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SECTION 19

CHAPTER 1

REMOTE INDICATION AND CONTROL

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REMOTE INDICATION AND CONTROL

Introduction

1. It is often necessary to note or record the value or any change in value of physical quantities (e.g., angular position, speed, temperature, etc.) at a point remote from the physical quantity itself.

There are many instances in radio engineering where angular movement of an input shaft must be reproduced accurately by motion of a second shaft, often at some considerable distance from the first. For example, in an aircraft, the loop aerial used for direction finding is placed at a suitable point in the aircraft and is often not readily accessible to the operator. A bearing indicator, if mounted at the base of the aerial shaft, would be inconvenient. This difficulty is overcome by ensuring that the movement of the loop aerial shaft is reproduced accurately by the motion of a second shaft in a *remote* indicator, placed at some convenient point in the aircraft.

A direct mechanical linkage, such as a flexible drive, between the two shafts is possible, but because of their separation distance there are practical difficulties of installation: in addition, there are inherent inaccuracies, and the efficiency of the system is poor. Much more satisfactory results are obtained by using electrical remote indication systems.

Electrical remote indication systems are sometimes referred to as '*data transmission systems*'. This term, however, is nowadays normally taken to have a much wider meaning: it is used, for example, to describe the method by which information is fed to a computer. Because of this, in order to avoid confusion, the term 'data transmission' is not used in this Chapter.

2. In electrical remote indication systems, the movements of the input shaft are translated into suitable electrical signals by a device known as a *transducer* or *transmitter unit*. A transducer (not to be confused with the transductor in a magnetic amplifier) measures the physical movement in terms of some electrical quantity whose magnitude is a strict measure of the movement. The electrical signals from this transmitter unit are then transmitted through wire links (and in certain cases, radio links) to appropriate receiver units located at any desired position: the received signals are used to turn a shaft which gives the remote indication or the required movement.

In the simple system outlined above, no torque amplification is provided: the torque developed in the output shaft is therefore less than that developed in the input shaft and the power required is provided by the input. Thus only moderate torques can be developed—in many cases only sufficient to move a light pointer over a graduated scale. For remote *indication* of such things as D/F bearings, or the position of a radar scanner, this system is normally adequate.

There are many occasions, however, when accurate remote control of the *position* of

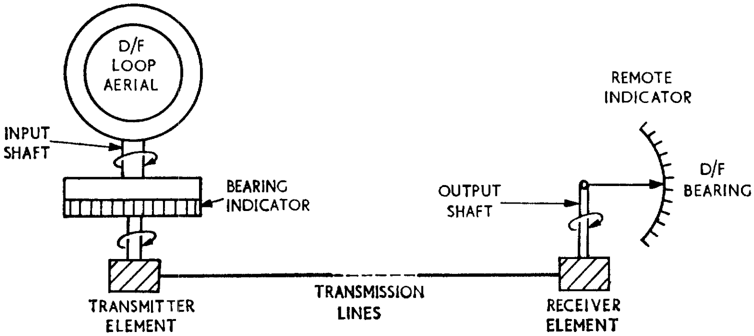

Fig. 1. ELECTRICAL REMOTE INDICATION

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a heavy load is required (e.g. remote rotation of a radar scanner). Torque amplification is now necessary and to provide the required torque, use is made of hydraulic or electric amplifiers.

Many different devices are used to give remote indication of angular position or to control the movement of heavy loads from a distance. Some are operated from a d.c. supply; others from an a.c. supply. Some of the methods used in the Service are considered in the following paragraphs.

D.C. SYSTEMS

Desynn

3. **Introduction.** The Desynn system of transmission is a simple system which, because of its low torque characteristic, is useful only for remote *indication* of angular position. It is ideal where a simple pointer and scale indicator is adequate. Aircraft applications include remote indication of flap, rudder and elevator positions, and of D/F loop and compass readings. It is also used in ground installations to repeat the reading of an instrument at a remote point. The accuracy of the system is of the order of ± 2°, and this is sufficient for the applications mentioned.

4. **Circuit.** As in all electrical remote indication systems, the input shaft is connected to a transmitter element, and the output shaft, which operates the remote indicator, is driven by a receiver element: the transmitter and receiver are connected by electrical lines.

In the Desynn system (Fig. 2) the transmitter is a continuous resistance ring or toroidal potentiometer, which has three fixed tappings A, B, C spaced 120° apart and connected to the receiver. A rotating spring-loaded mechanism mounted on the input shaft, carries two sliding contacts or wipers that are at diammetrically opposite points on the toroid. The wipers are fed, via slip rings and brushes, from the positive and negative lines of the d.c. supply.

The receiver has three high resistance coils with axes at 120° in space (like the star-connected stator winding of an a.c. induction motor): within them is a permanent magnet rotor which is capable of rotation and which carries a pointer over a calibrated scale. The three coils in the receiver are connected to the tapping points A, B, C on the transmitter by the three lines as shown in Fig. 2.

5. **Operation.** When a d.c. supply is connected to the transmitter wipers, the voltages at the tapping points A, B, C cause currents to flow through the three stator coils in the receiver, and a resultant magnetic field is produced. The rotor magnet aligns itself with this field. The magnitude and polarity of the voltage at each tapping point in the transmitter vary according to the position of the wipers. Thus, if the input shaft is rotated, the variation of voltage at A, B, C produces changes in the currents flowing in the stator coils and a magnetic field rotating in sympathy with the input shaft is produced. The rotor magnet remains aligned with this field at all times and so rotates in synchronism with the input shaft.

6. This action is illustrated in Fig. 3, where the wipers of the transmitter are connected to opposite poles of a 24V d.c. supply. With the input shaft in the position shown in Fig. 3(a), the voltage distribution round the toroid is such that point A is 24 volts positive with respect to supply negative, while B and C are both 8 volts

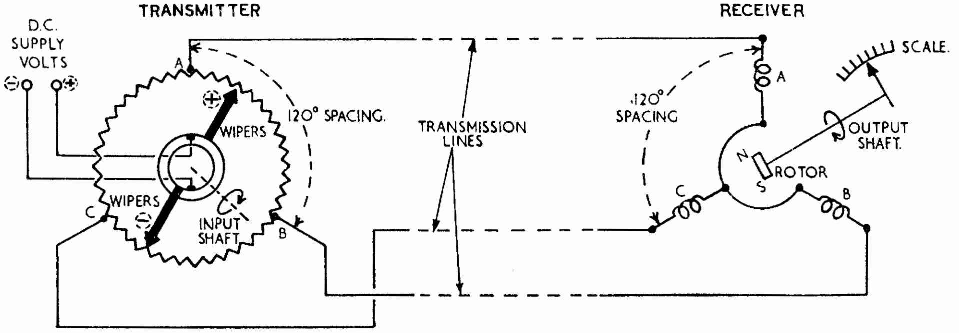


Fig. 2. DESYNN SYSTEM OF REMOTE INDICATION

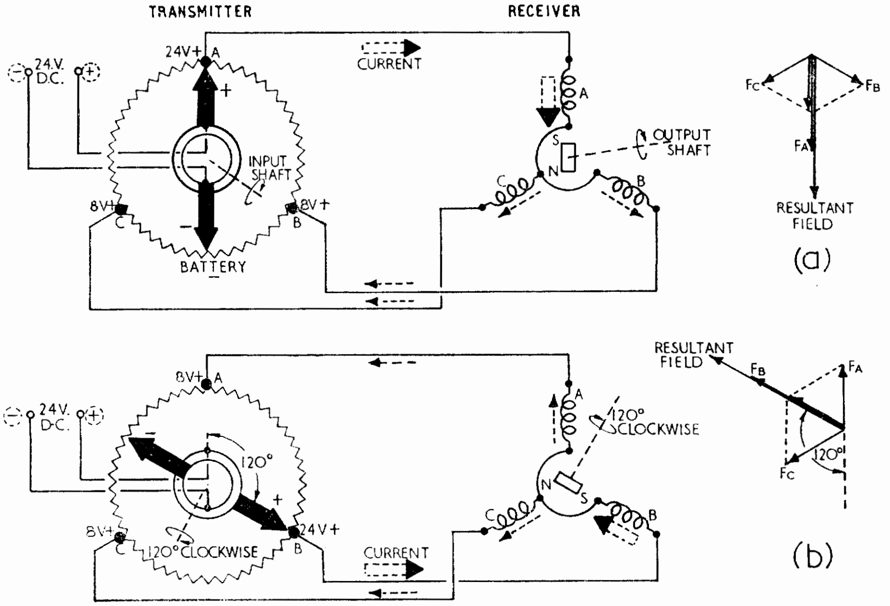


Fig. 3. OPERATION OF DESYNN

positive with respect to supply negative. With A positive by the same amount to both B and C, current flows from A through coil A in the receiver; it then divides equally at the star point and half the total current flows through coil B and half through coil C back to the transmitter. The individual and resultant magnetic fields produced by these currents are indicated by vectors, and with the input shaft in the position shown in Fig. 3(a), the axis of the resultant field lies vertically: the rotor magnet aligns itself with this axis.

If the input shaft is rotated 120° clockwise from its initial position, as shown in Fig. 3(b), the voltage distribution round the toroid is such that current flows from B through coil B in the receiver; it then divides equally and flows through coils A and C back to the transmitter. The vectors show that the resultant magnetic field has also rotated through 120° clockwise from its initial position and the rotor magnet aligns itself along this new axis.

7. **Summary.** Enough has been said to show that if the wipers in the transmitter are placed in any position by the input shaft, the resultant field at the receiver and hence the rotor magnet take up corresponding positions. Thus as the input shaft rotates through 360°, the rotor follows this movement *in the same direction;* if a pointer, moving over a calibrated scale, is attached to the rotor, remote indication of the position of the input shaft is immediately available. A typical example of the use of the Desynn is remote indication of bearing from the D/F loop—the loop shaft acting as the 'input' shaft.

M-type Transmission System

8. **Introduction.** Many practical indicators take the form of light geared mechanisms which are required to rotate fairly substantial drum-type indicators or comparable devices. For example, it may be required to rotate the deflection coils in a magnetic c.r.t. in synchronism with a radar aerial to produce the necessary trace on the screen. This requires a larger torque than is available with the Desynn system: in such circumstances, an M-type or 'step-by-step' transmission system can provide the moderate torque required.

9. **Circuit.** A toroidal potentiometer type of transmitter cannot control large currents to the receiver (i.e. allow the receiver to

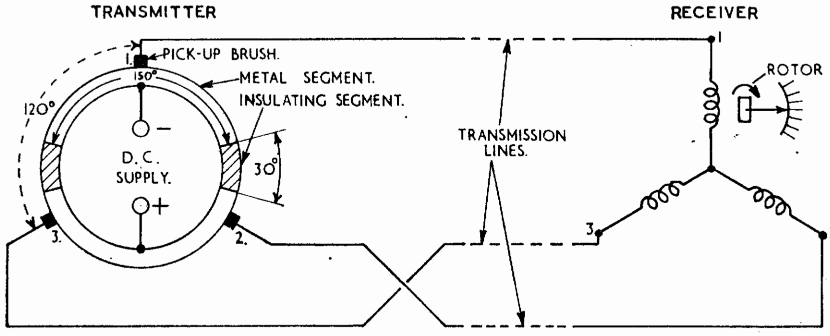


Fig. 4. M-TYPE TRANSMISSION

develop much torque) because a low-resistance transmitter would be needed and this would overheat and tend to burn out. In the M-type transmission system, therefore, the transmitter unit is modified considerably from that in the Desynn system: the receiver, however, operates on the same principle.

The essential features of a simple M-type transmission system are shown in Fig. 4. The transmitter is basically a drum-type switch, the metal drum of which consists of two segments each spanning an arc of 150°, separated by two sections of insulating material each extending over 30°. The two metal segments are connected to opposite poles of a suitable d.c. supply, and three 'pick-up' brushes are disposed round the drum at intervals of 120°.

The receiver unit (more than one unit may be operated from a single transmitter to give multiple indication) is similar to that in the Desynn system, although the rotor may be either a permanent magnet or a laminated soft-iron core. The outer end of each coil in the receiver is connected, via a transmission line, to one of the three pick-up brushes in the transmitter.

10. **Operation.** The action of the M-type transmission system is illustrated in Fig. 5.

In position 1, the input shaft driving the

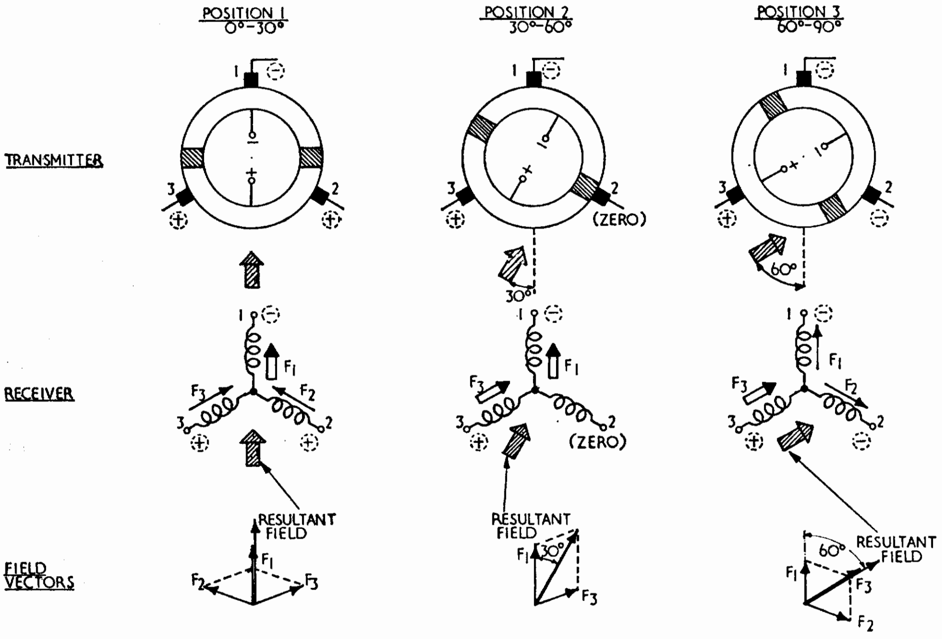


Fig. 5. OPERATION OF M-TYPE TRANSMISSION SYSTEM

transmitter drum is in such a position that brush 1 is connected to — of supply and brushes 2 and 3 to +. These polarities are applied to the three coils in the receiver, with the result that the current divides through coils 2 and 3, *all* the current flowing through coil 1. Magnetic fields F_1, F_2, F_3 are produced and resolving these three fields by vector gives a resultant in the direction shown.

If now the input shaft rotates through 30° clockwise (position 2), brush 1 is —, brush 2 is disconnected by the insulating segment and brush 3 is +. At the receiver, equal currents flow through coils 1 and 3, while coil 2 carries no current. By resolving the magnetic fields F_1 and F_3 produced by these currents, the resultant field is seen to have rotated through 30° in a clockwise direction in sympathy with the input shaft.

The condition after a further 30° rotation of the input shaft is shown at position 3. The resultant field at the receiver has now rotated through 60° clockwise from its initial position, thus following the input shaft.

In each case, the receiver rotor aligns itself with the axis of the resultant field and therefore follows the angular movement of the input shaft, *but only in discrete steps of* 30°.

11. With the arrangement shown, there is a change of pick-up brush polarity at one or other of the brushes each time the input shaft is turned through 30°. The complete pattern showing how in turn, the brushes are connected to +, —, 0 when the drum is rotated through 360° is given in Table 1. There are, of course, 12 steps in a complete rotation: the first 3 steps correspond to positions 1, 2 and 3 in Fig. 5.

For certain purposes, the 30° step is too large, and in such cases a modified transmission system giving 24 steps of 15° each may be used. The principle remains the same, but accuracy is improved.

The maximum operating rate of the M-type transmission system is dependent on the inductive time constant of the receiver coils. The system in general use is designed to give practical operating speeds of up to 180 steps per second.

Transmitter Position	**Pick-up Brush Polarity**		
	1	2	3
0° — 30°	—	+	+
30° — 60°	—	0	+
60° — 90°	—	—	+
90° — 120°	0	—	+
120° — 150°	+	—	+
150° — 180°	+	—	0
180° — 210°	+	—	—
210° — 240°	+	0	—
240° — 270°	+	+	—
270° — 300°	0	+	—
300° — 330°	—	+	—
330° — 360°	—	+	0

TABLE I.
POLARITY CHANGES DURING
360° ROTATION OF TRANSMITTER

12. **Drum transmitter.** The basic principle of the M-type transmission system has been described in a previous paragraph. A practical example of the transmitter unit used in this description is illustrated in Fig. 6. It is so constructed that the d.c. supply brushes are in contact at all times with opposite metal segments, whilst the pick-up brushes are in contact with either of the metal segments or with the insulated segment, depending on the position of the input shaft (i.e., connected to +, —, or 0 as previously explained).

13. **Commutator transmitter.** A schematic diagram of a commutator transmitter designed to give 24 step (15°) M-type sequence is shown in Fig. 7. It is similar to the drum type but much more compact. It consists of a thin commutator face plate rotating against five fixed brushes that are held in a support plate. The commutator is made up of three concentric rings of metal, separated by rings of insulating material. The outer and inner rings are both electrically con-

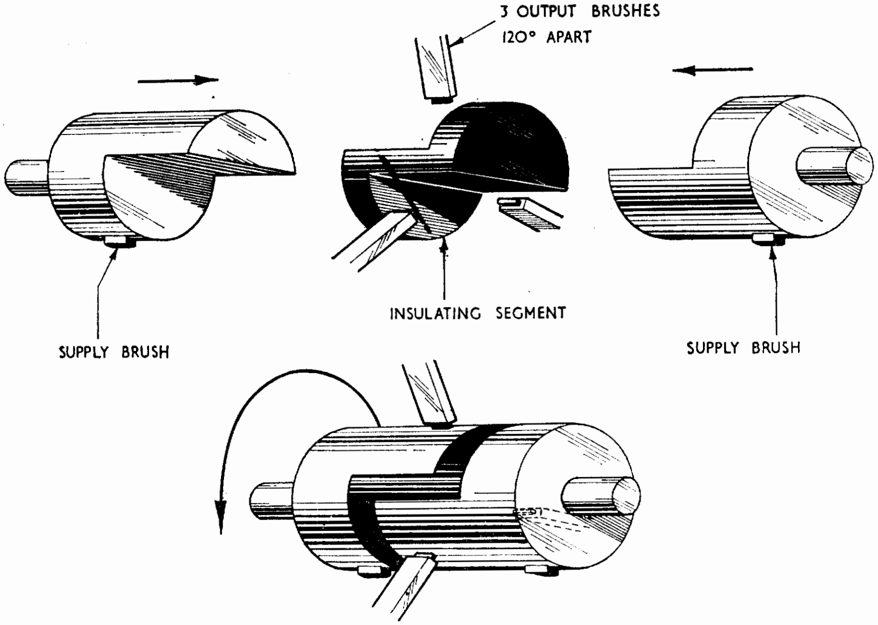


Fig. 6. M-TYPE DRUM TRANSMITTER

tinuous throughout and two of the five brushes, one connected to supply + and the other to supply −, bear on the inner and outer rings respectively. The centre ring is divided into four equal portions by four 'islands' of insulation, each extending over an arc of 15°: the segments so formed are connected to the outer and inner rings alternately. In the middle (divided) ring there is, therefore, a regular +, −, 0 sequence.

The remaining three brushes are positioned to bear on the middle ring, each of the outer brushes being displaced from the centre brush by 60°. With this arrangement there is a change of polarity at one or other of the three pick-up brushes each 15° rotation of the face plate: a 24 (15°) step M-type sequence is thus produced at the output brushes.

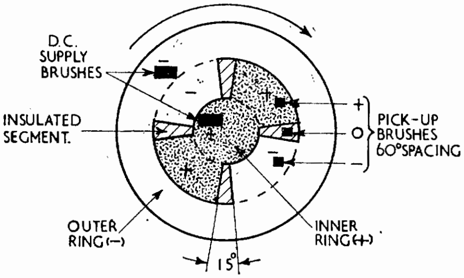


Fig. 7. COMMUTATOR TRANSMITTER

14. **Cam-type transmitter.** There are two main types of cam-operated transmitter, but the more common of the two types, and the one considered here, is the eccentric cam transmitter. It consists of a single circular cam, mounted *eccentrically* on the input shaft and operating three pairs of two-position switches, via push rods. The switches are fitted radially around the cam with 60° spacing as shown in Fig. 8, and the inner contact of each switch is permanently energised, + or − as illustrated. The two switches in a pair are diammetrically opposed and control the polarity on one line feeding the receiver.

With the input shaft in the position shown at (a) of Fig. 8, with maximum eccentricity opposite switch 2, switches 1, 2 and 3 are open; switches 4, 5 and 6 are closed. Thus line 1 is −, line 2 is +, and line 3 is −.

On turning the input shaft through 30° in either direction from the initial position, the maximum eccentricity of the cam wheel is midway between two of the switches. Thus, at position (b) of Fig. 8, switches 1, 2, 3 and 4 are open, and switches 5 and 6

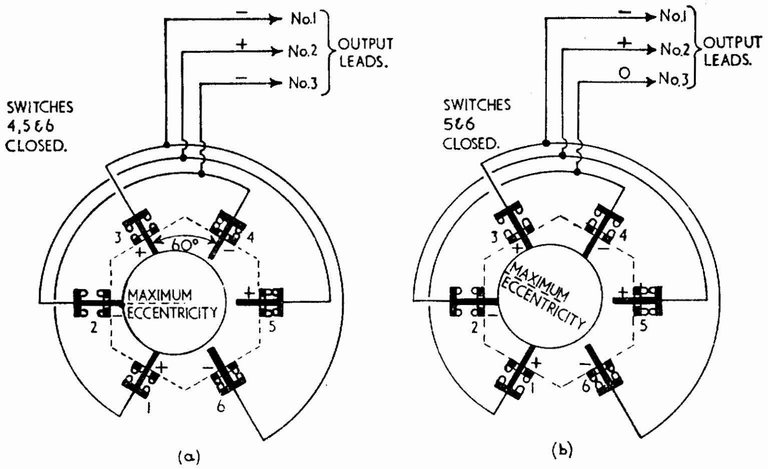


Fig. 8. ECCENTRIC CAM TRANSMITTER

only are closed. In this condition, line 1 is −, line 2 is +, and line 3 is 0.

A standard M-type sequence of line polarity changes at 30° steps is therefore established, 12 steps being provided for each complete revolution.

The drum and commutator transmitters both suffer from brush wear. The eccentric cam transmitter does not. Because of this, the eccentric-cam type is used to a greater extent than the others where a high operating rate has to be maintained.

15. **M-type receivers.** As has already been stated, the stator of an M-type receiver is similar to that of an a.c. induction motor and to that in a Desynn receiver. The rotor, however, may be of the soft iron (inductor) type or it may be a permanent magnet.

The inductor rotor is built up of iron and aluminum laminations, and the laminated rotor continuously re-aligns itself with the resultant field axis of its stator to offer the path of lowest reluctance—i.e., when the laminations are in line with the resultant flux. Since this type of rotor is non-polarized it is possible for it to align itself in either of two positions 180° apart.

The permanent magnet rotor is more common. A disadvantage of the earlier types of rotor magnet was that they tended to become demagnetised after a time. This does not happen with modern materials such as Alnico. Because of the relatively strong magnetic field produced by the magnet, the rotor torque is considerably higher than that of the inductor rotor unit. Higher stepping rates are also achieved for the same reason and, being polarized, the rotor lines up in one position only.

16. **Transmitter and receiver synchronisation.** The fact that the receiver in an M-type transmission system moves in 30° (or 15°) steps is a disadvantage. If greater accuracy is required, the input shaft can be geared up to the transmitter shaft: a 60:1 gear system is common, the transmitter shaft completing 60 revolutions for each revolution of the input shaft. The receiver is equally geared *down* to the output shaft, if a 1:1 input-to-output ratio is required. Although the accuracy of the system is improved 60 times by this means, there is now the possibility of ambiguity. This can be seen as follows:—

The switching sequence is completed in 12 (30°) steps, and with a 60:1 gear system between the input shaft and the transmitter, the sequence is completed for a rotation of only $\frac{360^\circ}{60} = 6^\circ$ of the primary drive, i.e. in 12 steps of $\frac{1}{2}^\circ$ each. Since the transmitter completes 60 revolutions for each revolution of the input shaft, there are 60 different positions in the full 360° movement of the *primary* drive, each separated by 6°, into which the receiver rotor can 'lock' and still follow the M-type sequence. However, in all but one of these positions, the

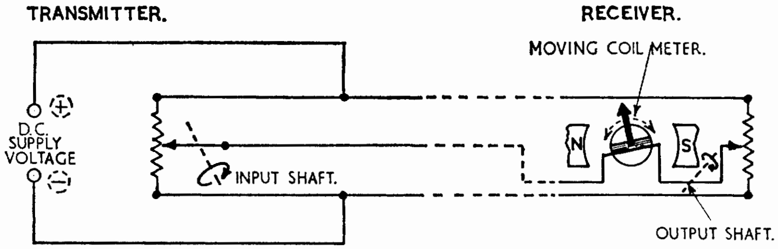


Fig. 9. SIMPLE WHEATSTONE DRIVE

output shaft will be out of synchronisation with the input shaft.

In such circumstances it is necessary to connect to the receiver a local manually-controlled transmitter acting as a 'coarse' control. The coarse control is needed to bring the output shaft into synchronism with the input shaft by comparison of dial readings. When this has been done, the local transmitter is disconnected and the receiver again connected to the transmission line and hence to the remote transmitter.

Wheatstone Bridge System

17. **Introduction.** The accuracies of the Desynn and M-type transmission systems can never be better than about ± 2° because of frictional and resistive losses. Where greater accuracy is required, an error-operated or follow-up system can be used. The Wheatstone bridge system is a typical example for d.c., when continuous rotation is not a requirement.

18. **Circuit and action.** A circuit arrangement is illustrated in Fig. 9. The transmitter and receiver are both potentiometers connected to form a Wheatstone bridge. The wiper on the transmitter potentiometer is controlled by the input shaft. A moving coil meter, acting as the remote indicator is connected between the two wipers, and the arrangement is such that rotation of the moving coil moves the wiper on the receiver: the sense of rotation tends to reduce the coil current to zero.

If the input shaft is rotated, the bridge becomes unbalanced and current flows through the moving coil, which also rotates, moving the pointer and the receiver wiper. This movement continues until the receiver wiper reaches the position at which the bridge becomes balanced. In this way, the receiver wiper (and pointer) copy exactly the movements of the transmitter wiper (and input shaft). The accuracy of this system is better than ± 1°, but the torque developed at the receiver is very small.

Greater output driving torque can be developed by modifying the basic Wheatstone bridge system. The moving coil meter can be replaced by a polarized relay which is used to switch a d.c. supply to a small motor, as shown in Fig. 10.

At balance, the relay is de-energised and the supply to the motor is disconnected.

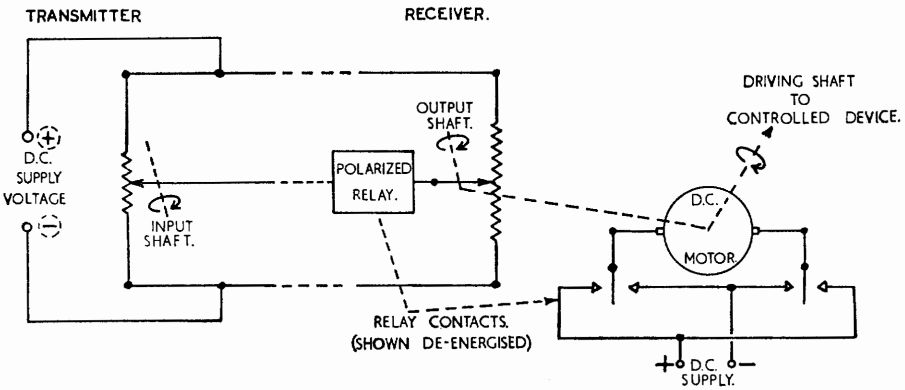


Fig. 10. TORQUE-AMPLIFIED WHEATSTONE DRIVE

If the input shaft is rotated, the bridge becomes unbalanced and the relay is energised. The sense of unbalance determines the direction in which the relay is energised: this, in turn, determines which set of contacts is closed and thus the direction of rotation of the motor. The motor rotates in such a direction that the receiver wiper moves towards the balance condition: at the same time the controlled device is moved to the desired position.

This system is used for remote control and tuning of radio equipment.

A.C. SYSTEMS

Introduction

19. The d.c. transmission systems described earlier are limited in their practical application to remote *indication* of position of a shaft and the transmission of *moderate* torque to a remote device: also, in general, the degree of accuracy is of the order of $\pm 2°$.

Where a remote transmission system is required to operate efficiently with a high degree of accuracy, or where it is required to be used as part of a servomechanism to move a heavy load at a remote point, an a.c. system is generally preferred.

20. A.C. transmission systems have many applications: they include:—

(*a*) Remote indication of position or movement.

(*b*) The transmission of moderate torque to a remote device with a high degree of accuracy.

(*c*) The controlling element in a servomechanism system used to control the position and speed of heavy loads at a remote point.

(*d*) The summation of two or more mechanical movements.

(*e*) Analogue computation.

21. A.C. transmission systems are referred to generally as '*synchros*' because of the self-synchronous characteristic of the systems, i.e., any movement of the input shaft connected to the transmitter is exactly reproduced in the angular movement of the remote output shaft connected directly or indirectly to the receiver.

Synchros are manufactured by many firms and are known by various trade names such as Selsynn, Magslip, Synchrotic, Autosyn, Aysynn, and Telesyn. All of them, however, work on the same basic principles.

22. Synchro systems can be divided into several categories according to their function. The three main categories are as follows:—

(*a*) **Torque synchros.** These are the simplest form of synchro: *no torque amplification* is provided. They are used for the transmission of angular position information by electrical means and for the reproduction of this information by the position of the shaft of the receiver element. Moderate torque only is developed in the output shaft and the main use of torque synchros is in instrument repeater systems.

(*b*) **Control synchros.** These normally form part of a power amplifying servomechanism system. Such a system can provide almost any degree of torque amplification and can therefore be designed to handle heavy loads such as a directional aerial array on a turntable. The control synchro, in effect, provides the data on which the servomechanism acts.

(*c*) **Resolver synchros.** These are used extensively in computers to convert voltages, which represent the cartesian coordinates of a point into a shaft position and a voltage which together represent the polar co-ordinates of the point. They can also be used for conversion from polar to cartesian co-ordinates.

Although the construction of these different categories differs in detail, their action can be appreciated by considering the elements used in a basic synchro system.

Basic Synchro System

23. The basic synchro system for transmission of continuous rotation is illustrated in schematic form in Fig. 11. The transmitter and receiver are electrically similar. Each consists of a rotor carrying a single winding, round which is a stator on which are three windings arranged with their axes at 120° in space.

The principle physical difference between transmitter and receiver is that the receiver is usually fitted with low-friction ball bearings on the rotor and a mechanical damper to

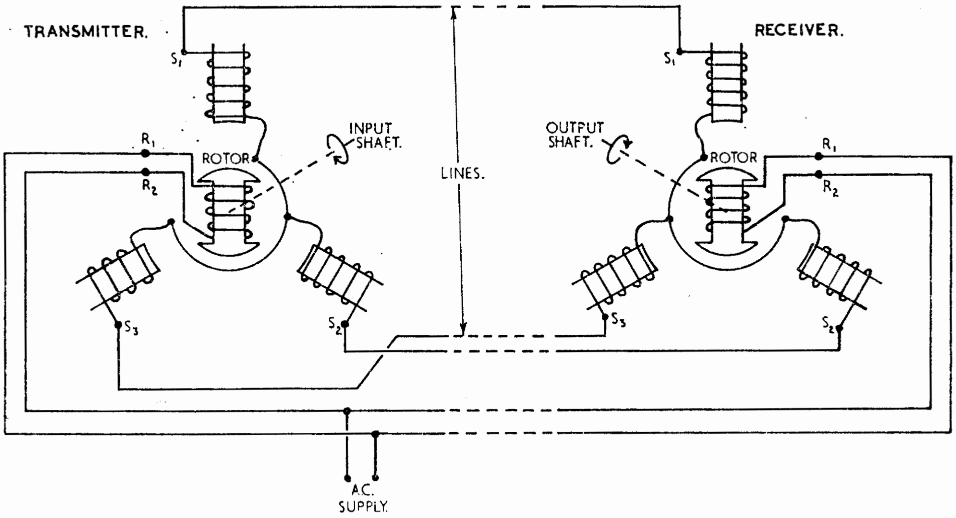


Fig. 11. BASIC SYNCHRO SYSTEM

reduce oscillation, whereas the transmitter is not damped and often has no ball bearings.

In operation, both rotors are energised from an a.c. supply (often 115V 400 c/s) and the corresponding stator connections are joined together by transmission lines.

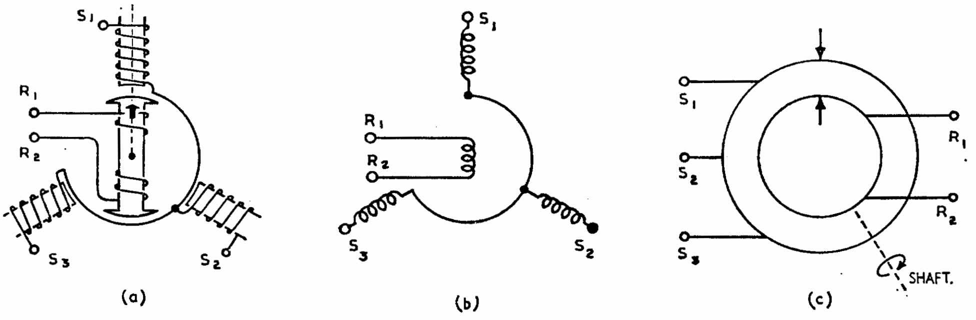
24. The schematic representation of the synchro unit used in Fig. 11 and shown at (a) of Fig. 12 is useful for certain purposes, but the simplified version of the same symbol, shown at (b) of Fig. 12, is generally sufficient. For detailed circuit diagrams, the symbol shown at (c) is used.

A synchro unit is said to be positioned at *electrical zero* when the axis of the rotor is in line with the axis of the S_1 winding of the stator. This same position is indicated in Fig. 12(c), when the two arrows are lined up.

Construction of Synchro Unit

25. The construction of a simple form of synchro transmitter is shown in Fig. 13. The construction of a synchro receiver is similar with the addition of an oscillation damper.

The stator body is made up of internally-slotted laminations, in the slots of which are fitted the three sets of windings S_1, S_2, S_3 spaced 120° apart and arranged in a similar fashion to the stator coils of a small three-phase induction motor. Despite the similarity, the stator windings of a synchro unit must not be confused with normal three-phase windings. In a three-phase machine, the voltages in the three windings of the stator are equal in magnitude and 120° apart in phase: in a synchro unit, the voltages are *not equal* in magnitude and



(a) (b) (c)

Fig. 12. TORQUE SYNCHRO SYMBOLS

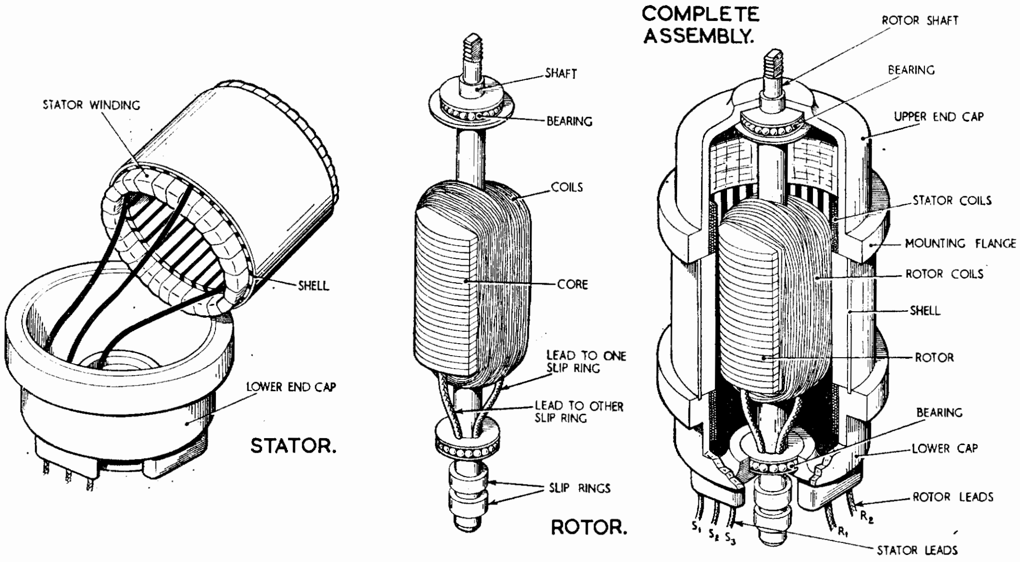


Fig. 13. CONSTRUCTION OF TORQUE SYNCHRO

are either in phase or 180° out of phase with each other: in a synchro unit, the stator windings are said to be "space-phased".

The laminated rotor carries a single winding, the two ends of which are connected, via slip rings and brushes, to two terminals R_1 and R_2, which are in turn connected to the a.c. supply.

Principle of Torque Synchro System

26. **Basic operation.** A simple torque synchro system is illustrated in Fig. 14. The rotors of transmitter (TX = torque transmitter) and receiver (TR = torque receiver) are both energised from the a.c. supply and produce an alternating flux which links with their corresponding stators. Should the relative dispositions of rotor to stator in the two elements be different, the three voltages induced in each of the two stator windings by the alternating fluxes differ: currents then flow between the two stators and a torque is produced in each synchro which is so directed as to eliminate the discrepancy; thus, in effect, to align the two rotors.

Normally, the transmitter rotor is held mechanically by the input shaft and the

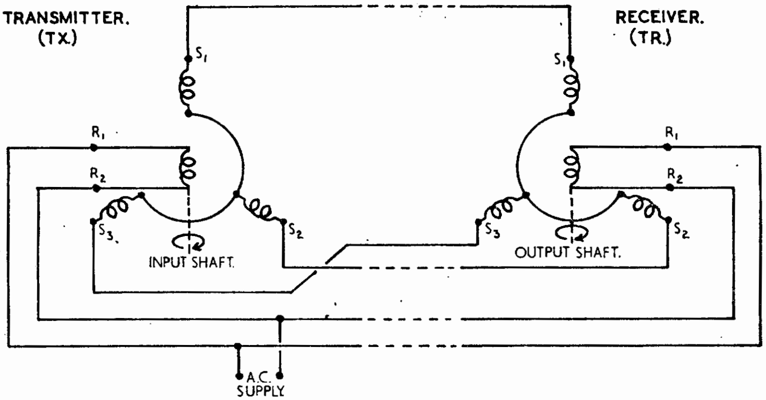


Fig. 14. TORQUE SYNCHRO SYSTEM

receiver rotor is free to turn so that it aligns itself with the transmitter rotor. Thus, in Fig. 14 any movement of the transmitter rotor is repeated synchronously by the movement of the receiver rotor.

27. **Operation of transmitter.** To understand why the receiver rotor follows the transmitter rotor, it is necessary to consider the manner in which the transmitter stator voltages change as the input shaft is turned.

Consider Fig. 15, in which the transmitter rotor is connected to the a.c. supply but the stator windings are disconnected from the receiver. A current flows in the rotor and sets up an alternating magnetic flux in the transmitter: the direction of this flux is along the axis of the rotor winding. The flux links with the stator windings, and induces alternating voltages in each of them. The synchro unit is therefore, like a single-phase transformer in which the rotor winding is the primary and the stator windings are three secondary coils.

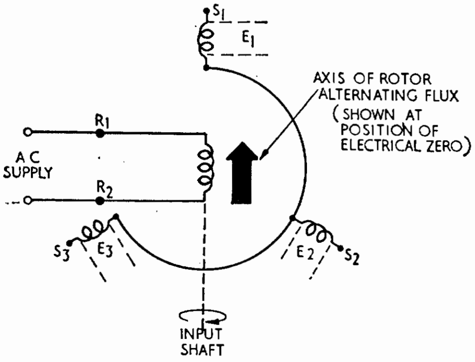


Fig. 15. OPERATION OF SYNCHRO TRANSMITTER (TX)

28. The magnitudes of the voltages induced in the stator windings depend on the relative number of turns in rotor and stator coils and on the orientation of the rotor.

For the position of the rotor in Fig. 15, voltage E_1 has its maximum value (the axis of the rotor winding and the axis of stator coil S_1 are in line): E_1 is also *in phase* with the applied voltage E. As the rotor is turned clockwise from this position, E_1 decreases and becomes zero when the rotor has turned through 90°. Further turning of the rotor causes a voltage of *reversed* phase to appear across the stator coil S_1.

29. Similar reasoning applies for the voltages E_2 and E_3 induced in the stator coils S_2 and S_3 respectively. A graph showing the variations in the magnitudes of the stator voltages with the angular position of the rotor is plotted in Fig. 16.

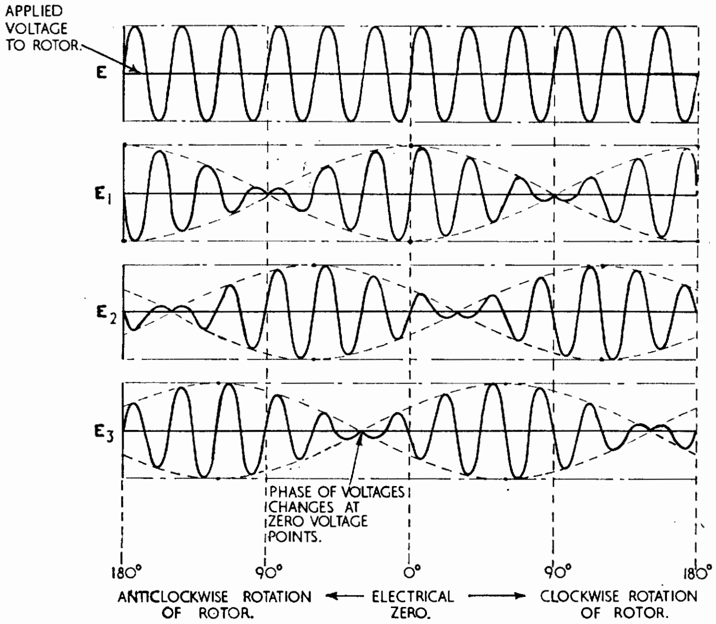


Fig. 16. OUTPUT FROM TRANSMITTER (TX)

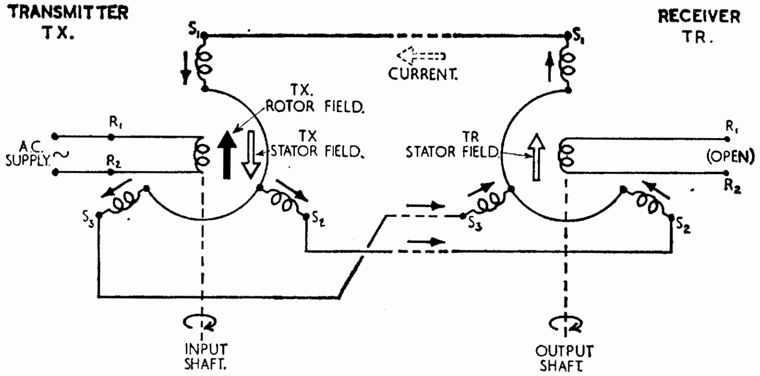


Fig. 17. PRODUCTION OF RECEIVER (TR) STATOR FIELD

It is again emphasised that the stator voltages do *not* constitute a set of three-phase voltages. The stator voltages, in effect, are modulated with sinusoidal envelopes that differ in phase by 120° as the rotor is turned at a constant speed. The individual cycles of the stator voltages, however, are either in phase or 180° out of phase with each other and with the rotor voltage.

30. Consider now what happens when the stator coils in the transmitter and receiver are connected: for the moment, the receiver rotor is disconnected from the supply. The arrangement is shown in Fig. 17.

The voltages induced in the transmitter stator coils by the alternating rotor flux are applied to the receiver stator coils and currents flow through the closed circuits formed by the two sets of stator windings. The magnitude and phase of the current through each coil of the *transmitter* stator depend on the magnitude and phase of the induced voltage in each coil, and this in turn depends on the orientation of the transmitter rotor. The current through each coil of the transmitter stator produces a magnetic field and the three fields combine to form a single resultant magnetic field inside the stator. Since the rotor winding is, in effect, the primary winding of a transformer with the stator windings acting as three secondary coils, the resultant flux produced by the currents in the stator coils must at all times balance that produced by the rotor current: this is normal transformer action. The directions of the transmitter rotor and stator magnetic fields are therefore *opposite* as shown in Fig. 17.

31. **Operation of receiver.** The current flowing through each coil of the *receiver* stator is of the same magnitude as that flowing through the corresponding coil of the transmitter stator. It is however, in the *opposite* direction. Thus, since the transmitter and receiver stators are identical in form, the resultant magnetic field established inside the receiver stator is equal in magnitude but opposite in direction to that produced in the transmitter stator. The receiver stator field thus coincides, both as regards axis line and direction of flux, with that of the *transmitter rotor.* This is also indicated in Fig. 17.

32. A bar of soft iron placed in a magnetic field tends to align itself parallel to the field. Thus the rotor of the synchro receiver tends to turn into alignment with the receiver stator field, even though the rotor winding is open. Operation with open rotor winding is undesirable however, because for a given position of the transmitter rotor, the receiver rotor can take up one of two positions 180° apart: in addition, the torque developed by the receiver is small.

33. These difficulties are avoided if the rotor winding of the receiver is connected to the a.c. input as in Fig. 18. The rotor is now an electromagnet excited by alternating current and is said to be *polarized.* The magnetic field produced by the current in the two rotors are, of course, identical both in magnitude and direction.

The receiver rotor is normally free to turn under the influence of any applied magnetic force: such a force is developed by interaction of receiver rotor and stator fields

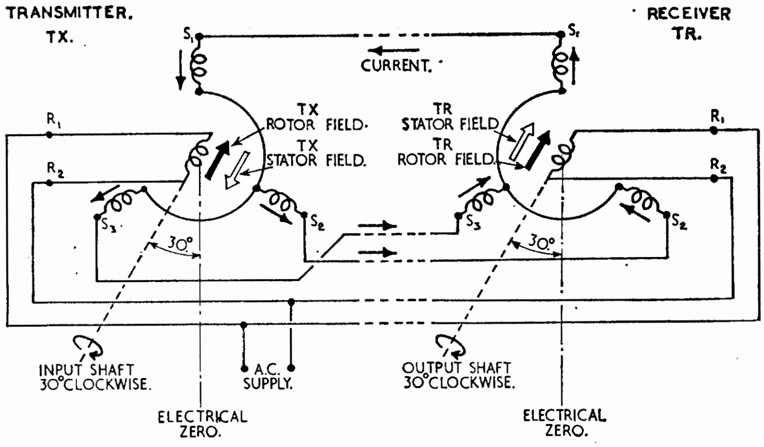


Fig. 18. ALIGNMENT OF OUTPUT AND INPUT SHAFTS

and the receiver rotor turns until the two fields are in alignment. It has already been stated that the receiver stator field coincides with the field of the *transmitter rotor:* hence the receiver rotor synchronously follows any movement of the remote transmitter rotor.

34. **Accuracy and efficiency.** The torque synchro draws negligible current from the supply. This is because the voltage induced in each set of stator windings from their respective rotors are in opposition: thus, when the receiver rotor is correctly aligned with the input shaft, the two sets of voltages balance and negligible stator current is drawn. The only current drawn from the supply under this condition is that required to energise the rotors.

Because the stator currents decrease as the receiver rotor comes into alignment, the torque developed by the receiver rotor also decreases and this produces an inherent inaccuracy in the system: the accuracy is of the order of ± 1°. As the load increases so does the degree of error and also the current drawn from the supply. The torque synchro is, therefore, suitable only for driving relatively light loads such as those used in instrument repeaters.

35. **Magslip.** It is possible to connect several receivers in parallel and drive them from a single transmitter, to give indication in a number of places simultaneously. But in this case, all the units react on each other, so that if one receiver develops a fault all the other receivers give false indications. The interaction can be reduced by using a 'magslip' as the synchro receiver (Fig. 19). The magslip has the normal three-coil stator, but the rotor is a disc of iron having a single tongue projecting under the stator winding. The 'rotor' coil does not in fact rotate, which removes any slip ring friction and the extra friction on the bearings due to the weight of the coil. It is fed from the a.c. supply, and the flux it produces is coupled to the stator by the magnetic slip ring (magslip) between the rotor disc and the rotor polarizing coil. The rotor disc turns until the current in the transmitter and receiver stator coil is zero: the rotor is then in alignment.

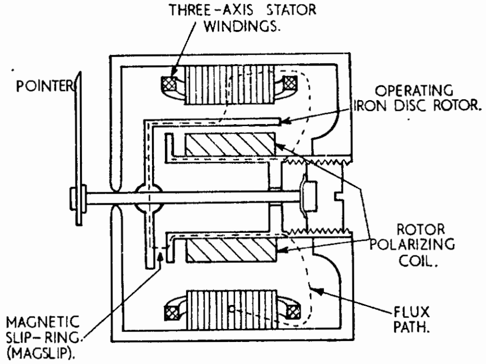
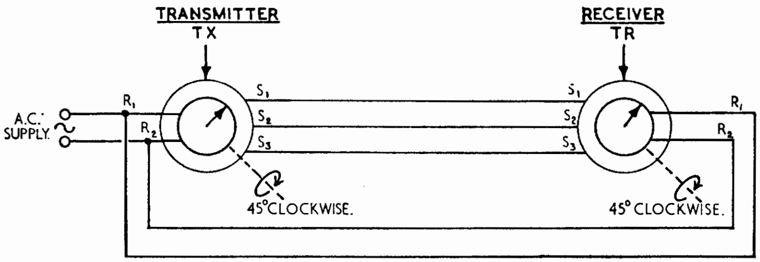
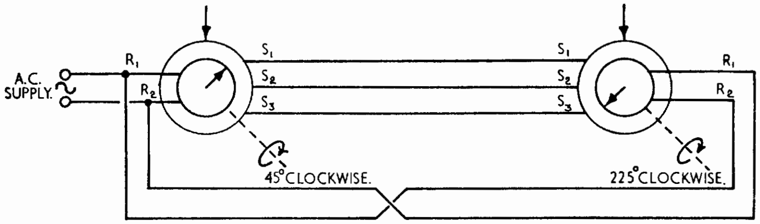


Fig. 19. MAGSLIP

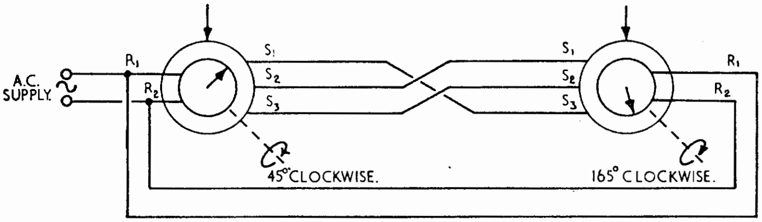
It will be seen that there is a long air-gap in the rotor flux path: consequently, any rotor misalignment has little reaction on the stator flux distribution, and therefore there is little reaction between receivers connected



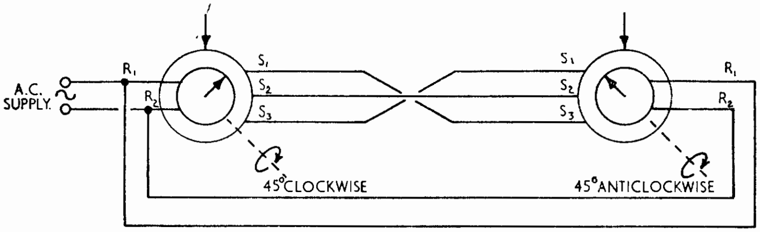
(a) SYMMETRICAL CONNECTIONS – ROTORS MOVE THROUGH SAME ANGLE.



(b) ROTOR CONNECTIONS REVERSED – OUTPUT ROTOR 'LEADS' BY 180°.



(c) 'CYCLIC' SHIFT OF STATOR CONNECTIONS – OUTPUT ROTOR 'LEADS' BY 120°.



(d) TWO STATOR LEADS INTERCHANGED – OUTPUT ROTOR REVERSES DIRECTION OF ROTATION.

Fig. 20. VARIOUS INTERCONNECTIONS IN TORQUE SYNCHRO SYSTEM

in parallel. But the long gap means that the rotor flux is weak and the torque available is very small.

36. **Torque synchro connections.** So far, symmetrical connections only between transmitter and receiver windings have been considered. However, re-arrangement of rotor and stator connections between transmitter and receiver produces different results. The receiver rotor still moves synchronously with the transmitter rotor, but it can do so from a different reference position or in the reverse direction. Fig. 20 illustrates the possibilities.

Torque Differential Synchro Systems

37. **Introduction.** In the torque synchro transmission systems so far considered the 'output' as represented by the angular move-

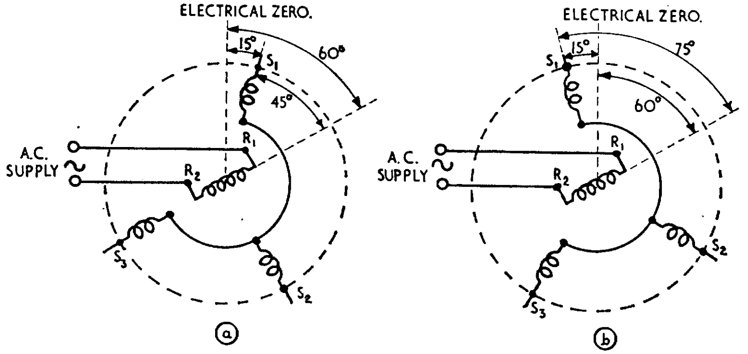


Fig. 21. DIFFERENTIAL ACTION IN TORQUE SYNCHRO SYSTEM

ment of the receiver rotor, is simply a reproduction of a single 'input', i.e., the angular movement of the transmitter rotor.

Under certain conditions, however, it is necessary to transmit *two* angular positions, the synchro receiver indicating the difference or the sum of the two angles.

38. One simple way of achieving this is to rotate the *stator* coils of the synchro transmitter through one angle and the *rotor* through the other angle. This is indicated in Fig. 21. In (a) the rotor is rotated through 60° clockwise from electrical zero and the stator is rotated 15° *in the same direction:* the *relative* angle between rotor and stator is the *difference* between the two angles, namely 45°, and the electrical output of the transmitter is such that the receiver turns 45° clockwise. In (b) the addition of two angles is shown.

Mechanical displacement of both rotor and stator in a synchro transmitter is not generally practicable. It is normally better to insert a torque differential synchro in the transmission chain. This differential synchro can operate either as a transmitter or as a receiver. Since the torque differential transmitter is more common, it will be considered first.

39. **Torque differential transmitter (TDX).** The differential transmitter has a stator identical with that of a synchro transmitter

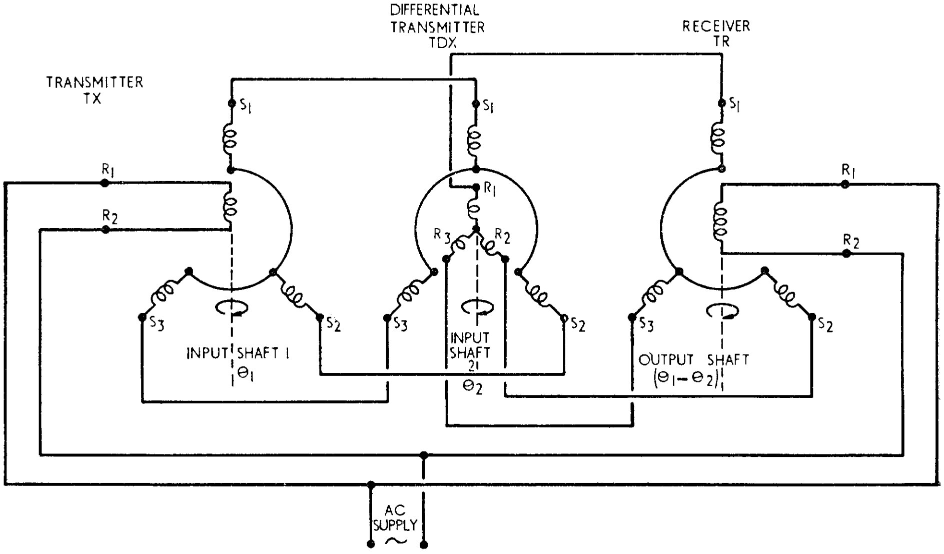


Fig. 22. TORQUE DIFFERENTIAL SYNCHRO SYSTEM

or receiver. It differs from the transmitter or receiver in that it has a *cylindrical*, instead of a two-pole rotor; and the rotor like the stator, has three distributed windings spaced 120° apart.

40. The circuit shown in Fig. 22 is that of a differential synchro system set up for the *subtraction* of two inputs. The arrangement is such that one input shaft turns the transmitter (TX) rotor and a second input shaft drives the differential transmitter (TDX) rotor. The differential transmitter receives an electrical signal corresponding to a certain angular position of the transmitter (TX) rotor: it modifies this signal by an amount corresponding to the angular position of its own rotor: it then transmits the modified electrical output signal to the receiver (TR).

This modified output signal produces an angular position of the flux in the receiver which, for Fig. 22, is the *difference* of the rotor angles of the two transmitters (TX and TDX).

The circuit symbol for a differential synchro transmitter is shown in Fig. 23.

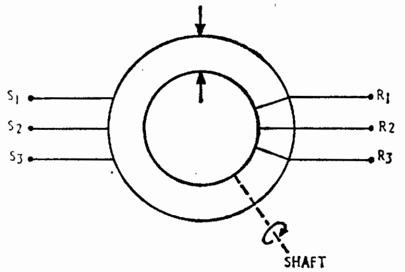


Fig. 23. SYMBOL FOR TORQUE DIFFERENTIAL TRANSMITTER (TDX)

In the differential synchro system, the rotors of the normal transmitter (TX) and receiver (TR) are supplied in parallel with single-phase a.c. The stator windings of the transmitter are connected to the stator windings of the differential transmitter (TDX) and the three windings on the rotor of the latter are connected to the windings of the receiver stator. Note that the rotor of the differential transmitter is *not* connected to the a.c. supply.

41. **Action of TDX.** The action of the torque differential synchro system set up for subtraction is illustrated in Fig. 24.

In (a) both input shafts are at electrical zero and the distribution of current throughout the system is such that the magnetic fields are in the direction shown. Thus the output (TR) rotor also takes up the position of electrical zero.

In (b) shaft 1 is rotated through 60° clockwise and shaft 2 remains at electrical zero. All magnetic fields rotate as shown and the output (TR) rotor also rotates 60° from electrical zero.

In (c) shaft 1 is at electrical zero and shaft 2 is rotated 15° clockwise. The magnetic fields of the transmitter (TX) and the differential transmitter (TDX) remain in the electrical zero position because their position is determined by the orientation of the transmitter (TX) rotor. However a 15° clockwise rotation of the TDX rotor without a change in the position of its field is equivalent to moving the rotor field 15° *anti-clockwise* whilst leaving the rotor at electrical zero. This shift in the position of the TDX rotor field relative to the rotor itself is duplicated in the receiver (TR) stator windings and the output rotor aligns itself with its stator field. Thus the output rotor moves 15° *anti-clockwise* for a 15° *clockwise* movement of the differential (TDX) rotor.

42. It is now easy to see that if both input shafts are rotated simultaneously in a clockwise direction, the receiver rotor turns through an angle equal to the *difference* between the two input angles, i.e., a clockwise movement of the TX rotor gives a clockwise movement of the TR rotor, whereas a clockwise movement of the TDX rotor gives an anti-clockwise movement of the TR rotor. This is illustrated in Fig. 24(d) where the TR rotor turns through $(60° - 15°) = 45°$ clockwise.

43. The differential effect is of course reversed when the differential rotor is moved in the opposite direction to the transmitter rotor. The receiver rotor now moves through an angle equal to the *sum* of the two input angles. However, it is more usual to rotate the input shafts in the same direction and to alter the connections between the various elements to obtain the required output. Various possibilities are illustrated in Fig. 25.

44. **Torque differential receiver (TDR).** A torque differential synchro system can use a

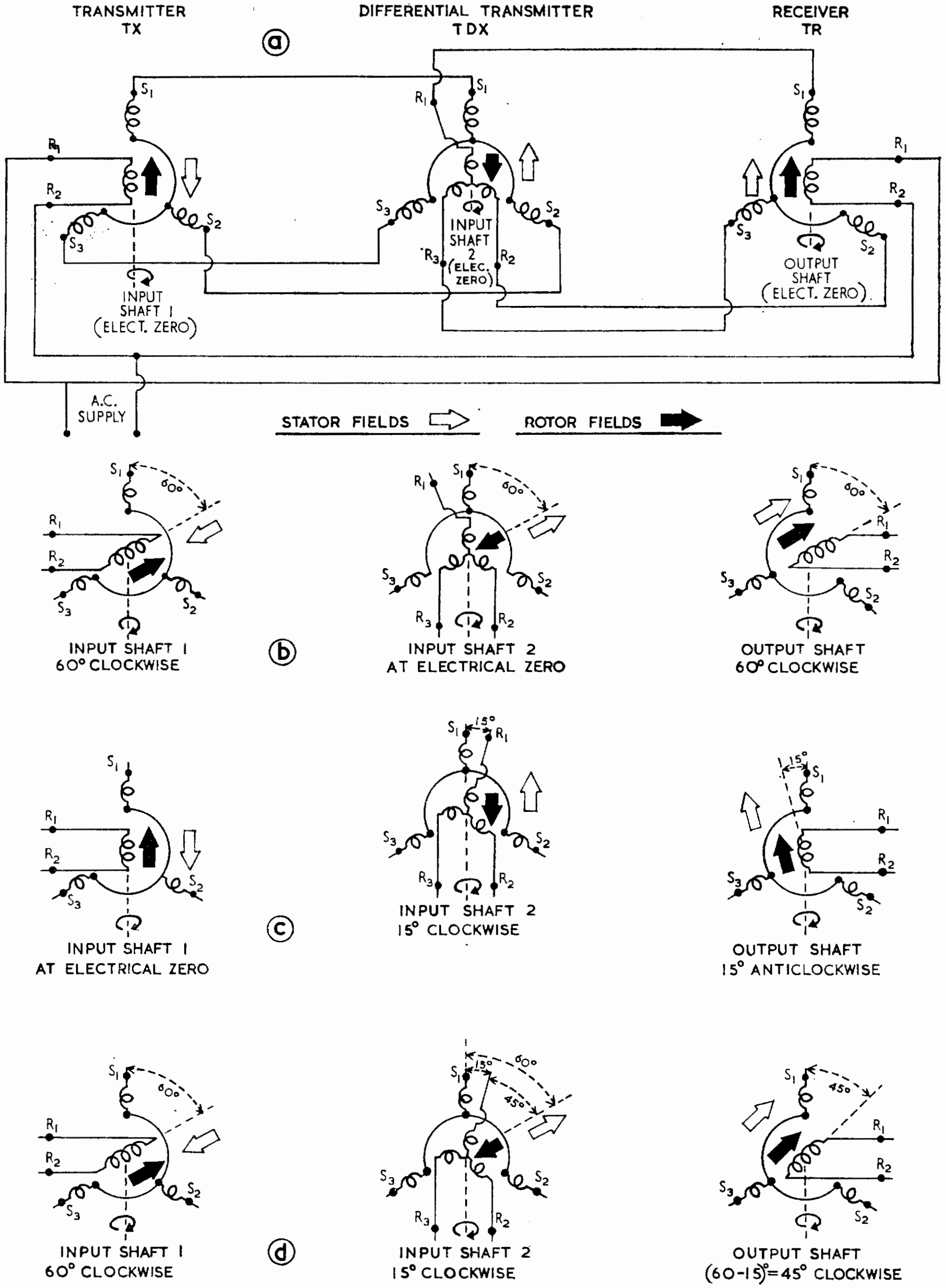
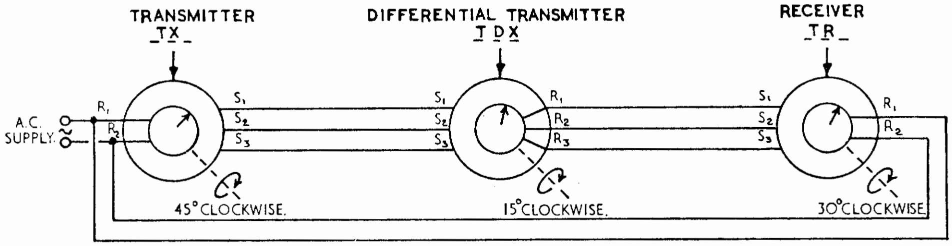


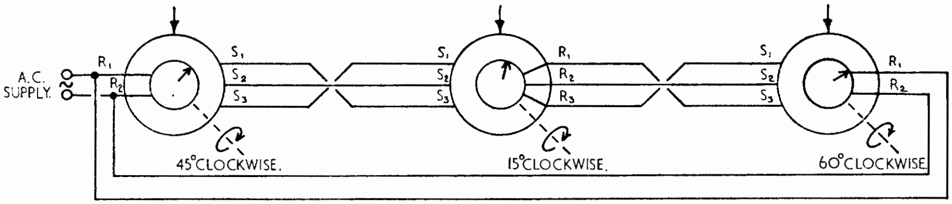
Fig. 24. ACTION OF TORQUE DIFFERENTIAL TRANSMITTER SYSTEM

differential *receiver* in conjunction with two synchro transmitters as shown in Fig. 26.

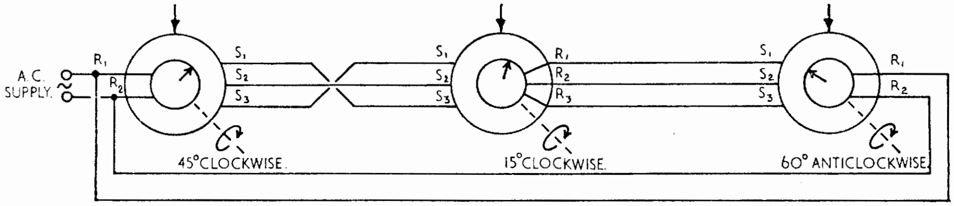
Voltages indicating a 60° clockwise rotation from electrical zero are applied from transmitter A to the stator windings of the differential receiver, and a magnetic field Φ_1 is created along an axis 60° clockwise from electrical zero. The 15° clockwise electrical signal from transmitter B is applied to the rotor windings of the differential receiver and establishes a magnetic field Φ_2 that is 15° clockwise from the rotor electrical



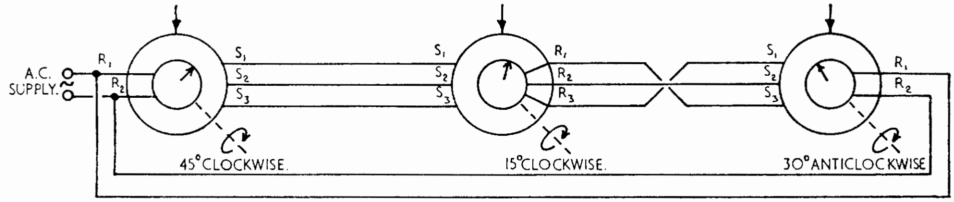
(a) SYMMETRICAL CONNECTIONS: TR.ANGLE = TX.ANGLE. — TDX. ANGLE.



(b) TWO INPUT & OUTPUT LEADS INTERCHANGED: TR. ANGLE. = TX.ANGLE.+ TDX. ANGLE.



(c) TWO INPUT LEADS INTERCHANGED: TR.ANGLE. = −(TX.ANGLE. + TDX.ANGLE.).



(d) TWO OUTPUT LEADS INTERCHANGED: TR.ANGLE. = TDX.ANGLE. — TX.ANGLE.

Fig. 25. VARIOUS INTERCONNECTIONS IN TORQUE DIFFERENTIAL SYSTEM

zero point (R_1 in line with S_1). The differential rotor, if free to turn assumes the position in which Φ_1 and Φ_2 are aligned: this requires a clockwise movement of only 45°. Thus, the output shaft indicates the *difference* (60° clockwise minus 15° clockwise) in the angular displacement of the two input shafts connected to the transmitter rotors.

For the connections shown, the output angle is the angle of transmitter A *minus* the angle of transmitter B. Reversing pairs of connections at the differential receiver can change the relative directions of motion in much the same way as illustrated in Fig. 25 for the differential transmitter.

Control Synchro Systems

45. **Introduction.** In a torque synchro system, the output element exerts a torque which tends to align its rotor with the angle of the input shaft. The action is similar in torque differential synchro systems.

In *control* synchro systems, however, the rotor of the output element does not exert any such torque. Instead, it produces a voltage, sometimes called an *error signal*, which indicates the error of alignment between the input shaft and the output shaft: this has important practical applications in electrical servomechanisms.

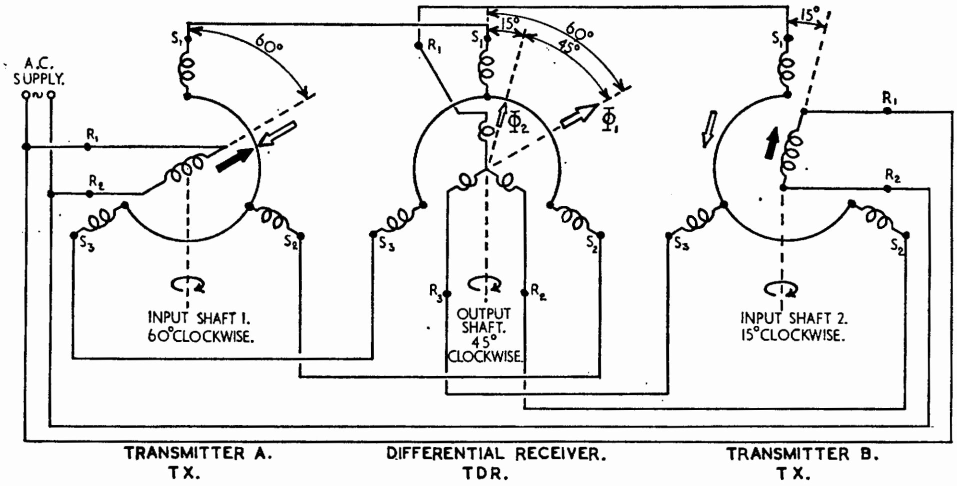


Fig. 26. TORQUE DIFFERENTIAL RECEIVER (TDR) SYSTEM

46. **Circuit.** The basic control synchro system has two elements—a synchro transmitter (TX) and a synchro control transformer (CT) connected as shown in Fig. 27. The transmitter is similar to that used in torque systems: it consists of three stator coils spaced 120° apart, inside which a single-winding, two-pole rotor, energised from the a.c. supply, can be rotated by the input shaft.

The control transformer has a stator similar in design and appearance to that of other synchro units, but with high impedance coils to limit the alternating currents through the windings. The rotor, like that of a normal synchro receiver, carries a single winding which is brought out via slip rings and brushes, to terminals R_1 and R_2. Unlike the receiver rotor, the winding of the control transformer rotor is wound on a *cylindrical* former, thereby ensuring that the rotor is not subjected to any torque when the magnetic field of the transformer stator is displaced. In addition, the rotor of the control transformer is *not energised:* it acts merely as an inductive 'error detector'.

47. **Action.** The control transformer operates as a single-phase transformer having three stationary primary windings and one moveable secondary winding.

When the rotor of the synchro transmitter (TX) is energised, voltages are induced in the transmitter stator windings and applied to the stator windings of the control transformer. The resultant magnetic fields produced when the input shaft is in such a position that the transmitter rotor is at electrical zero are illustrated at (a) of Fig. 28. The alternating stator flux of the control

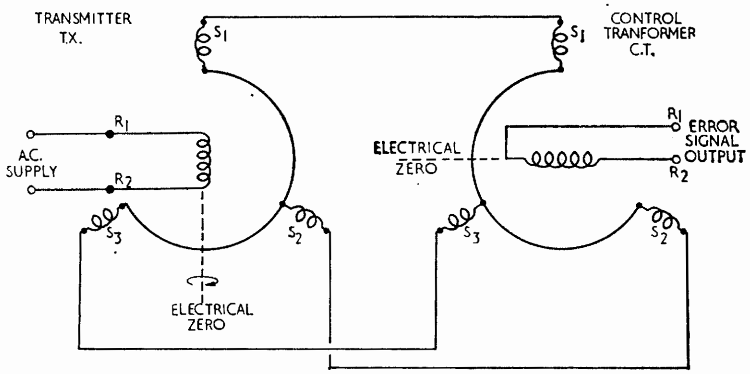


Fig. 27. CONTROL SYNCHRO SYSTEM

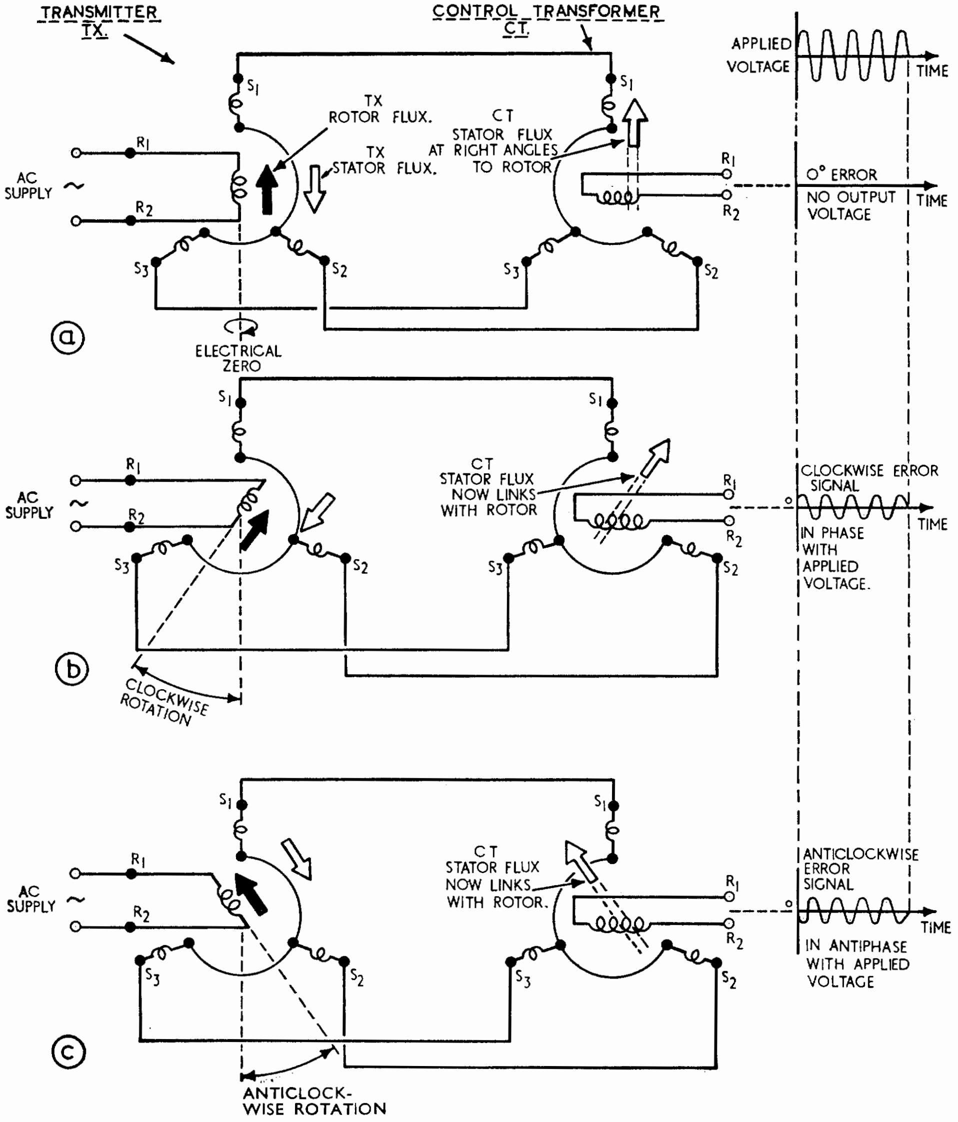
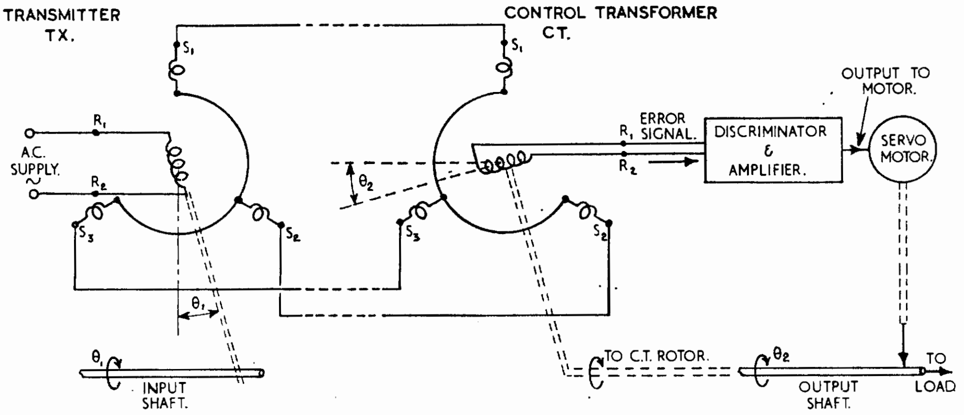


Fig. 28. ACTION OF CONTROL SYNCHRO SYSTEM

transformer induces a voltage in its rotor, the magnitude of which depends upon the position of the rotor relative to the flux: that is, when the rotor axis is at 90° to the flux direction as shown at (a), the induced voltage is zero. Thus note that the electrical zero point of a control transformer is at 90° to the zero points of a synchro transmitter and receiver.

48. If now the input shaft is rotated clockwise from the electrical zero position, the resultant flux in the control transformer stator is displaced from its datum point by the same angle, and the magnitude of the voltage induced in the transformer rotor increases from zero. For the connections shown, the voltage is also *in phase* with the line voltage applied to the transmitter rotor (Fig. 28(b)).

For an anti-clockwise rotation of the input shaft from the electrical zero position, the transformer rotor voltage again increases in magnitude, but this time it is in *anti-phase*



WHEN $\theta_2 = \theta_1$, ERROR VOLTAGE IS ZERO, AND SERVOMECHANISM IS STABLE.

Fig. 29. APPLICATION OF CONTROL SYNCHRO SYSTEM

with the line voltage applied to the transmitter rotor (Fig. 28(c)).

49. **Use.** The error voltage derived from the control transformer rotor varies with the misalignment between the input shaft and the rotor of the transformer (remembering that, in any case, the electrical zero points are displaced from each other by 90°). When the two are 'aligned', there is no error voltage: a misalignment in one sense provides an in-phase error voltage: a misalignment in the other direction produces an anti-phase error voltage: the magnitude of the error voltage in each case depends on the degree of misalignment.

As commonly used in electrical servomechanisms, the synchro control transformer supplies an error signal from its rotor winding to an amplifier that controls a d.c. or a.c. motor. The circuit (Fig. 29) is such, that the speed of the motor is proportional to the magnitude of the error voltage, and the direction of rotation is determined by the phase of the error voltage with respect to the applied a.c.

In normal operation, the servo motor drives the mechanism being controlled (e.g. a radar scanner) and also turns the rotor of the control transformer. The circuit arrangement is such that the transformer rotor is turned into alignment with the input shaft, thereby reducing the error voltage to zero, at which point the servomechanism is stable.

The use of an amplifier and rotor makes the

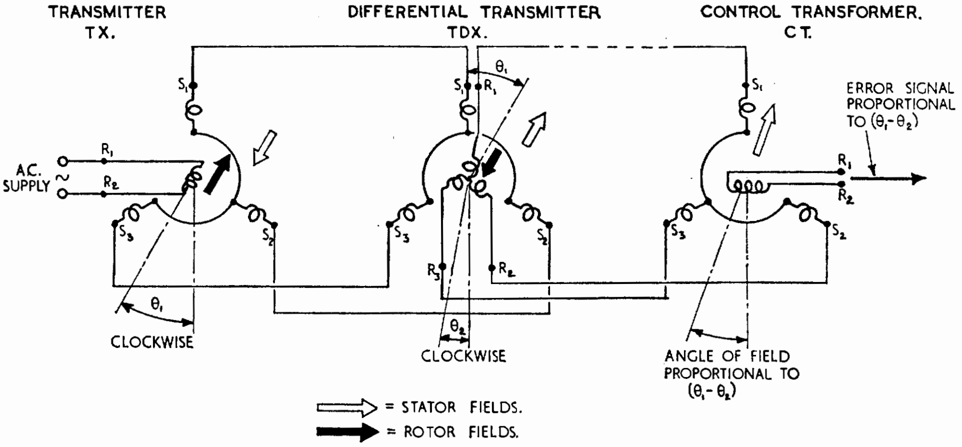


Fig. 30. CONTROL DIFFERENTIAL SYNCHRO SYSTEM

system *torque amplifying* and the output of such a system depends solely upon the power output of the amplifier and servo motor. By means of control synchros, very small units and light controlling forces can operate heavy mechanisms remote from the control point.

50. In the same way that differential synchros can be used in torque transmission systems, so they can be used in control synchro systems to transmit information on the sum or difference of two angles. A simple arrangement is illustrated in Fig. 30.

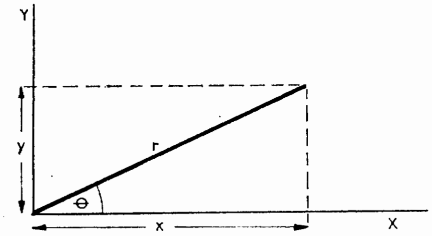


Fig. 31. CO-ORDINATES OF A POINT

Resolver Synchro System

51. **Introduction.** A vector representing an alternating voltage (Fig. 31) can be defined in terms of the *modulus* or length of the vector r, and the *argument* or angle θ it makes to the X axis: these are the polar co-ordinates $r\angle\theta$ of a vector. This same vector can be defined in terms of x and y where $x = r \cos \theta$ and $y = r \sin \theta$: these expressions give the cartesian co-ordinates of the vector.

52. Resolver synchros are employed, generally in analogue computers (see Sect. 20), to convert voltages which represent the cartesian co-ordinates of a point, into a shaft position and a voltage which together represent the polar co-ordinates of that point. They are also used in the reverse manner for conversion from polar to cartesian co-ordinates.

53. **Construction of resolver synchros.** Outwardly, a resolver synchro looks like all the other synchros already dealt with. It has however, four stator and four rotor windings, arranged as shown in Fig. 32. Stator windings S_1 and S_2 are in series and have a common axis which is at right angles to that formed by S_3 and S_4 in series: similarly, rotor windings R_1 and R_2 in series have a common axis which is at right angles to that formed by R_3 and R_4 in series.

54. **Resolution from polar to cartesian co-ordinates.** In Fig. 33 an alternating voltage of magnitude r applied to one of the rotor windings represents the modulus of polar co-ordinate, and the angle θ through which the rotor shaft has turned represents the argument. In this application, only one of the rotor windings is used and the unused winding is normally short-circuited to improve the accuracy, and limit spurious response.

The alternating flux produced by the rotor current links with the stator windings, and voltages are induced in each of the stators. In the position shown in Fig. 33, maximum voltage is induced across that stator coil which is aligned with the rotor in use,

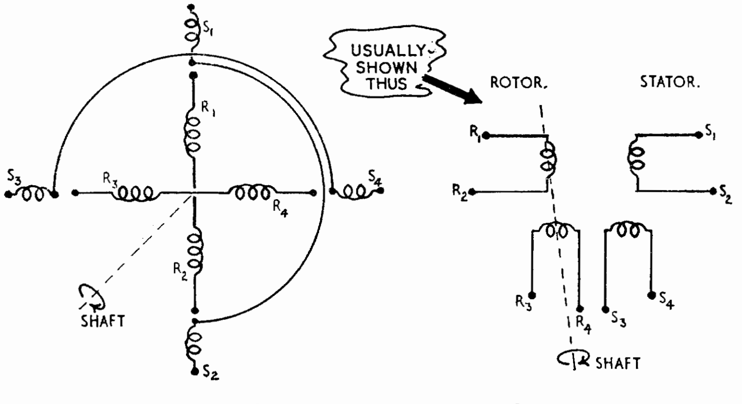


Fig. 32. RESOLVER SYNCHRO

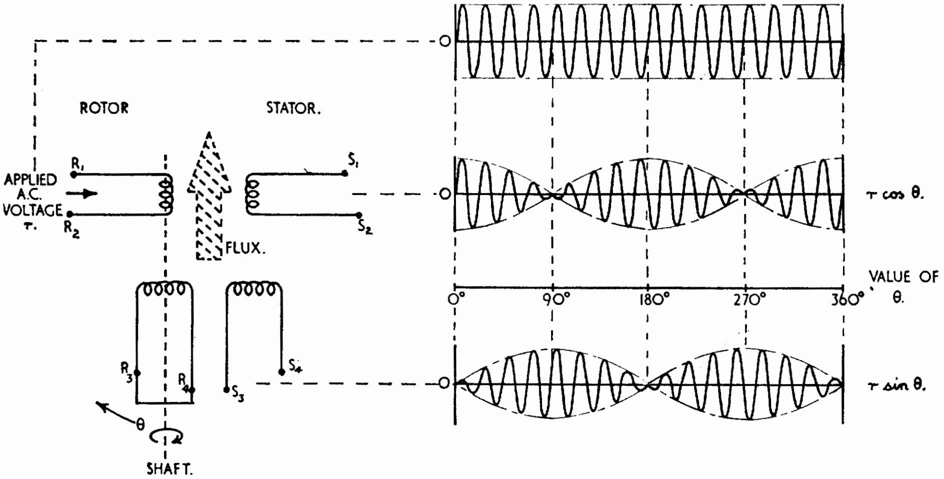


Fig. 33. CONVERSION FROM POLAR TO CARTESIAN CO-ORDINATES

i.e., S_1 S_2 in line with R_1 R_2. No voltage is induced in the other stator coil which is at right angles to the rotor flux. Movement of the rotor at a constant speed will induce voltages across the two stator coils which will vary sinusoidally.

The voltage across that stator coil which is aligned with the rotor at electrical zero will be a maximum at that position and will fall to zero after 90° displacement: this voltage is therefore a measure of the *cosine* of the angle of displacement (cos θ). It is *in phase* with the energising voltage during the first 90° displacement and *in anti-phase* from 90° to 270°, finally rising from zero at 270° to maximum in-phase at 360°. Any angle of displacement can therefore be identified by the amplitude and phase of the induced stator voltages.

Similarly, the stator coil which at datum is at right angles to the energised rotor coil will at that point have zero voltage induced in it. Through a displacement of 90°, this voltage will rise to maximum *in-phase* sinusoidally and is therefore directly proportional to the sine of the displacement angle (sin θ). Again, the phase depends on the angle of displacement and any angle can be identified by the amplitude and phase of the induced stator voltages.

The output from one stator is of the form r cos θ and from the other r sin θ: the sum of these two defines in cartesian co-ordinates the input voltage and shaft rotation $r\angle\theta$.

55. **Resolution from cartesian to polar co-ordinates.** To convert from cartesian to polar co-ordinates a zero-nulling device is required. One arrangement is illustrated in the circuit of Fig. 34. An alternating voltage $V_x = r \cos \theta$ is applied to the cos

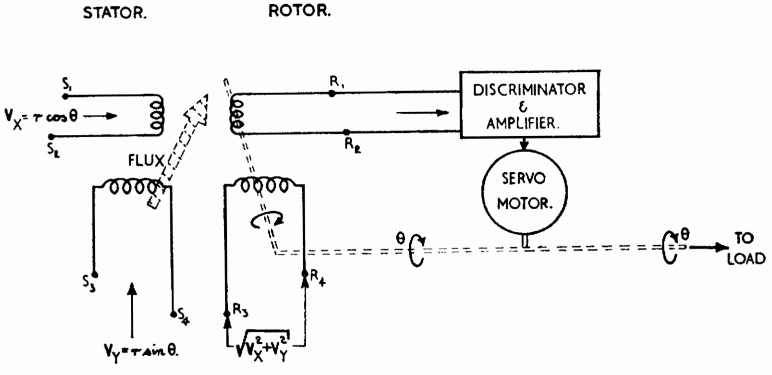


Fig. 34. CONVERSION FROM CARTESIAN TO POLAR CO-ORDINATES

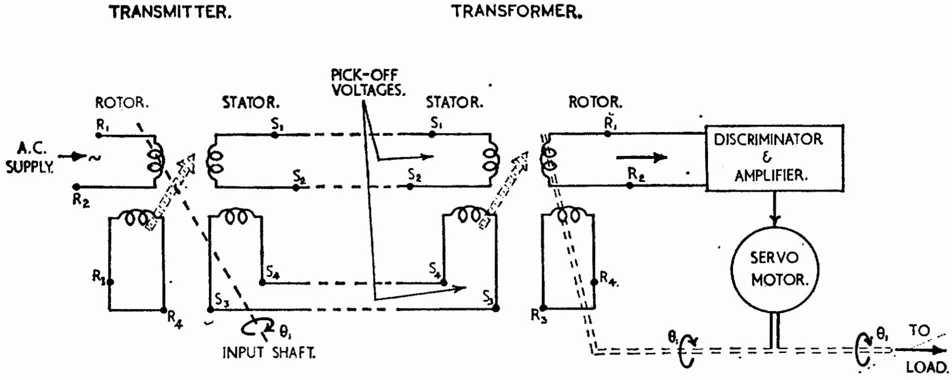


Fig. 35. RESOLVER SYNCHRO AS A REMOTE INDICATOR

stator winding S_1 S_2, and $V_y = r \sin \theta$ is applied to the sin stator winding S_3 S_4. An alternating flux of amplitude and direction dependent upon these voltages representing the cartesian co-ordinates, is therefore produced inside the stator.

One of the rotor windings R_1 R_2 is connected to an amplifier and servo motor which drives the output load and also the rotor in such a direction as to return the rotor to a null position: the motor then stops.

The other rotor winding R_3 R_4 has induced in it a voltage proportional to the amplitude of the alternating flux, i.e., proportional to $\sqrt{V_x^2 + V_y^2}$. This voltage represents the modulus r. The shaft position of the rotors represents the argument θ. Thus the input defined in cartesian co-ordinates has been converted to an output in terms of the polar co-ordinates.

56. **Remote indication by resolver synchros.** In some instances it is more convenient to have positional information transmitted in cartesian co-ordinates. The information is then readily available for application to the horizontal and vertical plates of a c.r.t., or for modification by other computer elements. Such instances occur, for example, when transmitting the position of a radar scanner. A typical arrangement is illustrated in Fig. 35. It will be seen that this application is very similar to that of a *control* synchro system with the added advantage that voltages corresponding to the cartesian co-ordinates can be picked off the resolver transformer stator windings.

The voltages induced in the transmitter stator windings from the energised rotor are transmitted via the connecting leads to the stator coils of the transformer, and the resulting magnetic flux of the transformer stator lines up with that of the transmitter rotor. By normal transformer action a voltage is induced in the transformer rotor windings and the output of one of them is fed to an amplifier which, in turn, controls a servo motor. The motor drives the load and at the same time turns the rotor to the null position, i.e., at right angles to the axis of the stator magnetic field. Thus, note that the electrical zero of a resolver transformer, like that of a control transformer, is displaced 90° from that in other synchros. When the rotor is in the null position, the servo motor stops having turned the output shaft through the same angle as the input shaft. Transmission of position has therefore been achieved.

57. **Resolver synchro as a phase-shift device.** A resolver synchro can be used in conjunction with a resistor and a capacitor connected in series across both stator windings, as shown in Fig. 36: this arrangement gives a phase-shifting device. If the rotor is energised, a voltage can be obtained between

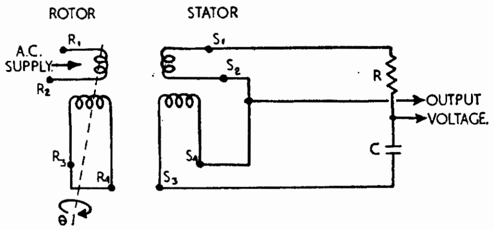


Fig. 36. RESOLVER SYNCHRO AS A PHASE-SHIFT DEVICE

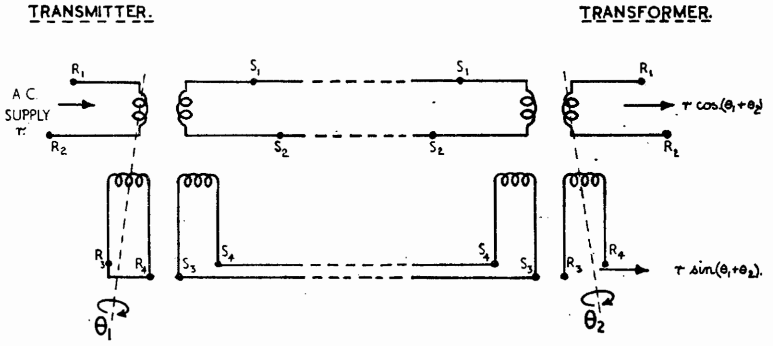


Fig. 37. RESOLVER DIFFERENTIAL SYNCHRO SYSTEM

the common point of both stator windings and a point between the resistor and the capacitor. The phase of this output voltage relative to the input depends on the orientation of the rotor relative to the stator windings: the phase can in fact be varied through 360° by turning the rotor through one complete revolution.

58. **Differential resolution.** It is sometimes necessary to obtain the sine and cosine values of the sum or difference of two inputs. A resolver synchro system arranged to give this is illustrated in Fig. 37.

One input shaft, connected to the transmitter rotors, turns through the angle θ_1: the other input shaft, connected to the transformer rotors, turns *in the same direction* through the angle θ_2. Since the axes of the two rotor windings on the transformer are at right angles to each other, one will give a cos output and the other a sin output. The magnitude and phase of the voltage induced in each output rotor depends on the orientation of each set of rotors relative to their respective set of stator windings, i.e., on the angles through which the input shafts have turned. With the connections shown, the outputs are $\mathbf{r}\cos(\theta_1 + \theta_2)$ and $r \sin(\theta_1 + \theta_2)$. A re-arrangement of the connections between transmitter and transformer will give the *difference* of two angles.

59. An alternative arrangement that gives similar results is shown in Fig. 38. In this circuit, a synchro known as a *resolver differential synchro* is used in conjunction with a normal synchro transmitter. In the resolver differential synchro there are two stator windings at right angles to each other, but the rotor is a three space-phased winding. The differential rotor produces a magnetic

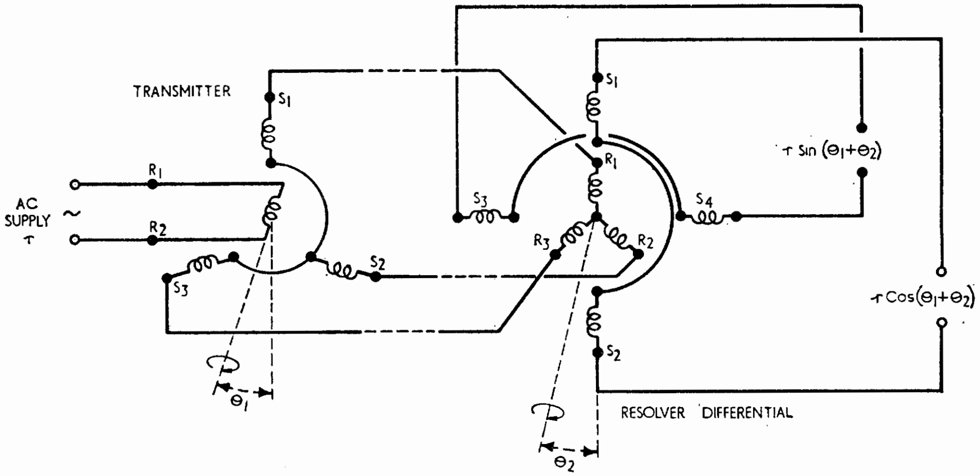


Fig. 38. RESOLVER DIFFERENTIAL SYNCHRO

field in accordance with the electrical signals received from the transmitter.

Due to the normal differential action described earlier, the amplitude and phase of the voltage induced in each stator winding of the differential depends on the relative directions of the stator windings and the rotor flux. The stator windings are arranged with their axes at right angles to give cos and sin outputs, and the position of the rotor flux is determined by the angles of the two input shafts — θ_1 to the transmitter

Systems	Remarks
D.C. SYSTEMS	
Desynn	Provides only sufficient torque to operate small instruments: gives remote indication of dial readings to an accuracy of about ±2°.
M-type	Provides moderate torque, sufficient to drive small mechanisms: accurate to about ±2°. Typical use is to rotate the scanning coils in a c.r.t. in synchronism with a radar aerial.
Wheatstone bridge	An error-operated system, accurate to within ±1°. Does not provide continuous rotation and gives very little torque: can be used as the controlling element in a torque-amplifying system, e.g., remote tuning of radio equipment.
A.C. SYSTEMS	
Torque synchro	Provides only sufficient torque to operate small instruments: efficient and accurate to within ±1°: often used to transmit data such as radar bearings to the place where the information is required.
Torque differential synchro	As for the torque synchro, but provides summation of two input shaft angles: used, for example, to combine a D/F loop reading and a compass reading to give a true bearing.
Control synchro	Gives an electrical output that is dependent on the error in alignment between driving shaft and load shaft. The error signal is normally used as the input to a control system driving a heavy load.
Control differential synchro..	As for control synchro, but provides summation of two input shaft angles.
Resolver synchro	Used in computers to give either cartesian or polar co-ordinates of an input, and for conversation of one to the other: can also be used in a manner similar to that of a control synchro.
Resolver differential synchro	Gives an electrical output in the form of sine and cosine values of the sum or difference of two inputs.

TABLE 2—SUMMARY OF REMOTE INDICATION SYSTEMS

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rotor and θ_2 to the differential rotor. Thus, outputs of r cos ($\theta_1 + \theta_2$) and r sin ($\theta_1 + \theta_2$) or of r cos ($\theta_1 - \theta_2$) and r sin ($\theta_1 - \theta_2$) are obtained, depending on the connections between the synchros.

Summary

60. This chapter has considered electrical remote indication systems in a general way. It has shown how changes in a physical quantity at one point, as represented by rotation of an input shaft, can be accurately reproduced at a remote point. It has also shown how transmission devices can be incorporated into control systems to give accurate remote control of heavy loads from small units and light operating forces. These control systems will be considered in greater detail in the next chapter (servo-mechanisms). Table 2 lists the devices and systems discussed in this Chapter.