DC MACHINE

Md. Kamrul Hasan

Preliminary Notes

- DC power systems are not very common in the contemporary engineering practice. However, DC motors still have many practical applications, such automobile, aircraft and portable electronics, in speed control applications….

- Advantage of DC motor is that it is easy to control their speed in a wide variation.

- DC machines have DC outputs just because they have a mechanism converting AC voltages to DC voltages

- This converting mechanism is called commutation

- DC machines are also called commutating machines

Electromagnetic Induction

- Magnetic Field
- Faraday’s law of electromagnetic induction
- Voltage induced in a conductor
- Direction of induced voltage
- Lenz’s law

MAGNETIC FIELDS

- Surrounding a permanent magnet there exists a magnetic field, which can be represented by magnetic flux lines similar to electric flux lines

- Magnetic flux lines, however, do not have origins or terminating points as do electric flux lines but exist in continuous loops, as shown in Fig. 11.1. The symbol for magnetic flux is the Greek letter ϕ

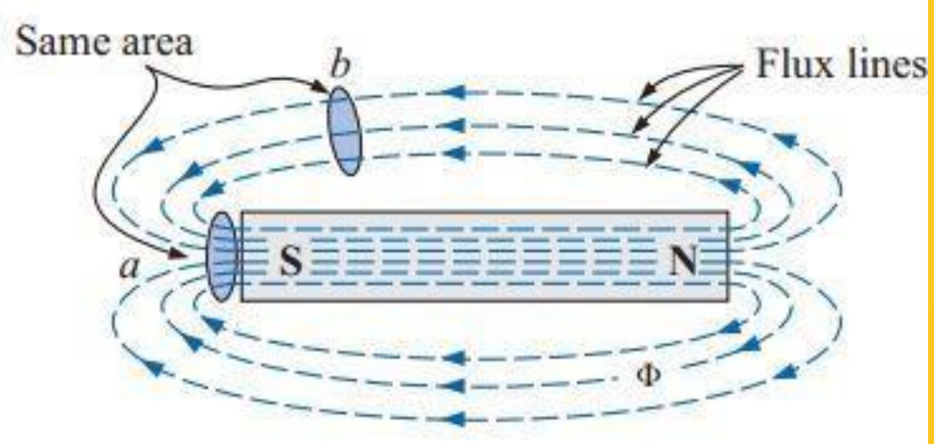


FIG. 11.1
Flux distribution for a permanent magnet.

MAGNETIC FIELDS

- The magnetic flux lines radiate from the north pole to the south pole, returning to the north pole through the metallic bar.

- The strength of a magnetic field in a particular region is directly related to the density of flux lines in that region.

- For example, the magnetic field strength at *a* is twice that at *b* since twice as many magnetic flux lines are associated with the perpendicular plane at *a* than at *b*.

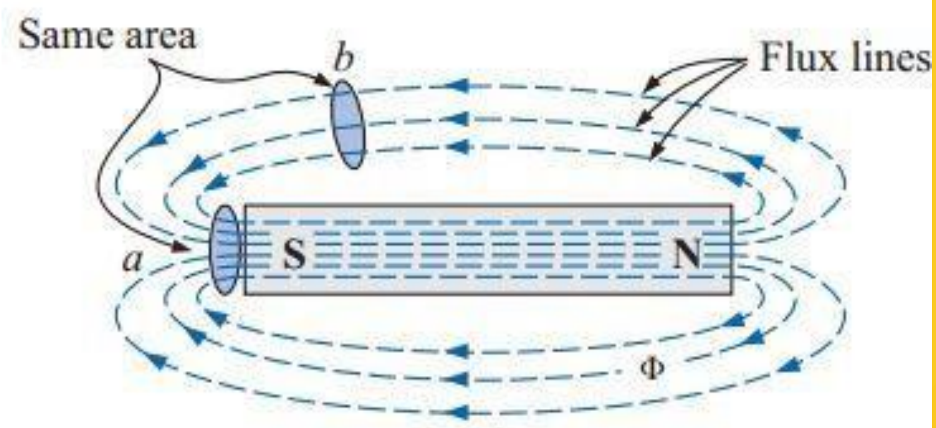


FIG. 11.1
Flux distribution for a permanent magnet.

MAGNETIC FIELDS

- The continuous magnetic flux line will strive to occupy as small an area as possible. This will result in magnetic flux lines of minimum length between the poles, as shown in Fig. 11.2

- If like poles are brought together, the magnets will repel and the flux distribution will be as shown in Fig. 11.3

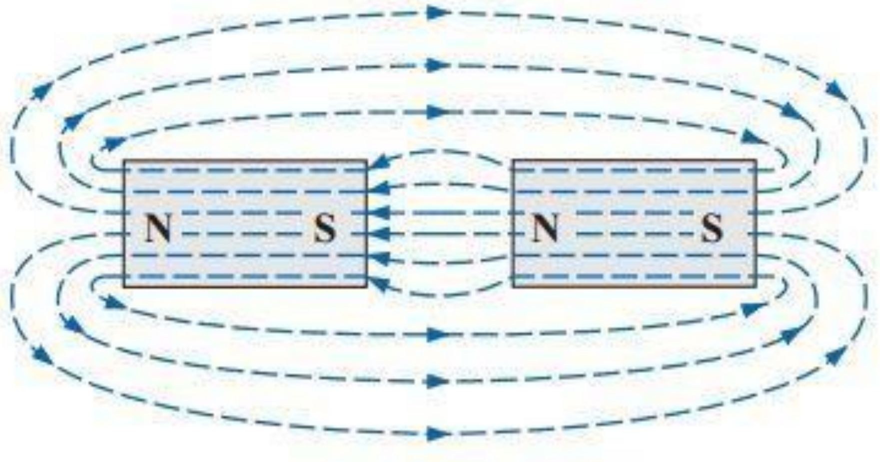


FIG. 11.2
Flux distribution for two adjacent, opposite poles.

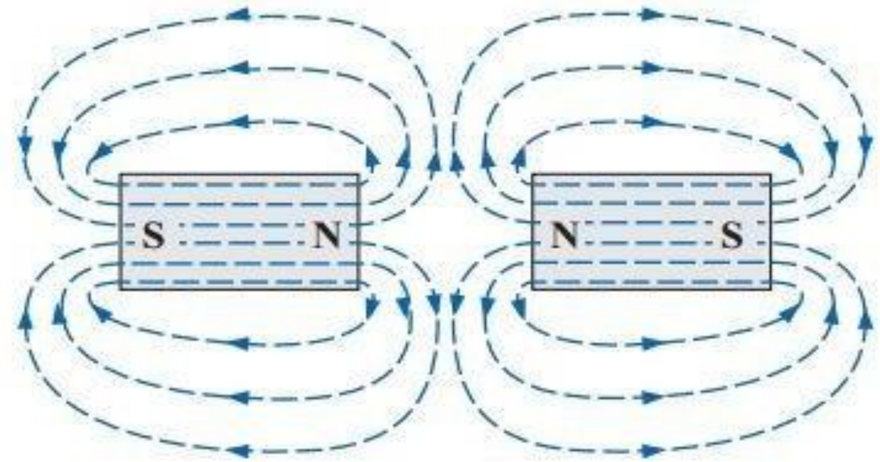


FIG. 11.3
Flux distribution for two adjacent, like poles.

MAGNETIC FIELDS

- If a nonmagnetic material, such as glass or copper, is placed in the flux paths surrounding a permanent magnet, there will be an almost unnoticeable change in the flux distribution

- if a magnetic material, such as soft iron, is placed in the flux path, the flux lines will pass through the soft iron rather than the surrounding air because flux lines pass with greater ease through magnetic materials than through air.

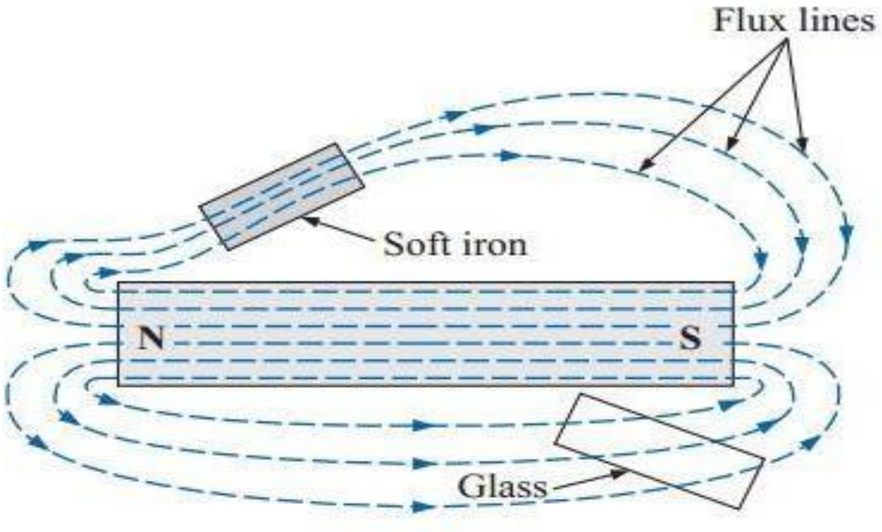


FIG. 11.4
Effect of a ferromagnetic sample on the flux distribution of a permanent magnet.

MAGNETIC FIELDS

- This principle is put to use in the shielding of sensitive electrical elements and instruments that can be affected by stray magnetic fields.

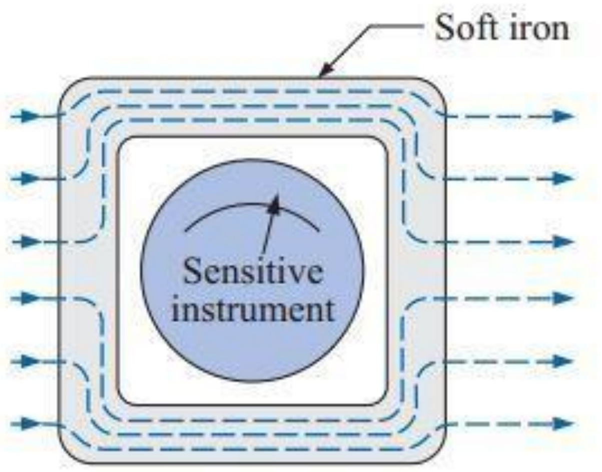


FIG. 11.5
Effect of a magnetic shield on the flux distribution.

MAGNETIC FIELDS

- A magnetic field is present around every wire that carries an electric current.
- The direction of the magnetic flux lines can be found simply by placing the thumb of the right hand in the direction of conventional current flow and noting the direction of the fingers

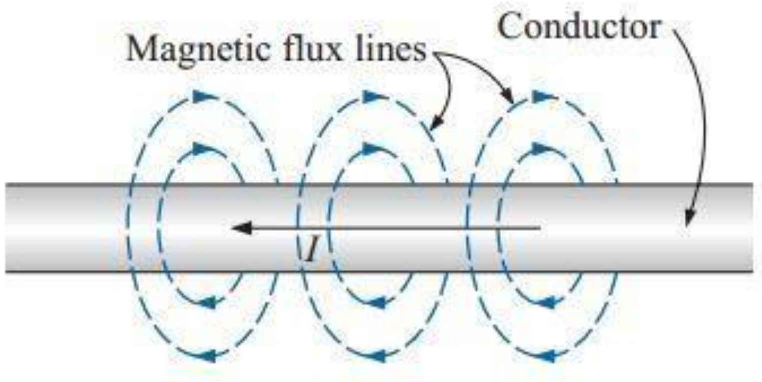


FIG. 11.6
Magnetic flux lines around a current-carrying conductor.

MAGNETIC FIELDS

- If the conductor is wound in a single-turn coil, the resulting flux will flow in a common direction through the center of the coil.

- A coil of more than one turn would produce a magnetic field that would exist in a continuous path through and around the coil.

- The flux distribution of the coil is quite similar to that of the permanent magnet.

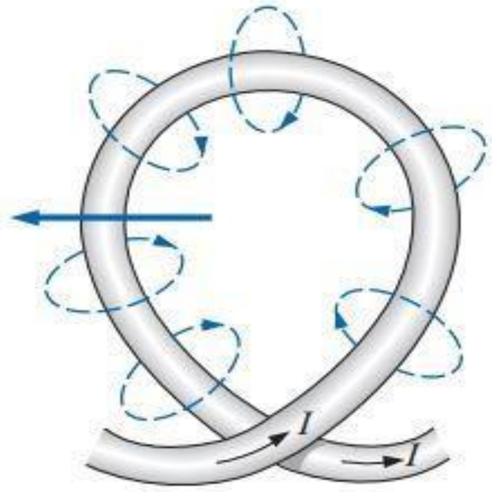


FIG. 11.7
Flux distribution of a single-turn coil.

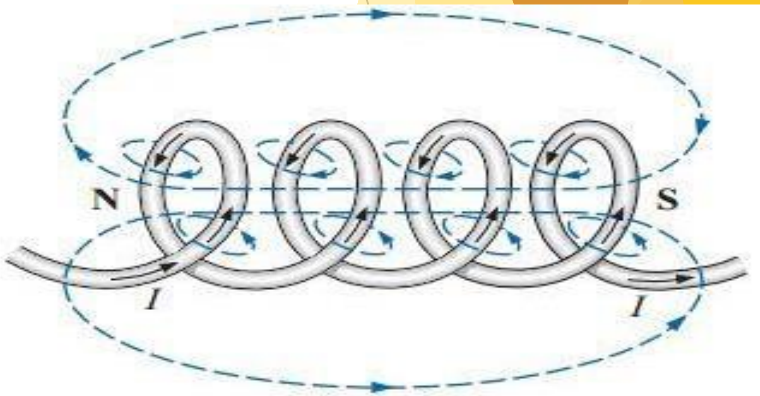


FIG. 11.8
Flux distribution of a current-carrying coil.

MAGNETIC FIELDS

- The principal difference between the two flux distributions is that the flux lines are more concentrated for the permanent magnet than for the coil.

- So the coil has a weaker field strength.

- The field strength of the coil can be effectively increased by placing certain materials, such as iron, steel or cobalt, within the coil to increase the flux density within the coil.

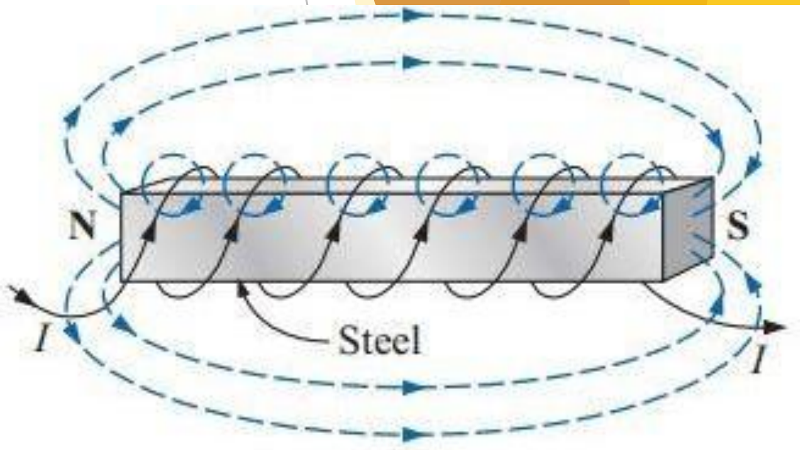


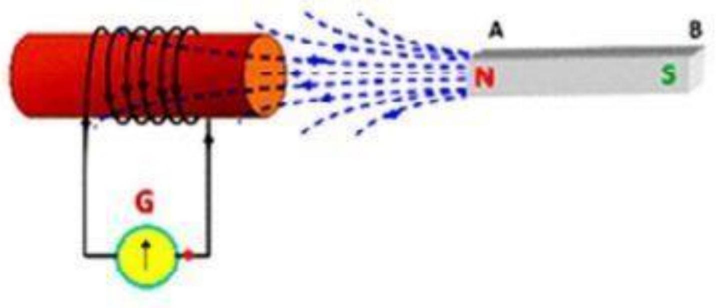
FIG. 11.9
Electromagnet.

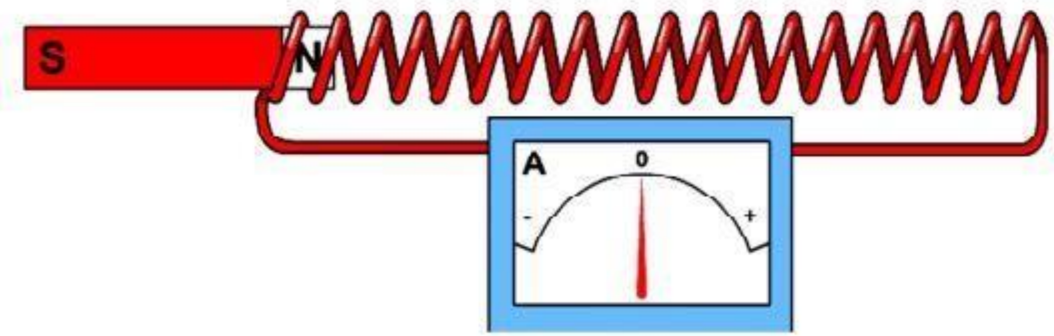
DC Generator

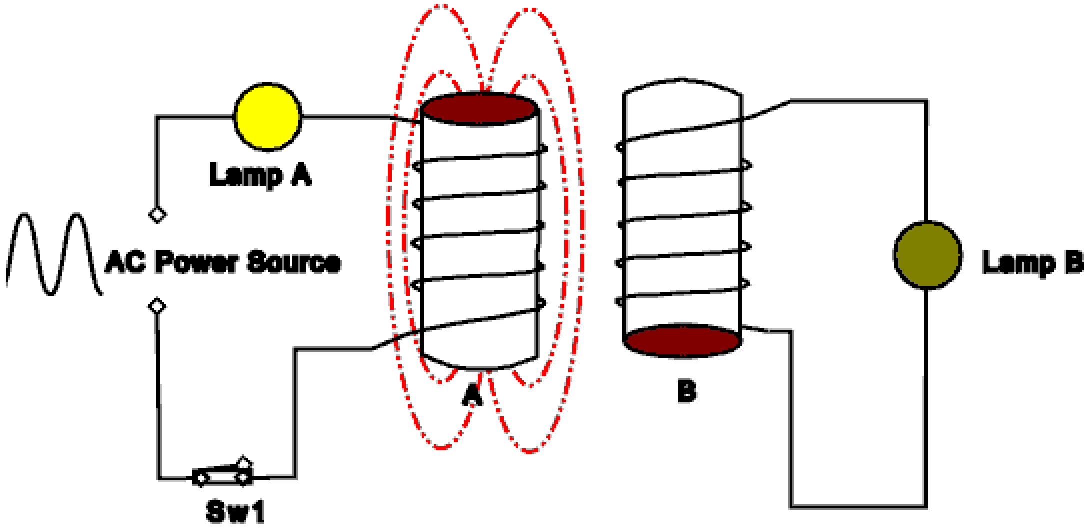
- There are two types of generators–**DC generators** and AC generators.
- Both DC and AC generators convert mechanical power to electrical power.
- A DC generator produces direct power, while an AC generator produces alternating power.
- Both of these generators produce electrical power based on the principle of Faraday's law of electromagnetic induction

Faraday's First Law

- Whenever a conductor is rotated in magnetic field emf is induced in it. If the conductor is closed, current will flow through it which is known as induced current.



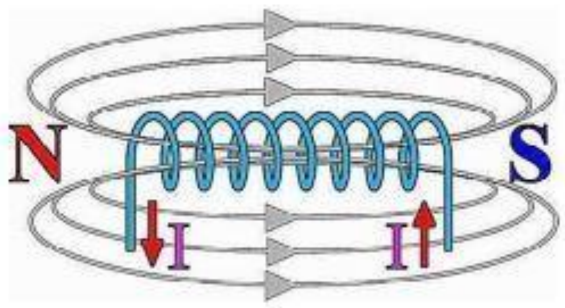


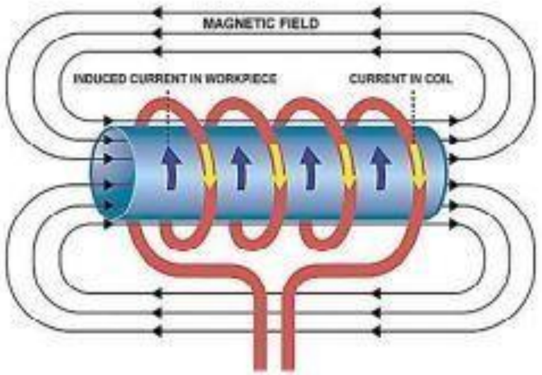


Faraday’s Second Law

- Second law states that induced emf is equal to the rate of change of linkage or flux cut.
- This EMF will cause a current to flow if the conductor circuit is closed.

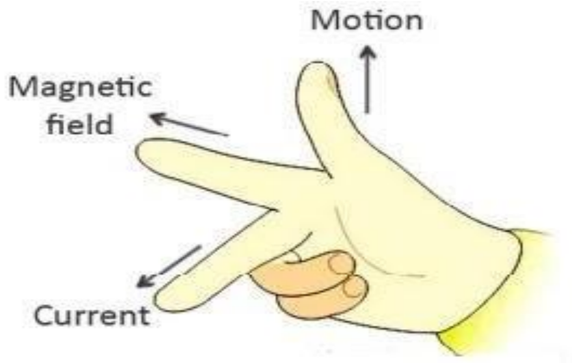
$$EMF = -N\frac{d\Phi}{dt}$$

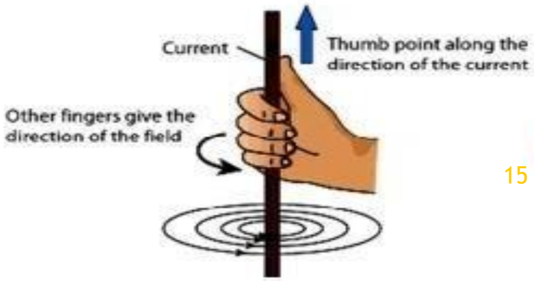


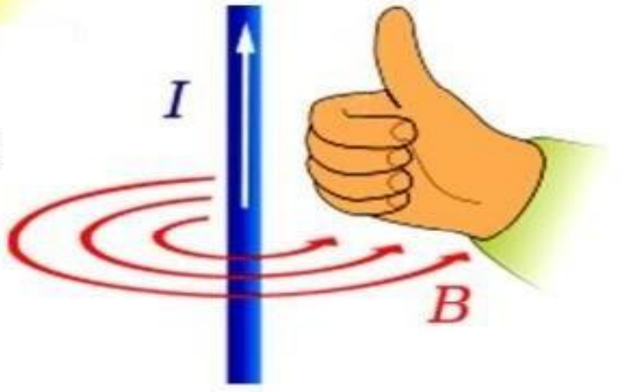


Flemming’s Right Hand Rule

- If you stretch the thumb, index finger, and middle finger of your right-hand perpendicular to each other,
- **Thumbs** indicates the direction of **motion** of the conductor,
- **Index finger** indicates the direction of **the magnetic field,** i.e., N – pole to S – pole, and
- **Middle finger** indicates the direction of flow of **current** through the conductor.

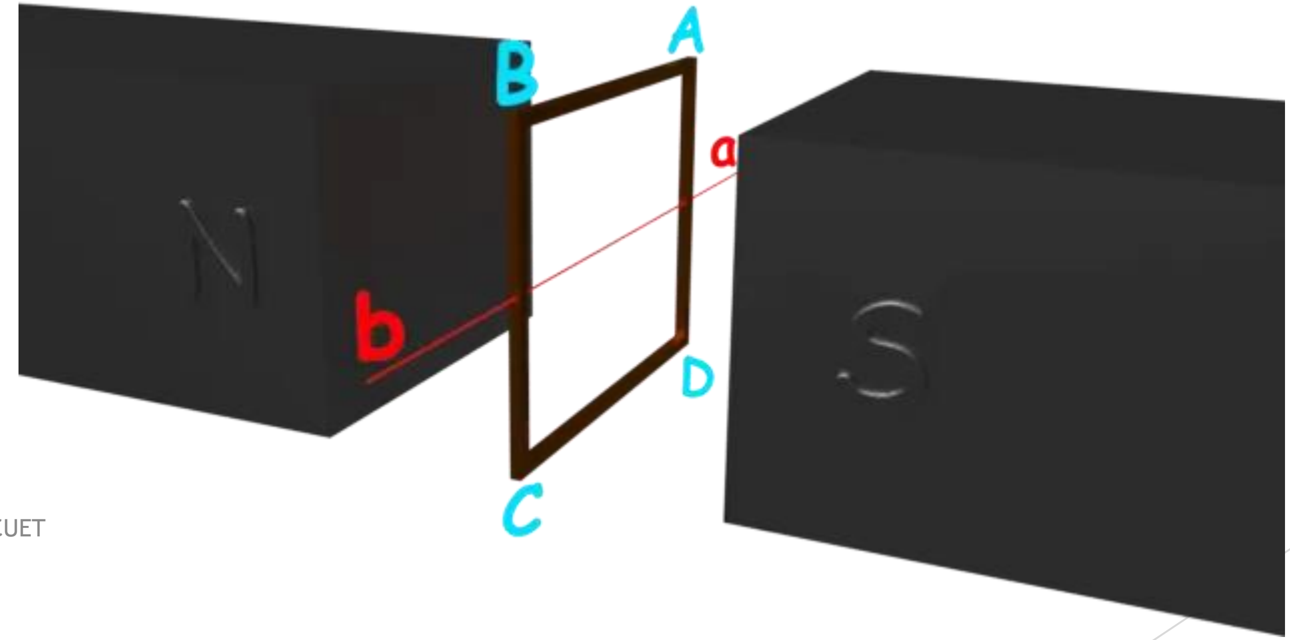






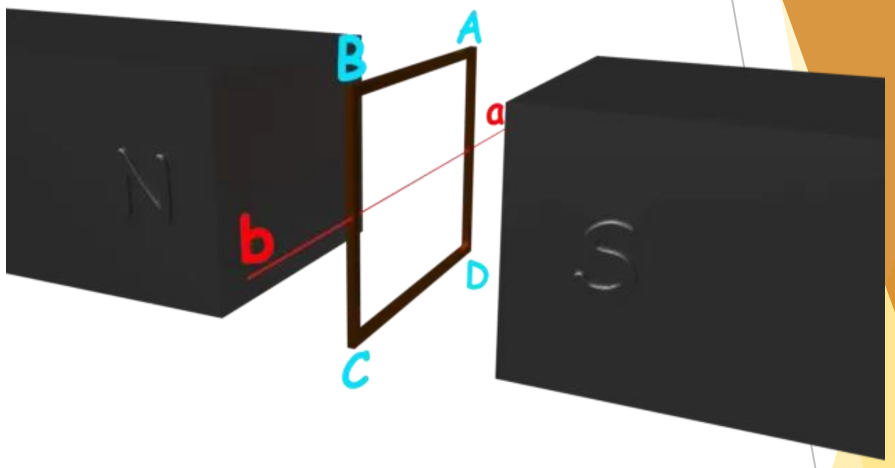
Single Loop DC Generator

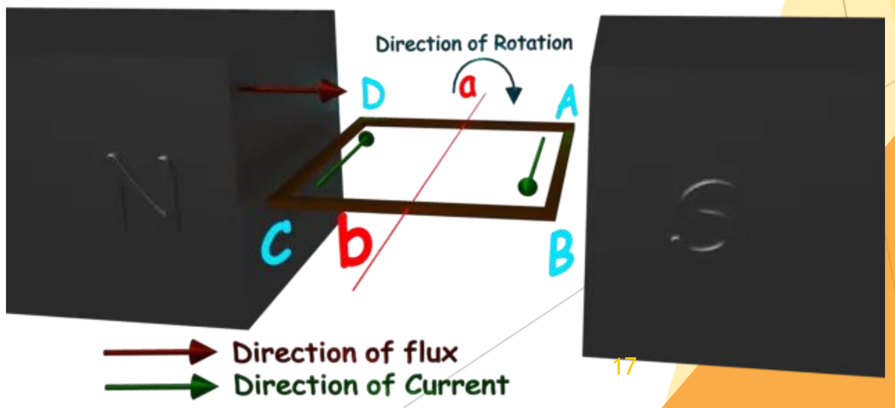
- In the figure below, a single loop of a conductor of rectangular shape is placed between two opposite poles of a magnet.
- Let's consider, the rectangular loop of the conductor is ABCD which rotates inside the magnetic field about its axis ab



Single Loop DC Generator

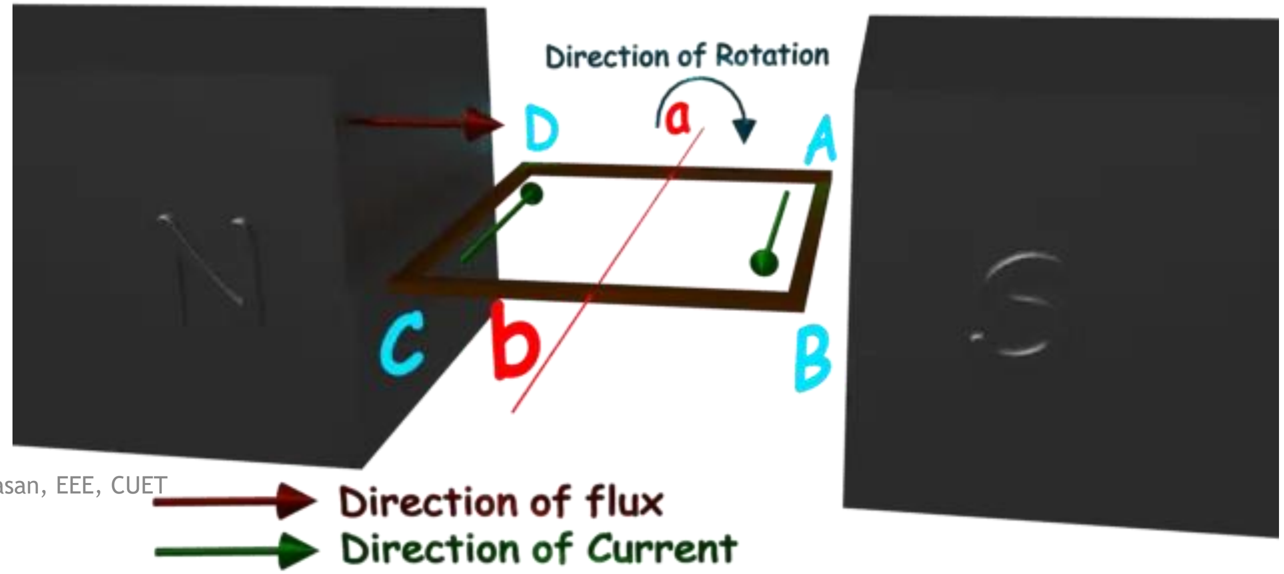
- When the loop rotates from its vertical position to its horizontal position, it cuts the flux lines of the field. As during this movement two sides, i.e., AB and CD of the loop cut the flux lines there will be an EMF induced in both of the sides (AB and BC) of the loop.





Single Loop DC Generator

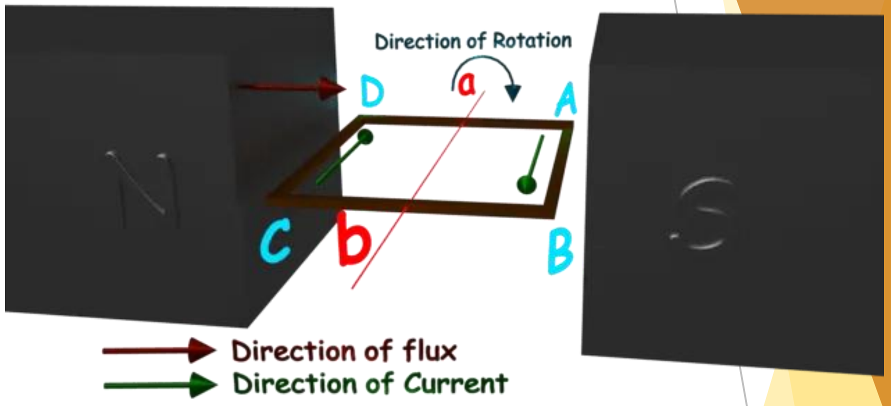
- Now if we apply this right-hand rule, we will see at this horizontal position of the loop, **current will flow from point A to B** and on the other side of the loop, the **current will flow from point C to D**.

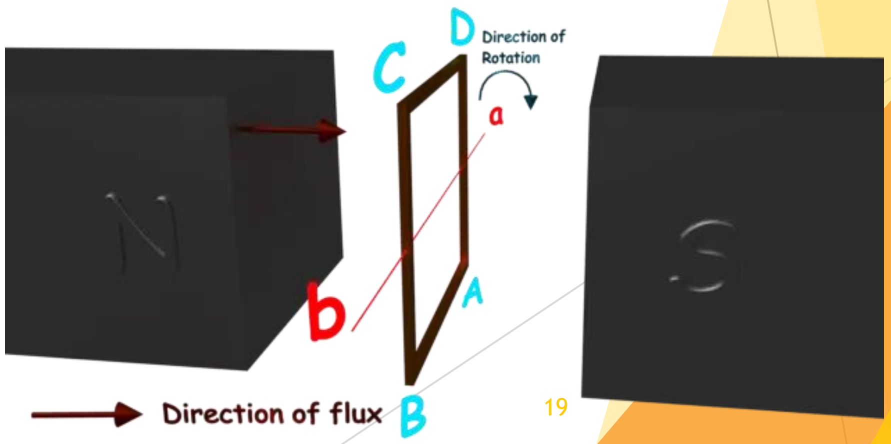


Single Loop DC Generator

- Now if we allow the loop to move further, it will come again to its vertical position, but now the upper side of the loop will be CD, and the lower side will be AB (just opposite of the previous vertical position)

- At this position, the tangential motion of the sides of the loop is parallel to the flux lines of the field. Hence there will be no question of flux cutting, and consequently, there will be no current in the loop.

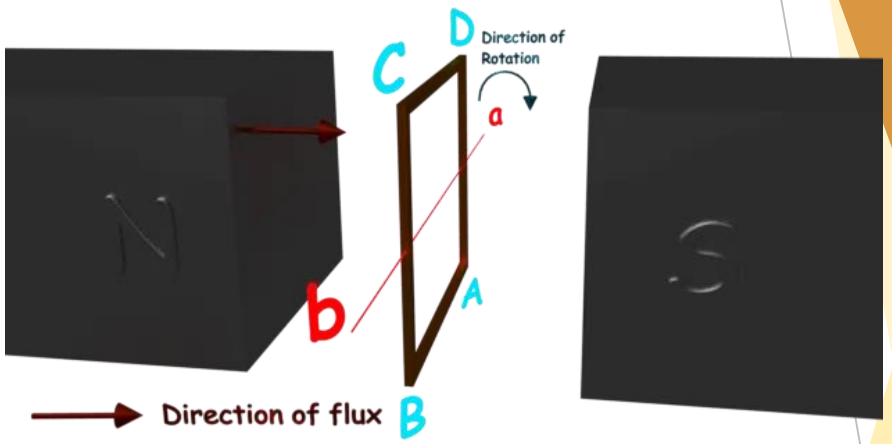


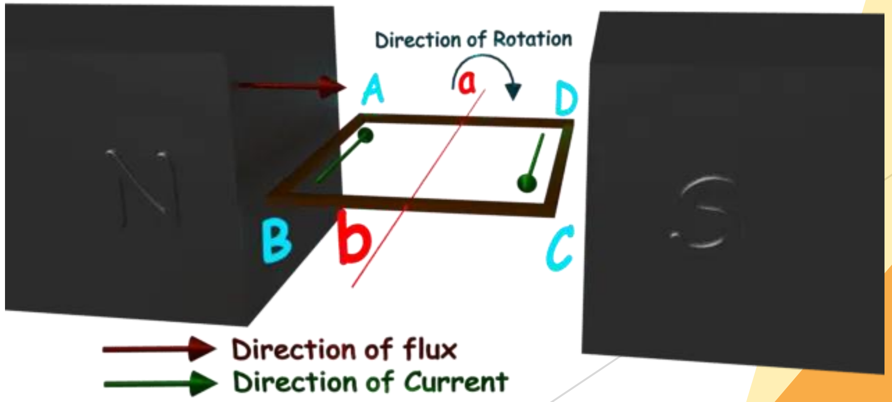


Single Loop DC Generator

- If the loop rotates further, it comes again in a horizontal position. But now, said AB side of the loop comes in front of N pole, and CD comes in front of S pole.

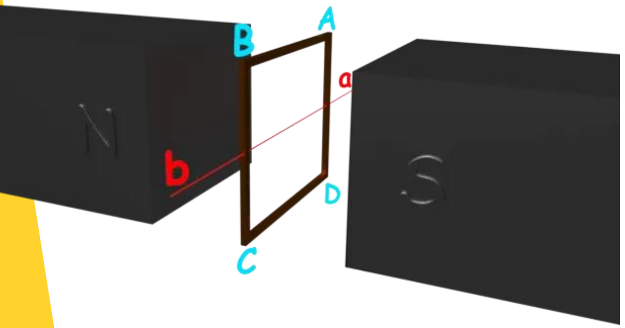
- Here the tangential motion of the side of the loop is perpendicular to the flux lines; hence rate of flux cutting is maximum here, and according to **Flemming's right-hand Rule** , at this position current flows from B to A and on another side from D to C.

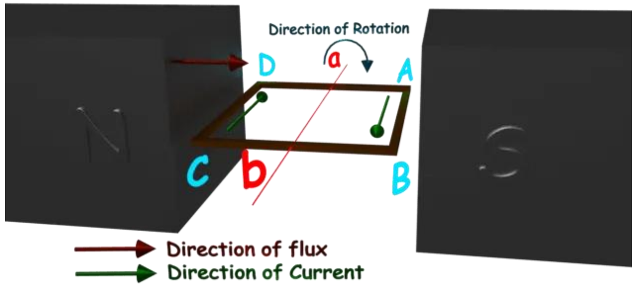


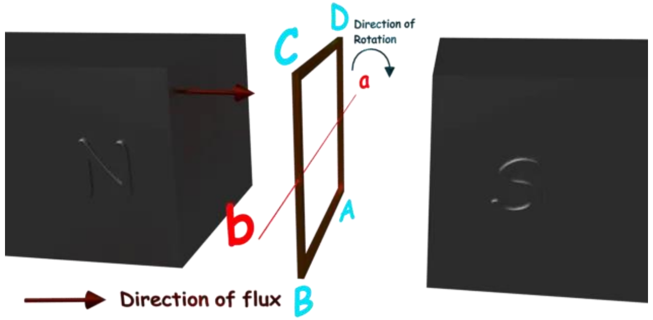


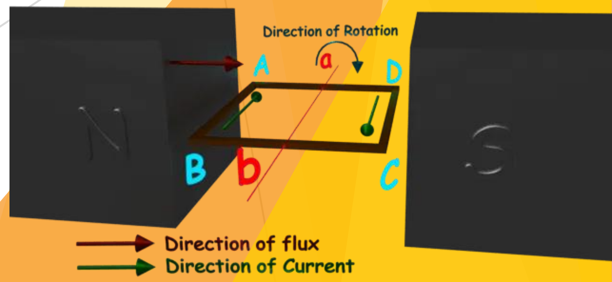
Single Loop DC Generator

- Now if the loop is continued to rotate about its axis. Every time the side AB comes in front of S pole, the current flows from A to B. Again, when it comes in front of N pole, the current flows from B to A.
- Similarly, every time the side CD comes in front of the S pole the current flows from C to D. When the side CD comes in front of the N pole the current flows from D to C.





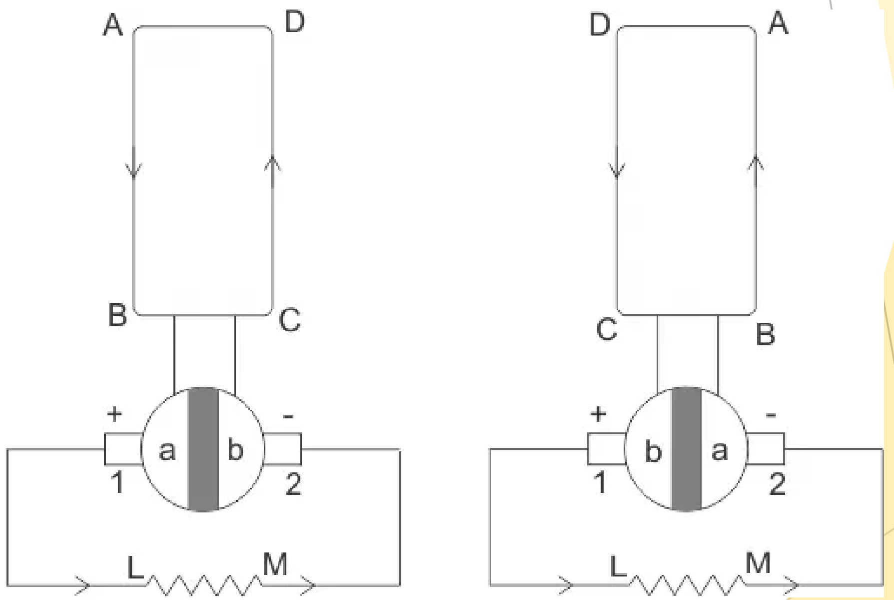




Single Loop DC Generator

- Now the loop is opened and connected with a split ring as shown in the figure below. Split rings, made of a conducting cylinder, get cut into two halves or segments insulated from each other.

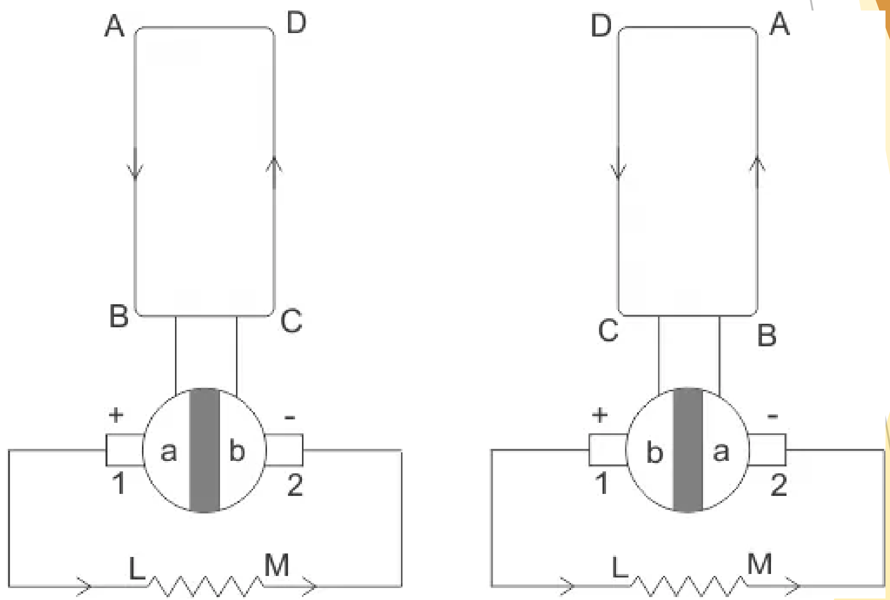
- We connect the external load terminals with two carbon brushes which rest on these split slip ring segment

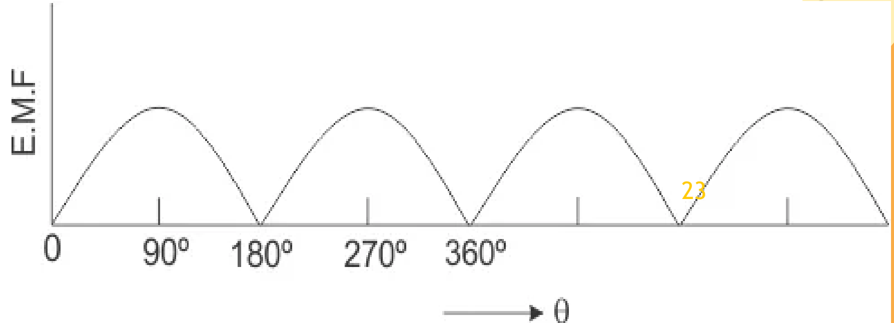


Single Loop DC Generator

- We can see that in the first half of the revolution current always flows along ABLMCD, i.e., brush no 1 in contact with segment a.

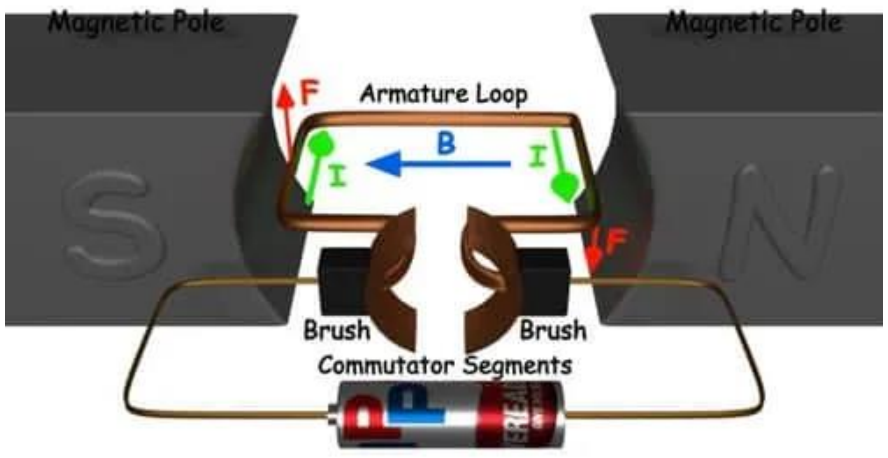
- In the next half revolution, the direction of the induced current in the coil is reversed. But at the same time the position of **segments a and b** are also reversed which results that brush no 1 comes in touch with segment b.



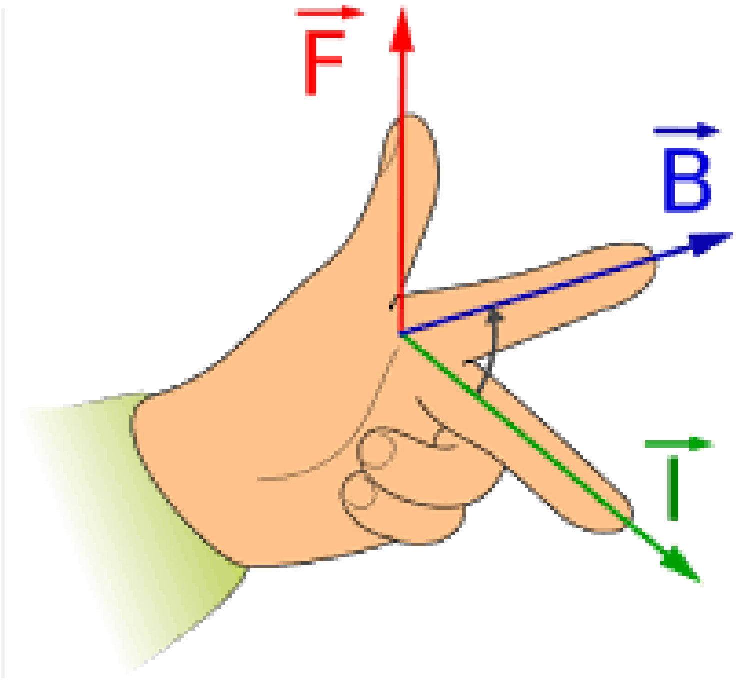


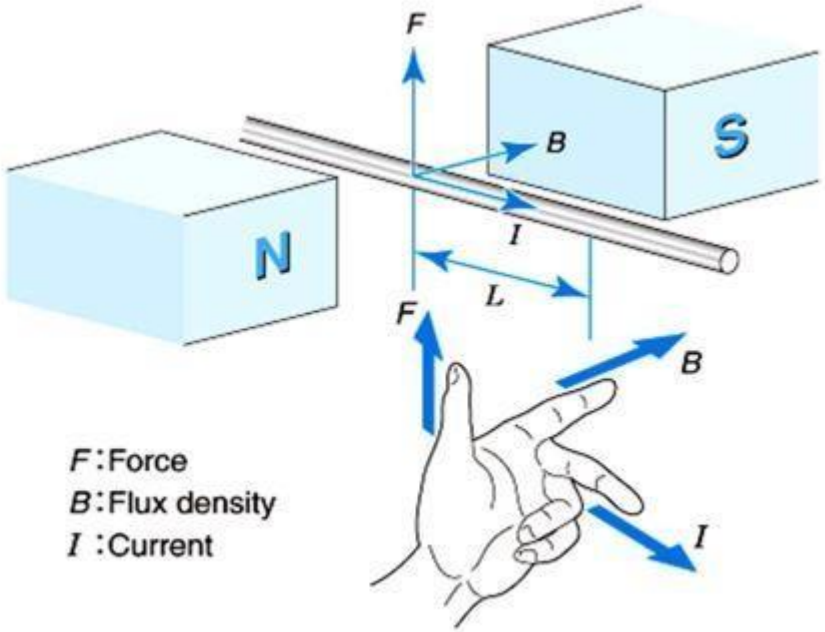
DC Motor

- To understand the **operating principle of DC motor** we need to first look into its single loop constructional feature.



Fleming’s Left Hand Rule





Operation of DC Motor

For the **operation of DC motor**, considering E = 0.

$$dF = dq \times v \times B$$

i.e. it's the cross product of dq v and magnetic field B.

$$dF = dq\frac{dL}{dt} \times B \qquad \left[V = \frac{dL}{dt}\right]$$

Where, dL is the length of the conductor carrying charge q.

$$dF = dq\frac{dL}{dt} \times B$$

$$or,\ dF = IdL \times B \qquad \left[Since,\ current\ I = \frac{dq}{dt}\right]$$

$$or,\ F = IL \times B = ILB\sin\theta$$

$$or,\ F = BIL\sin\theta$$

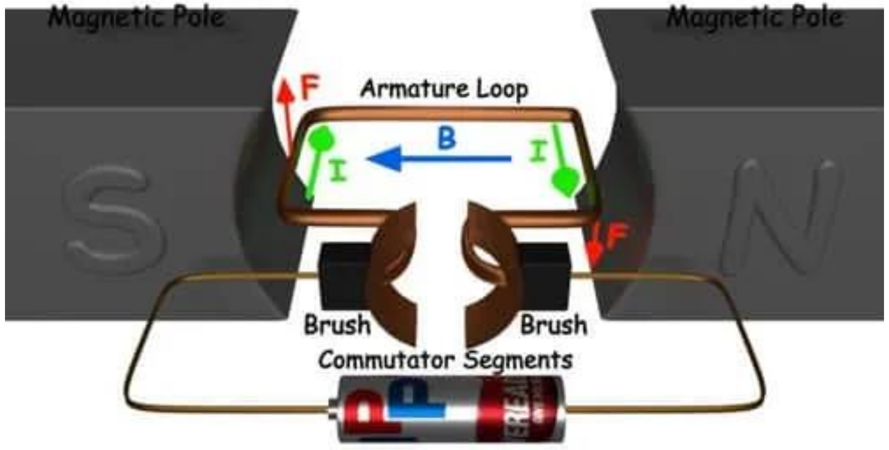
Operation of DC Motor

Then the force on the left-hand side armature conductor,

$$F_l = BIL\sin 90^\circ = BIL$$

Similarly, the force on the right-hand side conductor,

$$F_r = B(-I)L\sin 90^\circ = -BIL$$



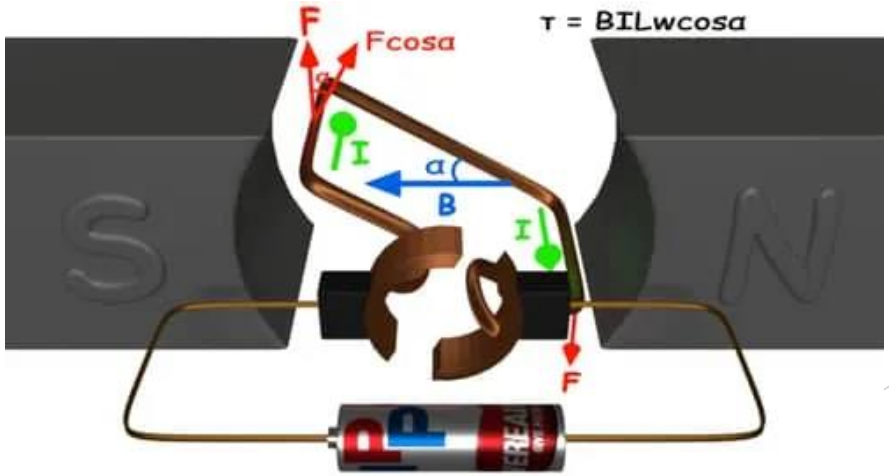
Operation of DC Motor

The torque produced is given by,

$$Torque = (force,\ tangential\ to\ the\ direction\ of\ armature\ rotation) \times (distance)$$

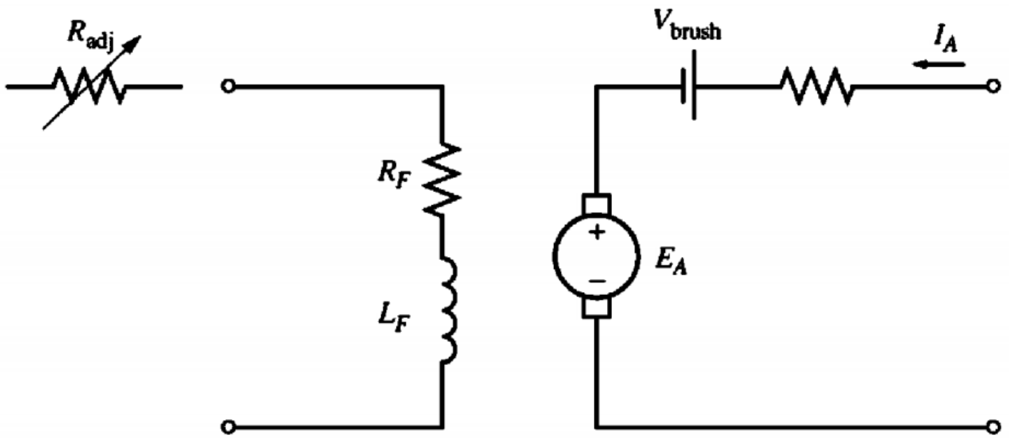
$$or,\ \tau = F\cos\alpha \times w$$

$$or,\ \tau = BILw\cos\alpha$$



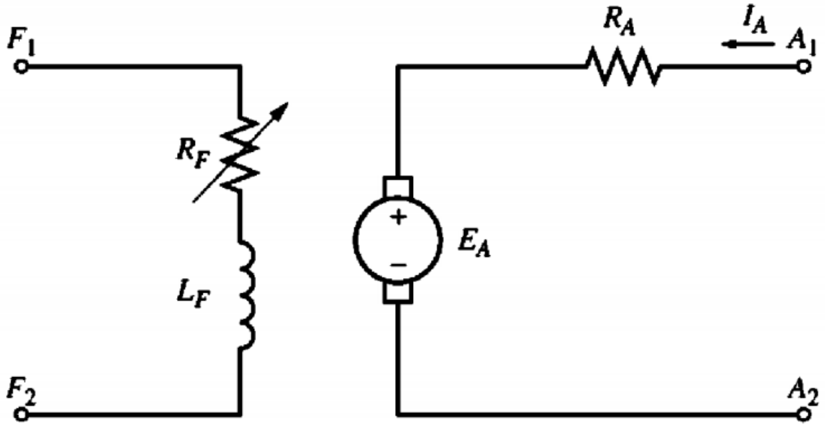
Equivalent Circuit of DC Motor

The equivalent circuit of a dc motor is shown in Figure 9–2. In this figure, the armature circuit is represented by an ideal voltage source E_A and a resistor R_A. This representation is really the Thevenin equivalent of the entire rotor structure, including rotor coils, interpoles, and compensating windings, if present. The brush voltage drop is represented by a small battery V_{brush} opposing the direction of current flow in the machine. The field coils, which produce the magnetic flux in the generator, are represented by inductor L_F and resistor R_F. The separate resistor R_{adj} represents an external variable resistor used to control the amount of current in the field circuit.



Simplified Equivalent Circuit of DC Motor

There are a few variations and simplifications of this basic equivalent circuit. The brush drop voltage is often only a very tiny fraction of the generated voltage in a machine. Therefore, in cases where it is not too critical, the brush drop voltage may be left out or approximately included in the value of R_A. Also, the internal resistance of the field coils is sometimes lumped together with the variable resistor, and the total is called R_F (see Figure 9–2b). A third variation is that some generators have more than one field coil, all of which will appear on the equivalent circuit.



References

- Book:
  - Chapman- Chapter 9
  - V.K. Mehta- Chapter 1, Chapter 4

- Internet Source:
  - https://www.electrical4u.com/working-or-operating-principle-of-dc-motor/
  - https://www.electrical4u.com/principle-of-dc-generator/

Generator Operation Video: https://youtu.be/Ylgb8FFMgd4?si=8t_x-FspScctbwCT

1.22 Types of D.C. Generators

The magnetic field in a d.c. generator is normally produced by electromagnets rather than permanent magnets. Generators are generally classified according to their methods of field excitation. On this basis, d.c. generators are divided into the following two classes:

(i) Separately excited d.c. generators
(ii) Self-excited d.c. generators

The behaviour of a d.c. generator on load depends upon the method of field excitation adopted.

1.24 Self-Excited D.C. Generators

A d.c. generator whose field magnet winding is supplied current from the output of the generator itself is called a self-excited generator. There are three types of self-excited generators depending upon the manner in which the field winding is connected to the armature, namely;

(i) Series generator;
(ii) Shunt generator;
(iii) Compound generator

(ii) Shunt generator

In a shunt generator, the field winding is connected in parallel with the armature winding so that terminal voltage of the generator is applied across it. The shunt field winding has many turns of fine wire having high resistance. Therefore, only a part of armature current flows through shunt field winding and the rest flows through the load. Fig. (1.34) shows the connections of a shunt-wound generator.

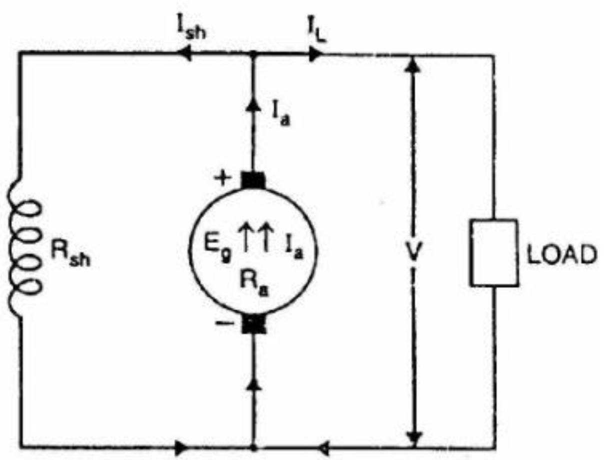
Shunt field current, $I_{sh} = V/R_{sh}$

Armature current, $I_a = I_L + I_{sh}$

Terminal voltage, $V = E_g - I_aR_a$

Power developed in armature $= E_gI_a$

Power delivered to load $= VI_L$



Example 26.3. *A shunt generator delivers 450 A at 230 V and the resistance of the shunt field and armature are 50 Ω and 0.03 Ω respectively. Calculate the generated e.m.f.*

Solution. Generator circuit is shown in Fig. 26.46.

Current through shunt field winding is

$$I_{sh} = 230/50 = 4.6 \text{ A}$$

Load current $I = 450$ A

$\therefore$ Armature current $I_a = I + I_{sh}$

$$= 450 + 4.6 = 454.6 \text{ A}$$

Armature voltage drop

$$I_a R_a = 454.6 \times 0.03 = \mathbf{13.6 \text{ V}}$$

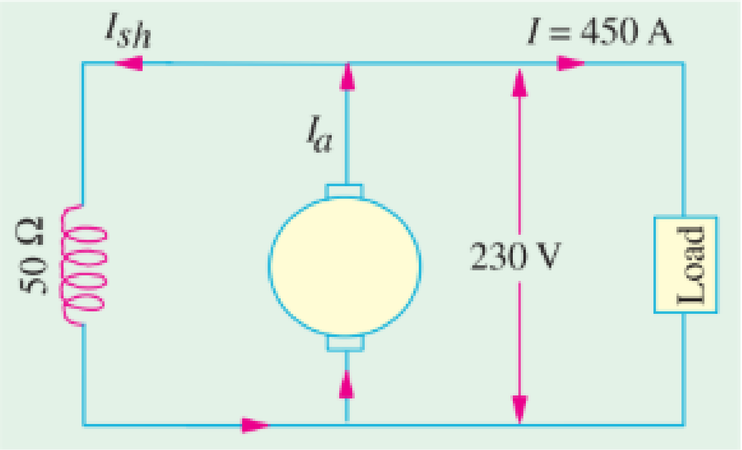


Fig. 26.46

DC Motor

Back emf:

- When the armature winding of dc motor is start rotating in the magnetic flux produced by the field winding, it cuts the lines of magnetic flux and induces the emf in the armature winding.
- According to Lenz's law (*The law that whenever there is an induced electromotive force (emf) in a conductor, it is always in such a direction that the current it would produce would oppose the change which causes the induced emf.*), this induced emf acts in the opposite direction to the armature supply voltage. Hence this emf is called as back emfs.

$$E_b = \frac{N \emptyset Z}{60} \frac{P}{A} \text{ Volts}$$

N= speed in rpm

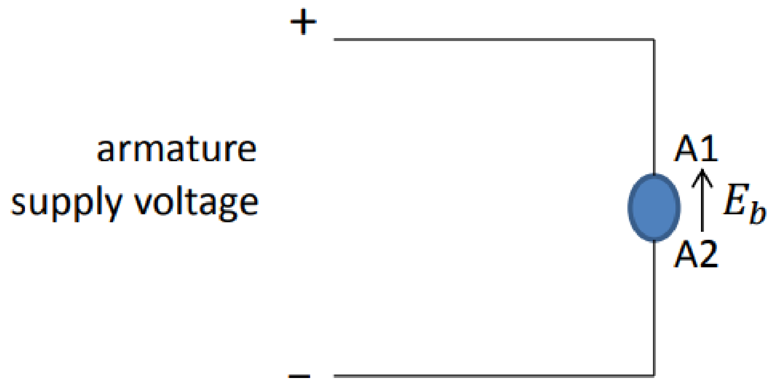
$\emptyset$= flux per pole

Z= no of conductors

P=no of pole pairs

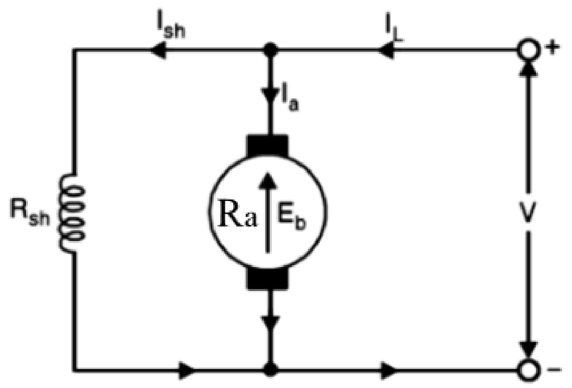
A=area of cross section of conductor

E_b= back emf



Motor Operation Video: https://youtu.be/fWyzPdyCAzU?si=Zjx-UvUxg-KXA5gi

Shunt DC motor



$$V = E_b + I_a R_a$$

$$I_{sh} = V / R_{sh}, \; I_L = I_a + I_{sh}$$

Speed of DC motor

$$E_b = \frac{P\phi Z N}{60\,A}$$

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

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

$$N_1 \propto \frac{E_{b1}}{\phi_1} \quad \text{and} \quad N_2 \propto \frac{E_{b2}}{\phi_2}$$

$$\frac{N_2}{N_1} = \frac{E_{b2}}{E_{b1}} \times \frac{\phi_1}{\phi_2}$$

For a shunt motor, flux practically remains constant so that $\phi_1 = \phi_2$.

$$\therefore \quad \frac{N_2}{N_1} = \frac{E_{b2}}{E_{b1}}$$

Example 29.21. *A 250-V shunt motor runs at 1000 r.p.m. at no-load and takes 8A. The total armature and shunt field resistances are respectively 0.2 Ω and 250 Ω. Calculate the speed when loaded and taking 50 A. Assume the flux to be constant.* **(Elect. Engg. A.M.Ae. S.I. June 1991)**

Solution. Formula used : $\frac{N}{N_0} = \frac{E_b}{E_{b0}} \times \frac{\Phi_0}{\Phi}$; Since $\Phi_0 = \Phi$ (given); $\frac{N}{N_0} = \frac{E_b}{E_{b0}}$

$$I_{sh} = 250/250 = 1 \text{ A}$$

$$E_{b0} = V - I_{a0} R_a = 250 - (7 \times 0.2) = 248.6 \text{ V}; \; E_b = V - I_a R_a = 250 - (49 \times 0.2) = 240.2 \text{ V}$$

$$\therefore \quad \frac{N}{1000} = \frac{240.2}{248.6}; \; N = \textbf{9666.1 r.p.m.}$$