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Synchros

It is a general name for self-synchronizing machines which, when electrically energized and electrically interconnected, exert torques which cause two mechanically independent shafts either to run in synchronism or to make the rotor of one unit follow the rotor position of the other. They are also known by the trade names of selsyns and autosyns. Synchros, in fact, are small cylindrical motors varying in diameter from 1.5 cm to 10 cm depending on their power output. They are low-torque devices and are widely used in control systems for transmitting shaft position information or for making two or more shafts to run in synchronism. If a large device like a robot arm is to be positioned, synchros will not work. Usually, a servomotor is needed for a higher torque.

Types of Synchros

There are many types of synchros but the four basic types used for position and error-voltage applications are as under :

Synchros

(i) Control Transmitter (denoted by CX) – earlier called generator ***(ii)*** Control Receiver (CR) – earlier called motor ***(iii)*** Control-Transformer (CT) and ***(iv)*** Control Differential (CD). It may be further subdivided into control differential transmitter (CDX) and control differential receiver (CDR).

All of these synchros are single-phase units except the control differential which is of three-phase construction.

(*a*) Constructional Features

1. Control Transmitter

Its constructional details are shown in Fig. 1 (*a*). It has a three-phase stator winding similar to that of a three-phase synchronous generator. The rotor is of the projecting-pole type using dumbell construction and has a single-phase winding. When a single-phase ac voltage is applied to the rotor through a pair of slip rings, it produces an alternating flux field along the axes of the rotor . This alternating flux induces three unbalanced single phase/voltage in the three stator windings by transformer action. If the rotor is aligned with the axis of the stator winding 2, flux linkage of this stator winding is maximum and this rotor position is defined as the electrical zero. In Fig.1 (*b*), the rotor axis is displaced from the electrical zero by an angle displaced 120º apart.

(*b*) Control Receiver (CR)

Its construction is essentially the same as that of the control transmitter shown in Fig. 39.1 (*a*). It has three stator windings and a single-phase salient-pole rotor. However, unlike a *CX*, a *CR* has a mechanical viscous damper on the shaft which permits *CR* rotor to respond without overshooting its mark. In normal use, both the rotor and stator windings are excited with single-phase currents. When the field of the rotor conductors interacts with the field of the stator conductors, a torque is developed which produces rotation.

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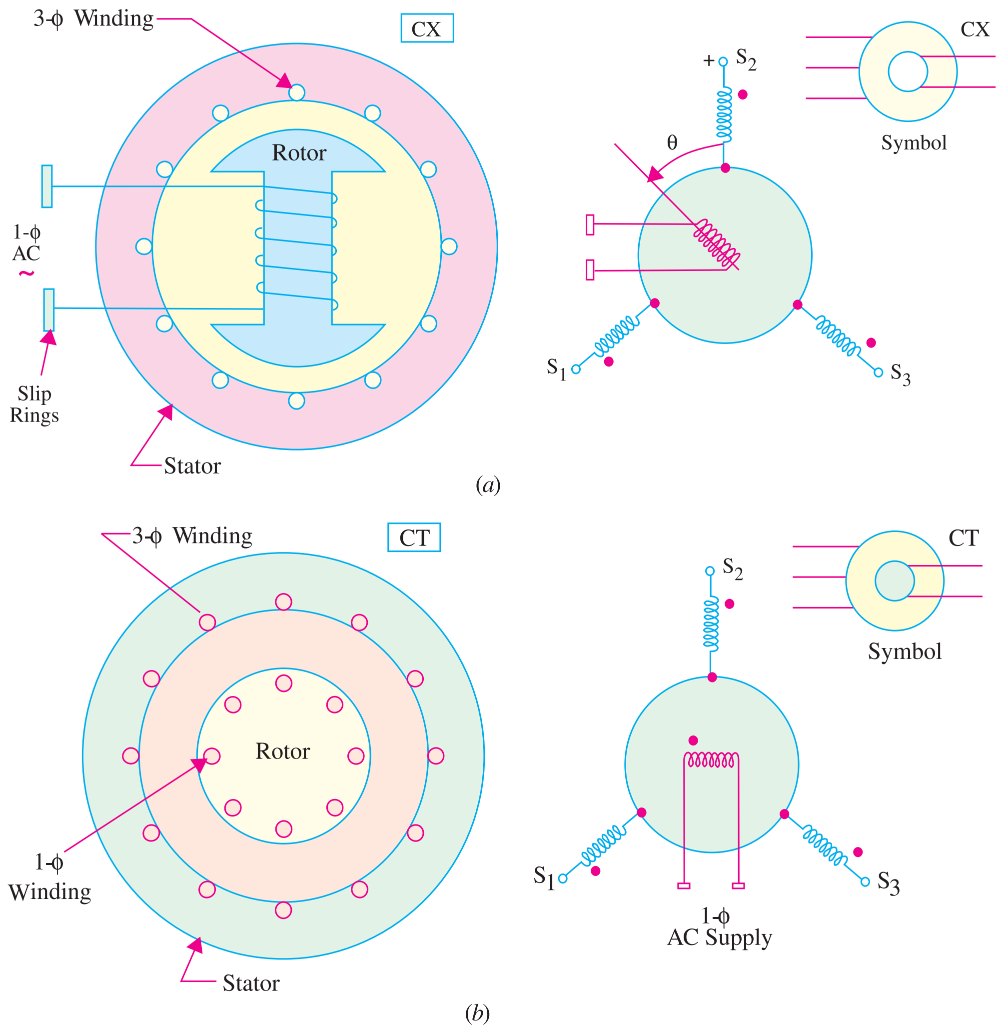

Fig.1

(*c*) Control Transformer (CT)

As shown in Fig. 1 (*b*) its stator has a three-phase winding whereas the cylindrical rotor has a single-phase winding. In this case, the electrical zero is defined as that position of the rotor that makes the flux linkage with winding 2 of the stator zero. This rotor position has been shown in Fig. 39. 1 (*b*) and is different from that of a control transmitter.

(*d*) Control Differential (CD)

The differential synchro has a balanced three-phase distributed winding in both the stator and the rotor. Moreover, it has a cylindrical rotor as shown in Fig.2 . Although three-phase windings are involved, it must be kept in mind that these units deal solely with single-phase voltages. The three winding voltages are not polyphase voltages. Normally , the three-phase voltages are identical in magnitude but are separated in phase by 120º. In synchros, these voltages are in phase but differ in magnitude because of their physical orientation.

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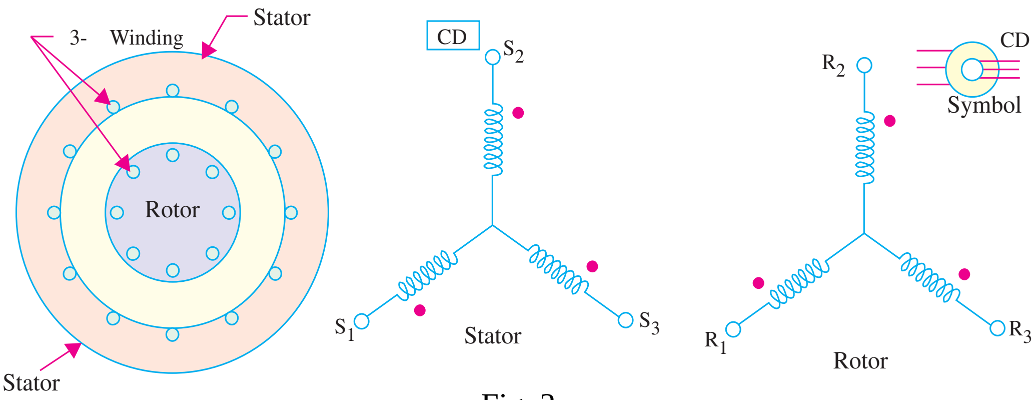

Fig. 2

(*e*) Voltage Relations

Consider the control transmitter shown in Fig. 3 . Suppose that its rotor winding is excited by a single-phase sinusoidal ac voltage of rms value E_r and that rotor is held fast in its displaced position from the electrical zero. If K = stator turns / rotor turns, the rms voltage induced in the stator winding is $E = KE_r$. However, if we assume $K = 1$, then $E = E_r$.

The rms value of the induced emf in stator winding 2 when the rotor displacement is 'α' is given by

$$E_{2s} = E_r \cos \alpha.$$

Since the axis of the stator winding 1 is located 120º ahead of the axis of winding 2, the rms value of the induced emf in this winding is

$$E_{1s} = E_r \cos (\alpha - 120^\circ).$$

In the same way since winding 3 is located behind the axis of winding 2 by 120º, the expression for the induced emf in winding 3 becomes

$$E_{3s} = E_r \cos (\alpha + 120^\circ).$$

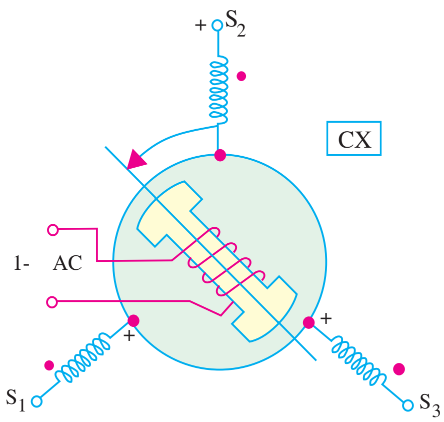

Fig. 3

We can also find the values of terminal induced voltages as

$$\begin{aligned}
E_{12} &= E_{1s} + E_{s2} = E_{1s} - E_{2s} \\
&= E_r \cos \alpha \cos 120^\circ + E_r \sin \alpha \sin 120^\circ - E_r \cos \alpha \\
&= E_r \left(-\frac{3}{2} \cos \alpha + \frac{\sqrt{3}}{2} \sin \alpha \right) \\
&= \sqrt{3}\, E_r \left(-\frac{1}{2} \cos \alpha + \frac{1}{2} \sin \alpha \right) \\
&= \sqrt{3}\, E_r \cos (\alpha - 150^\circ)
\end{aligned}$$

$$\begin{aligned}
E_{23} &= E_{2s} + E_{s3} = E_{2s} - E_{3s} \\
&= E_r \left(\frac{3}{2} \cos \alpha + \frac{\sqrt{3}}{2} \sin \alpha \right) = \sqrt{3}\, E_r \left(\frac{\sqrt{3}}{2} \cos \alpha + \frac{1}{2} \sin \alpha \right) = \sqrt{3}\, E_r \cos (\alpha - 30^\circ)
\end{aligned}$$

$$\begin{aligned}
E_{31} &= E_{3s} + E_{s1} = E_{3s} - E_{1s} \\
&= E_r \cos (\alpha + 120^\circ) - E_r \cos (\alpha - 120^\circ) \\
&= -\sqrt{3}\, E_r \sin \alpha = \sqrt{3}\, E_r \cos (\alpha + 90^\circ)
\end{aligned}$$

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Example 1. *The rotor of a control transmitter(CX) is excited by a single-phase ac voltage of rms value 20 V. Find the value of E_{1s}, E_{2s} and E_{3s} for rotor angle α = + 40º and – 40º. Assume the stator/rotor turn ratio as unity. Also, find the values of terminal voltages when α = + 30º.*

Solution. Since $K = 1$, the voltage relations derived in will be used.

(*a*) $\alpha = +40^\circ$

$$E_{2s} = E_r \cos\alpha = 20\cos 40^\circ = 15.3\text{ V}$$
$$E_{1s} = E_r \cos(\alpha - 120^\circ) = 20\cos(40^\circ - 120^\circ) = \mathbf{3.5\ V}$$
$$E_{3s} = E_r \cos(\alpha + 120^\circ) = 20\cos 160^\circ = \mathbf{-18.8\ V}$$

(*b*) $\alpha = -40^\circ$

$$E_{2s} = 20\cos(-40^\circ) = 15.3\text{ V}$$
$$E_{1s} = 20\cos(-40^\circ - 120^\circ) = 20\cos(-160^\circ) = -18.8\text{ V}$$
$$E_{3s} = 20\cos(-40^\circ + 120^\circ) = 20\cos 80^\circ = \mathbf{3.5\ V}$$

(*c*)

$$E_{12} = \sqrt{3} \times 20 \times \cos(30^\circ - 150^\circ) = -17.3\text{ V}$$
$$E_{23} = \sqrt{3}\,E_r\cos(\alpha - 30^\circ) = \sqrt{3}\,E_r\cos(30^\circ - 30^\circ) = 34.6\text{ V}$$
$$E_{31} = \sqrt{3}\,E_r\cos(\alpha + 90^\circ) = \sqrt{3} \times 20 \times \cos(30^\circ + 90^\circ) = \mathbf{-17.3\ V}$$

Applications of Synchros

The synchros are extensively used in servomechanism for torque transmission, error detection and for adding and subtracting rotary angles. We will consider these applications one by one.

(*a*) Torque Transmission

Synchros are used to transmit torque over a long distance without the use of a rigid mechanical connection. Fig. 4 represents an arrangement for maintaining alignment of two distantly-located shafts. The arrangement requires a control transmitter (CX) and a control receiver (CR) which acts as a torque receiver. As *CX* is rotated by an angle α, *CR* also rotates through the same angle α. As shown, the stator windings of the two synchros are connected together and their rotors are connected to the same single-phase ac supply.

Working. Let us suppose that *CX* rotor is displaced by an angle α and switch SW_1 is closed to energize the rotor winding. The rotor winding flux will induce an unbalanced set of three single-phase voltages (in time phase with the rotor voltage) in the *CX* stator phase windings which will circulate currents in the *CR* stator windings. These currents produce the *CR* stator flux field whose axis is fixed by the angle α. If the *CR* rotor winding is now energized by closing switch SW_2, its flux field will interact with the flux field of the stator winding and thereby produce a torque. This torque will rotate the freely-moving *CR* rotor to a position which exactly corresponds with the *CT* rotor *i.e.* it will be displaced by the same angle α as shown in Fig. 4. It should be noted that if the two rotors are in the same relative positions, the stator voltages in the two synchros will be exactly equal and opposite. Hence, there will be no current flow in the two stator windings and so no torque will be produced and the system will achieve equilibrium. If now, the transmitter rotor angle changes to a new value, then new set of voltages would be induced in the transmitter stator windings which will again drive currents through the receiver stator windings. Hence, necessary torque will be produced which will turn the *CR* rotor through an angle corresponding to that of the *CT* rotor. That is why the transmitter rotor is called the master and the receiver rotor as the slave, because it follows its master. It is worth noting that this master-slave relationship is reversible because when the receiver rotor is displaced through a certain angle, it causes the transmitter rotor to turn through the same angle.

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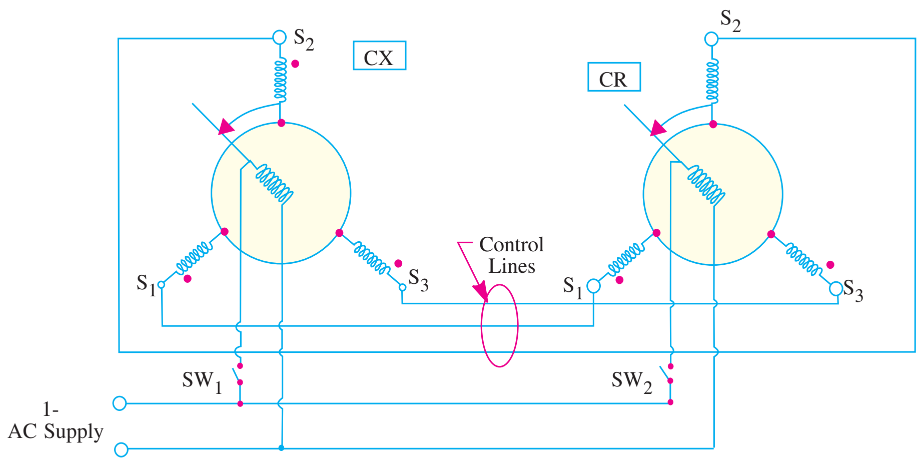

Fig. 4

(*b*) Error Detection

Synchros are also used for error detection in a servo control system. In this case, a command in the form of a mechanical displacement of the *CX* rotor is converted to an electrical voltage which appears at the *CT* rotor winding terminals which can be further amplified by an amplifier

For this purpose, we require a *CX* synchro and a *CT* synchro as shown in Fig. 5. Only the *CX* rotor is energized from the single-phase ac voltage supply which produces an alternating air-gap flux field. This time-varying flux field induces voltages in the stator windings whose values for $\alpha = 30°$ are as indicated in the Fig. 5. The *CX* stator voltages supply magnetizing currents in the *CT* stator

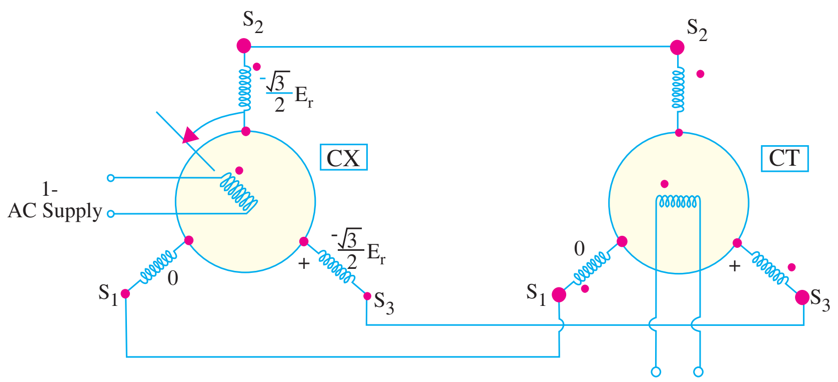

Fig. 5

windings which, in turn, create an alternating flux field in their own air-gap. The values of the *CT* stator phase currents are such that the air-gap flux produced by them induces voltages that are equal and opposite to those existing in the *CX* stator. Hence, the direction of the resultant flux produced by the *CX* stator phase currents is forced to take a position which is exactly identical to that of the rotor axis of the *CT*.

If the *CT* rotor is assumed to be held fast in its electrical zero position as shown in Fig. 5, then the rms voltage induced in the rotor is given by $E = E_{max} \sin \alpha$, where E_{max} is the maximum voltage induced by the *CT* air-gap flux when coupling with the rotor windings is maximum and α is the displacement angle of the *CT* rotor.

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In general, the value of the rms voltage induced in the *CT* rotor winding when the displacement of the *CX* rotor is α_x and that of the *CT* rotor is α_T is given by

$$E = E_{max} \sin(\alpha_x - \alpha_T)$$

Control Differential Transmitter

It can be used to produce a rotation equal to the sum of difference of the rotations of two shafts. The arrangement for this purpose is shown in Fig. 6 (*a*). Here, a CDX is coupled to a control transmitter on one side and a control receiver on the other. The *CX* and *CR* rotor windings are energized from the same single-phase voltage supply.

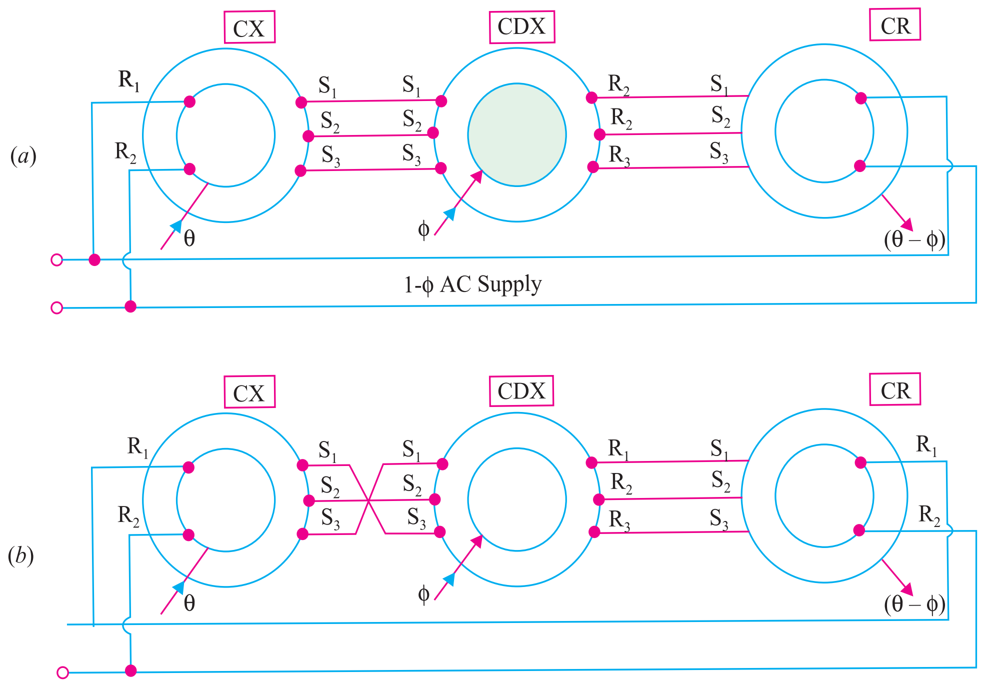

Fig.

It has two inputs : Mechanical θ and Electrical ϕ and the output is Machnical (θ – ϕ). The mechanical input (θ) to *CX* is converted and applied to the *CDX* stator. With a rotor input (ϕ), the electrical output of the *CDX* is applied to the *CR* stator which provides the mechanical output θ – ϕ).

As shown in Fig. 6 (*b*), if any two stator connections between *CX* and *CDX* are transposed, the electrical input from *CX* to *CDX* becomes –θ, hence the output becomes (–θ – ϕ) = – (θ + ϕ).