Chapter 1

CONTROL DEVICES FOR INDUSTRIAL MOTOR

1.1 INTRODUCTION

Industrial control in its expanded meaning encompasses all the methods used to control and maintain the performance of an electrical system. When applied to machinery it includes the starting, acceleration, reversal and stopping of a motor and its load. For this purpose semiconductor devices are becoming more and more popular these days. It, therefore, becomes very important to understand the principle of their working as various control devices.

1.2 SEMICONDUCTOR DEVICES

A semiconductor is a substance, which has resistivity (10^{-4} to 0.5 Ωm) in between that of conductors and insulators. These materials have very limited number of free electrons and holes, which accounts for only partial conduction. These materials have negative temperature coefficient of resistance. These materials may be of silicon or germanium base and depending upon whether these are doped with donor or acceptor, we get P type N type of crystals. This is explained in the following paragraphs.

1.2.1 Diode

The term diode denotes two electrode device. A semiconductor diode is simply a P-N junction connecting leads or terminals on the two sides of the junction. A diode is a unidirectional device permitting the easy flow of current in one direction but restraining the flow in opposite direction. A major application of diodes is rectification, i.e. conversion of AC into DC. Semiconductor diode is gaining more popularity these days due to its smaller size, cheapness, robustness and higher operating efficiency.

Circuit symbol of a semiconductor diode is given in Fig. 1.1a. The graphical symbol for a diode is shown in Fig. 1.1b. The arrow in the symbol indicates the direction of conventional current flow when the diode is on, i.e. from the positive terminal through the device to the negative terminal. The P-side of the diode is always the positive terminal for forward bias and is designated the anode. The N side is called the cathode and is the negative terminal when the device is forward biased.

2. **Nature of the drive:** Whether motor is to drive individual machines or a group of machines.
3. **Electrical characteristics of motors**
   a. Starting characteristic.
   b. Running characteristic.
   c. Speed control.
   d. Braking characteristic.
4. **Size and rating of motors**
   a. Requirement for continuous, intermittent or variable load cycle.
   b. Overload capacity.
5. **Mechanical considerations**
   a. Type of enclosures.
   b. Type of bearings.
   c. Transmission of drive.
   d. Noise level.
   e. Heating and cooling time constant of the motor.
6. **Cost**
   a. Capital cost.
   b. Running cost.

Proper choice of motor in the first place, saves lots of worries later on. Moreover due to practical difficulties it is not always possible to satisfy all the above considerations. For instance, either due to non-availability of particular type of motor or its prohibitive cost, we may select some other type of motor. In such circumstances, it is the experience and insight which an engineer has to fallback upon in the final selection of motor.

2.3 NATURE OF ELECTRIC SUPPLY

Wherever AC supply is available, choice should always be made for AC motors. AC motors have the advantage of possessing few working parts, requiring less maintenance and replacement of spares, giving an uninterrupted long service life. These motors, however, suffer from heavy starting current and fixed speed. As against this DC have many working parts such as commutator, brush goes, etc. All of which tend to give trouble. Advantages of DC motor are in no way loss prominent than maintenance troubles and can be found in ease of starting and speed control. Therefore; for certain applications, DC motors have privileged position such as in traction, rolling mills and lift services where frequent starting, stopping, reversing and speed control are required. In case of AC motors, we should try to use three phase motors in the interest of better efficiency, high starting and uniform running torques and balanced loading of supply. Single phase motors are limited to small loads only.

Nature DC supply available, to some extent affects the size of motor required. DC supply available from a DC generator will be more or less smooth as shown in Fig. 2.1.

As against this, DC supply available from rectifiers is undulating as shown in Fig. 2.2. This undulating DC supply, according to Fourier principle, is equal to DC component and AC harmonics. Mechanical power produced by motor is due to DC component only whereas armature heating will be produced by rms value of the total

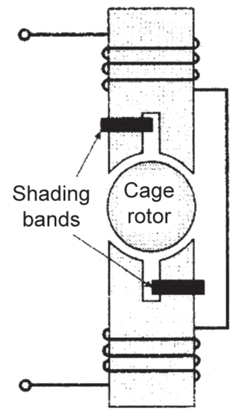


Fig. 2.8: Shaded pole motor.

A rotating magnetic field is obtained in the air gap. There are two types of capacitor motors; the "capacitor start" motor, in which case the capacitor is in circuit only during the starting period and is disconnected at a predetermined speed by a centrifugal switch, the other type is the "capacitor start and run" motor where the capacitor is connected permanently and improves the power factor of the motor (Fig. 2.9).

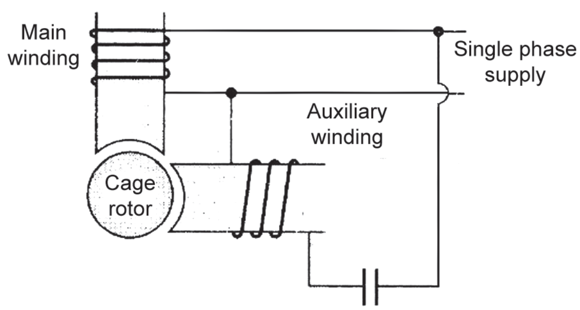
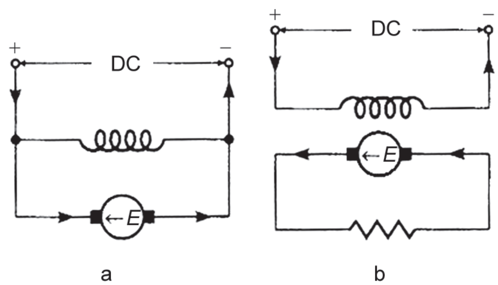


Fig. 2.9: Capacitor motor.

c. **Repulsion motor starting:** The rotor has a repulsion motor winding and therefore starts as a repulsion motor giving a high starting torque. As it runs to speed a centrifugal device short-circuits the commutator bars and lifts the brushes, converting the motor into a plain squirrel cage one.

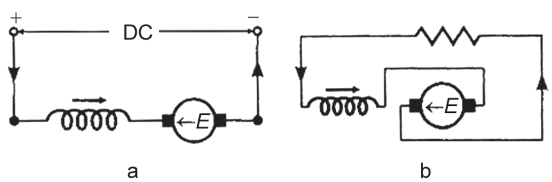
2.5.6 Synchronous Motors

Synchronous motor is not self-starting as there is no starting torque. It has to be run up to synchronous speed by another motor and synchronised to the supply. To make it self-starting a cage winding is provided on the poles. It starts as a plain squirrel cage motor and when it has attained nearly synchronous speed at no load, the DC excitation is switched on and the rotors pulls into synchronism. Starting torque between 50 and 100 percent full-load torque can be obtained with twice full-load current. The "synchronous induction motor" has a cylindrical rotor with a slip-ring induction motor winding. It starts as a slip-ring induction motor with good starting



Figs 2.33a and b: Rheostatic braking of shunt motor: (a) Normal running, (b) Resistance braking.

b. **DC motor-series:** The after being disconnected from the supply is made to excite as a series generator. For this it is necessary that the total resistance in the motor circuit should less than the critical resistance, so that the generator may self-excite. Also in order that the flux may build-up, the connection of the armature with respect to the field have to be reversed (Figs 2.34a and b).



Figs 2.34a and b: Rheostatic braking of shunt motor: (a) Normal running, (b) Braking.

Normally, the starting resistance is employed for braking purposes. Since torque is proportional to the product of flux and current, we have in a series motor electric braking torque = $k_1\phi I$ and braking current I = $\frac{E}{R}$ where E is the induced emf in the armature and R is the total resistance in the motor circuit.

∴
$$EBT = k_1\phi\frac{E}{R} = \frac{k_1}{R}\phi E = \frac{k_1}{R}\phi(k_2N\phi)$$
$$= \frac{k_1k_2}{R}\phi^2N = k_3N\phi^2$$

For a shunt motor ϕ is constant.

∴
$$\text{EBT} = k_4N$$

c. **Synchronous motors:** The field excitation is maintained and the motor after being disconnected from the supply is connected to resistances in star or delta. It now works as an alternator and the kinetic energy is dissipated in the form of losses in the resistance.

d. **Induction motors:** The stator is disconnected from the supply and direct steady current is passed through its windings. A flux is produced. When the short-circuited rotor conductors cut this steady flux emf is induced in them which provide the necessary braking effect. If the rotor is wound, the braking torque can be controlled by the insertion of suitable resistance in the rotor circuit.

If speed is reduced from ω_0 to ω.
The energy given up by flywheel is

$$= \frac{1}{2}\frac{I}{g}\left(\omega_0^2 - \omega^2\right)$$

$$= \frac{1}{2}\frac{I}{g}(\omega_0 + \omega)(\omega_0 - \omega) \quad (2.10)$$

$\left(\frac{\omega_0 + \omega}{2}\right)$ mean speed. Assuming speed drop of not more than 10%, this may be assumed equal to ω.

$\therefore \left(\frac{\omega_0 + \omega}{2}\right) \cong \omega$ Also $(\omega_0 - \omega) = S$

$\therefore$ From equation (2), energy given up = $\frac{I}{g}\omega S$

Power given up = $\frac{I}{g}\omega\frac{ds}{st}$

but torque = $\frac{\text{Power}}{}$

$\therefore$ Torque supplied by flywheel.

$$T_f = \frac{I}{g}\frac{ds}{dt}$$

$\therefore$ From equation (1),

$$T_m = T_L - \frac{I}{g}\frac{ds}{dt}$$

For values of slip speed up to 10% of No - load speed, slip is proportional to torque

Or $$s = K\,T_m$$

This equation is similar to the equation for heating of the motor $W - A\lambda\theta = G.S.\frac{d\theta}{dt}$

i.e. $$\left(T_L - T_m\right) = \frac{I}{g}K\frac{dT_m}{dt}$$

$$g\frac{dt}{IK} = \frac{dT_m}{\left(T_L - T_m\right)}$$

By integrating both sides.

$$-\text{In}\left(T_L - T_m\right) = \frac{gt}{IK} + C_1 \quad (2.11)$$