CHAPTER 12

FUNDAMENTAL CONCEPTS OF ELECTRICAL MACHINES

Objectives :

This Chapter will help to understand

- *Construction of D.C. Machine*
- *Principle of Operation of Generator and types of Generator*
- *Principle of Operation of Motor Types of Motor*
- *EMF Equation and Characteristics of Motors and Generators*
- *Starters of D.C. Motors*
- *Construction and Principle of Operation of 3 Phase Induction Motors*
- *Types of Induction Motor*
- *Different Types of Single Phase Induction Motor*

12.1. INTRODUCTION

Since we know each rotating electrical machine has a separate entity and based on different principles. These rotating machines are used for generation purpose, control systems or as a mechanical drive.

Generator. It is a machine, which converts mechanical energy into electrical energy. It is driven by mechanical machine, usually called as prime mover such as turbine, diesel engine, motor or hand operated crank.

Motor. It is a machine, which converts electrical energy into mechanical energy in the form of rotation.

The above processes are called as electromechanical energy conversion.

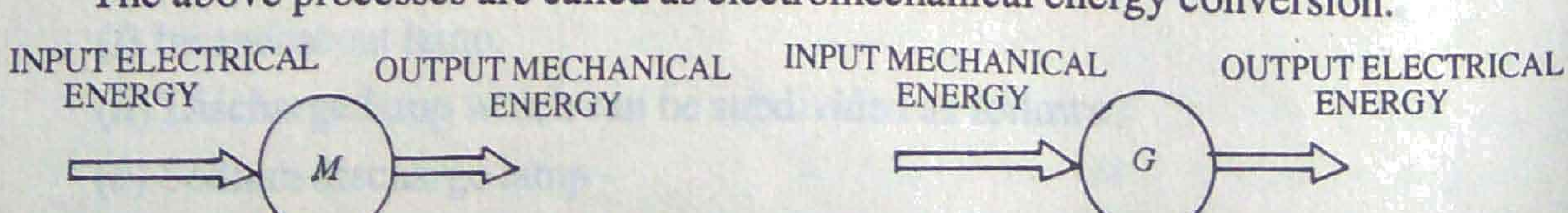


Fig. 12.1. Energy conversion.

The sources of energy available in nature are in different forms *i.e.*, in form of water, coal, Uranium etc. This energy can be converted into electrical energy because this electrical energy can be reconverted into useful forms such as sound, light, heat or mechanical energy.

Potential energy of water available can be converted into electrical energy in a hydroelectrical power station. The potential energy of water rotate the turbine which drives the generator, thus electricity will be produced. If we give electrical energy to heater, it will be converted into heat energy, if we give electrical energy to motor, the motor will start rotating and will give mechanical energy to drive different types of loads such as Lathe, Crane etc.

Before studying any electrical machine, it is necessary to study some fundamental principles and rules on which the operation of these machines will depend.

12.1.1. Cross–And Dot Convention of Current. Fig. 12.2 (*a*) and (*b*), illustrates the conventional representation of current carrying conductor alongwith the direction of current flowing through it.

The *cross* represents the current flowing into the plane of the paper (away from observer). The *Dot* represents a current flowing out of the plane of the paper (*i.e.* towards the observer).

(a) Cross convention (b) Dot convention

Fig. 12.2.

The direction of the field may be quickly determined by the use of following rules :

12.1.2. Right Hand Thumb Rule. Grip the current carrying conductor in the right hand as shown in Fig. 12.3 (*a*). The thumb indicates the direction of current, and then the curled fingers indicate the direction of flux produced around the conductor.

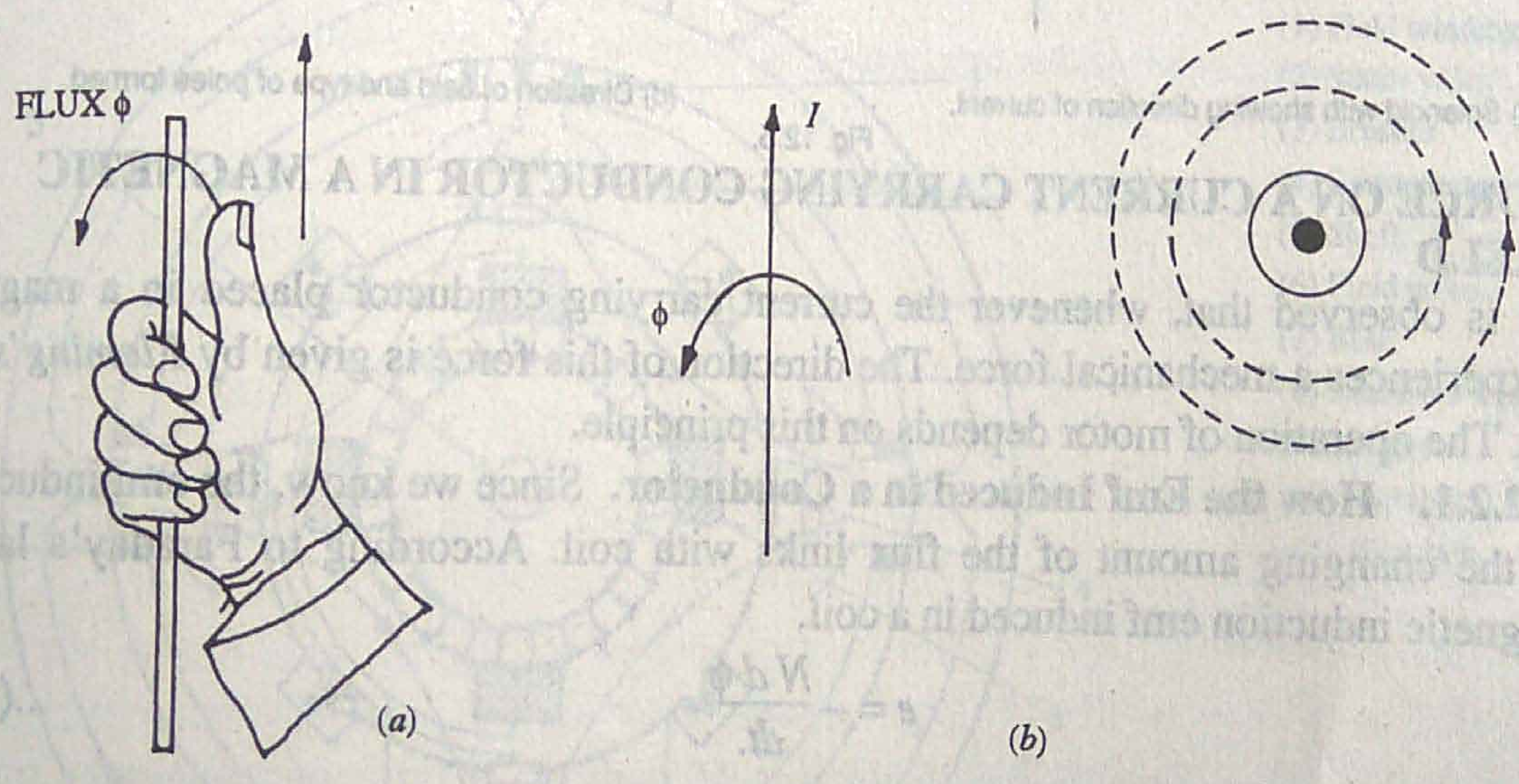


Fig. 12.3. (a) Right hand thumb's rule showing magnetic field. (b) Dot convention and according to thumb's rule, the direction of the magnetic field.

12.1.3. Cork Screw Rule. Place a screw along the side of the current carrying conductor. Advance the screw in the direction of current, so it has to be turned clockwise as shown in Fig. 12.4.

The direction of the magnetic field is given by the direction of turning of screw, which is clockwise as shown in Fig. 12.4.

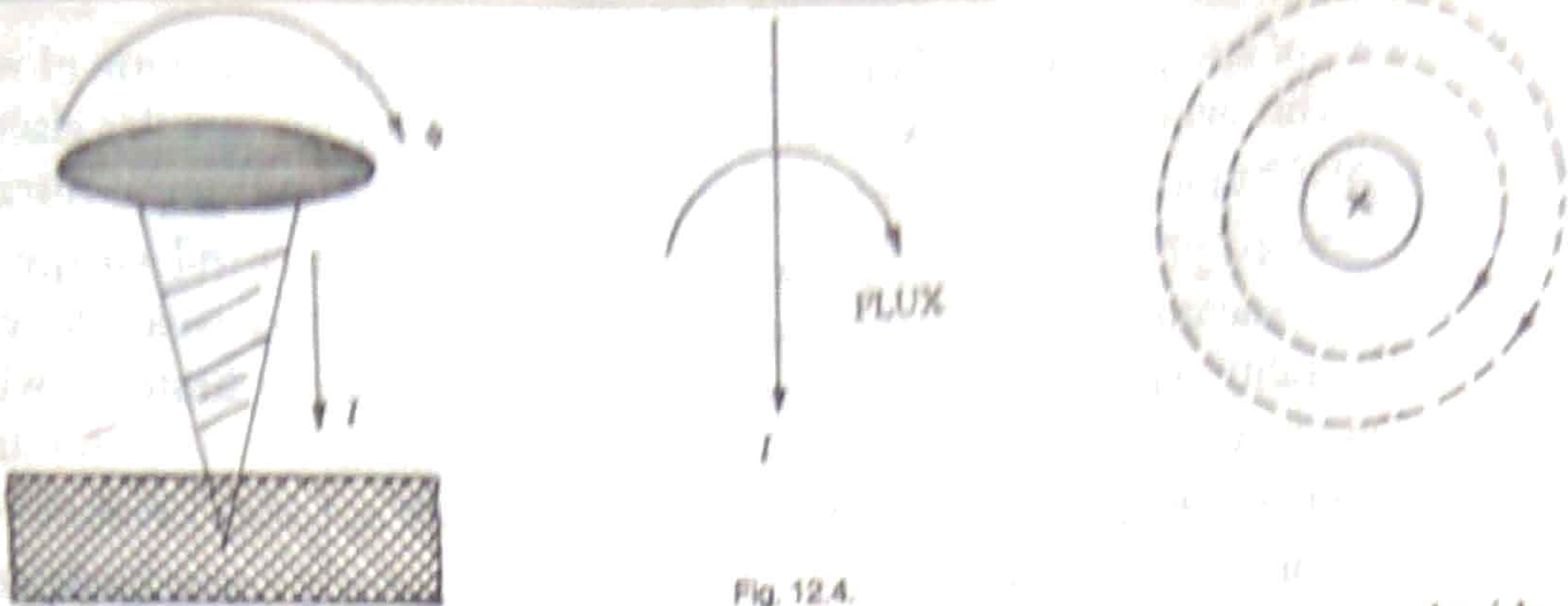


Fig. 12.4.

12.1.4. How the Poles Formed. Fig 12.5. (*a*), (*b*), (*c*) and (*d*) shows the idea about, how the poles are formed on iron core. Fig. 12.5 (*c*) shows the direction of current. Once the direction of current is known so according to Right hand thumb's rule, direction of flux produced, can be obtained which is shown in Fig. 12.5 (*d*). The end at which, the flux leaves is known as *North pole* and the end at which flux enters the core is called as *South pole.*

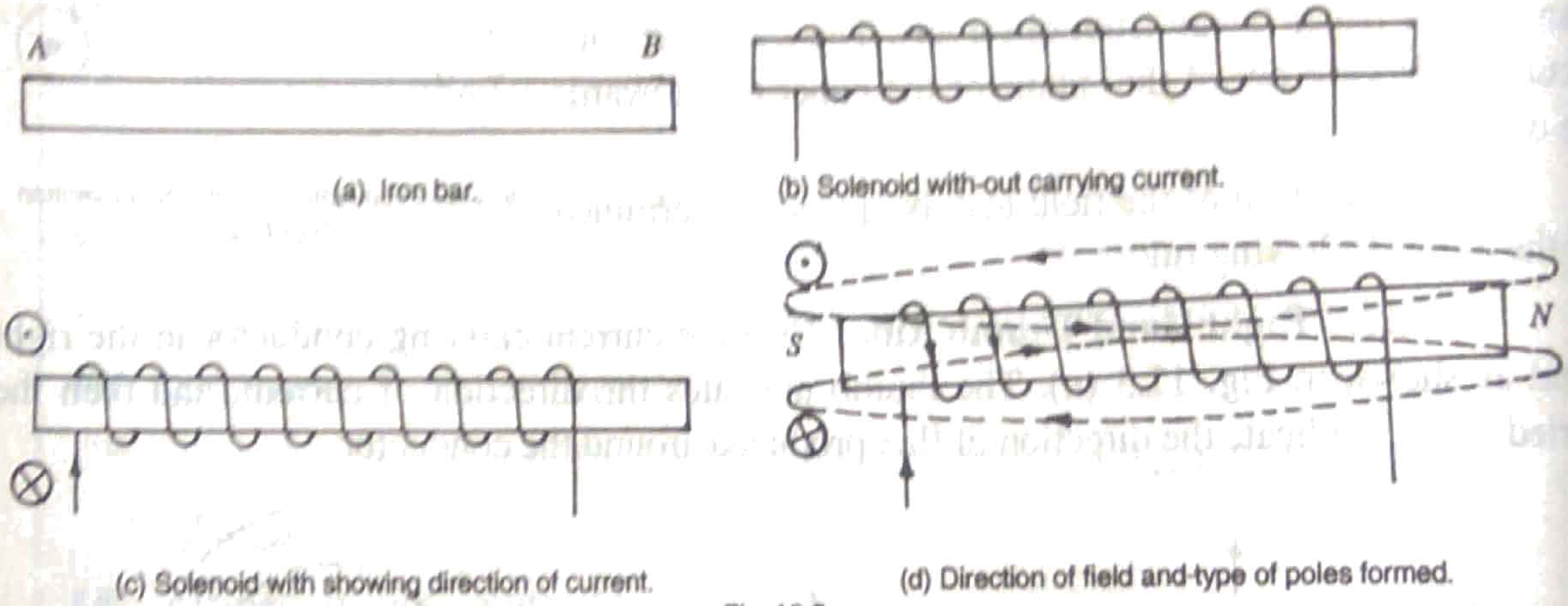


Fig. 12.5.

12.2. FORCE ON A CURRENT CARRYING CONDUCTOR IN A MAGNETIC FIELD

It is observed that, whenever the current carrying conductor placed in a magnetic field, it experiences a mechanical force. The direction of this force is given by *Fleming's Left hand rule.* The operation of motor depends on this principle.

12.2.1. How the Emf Induced in a Conductor. Since we know, the emf induced in a coil, if the changing amount of the flux links with coil. According to Faraday's law of electromagnetic induction emf induced in a coil.

$$e = -\frac{N\,d\phi}{dt.} \qquad ...(12.1)$$

When the coil rotates in a magnetic field, this coil cuts the flux so changing amount of flux links with coil and according to Faraday's law of electromagnetic induction emf induced in a coil whose direction will be given by *Fleming's right hand rule.*

12.2.2. Fleming's Left Hand Rule. Keep the first finger, second finger and thumb of the left hand mutually perpendicular to each other as shown in Fig. 12.6 If the first finger indicates the direction of magnetic field, second finger indicates the direction of current then thumb will indicate the direction of force.

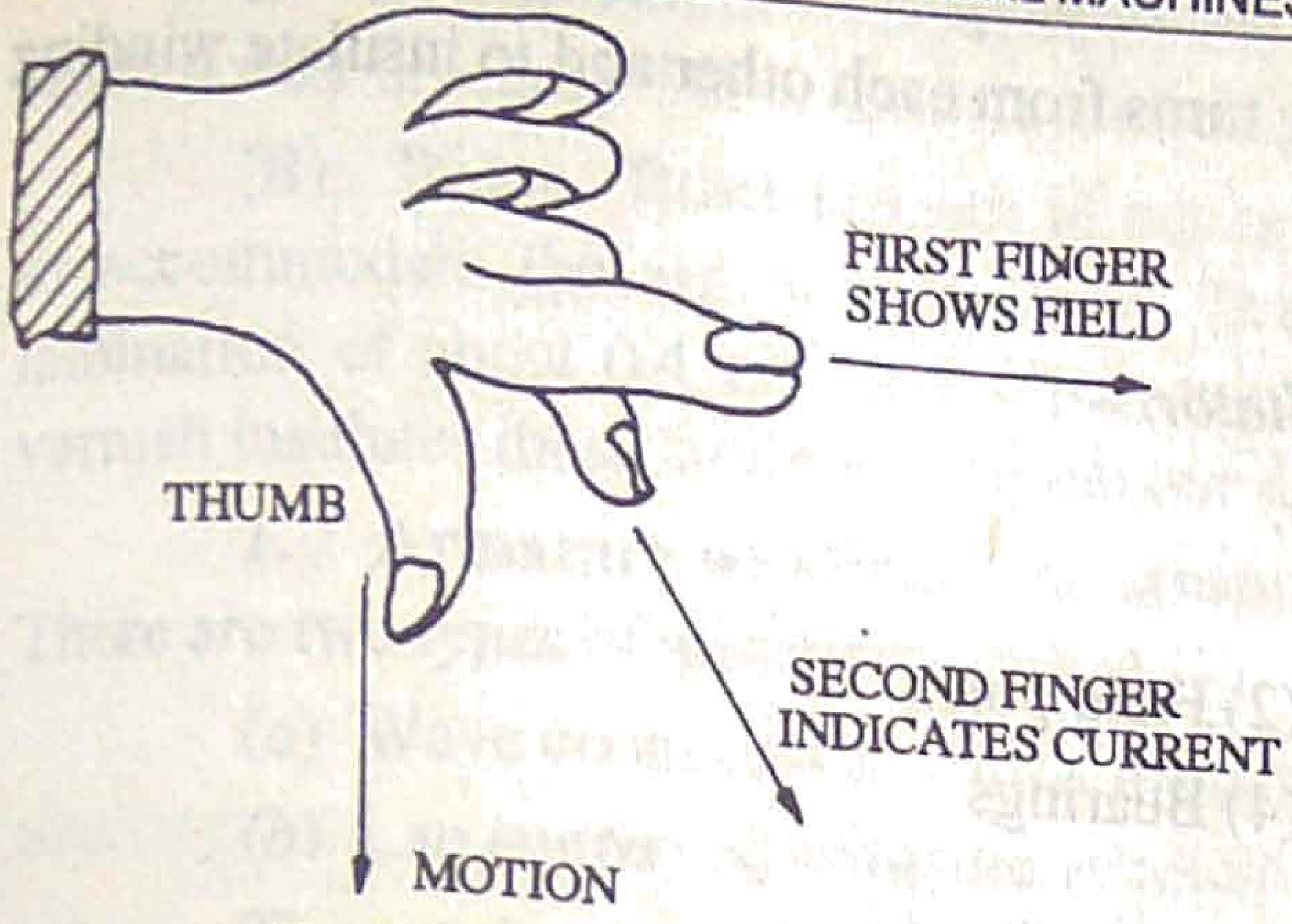


Fig. 12.6. Fleming's left hand rule.

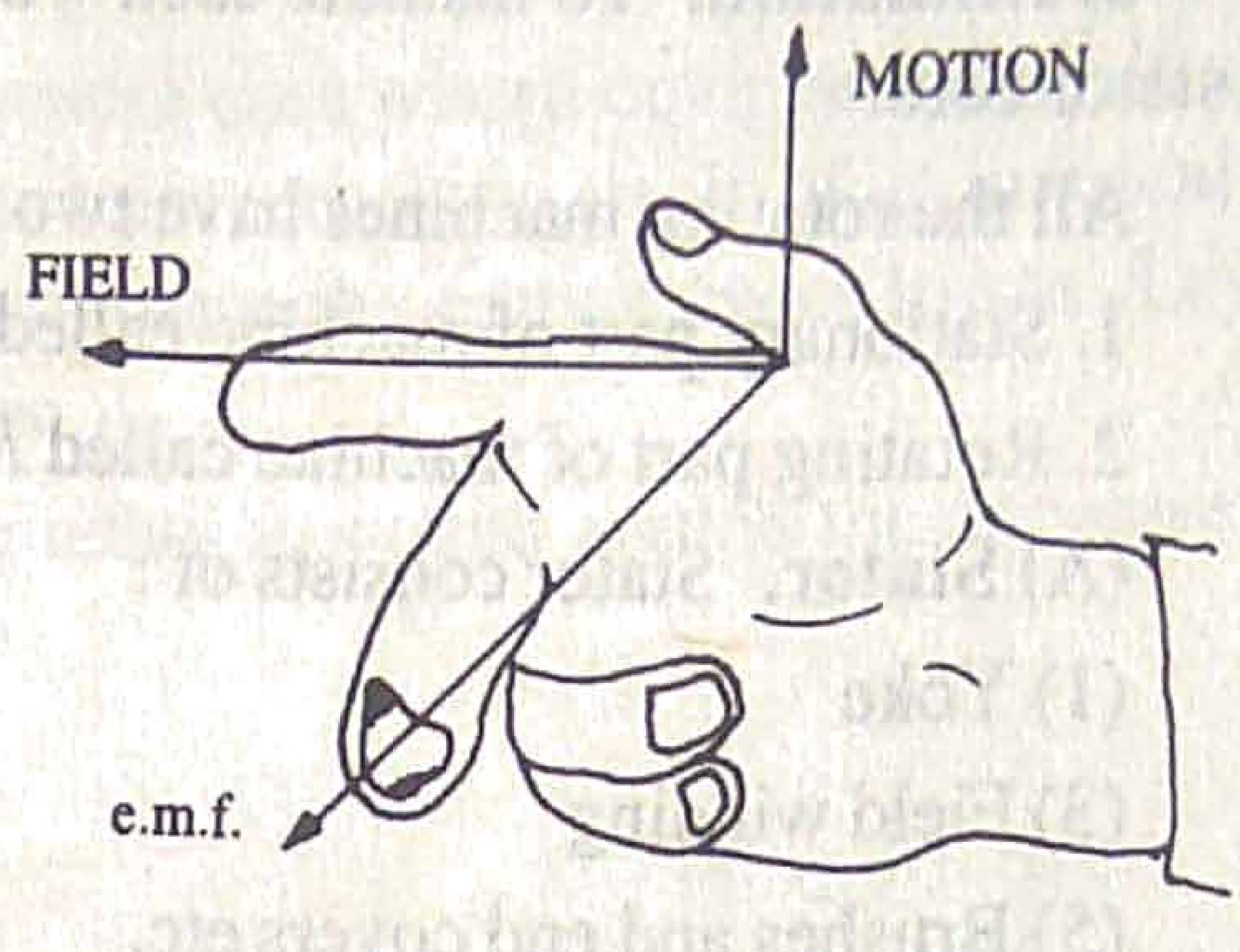


Fig. 12.7. Fleming's right hand rule.

On applying the above rule, to the current carrying conductor placed in a magnetic field. So the direction of force can be obtained.

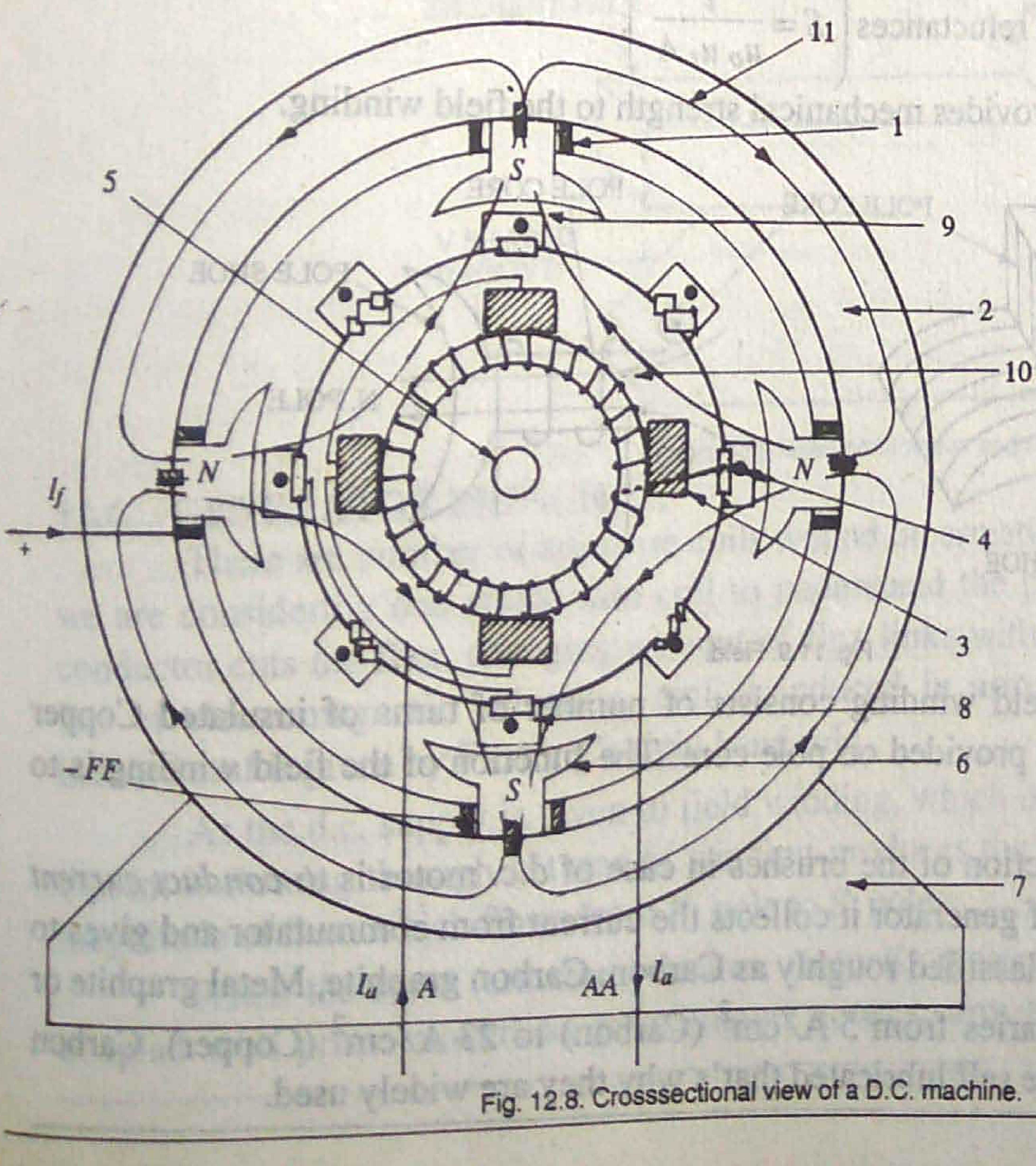
12.2.3. Fleming's Right Hand Rule. Arrange the thumb, first and second fingers of our right hand mutually perpendicular to each other. So first finger indicates the direction of field, thumb indicates the direction of motion of conductor. Then the second finger will point in the direction of the induced emf (or current).

12.3. CONSTRUCTION OF D.C. MACHINE

Three materials are used to manufacture a machine :

1. Steel. To carry magnetic flux.

2. Copper or aluminium. To carry electric current.



Notation :
(1) Field winding.
(2) Stator yoke.
(3) Brushes.
(4) Commutator.
(5) Shaft.
(6) Field poles.
(7) Base.
(8) Armature winding.
(9) Air gap.
(10) Laminated armature core.
(11) Flux path.

Fig. 12.8. Crosssectional view of a D.C. machine.

3. Insulation. To insulate each winding turns from each other and to insulate winding from stator core.

All the rotating machines have two parts :

1. Stationary part of machine called as *Stator.*
2. Rotating part of machine called *Rotor.*

(A) Stator. Stator consists of :

(1) Yoke (2) Field poles
(3) Field winding (4) Bearings
(5) Brushes and end covers etc.

1. Yoke. The cylindrical yoke is made up of unlaminated ferromagnetic material serves the following purpose :

(*a*) It provides mechanical support for field poles.
(*b*) It serves as a protecting cover for whole machine.
(*c*) It carries magnetic flux, produced by the magnetic poles.

2. Field poles. Field poles are made of stack of steel laminations. (1 to 1.5 mm thick) riveted together. The cross-sectional area of pole core where the field winding is wound is less than the area of pole shoe due to the following reasons :

(*a*) The reduced cross section of the pole core requires less copper for the field windings.
(*b*) The large pole shoe area increases the flux per pole entering the armature due to reduction in the air gap reluctances $\left(S = \frac{l}{u_o \, u_r \, A}\right)$.
(*c*) Large pole shoe area provides mechanical strength to the field winding.

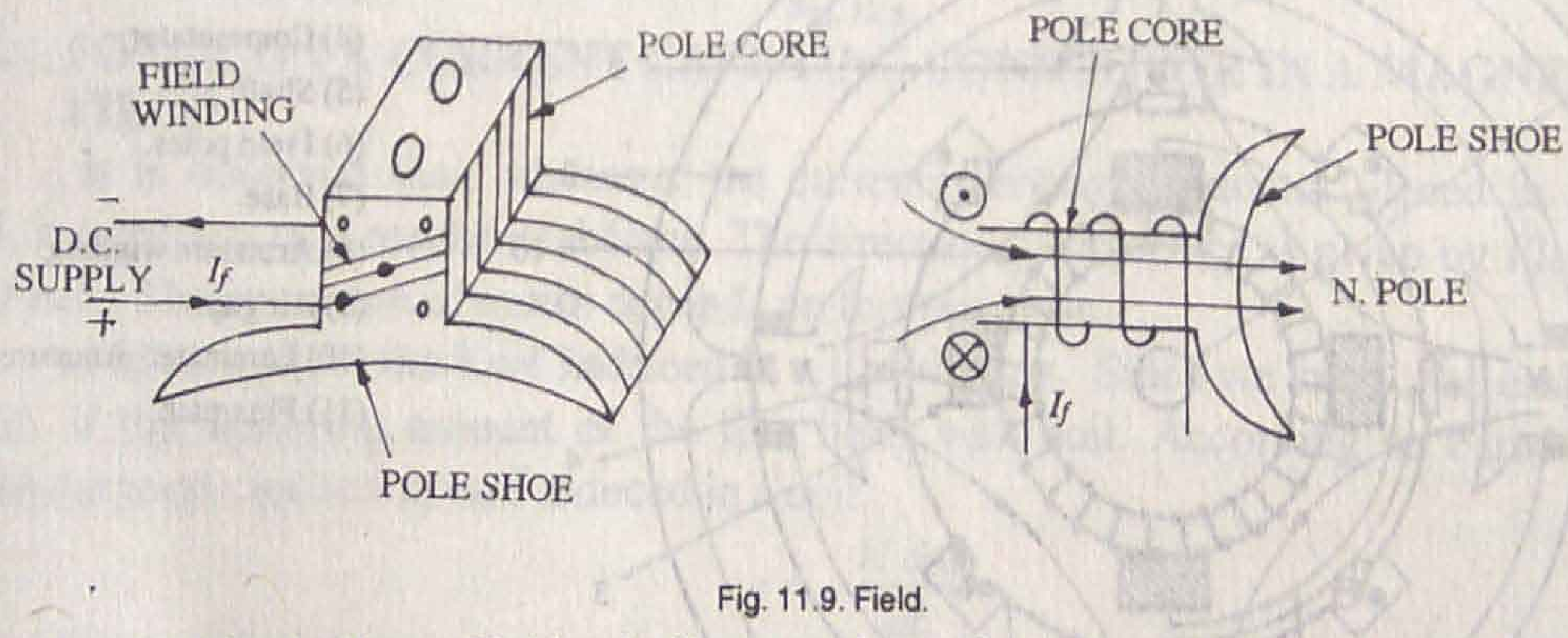


Fig. 11.9. Field.

3. Field winding. Field winding consists of number of turns of insulated Copper conductor. These windings are provided on pole core. The function of the field winding is to produce the flux.

4. Brushes. The function of the brushes in case of d.c. motor is to *conduct current to the armature coils.* In case of generator it collects the current from commutator and gives to the external circuit. These are classified roughly as Carbon, Carbon graphite, Metal graphite or Copper. The current density varies from 5 A/cm^2 (Carbon) to 23 A/cm^2 (Copper). Carbon and Carbon graphite brushes are self lubricated that's why they are widely used.

5. Brush Holder. The brushes are housed in a brush holder, which are mounted on brush holder brackets. These brushes are held under pressure over commutator by spring.

(B) Rotor. Rotor consists of mainly armature core whose outer periphery is slotted to accommodate the armature winding. The armature core is a stack of cylindrical steel lamination of about 0.4 mm to 0.6 mm thick to decrease the eddy current losses. Layer of varnish insulates these laminations from one another.

1. Armature winding. The armature winding is wound around the armature core. There are two types of armature winding :

(*a*) Wave connected armature winding.

(*b*) Lap connected armature winding.

These two types of connections are different in the manner in which ends of armature winding connected to commutator. The function of armature winding is to induce an emf due to cutting of flux.

Commutator. Commutator is a group of wedge shaped Copper segment of 0.5 mm to 1.00 mm thick, these segments are insulted from each other by Mica sheet. Current is conducted to the armature coils by Carbon brushes that are held against the cylindrical surface of the Commutator by the force of spring. *For a d.c. motor Commutator acts like a mechanical inverter to invert direct applied voltage to the alternating voltage in the armature winding. It acts like converter to convert a.c. generated emf in armature winding to d.c. in case of d.c. generator.*

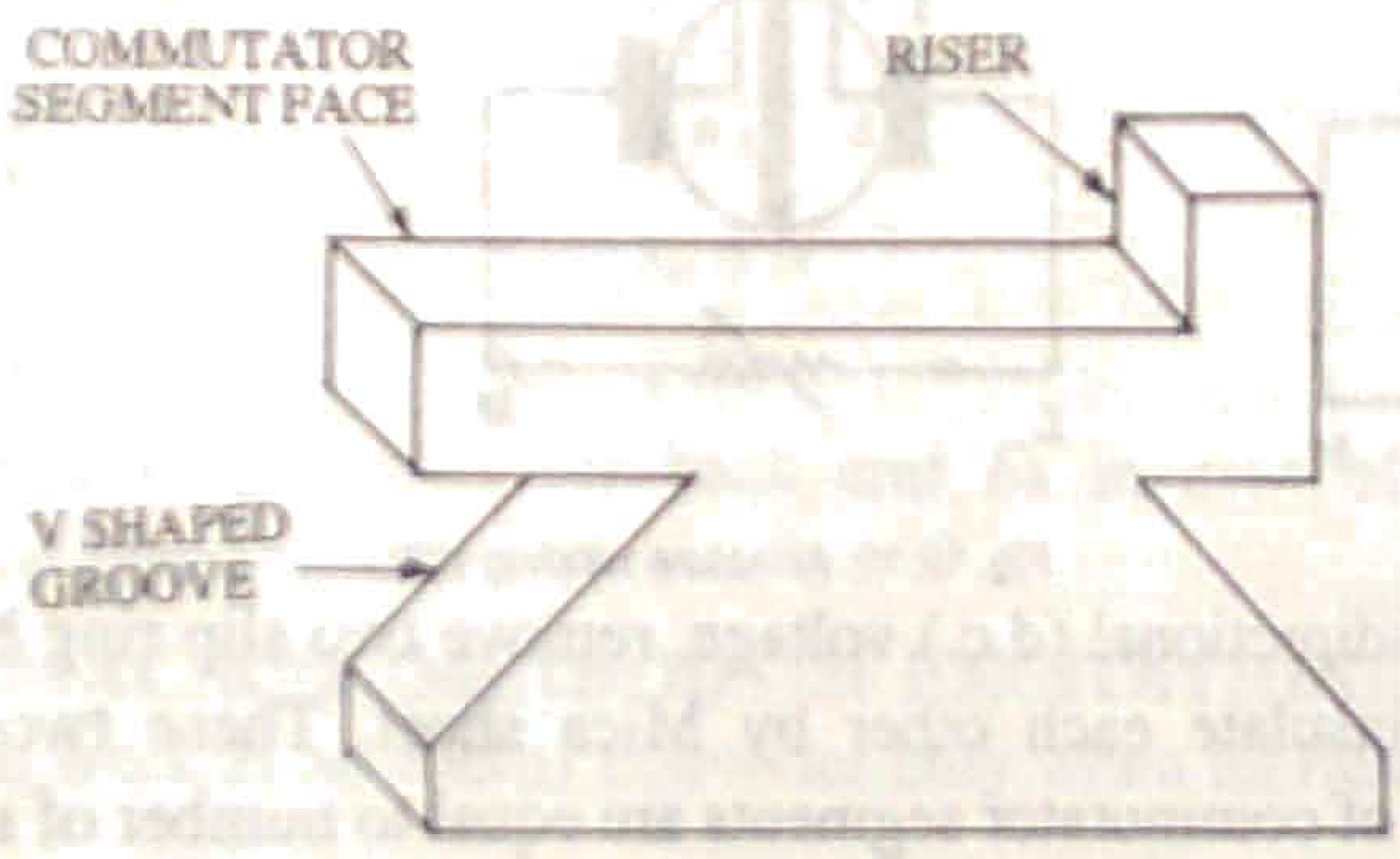


Fig. 12.10. Wedge shaped commutator segment.

12.4. GENERATOR PRINCIPLE

There are number of armature coils wound on armature core but for convenience here we are considering one single turn coil to understand the principle of generator. Whenever conductor cuts the flux, changing amount of flux links with coil and according to Faraday's law of electromagnetic induction, emf is induced in armature winding. The direction of induced emf is given by Fleming's right hand rule.

As the d.c. supply is given to field winding, which is wound on field poles. This field current is flowing through N turns of winding produces the mmf, which sets up the constant magnitude of flux, which flows from N pole to S pole.

When the rotor (armature) rotates, (actually generator is not self rotating, but it is coupled with prime-mover) as prime-mover rotates, armature of generator will rotate, the

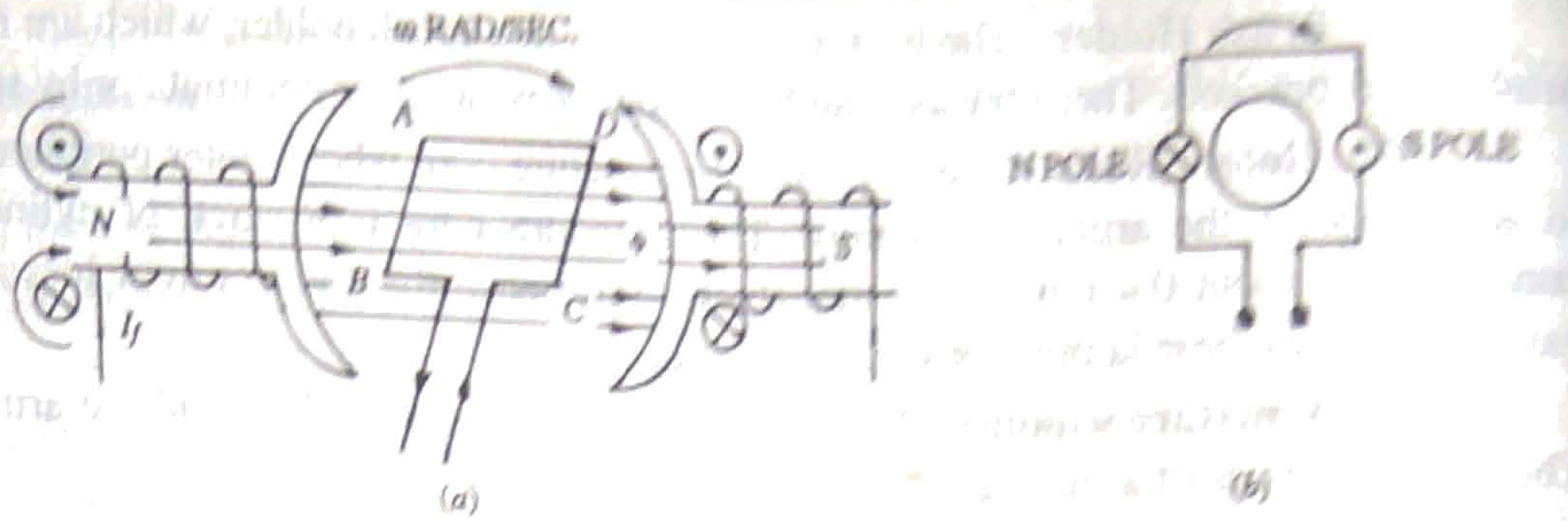


Fig. 12.11. I.D.C. generator principle.

armature winding will cut the flux and according to Faraday's law of electromagnetic induction, dynamically induced emf will induce in armature winding.

In Fig. 12.11, coil *ABCD* has *N* turns rotating in clockwise direction with ω rad/sec. The ends of coil joined to two slip ring *a* and *b* through brushes 1 and 2 as shown in Fig 12.12. The voltages available at load will be alternating in nature because after every 180°, coil changes their positions so the direction of current will also be changed.

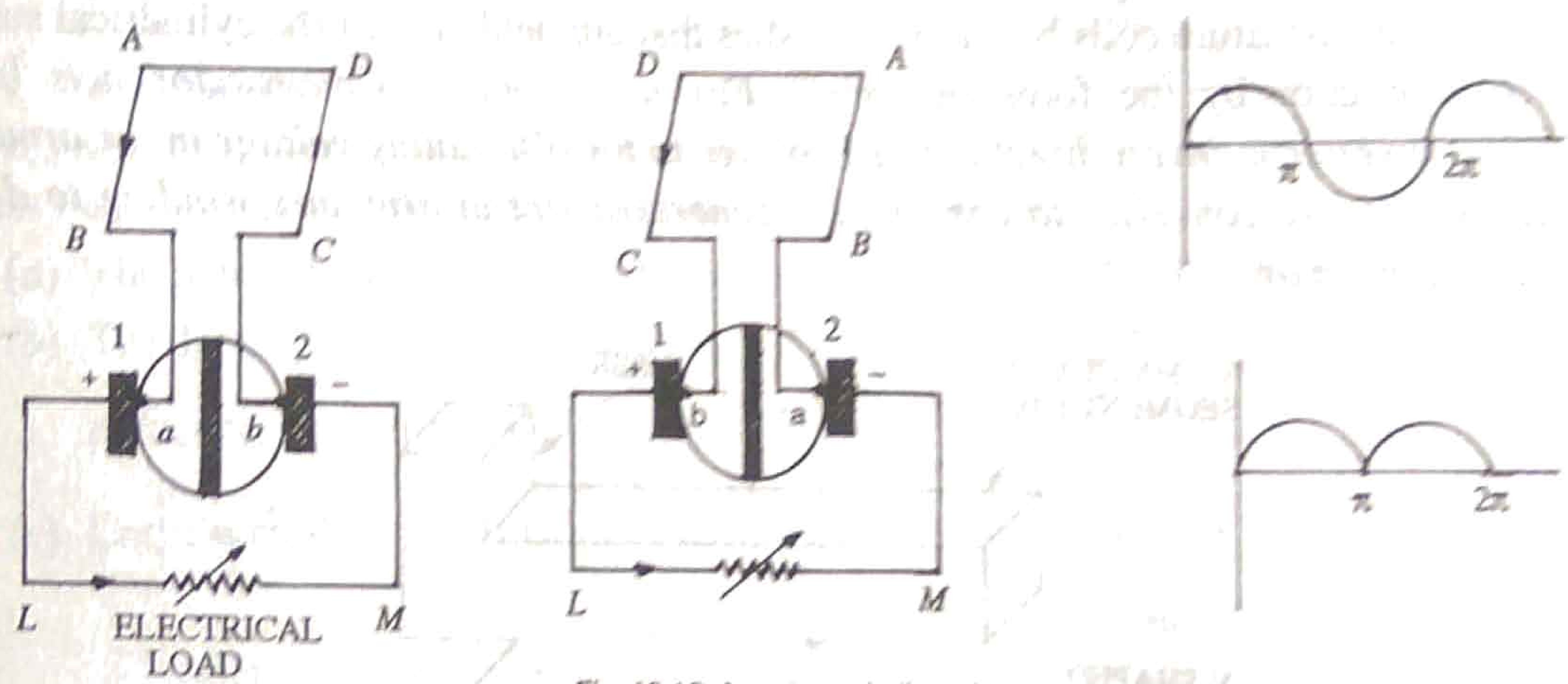


Fig. 12.12. Armature winding with.

For getting unidirectional (d.c.) voltage, remove two slip ring by one split ring, cut it into two halves and insulate each other by Mica sheet. These two halves are called as commutator. Numbers of commutator segments are equal to number of armature coils.

In first half (0 – 180°) current flows along *ABLMCD* *i.e.* brush No. 1 is connected to + ve supply. From (180° – 360°), direction of current is reversed but at the same instant of time, position of segments *a* and *b* have also reversed so again brush No. 1 comes into touch with + ve supply and the direction of current through load will be same *i.e.*, *L* to *M*.

Hence in this way we can get unidirectional current.

12.5. EMF EQUATION OF D.C. M/C

Let ϕ = flux/pole in Weber

Z = Total no. of armature conductor = No. of slots × No. of conductor/Slot

P = No. of poles

A = No. of parallel path in armature

N = Armature rotation in r.p.m.

E_a = Emf induced in any parallel path in armature.

From Faraday's law of electromagnetic induction,

Average emf generated/conductor $= \frac{d\phi}{dt}$ volts

Let the flux cut/conductor in one revolution $= d\phi = P.\phi$

And number of revolution/second $= \frac{N}{60}$

Hence time required to complete one revolution,

$dt = \frac{60}{N}$ (Since N is the speed in rpm)

Hence average emf induced/conductor $= \frac{d\phi}{dt} = \frac{P\phi}{60/N} = \frac{P\phi N}{60}$ volts

If A are the number of parallel path and Z are the total no. of conductor.

$\therefore$ No. of conductor/path $= \frac{Z}{A}$

$\therefore$ Total emf induced/parallel path $= \frac{P\phi N}{60}\left(\frac{Z}{A}\right)$

$$\text{Emf generated/path } E_a = \frac{P\phi Z N}{60 \times A} \qquad ...(12.1)$$

where $A = 2$ for wave wound armature and $A = P$ for Lap wound armature.

In equation 12.1, the terms P, Z and A are constant.

Hence $K_a = \frac{PZ}{60\text{ A}}$

$\therefore$ $E_a = K_a \phi N$

or $E_a \propto \phi N$

The generated emf in generator (or back emf E_b in case of motor) is directly proportional to the flux and speed of rotor.

12.6. TYPES OF D.C. MACHINE (METHODS OF EXCITATION)

D.C. machine can work as an energy converter only when its field winding is excited with direct current.

There are in general two ways of exciting the field :

1. **Separately excitation.** The d.c. machine is called as separately excited machine.
2. **Self excitation.** The machine is called as self-excited machine.

1. **Separately Excitation.** In this case field winding is connected to an external d.c.

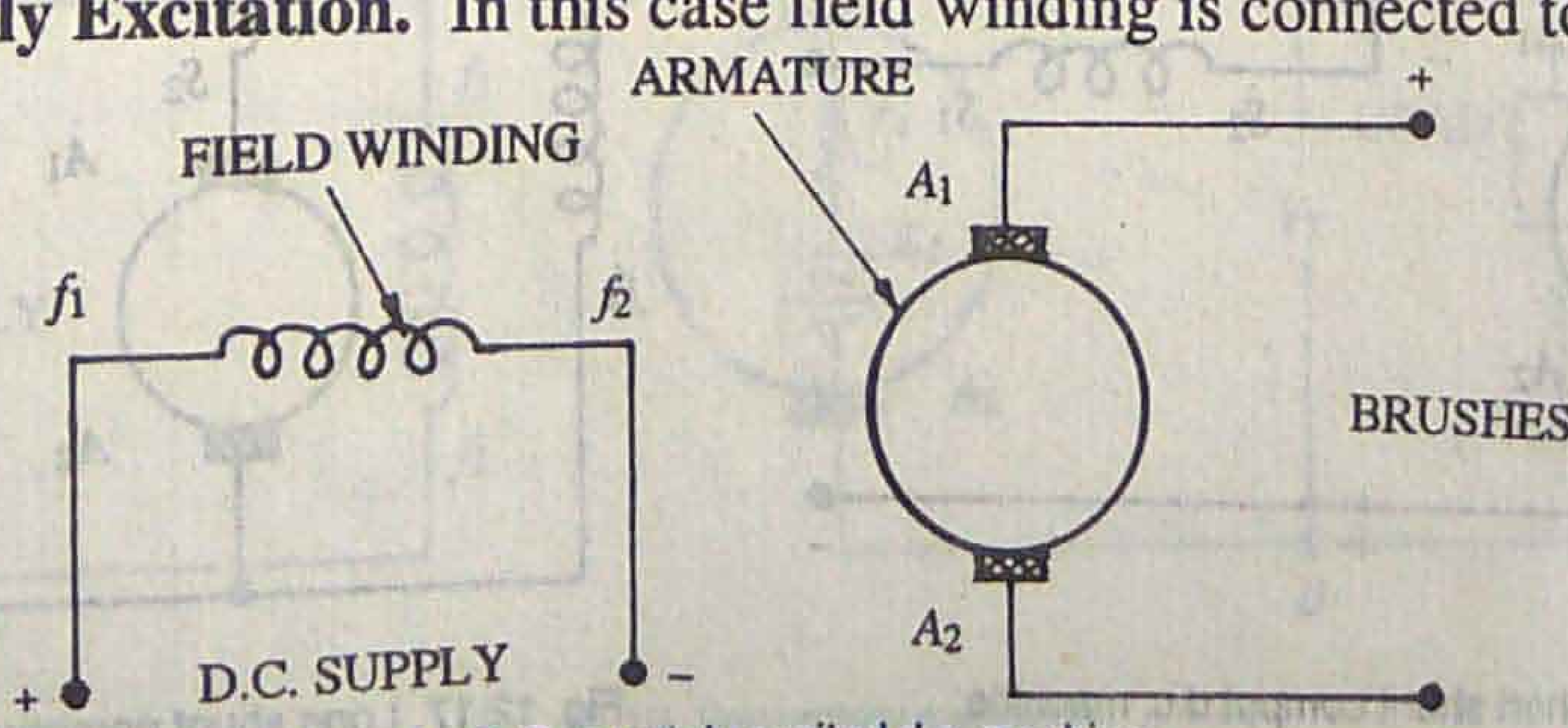


Fig. 12.13. Separately excited d.c. machine.

source, and voltage of external d.c. source has no relation with the armature voltage. The field winding can be designed for any convenient voltage.

2. Self excitation. When the field winding is energized from its own armature, the machine is called as self excited machine. In this type of machine, field poles must have some residual magnetism. When the armature rotates, it cuts the residual flux, small voltage (called residual voltage) appears across the brushes. This voltage establishes a current in field winding.

Self excited d.c. machine can be sub-divided as follows :

(*a*) Series excited d.c. machine. (*b*) Shunt excited d.c. machine.

(*c*) Compound excited d.c. machine.

1. Series excited machine. In series machine the field winding will be connected in series with armature winding. However field winding consists of few turns of thick conductor. In this type of machine field currents and armature current will be same. Since cross-sectional area is more and number of turns are less so length of conductor will be less. Hence resistance of series field winding will be less.

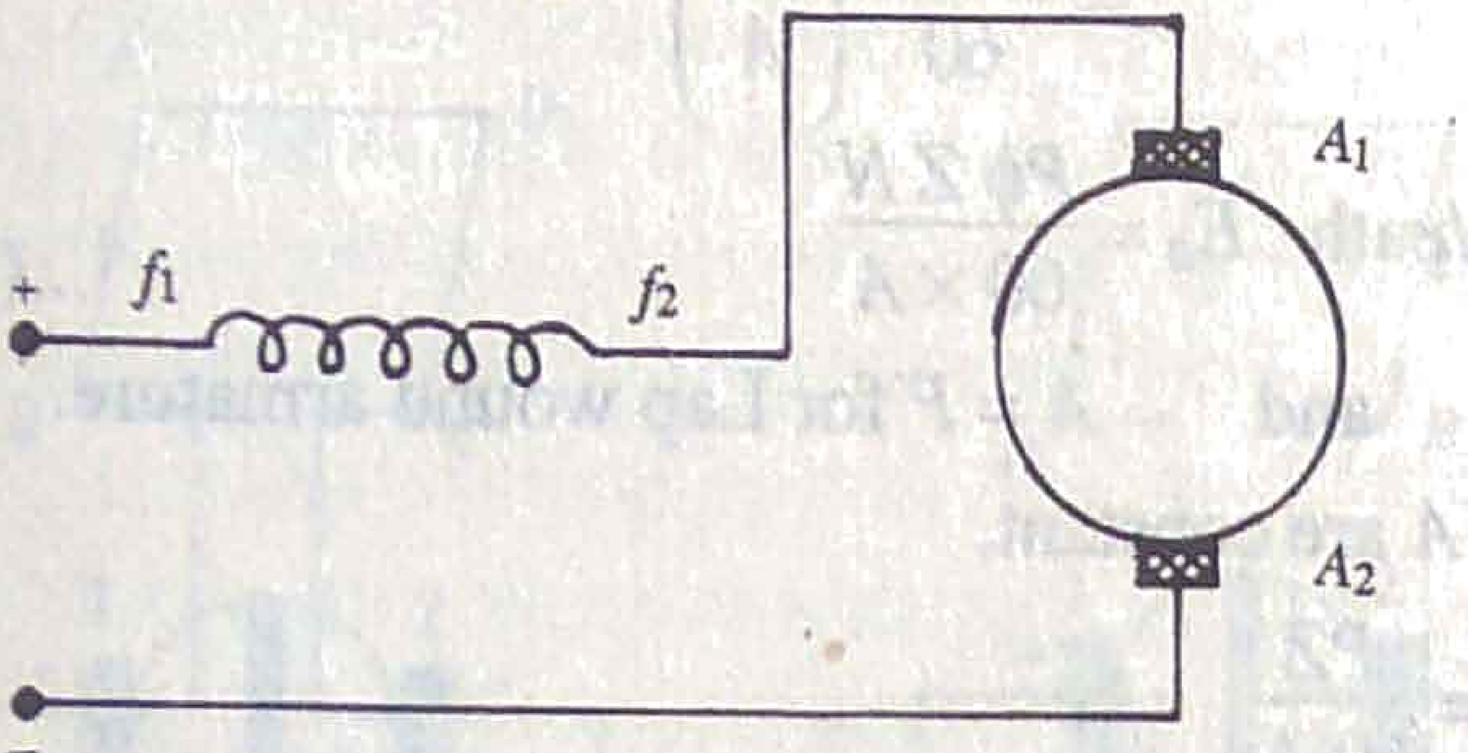


Fig. 12.14. Series excited D.C. machine.

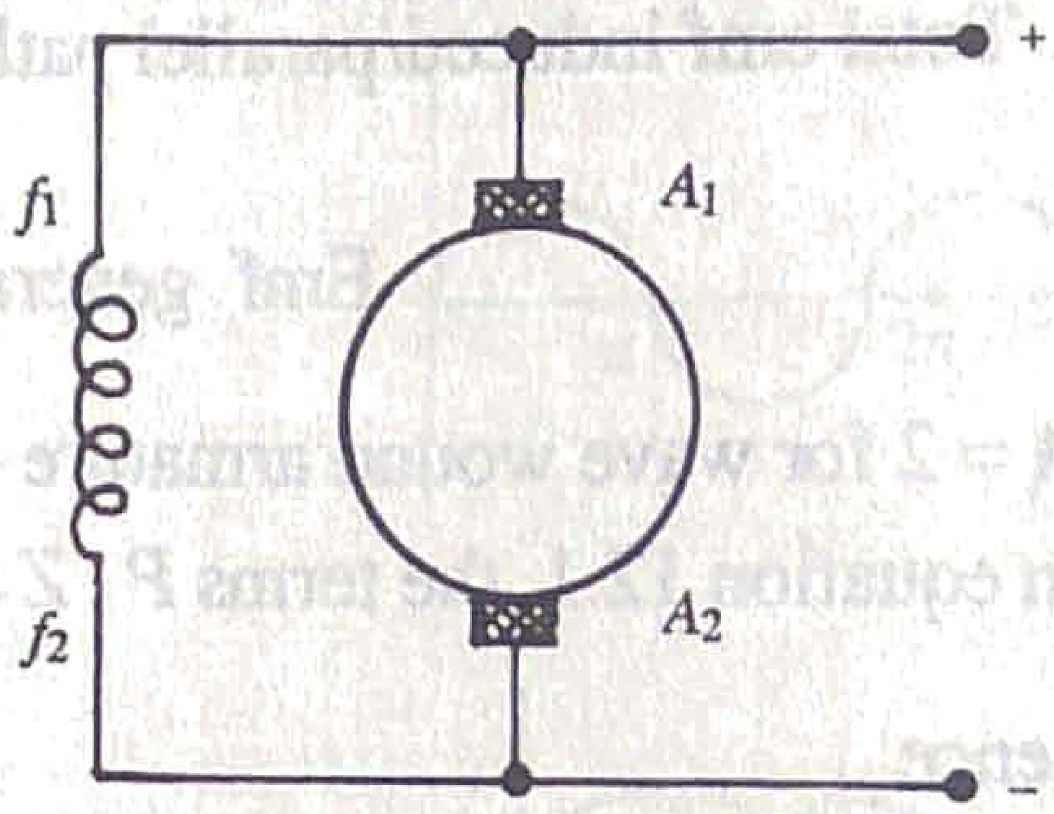


Fig. 12.15. Shunt excited D.C. machine.

2. Shunt excited D.C. machine. In shunt excited d.c. machine, the field winding consists of large number of turns of fine wire and is connected in parallel with armature. Since cross sectional area of conductor is less and no. of turns are more hence resistance ($R = \rho l/A$) of shunt field winding is more.

3. Compund excited D.C. machine. In this type of d.c. machine, it consists both shunt and series connected field winding. There are two types d.c. machine

1. Short shunt compound d.c. machine.

2. Long shunt compound d.c. machine.

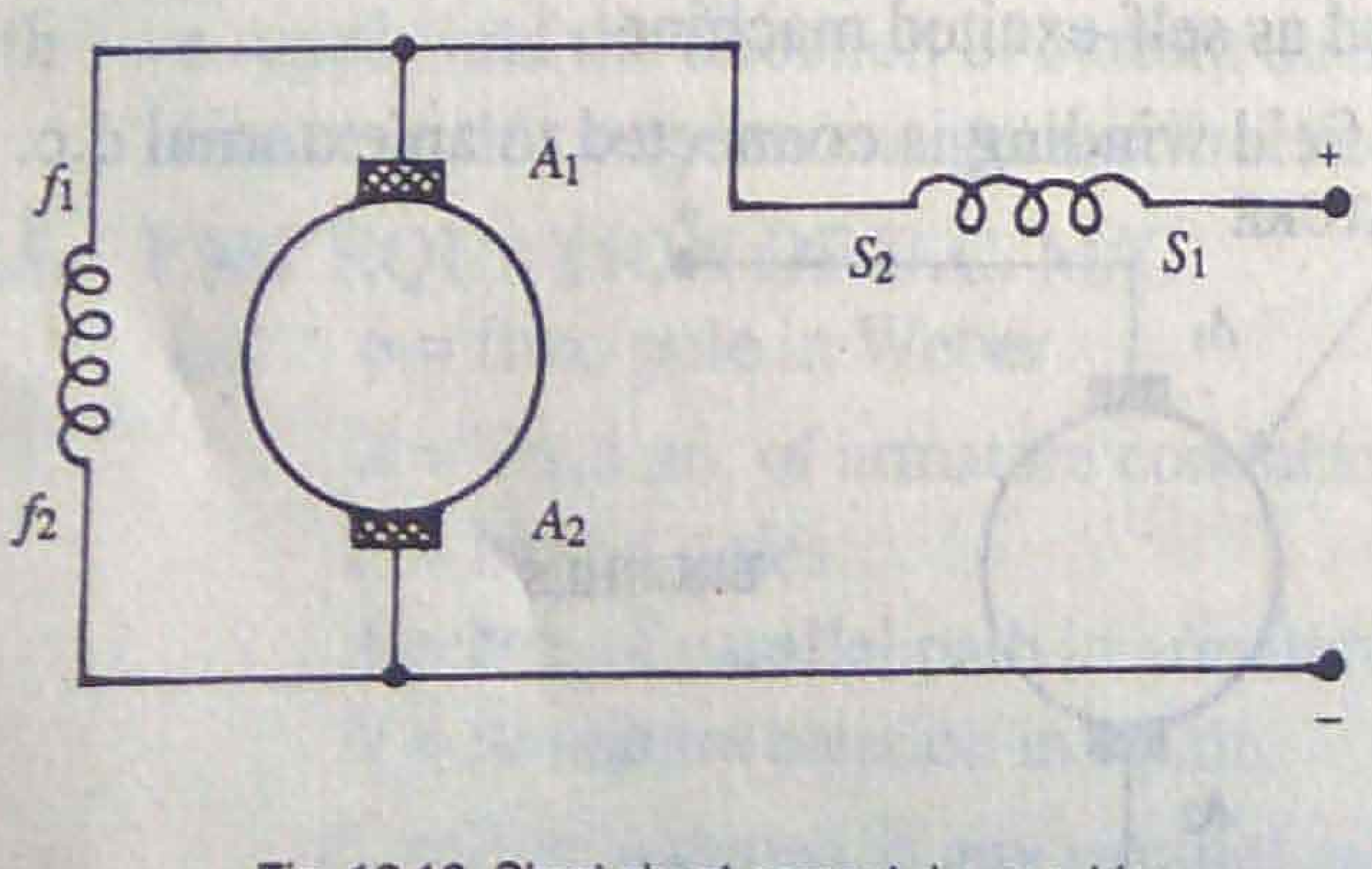


Fig. 12.16. Short shunt comput d.c. machine.

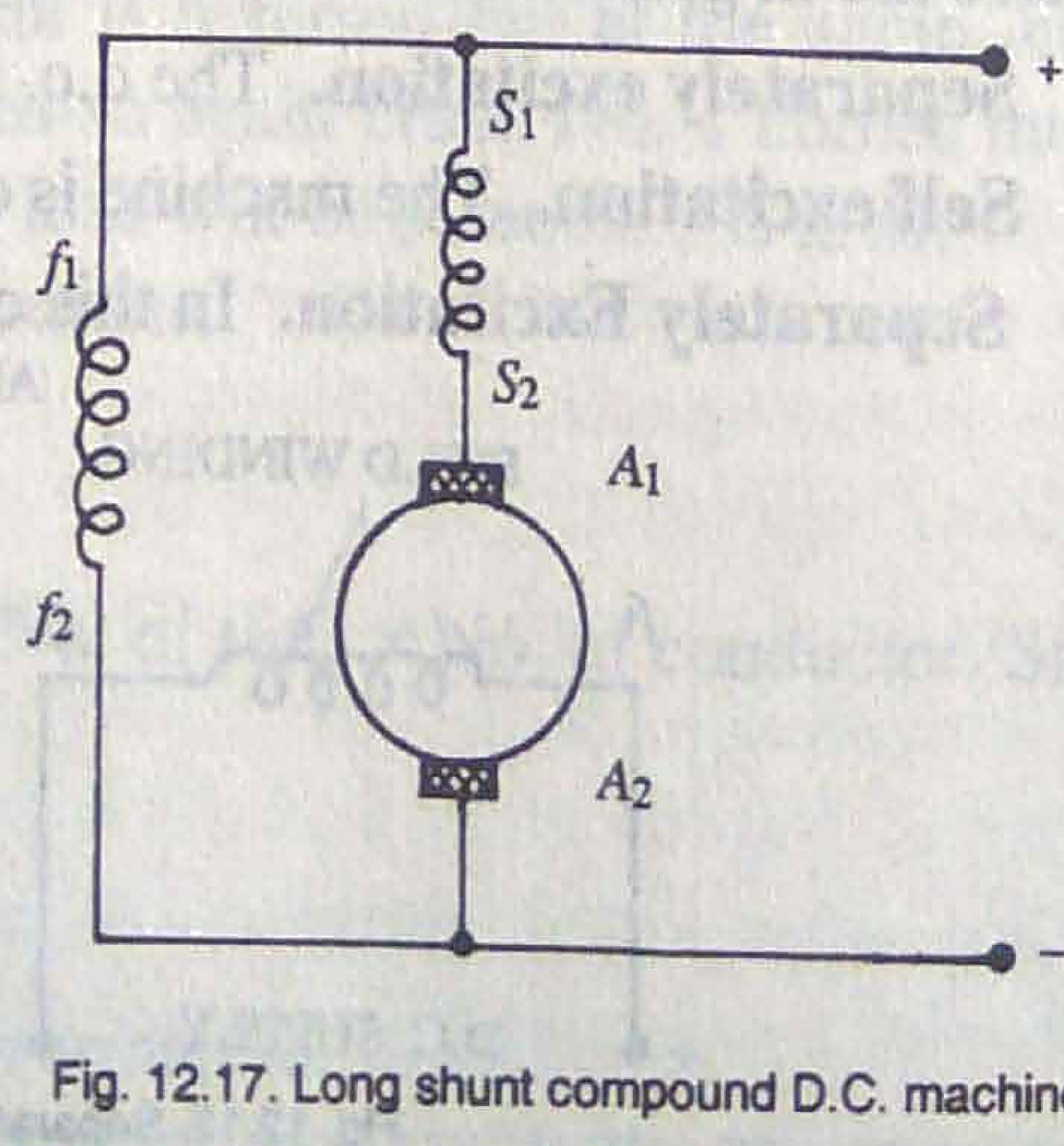


Fig. 12.17. Long shunt compound D.C. machine.