CHAPTER 9

Control System Components

CHAPTER OUTLINES

■ Introduction; ■ Potentiometers; ■ Servomotors; ■ Types of Servomotors; ■ Tachogenerators (Tachometers); ■ Stepper Motors; ■ Synchros

9.1. INTRODUCTION

In control system, the devices which are used to convert the process variables in one form to another from is known as *transducers*. Transducers can also be defined as a device which transforms the energy from one form to another, for example, a thermocouple converts the heat energy into electrical voltage. In control system the following devices are used as a transducer.

1. Potentiometers
2. D.C. servomotors
3. A.C. servomotors
4. Synchros
5. Stepper motors
6. Magnetic amplifier
7. Tachogenerators
8. Gyroscope
9. Differential transformer

9.2. POTENTIOMETERS

A potentiometer is a simple device which is used for mechanical displacement either linear or angular. Thus, a potentiometer is an electromechanical transducer which converts the mechanical energy into electrical energy. The input to the device is in the form of linear mechanical displacement or rotational mechanical displacement, when the voltage is applied across the fixed terminals, the output voltage is proportional to the displacement.

Consider the Fig. 9.1 (translational potentiometer).

Let E_i = input voltage

E_0 = output voltage

x_i = displacement from zero position

x_t = total length of translational potentiometer

R = total resistance of potentiometer

Under ideal condition the output voltage E_0 is given by

$$E_0 = \frac{x_i}{x_t} E_i \qquad ...(9.1)$$

Equation (9.1) shows a linear relationship shown in Fig. 9.2.

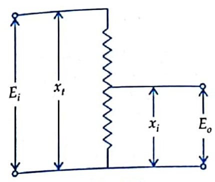


Fig. 9.1.

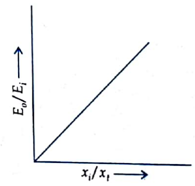


Fig. 9.2

Similarly for rotational motion, the output voltage E_0 is given by

$$E_0 = E_i \cdot \frac{\theta_i}{\theta_t} \qquad ...(9.2)$$

where θ_i = input angular displacement (degree or radians)

θ_t = total travel of wiper (degree or radians)

Figure 9.3(*a*) Shows an arrangement of error sensing transducer. In this arrangement two potentiometers are connected in parallel. The output voltage taken across the variable terminals of the two potentiometer. The output voltage E_0 is given by

$$E_o = K(\theta_1 - \theta_2) \qquad ...(9.3)$$

E_i is the voltage applied, θ_1 and θ_2 are the angular displacement of the wiper, K is constant and is known as sensitivity. The block diagram is shown in Fig. 9.3 (*b*).

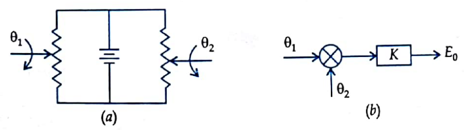


Fig. 9.3.

9.3. SERVOMOTORS

Servomotors are used in feedback control systems. Servomotors have low rotor inertia and high speed of response. The servomotors are also know as control motors. The servomotors which are used in feedback control system should have linear relationship between electrical control signal and rotor speed, torque speed characteristic should be linear, the response of the servomotor should be fast and inertia should be low.

9.4. TYPES OF SERVOMOTORS

The servomotors are classified as :

(*i*) A.C. servomotors

(*ii*) D.C. servomotors

(*iii*) Special servomotors

D.C. servomotors are further classified as armature controlled d.c. servomotors and field control d.c. servomotors.

9.4.1. A.C. Servomotors

These motors having two parts namely stator and rotor. A.C. servomotors are two phase induction motor. The stator has two distributed windings. These windings are displaced from each other by 90° electrical. One winding is called *main winding* or *reference winding*. The reference winding is excited by constant a.c. voltage. The other winding is called *control winding*. This winding is excited by variable control voltage of the same frequency as the reference winding, but having a phase displacement of 90° electrical. The variable control voltage for control winding is obtained from a servoamplifier. The direction of rotation depends upon phase relationship of voltages applied to the two windings. The direction of rotation of the rotor can be reversed by reversing the phase difference between control voltage and reference voltage.

The rotor of a.c. servomotors are of two types : (*a*) squirrel cage rotor, (*b*) drag cup type rotor. The squirrel cage rotor having large length and small diameter, so its resistance is very high. The air gap of squirrel cage is kept small. In drag cup type there are two airgaps. For the rotor a cup of non-magnetic conducting material is used. A stationary iron core is placed between the conducting cup to complete the magnetic circuit. The resistance of drag cup type is high and therefore having high starting torque. Generally aluminium is used for cup. Figure 9.4. Shows the schematic diagram of two phase a.c. servomotor and Fig. 9.5(*a*), and (*b*) shows the two types of rotor.

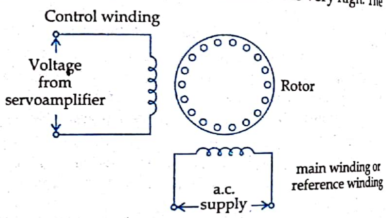


Fig. 9.4. A.C. servomotor

Fig. 9.5 (a) Squirrel cage rotor

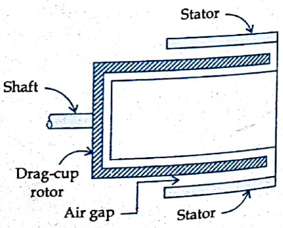


Fig. 9.5 (b) Drag cup type rotor

9.4.2. Torque-speed Characteristic

The torque speed characteristic of two phase induction motor depends upon the ratio of reactance to resistance. For high resistance and low reactance, the characteristic is linear and for large ratio of X to R it becomes non-linear as shown in Fig. 9.6(*a*). The torque-speed characteristics for various control voltages are almost linear as shown in Fig. 9.6(*b*).

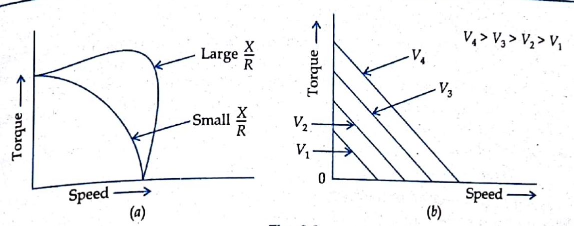
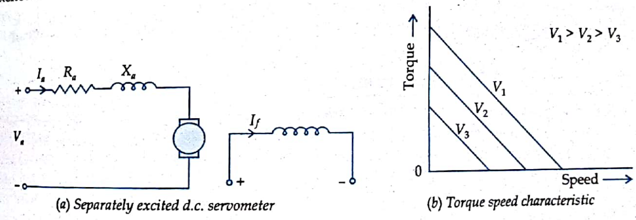


Fig. 9.6.

9.4.3. D.C. Servomotors

D.C. servomotors are separately excited or permanent magnet d.c. servomotors. The armature of d.c. servomotor has a large resistance, therefore torque speed characteristic is linear. The torque speed characteristic shows in Fig. 9.7(*b*). Fig 9.7(*a*) shows the schematic diagram of separately excited d.c. servomotor.



(*a*) *Separately excited d.c. servometer* (*b*) *Torque speed characteristic*

Fig. 9.7.

The d.c. servomotors can be controlled from armature side or from field. In field controlled d.c. servomotors the ratio of L/R is large *i.e.*, the time constant for field circuit is large. Due to large time constant, the response is slow and therefore they are not commonly used. Transfer function of field controlled d.c. servomotor is given in Chapter 1. The speed of the motor can be controlled by adjusting the voltage applied to the armature. In armature controlled d.c. servomotor the time constant is small and hence the response is fast. The efficiency is better than the field controlled motor. The transfer function of armature controlled d.c. servomotor is derived in Chapter 1.

9.4.4. Application of Servomotors

Servomotors are widely used in radars, electromechanical actuators, computers, machine tools, tracking and guidance system, process controllers and robots.

9.5. TACHOGENERATORS (TACHOMETERS)

Tachometers are electromechanical devices, which transforms the mechanical energy into electrical energy. In tachometers its magnetic flux is constant and induced e.m.f is proportional to the speed of the shaft *i.e.*, angular speed. The tachometers are classified as d.c. tachometers and a.c. tachometers.

9.5.1. D.C. Tachometer

In control systems most common type of tachometers are d.c. tachometers. D.C. tachometers contains an iron core rotor and permanent magnet. The magnetic field is provided by the permanent magnet and no external supply voltage is necessary. The input to the tachometer is the speed of the shaft and the output is voltage which is proportional to the angular speed of the shaft.

$$\therefore \quad e = K\omega(t) \qquad ...(9.4)$$

where e = tachometer generator voltage

K = tachometer sensitivity

ω = angular speed of the shaft.

Laplace transform of equation 9.4

$$E(s) = K\omega(s) \qquad ...(9.5)$$

$\therefore$ Transfer function of tachometer is

$$K = \frac{E(s)}{\omega(s)} \qquad ...(9.6)$$

In d.c. tachometers the windings on rotor are connected to the commutator and the output voltage is taken across the brushes. The permanent magnet tachometers are compact and reliable but having high inertia. For reducing the voltage drop across the brushes, metal brushes with silver tips are used.

9.5.2. Advantages of D.C. Tachometers

1. At zero speed there is no residual voltage.
2. It is possible to generate a very high voltage gradients in small size.
3. It can be used with high pass output filters to reduce servo velocity lags.

9.5.3. A.C. Tachometers

A.C. tachometers are similar to two phase induction motor. The schematic diagram of a.c. tachometer is shown in Fig. 9.8. Here two stator windings are placed in quadrature with each other and rotor is short circuited. The rotor of tachometer is a thin aluminium cup. The two stator windings are known as *primary winding* and *secondary winding*. Primary winding also known as reference winding.

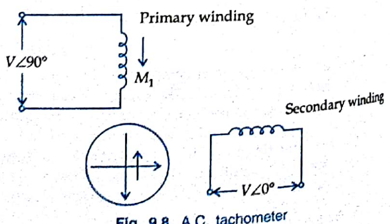


Fig. 9.8. A.C. tachometer

The primary winding carries a voltage $V\angle 90°$. This voltage is fixed in magnitude at fixed frequency known as *carrier frequency*. The coil axis of primary winding is called direct axis. When the current in primary winding flows a pulsating field M_1 is produced along direct axis. When the rotor is stationary an e.m.f. is induced in it. Since the motor is short circuited eddy current flows in it. Due to this eddy current a pulsating flux M_2 is produced opposite to the M_1. Therefore a pulsating flux ϕ_1 is produced due to the vector sum of M_1 and M_2. Since the secondary winding is in quadrature no e.m.f. will produced in it due to ϕ_1. Now if the rotor rotates it cuts the flux and an e.m.f is induced in it, due to this induced e.m.f a current will flow in the rotor and a

pulsating flux will appear along the coil axis of secondary winding. This flux ϕ_2 will induce the voltage in secondary winding. The magnitude of the output voltage will be proportional to the rotor speed.

9.6. STEPPER MOTORS

In stepper motors, the movement of the rotor is in discrete steps. A stepper motor is electromechanical device. There are three types of stepper motors:

(*i*) Variable reluctance motors

(*ii*) Permanent magnet motors

(*iii*) Hybrid type

9.6.1. Variable Reluctance Stepper Motors

Variable reluctance stepper motors are of two types namely, single-stack variable reluctance motor and multi stack variable reluctance motor.

9.6.1.1. Single-stack Variable Reluctance Motor

A 4-phase, 4-stator pole, 2-tooth rotor variable reluctance stepper motor is shown schematically in Fig. 9.9.

In Fig. 9.9. four phases are connected to d.c. source through switches S_1, S_2, S_3 and S_4. When phase 1 is excited, the rotor aligns with the axis of phase 1 as shown in Fig. 9.9. If now switch S_1 off and S_2 switched on, the rotor moves through 90° in clockwise to align with the resultant air gap field which lies along the axis of phase 2. Now, phase 3 is excited and phase 2 is disconnected, the rotor aligns with the resultant airgap field which now lies along phase 3 and so on. The windings of the stator are energized in sequence 1, 2, 3, 4, 1.

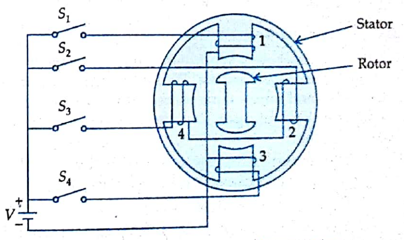


Fig. 9.9. Variable reluctance stepper motor

As the phases are energized as 1, 2, 3, 4, 1, the rotor moves through a step of 90° in clockwise direction. Rotor can be made to rotate in anticlockwise direction by reversing the switching sequence.

9.6.1.2. Multistack Variable Reluctance Stepper Motor

A multistack variable reluctance stepper motor is shown in Fig. 9.10. In this type of stepper motor, rotors have a common shaft and stator have a common frame. The stators and rotors have same number of poles with same teeth size. The stators are pulse excited while rotors are unexcited. The windings of all stator poles are excited simultaneously. Since, stators and rotors have same number poles, therefore pole pitch is also same. If T, is the number of rotor teeth and n is the number of stacks or phases, then tooth pitch is given by $360°/T$, and angular displacement or step angle is given by $360°/nTr$. For exmaple 12 pole rotor, the pitch is $360/12 = 30$ and the step angle will be $360/3 \times 12 = 10°$ *i.e.*, rotor poles are displaced from each other by 10°.

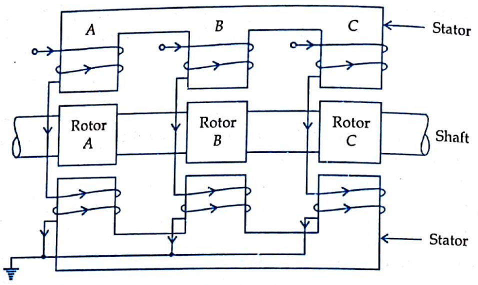


Fig. 9.10. Multistack variable reluctance stepper motor

9.7. SYNCHROS

A synchro is an electromagnetic transducer which converts the angular position of a shaft into an electric signal. Synchros are used as detectors and encoders.

9.7.1. Synchro Transmitter

The construction of synchro transmitter is very similar to that of a three phase alternator. The stator is made of laminated silicon steel and carries three phase star connected windings. The rotor is a rotating part, dumbbell shaped magnet with a single winding.

A single phase a.c. voltage is applied to the rotor through slip rings. Let applied a.c. voltage to the rotor is

$$e_r = E_r \sin \omega_0 t \qquad ...(9.7)$$

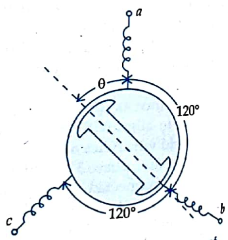


Fig. 9.11. Schematic diagram of synchro transmitter

due to this applied voltage a magnetizing current will flow in the rotor coil. This magnetizing current produces sinusoidally varying flux and distributed in the air gap. Because of transformer action voltages get induced in all stator coil which is proportional to cosine of angle between stator and rotor coil axes.

Now, consider the rotor of synchro transmitter is at an angle θ, then voltages in each stator coil with respect to neutral are

$$E_{an} = KE_r \sin \omega_0 t \cos \theta \qquad ...(9.8)$$

$$E_{bn} = KE_r \text{ son } \omega_0 t \cos (\theta + 120°) \qquad ...(9.9)$$

$$E_{cn} = KE_r \sin \omega_0 t \cos (\theta + 240°) \qquad ...(9.10)$$

Magnitudes of stator terminal voltages are

$$E_{cb} = E_{cn} - E_{bn}$$

$$= KE_r \sin \omega_0 t \, [\cos (\theta + 240°) - \cos (\theta + 120°)] = KE_r \sin \omega_0 t \left[\sqrt{3} \sin \theta\right]$$

$$\therefore \quad E_{cb} = \sqrt{3}\, KE_r \sin \omega_0 t \sin \theta \qquad ...(9.11)$$

Similarly,

$$E_{ac} = \sqrt{3}\, KE_r \sin \omega_0 t \sin(\theta + 120°) \qquad ...(9.12)$$

$$E_{ba} = \sqrt{3}\, KE_r \sin \omega_0 t \sin(\theta + 240°) \qquad ...(9.13)$$

When θ = 0, the maximum induced voltage will be E_{an} and E_{cb} will be zero. This position of the rotor is defined as electrical zero of the transmitter and is used as the reference for indicating the angular position of the rotor.

Thus, the input to the synchro transmitter is the angular position of the rotor shaft and the output are the three single phase voltages which are the function of the shaft position.

9.7.2. Synchro Control Transformer

Principle of operation of synchro control transformer is same as that of synchro transmitter. Rotor of snchro control transformer is cylindrical type. Synchro control transformer is an electromechanical device. The combination of synchro transmitter and synchro control transformer is used as an error detector. The function of error detector is to convert the difference of two shaft positions into an electrical signal. The Fig. 9.12, shows schematic diagram of synchro error detector.

The output of synchro transmitter is connected to the stator winding of the synchro control transformer. Therefore the same current will flow in the stator windings of synchro control transformer but in opposite direction. The voltage across the rotor terminals of control transformer is

$$e(t) = K_1 V_r \cos \phi \sin \omega_0 t \qquad ...(9.14)$$

where ϕ = angular displacement between the two rotors. When the two rotors are at an angle 90°, the voltage induced in control trnsformer is zero. This position is known as electrical zero position control transformer.

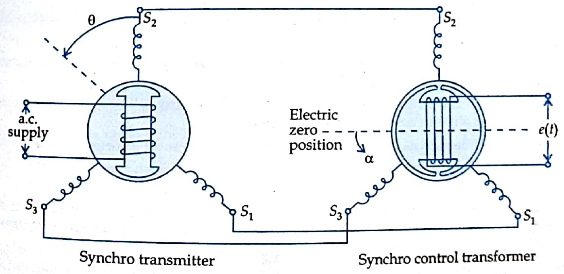


Fig. 9.12. Synchro error detector

Let the transmitter rotate through an angle 'θ' in the direction indicated and let control transformer rotor rotates in the same direction through an angle 'α'. Then

$$\phi = (90° - \theta + \alpha) \qquad ...(9.15)$$

Put the value of ϕ in equation 9.14, we get

$$e(t) = K_1 V_r \sin (\theta - \alpha) \sin \omega_0 t \qquad ...(9.16)$$

From equation (9.16) it is clear that when two rotor shafts are not in alignment, the rotor voltage of control transformer is approximately a sine function of the difference between the two shaft angles.

For small angular displacement between two rotor position

$$e(t) = K_1 V_r (\theta - \alpha) \sin \omega_0 t \qquad ...(9.17)$$