CHAPTER - 7

D.C. GENERATOR

7.1 Introduction:

A D.C. generator is an electrical machine which converts mechanical energy into electrical energy. The electrical energy is generated in the form of an alternating voltage in the windings of the D.C. generator. This alternating voltage is converted into direct or constant voltage by commutator. Hence, when a load is connected to the terminals of a D.C. generator, direct current flows through the load. The principle used for the generation of voltage is electromagnetic induction.

7.2 Working Principle:

A D.C. generator works on the principle of Faraday's laws of electromagnetic induction. The nature of the e.m.f. induced is dynamically induced e.m.f., which is explained in detail, in section 2.6 of chapter 2. In a D.C. generator, the conductors connected to one another rotate in a circular path in such a way that, when one conductor is rotating under the influence of a north pole, the conductor connected to it moves under the influence of a south pole, so that, even though the directions of e.m.f.s induced in them are in opposite directions, they are additive. This is best illustrated in Fig.7.1, in which, two conductors AB and CD, are connected together at the backside and connected to two separate copper slip rings R_1 and R_2 on the front side. The two rings rotate along with the conductors. Two brushes B_1 and B_2, just sit on the two rings and collect the current flowing through the load resistance R which is connected to these brushes.

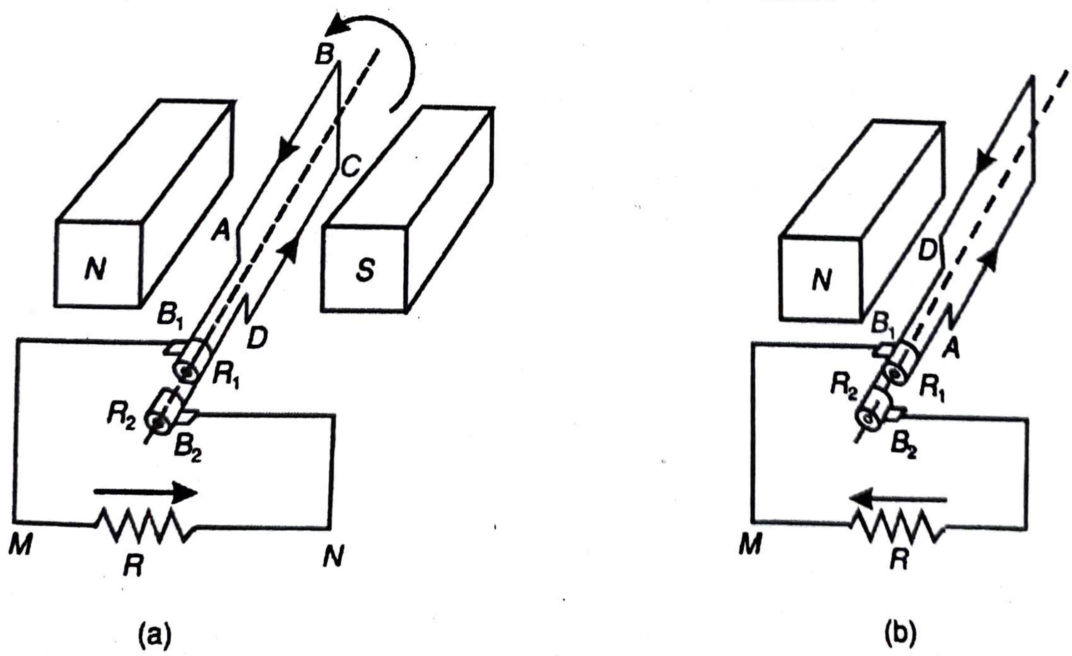


Fig.7.1

The two conductors which are connected together form a coil ABCD. When this coil starts rotating at a uniform speed in the anti-clockwise direction, conductor AB rotates under the influence of north pole and conductor CD rotates under the influence of south pole. According to Fleming's right hand rule, the direction of the e.m.f.s induced in AB and CD are as shown. Hence, the current flows from M to N through the resistance R as shown in Fig. 7.1 (a). This direction of current remains the same, when the coil rotates through 180°. For the rotation of the coil from 180° to 360°, the conductor CD rotates under the influence of north pole and the conductor AB rotates under the influence of south pole. Hence, the e.m.f.s induced in them gets reversed and now the current flows from N to M through the resistance R as shown in Fig 7.1 (b). The whole process repeats for the subsequent revolutions of the coil. During one revolution, each of the conductors cut the flux from zero value to maximum value and again zero value, when it is moving under a pole. The nature of the e.m.f. induced is alternating in nature.

If the pole faces are so shaped that the flux produced by them is radial and the air gap is uniform, by having more number of alternate north and south poles and a large number of conductors distributed uniformly on the outer periphery of a circular cylindrical drum, the nature of the e.m.f. induced in the conductors is sinusoidal in nature, which is shown in Fig. 7.2.

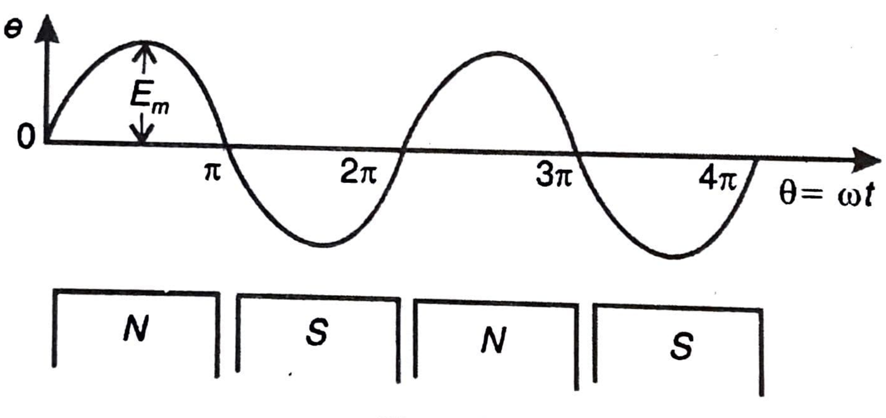


Fig. 7.2

The equation for the e.m.f. induced in each conductor is given by,

$e = B\, l\, v \sin\theta = E_m \sin\theta$

Where, B = flux density produced by the poles in Wb/m^2 or Tesla.

l = length of the conductor in metres

v = velocity with which the conductor is moving in m/s

To convert this alternating current voltage into a direct current voltage, instead of using two separate rings R_1 and R_2, a split ring is used as shown in Fig. 7.3.

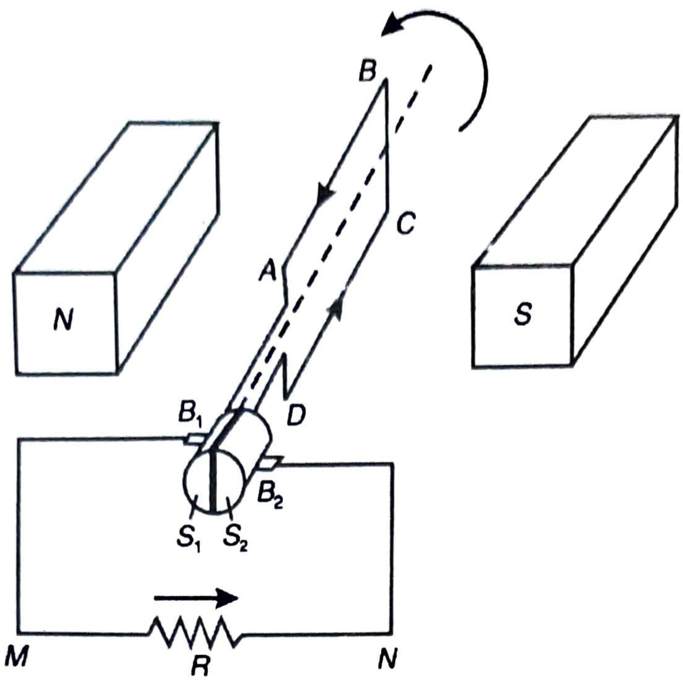


Fig.7.3

The ring has two segments S_1 and S_2, separated by an insulating medium. B_1 and B_2 are the two brushes, which just slide on the split ring. When the coil rotates through an angular displacement of 180°, the conductor AB is moving under the influence of north pole and conductor CD is moving under the influence of south pole. The direction of the e.m.f.s induced in AB and CD and the current flowing through the resistance R are as shown in Fig. 7.3.

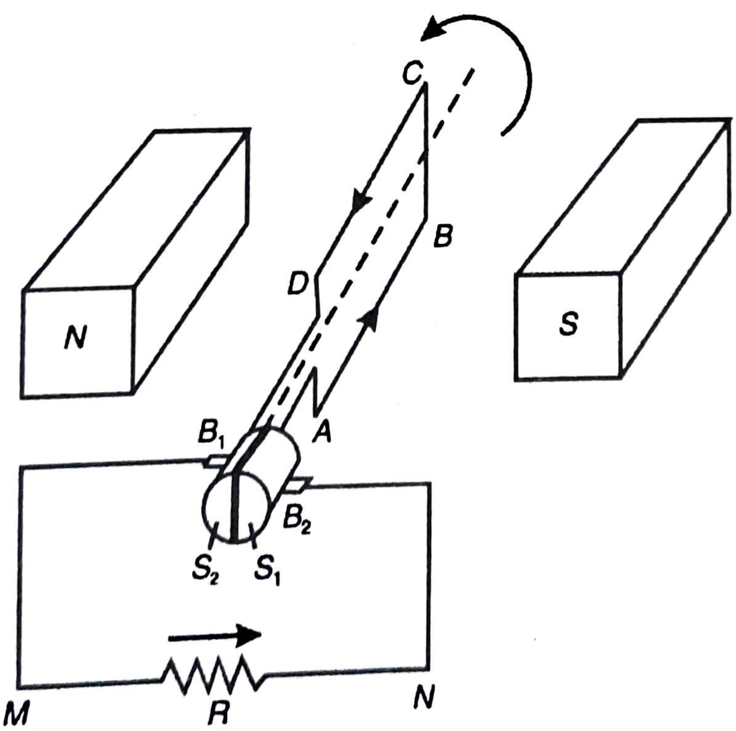


Fig.7.4

In the next half rotation i.e. when the coil rotates through 180° to 360°, the conductor AB rotates under the influence of south pole and the conductor CD rotates under the influence of north pole and the directions of the e.m.f.s induced in them are reversed as shown in Fig. 7.4. But the direction of current flowing through the resistance R remains the same, as shown in Fig. 7.4.

Even though, the nature of the e.m.f. induced in the coil is sinusoidal in nature, the voltage applied across the external resistance or the current flowing through it is as shown in Fig. 7.5.

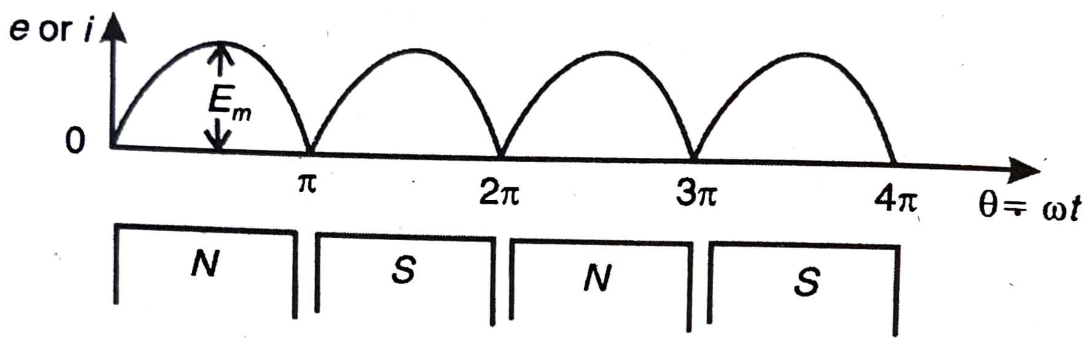


Fig. 7.5

Hence, the split ring S_1S_2 converts the alternating e.mf. into unidirectional voltage across the load. Instead of splitting the ring into only two parts, if it is split into a large number of wedge shaped segments, which are insulated from one another, the voltage delivered by the generator to the load resistance and hence the current flowing through it, will not only be unidirectional, but also of almost a constant magnitude as shown in Fig.7.6.

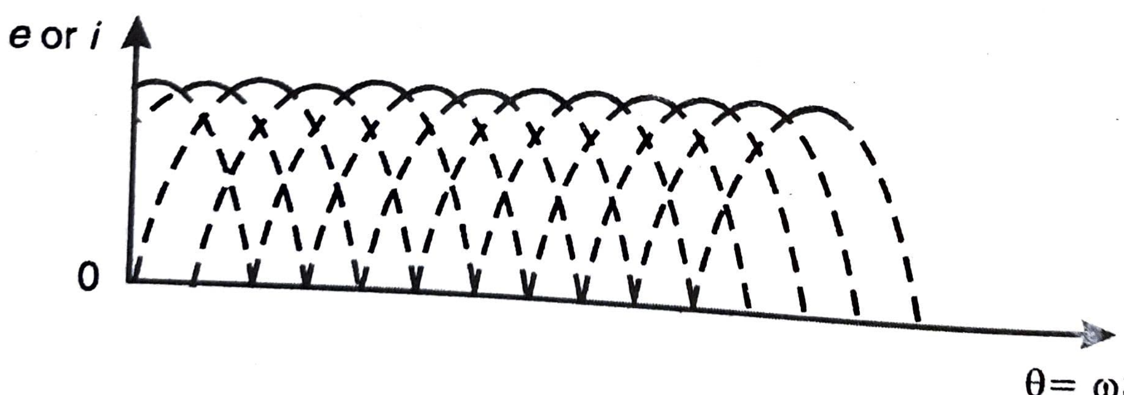


Fig.7.6

Such a circular split ring is known as the *commutator*, which converts alternating e.m.f. induced in the conductors to a direct current voltage across the load.

7.3 Construction:

Fig.7.7 shows the various parts of a D.C. generator.

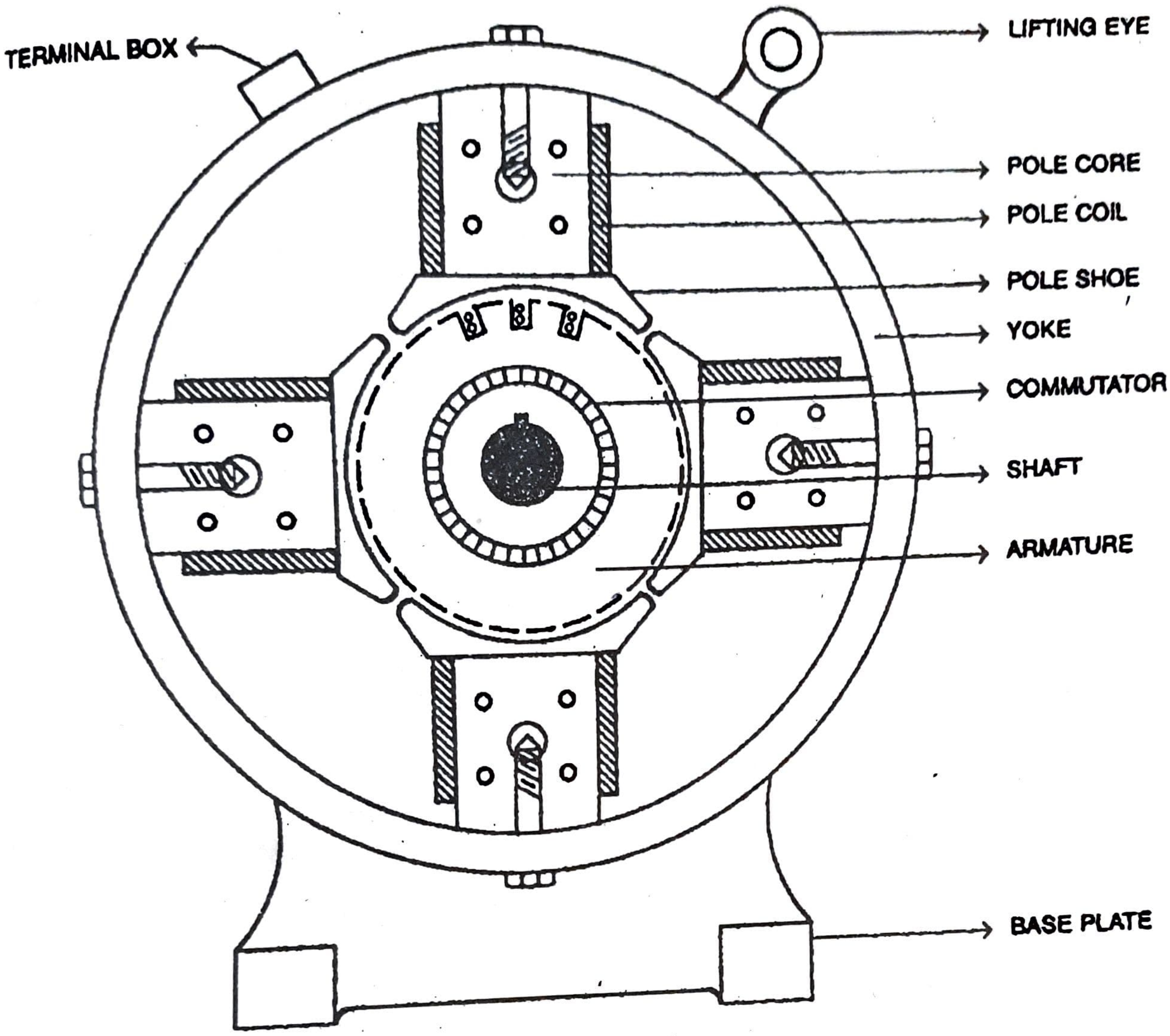


Fig.7.7

A D.C. generator mainly consists of two parts (i) Stationary part and (ii) Rotating part. The stationary part produces a constant magnetic flux and the rotating part converts the mechanical energy into electrical energy. The stationary part and the rotating part are separated by a small air gap.

The stationary part consists of (i) Yoke or magnetic frame (ii) Main poles along with pole shoes and pole coils (iii) Base plate (iv) Lifting eye (v) Brush box with brushes and (vi) Terminal box.

The rotating part consists of the (i) Armature (ii) Armature windings (iii) Commutator and (iv) Shaft. The construction of the various parts and the purpose they serve in the D.C. generator are described in the following sections:

7.4 Yoke or Magnetic Frame:

Yoke forms the outer cover for the D.C. generator and is cylindrical in shape as shown in Fig.7.8. For small generators, yoke is made of cast iron, whereas for large generators, it is made of cast steel. Cast iron gets saturated at about 0.8 Wb/m^2, whereas, cast steel gets saturated at 1.5 Wb/m^2. If the flux density is more than 0.8 Wb/m^2, as in the case of large machines, for the same flux density, the cross section of cast iron has to be nearly double the cross section of cast steel frame.

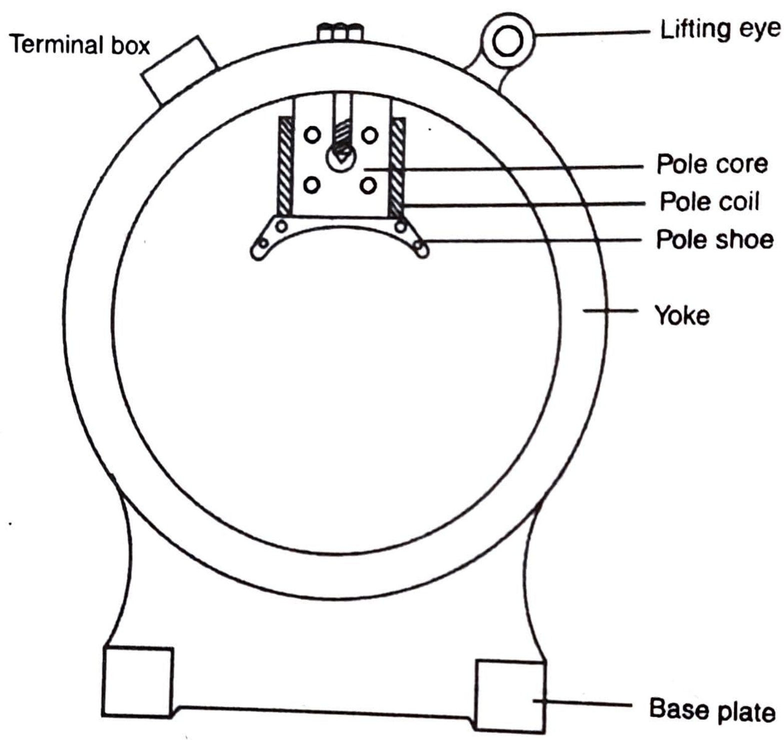


Fig.7.8

Another disadvantage of cast iron is that, its mechanical and magnetic properties are uncertain due to the presence of blow holes in the casting. Hence, in order to reduce the weight and also to have better magnetic properties, yokes of large generators are made of cast steel. For small generators, cast iron yokes are used, as they are cheap. The yoke supports the field system and also forms the part of the magnetic circuit. The lifting eye, the base plate and the terminal box are cast integral with the yoke.

7.5 Main Poles, Pole Shoes and Pole Coils:

The main poles are made of an alloy steel of high relative permeability. The pole core is laminated to reduce eddy current losses. Thin sheets of alloy steel are insulated from one another and pressed together to form the core. The laminations are held tightly with the help of end plates, which are rivetted together. The poles are fixed to the yoke with the help of bolts. The tail end of the bolt is screwed into the threaded holes of the steel bar, so that, the poles are held tightly to the yoke. The pole core supports the field coils.

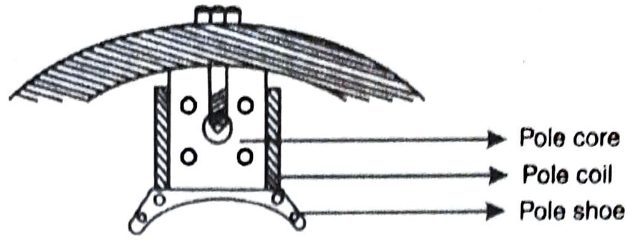


Fig.7.9

For small machines, the laminations of pole core and pole shoe are cast together as a single piece. For large machines the laminations of pole core and pole shoes are cast as different pieces, but are made of the same material. The pole shoes are also laminated, each lamination being insulated from one another, pressed together and riveted, so that, they are held together very tightly. The pole shoe is fixed to the pole core by means of counter sunk screws. The shape of the pole shoe is cylindrical at the bottom, so that, the flux produced is spread out uniformly in the air gap and also it reduces the reluctance of the magnetic path, because of the larger area of cross section. The pole shoe supports the field coils, which are former wound and fixed on the pole cores. When a direct current is passed through the field coils, the pole core becomes an electromagnet and produces the main flux required for the generation of e.m.f. The field coil and the pole shoe are also shown in Fig. 7.9.

The base plate, the lifting eye, the terminal box and the brush box are cast integral with the yoke. The base plate enables the generator to be placed conveniently on the ground or any platform. The lifting eye is used to lift the generator and to transfer it from one place to the other. The terminal box contains the output terminals of the D.C. generator, to which, any load can be connected. The brush box carries the brushes inside them, which are made of carbon or graphite. The brushes are held on the commutator segments by means of a latch or a spring, whose tension is adjustable, so that, the brush is in contact with the rotating commutator all the time. The brushes are connected to the terminals of the terminal box by means of stranded conductors, usually called as pigtails. The brushes collect current from the armature conductors via commutator segments and deliver it to the external load.

7.6 Armature:

The armature consists of armature core and armature winding. The armature core is made of high permeability and low loss silicon steel laminations, which are usually 0.4 to 0.5 mm thick and are insulated from one another by varnish. The laminations are clamped together tightly between two flanges. There are slots cut uniformly on the outer periphery of the armature core and armature conductors are placed in these slots as shown in Fig.7.10.

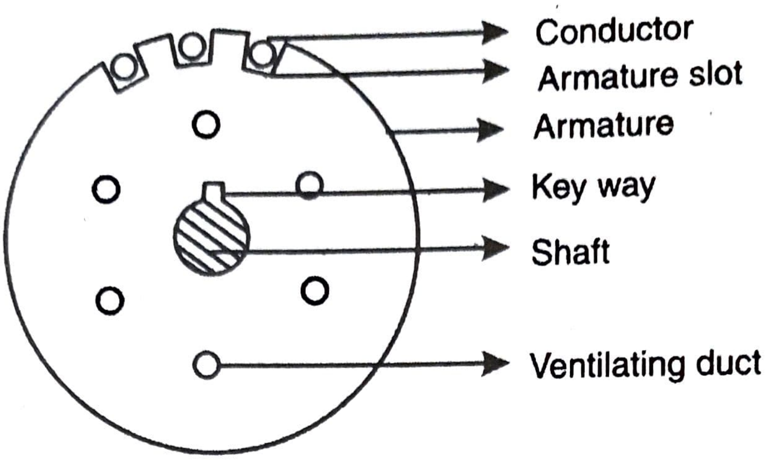


Fig. 7.10

The conductors placed in the slots are not only insulated from one another but also from the slots of the armature core. The armature laminations are directly keyed to the shaft and hence, the armature also rotates, when the shaft is rotated. Axial ventilating ducts are provided through the armature core, so that, free air can circulate through them and cool the armature. For small generators, each lamination is a single piece. But for large generators, each lamination is made of two or more segments, which form parts of a complete circular lamination. Key ways are provided on each segment, which are wedge or dove-tail shaped, so that, when placed in position, they are secured tightly to the armature shaft.

7.7 Armature Windings:

The armature conductors are placed in the slots of the armature. The conductors are not only insulated from one another but also from the armature slots. The armature conductors are connected together either as a *lap winding* or a *wave winding*. More discussion is made on armature windings in the later sections of this chapter.

7.8 Commutator:

As already explained in section 7.2 of this chapter. The commutator converts the alternating e.m.f. generated in the armature windings into direct current voltage in the external circuit. The cross sectional view of the commutator is shown in Fig.7.11.

7.	I_a = Armature Current $= A\ I_c$ Where I_c = current flowing through each conductor or coil or parallel path	$I_a = AI_c$
8.	The lap winding is used when a low voltage, high current supply is required.	The wave winding is used when a high voltage, low current supply is required.

7.13 E.M.F. Equation:

Let
- Z = Total number of armature conductors.
- ϕ = Useful flux per pole in webers.
- N = Speed of the armature in revolutions per minute. (r.p.m.).
- P = Number of poles
- A = Number of parallel paths.

The flux cut by a conductor in one revolution = $\phi P = d\phi$.

The time taken by the conductor to make one revolution = 60/N Sec = dt. Hence,

The E.M.F. induced in one conductor $= \dfrac{d\phi}{dt} = \dfrac{\phi P}{60/N} = \dfrac{\phi PN}{60}$ volts

The E.M.F. induced per parallel path = E.M.F. induced per conductor x Number of conductors per parallel path.

$$E = \frac{\phi PN}{60} \times \frac{Z}{A} = \frac{\phi ZNP}{60A} \text{ volts} \qquad (7.2)$$

Equation (7.2) is the E.M.F. Equation of a D.C. generator.

For lap winding, $A = P$

$$\therefore E = \frac{\phi Z N}{60} \text{ Volts} \qquad (7.3)$$

For wave winding, $A = 2$

$$\therefore E = \frac{\phi Z N P}{120} \text{ Volts} \qquad (7.4)$$

CHAPTER – 8

D.C. MOTOR

8.1 Introduction:

A direct current motor converts electrical energy into mechanical energy. It is similar in construction to a D.C. generator. Hence, a D.C. motor can be used as a D.C. generator and vice-versa. The external appearance of a D.C. motor may be slightly different from that of the D.C. generator, mainly due to the fact that, the frame of the generator may be partially open, as it is usually located in a clean environment and operated only by skilled workers. A motor is always operated in a dusty environment and usually unskilled workers operate them. Hence, the frames of the motors are usually closed.

8.2 Working Principle:

A D.C. motor works on the principle that "*whenever a current carrying conductor is placed in a magnetic field, it experiences a force*". The magnitude of the force experienced by the conductor is given by,

$$F = B I \ell, \qquad (8.1)$$

Where, F = Force experienced in Newtons
B = Flux density of the magnetic field in Wb/m^2
I = Current flowing through the conductor in amperes
ℓ = Length of the conductor in metres

The direction of the force is given by Fleming's left hand rule.

8.3 Fleming's Left Hand Rule:

It states that "*when the thumb, fore finger and the middle finger of the left hand are held mutually perpendicular to each other, the fore finger in the direction of the magnetic field, the middle finger in the direction of the current, then the direction of the thumb indicates the direction of the force experienced by the conductor*".

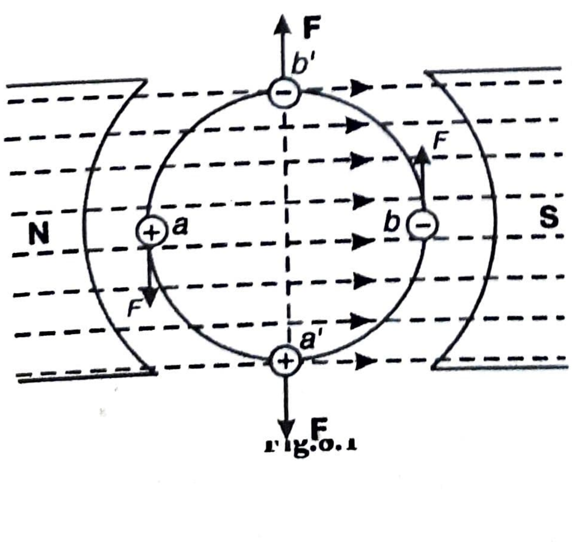


Fig.8.1

Consider a D.C. motor having two poles north and south represented by N and S as shown in Fig. 8.1. There will be conductors placed uniformly in the slots of the armature.

For the sake of explaining the a principle of working of a D.C. motor, only two conductors **a** and **b**, which are placed under the influence of N-pole and S-pole respectively and which are connected together by an end connection at the back side of the armature and to the commutator segments at front side of the armature are considered. When a D.C. supply is given to the motor terminals, the current flows through the conductors **a** and **b** via the commutator. In conductor **a**, the +ve sign marked indicates that the current is flowing inwards and the –ve sign in conductor **b** indicates that the current is flowing outwards. The direction of the magnetic field is represented by the lines of magnetic force, which emanate from the north pale N and go into the south pale S as shown in the Fig. 8.1.

According to Fleming's left hand rule, the conductor **a** experiences a force F in the downward direction and the conductor **b,** experiences an equal force F in the upward direction. As the two conductors are connected together, the two equal and opposite forces F acting on them, constitute a couple, tending to rotate the armature in anti-clockwise direction. Due to the action of this couple, let the armature rotate by 90° in the anti-clockwise direction and the conductors **a** and **b** occupy positions **a^1** and **b$^{\mathrm{l}}$** respectively.

In this position, they experience a force F in opposite directions along the same line and hence the torque experienced by them is zero. This position is known as **"dead center"** for the conductors **a** and **b**. If the armature contains only these two conductors, then the armature would stop in the position **a$^{\mathrm{l}}$b$^{\mathrm{l}}$**. But the armature consists of several other conductors which are uniformly distributed in the slots of the armature, which are connected together and experiencing a torque in the anti-clockwise direction. Thus the armature continues to rotate in the anti-clockwise direction.

For the armature to experience a continuous anti-clockwise torque, it is necessary that the directions of currents in conductors **a** and **b** must be reversed, after they cross the positions **a$^{\mathrm{l}}$** and **b$^{\mathrm{l}}$** respectively. Otherwise, the armature experiences a torque in the clockwise direction, thereby producing a pulsating torque in the dead centre position **a$^{\mathrm{l}}$ b$^{\mathrm{l}}$**. This reversal of current in conductors **a** and **b** after they cross positions **a$^{\mathrm{l}}$** and **b$^{\mathrm{l}}$** respectively, is effected by the commutator and thus makes the armature to experience a continuous anti-clockwise torque and makes it rotate continuously in the anti-clockwise direction.

8.4 Back E.M.F. (E_b):

Fig. 8.2 symbolically represents a D.C. shunt motor. V is the applied voltage, due to which a current I_a flows through the armature conductors. I_L is the line current and I_{sh} is the current flawing through the shunt field winding

$$I_L = I_a + I_{sh} \tag{8.2}$$

When a current I_a flows through the armature conductors, a torque is produced and the armature rotates. The current I_{sh} flowing through the shunt field winding produces a flux ϕ and hence, an E.M.F. E_b is induced in the armature conductors. The direction of this induced E.M.F. is such as to oppose the applied voltage. Hence, this induced E.M.F. E_b is called as the *back E.M.F*. The directions of the applied voltage V and the back E.M.F. E_b are shown in fig.8.2

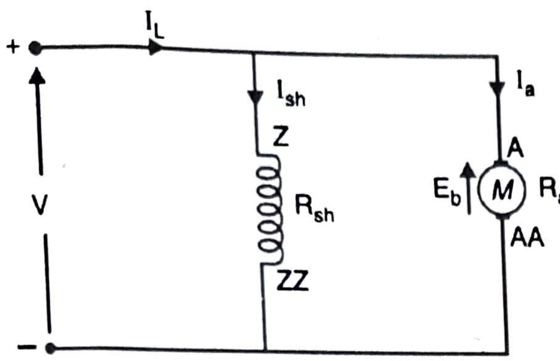


Figure.8.2

The applied voltage V has to drive current through the armature conductors against the opposition of the back E.M.F. and hence work has to be done. This work done is manifested in the form of mechanical power developed by the armature. In the absence of back E.M.F., no mechanical power can be developed by the armature.

The armature current I_a is given by,

$$I_a = \frac{V - E_b}{R_a} \quad (8.3) \qquad \text{or} \qquad V = E_b + I_a R_a \quad (8.4)$$

The back E.M.F. is nothing but the induced E.M.F. and hence its equation is,

$$E_b = \frac{\phi ZNP}{60A} \quad (8.5)$$

Multiplying equation (8.4) by I_a, we get, $V I_a = E_b I_a + I_a^2 R_a$ (8.6)

Where, $V I_a$ = Electrical power input to the armature.

$I_a^2 R_a$ = Copper loss in the armature.

and $E_b I_a$ = Electrical equivalent of the mechanical power developed by the armature, which includes iron losses and mechanical losses.

The efficiency of the D.C. motor is given by

$$\eta = \frac{\text{Mechanical power developed by the armature}}{\text{Electrical power input to the motor}} = \frac{E_b I_a}{V I_a} = \frac{E_b}{V} \quad (8.7)$$

Higher the value of E_b, higher will be the motor efficiency. The mechanical power developed by the armature is given by,

$$P_m = VI_a - I_a^2 R_a, \qquad \text{i.e.} \qquad \frac{dP_m}{dI_a} = V - 2 I_a R_a$$

For maximum power to be developed, $\frac{dP_m}{dI_a} = 0$

$$\therefore \; V - 2 I_a R_a = 0 \qquad \text{or} \qquad I_a R_a = \frac{V}{2} \quad (8.8)$$

But, $E_b + I_a R_a = V$

$$\therefore \quad E_b + \frac{V}{2} = V \qquad \text{or} \qquad E_b = \frac{V}{2} \tag{8.9}$$

But in practice, D.C. motors are not designed to satisfy the conditions given in equations (8.8) and (8.9), because, if $E_b = V/2$, the current flowing through the armature will be far more than the rated current and lot of input power will be wasted in the form of heat, thus increasing the losses and the efficiency of the D.C. motor for the condition $E_b = V/2$ will be less than 50%.

8.5 Torque Equation:

Torque is the turning moment about an axis. It is equal to the product of the force and the radius at which it acts.

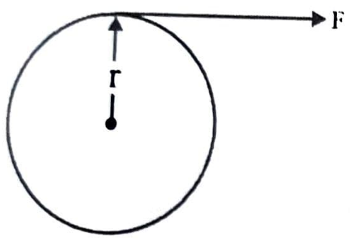


Fig.8.3

Consider the armature of the D.C. motor to have a radius r and let F be the force acting tangential to its surface as shown in Fig. 8.3. The torque exerted by the force F on the armature is given by,

$$T_a = F \times r \ \ \text{Nm}$$

The work done by this force F, in one revolution is given by,

$$W = \text{Force x distance covered in one revolution} = F \times 2\pi r \ \ \text{W–S} \tag{8.11}$$

The power developed by the armature = Work done in one second

$$= F \times 2\pi r \times \text{number of revolutions per second}$$

$$= F \times 2\pi r \times \frac{N}{60} = \frac{2\pi N}{60}(F \times r) = \frac{2\pi N T_a}{60} \ \text{watts} \tag{8.12}$$

We have already learnt in section 8.4 of this chapter that, the electrical equivalent of the mechanical power developed by the armature of the D.C. motor is equal to $E_b I_a$.

$$\therefore \quad \frac{2\pi N T_a}{60} = E_b I_a = \frac{\phi Z N P}{60 A} I_a$$

$$\therefore \quad T_a = \frac{1}{2\pi}\phi Z I_a \left(\frac{P}{A}\right) \text{Nm} = 0.159\,\phi Z I_a \left(\frac{P}{A}\right) \text{Nm} \tag{8.13}$$

$$= 0.0163\,\phi Z I_a \left(\frac{P}{A}\right) \text{Kgm} \tag{8.14}$$

Equation (8.13) gives the *gross torque* developed by the armature, which includes *iron losses* and *mechanical losses* of the motor. The actual torque available at the shaft to do useful work, which is known as *shaft torque* or *useful torque* T_{sh}, is less than T_a by an amount of torque which is equivalent to iron losses and mechanical losses in the D.C. motor.

$\therefore \quad T_{sh} = T_a - T_L$

Where, T_{sh} = Shaft torque

T_a = Armature torque

T_L = Torque lost due to iron losses and mechanical losses

The useful torque or shaft torque is given by,

Output of the motor in watts $= \dfrac{2\pi N T_{sh}}{60}$ as per equation (8.12)

$$\therefore \quad T_{sh} = \frac{\text{Output of the motor in watts}}{2\pi \frac{N}{60}} \text{ Nm} \tag{8.16}$$

The output of a D.C motor is usually expressed in H.P.

$$\therefore \quad T_{sh} = \frac{\text{Output in H.P.} \times 735.5}{2\pi \frac{N}{60}} \text{ Nm} \tag{8.17}$$

8.6 Types of D.C. motors:

Depending on the way in which the field windings are connected to the armature, D.C. motors are classified into three types.

(1) D.C. shunt motor (2) D.C. series motor and (3) D.C. compound motor

The D.C. compound motor may be further classified into two types:

(a) *Cumulatively* compounded D.C. motor, which may be connected either as *long shunt* or *short shunt.*

(b) *Differentially* compounded D.C. motor, which may be connected either as *long shunt* or *short shunt.*

8.7 D.C. Shunt Motor:

Fig.8.4 represents a D.C. shunt motor. In this type of motor, the shunt field winding is connected across the armature. V is the applied voltage due to which a current I_L flows through the line, a current I_{sh} through the shunt field winding and I_a through the armature conductors. The shunt field current is given by,

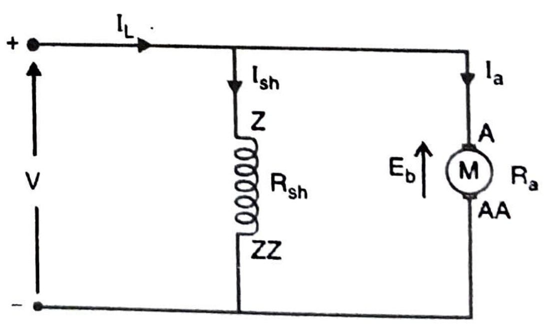


Fig.8.4

$$I_{sh} = \frac{V}{R_{sh}} \tag{8.18}$$

The armature current is given by,

$$I_a = I_L - I_{sh} \tag{8.19}$$

The back E.M.F. induced in the armature is given by,

$$E_b = V - I_a R_a - \text{B.C.D.} - \text{A.R.D.} \tag{8.20}$$

Where, B.C.D. = Brush contact drop and A.R.D. = Armature reaction drop.

8.8 D.C. Series Motor:

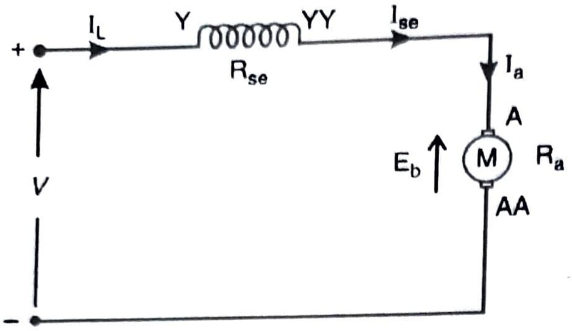


Fig. 8.5

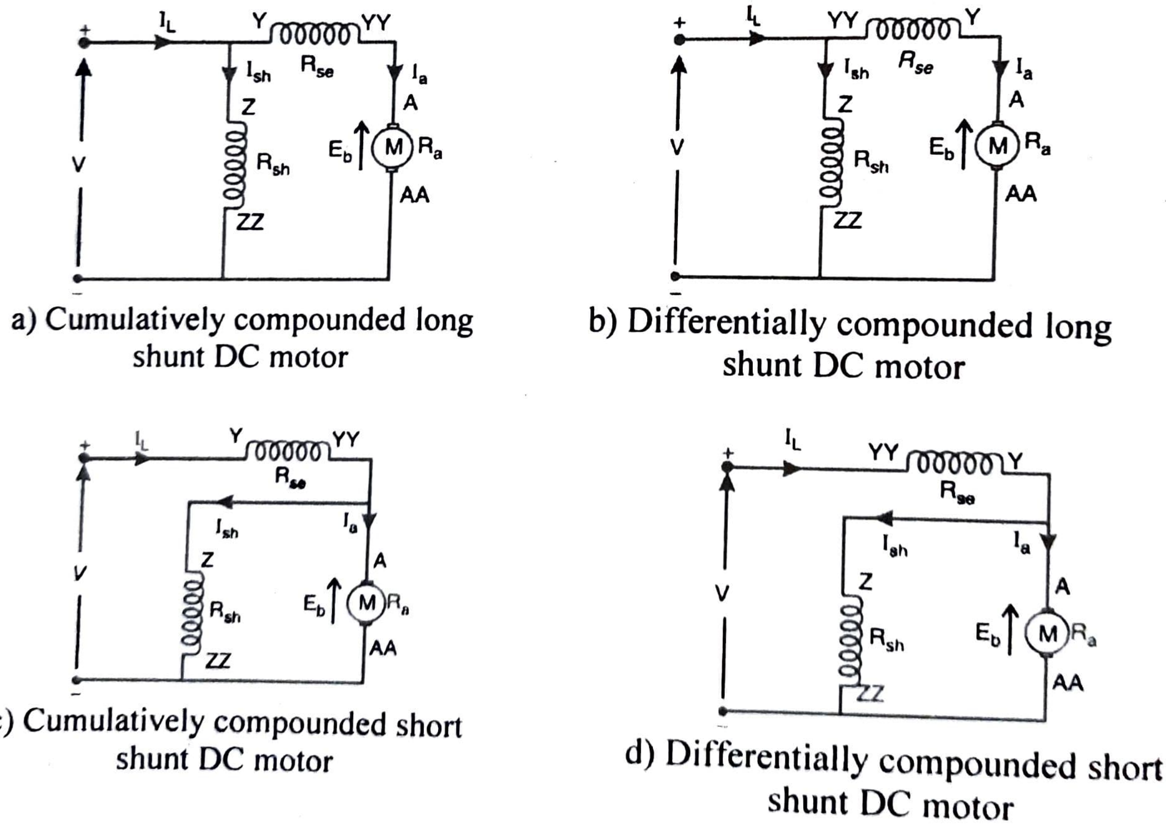
Fig. 8.5 represents a D.C. series motor. In this type of motor, the series field winding is connected in series with the armature. V is the applied voltage due to which a current I_L flows through the line, the series field winding and also through the armature conductors.

$\therefore \quad I_L = I_{se} = I_a$

The series field winding carries the armature current and should have very small resistance so that the voltage drop across it is very small. Hence, it is made of a few thick turns of copper. The back E.M.F. induced in the armature is given by,

$$E_b = V - I_a (R_a + R_{se}) - \text{B.C.D.} - \text{A.R.D.} \tag{8.22}$$

8.9 D.C. Compound Motor:



a) Cumulatively compounded long shunt DC motor

b) Differentially compounded long shunt DC motor

c) Cumulatively compounded short shunt DC motor

d) Differentially compounded short shunt DC motor

Fig.8.6

A D.C. compound motor contains both shunt field winding and series field winding. If the fluxes, ϕ_{sh} produced by the shunt field winding and ϕ_{se} produced by the series field winding are in the same direction and are additive, then the motor is said to be *cumulatively compounded.* If the two fluxes oppose each other, then the motor is said to be *differentially compounded.* Depending on the way in which the two field windings are connected, the compound motors can be either *long shunt* or *short shunt*. All the four possible types of D.C. compound motors are shown in Figs. 8.6 (a), (b), (c) and (d).

For cumulatively compounded motors, we observe that the currents enter the positive terminals of the two field windings and hence the fluxes produced by them are in the same direction and they are additive. In the case of differentially compounded motors, the current through the series field winding enters the negative terminal and the current through the shunt field winding enters the positive terminal. Hence, the two fluxes produced are in opposite directions and hence they oppose each other.

For a cumulatively or differentially compounded long shunt, D.C. motor, the following equations hold good.

$$I_{sh} = \frac{V}{R_{sh}} \quad (8.23) \qquad I_a = I_L - I_{sh} \quad (8.24)$$

And $E_b = V - I_a (R_a + R_{se}) - \text{B.C.D.} - \text{A.R.D.}$ (8.25)

For a cumulatively or differentially compounded short shunt, D.C. motor, the following equations hold good.

$$I_{sh} = \frac{V - I_L R_{se}}{R_{sh}} \quad (8.26) \qquad I_a = I_L - I_{sh} \quad (8.27)$$

And $E_b = V - I_L R_{se} - I_a R_a - \text{B.C.D} - \text{A.R.D.}$ (8.28)

8.10 Characteristics of D.C. Motors:

The characteristics of D.C. motors are studied keeping the applied voltage constant. The following are the three important characteristics of D.C. motors.

i) Electrical characteristic or T_a / I_a characteristic
ii) N / I_a characteristic and
iii) Mechanical Characteristic or N / T_a characteristic.

8.11 Characteristics of D.C. Shunt Motors:

(i) T_a / I_a Characteristic:

Fig. 8.7 represents a D.C. shunt motor on load. In a D.C. shunt motor, the field current I_{sh} remains constant irrespective of the load connected to the motor, because, the applied voltage remains constant for all loads. Hence the flux produced also remains constant.

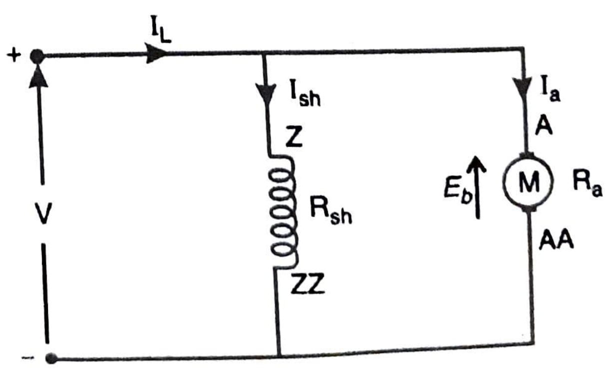


Fig.8.7

$$T_a = 0.159\,\phi\,Z\,I_a\left(\frac{P}{A}\right)$$

In the above equation, Z, P, A and ϕ are constants. $\therefore\ T_a \propto I_a$ (8.29)

Hence T_a / I_a characteristic is a straight line passing through the origin as shown fig. 8.8.

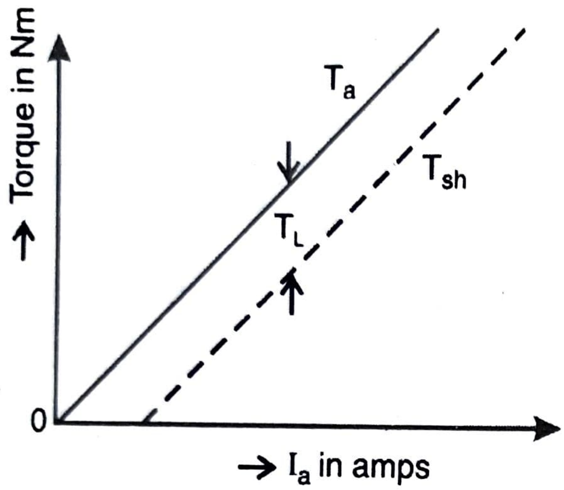


Fig.8.8

The shaft torque T_{sh} is always less than the armature torque T_a due to iron losses and mechanical losses in the D.C. motor. Hence it is shown always to be less than T_a by a torque T_L, which is the torque lost due to the above losses. From the characteristic, we learn that, a D.C. shunt motor has a medium starting torque and hence does not suit where, very large loads are required to be started.

(ii) N / I_a Characteristic:

The equation for the back E.M.F. E_b is given by,

$$E_b = \frac{\phi Z N P}{60A}, \quad \therefore \quad N \propto \frac{E_b}{\phi} \tag{8.30}$$

as the other quantities are constant.

For D.C. shunt motor, ϕ is constant

$$\therefore\ N \propto E_b \propto V - I_a R_a \tag{8.31}$$

As I_a increases, $I_a R_a$ increases and hence the speed decreases. But the drop I_aR_a is very small compared to V and hence, the decrease of speed as the armature current increases is also small. The variation of speed with respect to armature current is as shown in Fig.8.9.

N_0 is the no load speed of the motor. From this characteristic, we understand that the change in the speed of a D.C. shunt motor is small, when the armature current or load on the motor is increased. Hence for all practical purposes, a D.C. shunt motor may be considered as almost a constant speed motor.

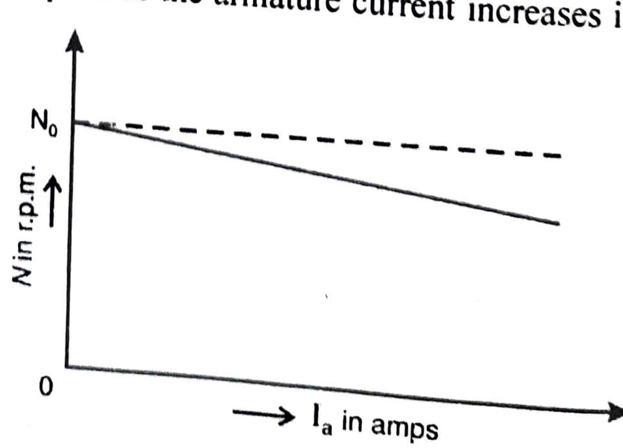


Fig.8.9

iii) N / T_a Characteristic:

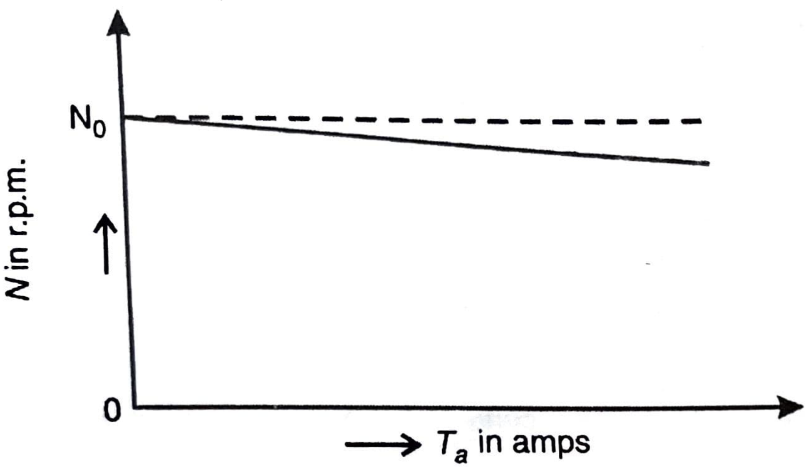


Fig.8.10

From the equation (8.29), we know that $T_a \propto I_a$ and hence, N/T_a characteristic is similar to N/I_a characteristic as shown in fig.8.10. N_0 is the no load speed of the motor.

8.12 Characteristics of D.C. Series Motors:

(a) T_a / I_a Characteristic:

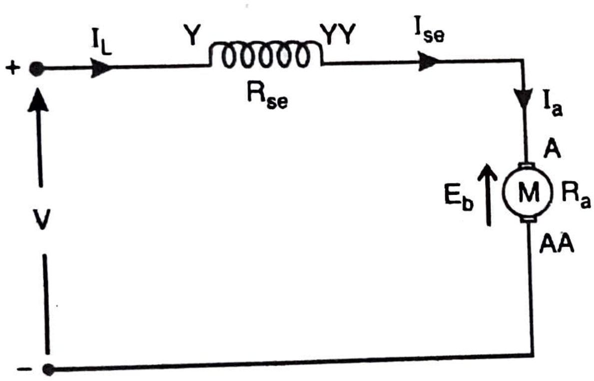


Fig.8.11

Fig. 8.11 represents a D.C. series motor on load. As the load on the motor increases, the current through the series field winding also increases and hence the flux produced also increases. The torque equation of a D.C. motor is given by,

$$T_a = 0.159\, \phi\, Z\, I_a \left(\frac{P}{A}\right)$$

Or $\quad T_a \propto \phi I_a$, but $\phi \propto I_a \quad \therefore \; T_a \propto I_a^2$

But after saturation, the flux remains constant and $T_a \propto I_a$.

The variation of T_a with respect to I_a is as shown in Fig. 8.12.

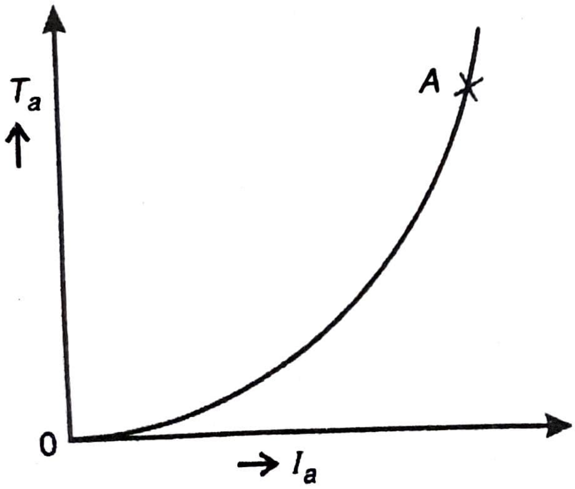


Fig.8.12

Upto saturation i.e., upto point A, $T_a \propto I_a^2$ and hence the curve is a parabola. After saturation i.e., beyond point A, $T_a \propto I_a$ and hence the curve is a straight line. From the characteristic, we find that the starting torque of a D.C. series motor is very high.

(b) N / I_a Characteristic:

From equation (8.30), we know that, $N \alpha \frac{E_b}{\phi} \alpha \frac{V - I_a(R_a + R_{se})}{\phi}$ (8.33)

From the equation (8.33), we find that as the load on the motor increases, there are two factors which influence the speed of the motor.

(i) $I_a (R_a + R_{se})$ increases and hence the speed decreases.
(ii) The flux ϕ also increases due to which the speed decreases.

But it has been observed that the decrease of speed due to the first factor is negligibly small as compared to the decrease in speed due to the second factor. Hence for all practical purpose, we can say

$$N \alpha \frac{1}{\phi} \quad \text{but} \quad \phi \alpha I_a, \quad \therefore N \alpha \frac{1}{I_a} \qquad (8.34)$$

The variation of speed with respect to I_a is as shown in fig. 8.13.

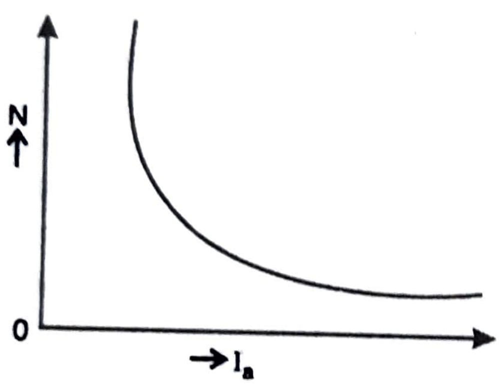


Fig.8.13

From the characteristic, we observe that, as the load increases, the speed decreases over a wide range. Hence, a D.C. series motor is considered as a variable speed motor.

At no load, I_a is very small and hence the speed will be dangerously high as per equation (8.34). Hence, if a D.C. series motor is started without any load on it, the speed is very high and it may run out of the foundation due to the centrifugal forces set up. Hence, a D.C. series motor should never be started without load.

(c) N / T_a Characteristic:

From the N / I_a characteristic of a D.C. series motor shown in fig.8.13, we find that, when I_a is small, N is very high.

But, $T_a \alpha I_a^2$ or $I_a \alpha \sqrt{T_a}$

$$\therefore N \alpha \frac{1}{\sqrt{T_a}} \qquad (8.35)$$

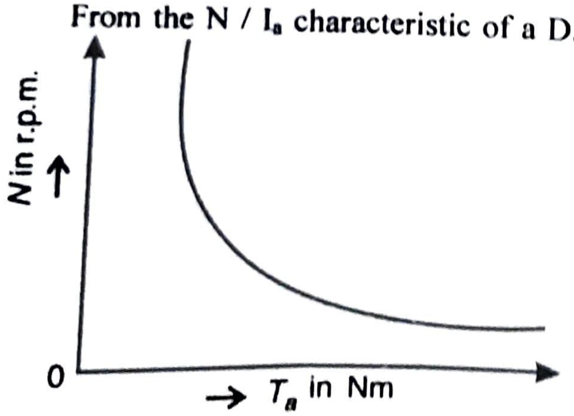


Fig.8.14

For smaller values of T_a, N is very large and for higher value of T_a the speed decreases. The variation of speed with respect to torque T_a is as shown in Fig.8.14.

8.13 Characteristics of D.C. Compound Motors:

(a) T_a / I_a Characteristic:

In the case of a cumulatively compounded D.C. motor, as the load increases, I_a also increases. As the current I_a increases, the flux ϕ_{se} produced by the series field also increases but as the shunt field current I_{sh} remains constant, the flux ϕ_{sh} produced by it also remains constant. However the total flux ϕ which is the sum of ϕ_{se} and ϕ_{sh} increases.

We know that, $T_a \alpha \phi I_a$

Hence, the torque produced also increases, but at a faster rate than in the case of D.C. shunt motor, and at a lesser rate than in the case of D.C. series motor. The variation of T_a with respect to I_a is shown in Fig. 8.15.

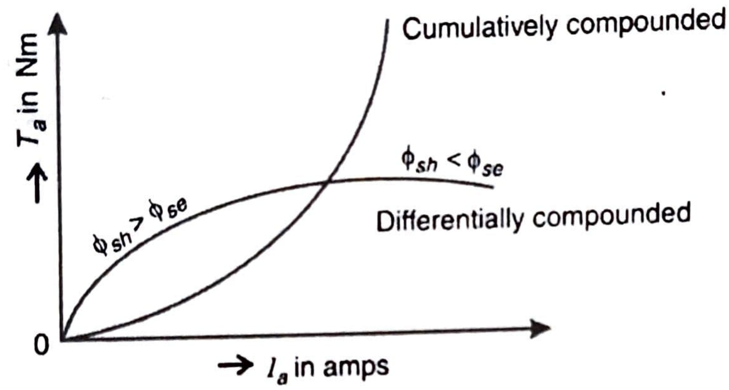


Fig.8.15

A cumulatively compounded D.C. motor has a starting torque more than that of a D.C. shunt motor and less than that of a D.C. series motor.

In the case of a differentially compounded D.C. motor, as the load increases, I_a increases. As I_a flowing through the series field winding increases, the flux ϕ_{se} produced by it also increases. The flux ϕ_{sh} produced by the shunt field winding remains constant. ϕ_{se} opposes ϕ_{sh} and hence the resultant flux is given by,

$$\phi = \phi_{sh} - \phi_{se}$$

As the armature torque $T_a \alpha \phi I_a$, the increase of I_a increases the torque T_a, but the decrease of ϕ decreases the torque T_a.

As long as $\phi_{sh} > \phi_{se}$, the torque T_a increases with I_a, but once $\phi_{se} > \phi_{sh}$ the torque T_a starts decreasing with the increase of I_a. The variation of T_a with respect to I_a is as shown in Fig. 8.15. The decrease of torque with the increase of load is an undesirable characteristic.

(b) N / I_a Characteristic:

We know that, for a D.C. motor, $N \alpha \dfrac{E_b}{\phi} \alpha \dfrac{V - I_a R_a}{\phi}$ (8.36)

For a cumulatively compounded D.C. motor, as the load increases I_a also increases and the resultant flux is given by,

$$\phi = \phi_{sh} + \phi_{se}$$

As I_a increases, ϕ_{se} increases and hence, the resultant flux also increases. Hence, due to increase of I_a, the speed decreases as I_aR_a increases and it is further decreased due to increase of ϕ_{se}. Hence, the speed decreases faster than a D.C. shunt motor and slower than a D.C. series motor. The variation of N with respect to I_a is as shown in Fig.8.16.

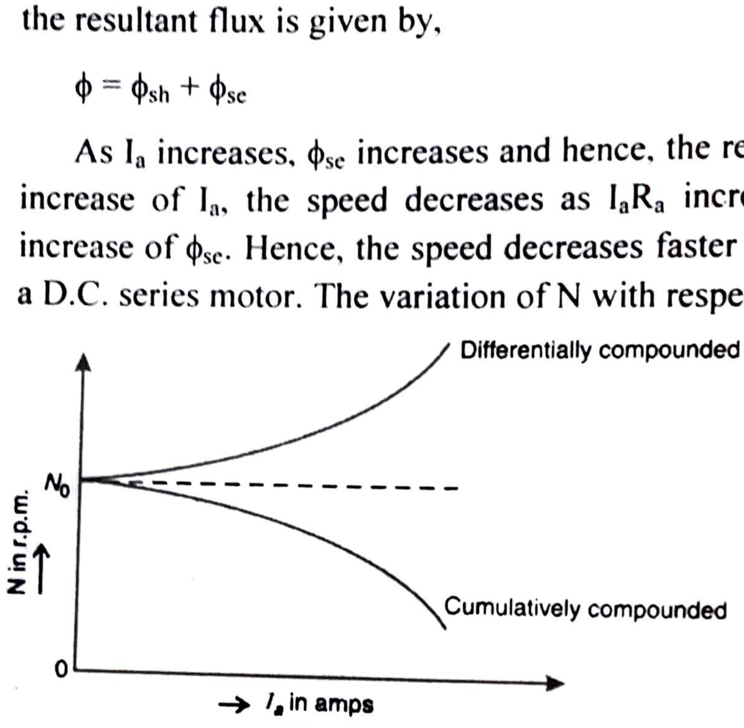


Fig.8.16

In the case of a differentially compounded motor, as I_a increases, the speed decreases due to increase of I_aR_a, but the resultant flux $\phi = \phi_{sh} - \phi_{se}$ decreases due to which the speed increases. The decrease of speed due to increase of I_aR_a is very small compared to the increase of speed due to the decrease of ϕ. Hence, with the increase of I_a, the speed actually increases. This characteristic of the speed increasing on load is also an undesirable characteristic.

(c) N / T_a Characteristic:

We know that, for a D.C. motor, $T_a \alpha \phi I_a$ (8.37)

For a cumulatively compounded motor as the load increases, I_a also increases. As I_a increases, the flux $\phi = \phi_{sh} + \phi_{se}$ also increases. Hence, T_a increases faster and the speed also decreases faster.

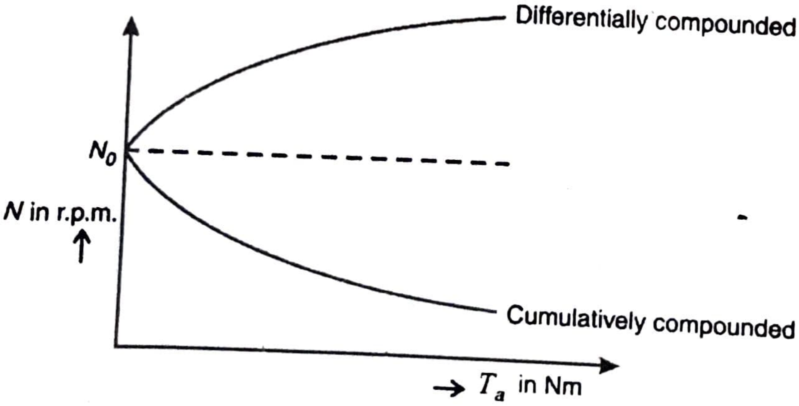


Fig.8.17

For a differentially compounded motor, as the load increases, I_a also increases. As I_a incre-ases, the flux $\phi = \phi_{sh} - \phi_{se}$ decreases and hence torque T_a decreases faster and the speed also increases faster. The plot of N with respect to T_a is as shown in Fig. 8.17.

8.14 Applications of D.C. Motors:

(a) D.C. Shunt Motors:

From the study of the characteristics of a D.C. shunt motor, we realize that it has a medium starting torque and its speed remains almost constant from no load to full load. Hence, it is used where constant speed is required and the starting torque required is not very high, such as for lathes, centrifugal pumps, fans, reciprocating pumps, drilling machines, boring machines, spinning and weaving machines etc.,

(b) D.C. Series Motors:

From the study of the characteristics of D.C. series motor, we realize that, it has a very high starting torque and its speed varies widely from no load to full load. Hence, it is used where very high starting torque and variable speed is required, such as for electric traction work, electric locomotives, trolleys, cranes, hoists, conveyors, air compressors, vacuum cleaners, hair driers, sewing machines etc.,

(c) D.C. Compound Motors:

The characteristics of cumulatively compounded D.C. motor is between those of D.C. shunt motor and D.C. series motor. It has high starting torque and a variable speed. It is used where sudden loads are applied or removed such as for shears, punches, coal cutting machines, elevators, conveyors, heavy planers, rolling mills, ice machines, printing presses, air compressors etc. The differentially compounded D.C. motor has no practical applications, because of its undesirable characteristics.

8.15 Necessity of a Starter for a D.C. Motor:

For a D.C. motor, we know that the armature current is given by,

$$I_a = \frac{V - E_b}{R_a} \tag{8.38}$$

When the motor is at rest, $E_b = 0$, $\therefore \quad I_a = \dfrac{V}{R_a}$

The armature resistance R_a is very small and is usually of the order of 0.5 Ω, for a 5 HP, 220V motor. If a voltage of 220V is applied to the motor, the starting current that flows through the armature is given by,

$$I_a = \frac{220}{0.5} = 440 \text{ A}$$

This current is very large compared to the rated current of the motor which is given by,

$$I_{f\cdot\ell} = \frac{5 \times 735.5}{220} = 16.72 \text{ A}$$

The large current of 440 A that flows through the armature will blow out the fuses or damage the commutator, brushes and the armature winding. Hence, a starter is necessary for a D.C. motor.

A starter for a D.C. motor is nothing but a resistance connected in series with the armature during starting and which is gradually cut out, so that, the motor picks up its rated speed. When the motor is running, back E.M.F. is developed and the armature current will be within the limits and the starting resistance is not required.