ROYAL SCHOOL OF ARTILLERY

BASIC SCIENCE & TECHNOLOGY SECTION
GUNNERY STAFF/CAREER COURSES

AC SYNCHRONOUS TRANSMISSION

INTRODUCTION

1. AC synchronous transmission systems are better known by the names magslip, synchromechanism or synchro. A synchro element, whether transmitter or receiver, consists essentially of a series of three stators and a rotor. The stators consist of three windings with their axes 120° apart, connected in star, as for three phase supply. In its simplest form, the rotor consists of a laminated iron core carrying a single winding, the ends of which are brought out to slip-rings. The electrical and schematic diagrams are illustrated at Fig.1.

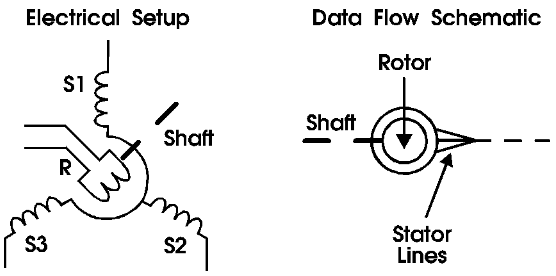


Fig.1. AC Synchronous Transmission Element

2. Fig.2, shows how the instantaneous electromagnetic vectors for both rotor and stators change, for different positions of the rotor, when it is excited by an AC supply. The effect is reversible and, given appropriate vectors in the stators, a summation of all three forms at the rotor. In practice, a wide range of AC excitation can be used such as 240V @ 50Hz, 115V @ 400Hz and 26V @ 400Hz.

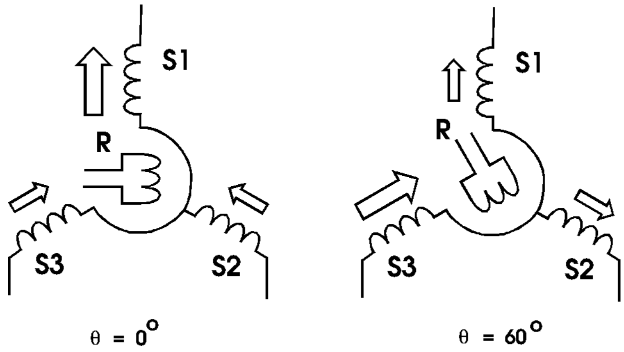


Fig.2. Stator Vectors for Rotor Induced EMF's

TORQUE SYNCHRO

3. At Fig.3, two elements are connected together to form a synchronous transmission link, their data flow schematic is shown below. Both rotors are supplied from the same AC source. If the rotor positions in the two elements coincide, then the EMF's induced in the corresponding coils of both transmitter and receiver are equal, and no circulating current can flow between the two stators. This is the equilibrium condition which is always sought by the system. The notation used for this type of system is TX for Torque Transmitter and TR for Torque Receiver.

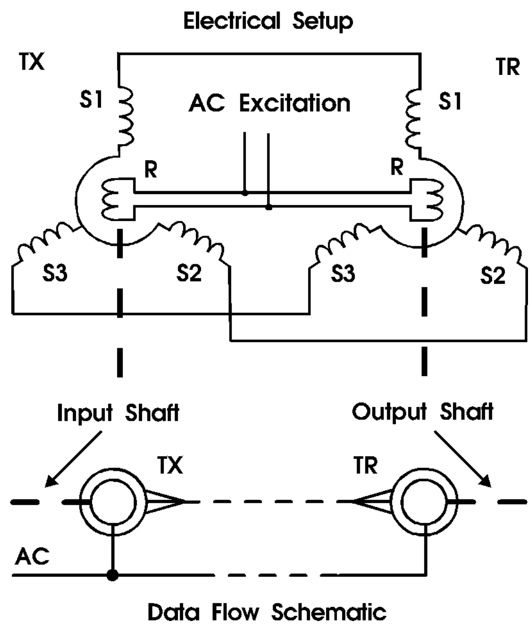


Fig.3. The Torque Synchro

4. If the rotor of one element is turned, the EMF's induced in the two stators will no longer be equal and currents will circulate in the stator windings. As a result of these currents a torque is produced which tries to bring the rotors back into alignment. Since the transmitter has its rotor position fixed by the input shaft, to the value of the quantity being transmitted, it is the receiver rotor that is free to move into alignment. The output shaft will normally carry a very small load requiring relatively small torque to align it. Torque increases with angle of misalignment, the proof of which is beyond the scope of these notes.

5. The difference between a synchro transmitter and receiver is mechanical only. A mechanical damper in the form of a small flywheel is attached to the shaft of the receiver. Any tendency for the receiver rotor to oscillate about its new position following a change in the transmitter position is opposed by the inertia of the damper.

CONTROL SYNCHRO

6. Torque synchro's can produce high accuracy angular information in response to input shaft position, however, the power available at the TR output shaft is very limited. At best a light pointer or indicator can be driven by such a system. If the accuracy inherently available from synchro devices is to be used in heavier, high inertia, control applications, more output power must be obtained. Control synchro's provide the answer to this problem.

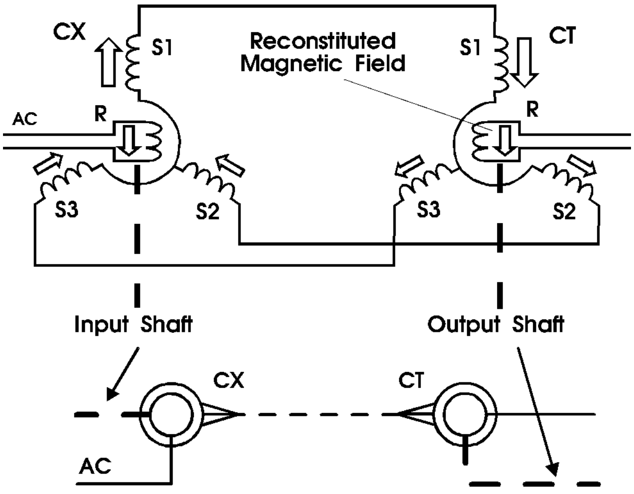


Fig.4. Control Synchro

7. Fig.4, shows a control synchro set up. The first point to be noticed is that the AC excitation is fed only to the input device. In this case called the Control Transmitter, CX. The output is taken from the rotor of a similar device, called the Control Transformer, CT, as a voltage signal. The rotor is also mounted on a shaft and the connection between the two will be discussed later in the text.

8. In Fig.4, the electromagnetic vectors associated with the AC excitation at some instant are shown. The excitation occurs at the CX and, since there is no excitation at the CT, the same electromagnetic vectors will occur there but in the opposite direction for each. A magnetic field is produced at the centre of the CT which is the resultant of all three stator vectors and is called the reconstituted field. Clearly, this field is in the same direction as the original field, which created all the vectors, in the rotor of the CX. If the CX rotor is angularly displaced, the reconstituted field at the CT rotor will move with it.

9. The vectors associated with this system are shown as instantaneous because it is convenient for the purposes of explanation. However, in reality, the AC excitation is changing all the time and therefore inducing the EMF's illustrated at some time. At the CT rotor, an EMF will be induced that is dependent upon the rotor position with respect to the reconstituted field. If the rotor and field are in alignment the EMF induced will be maximum. If the rotor is perpendicular to the field the induced EMF will be zero.

10. Rotation of the CT shaft will produce an EMF at the CT rotor which is dependent upon its angular position with respect to the reconstituted field. Fig.5, illustrates the process starting from the point when the rotor is perpendicular to the field. The change of phase at the 180° point should be noted. Thus when the rotor and field are coincident, maximum EMF is induced, and when they are perpendicular zero EMF is induced.

11. In control applications the rotor output is used as an error input to an amplifier, or processor. If the maximum point of the field is sought in order to bring it into line with the CX rotor a problem arises. Any slight changes of AC excitation will produce error because the maximum must be compared with some reference. However, if the zero point is used then changes in the AC excitation will have no effect upon the accuracy of the output alignment signal. This effect can be achieved by placing the CT shaft in the correct position for alignment with the CX, and then misaligning the CT rotor by 90° to produce the zero output.

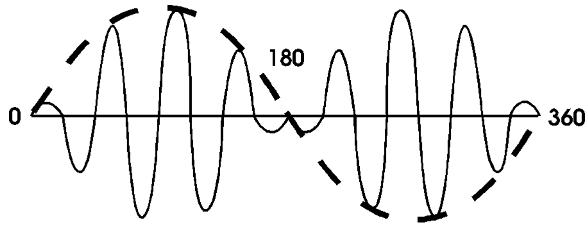


Fig.5. CT Rotor Output

CONTROL SERVOMECHANISM

12. Fig.6, shows the CT in combination with a servomechanism. It is actually acting as the error detector. The input to the CT is a shaft angle on the three stator lines, from which the field is reconstituted at the rotor. If the rotor is not exactly aligned to give a zero signal into the amplifier, the error signal is amplified and drives the motor to reposition the output shaft. The output shaft position is fed back to the CT rotor and brings it into alignment, reducing the error signal to zero. At this point the motor ceases to drive and the new angular output is held.

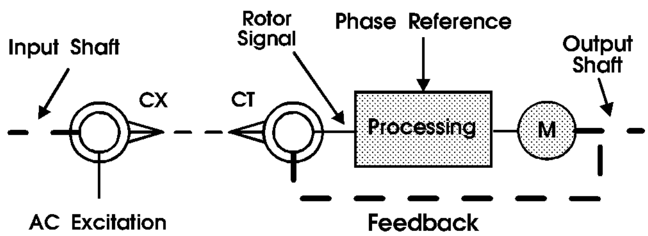


Fig.6. Control Synchro System with Servomechanism

13. A phase reference is fed into the signal processing stage so that the motor can be caused to rotate in the correct direction to reduce the error on the output shaft. The reference is compared with the phase of the error signal. If they are in-phase the motor is turned in one direction. If they are 180° out of phase it will be turned in the opposite direction. It is possible to misalign the servo by 180° by setting it deliberately, however, any small noise signal, vibration or input will immediately cause the system to align correctly, so the probability of this occurring in operation is very remote.

14. The power available on the output shaft is almost unlimited. Drive motors do not need to be electrical. They could, for example, be hydraulic as used in many weapon system platforms. As long as the feedback to the CT shaft is available, the means by which output shaft movement is produced is of no consequence as far as the actual control function is concerned.

DIFFERENTIAL SYNCHRO

15. This is a device designed to provide the difference between two input shaft angles. The mechanism is shown at Fig.7, together with the data flow schematic The Control Differential Synchro element is titled CDX and its rotor construction is identical to that for the stator windings, in that it consists of three coils mounted at 120° to each other, however, they are all free to rotate with the rotor shaft.

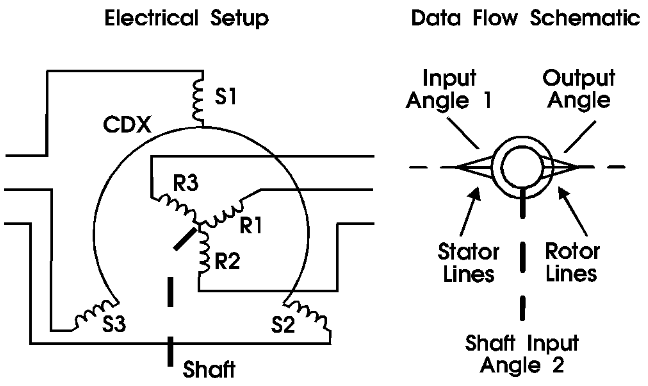


Fig.7. The Control Differential Synchro

16. The first shaft angle, θ1, is delivered to the stators of the CDX and sets up a magnetic field that would be identical to those which would be set up in the stators of a CT. In other words it reconstitutes the input synchro angle as a field at the centre of the CDX. The reconstituted field is able to induce EMF's in the CDX rotor windings, in exactly the same way that a CX rotor field induces EMF's in its stator windings. For the case illustrated by Fig.7, a reference line for angular measurement, which is perpendicularly upwards on the diagram, is in use.

17. The second shaft angle, θ2, is delivered to the rotor of the CDX. Since the angular reference is perpendicularly upwards on the diagram. It can be seen that the CDX rotor is at an angle of 60°. Hence, the EMF's induced in the CDX rotor will depend upon its angular position with respect to the input 1 shaft angle from the CDX stators. If the electrical shaft angle at input 1 is in alignment with the mechanical shaft angle at input 2 the induced EMF's at the CDX rotor will be identical to those induced at its stators, assuming no losses in transformation, which can be ignored anyway.

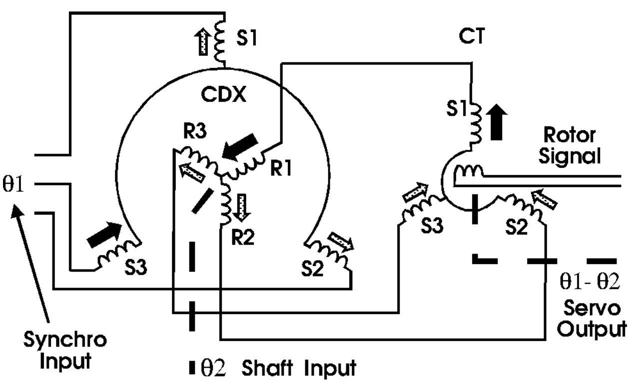


Fig.8. Control Differential Servomechanism

CONTROL DIFFERENTIAL SERVOMECHANISM

18. A control differential synchro, CDX, as used in a full control system is illustrated at Fig.8. The control transmitter, CX, has been left off the diagram in the interests of space. The output synchro angle is fed to the stators of a control transformer, CT, from which the rotor error signal is delivered to the signal processing stage of a standard control servomechanism. Its output shaft feeds back to the CT rotor in the usual way.

19. The electromagnetic field arrows are self-explanatory, with the proviso that the fields induced in the rotor windings of the CDX will be in the opposite direction to the field that produces them. Assuming that θ1 is at 60° clockwise, rotation of θ2 by 60° causes R1 of the CDX rotor to come into line with S3. This means that maximum EMF is induced in R1, as shown by the arrows on the diagram, causing the same field strength to occur around S1 of the CT, the other windings following suit as shown by the arrows.

20. The field reconstituted at the CT centre is in the vertical, 0°, position and the CT rotor now seeks to null with this using the attached servomechanism. As a result, the output shaft moves into the reference position of 0°, whereupon the error output from the CT rotor falls to zero and the output shaft holds θ(out) = θ1 – θ2 = 0°. Should θ1 give an angle of 0° at the CDX stators, then movement of the CDX shaft, θ2, clockwise with respect to it, will cause the CT rotor shaft to align clockwise, giving θ1 – θ2 = 60°. So, whenever the difference between two shaft angles is required, the differential synchro together with a servo-mechanism is able to provide the necessary electrical function. Fig.9, shows the data flow diagram for a complete system.

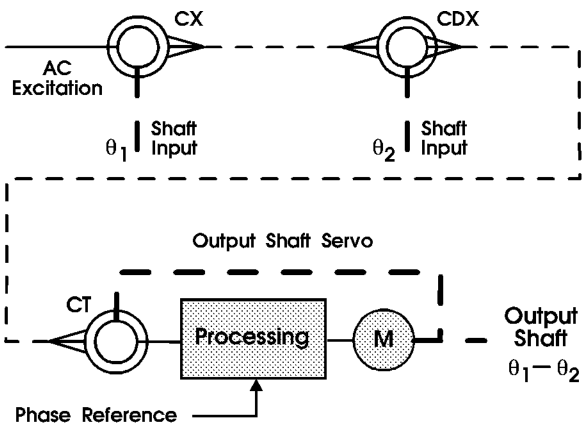


Fig.9. Complete Control Differential Servo

RESOLVER SYNCHRO

21. The resolver synchro is essentially similar to the other synchros, however, this type has only two windings in the stators and the rotor, as illustrated at Fig.10. In both cases the two windings are placed at 90° to each other. This type of device finds its most important application in areas where polar to rectangular, and rectangular to polar conversions are required. To most gunners, this means that Bearing, θ, and Range, R, can be found from a knowledge of Eastings, dE, and Northings, dN, or vice versa. However, the range of applications is far wider than that.

POLAR TO RECTANGULAR CONVERSION

22. In Fig.10, the rotor winding R1 is energised by an alternating signal of magnitude proportional to range, R, and the shaft input is rotated by an amount equal to the angular measure in use for bearing, θ. The two stator windings, S1 and S2, are wound perpendicular to each other, so that when one is induced at maximum the other is zero and vice versa.

23. S1, which is in parallel with the reference position of Fig.10, will be energised to maximum when the shaft is positioned at 0°, the reference position, or 180°, which is reversed. It will be energised to zero when the shaft is positioned at 90° or 270°, hence, overall, it can be shown to produce e1×Cos(θ) as its output. On the other hand, S2, which is perpendicular to the reference position, will be energised to minimum when the shaft is at zero, or 180°, and to maximum when it is at 90° or 270°, hence, it can be shown to produce e1 × Sin(θ)

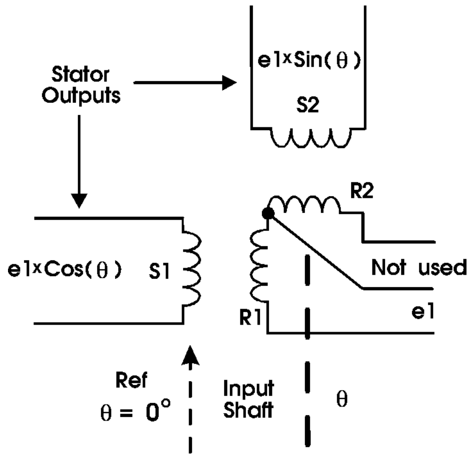


Fig.10. Resolver Synchro, Polar to Rectangular Mode

24. The ambiguous position of two angles giving the same magnitude of output is resolved by checking the phase of the stator signal in a similar manner to phase referencing in the control servo. This must be achieved by the circuits employing S1 and S2. Hence, dE and dN are produced at S1 and S2 from inputs of Range at R1 and bearing, θ, at the input shaft. The second rotor winding, R2, is normally shorted out to avoid affecting the magnetic fields in the armature when not required.

RECTANGULAR TO POLAR CONVERSION

25. When used in the rectangular to polar conversion mode the resolver synchro must be coupled to a servomechanism. The servo is responsible for providing the correct bearing shaft output angle. As with the control synchro system, one output from the rotor is used to null the servo drive when it reaches a position parallel to the sum field provided by the S1 and S2 inputs. This is achieved by using the second rotor winding R2 for the servo control and R1 for the range output.

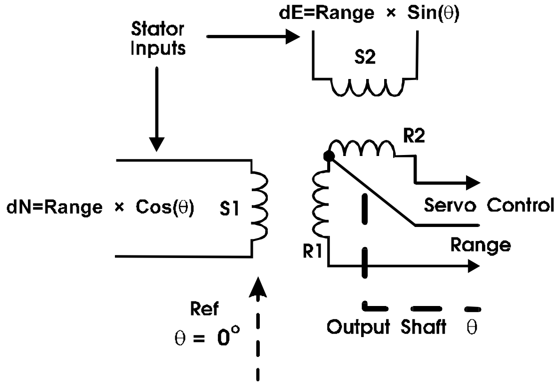


Fig.11. Resolver Synchro, Rectangular to Polar Mode

26. Fig.11, indicates the layout in this configuration. The two cartesian inputs, dE and dN, are applied at S1 and S2 respectively and they combine to form a resultant field at the centre of the resolver synchro. When the servo control output has driven the output shaft to the correct bearing angle, the voltage output at R2, is then proportional to range.

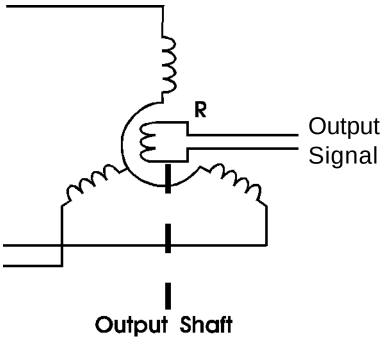
27. Any doubt over this can be removed by considering the position with either zero northings or zero eastings. At zero northings, the target is either east or west, hence, dE specifies its range. The servo control drives through 90° to place the rotor winding R1 perpendicular to S1, in which position the range output is correct and extracted from R2, which is parallel to S2.

28. On the other hand, at zero eastings, the target is either north or south, hence, dN specifies its range. The servo drives through 90° to place the rotor winding R1 perpendicular to S2, in which position the range output is correct and extracted from R2, which is now parallel to S2. This is actually the position shown by Fig.11. The required direction of rotation is once again taken care of by phase control.

SELF TEST QUESTIONS

Each question has a single fully correct answer. Check each answer carefully before making your selection.

1. The following illustration is an example of a:-



a. Torque Receiver
b. Control Transmitter
c. Differential Transmitter
d. Control Transformer

2. The AC excitation used for a torque synchro could be:-

a. 240V @ 50Hz
b. 115V @ 400Hz
c. 26V @ 400Hz
d. any of the above

3. The reason that a torque synchro cannot be used as part of a servomechanism is because:-

a. the Torque Receiver is unable to drive more than a very light load
b. the Torque Transformer is more efficient
c. the Torque Transmitter normally rotates in the opposite direction to that of the Torque Receiver
d. the Control Transformer is unable to handle the AC excitation

4. When comparing a control synchro system with a torque synchro system, it is true to say that:-

a. torque synchros are inherently more accurate than control synchros
b. the control synchro only requires an AC supply to one of its two main components
c. control synchros are inherently more accurate than torque synchros
d. the torque synchro only requires an AC supply to one of its two main components

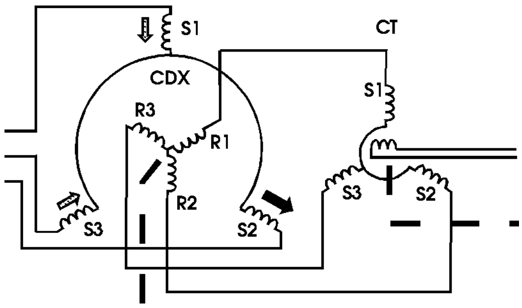
5. The reason for mounting a CT rotor at 90° to the correct alignment of the load shaft is:-

a. so that the phasing of the error signal can be detected
b. to avoid the zero position of the reconstituted magnetic field within the synchro
c. to ensure that the amplifier does not need to discriminate for both magnitude and phase of the error signal
d. so that the output shaft turns in the correct direction

6. In a differential control transmitter (CDX):-

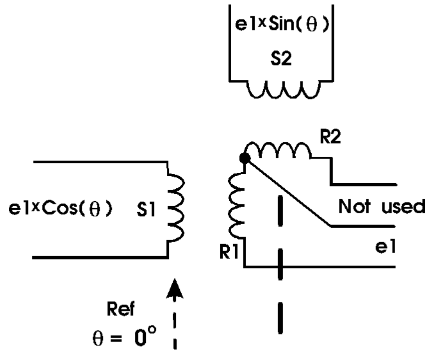
a. the stators are fed with an electrical signal relating to one angle whilst the rotor coils are fed mechani cally with the other
b. the rotor is fed with an AC excitation from the supply
c. the output is a mechanical shaft angle fed to the rotor
d. a torque transmitter is used to form θ2 - θ1

7. The following diagram shows the main elements of a differential control synchro. The magnetic field vectors at the stators are as shown, the angular displacement of the output shaft from its vertical reference would be:-



a. 30°
b. 60°
c. 90°
d. 120°

8. The following diagram shows a resolver synchro being employed in the Polar to Rectangular Conversion mode. When the R1 input has some specified value and the shaft angular input is at 45°, the outputs at S1 and S2 would be:-



a. S1 maximum and S2 minimum
b. S1 minimum and S2 maximum
c. S1 equal to S2
d. S1 and S2 both equal to zero

9. A resolver synchro is being used in Rectangular to Polar Conversion mode. Assuming that the system is at the reference angle of 0°, and the two signals at S1 and S2 are identical in magnitude, this will immediately result in the:-

a. range output being correct and the servo control output driving towards the correct angle
b. servo control output being zero and the range output driving towards the correct range
c. range output being in error and the servo control output driving for the correct angle and range
d. output shaft remaining stationary and the range output being given accurately