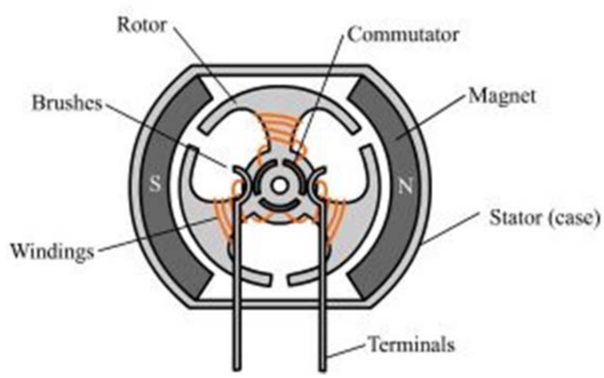
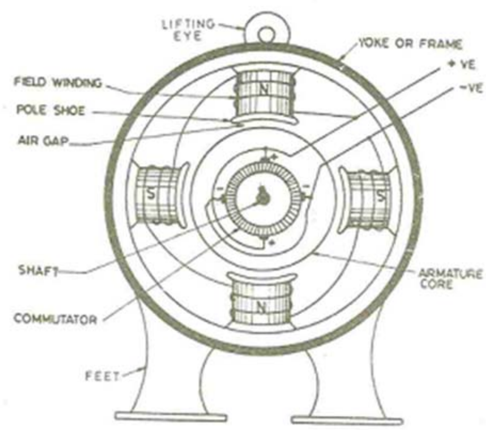
DC Machine

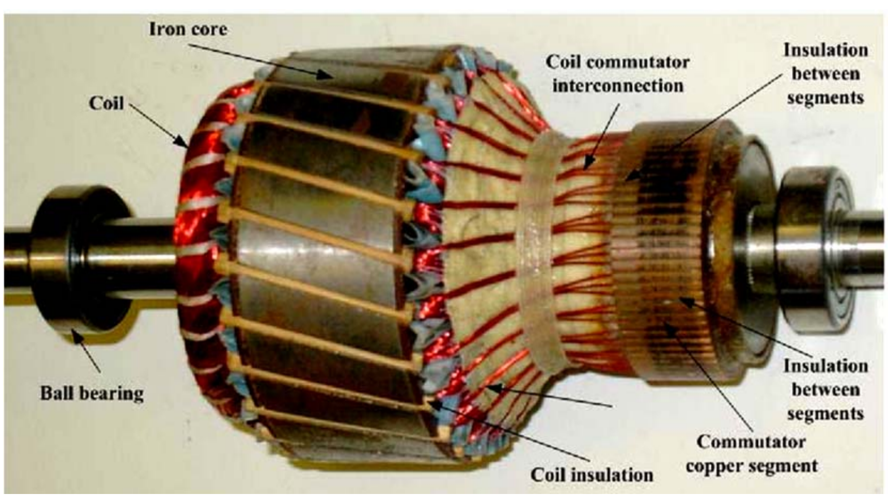
A dc machine is a device which converts mechanical energy into electrical energy into mechanical energy or vice versa. When the device or machine acts as a generator mechanical energy is converted into electrical energy and when machine acts as motor electrical energy is converted into mechanical energy. Dc generator and motors are very similar to each other in essential parts and construction.

Construction of a DC machine



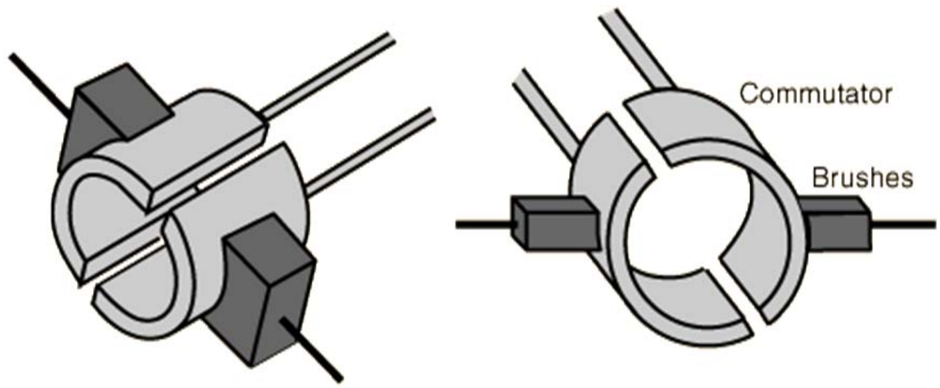


1) **Field Magnet**: It is a strong permanent magnet incase of small machine or an electromagnet incase of large machine which is comprise of following parts:
    a. Pole Pieces: They are pole cores made of cast steel with laminated shoes screws on the outer body of machine.
    b. Field windings (Pole Coils): It is a coil wound around the pole pieces. When dc current pass through it magnetic field required in machine is generated.
2) **Armature Coil**: it is a coil wound on a laminated core of soft iron. Armature is placed between the poles of magnets and is free to rotate about its central axis.



3) Commutator and Brushes:

Commutator and brush converts the ac current produced (or required) in armature conductors into (or from) DC current on terminals. Commutator consists of wedge-shaped copper segments, insulated fron each other a nd assembled side by side to form a ring.



Brushes ride on the commutators and collect(or supply) current from (or to) Armature conductors. They are made of carbon and held in contact with the commutator by using spring.

Working Principle of DC Generator:

Working Principle of DC machines are based on Faraday's laws of electromagnetic induction. In case of generator when a coil is rotated in a magnetic field the flux linked with the coil changes due to the motion of the coil and due to change in this flux linkage, an emf is induced on the coil ad per Faraday's Law. This EMF is given by:

$$e = Bl\ v\ sin\theta$$

Where ,

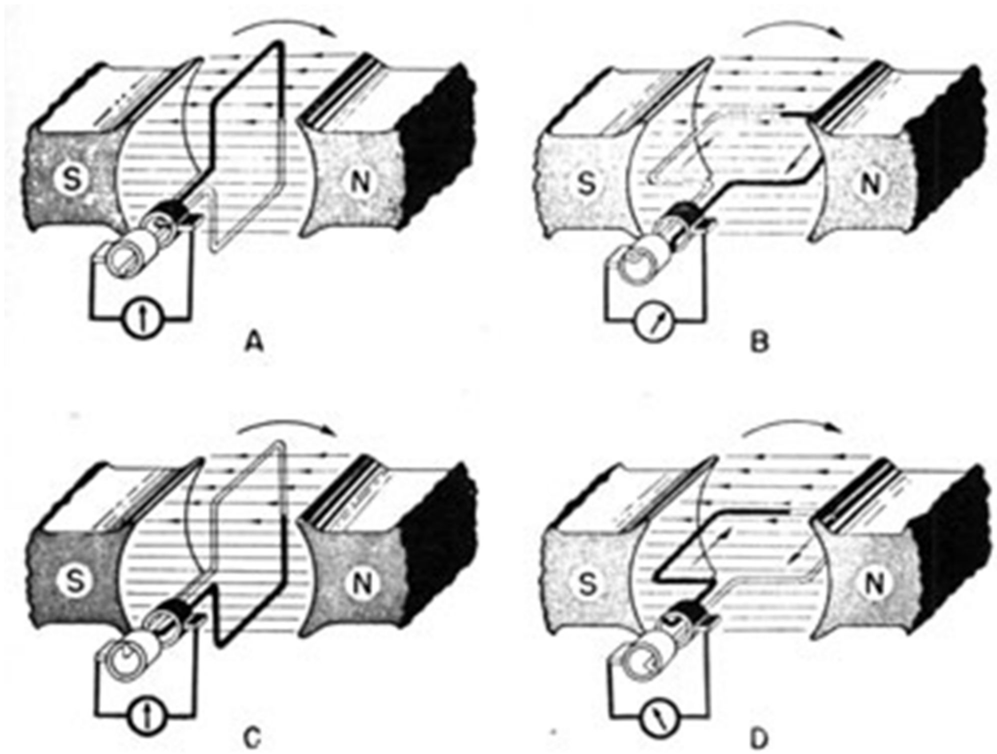
B is the magnetic flux density

l is effective length of conductor

V is velocity of conductor

θ is the angle between direction of magnetic field and motion of conductor

Let us consider a coil, rotating in a constant speed in a uniform magnetic field. Since the flux linked with the coil is different at different position of coil, emf induced also changes accordingly:

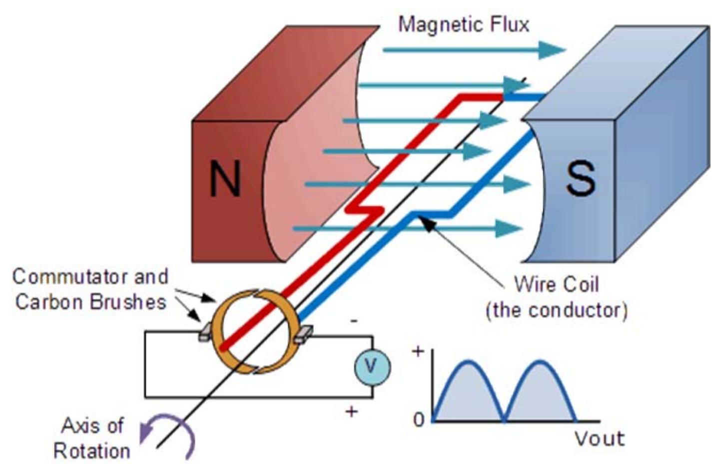


When coil is at vertical position (A) i.e. motion of the coil is making an angle $\theta = 0^0$ to the direction of magnetic field, the change of flux linkage is zero and hence the induced emf is also zero. As the coil rotates flux linkage increase till the angle becomes $\theta = 90^0$. In this position the rate of change of flux linkage is maximum. The direction of induced emf is given by Fleming's Right hand Rule.

For next 90° revolution the rate of change of flux linkage decrease gradually and becomes zero again at $\theta = 180^0$. After that the rate of change of flux linkage increases until the angle becomes 270° but the direction will be opposite, because $e = Bl\ v\ sin270$

As the coil rotates further the induced voltage reduced gradually and becomes zero at $\theta = 360^0$ and one cycle will be completed. Hence the completed cycle of internally induced emf on armature coil is sinusoidal or AC in nature.

Commutator converts the alternating current produced in the armature coil into direct current with the help of carbon brushes attached to it.



E.M.F Equation of DC Generator

Derive the emf equation of a DC generator.

E= dΦ/dt = ZΦN/60 x P/A Volt

Where, Φ = flux/pole in wb; Z = total number of armature conductors = No.of slots x No.of conductors/slot; P = No.of generator poles; A = No.of parallel paths in armature; N = armature rotation in revolutions per; minute (RPM); E = e.m.f induced in any parallel path in armature

Let

Φ = flux/pole in wb

Z = total number of armature conductors = No.of slots x No.of conductors/slot

P = No.of generator poles

A = No.of parallel paths in armature

N = armature rotation in revolutions per minute (RPM)

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

Then

Generated e.m.f E_g = e.m.f generated in any one of the parallel paths i.e E.

Average e.m.f geneated /conductor = **dΦ/dt** volt (n=1)

Now, flux linkage per conductor in one revolution **dΦ = ΦP** Wb

No.of revolutions per second = N/60

Time for one revolution, **dt = 60/N** second

Hence, according to Faraday's Laws of Electromagnetic Induction,

E.M.F generated/conductor is

dΦ/dt = ΦPN/60

For a **wave-wound** generator

No.of parallel paths (A)= 2

No.of conductors (in series) in one path = Z/2

E.M.F. generated/path is given by

E = ΦPN/60 x Z/2 = ZΦPN / 120 volt

For a **lap-wound** generator

No.of parallel paths (A) = P

No.of conductors (in series) in one path = Z/P

E.M.F.generated/path

E = ΦPN/60 x Z/P = ZΦN / 120 Volt

In general generated e.m.f

E= dΦ/dt = ZΦN/60 x P/A Volt

where A = 2 - for wave-winding

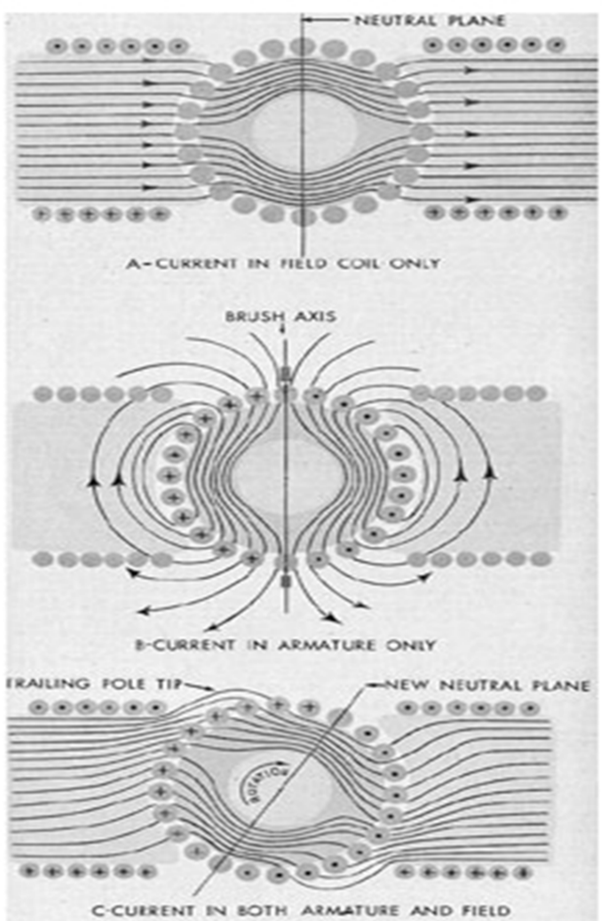
= P - for lap-winding

Commutation:

The armature conductor of dc generators produces an alternating current. The reversal of direction of generated current in armature conductor usually takes place along the Magnetic Neutral Axis MNA or brush axix. As the brush spans, during rotation, the particular coil undergoing the process of reversal of direction of current passing through, get short circuited. This process by which the direction of current in armature conductor while crossing the MNA, get short-circuited, is called Commutation and brief period during which the short circuiting of coil remains is known as commutation period . If current reversal takes more than commutation period, sparking between commutator and brushes occurs. Spark less commutation can be achieved by

- Using Interpoles
- increasing brush contact resistance
- Shifting brush axis

Armature Reaction:



There are two kinds of magnetic fluxes acting in DC Generator; the first one is because of the stator poles called main flux, while the second one is because of the current flowing in the armature called armature flux. The effect of armature magnetic field setup by armature current on main magnetic field is called armature reaction. Armature reaction weaken as well as distort the main flux, thus the overall effective flux in DC Generator decrease.

The armature reaction has two components namely: demagnetizing component and distorting component. With the increase in armature current, both components increase.

D.C. Motor

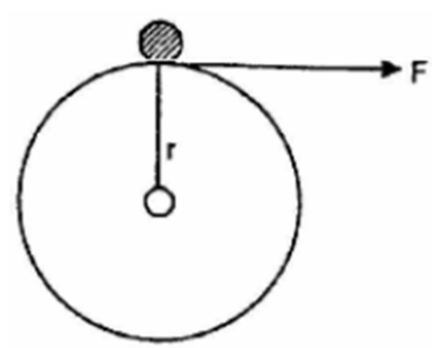
It is Similar in construction to a DC generator

D.C. Motor Characteristics

The performance of a d.c. motor can be judged from its characteristic curves known as motor characteristics, following are the three important characteristics of a d.c. motor:
(i) Torque and Armature current characteristic (Ta/Ia) It is the curve between armature torque Ta and armature current Ia of a d.c. motor. It is also known as electrical characteristic of the motor.
(ii) Speed and armature current characteristic (N/Ia) It is the curve between speed N and armature current Ia of a d.c. motor. It is very important characteristic as it is often the deciding factor in the selection of the motor for a particular application.
(iii) Speed and torque characteristic (N/Ta) It is the curve between speed N and armature torque Ta of a d.c. motor. It is also known as mechanical characteristic.

Armature Torque of D.C. Motor

Torque is the turning moment of a force about an axis and is measured by the product of force (F) and radius (r) at right angle to which the force acts.
T = F x r
In a d.c. motor, each conductor is acted upon by a circumferential force F at a distance r, the radius of the armature. Therefore, each conductor exerts a torque, tending to rotate the armature. The sum of the torques due to all armature conductors is known as gross or armature torque (Ta).
Let in a d.c. motor
r = average radius of armature in m



l = effective length of each conductor in m
Z = total number of armature conductors
A = number of parallel paths
i = current in each conductor = Ia/A
B = average flux density inWb/m2
f = flux per pole inWb
P = number of poles
Force on each conductor, F = B i l newtons

Torque due to one conductor = F x r (newton- metre)
Total armature torque, Ta = Z F r (newton-metre)
= Z B i l r
Now i = Ia/A, B = π /a where a is the x-sectional area of flux path per pole at radius r. Clearly,
a = 2π r l /P.

$$T_a = Z \times \left(\frac{\phi}{2}\right) \times \left(\frac{I_a}{A}\right) \times \ell \times r$$

$$= Z \times \frac{\phi}{2\pi r \ell / P} \times \frac{I_a}{A} \times \ell \times r = \frac{Z\phi I_a P}{2\pi A} \text{ N-m}$$

$$T_a = 0.159 Z\phi I_a \left(\frac{P}{A}\right) \text{ N-m}$$

Since Z, P and A are fixed for a given machine,

$$T_a \propto I_a$$

Hence torque in a d.c. motor is directly proportional to flux per pole and armature current.
(i) For a shunt motor, flux f is practically constant.

$$T_a \propto \phi I_a$$

(ii) For a series motor, flux f is directly proportional to armature current Ia provided magnetic saturation does not take place.

$$T_a \propto I_a^2$$

Speed of the DC motor

$$E_b = V - I_a R_a$$

$$E_b = \frac{P\phi ZN}{60\ A}$$

$$\frac{P\phi ZN}{60\ A} = V - I_a R_a$$

$$N = \frac{(V - I_a R_a)}{\phi} \frac{60\ A}{PZ}$$

$$N = K \frac{(V - I_a R_a)}{\phi} \qquad \text{where} \qquad K = \frac{60\,A}{PZ}$$

$$V - I_a R_a = E_a$$

$$\therefore \quad N = K \frac{E_b}{\phi}$$

$$N \propto \frac{E_b}{\phi}$$