Module 4

D. C. GENERATORS AND D. C. MOTORS

4.1. Construction of D.C. Generator

Fig. 4.1 shows the cross-sectional view of a practical d.c. generator. It consists of the following parts:

1. Field System:

The object of the field system is to *create a uniform magnetic field, within which the armature rotates*. Electromagnets are generally preferred in comparison with permanent magnets because they are cheap, small in size, produce greater magnetic effect and the field strength can be easily varied by changing the magnetising current.

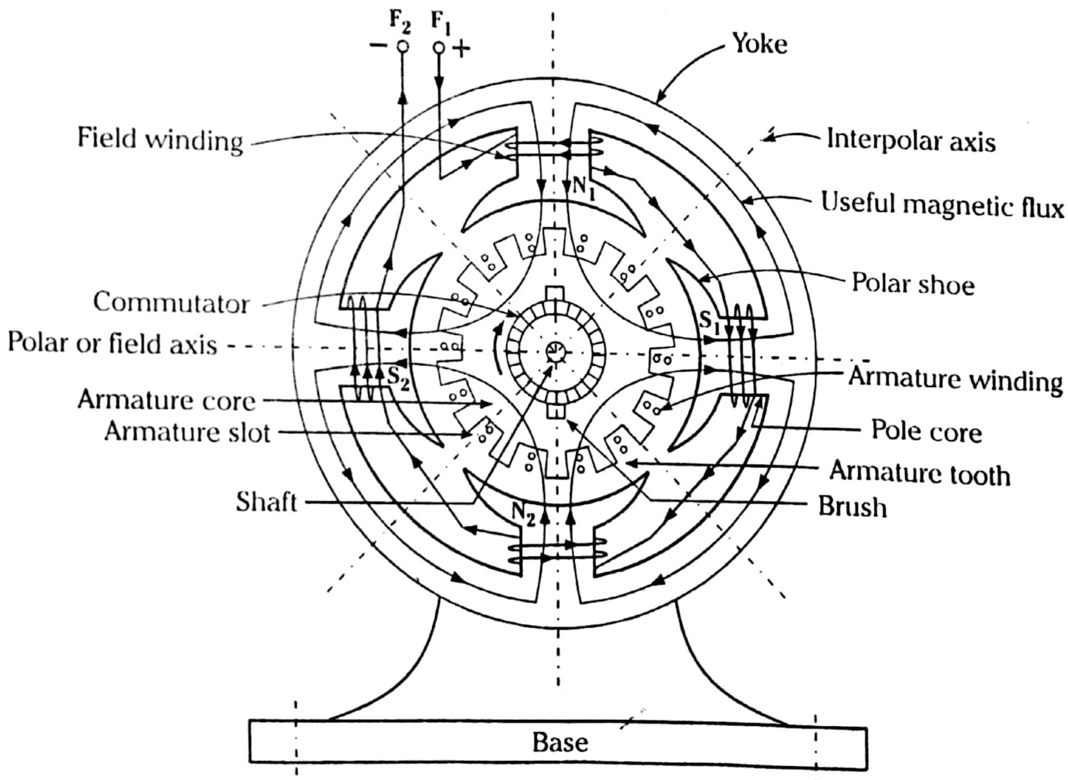

Fig. 4.1: Cross-section of a practical d.c. generator

The field system consists of the following parts

(i) Yoke (ii) Poles (iii) Field coils

(i) Yoke:

A cylindrical yoke is used which serves as a frame of the machine and has a twin function. Firstly, it provides mechanical support to the poles and protects the d.c. machine from harmful atmospheric elements like dust, moisture and gases like SO_2, acidic fumes etc. Secondly, it offers a path of low reluctance to the magnetic flux produced by the poles. It is made of cast iron, cast steel or forged steel. Usually, small machines have cast-iron yokes.

(ii) Poles:

The machine has salient poles. The *pole cores* are fixed inside the yoke, usually by bolts. The cross-section of the pole core is rectangular. By attaching a *pole shoe*, the end of the pole is made to have a cylindrical surface. The cross-sectional area of the pole shoe is considerably larger than that of the pole core to leave as little inter-pole space as possible. *This is done to reduce the leakage flux.* The poles are made of forged-steel. Each pole carries a *field coil* (or exciting coil). Small machines generally use permanent magnets.

(iii) Field Coils:

The field coils are wound on the pole cores and are supported by the pole shoes. All the coils are identical and are connected in series such that on excitation by a d.c. source, alternate *N* and *S* poles are made. Thus, a machine always has even number of poles. The magnetic flux distribution is almost a square wave, as shown in Fig. 4.2. The flux is taken positive in the radially inward direction. It is seen that the yoke carries one half of the pole flux ϕ. Hence, the cross-section of the yoke should be selected accordingly.

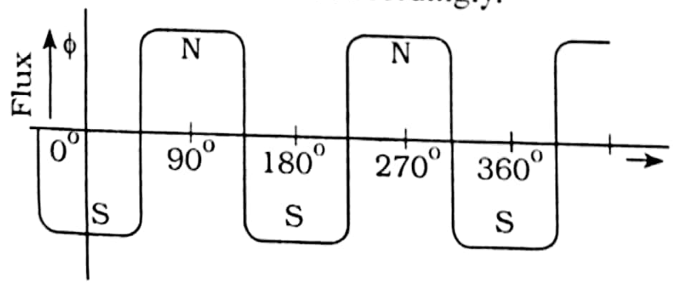

Fig. 4.2 : Magnetic Flux Distribution in a d.c. machine

2. Rotor

The rotor is the inner cylindrical part having armature and commutator - brush arrangement. It is mounted on the shaft of the motor.

(i) Armature:

The armature core consists of steel laminations, each about 0.4 – 0.6mm thick, insulated from each other. Laminating the core is done to reduce the eddy - current loss. Slots are stamped on the periphery of the laminations, in which conductors are placed. The top of each slot has a groove in which a wedge can be fixed. After the *winding conductors* are put into the slots, a wedge is inserted into each slot. The wedge prevents the conductors from flying out due to the centrifugal force when the armature rotates . The axial length of the armature is the same as that of the poles on the yoke. *Conductors are the active part of the armature winding,* which cut the flux **and generate an alternating e.m.f:**

(iii) Commutator:

A d.c. machine is required to produce a voltage that remains constant in direction and magnitude. A commutator converts the alternating e.m.f generated in the rotating armature conductors into a steady or direct voltage.

It is of cylindrical construction and is made up of wedge-shaped segments of high-conductivity, hard-drawn copper. These segments are insulated from each other by thin layers of mica (Fig.4.3). The number of segments is equal to the number of armature coils. Each commutator segment is connected to the armature conductor by means of a copper lug or strip. These segments have V-grooves so as to prevent them from flying out due to centrifugal forces. These grooves are insulated by conical magnetic rings.

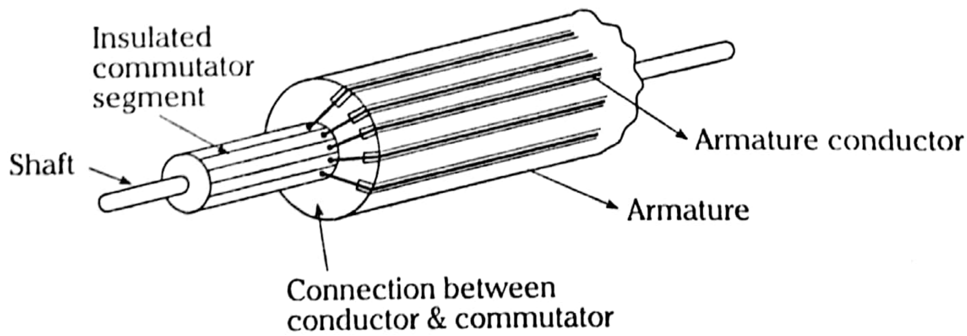

Fig.4.3: Commutator

(iv) Brushes and Brush-gear:

The function of brushes is to collect current from the commutator. They are normally made of carbon and are in the shape of a rectangular block. These brushes are housed in brush-holders, which are usually of the box-type variety. The brush-holder is mounted on a spindle and the brushes can slide in the rectangular box open at both the ends. The brushes are made to press down on the commutator by means of a spring, whose tension can be adjusted by operating a lever. A flexible copper pigtail, mounted at the top of the brush, carries the current from the brushes to the holder. The number of brushes per spindle depends on the magnitude of the current to be collected from the commutator.

v. Bearings:

Ball-bearings are usually used as they are more reliable. However, for heavy duty work, roller bearings are preferred. The ball and rollers are packed in hard oil for quieter operation and for minimizing wear of the bearings.

4.2 Principle of Operation

Whenever a conductor is moved in a magnetic field such that it cuts across lines of flux, dynamically induced e.m.f. is produced in it according to *Faraday's Laws of Electromagnetic Induction*. The magnitude of this induced e.m.f. in the conductor is given by the equation,

$$e = B\ l\ v \sin \phi$$

where

l = length of the portion of the conductor within the magnetic field,

v = velocity of the conductor,

B = magnetic flux density and

θ = angle between direction of movement of the conductor and the direction of magnetic flux.

This e.m.f. causes a current to flow in the conductor if the circuit is closed. Thus, electrical power develops in the conductor. If the conductor does not move or if it is moved parallel to the lines of flux, no e.m.f. is induced in it, and hence no power is generated. Hence it is clear that, for the *generation of e.m.f. there should be relative motion between the conductor and the magnetic field*. Hence, a generating action has the following requirements :

(i) The conductor (or coil),

(ii) The flux,

(iii) The relative motion between the conductor and the flux.

In a practical generator, the conductors are rotated to cut the magnetic flux, keeping the flux stationary. In order to obtain a large voltage as the output, several conductors are joined together in a particular manner, to form a winding. Such a winding is known as the *armature winding* of a d.c. machine. The part on which this winding is placed is called the *armature* of a d.c. machine.

The conductors situated on the armature are rotated by some external device called a *prime mover*. Some of prime movers used are steam engines, diesel engines, water turbines etc. The magnetic field is produced by a current-carrying winding known as *field winding*. The direction of the induced e.m.f. may be obtained by using *Fleming's Right Hand Rule*, as given below.

Fleming's Right Hand Rule (see Fig 4.4)

If three fingers of a right hand, namely the thumb, index finger and middle finger are outstretched so that every one of them is at right angles with the other two, and if in this position, the index finger points in the direction of lines of flux, the thumb in the direction of the relative motion of the conductor with respect to the flux, then *the outstretched middle finger gives the direction of the e.m.f induced in the conductor*. This Rule mainly gives the direction of current set up by the e.m.f. induced in the conductor when a closed path is provided to it.

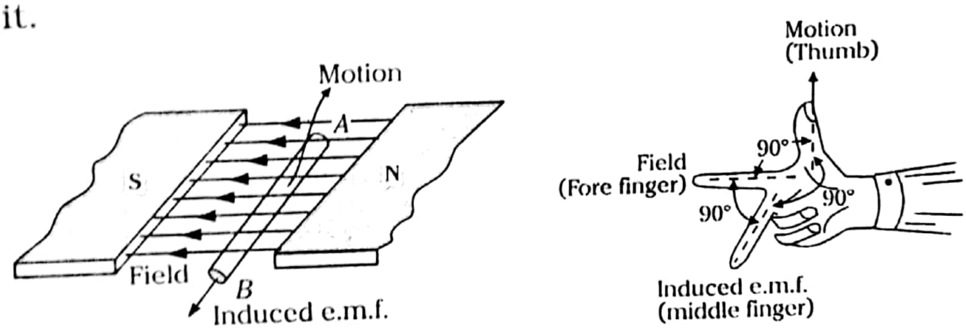

Fig.4.4:

4.3 Expression for Induced (or Generated) e.m.f.

Let ϕ = Flux/pole in webers

Z = Total number armature conductors or coil sides on armature

= No. of slots No. of conductors/slot

P = No. of generator poles.

A = No. of parallel paths in the armature

N = Rotational speed of armature in revolutions per minute (r.p.m.)

E = e.m.f. induced in any parallel path in armature.

Generated e.m.f Eg = e.m.f. generated in any of the parallel paths.

i.e., E. Average e.m.f. generated/conductor = $\frac{d\phi}{dt}$ volts (because n = 1)

During one revolution of armature in a P-pole generator, each armature conductor cuts the magnetic flux P times.

∴ Flux cut by one conductor in one revolution = P webers.

Flux cut by each conductor per second = Flux cut by the conductor per revolution × no. of revolutions of armature per second.

$$= P \times \frac{N}{60} \text{ webers} \quad \ldots \text{(i)}$$

As per Faraday's Laws of Electromagnetic Induction, E.M.F. generated per conductor $= \frac{d\phi}{dt} = \frac{\phi PN}{60}$ volts.

The number of conductors in series between a positive brush and a negative brush is equal to the total number of conductors divided by the number of parallel paths, or

No. of armature conductors per parallel path $\frac{Z}{A}$

The generated e.m.f, Eg (between the terminals)

= e.m.f generated per conductor No. of conductors in each parallel path.

OR

$$E_g = \frac{\phi PN}{60} \times \frac{Z}{A} \text{ volts} \quad \ldots \text{(i)}$$

For Simplex Lap-Wound Generator

No. of parallel paths, $A = P$.

∴ Eqn (i) becomes $E_g = \frac{\phi PN}{60} \times \frac{Z}{P} = \frac{\phi ZN}{60}$ volts

So re-writing equation (i), the general equation for e.m.f generated is

$$\mathbf{E_g = \frac{\phi ZN}{60} \times \left(\frac{P}{A}\right) volts} \quad \ldots \text{(ii)}$$

A = 2, for simplex wave-winding

= P, for simplex lap-winding

Also putting eqn (ii) in another form,