motor.

3 PHASE INDUCTION MOTOR

12.18. 3 PHASE INDUCTION MOTOR

In case of d.c. motors the electric power is conducted to armature winding through brushes and commutator, hence these are called as conduction machines. The induction motor is most common and widely used a.c. motor, in this case there is no electrical connection between stator and rotor, hence rotor voltage (which produces rotor current and rotor magnetic field) are produced by induction due to which it is called as induction motor. Induction motors are singly excited motors. The production of torque in induction motor depends totally on current induced in rotor which is only possible at speeds below synchronous. Hence induction motors are also called *asynchronous motors*. A polyphase induction motor is extensively used in various applications because of the following advantages :

Advantages of Induction motor :

1. It is very simple and extremely rugged, almost unbreakable construction (especially squirrel cage type).
2. Its cost is low and it is reliable.
3. It has sufficiently high efficiency.
4. It requires minimum maintenance.
5. It starts up from rest and hence requires no starting motor.

But induction motors are also has some disadvantages as below :

1. The speed is not easily controllable.

2. The starting current may be five to eight times of full load current (In case of squirrel cage motor with direct on line starting).
3. The power factor is low and lagging when the machine is lightly loaded.

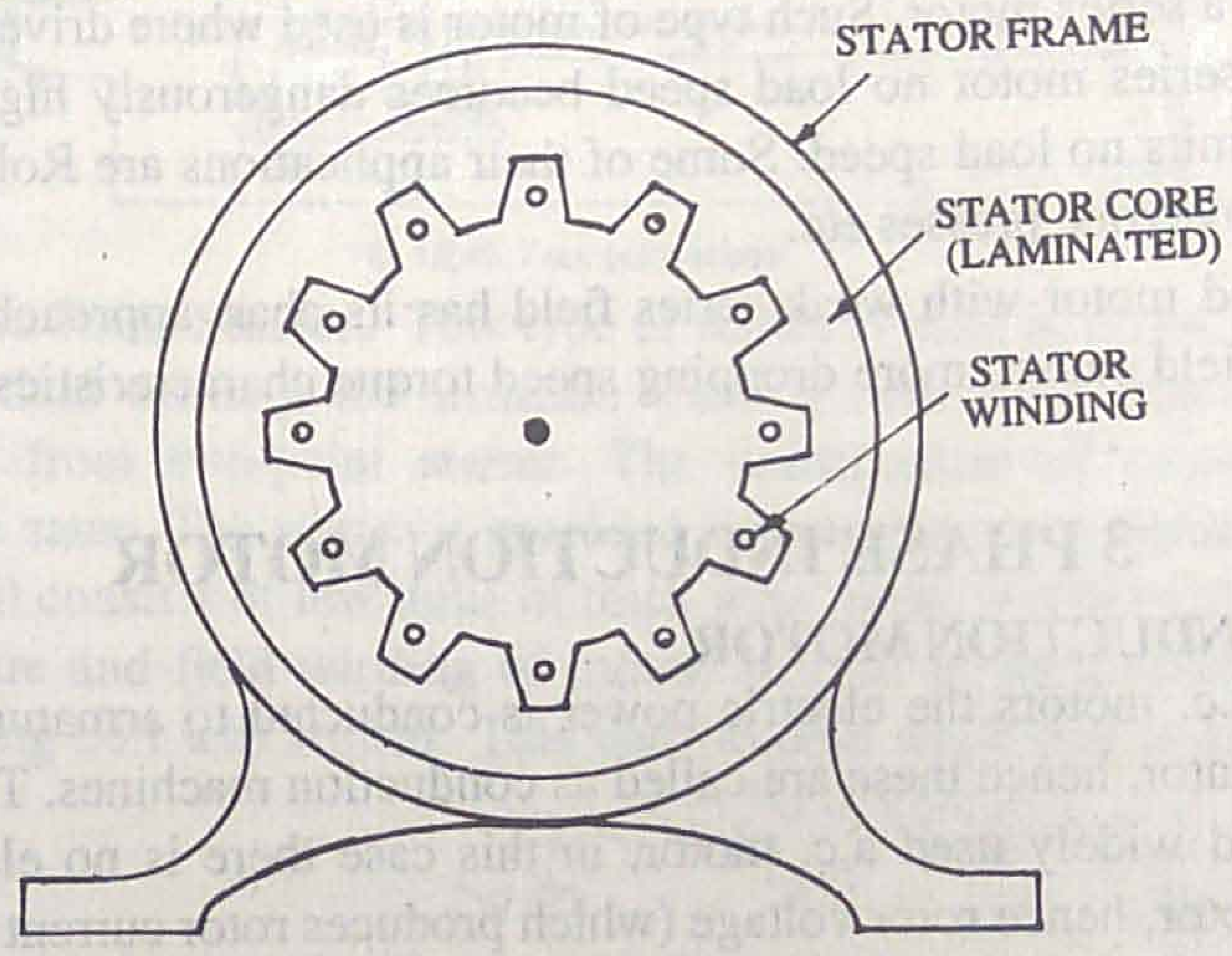
12.19. CONSTRUCTION OF INDUCTION MOTOR

A 3-phase induction motor has two main parts :

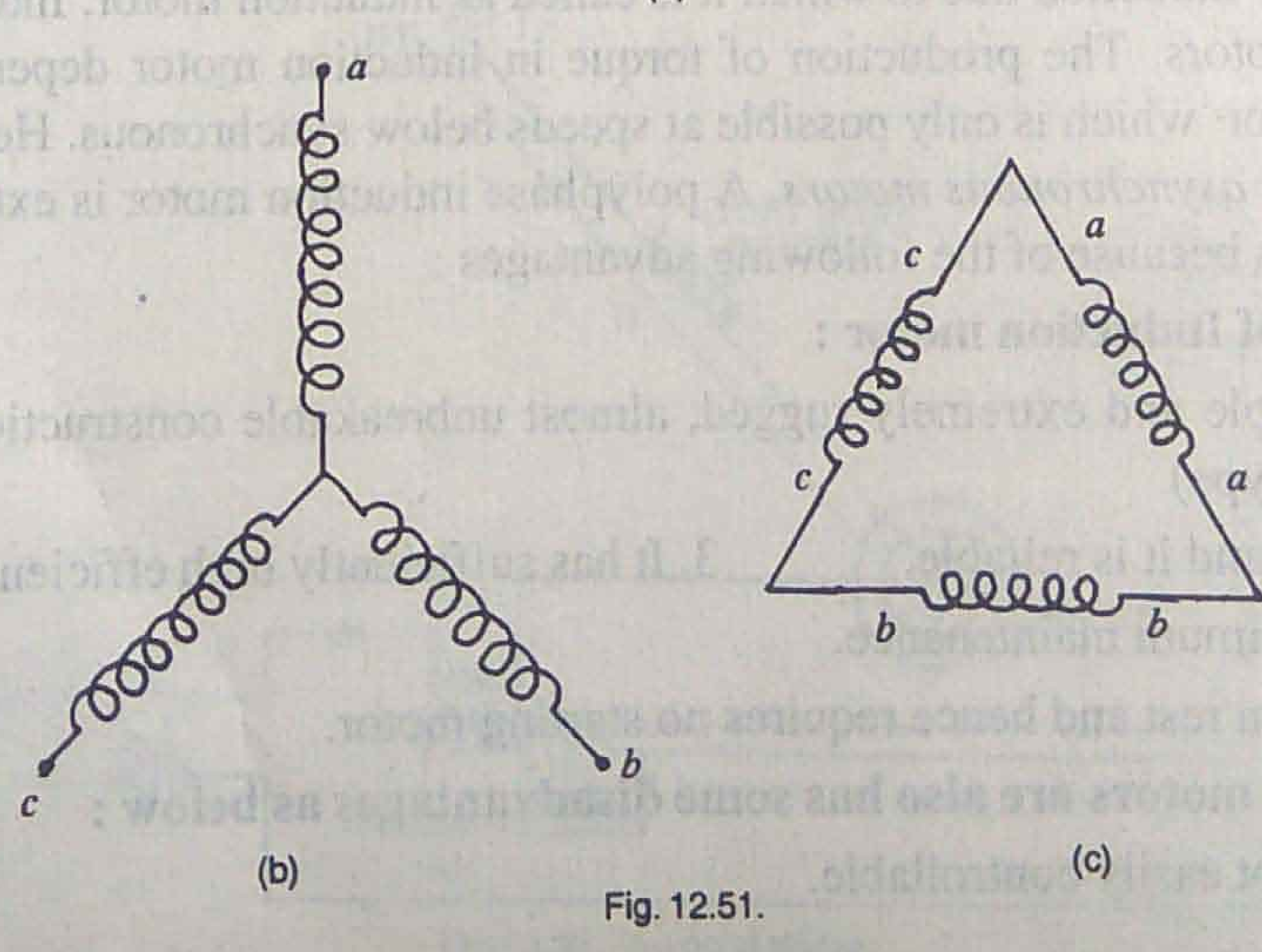
1. A stationary stator. 2. A revolving rotor.

The rotor is placed inside stator and is separated by a small air gap which ranges from 0.4 mm to 4 mm depending upon capacity of motor. Now let us study each part of induction motor.

12.19.1. Stator. The stator of an induction motor consists of steel frame, which support a hollow cylindrical core, called stator core, made up of stacked laminations. The inner periphery of stator core has evenly spaced slots provides the space for the stator winding. In order to reduce the eddy current losses in stator core, is made up of high grade silicon steel laminations of thickness 0.35 mm to 0.65 mm. The laminations are insulated from each other



(a)



(b) (c)

Fig. 12.51.

with a special coating of varnish and held togther in bolts passing through insulating sleeves. The stator windings are placed in the slots on the inner periphery of stator core. In the polyphase induction motor the stator windng is usually arranged for a 3-phase and it is wound for a definite number of poles as per the requirement of speed. Greater the number of poles lesser the speed and *vice versa* for a supply of given frequency. The 3-phase stator winding depending upon its size can be connected in star or in delta or all six terminals are brought outside as shown in Fig. 12.51 (*b*) and (*c*).

12.19.2. Rotor. There are two types of rotors, which are used in induction motor and are placed inside the stator. The induction motors are classified according to type of rotor used. The two types of rotor are :

1. Squirrel cage rotor. 2. Wound rotor.

The induction motor whose rotor is squirrel cage type is known as squirrel cage induction motor. The induction motor whose rotor is wound rotor type is known as wound rotor induction motor. Now we will study construction of each rotor in detail.

12.19.3. Squirrel Cage Rotor. Almost 90% of induction motor uses squirrel cage rotor because of its simple and robust construction. The rotor of squirrel cage induction motor is constructed of laminated core tightly pressed on a shaft. Along the slotted periphery of rotor, heavy bar of copper or aluminum are placed in various slots and at both ends these bars are connected to end rings of same material forming a closed rotor winding. The rotor conductors are not insulated from rotor core, because the natural tendency of current is always to adopt a path of least resistance *i.e.* through rotor bars. *The rotor slots are not usually quite parallel to the shaft but are purposely given a slight skew in order to*

1. Obtain more uniform torque.
2. Reduce the magnetic humming noise while running.
3. It helps in reducing locking tendency of the rotor.

From the construction of squirrel cage rotor, it is clear that the rotor bars are permanently welded to end rings. Hence it is not possible to add additional external resistance in the rotor circuit for improving starting characteristics of motor such as starting torque and starting power factor. The starting torque of the squirrel cage type induction motor is low

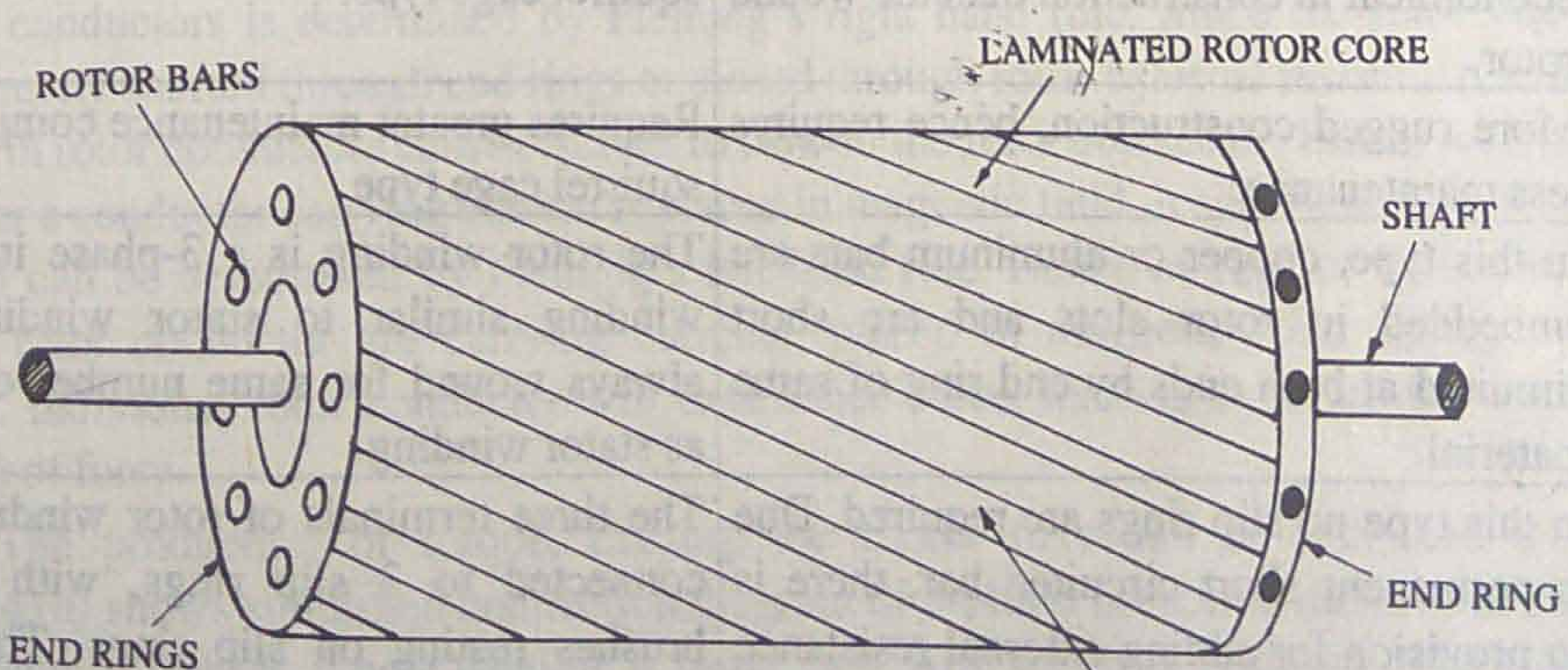


Fig. 12.52. Squirrel cage motor.

because there is no provision for adding external resistance during starting to improve starting torque. Hence squirrel cage induction motors are never used in applications where high starting torque is needed. Fig. 12.52 shows construction of squirrrel cage rotor.

12.19.4 Wound Rotor or Slip Ring Rotor. A wound rotor has three-phase winding similar to stator winding. The insulated ends of polyphase winding are placed in rotor slots in the rotor core. The rotor insulated polyphase winding is wound for same number of poles as that of stator and usually connected in star. The three terminals are connected to three slip rings of phosphor bronze material, which turns with rotor. These slip rings are externally connected to a 3 phase star connected rheostat the external resistors are only used during starting period. And these resistances are gradually cut but as the rotor pick's up the speed under normal running condition the three brushes are short-circuited. Hence in wound rotor induction motor external resistance is inserted during starting period, hence starting torque obtained is more. Fig. 12.53 shows wound rotor or slip ring rotor.

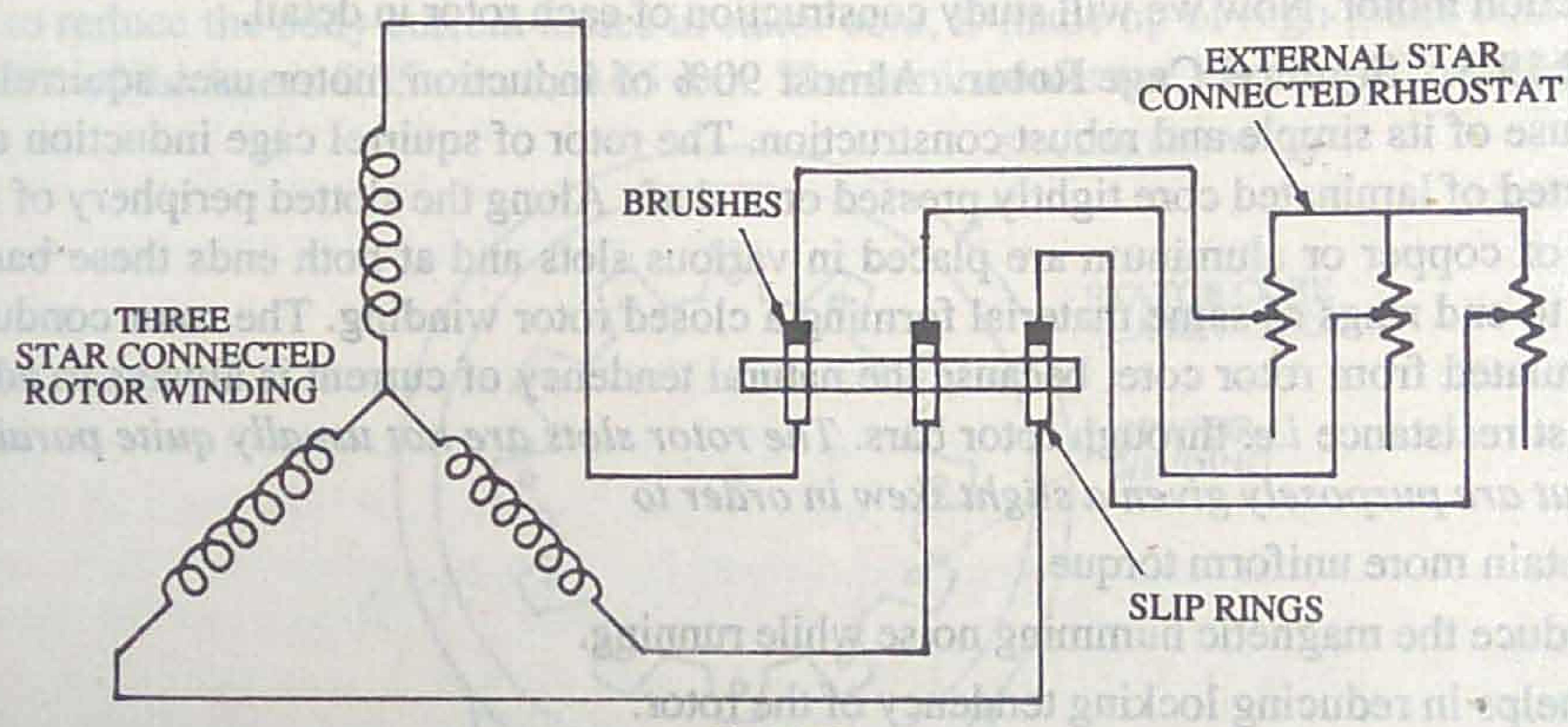


Fig. 12.53.

12.21. PRINCIPLE OF OPERATION OF INDUCTION MOTOR OR WHY DOES THE ROTOR OF INDUCTION MOTOR ROTATES ?

When the stator winding of the 3 phase induction motor is connected to 3 phase a.c. supply, as we know that rotating magnetic field will be set up. The characteristics of rotating magnetic field are as below :

1. Rotating magnetic field (rmf) rotates at synchronous speed given by relation, $N_S = 120\ f/p$ where P = No. of poles, f = frequency.
2. Rmf is having constant amplitude, $\phi_r = 1.5\ \phi_m$.
3. The direction of rotation of rmf will depend upon the phase sequence of stator winding currents, but phase sequence of stator currents depend upon the order of connection of stator winding terminals with respect to supply terminals.
4. The direction of rotation of rmf can be reversed by interchanging the connection of any two winding terminal with respect to supply.
5. The number of poles of the rmf is same as number of poles for which each phase of stator winding is wound.

When the rotor is at stand still and revolving magnetic field is rotating at synchronous speed, there is relative motion between stationary rotor conductor and revolving magnetic field. Due to relative motion stationary rotor conductors cut the rotating magnetic field. According to Faraday's law, emf is induced in rotor conductors. The direction of emf induced in rotor conductors is determined by Fleming's right hand rule. Since the rotor winding is either directly shorted through end rings or closed through some external resistance, hence emf induced in rotor conductors causes current to flow in the rotor conductor. But as we know that whenever a conductor carrying current is placed in magnetic field, it experience a force, whose direction can be determined by Fleming's left hand rule. Hence in case of induction motor, when a rotor conductor are carrying currents, placed in magnetic field set up by stator winding. Individual rotor conductor will experience force, tending to rotate the rotor in the direction of force.

The production of torque, causing the motor to rotate is explained as below. Fig 12.54 (*a*) shows simplified connection diagram of 3-phase induction motor. For simplicity on the stator, a 3 phase, 2 pole winding is made, only with six coils, is shown. The direction of rmf depends upon the sequence in which supply terminals are connected to stator winding. For

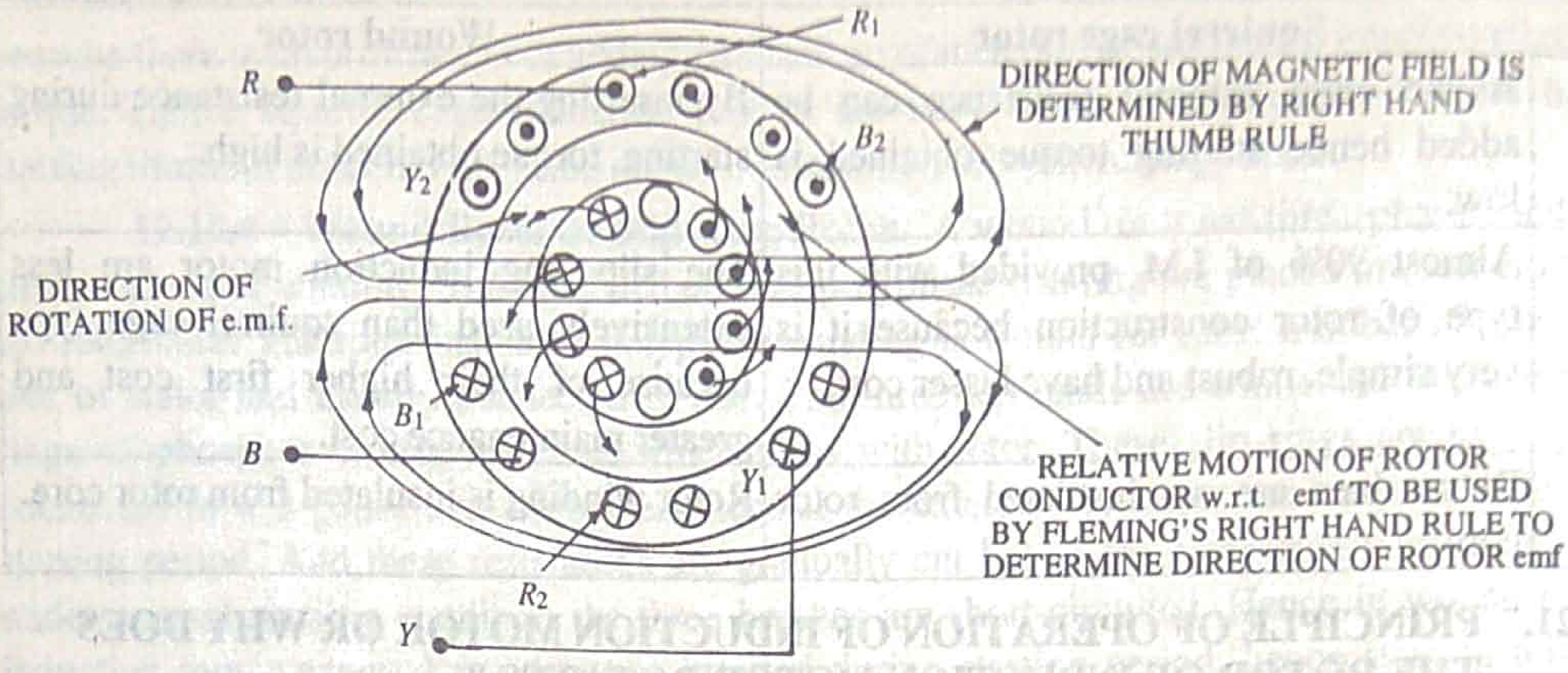


Fig. 12.54 (a)

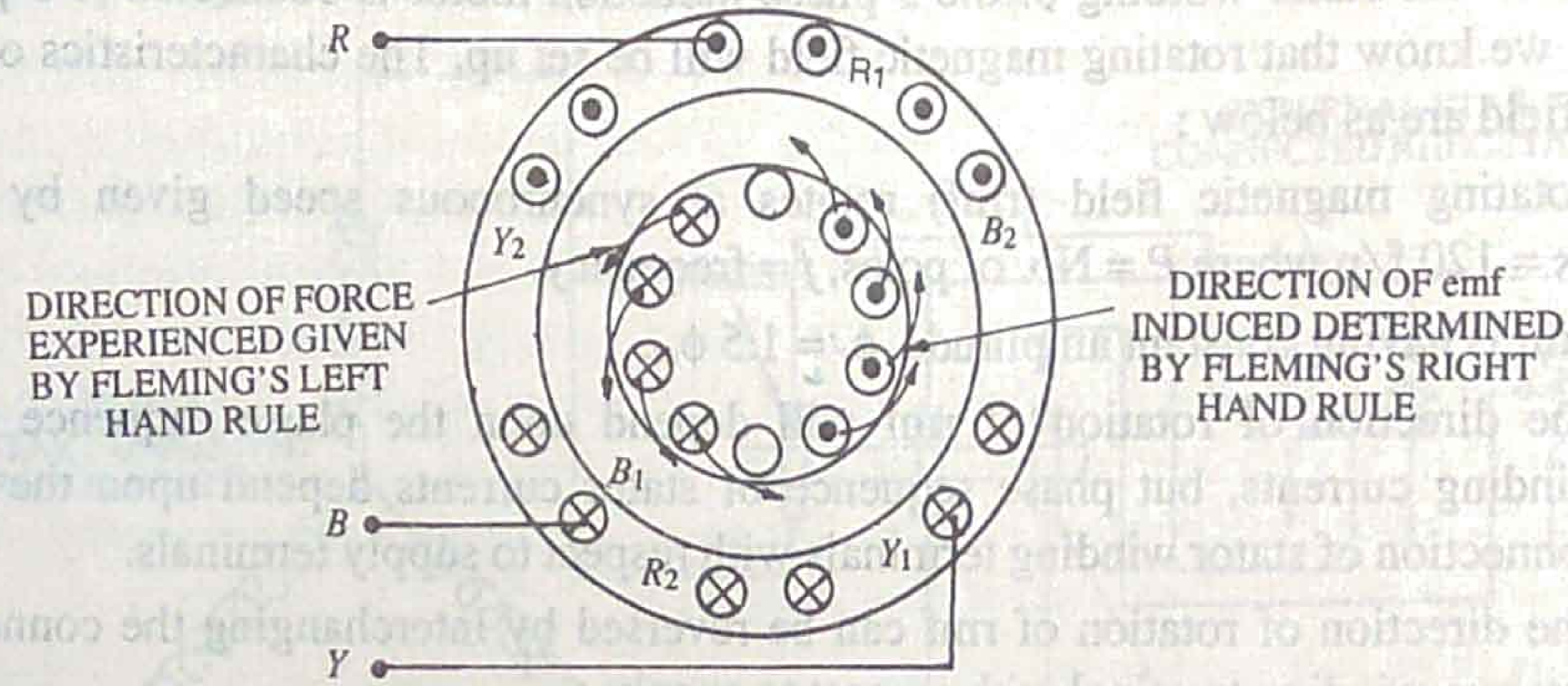


Fig. 12.54 (b) Principle of operation of induction motor.

a particular instant of time the direction of current through stator winding conductors are shown. Let us assume that stator field is rotating in anti-clockwise direction.

1. Due to relative motion, emf will get induced in rotor conductor whose direction is determined by Fleming's right hand rule.
2. When emf induced in rotor conductor circulates current through rotor conductors. Then current carrying conductor experiences force because they are placed in magnetic field. The direction of force is given by Fleming's left hand rule. The force acting on individual rotor current carrying conductors will cause the rotor to rotate the rotor in the counter clockwise direction.

12.21.1. Why Does Induction Motor Never Run at Synchronous Speed. Let us assume that the rotor of induction motor is turning at synchronous speed. Then there will be no relative motion between rotor conductors rotating at synchronous speed and rmf rotating at synchronous speed. Due to zero relative motion between rmf and rotor conductors, the rate of cutting of flux by rotor conductor will be zero. Hence no emf will get induced in rotor conductors, due to which current through rotor conductors will be zero. Hence no torque will be developed on rotor. Therefore, *the rotor of induction motor never runs at synchronous speed, its speed is always less than synchronous.*

An induction motor at no load will run at speed very close to the synchronous speed.

Therefore, due to less relative motion between rotor conductors and rmf, the emf induced in rotor will be less. This small emf circulates small current through rotor winding, producing a torque just sufficient to overcome the losses such as due to friction and maintain the rotor in motion. As the mechanical load is applied on shaft, the rotor of induction motor gets slow down, because the torque developed at no load will not be sufficient to keep the rotor revolving. As the rotor of induction motor gets slow down, the relative motion between rotor conductors and rmf gets increased. This increase in relative motion results in greater rotor current and greater developed torque. Thus as the load is increased the rotor gets slow down until the relative motion between rotor and rmf is just sufficient to result in the development of the torque necessary for that particular load.

12.21.2. Slip. As we know that the voltage induced in the rotor bars which circulates current through rotor bars depends upon relative motion between rotor and rotating magnetic field. At synchronous speed, the relative speed between rotor rotating at synchronous speed w.r.t. rmf, which is also rotating at synchronous speed is zero. Hence due to no relative motion, there will be no rate of cutting of flux and hence no rotor emf and current and no torque developed. Hence in case of induction motor torque is developed when the rotor speed will be less than synchronous speed.

The actual rotor speed is always less than synchronous speed so as to produce current in the rotor bars. Two terms are used to define relative motion between rotor and rmf.

One of them is slip speed. Slip speed is defined as the difference between synchronous speed and rotor speed.

Slip speed $= N_S - N$ where N_S = Synchronous speed in r.p.m.,

N = Actual speed of rotor in r.p.m.

The other term used to describe relative motion is *Slip*. It is defined as *difference between synchronous speed and rotor speed expressed as per unit basis of synchronous speed.*

$$\boxed{\text{Slip} = S = \frac{N_S - N}{N_S}}$$

and % slip, $\%S = \dfrac{(N_S - N)}{N_S} \times 100$ ... (12.32)

From equation 12.32, $N = N_S\,(I - S)$ .... (12.33)

(*i*) When rotor is a standstill, $N = 0$, hence slip $= \dfrac{N_S - 0}{N_S} = 1.$

(*ii*) At no load the difference between $N_S - N$ is less hence slip is very small.

(*iii*) As the load on induction motor increases, the speed N decreases due to which $N_S - N$ increases and slip increases.