BEE100

Basic Electrical Engineering

Module – 03

DC Machines

Electrical Machines

- Construction, working principle and applications of
  - DC Machines,
  - Transformers,
  - Three phase Induction motors,
  - synchronous generators,
  - single phase induction motors,
  - Special machines stepper motor, universal motor and BLDC motor.

Introduction

- The electromagnetic system is an essential element of all rotating electrical machines and electromechanical devices as well as static devices like transformer.

- An electric generator is an electrical machine which converts mechanical energy into electrical energy. A generator works on the principle of electromagnetic induction.

- A motor is an electrical machine which converts electrical energy into mechanical energy.

- Transformers do not actually make conversion between mechanical and electrical energy, but they transfer electric power from one circuit to another circuit.

- Other devices like circuit breakers, automatic switches, relays need the presence of a confined magnetic field for their proper operation.

- Hence, brief study about magnetic circuits and magnetic materials becomes essential.

Magnetically induced emf

- When the flux linking the electric circuit changes, an emf is induced, and the magnitude of emf is directly proportional to the rate of change of flux linkages or to the product of number of turns and rate of change of flux linking the coil (Faraday's Law)

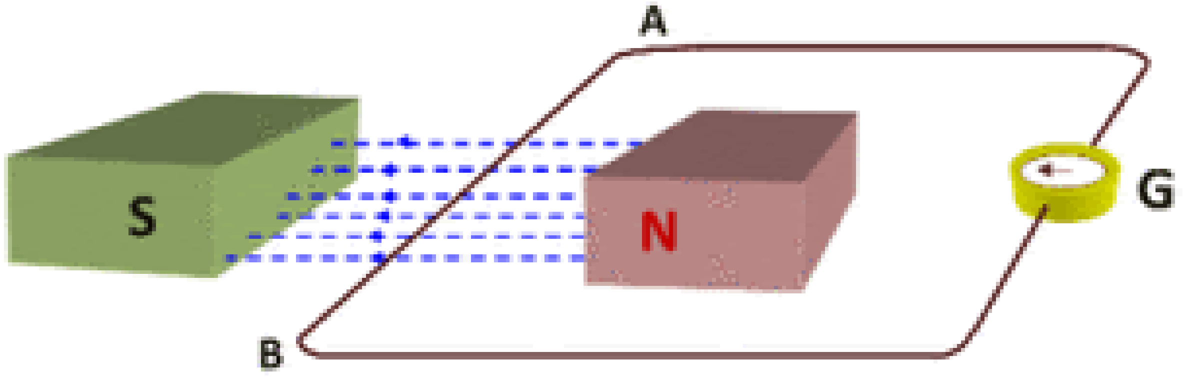
$$e = -N\frac{d\emptyset}{dt}$$

- The direction of induced emf is such that the current produced by its sets up a magnetic filed opposing the flux change. (Lenz's Law)

$$\text{Induced emf} \begin{cases} \text{Dynamically induced emf} \\ \text{Statically induced emf} \end{cases}$$

Electromagnetic Induction

Dynamically induced emf



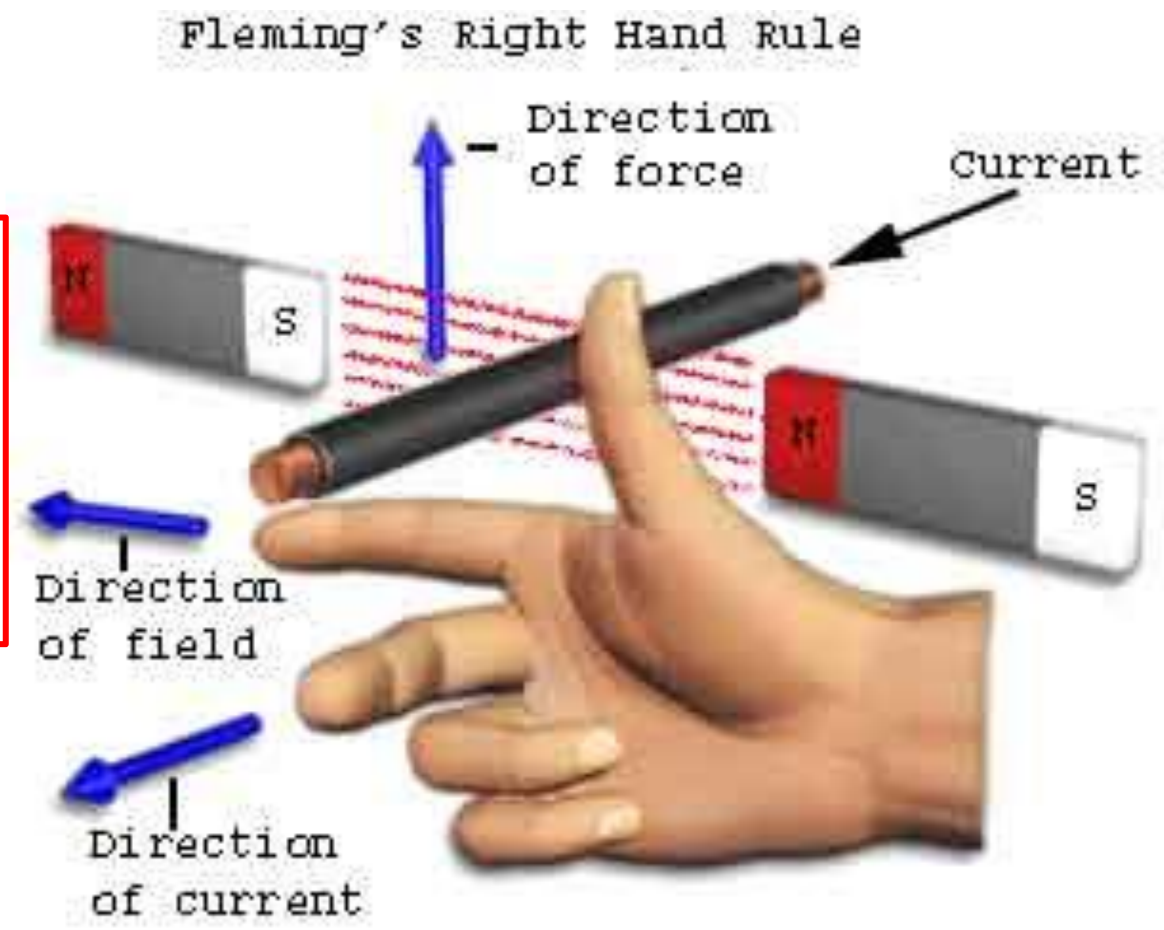
- By moving a conductor in a uniform magnetic field and emf produced in this way is known as dynamically induced emf
- How relative motion between the flux and conductor can be obtained
  - Flux – stationary; conductor – moving/rotating
  - Flux – moving; conductor – stationary

Electromagnetic Induction

Dynamically induced emf

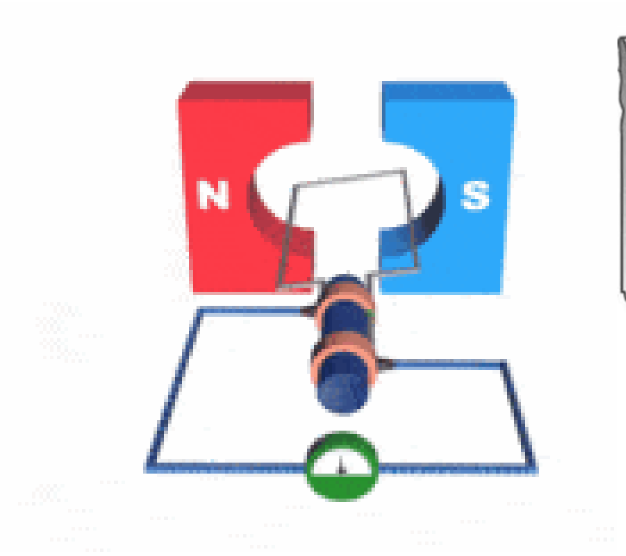
- The direction of this induced emf is given by Fleming's right hand rule

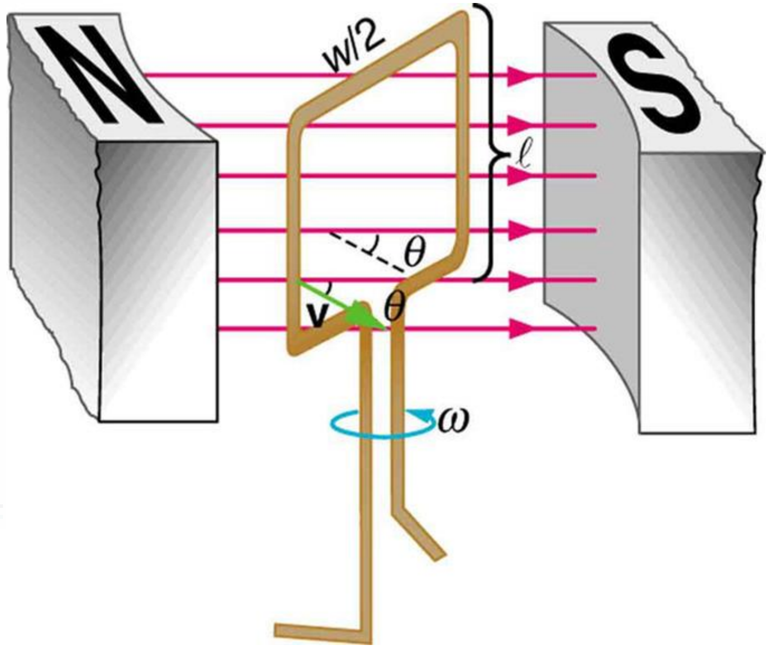
According to the Fleming's right hand rule, the thumb, fore finger and middle finger of the right hand are stretched to be perpendicular to each other as shown in the illustration at right, and if the thumb represents the direction of the movement of conductor, fore-finger represents direction of the magnetic field, then the middle finger represents direction of the induced current.



Electromagnetic Induction

Dynamically induced emf





- To determine the magnitude of EMF consider the plane of flux which is constant and the plane of conductor which is rotating

$$e = Blv \sin\theta$$

- ✓ B – flux density (wb/m^2);
- ✓ l – active length of conductor (m)
- ✓ v – relative velocity of conductor with respect to magnetic flux (m/s);
- ✓ θ – angle between two planes, plane of rotation and plane of magnetic flux.

Electromagnetic Induction

Statically Induced emf

- By increasing or decreasing the magnitude of the current producing the linking flux.
- In this case there is no motion of the conductor or of coil relative to the field and therefore, emf induced in this way is known as statically induced emf.

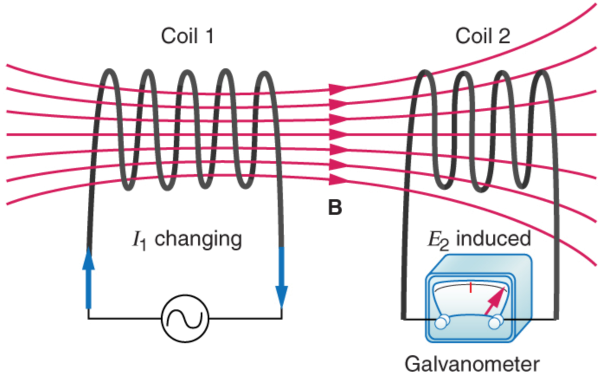
Statically Induced emf $\begin{cases} \text{Self induced emf} \\ \text{Mutual induced emf} \end{cases}$

Self induced emf

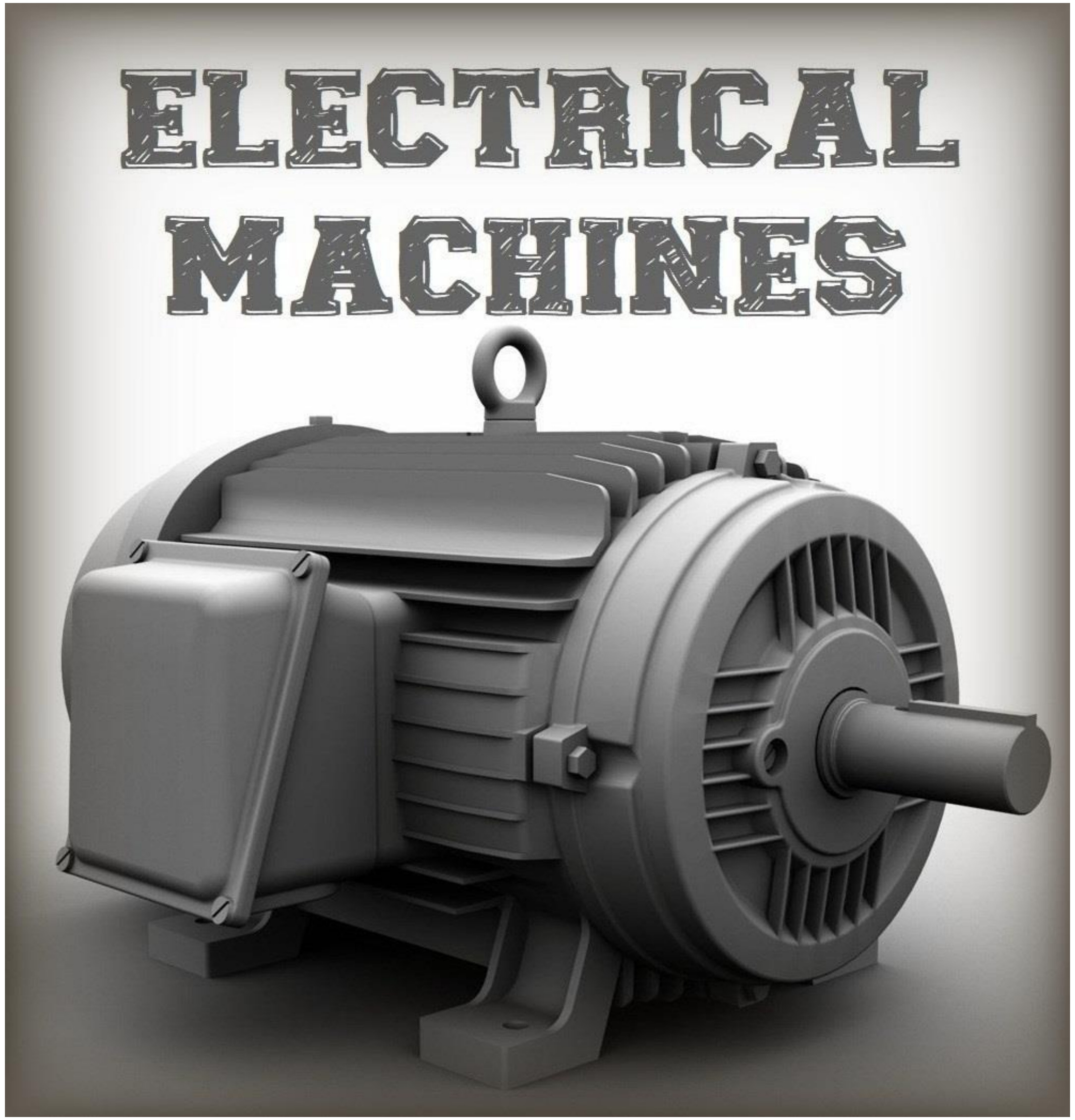
- When the current flowing through the coil is changed, the flux linking with its own winding changes and due to change in linking flux with the coil an emf, known as self induced emf.

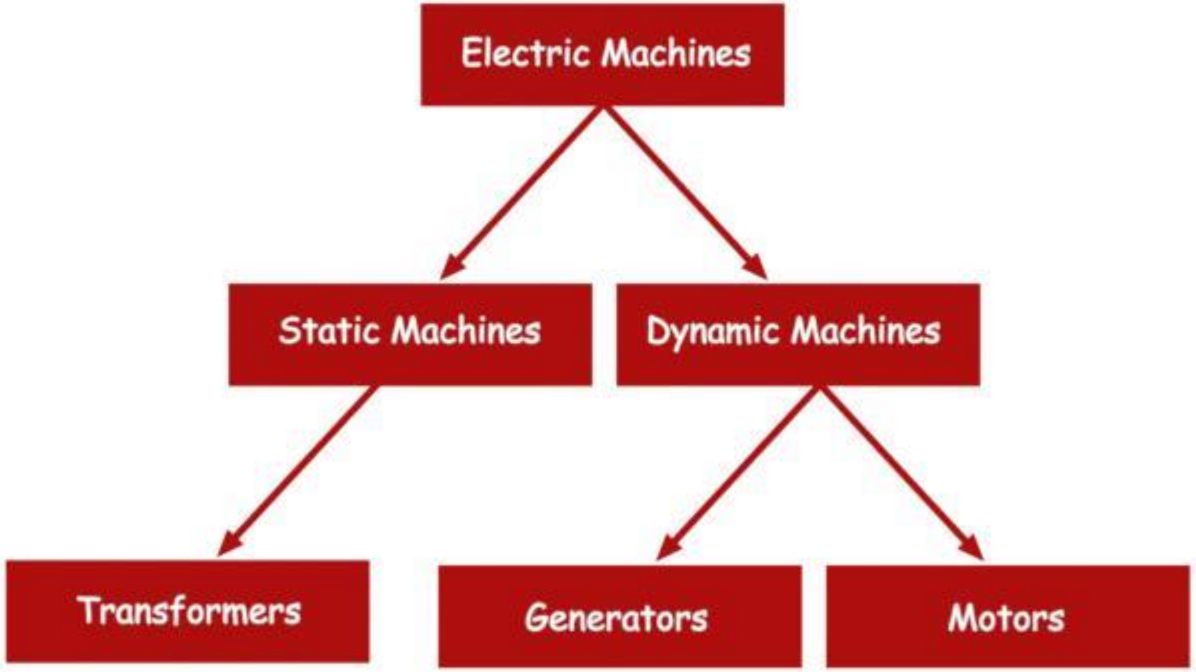
Mutual induced emf

- Whenever the current in coil 1 changes, the flux linking with coil 2 changes and an emf, known as mutually induced emf, is induced in coil 2



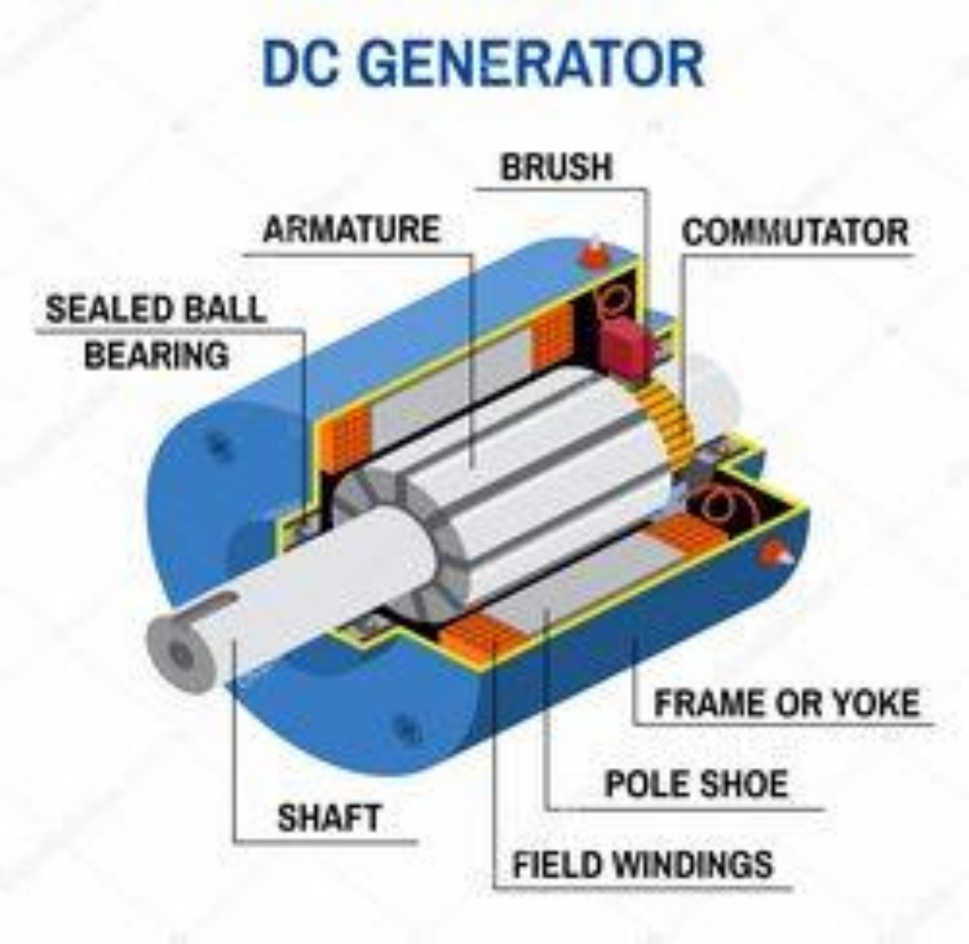
Electrical Machines





DC Machines

DC Machines — DC Generator / DC Motor

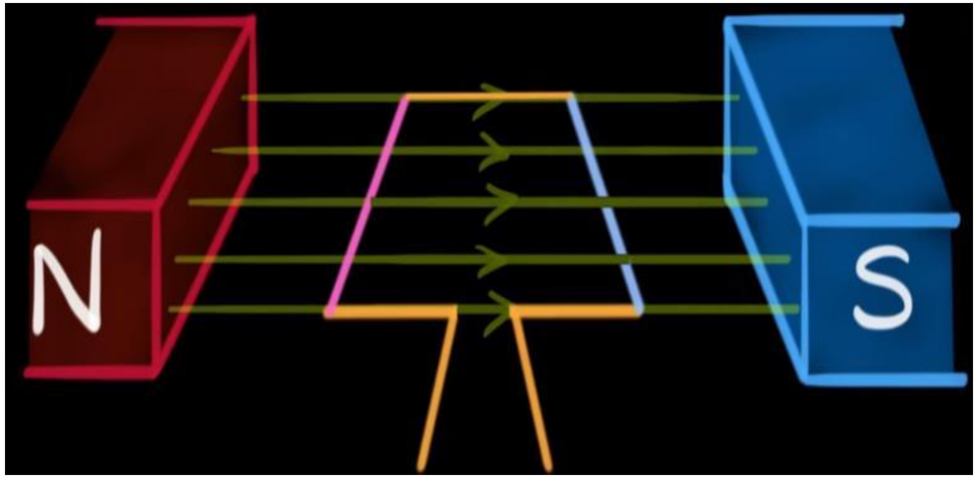


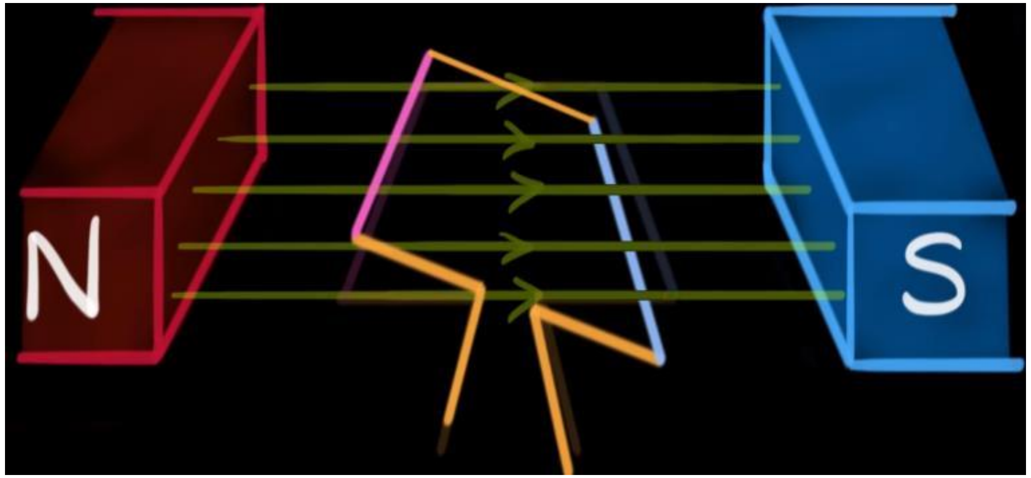
- DC generator is an electrical machine which converts mechanical energy into electrical energy.
- It is based on the principle that whenever flux is cut by a conductor, an e.m.f. is induced, which will cause a current to flow if the conductor circuit is closed.
- The essential components of a generator are:
  - Magnetic Field (stationary part-stator)
  - Conductor (Armature) – Rotating-rotor

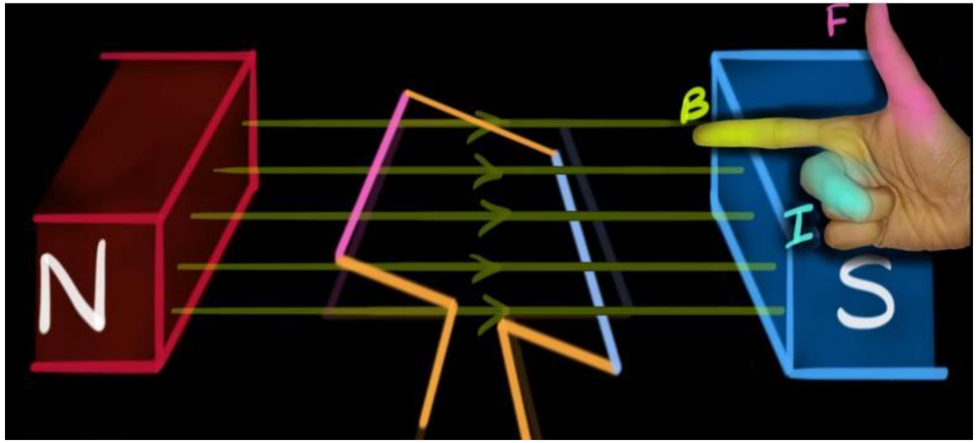
DC Generator

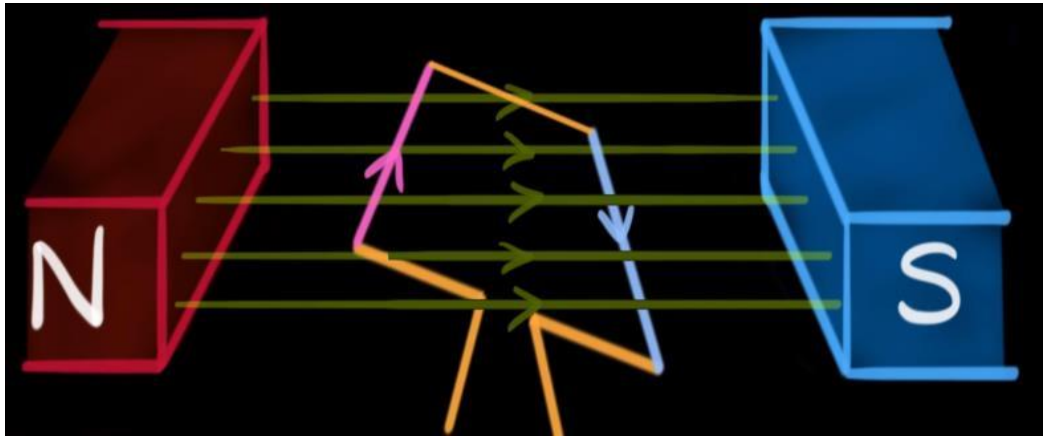
Working Principle

- In DC generator the field current is DC which produces the constant field flux. Hence, in DC generator the relative motion is obtained due to constant flux and rotating conductors.



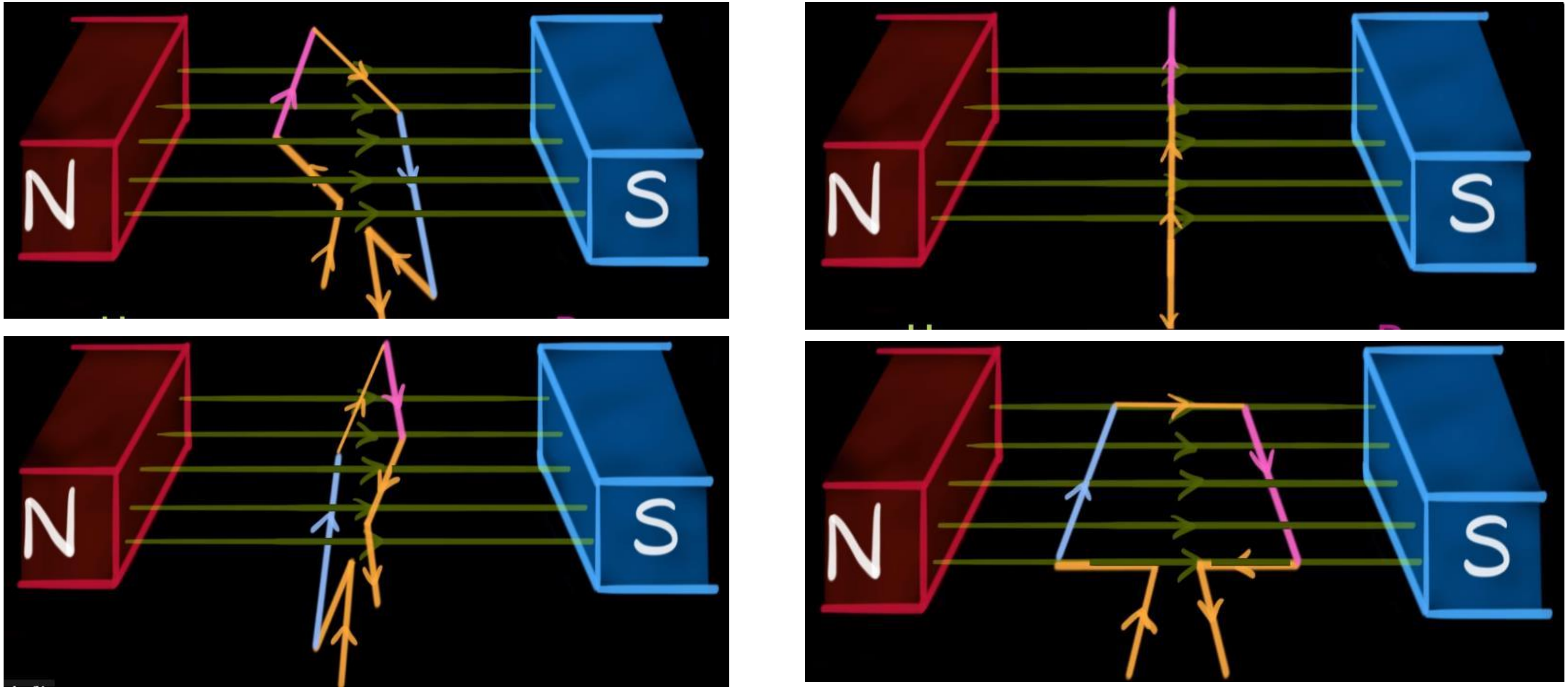






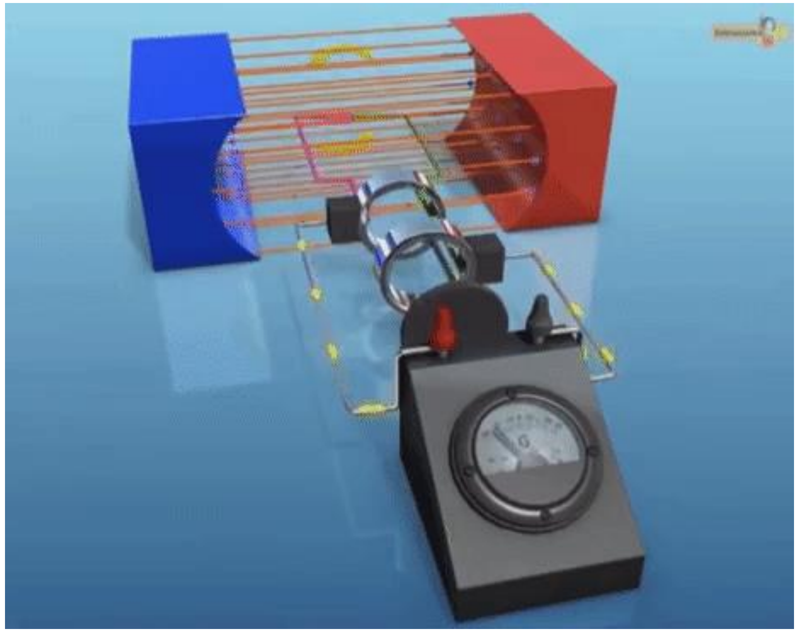
DC Generator

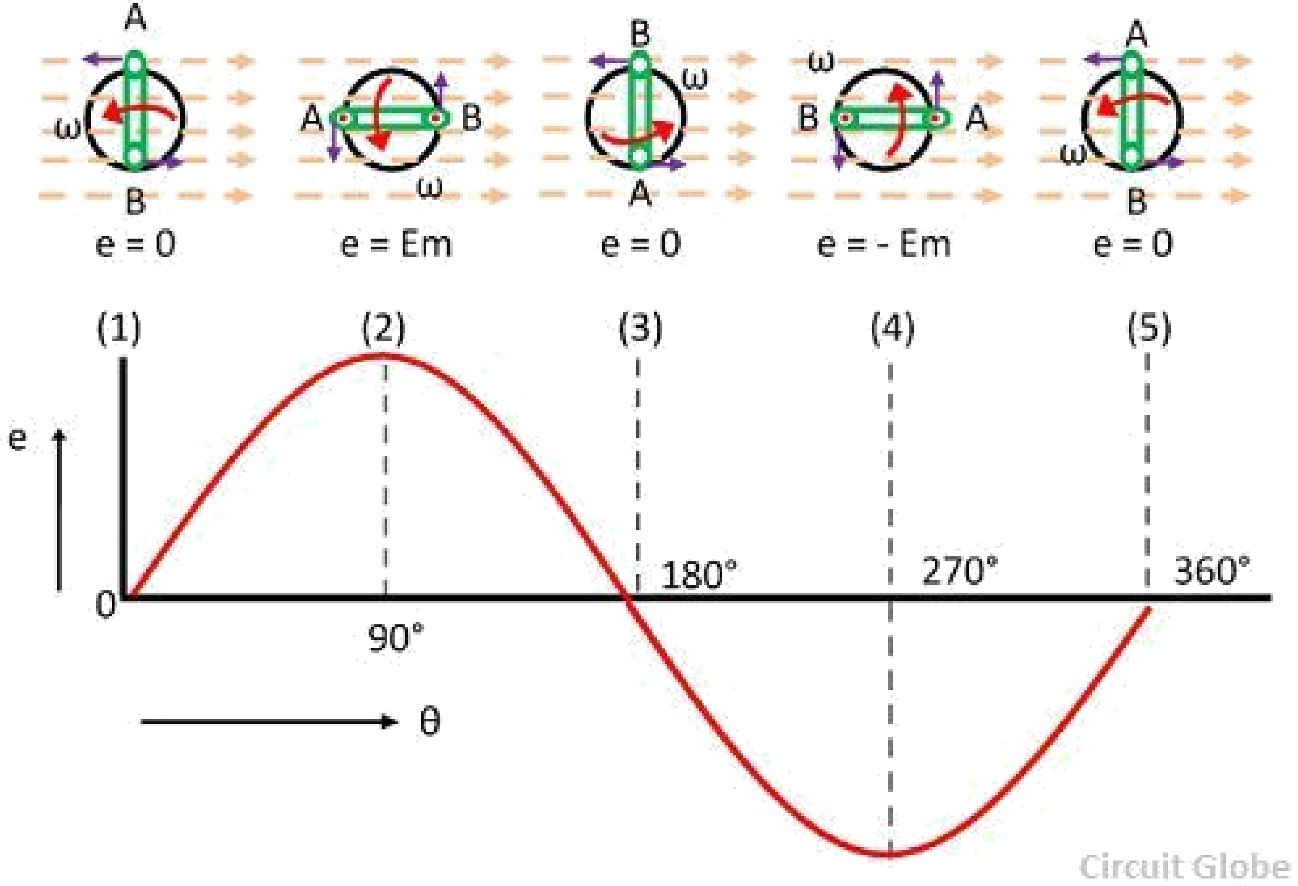
Working Principle



DC Generator

Generated EMF

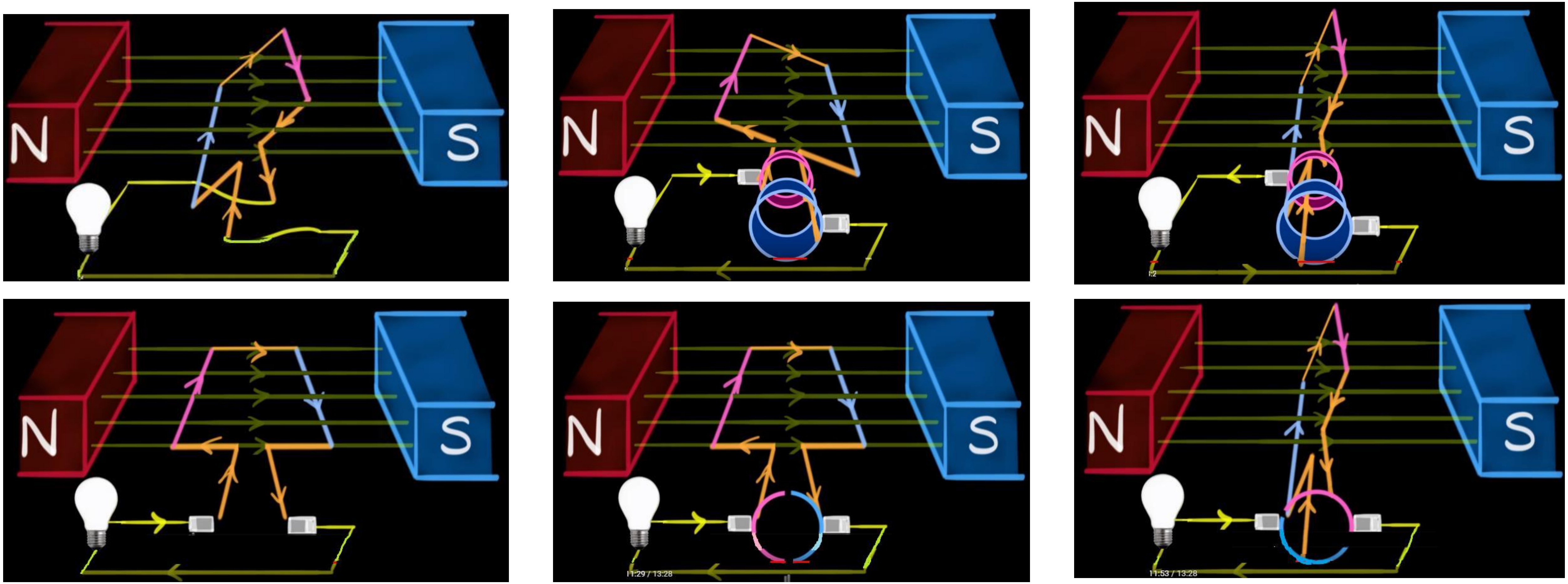




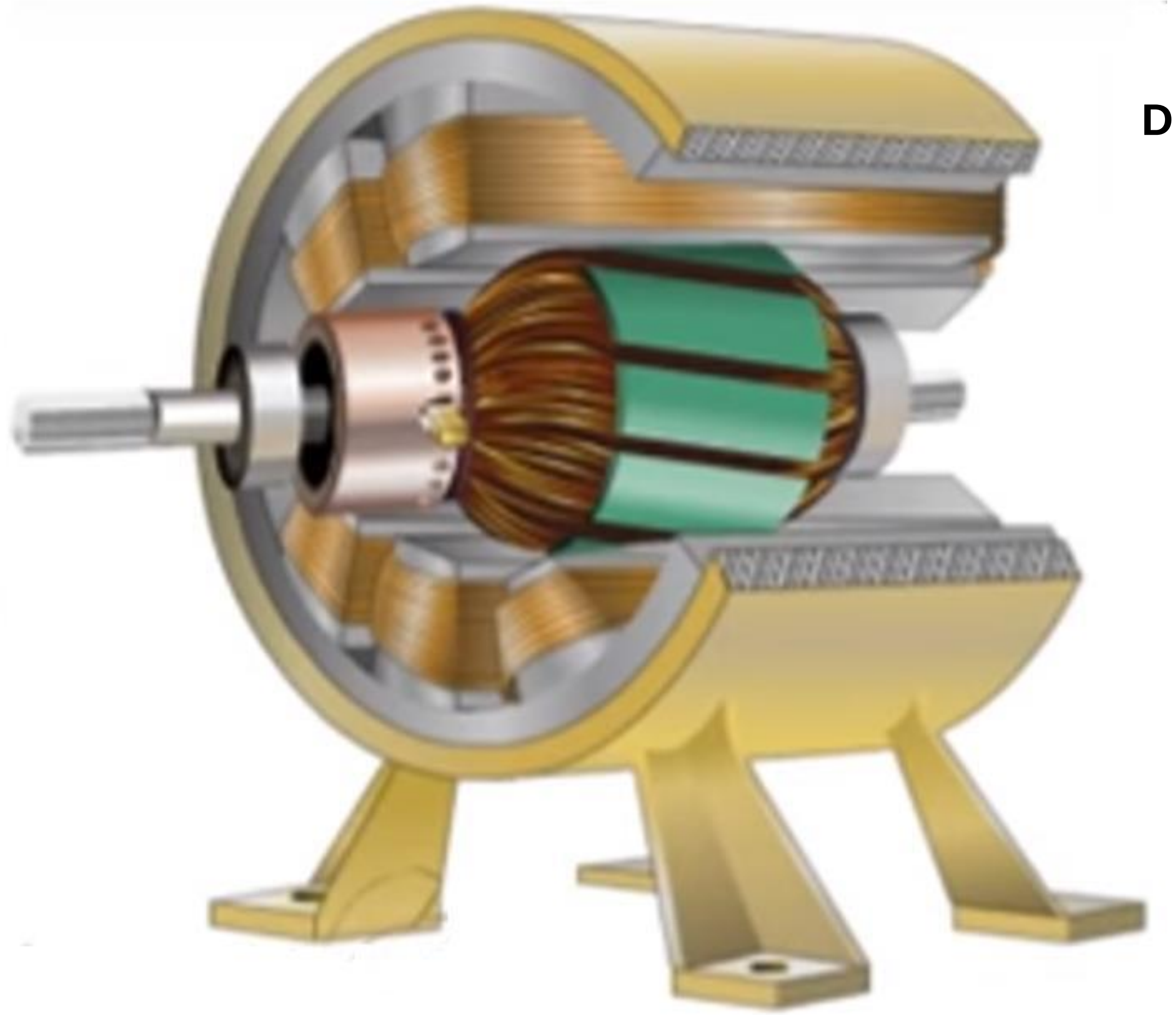
- ❖ The EMF generated in the loop is **alternating one**. If a load is connected to the ends of the loop, then alternating current flows through the load.
- ❖ The alternating voltage generated in the loop can be converted into direct voltage by a device called commutator. **Commutator** is a mechanical rectifier.

DC Generator

❖ The **commutator** reverses the connection of the coil side to the external load at the same instant the current in the coil side reverses, then the current through the load is direct current.



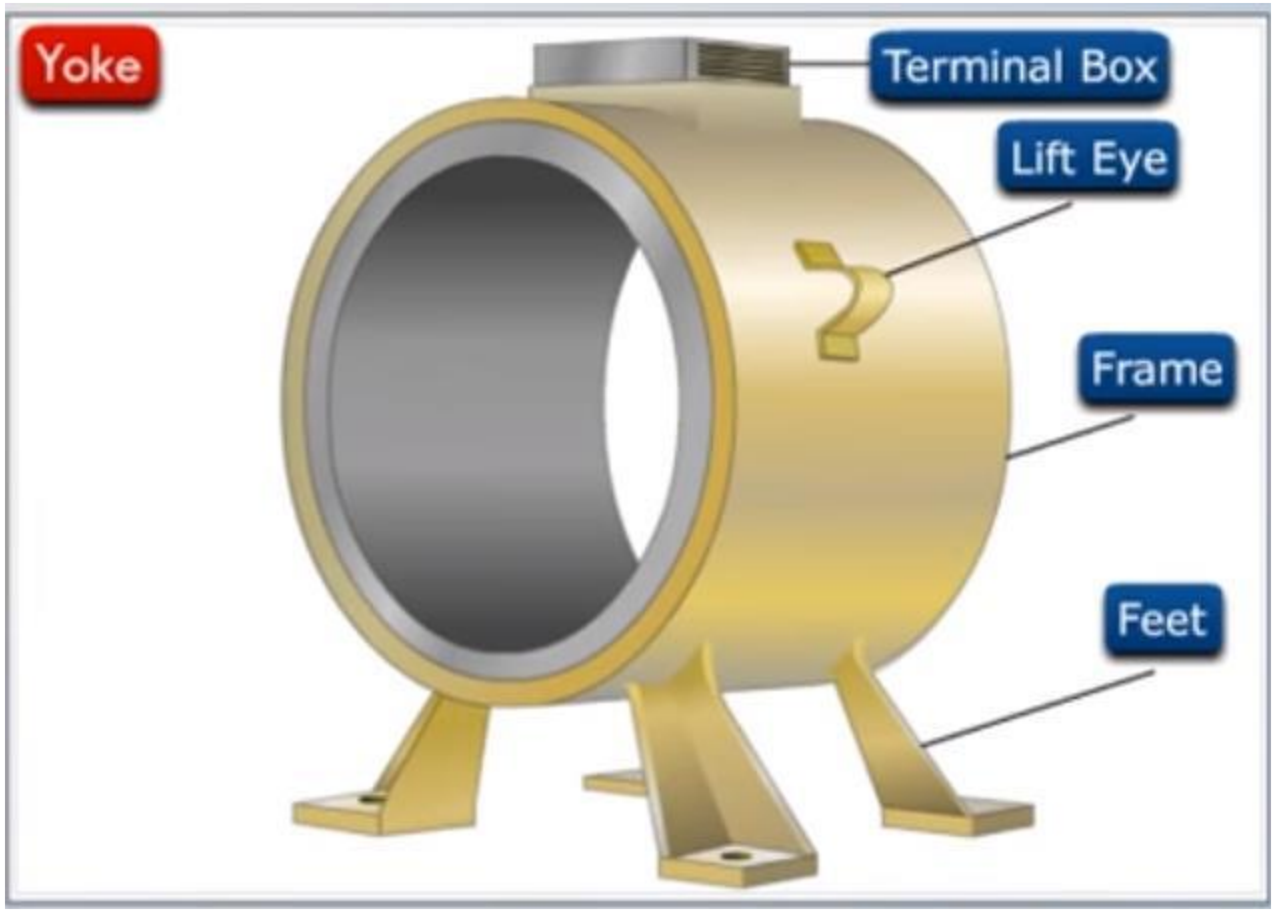
DC Machines - Constructions



D.C. machines have following components

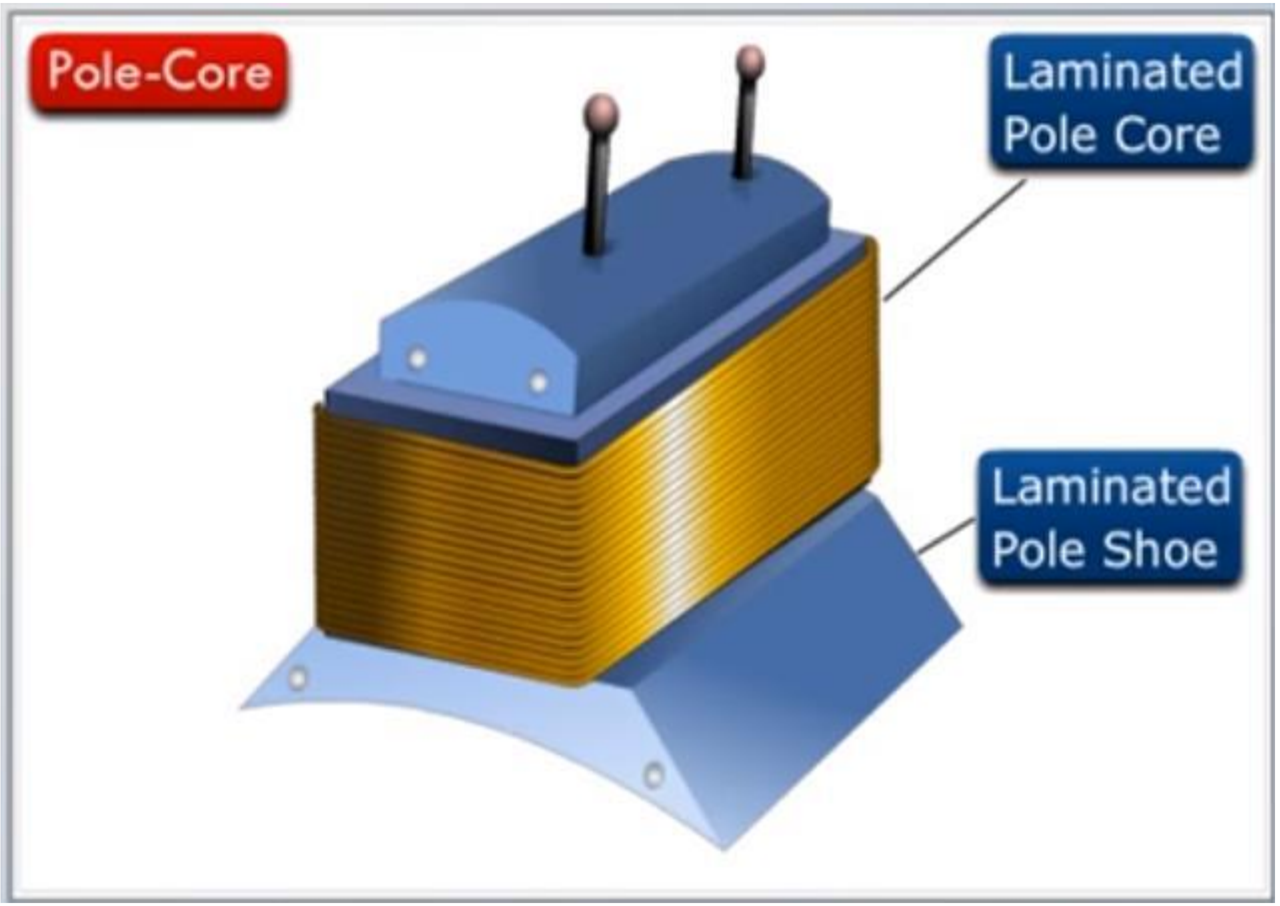
- ❖ Magnetic frame (or) yoke
- ❖ Pole cores
- ❖ Field winding
  (providing DC supply to this winding produce magnetic field, it is a stationary part)
- ❖ Armature core
- ❖ Armature winding (Rotating part)
- ❖ Commutator
- ❖ Brushes and bearing

DC Machines - Constructions



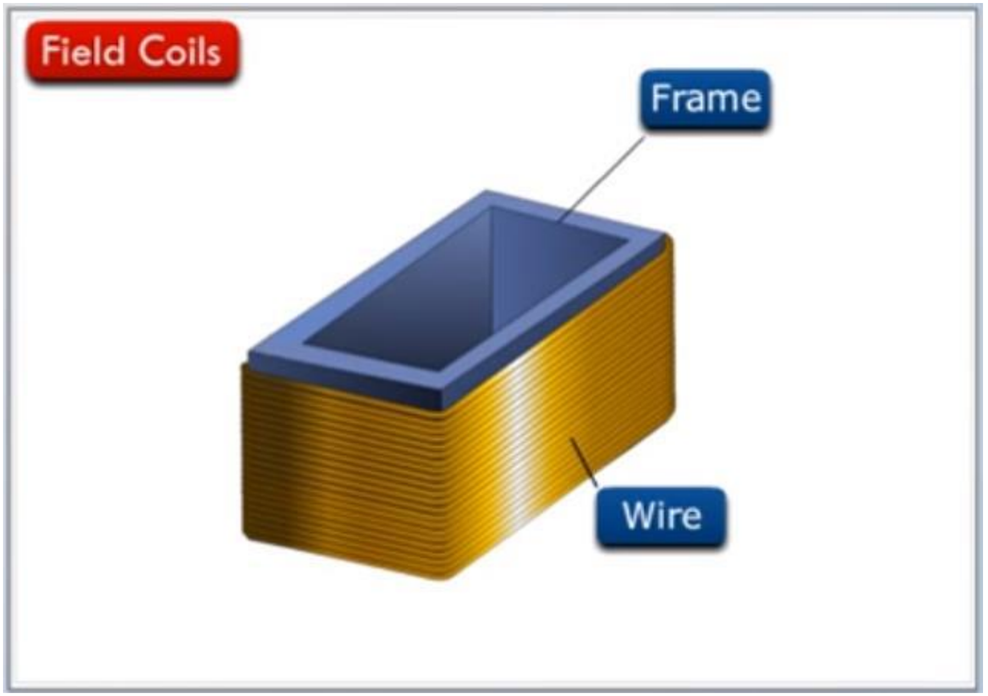
- ❖ It is the outer frame of the DC machine
- ❖ It acts as a protection shield for the machine
- ❖ It provides mechanical support to the poles
- ❖ It carries the magnetic flux produced by the poles.
- ❖ In small machines, yokes are made up of cast iron whereas in large machines it is made up of Cast Steel or Rolled Steel.

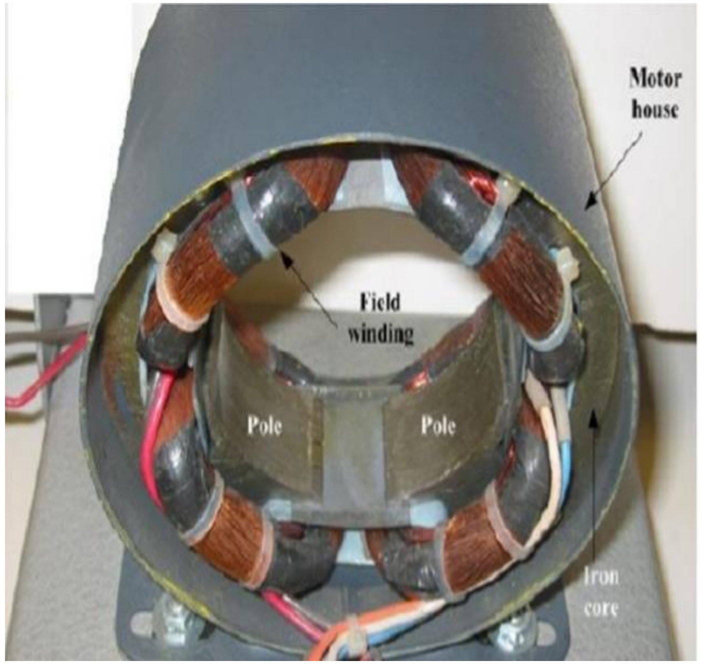
DC Machines - Constructions

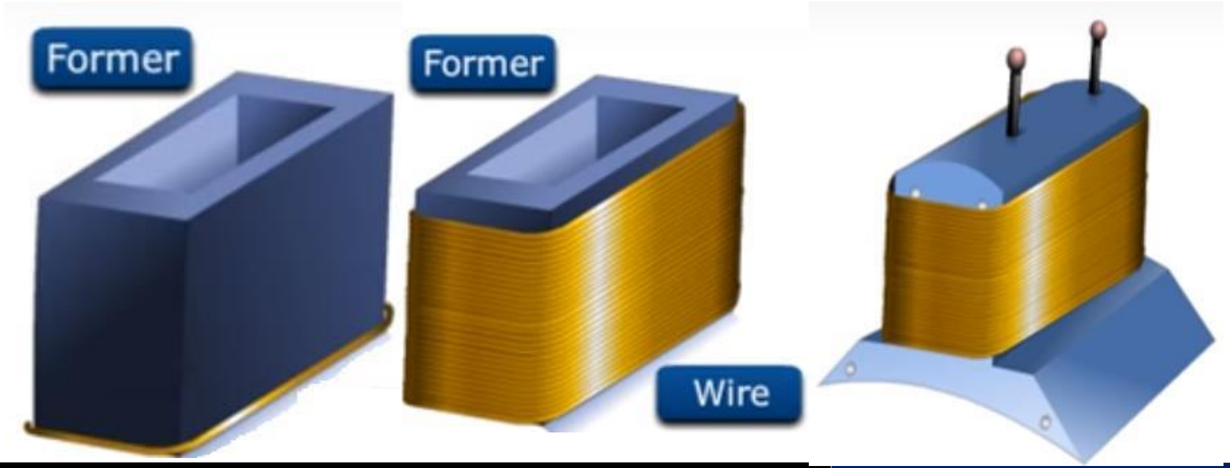


- The magnetic **poles of DC motor** are structures fitted onto the inner wall of the yoke with screws.
- The construction of magnetic poles basically comprises of two parts.
  - Pole core
  - Pole shoe
- The pole core is of small cross-sectional area and its function is to just hold the pole shoe over the yoke.
- The pole shoe having a relatively larger cross-sectional area spreads the flux produced over the air gap between the stator and rotor to reduce the loss due to reluctance.

DC Machines - Constructions

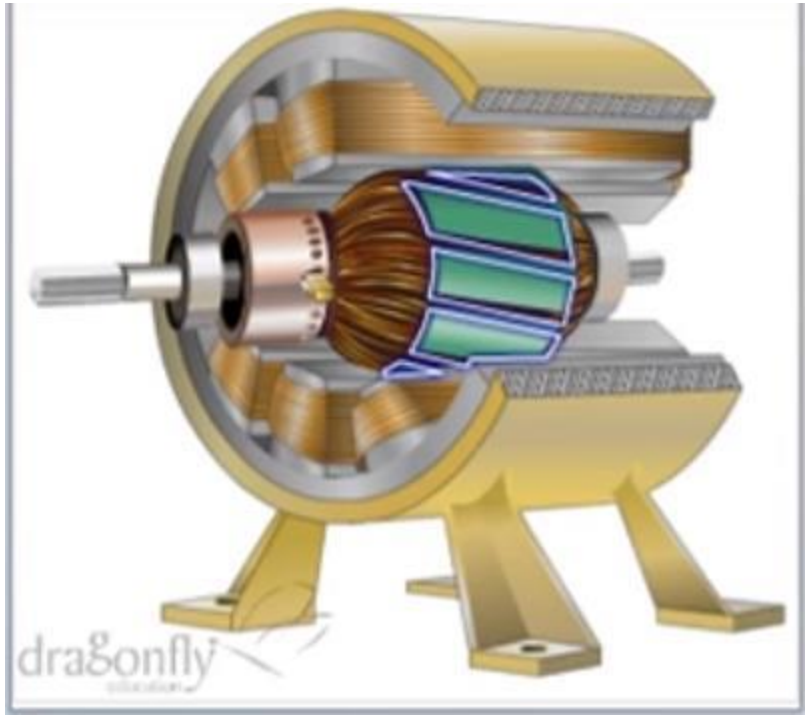


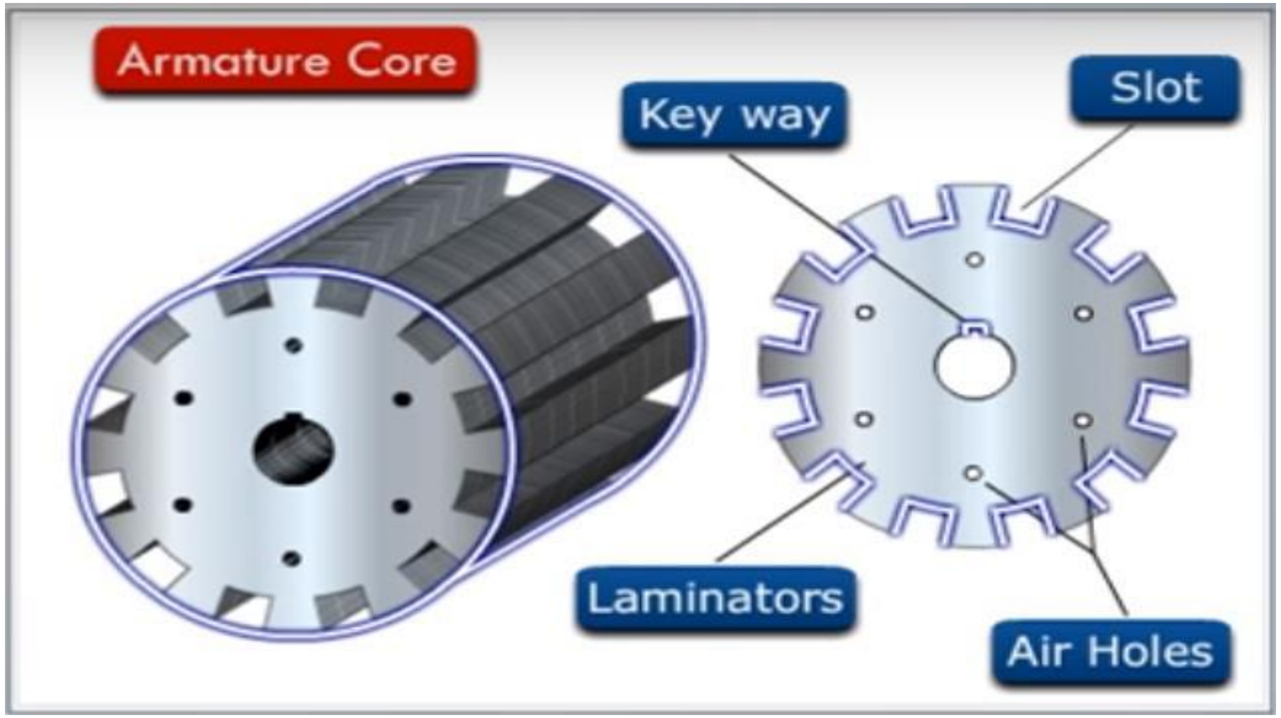




- The field winding of DC motor are made with field coils (copper wire) wound over the slots of the pole core in such a manner that when field current flows through it, then adjacent poles have opposite polarity are produced.
- The field winding basically form an electromagnet, that produces field flux

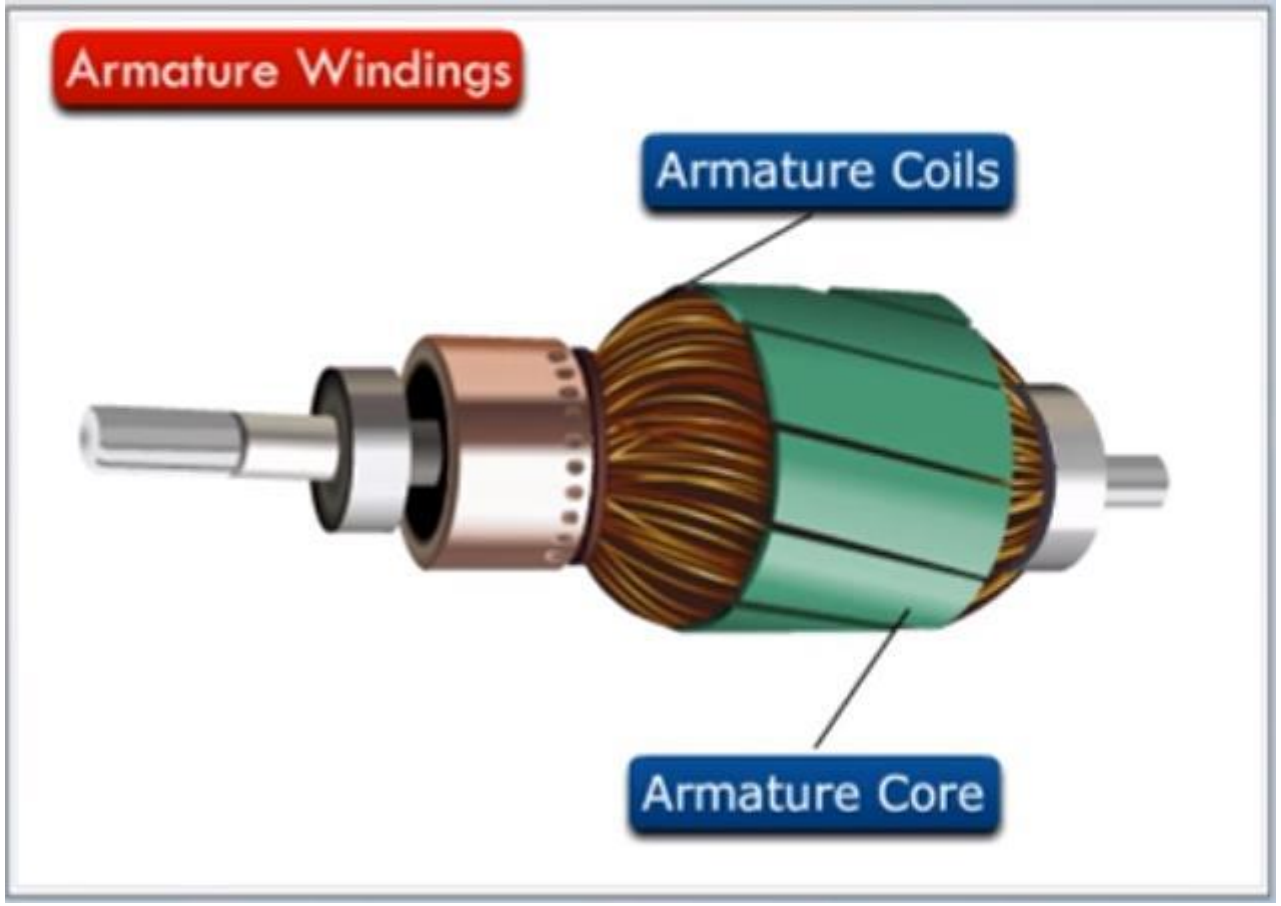
DC Machines - Constructions





- ❖ It houses the armature conductors
- ❖ It provides a path of very low reluctance to the flux through the armature
- ❖ The armature core is keyed to the machine shaft and rotates between the field poles.
- ❖ It is cylindrical or drum shaped. It is generally build up of circular sheet discs or laminations.
- ❖ The purpose of laminating the core is to reduce the eddy current loss

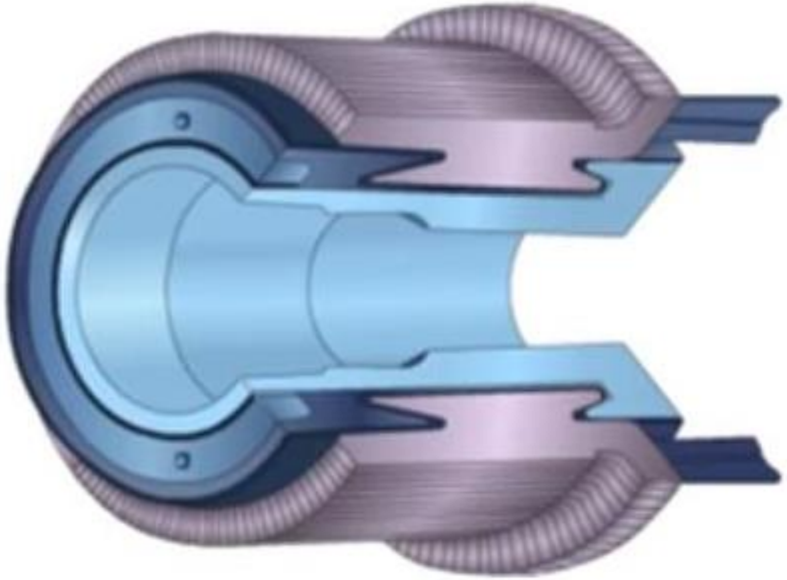
DC Machines - Constructions



- The armature winding is placed in armature slots.
- This is the winding in which 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.

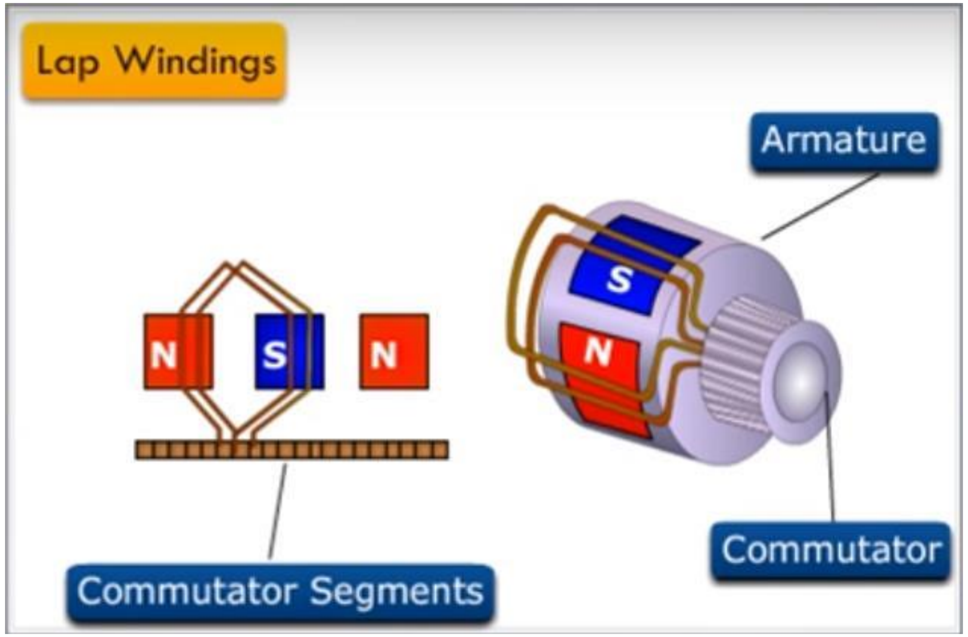
DC Machines - Constructions

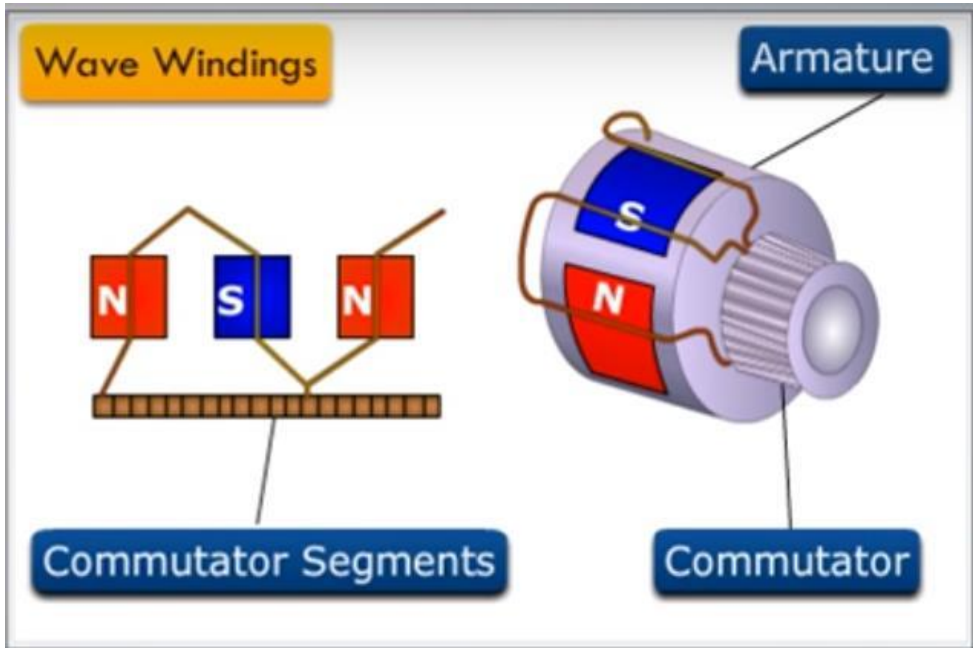
Commutator



- It facilitates the collection of current from the armature conductors
- It is a mechanical rectifier which converts the AC current into unidirectional current
- It is of cylindrical structure and is built up of wedge-shaped segments of high conductivity
- Segments are insulated from each other by thin layers of Mica
- The commutator is mounted on the shaft of the machine. The armature conductors are soldered to the commutator segments.
- Depending upon the manner in which the armature conductors are connected to the commutator segments, there are two types of armature winding in a DCmachine
  - lap winding
  - wave winding.

DC Machines - Constructions





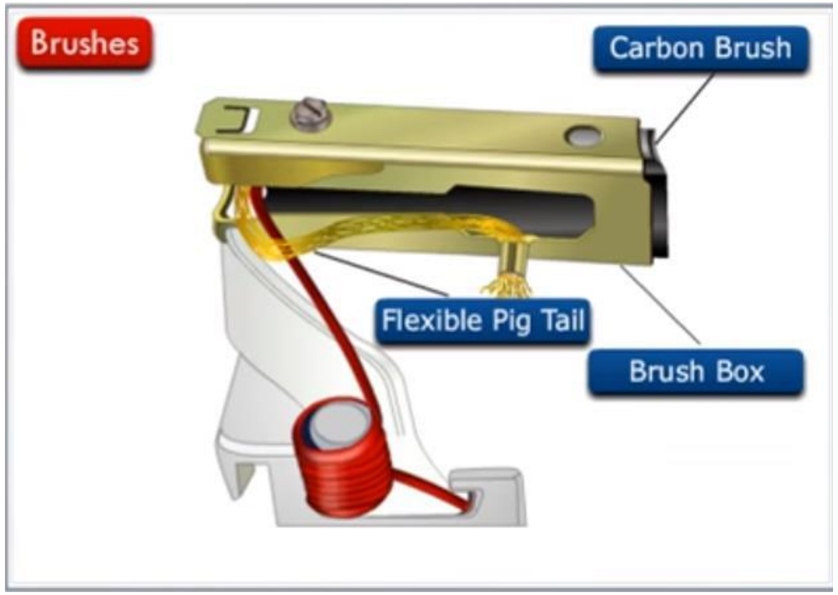
Number of parallel paths
= Number of Poles
= Number of Brushes

Suitable for High Current, Low Voltage Machines like welding Plants

Number of parallel paths = 2

Suitable for High Voltage, Low current Machines like generators used for lighting

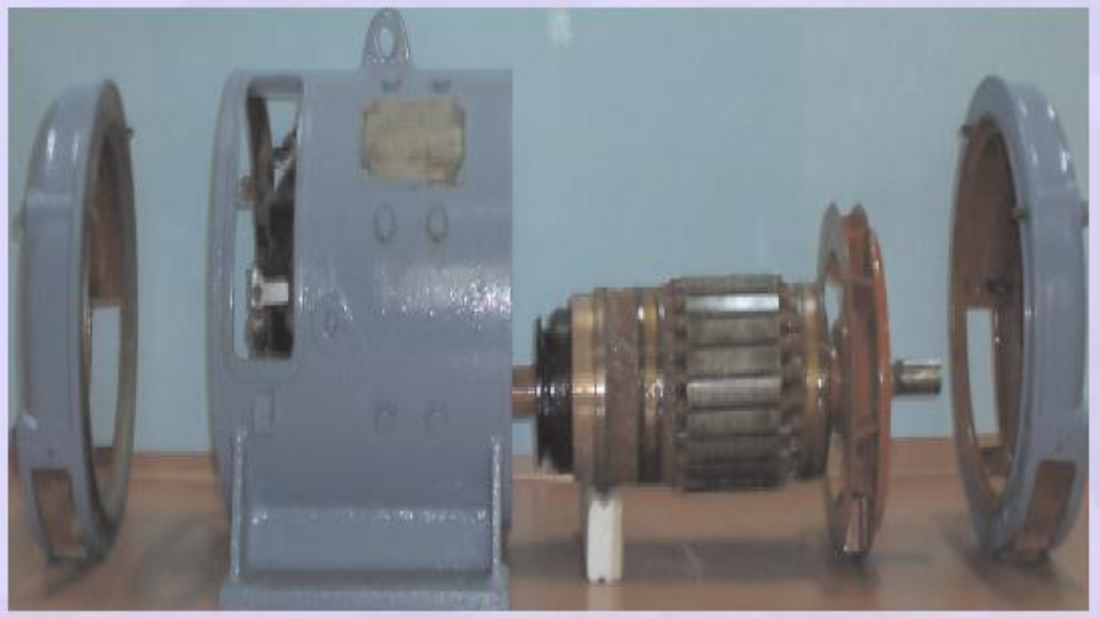
DC Machines - Constructions

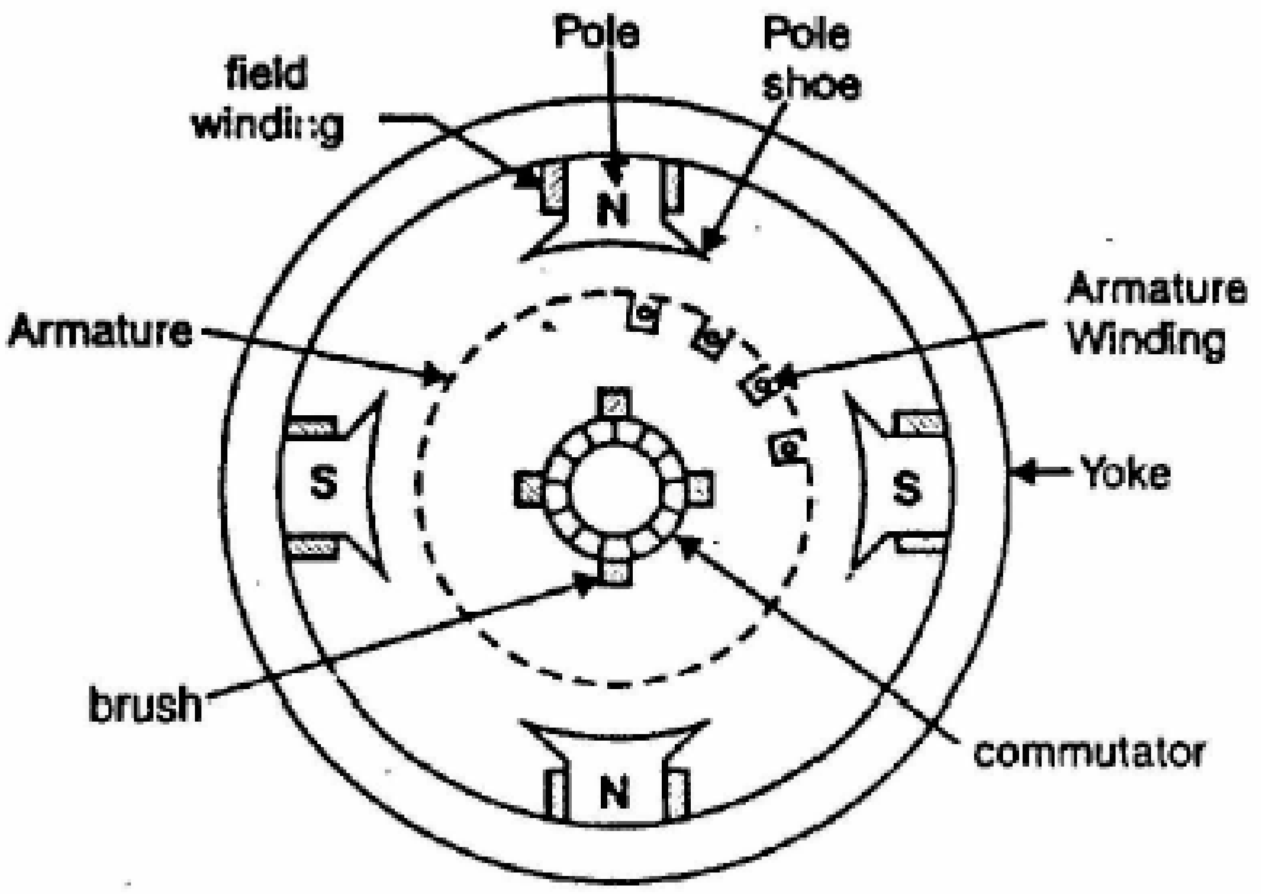


- They collect current from the commutator
- They are usually made of carbon or graphite and are in the shape of rectangular block
- They are housed in the brush-holder
- Number of brushes per spindle depends upon the magnitude of the current to be collected from the commutator.

- They are frequently employed because of their reliability
- Ball and rollers are generally packed in hard oil

DC Machines - Constructions





Cross sectional view of DC Machine

EMF Equation of DC Generator

Let Φ = flux/pole in weber

Z = total number of armature conductors

= No. of slots × No. of conductors/slot

P = No. of generator poles

A = No. of parallel paths in armature

N = armature rotation in revolutions per minute (r.p.m.)

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

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

Average e.m.f. generated/conductor $= \dfrac{d\Phi}{dt}$ volt $(\because n = 1)$

Now, flux cut/conductor in one revolution $d\Phi = \Phi P$ Wb

No. of revolutions/second = $N/60$ $\therefore$ Time for one revolution, $dt = 60/N$ second

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

E.M.F. generated/conductor $= \dfrac{d\Phi}{dt} = \dfrac{\Phi PN}{60}$ volt

For a simplex wave-wound generator

No. of parallel paths = 2

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

$$\therefore \quad \text{E.M.F. generated/path} = \frac{\Phi PN}{60} \times \frac{Z}{2} = \frac{\Phi ZPN}{120} \text{ volt}$$

For a simplex lap-wound generator

No. of parallel paths = P

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

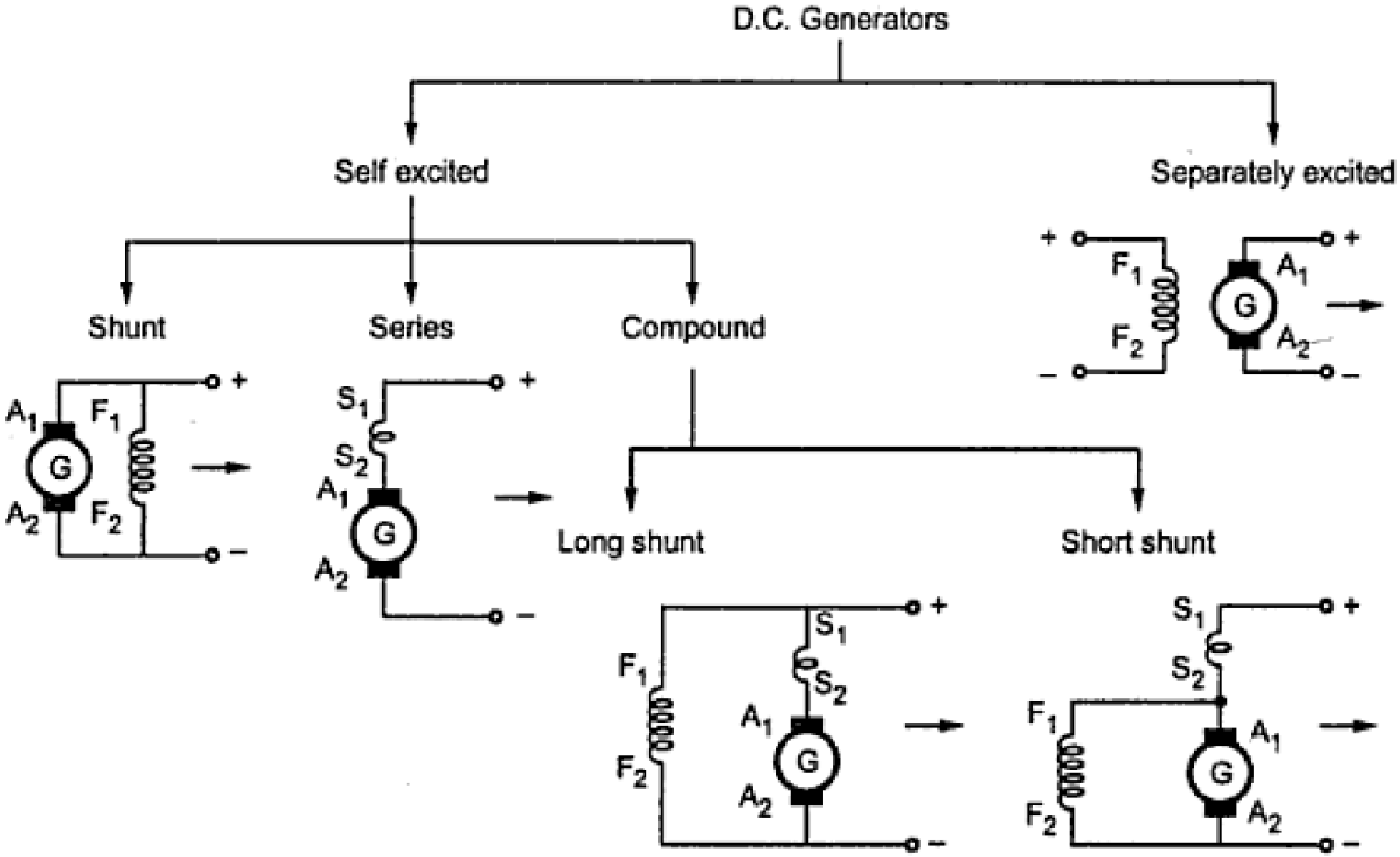
$$\therefore \quad \text{E.M.F. generated/path} = \frac{\Phi PN}{60} \times \frac{Z}{P} = \frac{\Phi ZN}{60} \text{ volt}$$

In general generated e.m.f. $E_g = \dfrac{\Phi ZN}{60} \times \left(\dfrac{P}{A}\right)$ volt

where A = 2-for simplex wave-winding

= P-for simplex lap-winding

Types of DC Generator

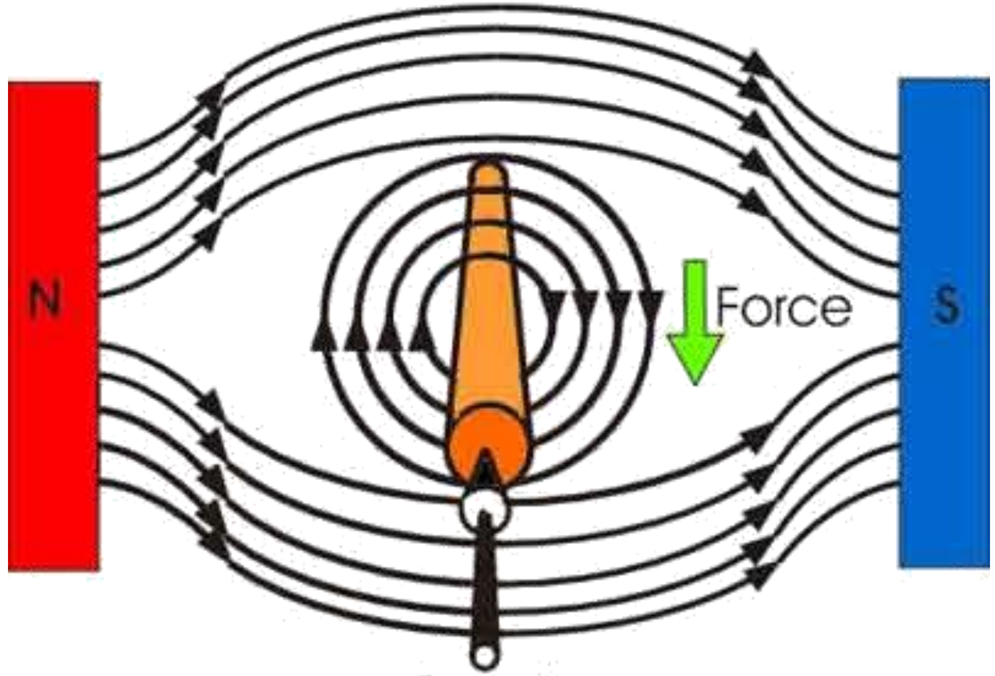


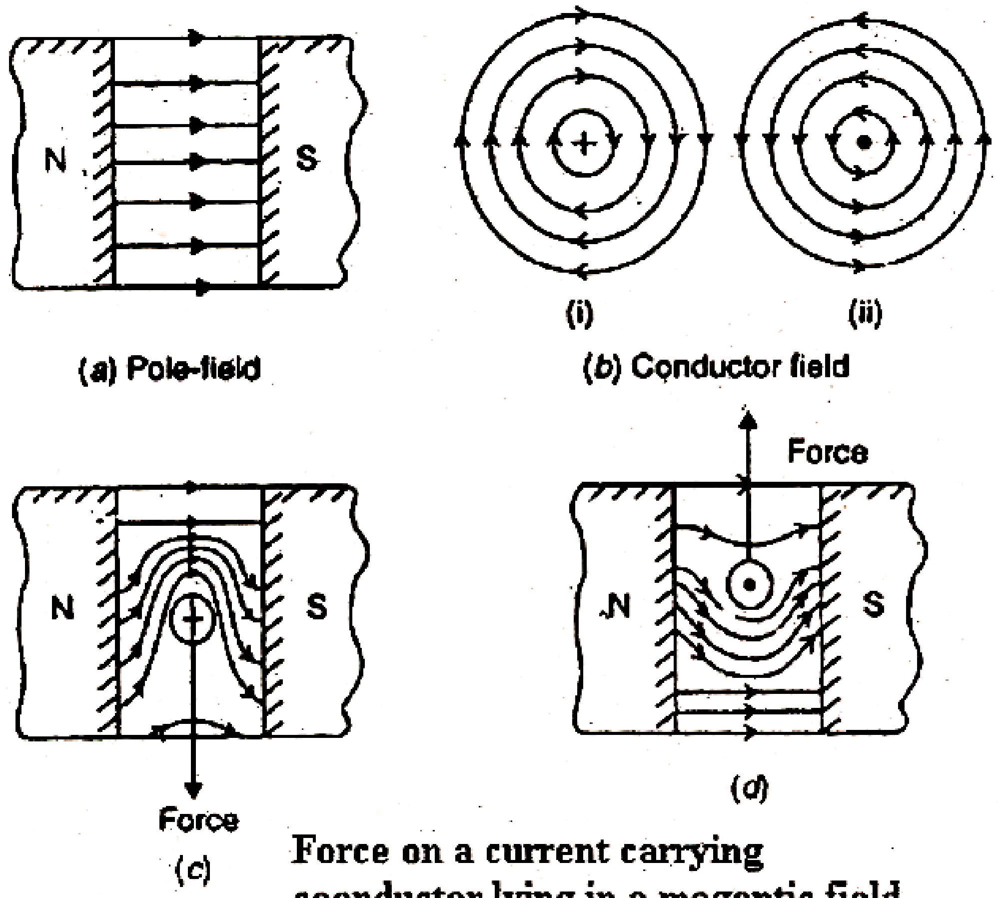
Application of DC Generators

Separately Excited Generator	**As a separately supply is required to excite the field, the use is restricted to some special applications like electro-plating, electro-refining of materials etc.**
Series Generator	**Commonly used as a boosters on DC feeders, as a constant current generator for welding generator and arc lamps.**
Cumulatively compound Generator	**Used for domestic lighting purposes and to transmit energy over long distance.**
Differential compound Generators	**Electric arc and welding**

Force on a current carrying conductor lying in the magnetic filed

- When a current carrying conductor is placed at right angle to the direction of magnetic field, a mechanical force is experienced on the conductor.



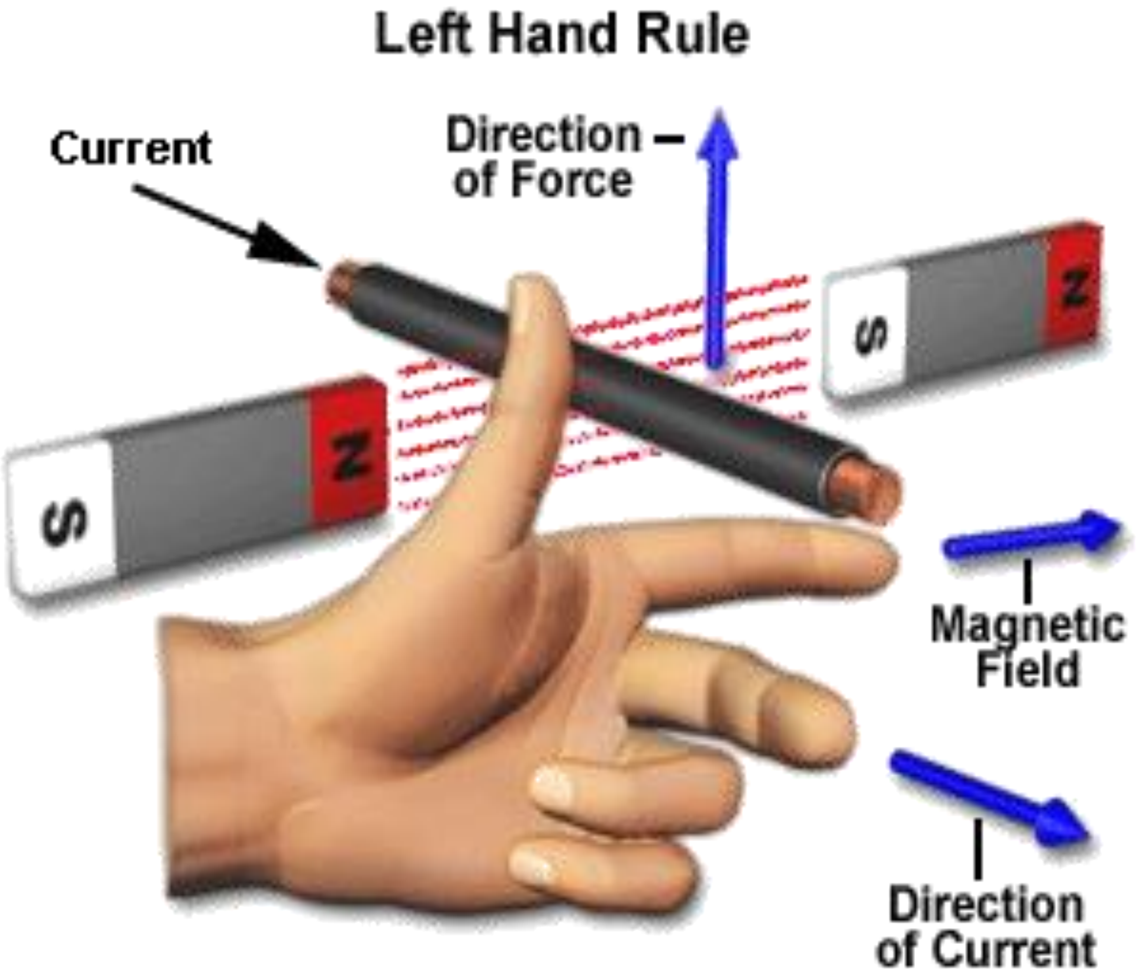


Force on a current carrying conductor lying in a megentic field.

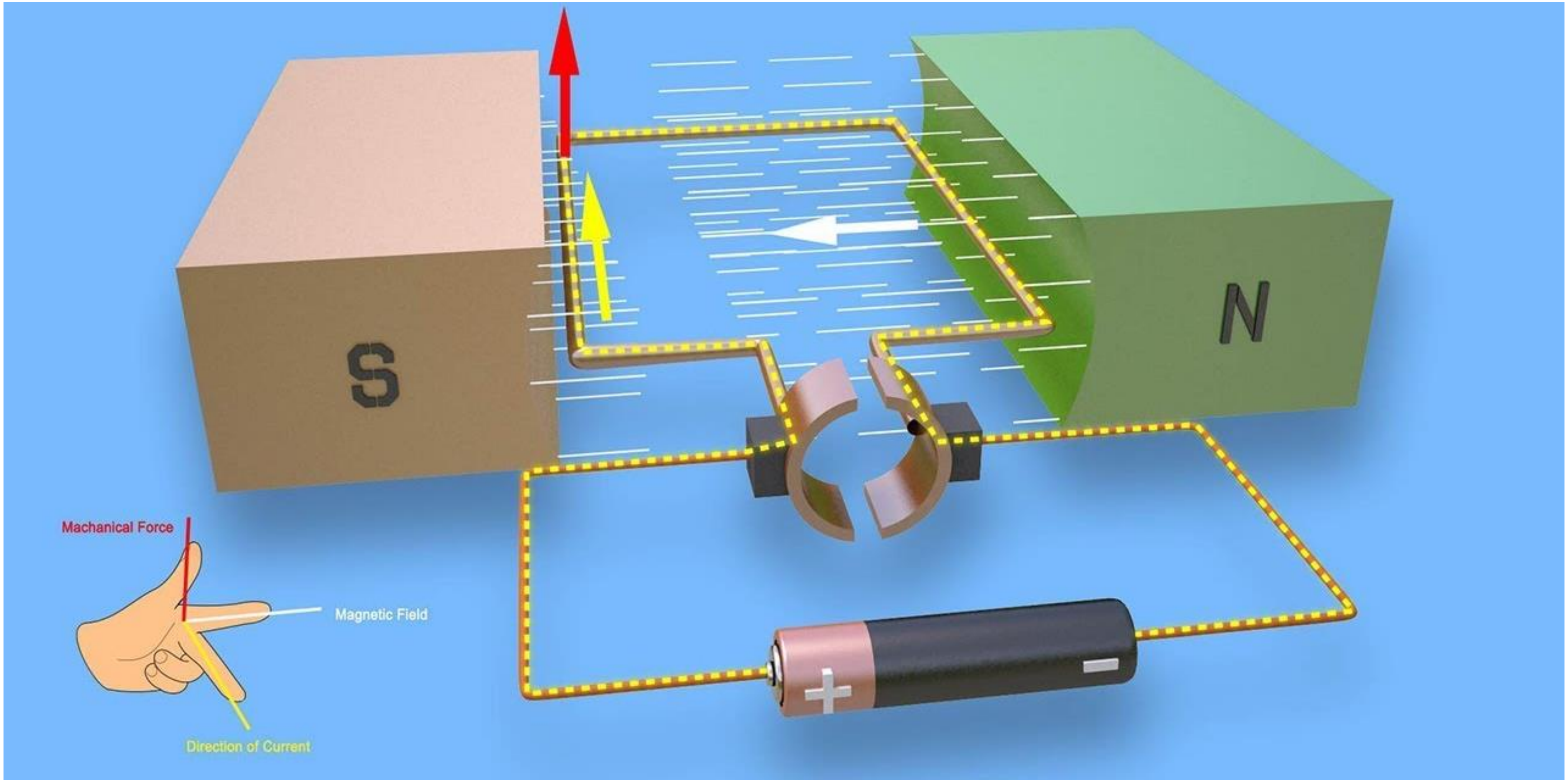
Force on a current carrying conductor lying in the magnetic filed

❖ The direction of this force can be determined by applying Fleming's Left Hand Rule

If the thumb, forefinger and middle finger of the left hand are stretched in such a way that they area at right angle to each other mutually and fore-finger points towards the direction of the magnetic field, middle finger towards the direction of flow of current then thumb will point the direction of force acting on the conductor



DC Motor



DC Motor

- When a DC machine is loaded either as a motor or as a generator, the rotor conductors carry current. These conductors lie in the magnetic field of the air gap. Thus each conductor experiences a force. The conductors lie near the surface of the rotor at a common radius from its center. Hence torque is produced at the circumference of the rotor and rotor starts rotating.

- **The term torque is the quantitative measure of the tendency of a force to cause a rotational motion, or to bring about a change in rotational motion.** It is in fact the moment of a force that produces or changes a rotational motion.

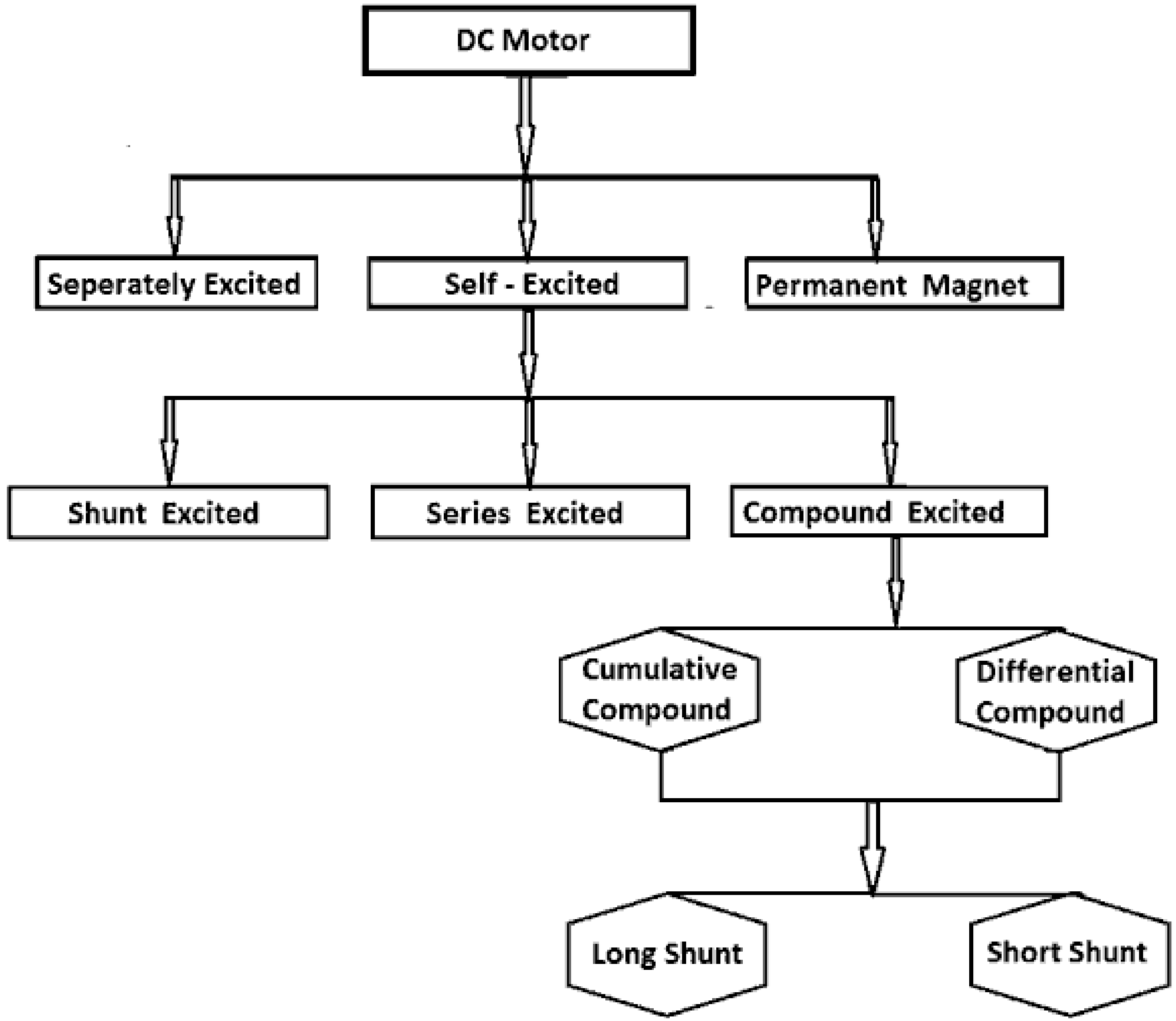
- When the armature of a DC motor rotates under the influence of the driving torque, the armature conductors move through the magnetic field and hence emf is induced in them as in a generator.

- The induced emf acts in opposite direction to the applied voltage V (Lenz's law) and is known as Back EMF or Counter EMF (Eb).

- The equation to find out back emf in a DC motor is given below,

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

DC Motor


DC Motor
Seperately Excited
Self - Excited
Permanent Magnet
Shunt Excited
Series Excited
Compound Excited
Cumulative Compound
Differential Compound
Long Shunt
Short Shunt

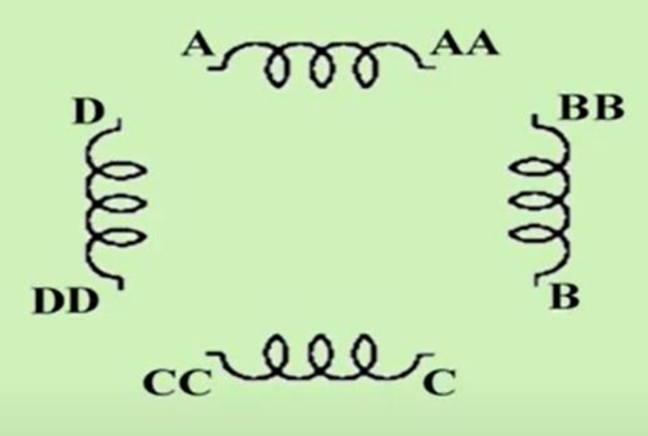

27
24
L 6MM
φ 2MM
RF-3000-11440
D/V3.0

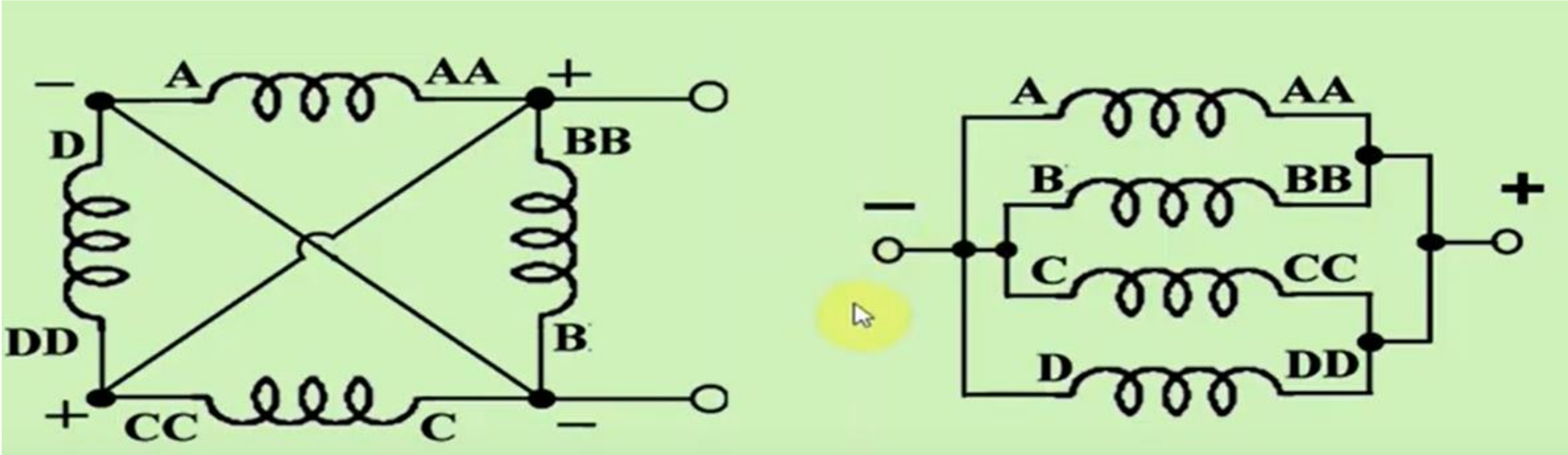
DC Motor Applications

Type of Motor	Characteristics	Applications
Shunt	Speed is fairly constant and medium starting torque.	1. Blowers and fans 2. Centrifugal and reciprocating pumps 3. Lathe machines 4. Machine tools 5. Milling machines 6. Drilling machines
Series	High starting torque. No load condition is dangerous. Variable speed.	1. Cranes 2. Hoists, Elevators 3. Trolleys 4. Conveyors 5. Electric locomotives
Cumulative compound	High starting torque. No load condition is allowed.	1. Rolling mills 2. Punches 3. Shears 4. Heavy planers 5. Elevators
Differential compound	Speed increases as load increases.	Not suitable for any practical applications

Thank You !

Parallel Paths





Parallel Paths