating device connected to the synchro shaft does not point to zero, loosen the synchro in its mounting and rotate it until the zero position of the indicator corresponds with the electrical zero of the synchro. As we stated previously, <u>you may use 115 volts as the power source instead of 78 volts, provided you do not leave the unit connected for more than 2 minutes.</u>

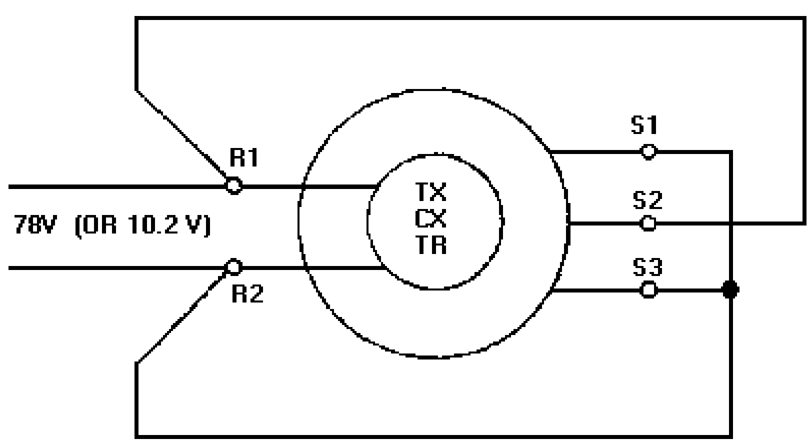


Figure 1-41.—Zeroing a synchro by the electrical lock method.

SYNCHRO TESTERS

Two types of synchro testers are shown in figure 1-42, view (A) and view (B). Each is nothing more than a synchro receiver on which a calibrated dial is mounted.

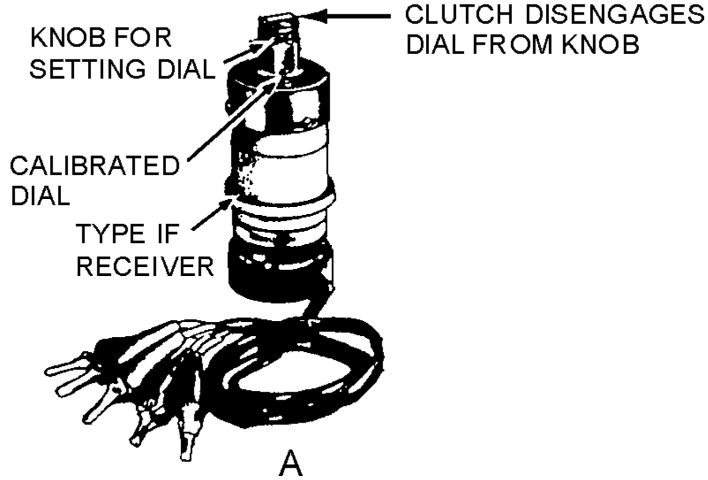


Figure 1-42A.—Synchro Testers.

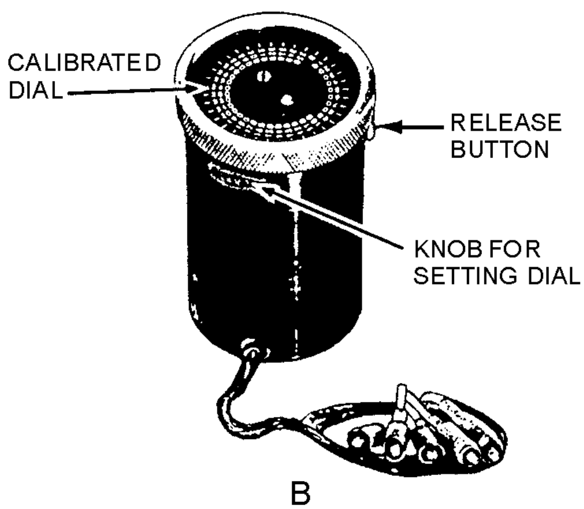


Figure 1-42B.—Synchro Testers.

These testers are used primarily for locating defective synchros. Although they do provide a method for zeroing synchros, they should not be relied on without question. It is possible for the calibrated dial to slip from its proper position, and since the dial is graduated only every 10º, it is difficult to read small angles with accuracy. Therefore, the synchro tester method of zeroing synchros is potentially less accurate than those previously described. To zero a TX, CX or TR using a synchro tester, use the following procedure:

1. Connect the synchro tester as shown in figure 1-43.

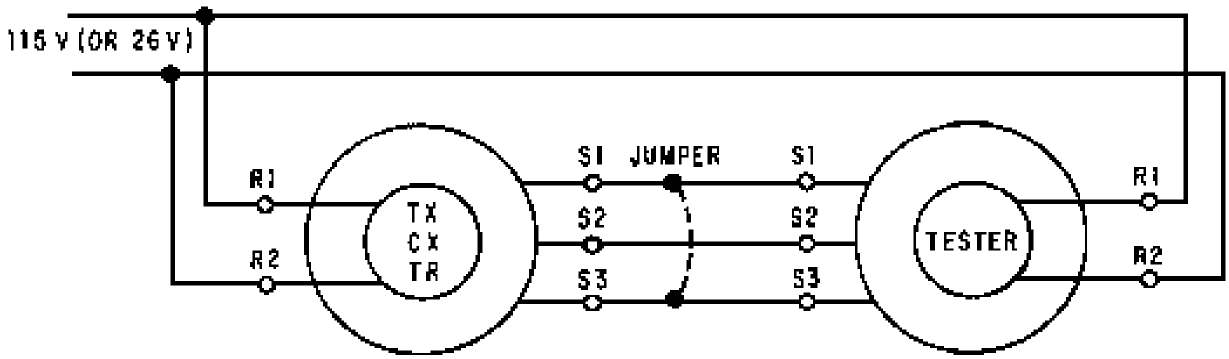


Figure 1-43.—Zeroing a synchro using a synchro tester.

2. Set the unit whose position the TX or CX transmits accurately on zero or on its reference position. In the case of the TR, set its rotor to zero or to its reference position.

3. Turn the stator of the synchro being zeroed until the synchro tester dial reads 0º. The synchro is now approximately on electrically zero.

4. Momentarily short S1 to S3 as shown. If the synchro tester dial moves when S1 is shorted to S3, the synchro is not zeroed. Check the tester dial to ensure it has not slipped. If the tester dial has not slipped, move the synchro stator until there is no movement when S1 and S3 are shorted. This is the electrical zero position of the synchro being aligned.

Q-68. What method of zeroing a synchro is perhaps the fastest but NOT necessarily the most accurate?

Q-69. What restrictions are placed on the use of the electrical lock method?

Q-70. When you zero a synchro with a synchro tester, what is indicated by a jump in the synchro tester's dial when the S1 and S3 leads are momentarily shorted?

TROUBLESHOOTING SYNCHRO SYSTEMS

One of your duties in the Navy is to keep the synchro systems in your equipment in good working order. Therefore, it is essential that you become familiar with the details of synchro maintenance and repair.

First, let's consider some of the more common problem areas you should avoid when working with synchros. As with any piece of electrical or electronic equipment, if it works—leave it alone. Do not attempt to zero a synchro system that is already zeroed just because you want to practice. More often than not, the system will end up more out of alignment than it was before you attempted to rezero it. Do not attempt to take a synchro apart, even if it is defective. A synchro is a piece of precision equipment that requires special equipment and techniques for disassembly. Disassembly should be done only by qualified technicians in authorized repair shops. A synchro, unlike an electric motor, does not require periodic lubrication. Therefore, never attempt to lubricate a synchro. Synchros also require careful handling. Never force a synchro into place, never use pliers on the threaded shaft, and never force a gear or dial onto the shaft. Finally, never connect equipment that is not related to the synchro system to the primary excitation bus. This will cause the system to show all the symptoms of a shorted rotor when the equipment is turned on; but, the system will check out good when the equipment is off.

Trouble in a synchro system that has been in operation for some time is usually one of two types. First, the interconnecting synchro wiring often passes through a number of switches; at these points opens, shorts, or grounds may occur. You will be expected to trace down these troubles with an ohmmeter. You can find an open easily by checking for continuity between two points. Similarly, you can find a ground by checking the resistance between the suspected point and ground. A reading of zero ohms means that the point in question is grounded. Secondly, the synchro itself may become defective, due to opens and shorts in the windings, bad bearings, worn slip rings, or dirty brushes. You can do nothing about these defects except replace the synchro.

Troubles in new and modified synchro systems are most often because of (1) improper wiring and (2) misalignment caused by synchros not being zeroed. You are responsible for finding and correcting these troubles. You can check for improper wiring with an ohmmeter by making a point-to-point continuity and resistance check. You can correct misalignment of a synchro system by rezeroing the entire system.

TROUBLE INDICATORS

When trouble occurs in an electronic installation that contains a large number of synchro systems, it may be very difficult to isolate the trouble to one particular system. Since it is vital that maintenance personnel locate the point of trouble and fix it in as short a time as possible, indicators, which aid in locating the trouble quickly, are included in the equipment. These indicators are usually signal lights, mounted on a central control board and connected to the different synchro systems. When trouble occurs in a synchro system, the signal light connected to it may either light or flash. Maintenance personnel identify the defective system by reading the name or number adjacent to the light.

Signal lights indicate either overload conditions or blown fuses. Overload indicators are usually placed in the stator circuit of a torque synchro system because the stator circuit gives a better indication of mechanical loading than does the current in the rotor circuit. One version of this type of indicator, as shown in figure 1-44, consists of a neon lamp connected across the stator leads of a synchro system by two transformers. The primaries, consisting of a few turns of heavy wire, are in series with two of the stator leads; the secondaries, consisting of many turns of fine wire, are in series with the lamp. The turns ratios are designed so that when excess current flows through the stator windings, the neon lamp lights. For example, when the difference in rotor positions exceeds about 18º, the lamp lights, indicating that the load on the motor shaft is excessive.

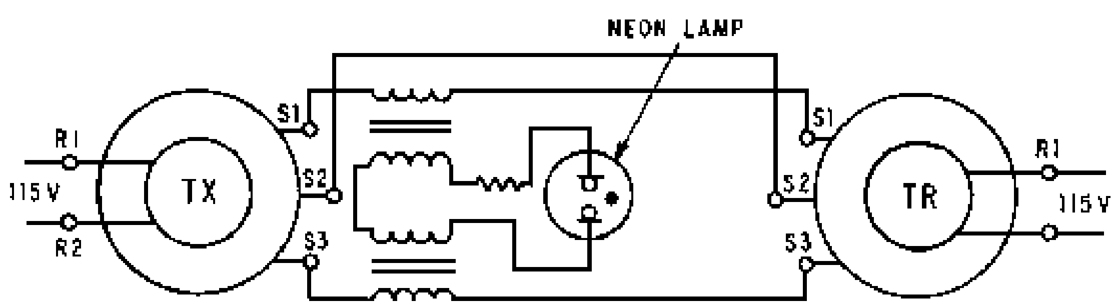


Figure 1-44.—Overload stator current indicator.

Blown fuse indicators are front panel lights which light when a protective fuse in series with the rotor blows. Figure 1-45 shows a typical blown fuse indicator. If excessive current flows in the rotor windings of this circuit because of a short or severe mechanical overload, one of the fuses will blow and the neon lamp across the fuse will light.

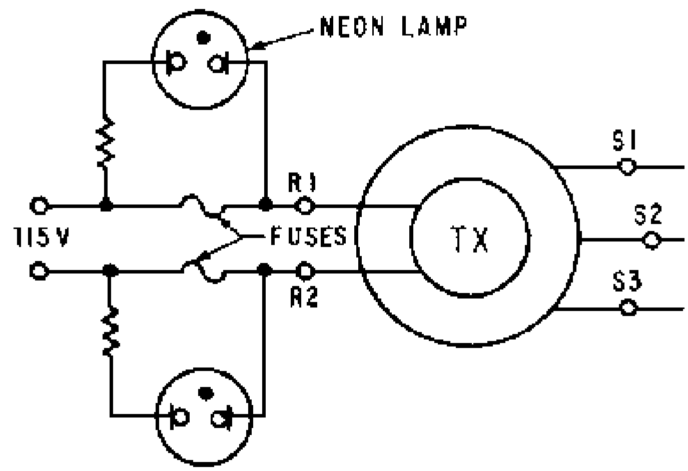


Figure 1-45.—Simple blown fuse indicator.

Another type of blown fuse indicator uses a small transformer having two identical primaries and a secondary connected, as shown in figure 1-46. With both fuses closed, equal currents flow through the primaries. This induces mutually canceling voltages in the secondary. If a fuse blows, the induced voltage from just one primary is present in the secondary, and the lamp lights.

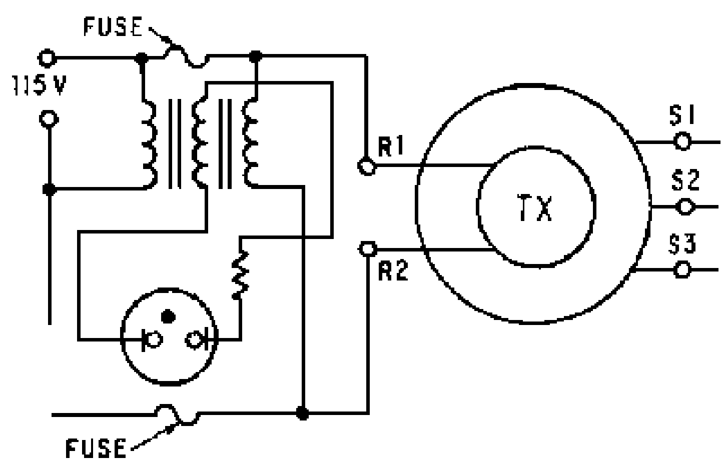


Figure 1-46.—Blown fuse indicator requiring only one lamp.

SYMPTOMS AND CAUSES

To help the technician further isolate synchro problems, many manufacturers furnish tables of trouble symptoms and probable causes with their equipment. These tables are a valuable aid in isolating trouble areas quickly. Tables 1-2 through 1-7 summarize, for a simple TX-TR system, some typical trouble symptoms and their probable causes. Keep in mind, if two or more receivers are connected to one transmitter, similar symptoms occur. However, if all the receivers act up, the trouble is usually in the transmitter or main bus. If the trouble appears in one receiver only, check the unit and its connections.

The angles shown in these tables do not apply to systems using differentials, or to systems whose units are incorrectly zeroed.

Table 1-2.—General Symptoms

Preliminary Actions: Be sure TR is not jammed physically. Turn TX slowly in one direction and observe TR.	
SYMPTOMS	**TROUBLE**
Overload Indicator lights Units hum at all TX settings One unit overheats TR follows smoothly but reads wrong	Rotor circuit open or shorted. See table 1-3.
Overload Indicator lights Units hum at all except two opposite TX settings Both units overheat TR stays on one reading half the time, then swings abruptly to the opposite one. TR may oscillate or spin.	Stator circuit shorted. See table 1-4.
Overload Indicator lights Units hum on two opposite TX settings Both units get warm TR turns smoothly on one direction, then reverses	Stator circuit open. See table 1-5.
TR reads wrong or turns backward, follows TX smoothly	Unit interconnections wrong. Unit not zeroed. See tables 1-6 and 1-7.

Table 1-3.—Open or Shorted Rotor

Preliminary Action: Set TX to 0˚ and turn rotor smoothly counterclockwise.	
SYMPTOMS	**TROUBLE**
TR turns counterclockwise from 0º in a jerky or erratic manner, and gets hot.	TX rotor open
TR turns counterclockwise from 0º or 180º in a jerky or erratic manner. TX gets hot.	TR rotor open
TR turns counterclockwise from 90º or 270º, torque is about normal, motor gets hot, and TX fuses blow.	TX rotor shorted
TR turns counterclockwise from 90˚ or 270˚, torque is about normal, TX gets hot, and TR fuses blow.	TR rotor shorted

Table 1-4.—Shorted Stator

SYMPTOMS		TROUBLE
SETTING OR CONDITIONS	**INDICATION**	
When TX is on 120º or 300º but When TX is between 340º and 80º, or between 160º and 260º	Overload Indicator goes out and TR reads correctly Overload Indicator lights, units get hot and hum, and TR stays on 120º or 300º, or may swing suddenly from one point to the other.	Stator circuit shorted from S1 to S2
When TX is on 60 º or 240º but When TX is between 280º and 20º, or between 100º and 200º	Overload Indicator goes out and TR reads correctly Overload Indicator lights, units get hot and hum, and TR stays on 60º or 240º or may swing suddenly from one point to the other	Stator circuit shorted from S2 to S3Stator circuit shorted from S2 to S3
When TX is on 0º or 180º but When TX is between 40º and 140º, or between 220º and 320º	Overload Indicator goes out and TR reads correctly Overload Indicator lights, units get hot and hum, and TR stays on 0º or 180º, or may swing suddenly from one point to the other	Stator circuit shorted from S1 to S3 Stator circuit shorted from S1 to S3

Table 1-5.—Open Stator

SETTINGS OR CONDITIONS	INDICATION	TROUBLE
When TX is on 150º or 330º and When TX is held on 0º	TR reverses or stalls and Overload Indicator lights TR moves between 300º and 0º in a jerky or erratic manner	S1 stator circuit open
When TX is on 90º or 270º and When TX is held on 0º	TR reverses or stalls and Overload Indicator lights TR moves to 0º or 180º, with fairly normal torque	S2 Stator circuit open
When TX is on 30º or 210º and When TX is held on 0º	TR reverses or stalls and Overload Indicator lights TR moves between 0º and 60º in a jerky or erratic manner	S3 stator circuit open
When TX is set at 0˚, and then moved smoothly counterclockwise		

Table 1-6.—Wrong Stator Connections, Rotor Wiring Correct

SETTING OR CONDITIONS	INDICATION	TROUBLE
TX set to 0º and rotor turned smoothly counterclockwise	TR indication is wrong, turns clockwise from 240º	S1 and S2 stator connections are reversed
	TR indication is wrong, turns clockwise from 120º	S2 and S3 stator connections are reversed
	TR indication is wrong, turns clockwise from 0º	S1 and S3 stator connections are reversed
	TR indication is wrong, turns counterclockwise from 120º	S1 is connected to S2, S2 is connected to S3, and S3 is connected to S1
	TR indication is wrong, turns counterclockwise from 240º	S1 is connected to S3, S2 is connected to S1, and S3 is connected to S2

Table 1-7.—Wrong Stator and/or Reversed Rotor Connections

SETTINGS OR CONDITIONS	INDICATION	TROUBLE
TX set to 0º and rotor turned smoothly counterclockwise	TR indication is wrong, turns counterclockwise from 180º	Stator connects are correct, but rotor connections are reversed
	TR indication is wrong, turns clockwise from 60º	Stator connections S1 and S2 are reversed, and rotor connections are reversed
	TR indication is wrong, turns clockwise from 300º	Stator connections S2 and S3 are reversed, and rotor connections are reversed
	TR indication is wrong, turns clockwise from 180º	Stator connections S1 and S3 are reversed, and rotor connections are reversed
	TR indication is wrong, turns counterclockwise from 300º	S1 is connected to S2, S2 is connected to S3, S3 is connected to S1, and rotor connections are reversed
	TR indication is wrong, turns counterclockwise from 60º	S1 is connected to S3, S2 is connected to S1, S3 is connected to S2, and rotor connections are reversed

In a control system, the trouble may be slightly more difficult to isolate. However, the existence of trouble is readily indicated when the system does not properly respond to an input order. For control systems, it is easier to locate the trouble by using a synchro tester or by checking the operating voltages.

VOLTAGE TESTING

Another good way to isolate the trouble in an operating synchro system is to use known operating voltages as references for faulty operation. Since the proper operation of a system is indicated by specific rotor and stator voltages, an ac voltmeter can be used to locate the trouble. When an ac voltmeter is connected between any two stator leads, the voltage should vary from 0 to 90 volts (0 to 11.8 volts for 26-volt systems) as the transmitter rotates. The zero and maximum voltage values should occur at the following headings:

Meter Connected Between	Zero Voltage Headings	Maximum Voltage Headings
S1 and S2	120º, 300º	30º, 210º
S2 and S3	60º, 240º	150º, 330º
S1 and S3	0˚, 180˚	90˚, 270˚

The rotor voltage should remain constant at all times, either 115 volts or 26 volts. In a system where the units are close enough to permit checking, the voltage between the R1 and R2 terminal of any unit energized by the primary ac source and the corresponding R1 or R2 terminal of any other unit energized by the primary ac source should be zero. When the excitation voltage (115 volts or 26 volts) is above or below the nominal value, the maximum stator voltages will also be above or below normal.

SYNCHRO TESTERS

Synchro testers, as stated earlier, are used primarily for quickly locating a defective synchro. These testers are capable of functioning as either transmitter or receiver.

When a transmitter is suspected of being defective, a synchro tester is usually substituted in its place to simulate its actions. When the tester is used in this manner, a braking arrangement on the tester applies the necessary friction to hold its shaft in different positions so you can determine whether the transmitter is good or bad. When using the tester as a transmitter, it is usually a good idea to use only one receiver so as not to overload the tester. If the tester is connected in place of a TR or used to check the output of a transmitter, the brake is released, allowing the rotor to turn and indicate the transmitter's position. By observing the tester's response to the transmitted signal, you can determine if the TR is defective or if the transmitter's output is incorrect.

Q-71. What should you do with a synchro that has a bad set of bearings?

Q-72. Name two types of trouble you would expect to find in a newly installed synchro system.

Q-73. What type of indicator is usually placed in the stator circuit of a torque synchro system?

Q-74. What is the most probable cause of trouble in a synchro system that has all of its receivers reading incorrectly?

Q-75. If an ac voltmeter is connected between the S2 and S3 windings on a TX, at what two rotor positions should the voltmeter read maximum voltage?

Q-76. What precaution should you take when substituting a synchro tester in a circuit for a transmitter?

You should now have a good working knowledge of synchro systems. For further study and assistance in applying this knowledge to synchro troubleshooting and alignment, consult the following references:

Pertinent PMS sources:

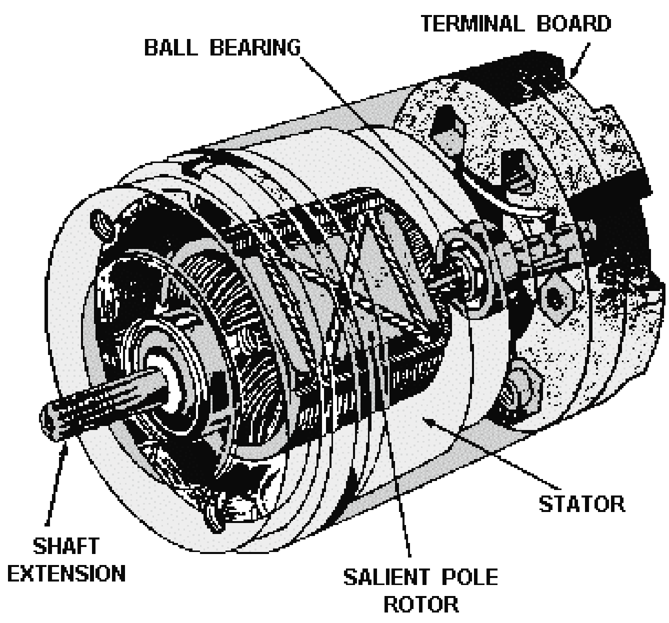
1. Applicable maintenance instruction manuals.
2. Military Handbook, *Synchros, Description and Operation*, MIL-HDBK-225A (March 91).

SUMMARY

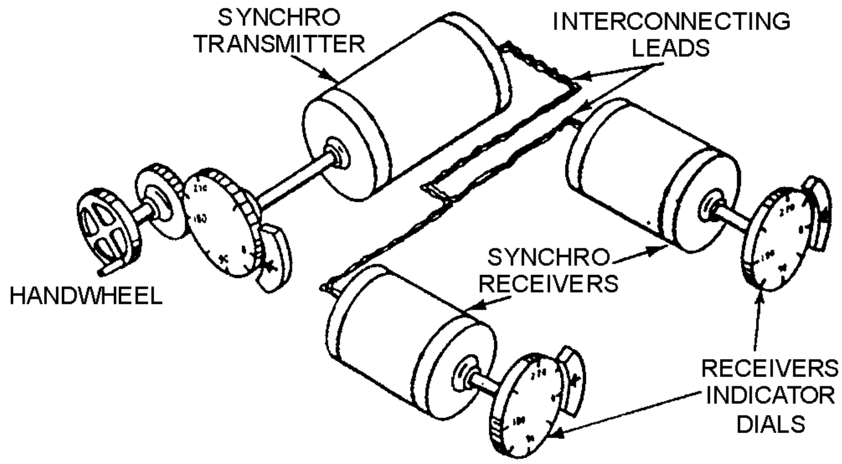
Now that you have completed this chapter, a short review is in order. The following review will refresh your memory of synchros, their principles of operation, and how they are tied together to form synchro systems.

A **SYNCHRO** resembles a small electric motor in size and appearance and operates like a variable transformer.

Synchros are used primarily for the rapid and accurate transmission of data. They are also used as control devices in servo systems.



A **SYNCHRO SYSTEM** consists of two or more synchros interconnected electrically.



TORQUE SYNCHRO SYSTEMS are systems that use torque synchros to move light loads, such as dials and pointers.

CONTROL SYNCHRO SYSTEMS are systems that use control synchros to control servo systems. The servo system, in conjunction with the control synchro system, is used to move heavy loads such as gun directors, radar antennas, and missile launchers.

MILITARY STANDARD SYNCHROS are synchros that conform to specifications that are uniform throughout the Armed Services. They replace the prestandard Navy synchros. A typical example of a military standard synchro designation code is 18TR6A. This code has the following interpretation:

18—Synchro diameter of 1.71 to 1.80 inches

T—Torque

R—Receiver

6—60-Hz frequency

A—Original design

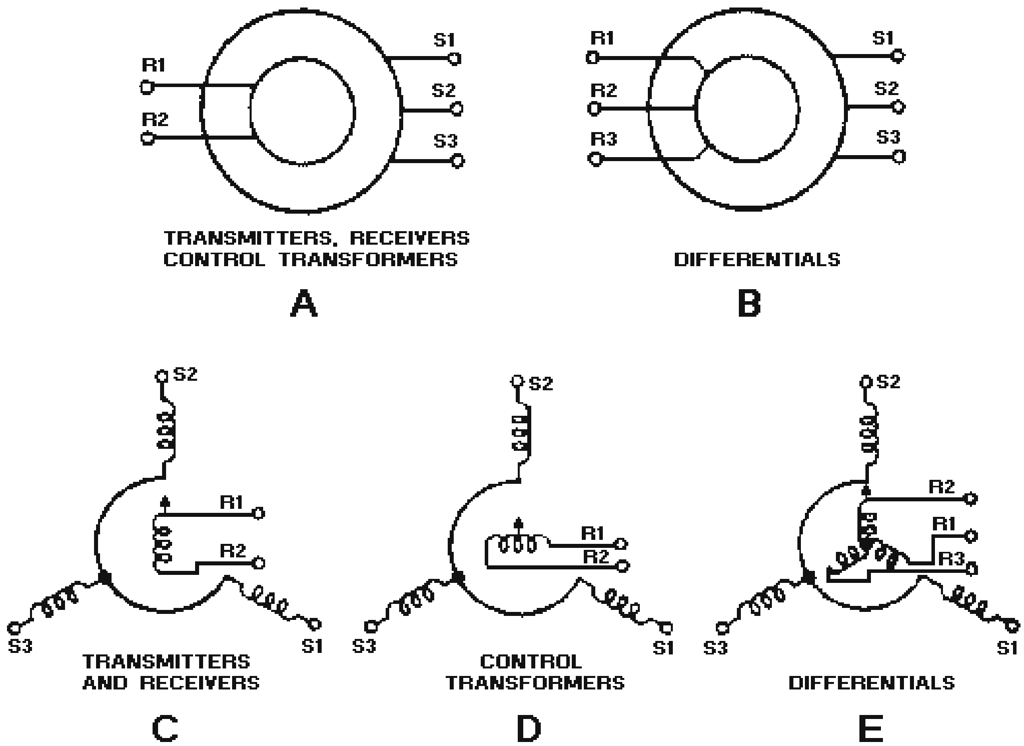
PRESTANDARD NAVY SYNCHROS are synchros designed to meet Navy, rather than service-wide, specifications. A typical example of a prestandard Navy synchro designation code is 5DG. This code has the following interpretation:

5—Synchro diameter of 3 3/8 to 3 5/8 inches, length

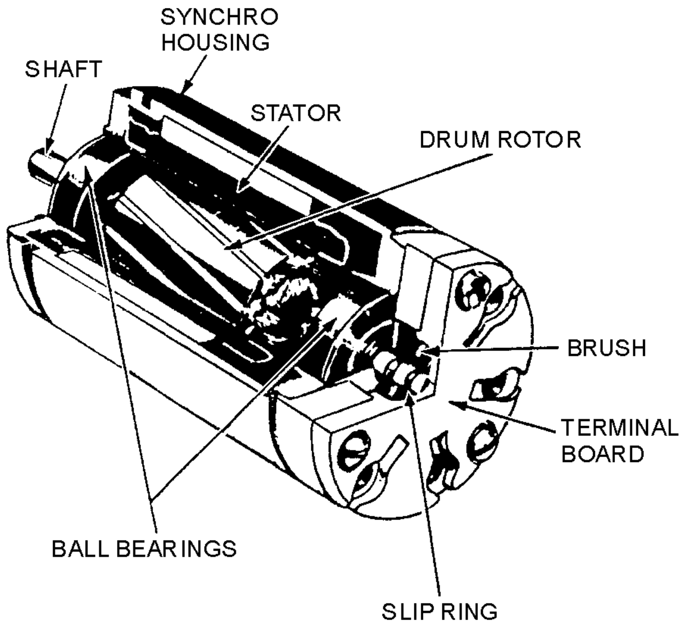
1/2 inches, weight 5 lbs.

DG—Differential transmitter

SCHEMATIC SYMBOLS for synchros are drawn in two different forms. Two of the five standard military symbols are drawn to show only the external connections to the synchro. The other three symbols are drawn to show both the external connections and the internal relationship between the rotor and the stator.

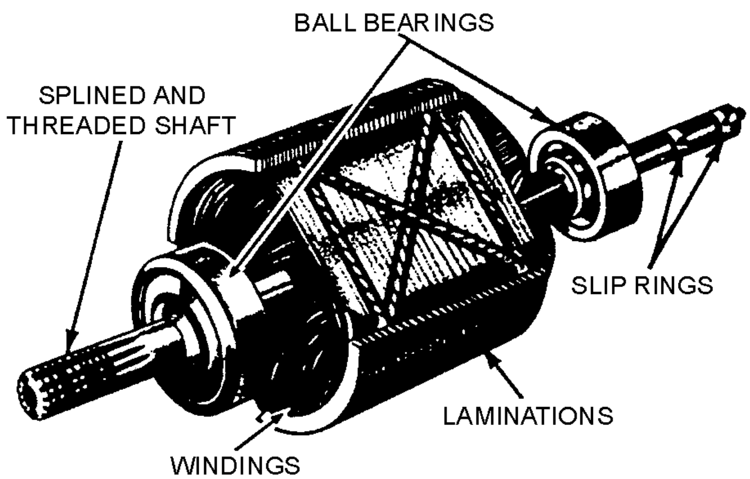


SYNCHROS ARE CONSTRUCTED like motors. Each contains a rotor, similar in appearance to the armature in a motor, and a stator which corresponds to the field in a motor.

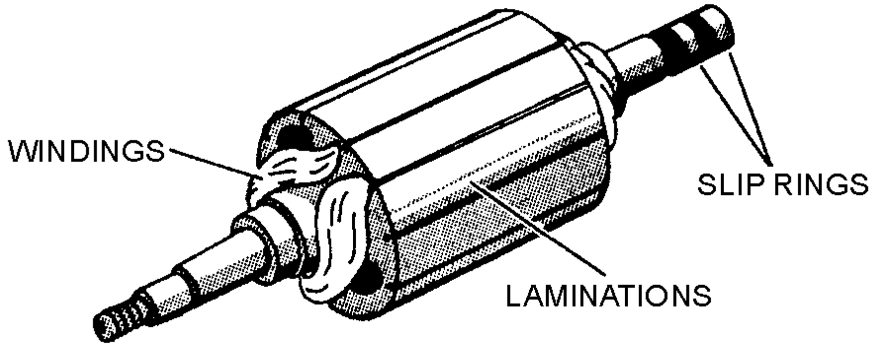


A **SYNCHRO ROTOR** is composed of either a single coil of wire wound on a laminated core or a group of coils wound in slots in a laminated core. The laminated core is rigidly mounted on a shaft that is free to turn inside the stator. Two slip rings are mounted on one end of the shaft to supply excitation voltage to the rotor. There are two common types of synchro rotors - the salient-pole rotor and the drum or wound rotor.

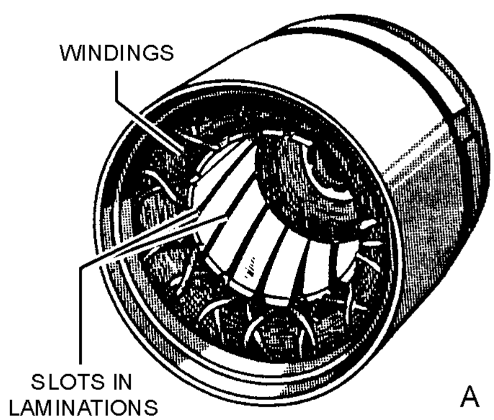
The **SALIENT-POLE ROTOR** has a single coil of wire wound on a laminated core, shaped like a dumbbell or the letter "H." This type of rotor is frequently used in transmitters and receivers.



The **DRUM OR WOUND ROTOR** may be wound continuously with a single length of wire or may have a group of coils connected in series. This type of rotor is used in most synchro control transformers and differential units, and occasionally in torque transmitters. When used in differential units, the rotor is wound with three coils so their magnetic axes are 120 degrees apart.



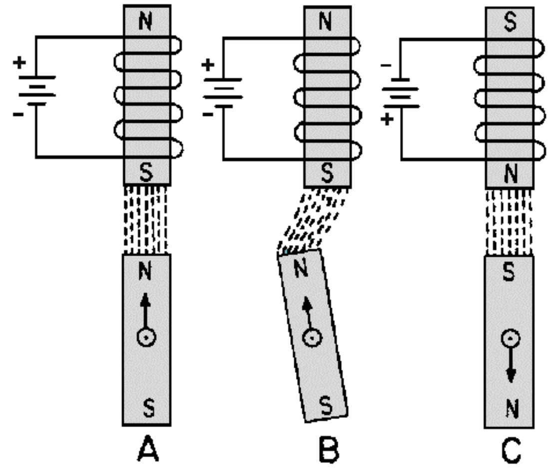
A **SYNCHRO STATOR** is a cylindrical structure of slotted lamination on which three Y-connected coils are wound with their axes 120º apart.



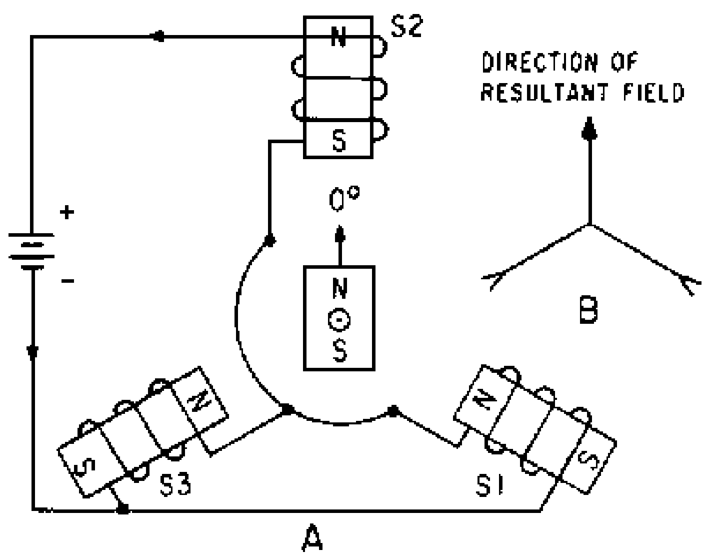
TORQUE is simply a measure of how much load a machine can turn. In heavy machinery, it is expressed in pound-feet and in torque synchro systems, it is expressed in ounce-inches.

SYNCHRO OPERATING VOLTAGES AND FREQUENCIES vary with different equipment. Synchros are designed for use on either a 115-volt or a 26-volt power source. They also operate on either a 60- or 400-Hz frequency.

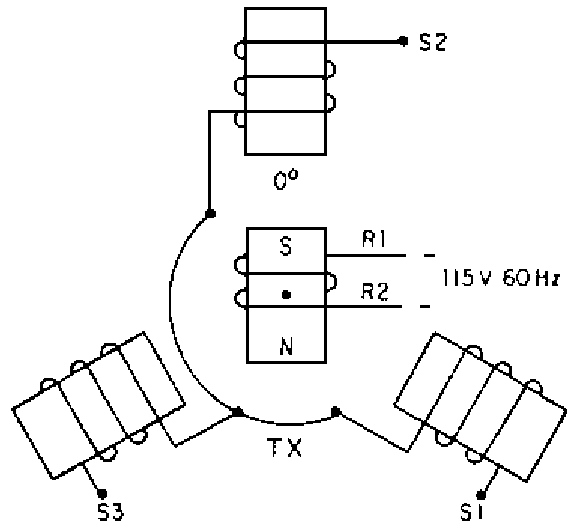
ELECTROMAGNETIC THEORY forms the basis for understanding all synchro operations.



The **RESULTANT MAGNETIC FIELD** in a synchro is the result of the combined effects of three stator fields spaced 120º apart. The stator coil with the strongest field has the greatest effect on the position of the resultant field.

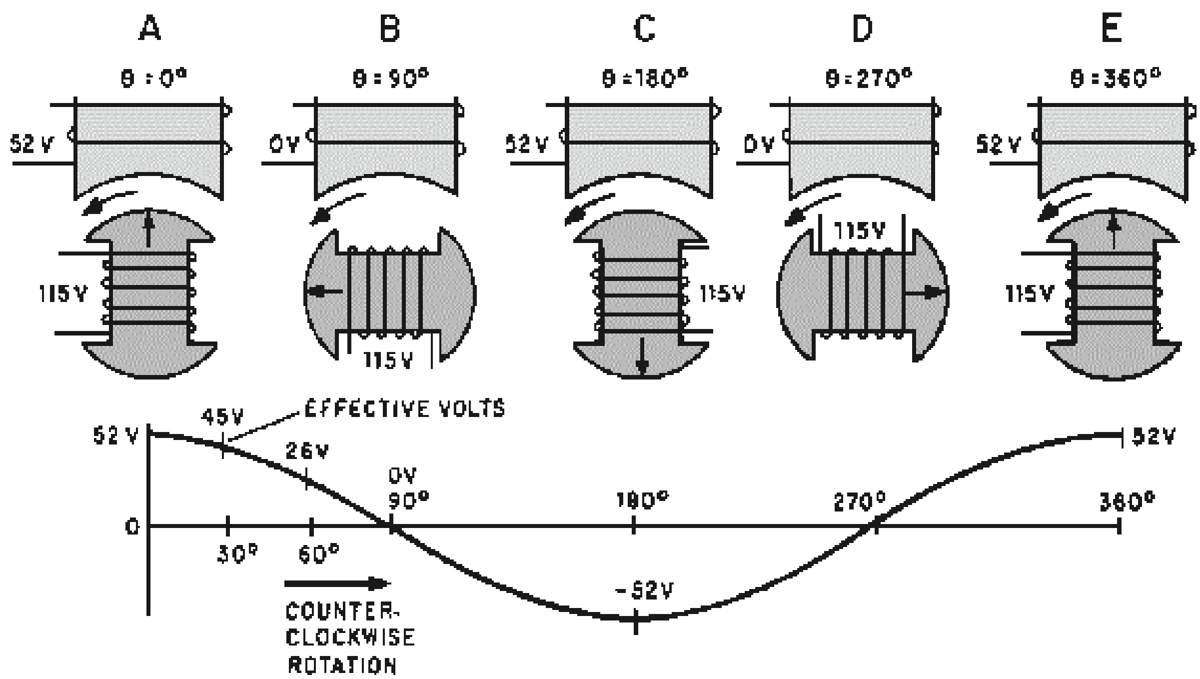


The **ZERO-DEGREE POSITION** of a synchro, transmitter is the position where the rotor and the S2 stator winding are parallel.



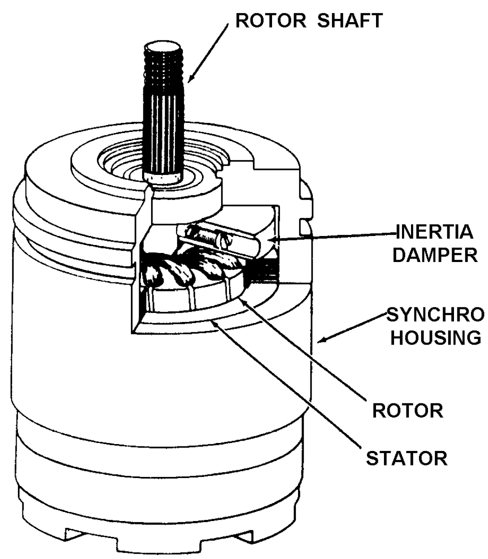
The **SYNCHRO TRANSMITTER (TX)** converts a mechanical input, which is the angular position of the rotor, into an electrical output signal. The output is taken from the stator windings and is used by a TDX, a TDR, or a TR to move light loads, such as dials and pointers.

MAXIMUM INDUCED STATOR VOLTAGE occurs in a single synchro stator coil each time there is maximum magnetic coupling between the rotor and the stator coil. This voltage is approximately equal to the product of the effective voltage on the primary, the secondary-to-primary turns ratio, and the magnetic coupling between the rotor and the stator coil.



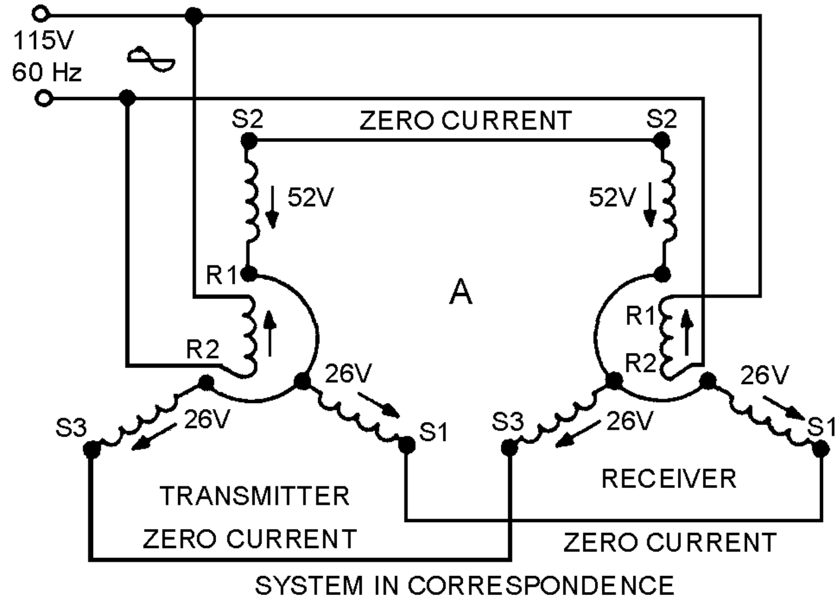
The **SYNCHRO RECEIVER (TR)** is electrically identical to the synchro transmitter. The receiver, however, uses some form of rotor damping that is not present in the transmitter. This real difference between a synchro transmitter and a synchro receiver lies in their applications. The receiver converts the electrical data, supplied to its stator from the transmitter, back to a mechanical angular output through the movement of its rotor.

DAMPING is a method used in synchro receivers to prevent the rotor from oscillating or spinning. There are two types of damping methods - ELECTRICAL and MECHANICAL. The electrical method is commonly used in small synchros, while the mechanical method is more effective in larger synchros.



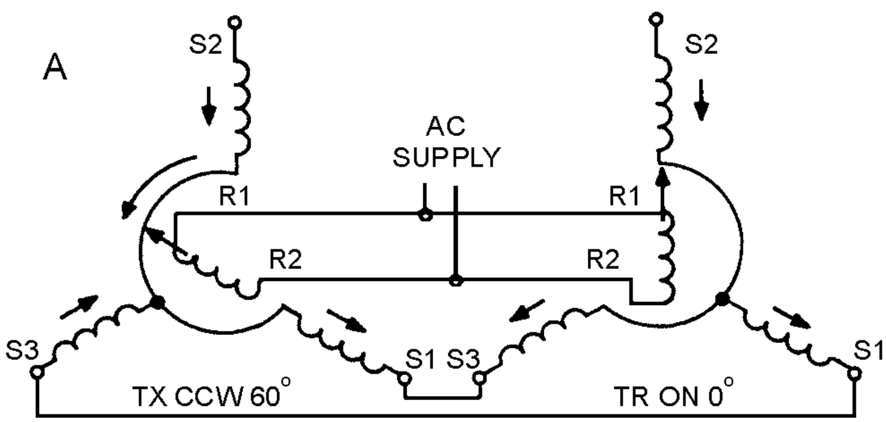
A **TORQUE SYNCHRO SYSTEM** consists of a torque transmitter (TX) electrically connected to a torque receiver (TR). In this system, the mechanical input to the TX is transmitted electrically to the TR. The TR reproduces the signal from the TX and positions either a dial or a pointer to indicate the transmitted information.

CORRESPONDENCE is the term given to the positions of the rotors of a synchro transmitter and a synchro receiver when both rotors are on 0º or displaced from 0º by the same angle.



SIGNAL is defined as the angle through which a transmitter rotor is mechanically turned. This term has the same meaning as "transmitter's mechanical input."

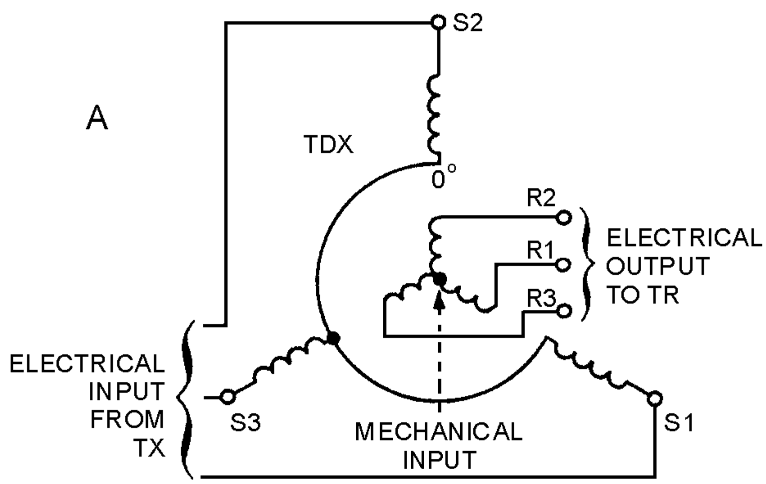
RECEIVER ROTATION may be in a direction opposite to that desired. When it is necessary to reverse receiver rotation, reverse the S1 and S3 connections on either the synchro transmitter or the synchro receiver. The causes both synchro rotors to turn through the same angle but in opposite directions.



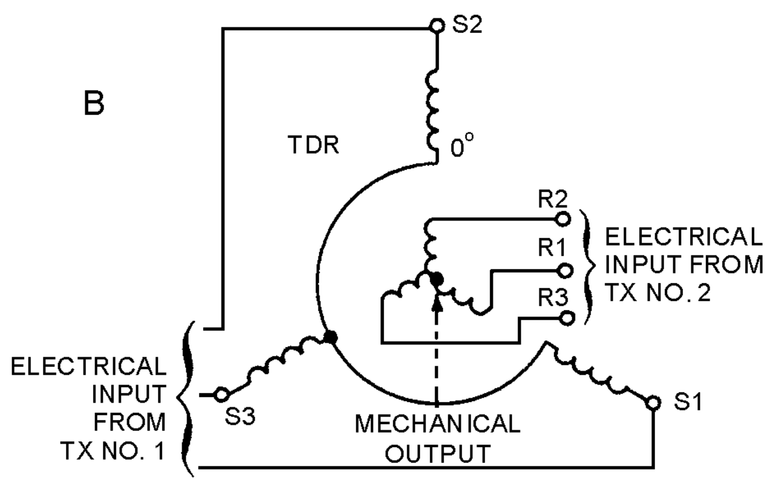
REVERSED ROTOR CONNECTIONS are common problems in new or modified synchro systems and should not be confused with the deliberate reversal of the stator connections. The reversal of the R1 and R2 connections on a synchro rotor causes a 180º error between the synchro transmitter and the synchro receiver, but the direction of rotor rotation still remains the same.

A **TORQUE DIFFERENTIAL SYNCHRO SYSTEM** consists either of a TX, a TDX, (torque differential transmitter), and a TR; or two TXs and one TDR (torque differential receiver). The system is used in applications where it is necessary to compare two signals, add or subtract the signals, and finish an output proportional to the sum of or difference between the two signals.

The **TORQUE DIFFERENTIAL TRANSMITTER (TDX)** has one electrical input to the stator and one mechanical input to the rotor. The TDX either adds or subtracts these inputs, depending upon how it is connected in the system, and provides an electrical output from its rotor proportional to the sum of or difference between the two signals.



The **TORQUE DIFFERENTIAL RECEIVER (TDR)** is electrically identical to the TDX. The only difference in their construction is that the TDR has some form of damping. The real difference between the two differentials lies in their applications. The TDR has two electrical inputs, one to the rotor and the other to the stator. The output is the mechanical position of the rotor. As is the case with the TDX, the addition or subtraction function of the TDR depends upon how it is connected in the system.



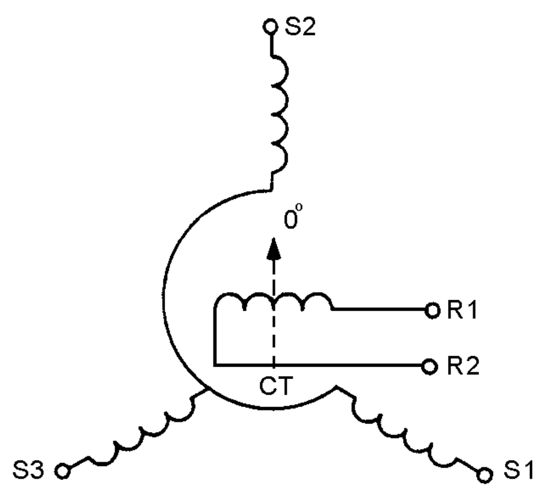
The **TX-TDX-TR SYSTEM** performs subtraction when the system contains standard synchro connections. Addition can also be performed with this system by reversing the S1 and S3 leads between the TX and the TDX, and the R1 and R3 leads between the TDX and the TR. Remember, this system works like a basic synchro system when the rotor of the TDX is on 0º; in this condition the TR rotor follows the TX rotor exactly.

The **TX-TDR-TX SYSTEM** performs subtraction when the system contains standard synchro connections. Addition can also be performed with this system when the R1 and R3 leads between the TDR rotor and TX No. 2 are reversed.

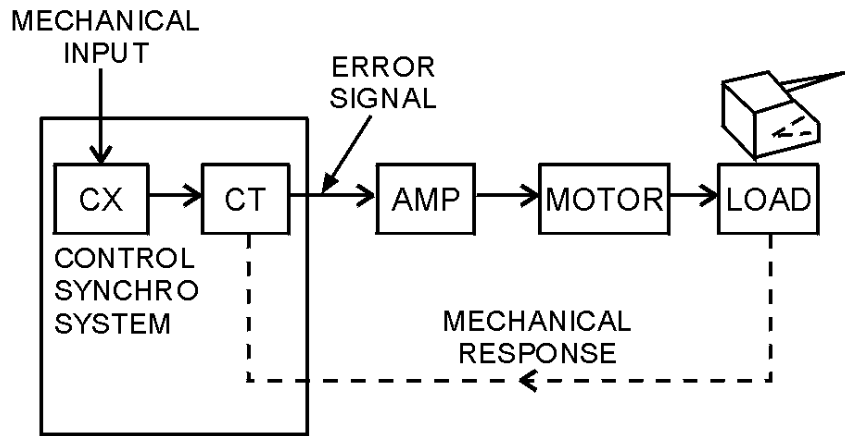
CONTROL SYNCHRO SYSTEMS contain control synchros and are used to control large amounts of power with a high degree of accuracy. These synchro systems control servos that generate the required power to move heavy loads.

CONTROL SYNCHROS are of three different types: the control transmitter (CX), the control transformer (CT), and the control differential transmitter (CDX). The CX and the CDX are identical to the TX and the TDX except for higher impedance windings. In theory, the CX and CDX are the same as the TX and TDX, respectively.

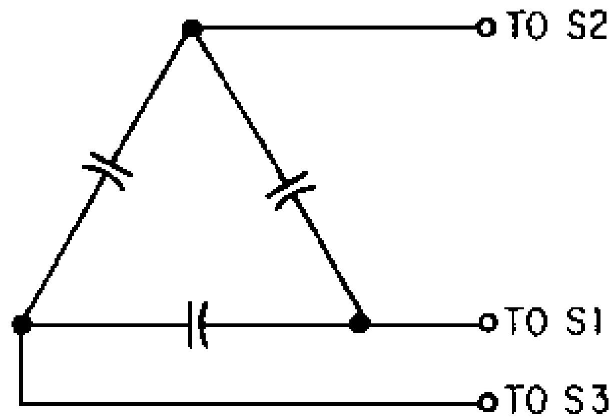
The **CONTROL TRANSFORMER (CT)** is a synchro device that compares two signals, the electrical signal applied to its stator, and the mechanical signal applied to its rotor. The output is an electrical voltage, which is taken from the rotor winding and used to control some form of power amplifying device. The phase and amplitude of the output voltage depend on the angular position of the rotor with respect to the magnetic field of the stator.



ERROR SIGNAL is the name given to the electrical output of a CT. The reason is that the electrical output voltage represents the amount and direction that the CX and CT rotors are out of correspondence. It is this error signal that eventually is used in moving the load in a typical servo system.



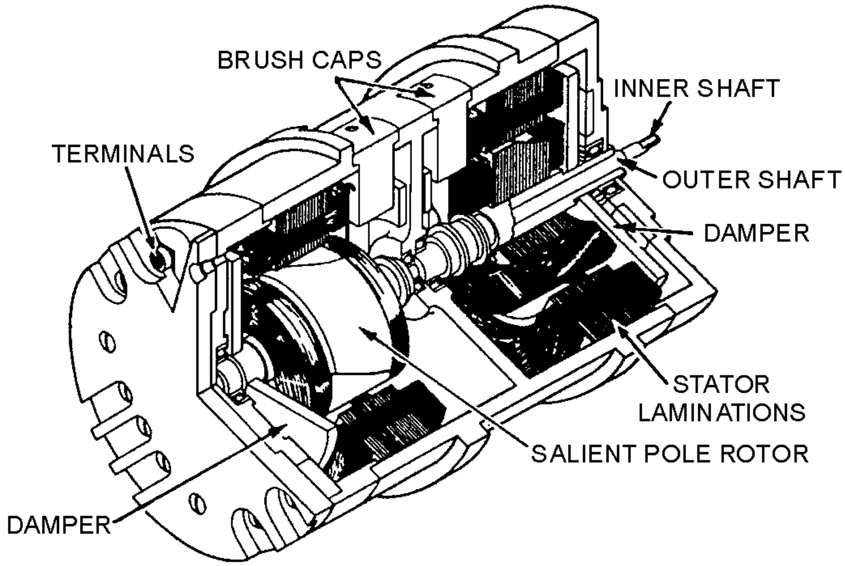
The **SYNCHRO CAPACITOR** is a unit containing three delta-connected capacitors. It is used in synchro systems containing either differential transmitters or CTs. The addition of the synchro capacitor to these systems greatly reduces the stator current and therefore increases the accuracy of the systems.



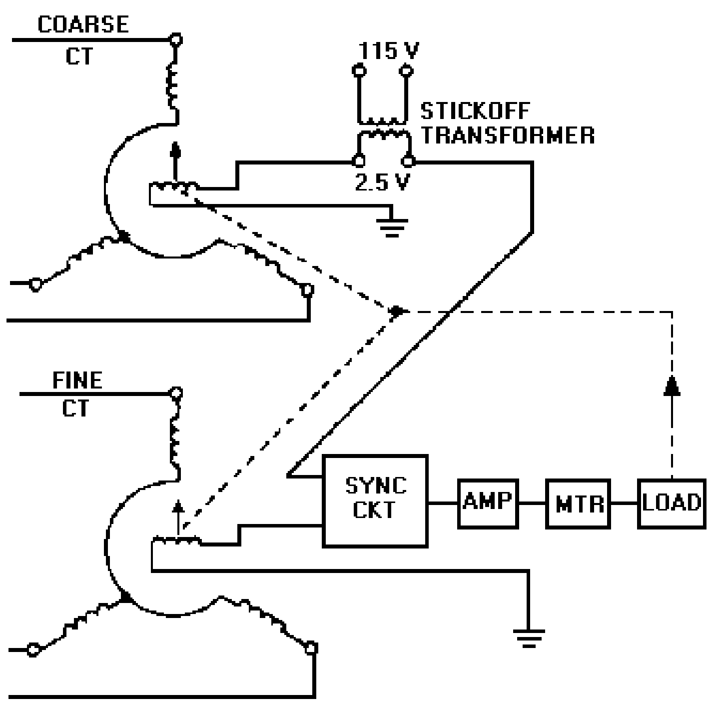
The **SPEED OF DATA TRANSMISSION** is simply the number of times a synchro transmitter rotor must turn to transmit a full range of values. You refer to the speed of data transmission as being 1-speed, 2-speed, 36-speed, or some other definite numerical ratio.

MULTISPEED SYNCHRO SYSTEMS transmit a wide range of data at different speeds and still maintain a high degree of accuracy. To indicate the number of different speeds at which data is transmitted, refer to the system as being a single-speed, dual-speed, or tri-speed synchro system.

A **DOUBLE RECEIVER** consists of a fine and a coarse receiver enclosed in a common housing. It has a two-shaft output (one inside the other), and its operation may be likened to the hour and minute hands of a clock.



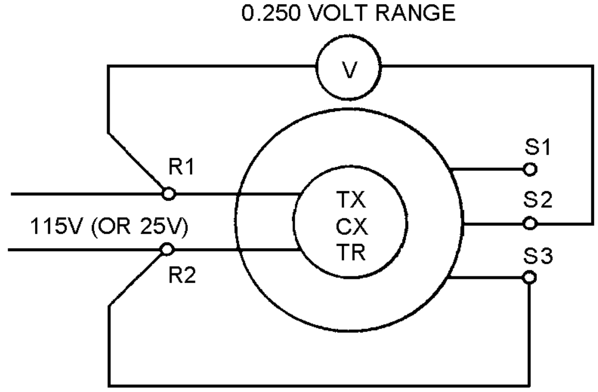
STICKOFF VOLTAGE is a low voltage used in multispeed synchro systems that contain CTs to prevent false synchronizations. The voltage is usually obtained from a small transformer and applied across the rotor terminals of the coarse CT.



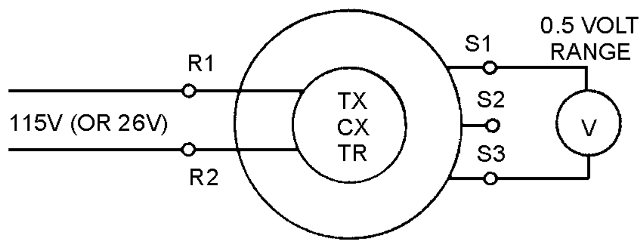
ELECTRICAL ZERO is the reference point for alignment of all synchro units.

SYNCHRO ZEROING METHODS are various and depend upon the facilities and tools available, and how the synchros are connected in the system. Some of the more common zeroing methods are the voltmeter, the electric-lock, and the synchro-tester methods.

The **VOLTMETER ZEROING METHOD** is the most accurate and requires a precision voltmeter. This method has two major steps-the coarse or approximate setting and the fine setting. The coarse setting ensures the synchro is not zeroed 180º away from its reference. This setting may be approximated physically by aligning two marks on the synchro. The fine setting is where the synchro is precisely set on 0º .

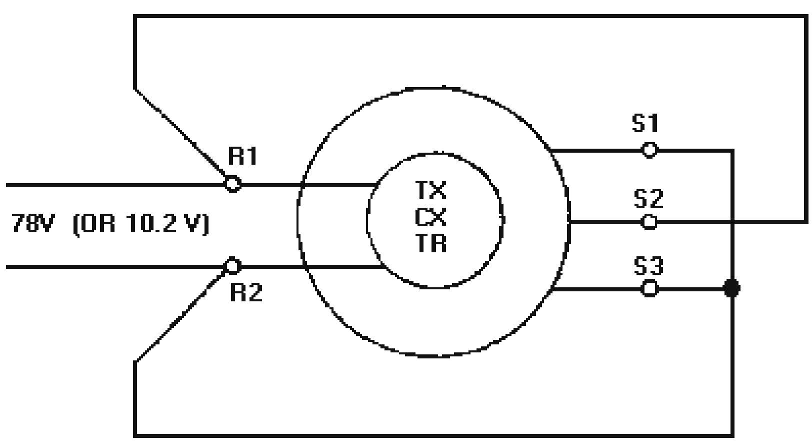


COARSE SETTING



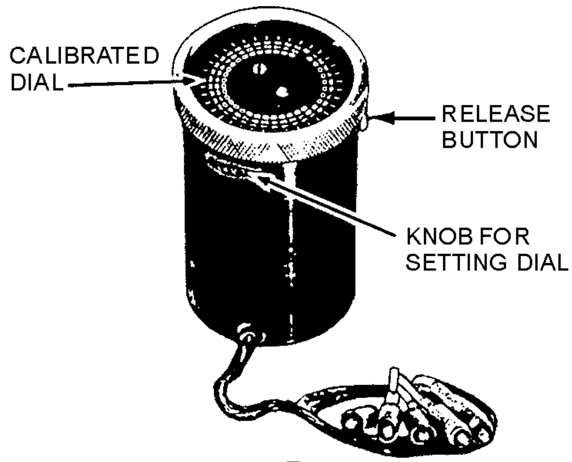
FINE SETTING

ELECTRICAL-LOCK ZEROING METHOD is perhaps the fastest. However, this method can be used only if the rotors of the synchros are free to turn and the leads are accessible. For this reason, this method is usually used on TRs.



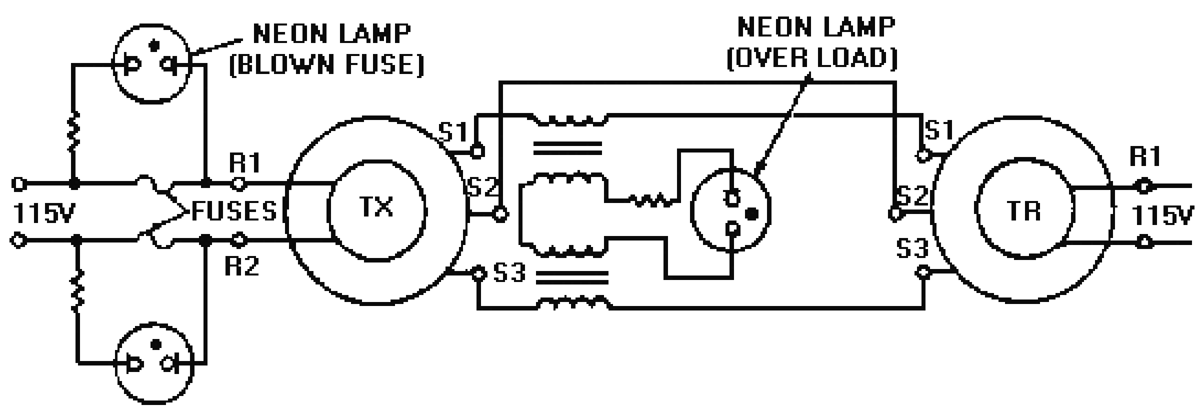
The **SYNCHRO-TESTER ZEROING METHOD** is potentially less accurate than the voltmeter or electric lock methods. This is because the dial on the tester is difficult to read and may slip from its locked position.

The synchro tester is nothing more than a synchro receiver on which a calibrated dial is mounted. The tester is used primarily for locating defective synchros but does provide a method for zeroing synchros.



B

TROUBLE INDICATORS are signal lights used to aid maintenance personnel in locating synchro trouble quickly. These lights are usually mounted on a central control board and connected to different synchro systems. The lights indicate either overload conditions or blown fuses.



SYNCHRO TROUBLESHOOTING is the locating or diagnosing of synchro malfunctions or breakdown by means of systematic checking or analysis. This is done by using trouble indicators, trouble tables furnished by manufacturers, known operating voltages as references, and synchro testers.

ANSWERS TO QUESTIONS Q1. THROUGH Q76.

A-1. The synchro.

A-2. Precise and rapid transmission of data between equipment and stations.

A-3. Torque and control.

A-4. A torque synchro is used for light loads and a control synchro is used in systems desired to move heavy loads.

A-5. The torque receiver (TR) and the torque differential receiver (TDR).

A-6. It is the third modification of a 26-volt 400-hertz (torque) synchro transmitter whose body diameter is between 1.01 and 1.10 inches.

A-7. The Navy prestandard designation code.

A-8. The position of the arrow.

A-9. The rotor and the stator.

A-10. The drum or wound rotor.

A-11. By the magnetic coupling from the rotor.

A-12. At the terminal board.

A-13. The number and type of synchro receivers, the mechanical loads on these receivers and the operating temperatures of both the transmitter and receivers.

A-14. A measure of how much load a machine can turn.

A-15. Ounce-inches.

A-16. Aircraft.

A-17. When it is overloaded.

A-18. Synchros have one primary winding that can be turned through 360º and three secondary windings spaced 120º apart.

A-19. The transmitter is in its zero-position when the rotor is aligned with the S2 stator winding.

A-20. When the rotor coil is aligned with the stator coil.

A-21. The amplitude of the primary voltage, the turns ratio, and the angular displacement between the rotor and the stator winding.

A-22. A synchro receiver uses some form of damping to retard excessive oscillations or spinning.

A-23. Mechanical damping.

A-24. A synchro transmitter and a synchro receiver.

A-25. The rotor leads.

A-26. The voltages are equal and oppose each other.

A-27. Signal.

A-28. 1 and S3.

A-29. The rotor leads on either the transmitter or the receiver are reversed.

A-30. Differential synchros can handle more signals than regular synchros and also perform addition and subtraction functions.

A-31. The TDX and the TDR.

A-32. Their application: a TDX has one electrical and one mechanical input with an electrical output.

A-33. The way the differential synchro is connected in a system is the deciding factor on whether the unit adds or subtracts its inputs.

A-34. When the TDX rotor is on 0º.

A-35. 240º.

A-36. 80º.

A-37. The S1 and S3 leads are reversed between the TX and the TDX, and the R1 and R3 leads are reversed between the TDX rotor and the TR.

A-38. The R1 and R3 leads between the TDR rotor and the TX to which it is connected.

A-39. Clockwise.

A-40. A control synchro.

A-41. CX, CT, and CDX.

A-42. The CX and CDX have higher impedance windings.

A-43. The rotor is specially wound, it is never connected to an ac supply, and its output is always applied to a high-impedance load.

A-44. They are perpendicular to each other.

A-45. The voltage is maximum and in phase with the ac excitation voltage to the CX.

A-46. Error signal.

A-47. When the CX and CT rotors are in correspondence.

A-48. To improve overall synchro system accuracy by reducing stator currents.

A-49. TDXs, CDXs, and Cts.

A-50. Magnetizing current.

A-51. They are delta-connected across the stator windings.

A-52. To keep the connections as short as possible in order to maintain system.

A-53. A dual or double-speed synchro system.

A-54. Greater accuracy without the loss of self-synchronous operation.

A-55. The gear ratio between the two transmitters.

A-56. A tri-speed synchro system.

A-57. If one of the receivers goes bad the entire unit must be replaced.

A-58. It is used in synchro systems to prevent false synchronizations.

A-59. Electrical zero.

A-60. The voltmeter method.

A-61. A61.It ensures the synchro is on 0º, not 180º.

A-62. A TR is zeroed when electrical zero voltages exist across its stator windings at the same time its rotor is on zero or on its mechanical reference position.

A-63. Approximately 37 volts.

A-64. Never leave the circuit energized for more than 2 minutes.

A-65. To ensure that it did not move off zero while it was being clamped.

A-66. Zero or minimum voltage.

A-67. The coarse synchro.

A-68. The electrical lock method.

A-69. It can be used only if the leads of the synchro are accessible and the rotor is free to turn.

A-70. The synchro under test is not on electrical zero.

A-71. Replace it.

A-72. Improper wiring and misalignment.

A-73. An overload indicator.

A-74. The transmitter or main bus.

A-75. 150º and 330º

A-76. Use only one receiver so as not to overload the tester.