

## D.C. Generators

### ✓ INTRODUCTION

Although a far greater percentage of the electrical machines in service are a.c. machines, the d.c. machines are of considerable industrial importance. The principal advantage of the d.c. machine, particularly the d.c. motor, is that it provides a fine control of speed. Such an advantage is not claimed by any a.c. motor. However, d.c. generators are not as common as they used to be, because direct current, when required, is mainly obtained from an a.c. supply by the use of rectifiers. Nevertheless, an understanding of d.c. generator is important because it represents a logical introduction to the behaviour of d.c. motors. Indeed many d.c. motors in industry actually operate as d.c. generators for a brief period. In this chapter, we shall deal with various aspects of d.c. generators.

### ✓ 2.1 GENERATOR PRINCIPLE

An electric generator is a machine that converts mechanical energy into electrical energy.

An electric generator is based on the principle that whenever flux is cut by a conductor, an e.m.f. is induced which will cause a current to flow if the conductor circuit is closed. The direction of induced e.m.f. (and hence current) is given by \*Fleming's right hand rule. Therefore, the essential components of a generator are :

- (a) a magnetic field
- (b) conductor or a group of conductors
- (c) motion of conductor *w.r.t.* magnetic field

### ✓ 2.2 SIMPLE LOOP GENERATOR

Consider a single turn loop *ABCD* rotating clockwise in a uniform magnetic field with a constant speed as shown in Fig. 2.1 As the loop rotates, the flux linking the coil sides *AB* and *CD* changes continuously. Hence the e.m.f. induced in these coil sides also changes but the e.m.f. induced in one coil side \*\*adds to that induced in the other.

- (i) When the loop is in position no. 1 [See Fig. 2.1], the generated e.m.f. is zero because the coil sides (*AB* and *CD*) are cutting no flux but are moving parallel to it.
- (ii) When the loop is in position no. 2, the coil sides are moving at an angle to the flux and, therefore, a low e.m.f. is generated as indicated by point 2 in Fig. 2.2.
- (iii) When the loop is in position no. 3, the coil sides (*AB* and *CD*) are at right angle to the flux and are, therefore, cutting the flux at a maximum rate. Hence at this instant, the generated e.m.f. is maximum as indicated by point 3 in Fig. 2.2.
- (iv) At position 4, the generated e.m.f. is less because the coil sides are cutting the flux at an angle.

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\* **Fleming's Right hand rule.** Stretch the thumb, fore-finger and middle finger of your right hand so that they are at right angles to each other. If the fore-finger points in the direction of field, thumb in the direction of motion of the conductor, then middle finger will point in the direction of induced e.m.f.

\*\* It is because the coil sides always remain under the influence of opposite poles *i.e.*, if one coil side is under the influence of the *N*-pole, then the other coil side will be under the influence of *S*-pole and *vice-versa*.



- (v) At position 5, no magnetic lines are cut and hence induced e.m.f. is zero as indicated by point 5 in Fig. 2.2.
- (vi) At position 6, the coil sides move under a pole of opposite polarity and hence the direction of generated e.m.f. is reversed. The maximum e.m.f. in this direction (*i.e.*, reverse direction, See Fig. 2.2) will be when the loop is at position 7 and zero when at position 1. This cycle repeats with each revolution of the coil.

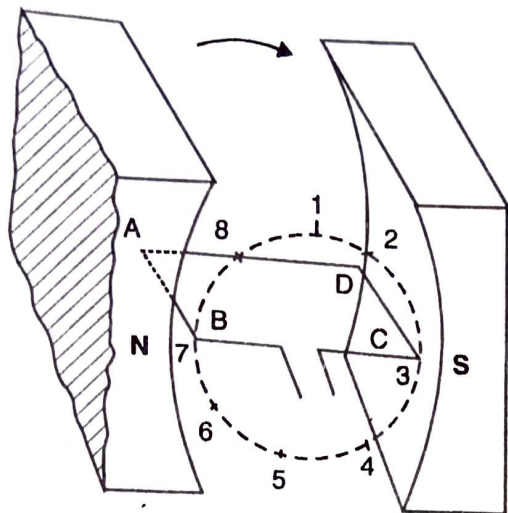


Fig. 2.1

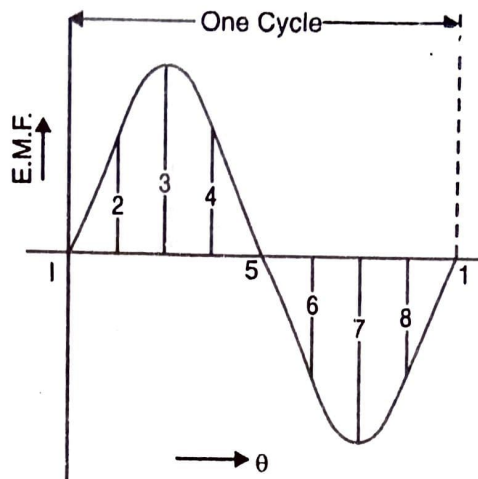


Fig. 2.2

Note that e.m.f. generated in the loop is alternating one. It is because any coil side, say  $AB$  has e.m.f. in one direction when under the influence of  $N$ -pole and in the other direction when under the influence of  $S$ -pole. If a load is connected across the ends of the loop, then alternating current will flow through the load. The alternating voltage generated in the loop can be converted into direct voltage by a device called *commutator*. We then have the d.c. generator. In fact, a commutator is a mechanical rectifier.

### 2.3 ACTION OF COMMUTATOR

If, somehow, connection of the coil side to the external load is reversed at the same instant the current in the coil side reverses, the current through the load will be direct current. This is what a commutator does. Fig. 2.3 shows a commutator having two segments  $C_1$  and  $C_2$ . It consists of a cylindrical metal ring cut into two halves or segments  $C_1$  and  $C_2$  respectively separated by a thin sheet of mica. The commutator is mounted on but insulated from the rotor shaft. The ends of coil sides  $AB$  and  $CD$  are connected to the segments  $C_1$  and  $C_2$  respectively as shown in Fig. 2.4. Two stationary carbon brushes rest on the commutator and lead current to the external load. With this arrangement, the commutator at all times connects the coil side under  $S$ -pole to the  $+ve$  brush and that under  $N$ -pole to the  $-ve$  brush.

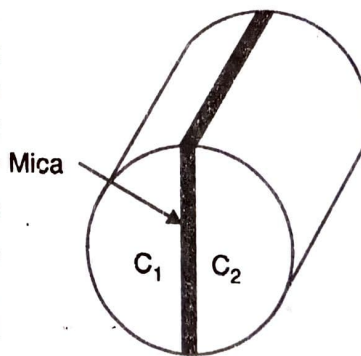


Fig. 2.3

- (i) In Fig. 2.4, the coil sides  $AB$  and  $CD$  are under  $N$ -pole and  $S$ -pole respectively. Note that segment  $C_1$  connects the coil side  $AB$  to point  $P$  of the load resistance  $R$  and the segment  $C_2$  connects the coil side  $CD$  to point  $Q$  of the load. Also note the direction of current through load. It is from  $Q$  to  $P$ .
- (ii) After half a revolution of the loop (*i.e.*,  $180^\circ$  rotation), the coil side  $AB$  is under  $S$ -pole and the coil side  $CD$  under  $N$ -pole as shown in Fig. 2.5. The currents in the coil sides now flow in the reverse direction but the segments  $C_1$  and  $C_2$  have also moved through  $180^\circ$  *i.e.*, segment  $C_1$  is now in contact with  $+ve$  brush and segment  $C_2$  in contact with  $-ve$  brush.



Note that commutator has reversed the coil connections to the load *i.e.*, coil side *AB* is now connected to point *Q* of the load and coil side *CD* to the point *P* of the load. Also note the direction of current through the load. It is \*again from *Q* to *P*.

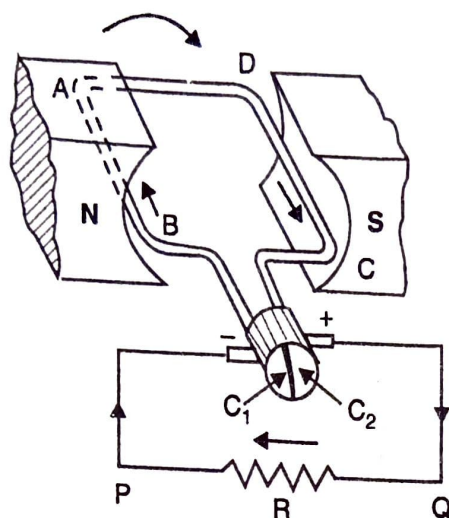


Fig. 2.4

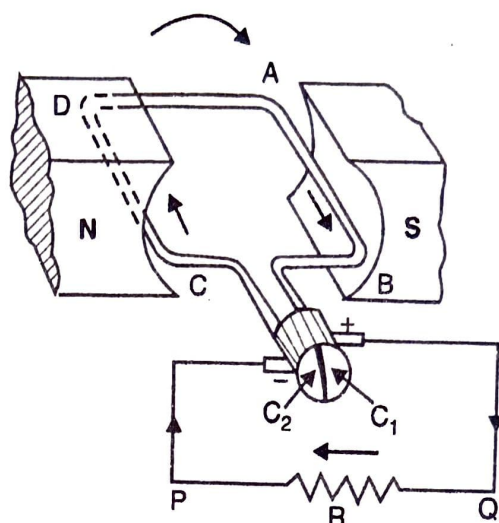


Fig. 2.5

Thus the alternating voltage generated in the loop will appear as direct voltage across the brushes. The reader may note that e.m.f. generated in the armature winding of a d.c. generator is alternating one. It is by the use of commutator that we convert the generated alternating e.m.f. into direct voltage. The purpose of brushes is simply to lead current from the rotating loop or winding to the external stationary load.

The variation of voltage across the brushes with the angular displacement of the loop will be as shown in Fig. 2.6. This is not a steady direct voltage but has a pulsating character. It is because the voltage appearing across the brushes varies from zero to maximum value and back to zero twice for each revolution of the loop. A pulsating direct voltage such as is produced by a single loop is not suitable for many commercial uses. What we require is the steady direct voltage. This can be achieved by using a large number of coils connected in series. The resulting arrangement is known as *armature winding*.

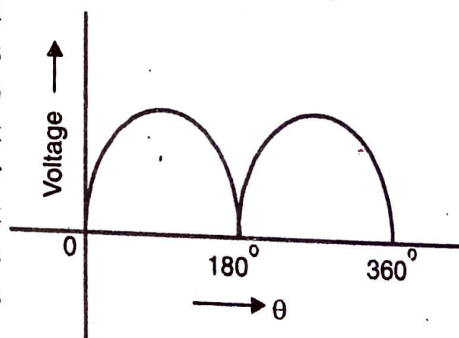


Fig. 2.6

## ✓ 2.4 CONSTRUCTION OF D.C. GENERATOR

The d.c. generators and d.c. motors have the same general construction. In fact, when the machine is being assembled, the workmen usually do not know whether it is a d.c. generator or motor. Any d.c. generator can be run as a d.c. motor and *vice-versa*. All d.c. machines have five principal components viz., (i) field system (ii) armature core (iii) armature winding (iv) commutator (v) brushes [See Fig. 2.7].

(i) **Field system.** The function of the field system is to produce uniform magnetic field within which the armature rotates. It consists of a number of salient poles (of course, even number) bolted to the inside of circular frame (generally called *yoke*). The yoke is usually made of solid cast steel whereas the pole pieces are composed of stacked laminations. Field coils are mounted on the poles and carry the d.c. exciting current. The field coils are connected in such a way that adjacent poles have opposite polarity.

\* The situation is that currents in the coil sides are reversed and at the same time the connections of the coil sides to the external load are reversed. This means that current will flow in the same direction through the load.



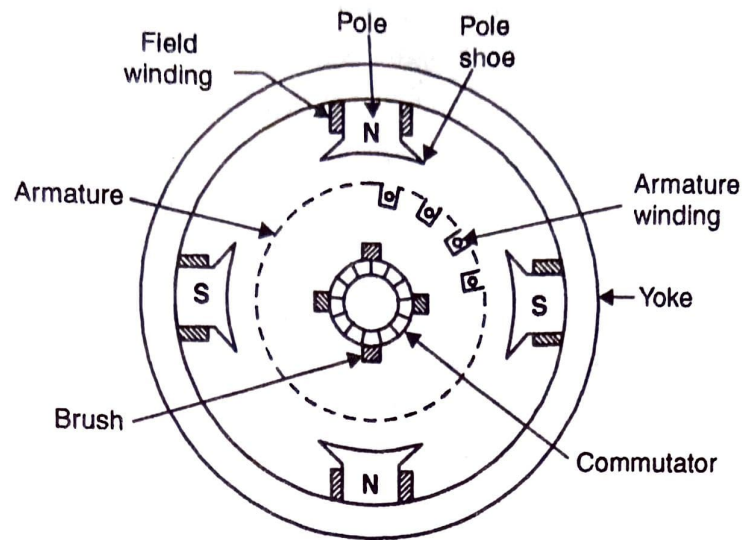


Fig. 2.7

The m.m.f. developed by the field coils produces a magnetic flux that passes through the pole pieces, the air gap, the armature and the frame (See Fig. 2.8). Practical d.c. machines have air gaps ranging from 0.5 mm to 1.5 mm. Since armature and field systems are composed of materials that have high permeability, most of the m.m.f. of field coils is required to set up flux in the air gap. By reducing the length of air gap, we can reduce the size of field coils (*i.e.* number of turns).

The yoke not only serves as a support for field poles, interpoles (not shown), compensating windings (not shown) etc. but it also provides return path for the magnetic flux created by the field windings.

(ii) **Armature core.** The armature core is keyed to the machine shaft and rotates between the field poles. It consists of slotted soft-iron laminations (about 0.4 to 0.6 mm thick) that are stacked to form a cylindrical core as shown in Fig 2.9. The laminations (See Fig. 2.10) are individually coated with a thin insulating film so that they do not come in electrical contact with each other. The purpose of laminating the core is to reduce the eddy current loss. The laminations are slotted to accommodate and provide mechanical security to the armature winding and to give shorter air gap for the flux to cross between the pole face and the armature “teeth”.

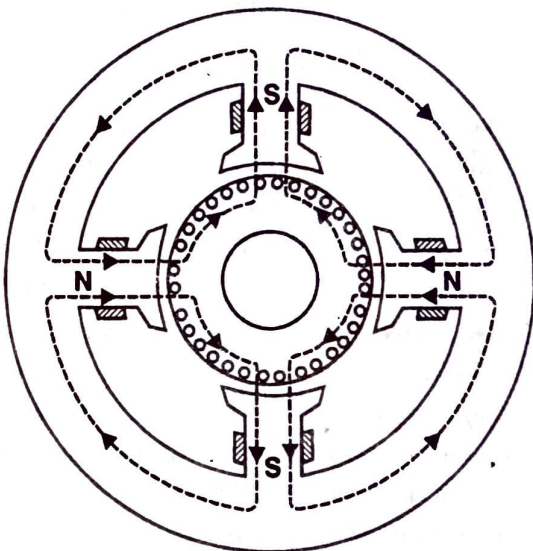


Fig. 2.8

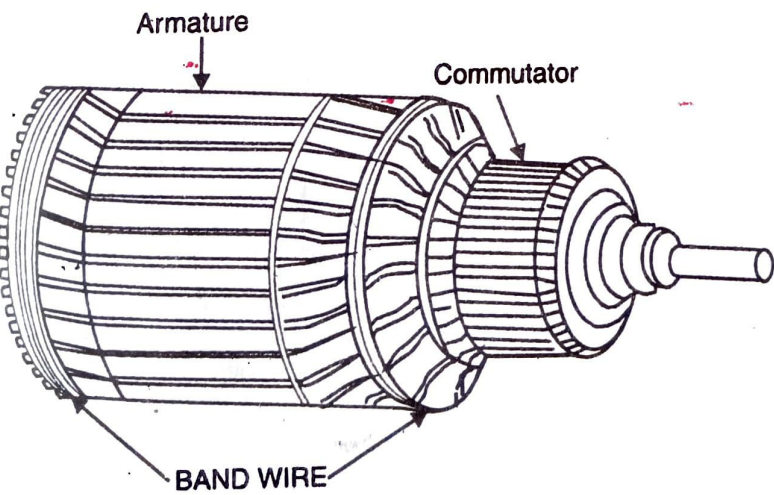


Fig. 2.9

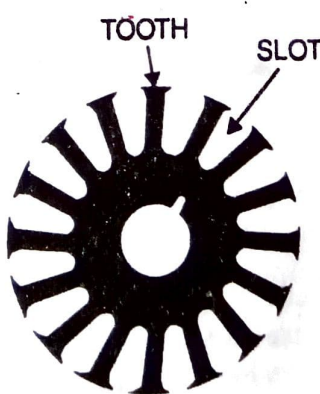


Fig. 2.10



✓ The armature of the d.c. generator performs the following three major functions :

- ✓ (a) It permits rotation for mechanical generator action.
- ✓ (b) Since it houses conductors, e.m.f. is induced in them.
- ✓ (c) It provides low reluctance path for the magnetic flux.

(iii) **Armature winding.** The slots of the armature core hold insulated conductors that are connected in a suitable manner. This is known as *armature winding*. This is the winding in which "working" e.m.f. is induced. The armature conductors are connected in series-parallel; the conductors being connected in series so as to increase the voltage and in parallel paths so as to increase the current. The armature winding of a d.c. machine is a closed-circuit winding; the conductors being connected in a symmetrical manner forming a closed loop or series of closed loops.

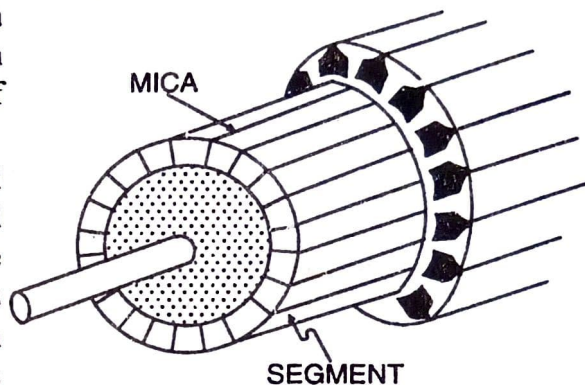


Fig. 2.11

(iv) **Commutator.** A commutator is a mechanical rectifier which converts the alternating voltage generated in the armature winding into direct voltage across the brushes. The commutator is made of copper segments insulated from each other by mica sheets and mounted on the shaft of the machine (See Fig. 2.11). The armature conductors are soldered to the commutator segments in a suitable manner to give rise to the armature winding.

Depending upon the manner in which the armature conductors are connected to the commutator segments, there are two types of armature winding in a d.c. machine viz., (a) lap winding (b) wave winding.

Great care is taken in building the commutator because any eccentricity will cause the brushes to bounce, producing unacceptable sparking. The sparks may burn the brushes and overheat and carbonise the commutator.

(v) **Brushes.** The purpose of brushes is to ensure \*electrical connections between the rotating commutator and stationary external load circuit. The brushes are made of \*\*carbon and rest on the commutator. The brush pressure is adjusted by means of adjustable springs (See Fig. 2.12). If the brush pressure is very large, the friction produces heating of the commutator and the brushes. On the other hand, if it is too weak, the imperfect contact with the commutator may produce sparking.

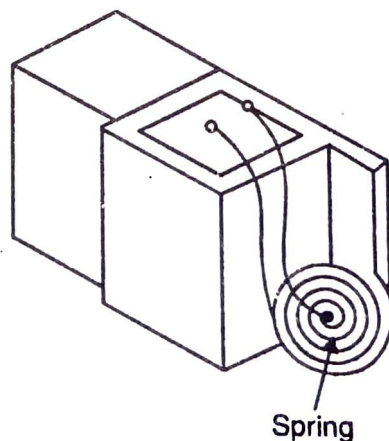
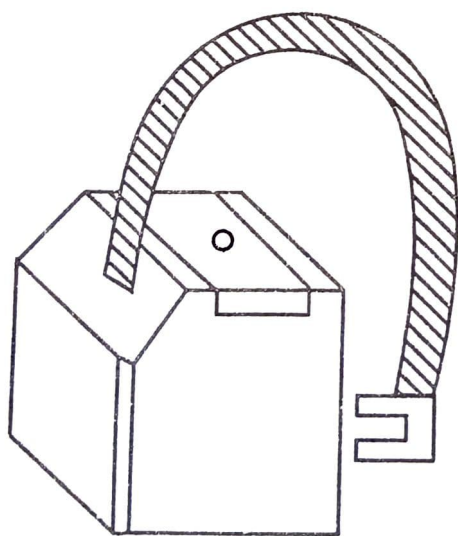


Fig. 2.12

- \* When the machine is acting as a generator, the brushes carry current from the commutator to the external stationary load. In case the machine is acting as a motor, they feed the supply current to the commutator.
- \*\* Because carbon has good electrical conductivity and is soft enough not to scratch the commutator. To improve the conductivity, sometimes we add a small amount of copper.