

# General Engineering



## Unit 5 ELECTRICAL TRANSMISSIONS



# Electric motor

- An electric motor is an electrical machine that converts electrical energy into mechanical rotational energy.
- Electric motors operate through the interaction between the motor's magnetic field and electric current in a wire winding to generate force in the form of torque applied on the motor's shaft.
- Electric motors can be powered by direct current (DC) sources, such as from batteries, or rectifiers, or by alternating current (AC) sources, such as a power grid, inverters or electrical generators.





# Purpose of electric motor

- The electric motor is used to rotate other mechanical devices.
- The applications of electrical motor mainly include blowers, fans, machine tools, pumps, turbines, power tools, alternators, compressors, rolling mills, ships, movers, paper mills.
- The electric motor is an essential device in different applications like HVAC- heating ventilating & cooling equipment, home appliances, and motor vehicles.





# Principle of D.C Motor

- Faraday's Laws of Electro magnetic Induction.

Whenever a conductor cuts the flux of a magnetic field, an emf is produced in the conductor. If the two ends of the conductor are connected to an outside circuit, the induced emf causes current to flow in the circuit.

When a current carrying conductor is placed in a magnetic field, the conductor experiences a mechanical force



# Principle of D.C Motor

Fleming's left - hand rule states that if we stretch the thumb, middle finger and the index finger of the left hand in such a way that they make an angle of 90 degrees (Perpendicular to each other) and the conductor placed in the magnetic field experiences Magnetic force.

Such that: Thumb: It points towards the direction of force (F)

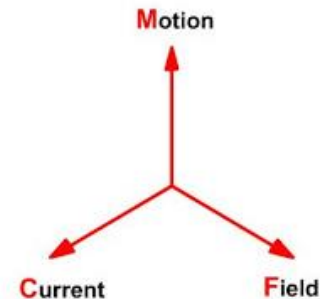
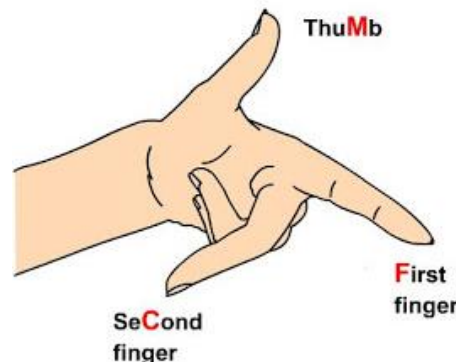
Middle Finger: It represents the direction of the current (I)

Index Finger: It represents the direction of the magnetic field (B)

$$\mathbf{F} = \mathbf{BIL} \text{ Newtons}$$

Where,

B = magnetic flux density, I = current and L = length of the conductor within the magnetic field.

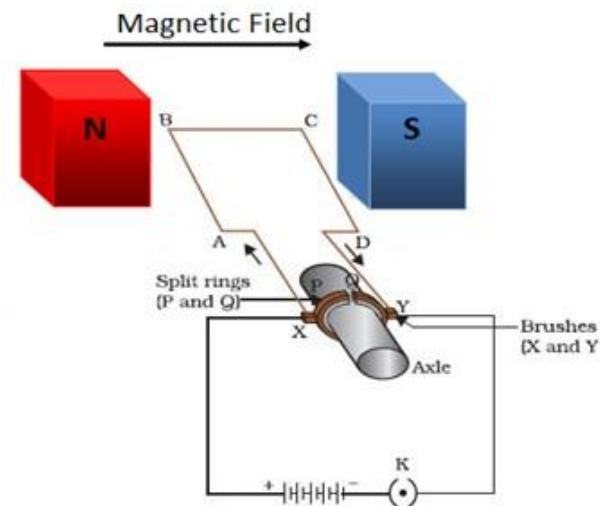




# Construction of D.C electric motor

## Parts of a Electric Motor

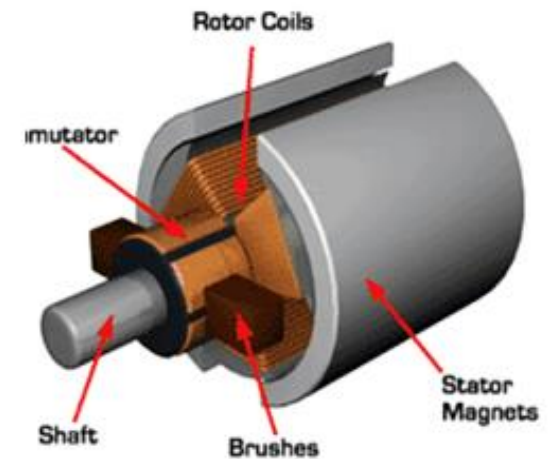
- Insulated Copper wire: A rectangular coil of wire ABCD
- Magnet Poles: A magnet as placed above ie North Pole and South Pole. This creates a magnetic field as shown above.
- Split Rings: Two disjoint C-shaped rings P and Q. It acts as a commutator (which can reverse the direction of current)
- Axle: The split rings are placed on the axle which can rotate freely.
- Brushes: The outside of the split rings are connected to conducting brushes X and Y.
- DC Source : To source current.





# Construction of D.C electric motor

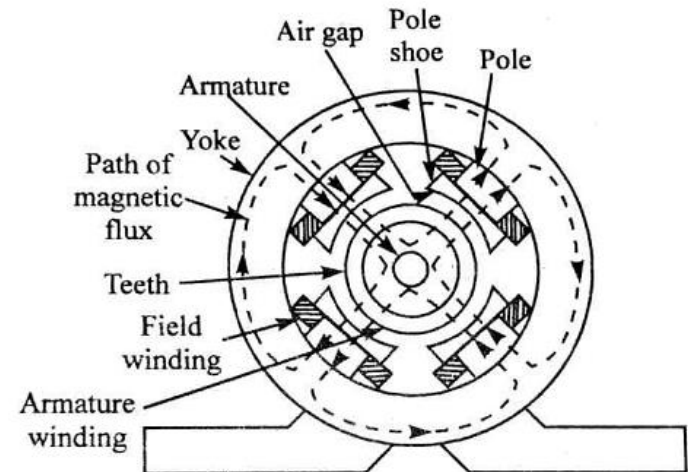
- There are two main parts of the DC motor.
  - Armature
  - Stator
- The rotating part is the armature and the Stator is their stationary part.  
The armature coil is connected to the DC supply.





# Construction of D.C electric motor

The armature coil consists the commutators and brushes. The commutator converts the AC induces in the armature into DC and brushes transfer the current from rotating part of the motor to the stationary external load. The armature places between the north and south pole of the permanent or electromagnet.



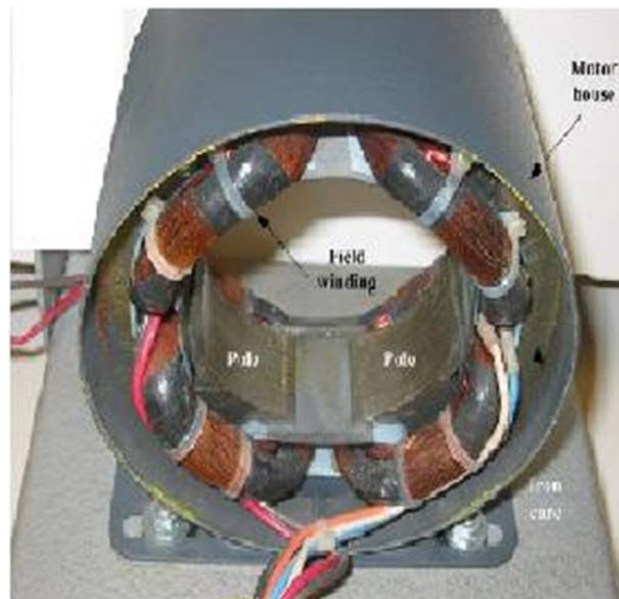




# Construction of D.C electric motor

## Yoke

- Hollow cylinder made of cast steel or roll steel Act as outer protective cover of machine.
- Provides mechanical support for poles. Carries flux produced by poles

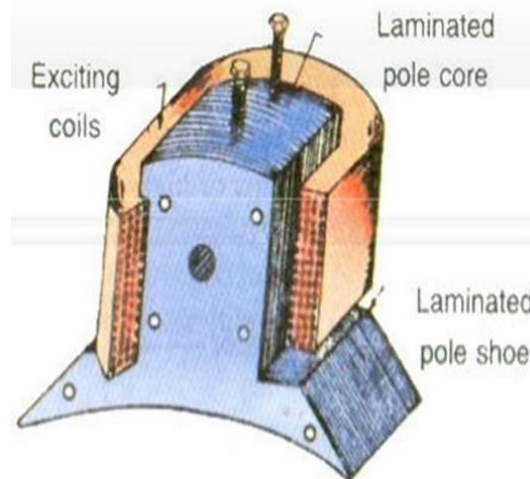




# Construction of D.C electric motor

## Pole Core and Pole Shoes

- Field windings are wound on pole core and supported by pole shoes. Are made of number of sheet steels stacked and riveted together. made of Silicon steel – to reduce hysteresis loss
- laminated – to minimize eddy currents Pole cores are then bolted to yoke.
- Pole shoes serve two functions : support field coils & spread out flux in airgap.

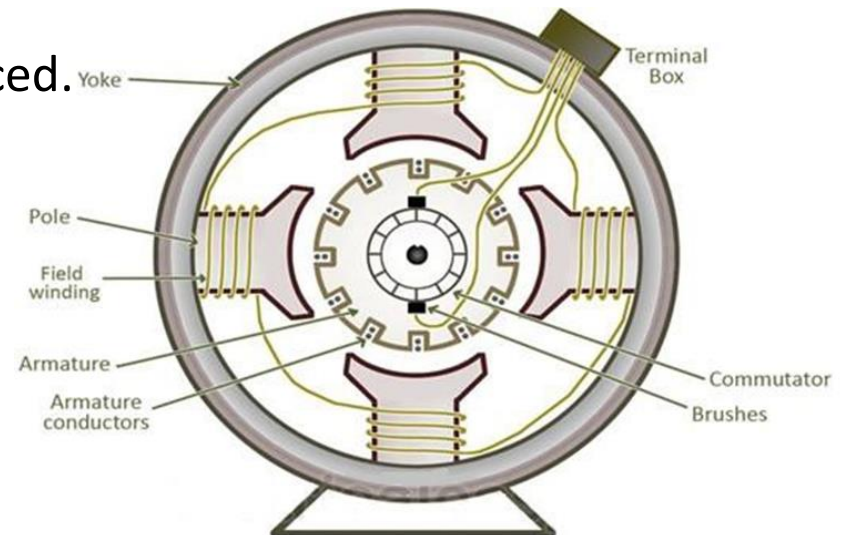




# Construction of D.C electric motor

## Field Windings

- They are made of copper wire
- Field coils are former wound to correct dimension and then put into place over the core.
- When energized with DC, electro magnetize the poles and provide the working flux. All coils are connected in series such that as current flows,
- alternate N and S poles are produced.





# Construction of D.C electric motor

## Inter Poles

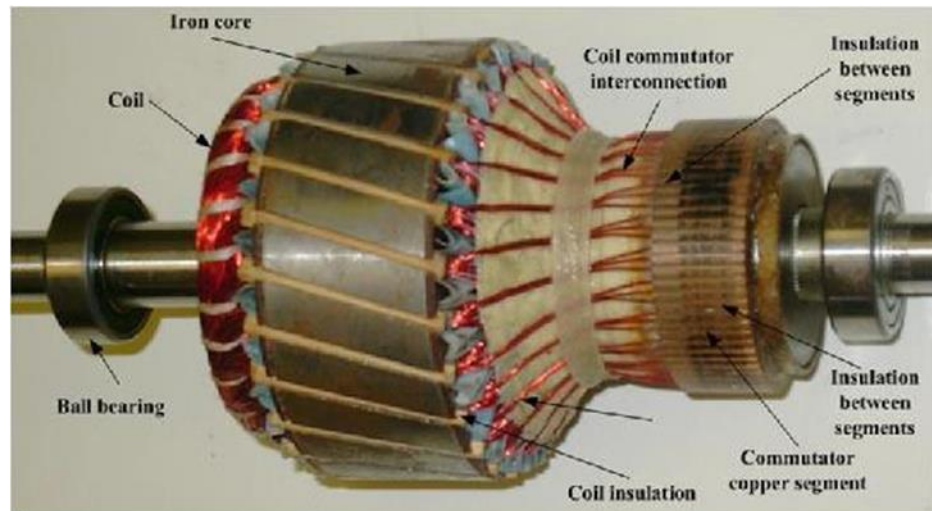
- Fitted to yoke between main poles.
- Windings are made of copper and are connected in series with field windings.
- Flux produced by inter poles provides spark less commutation.



# Construction of D.C electric motor

## Shaft

- Provides mechanical strength to armature and commutator.
- Rotor assembly is free to rotate by two bearing fixed between shaft and two end covers.
- Transfers mechanical energy to and from machine.

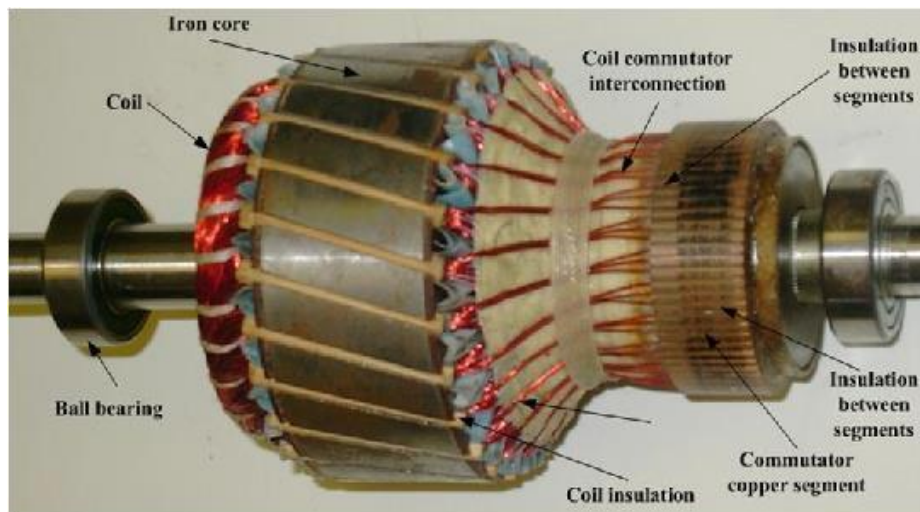




# Construction of D.C electric motor

## Armature Core and Windings

- Laminated cylinder mount on shaft.
- Are made of number of sheet steels stacked and riveted together.  
made of Silicon steel – to reduce hysteresis loss
- laminated – to minimize eddy currents
- Has slots on outer periphery to accommodate armature windings.

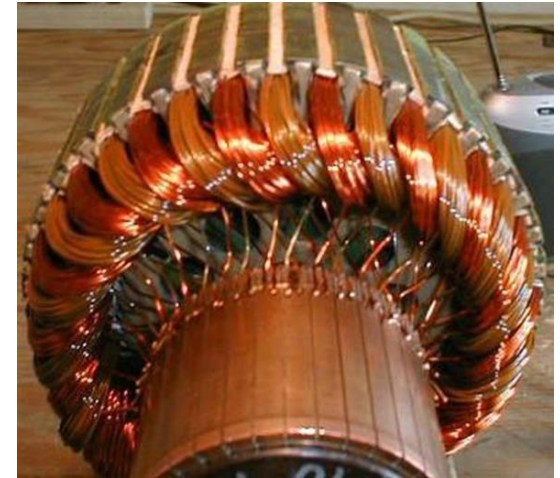




# Construction of D.C electric motor

## Commutator

- Ends of armature coils terminated at commutator segments
- Made of copper segments insulated by mica



## Functions :

- Collect current from armature conductors.
- The e.m.f. generated in the armature conductors is alternating e.m.f.
- The commutator helps in converting this alternating e.m.f. into a direct one.



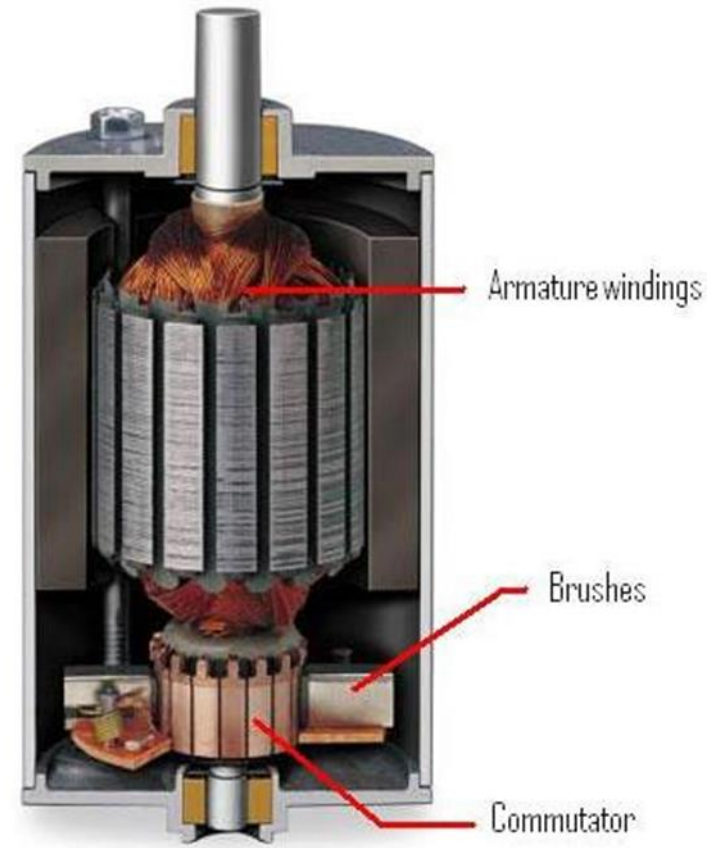
# Construction of D.C electric motor

## Brushes

- Made of graphite or carbon
- Held by brush holders
- Desirable Properties
- Good electrical conductivity
- Less co-efficient of friction.

## Functions :

- The brushes collect the armature current from the commutator segments and supply it to the load (in the case of generator) or feed the current into the commutator segments (in the case of motor).



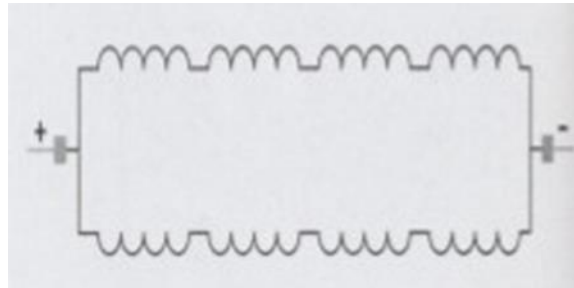




# Construction of D.C electric motor

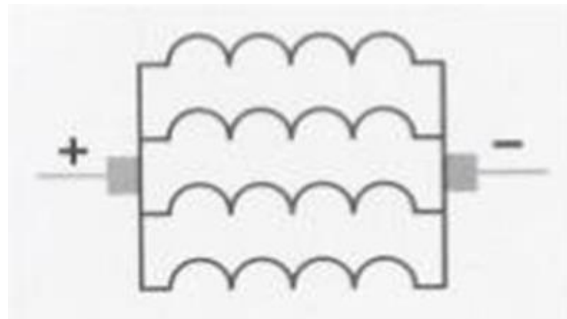
## Wave Winding

Armature winding is divided into two parallel paths.



## Lap Winding

Armature winding is divided into as many parallel paths as number of poles of machine



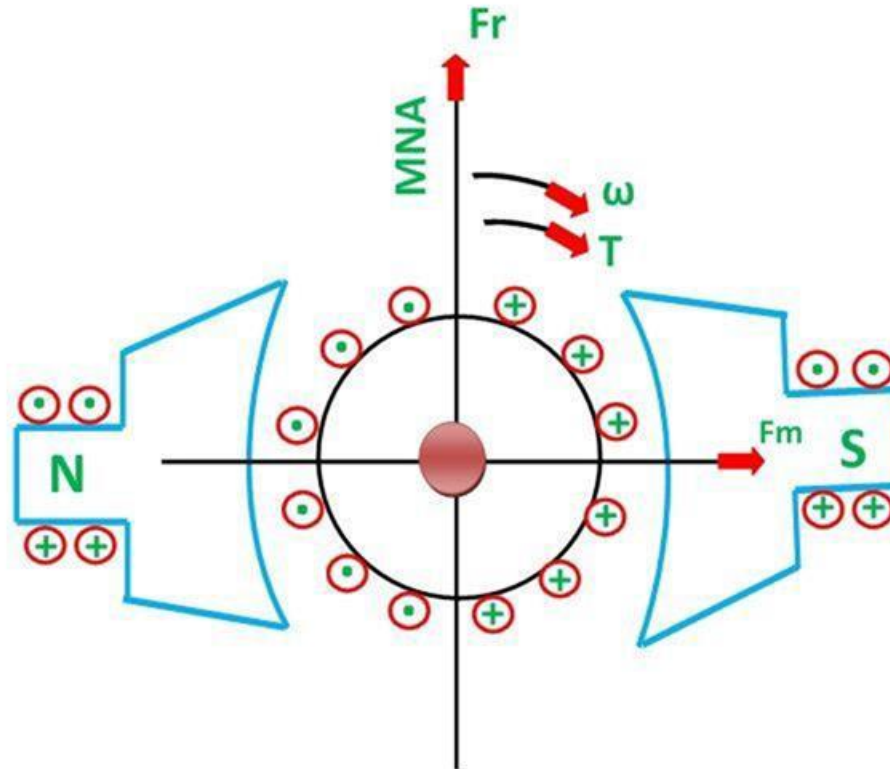


# Working principle of D.C electric motor

- The basic working principle of the DC motor is that whenever a current carrying conductor places in the magnetic field, it experiences a mechanical force.
- When armature winding is connected to a DC supply, an electric current sets up in the winding. Permanent magnets or field winding (electromagnetism) provides the magnetic field. In this case, current carrying armature conductors experience a force due to the magnetic field, according to the Fleming's Left Hand Rule.



# Working principle of D.C electric motor





# Working principle of D.C electric motor

When armature of dc motor rotates, the armature conductors move through the magnetic field, emf is induced in them. The induced emf acts in opposite direction to applied voltage. This voltage is known as back emf.

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



# Working principle of D.C electric motor

- Consider a two polar DC motor as shown in figure. When motor terminals are connected to DC mains, field gets excited and alternate N-pole and S- pole is created. Armature conductors under N-pole carry current in one direction while conductor carry current in opposite direction as shown in figure.
- By applying Flemings left hand rule, the armature conductors experience a force which tends to rotate armature in clockwise direction. These forces collectively produce a driving torque which sets armature rotating.



# Applications of DC Motor

## **Shunt Motor**

- Constant speed motor.
- Used in lathe, drills, boring mills, spinning and weaving mills etc.

## **Series Motor**

- Variable speed motor, high starting torque.
- Used in elevators, electric traction, cranes, vaccum cleaners etc.

## **Compound Motor**

- Differentially compound motor—rarely used
- Cumulatively compound motor – used in presses, reciprocating machines, etc.



# Induction motor

- Conversion of electrical power into mechanical power takes place in the rotating part of an electric motor. In A.C. motors, rotor receives electric power by induction in exactly the same way as the secondary of a two-winding transformer receives its power from the primary.
- An induction motor essentially consists of two main parts:
  - Stator
  - Rotor



# Induction Motors

- Widely used power drive.
- Run at constant speed.
- Working principle –electromagnetic induction. Hence the name induction motor.





# Induction Motors - Classification

Based on type of ac supply,

## **Single Phase Induction Motors**

- not self starting
- applications restricted to small power ratings.

## **Three Phase Induction Motors**

- Self starting
- Extensively used in industries and hence known as 'work horse' of modern industry



# Induction motor

## Advantages

- Simple design
- Rugged construction
- Reliable operation
- Low cost
- Minimum maintenance
- High efficiency and good pf at full load



# Induction motor Construction

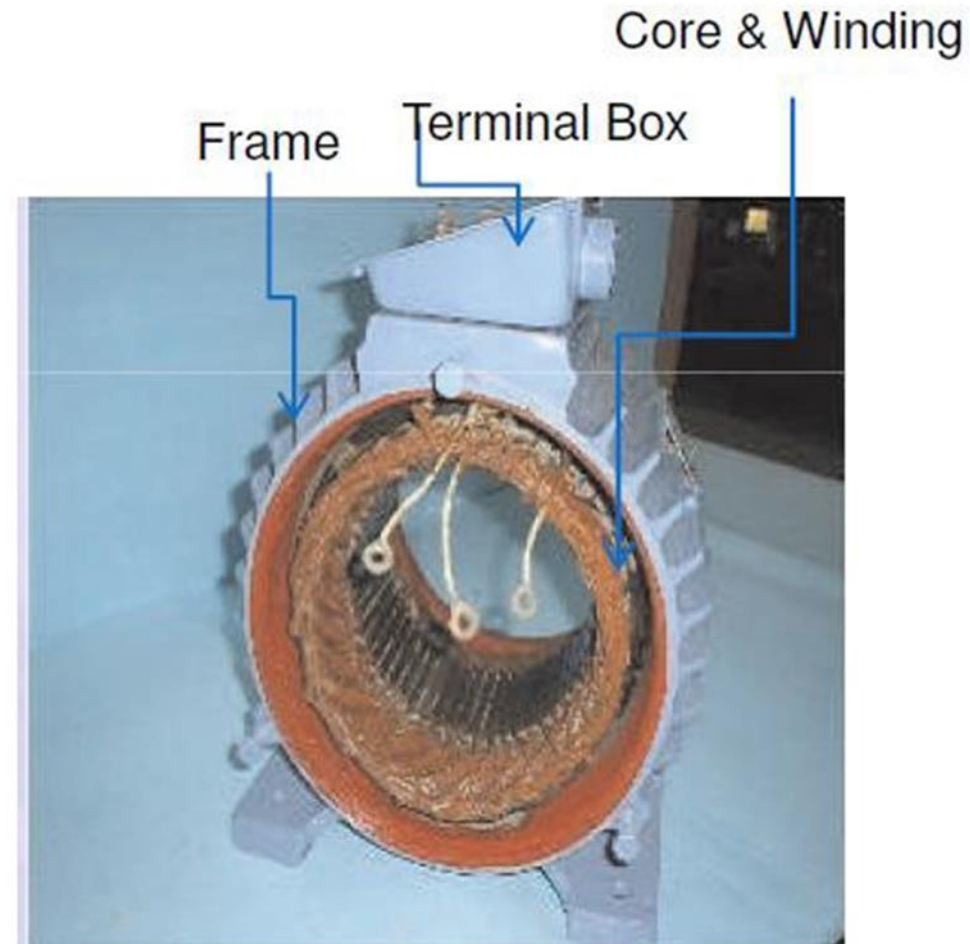
- Consists of Stator and Rotor.
- Rotor is separated from stator by a small airgap (0.4 mm to 4mm)
- Depending on rotor construction, induction motors are classified as
  - Squirrel Cage Induction Motor (SCIM)
  - Slip Ring Induction Motor (SRIM)



# Induction motor Construction

## Main Parts

- Frame
- Stator Core
- $3\phi$  distributed winding





# Induction motor Construction Main Parts

## Frame

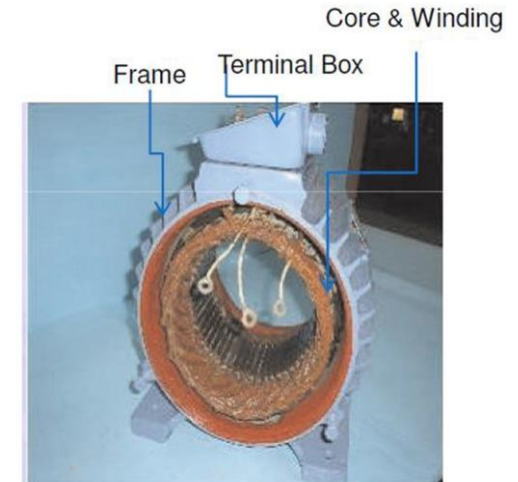
- Cylindrical in shape and made of cast iron
- Provides support and act as protective cover.
- Provided with fins to increase heat dissipation.

## Stator Core

- Cylindrical in shape and made of silicon steel laminations
- Provides space for accommodating 3 $\phi$  balanced winding.
- 3 $\phi$  distributed winding

## Stator Winding

- Made of copper wire.
- The 3 coils from 3 windings are distributed over slots





# Construction - Squirrel Cage Rotor Main Parts

## Shaft

## Rotor Core

- laminated cylindrical core .
- have slots on its outer periphery.

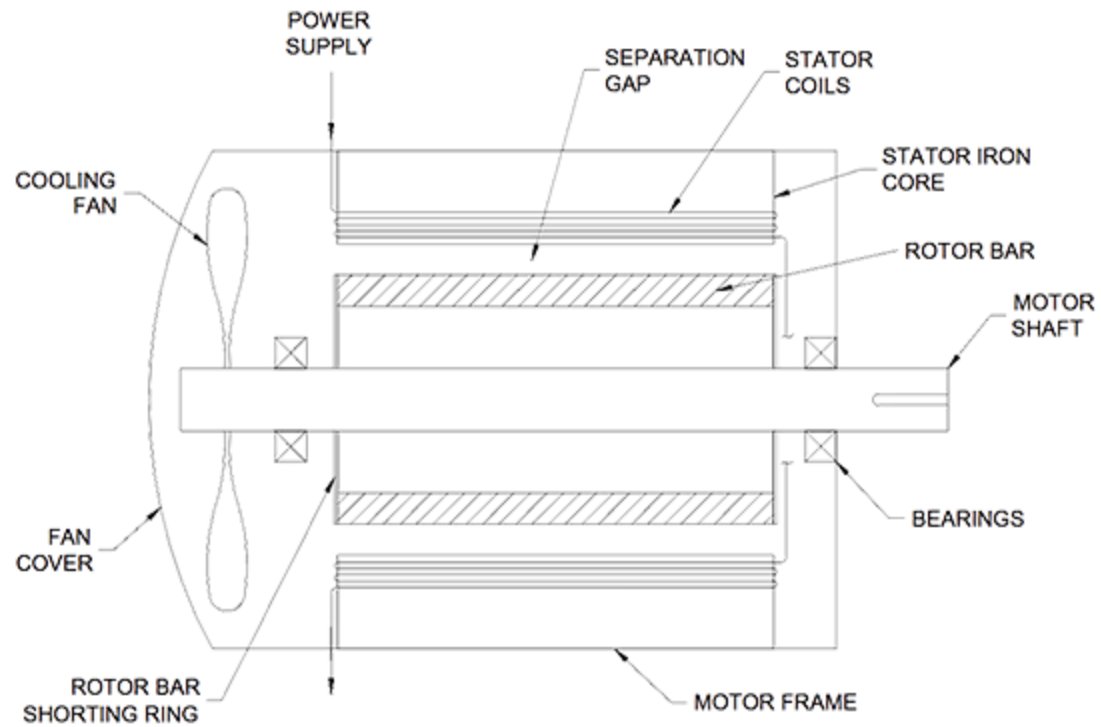


## Rotor Bars

- A thick copper or aluminum bar is placed in each slot.
- All these bars are joined together at both ends by metal rings called end rings.
- Rotor circuit is permanently closed circuit.
- Rotor bars and end rings together resembles the cage of squirrel and hence the name.



# Construction





# Induction motor Working

- When 3 $\phi$  stator winding is energized from a 3 $\phi$  supply, a rotating magnetic field is produced.
- The speed at which magnetic field rotates is called synchronous speed  $N_s$

$$N_s = 120 f / P$$

where,  $P$  – no. of poles

$f$  – supply frequency

- This field passes through the air gap and cuts the stationary rotor conductors which induces emf in the rotor conductors.
- Since rotor circuit is short circuited current starts flowing through rotor conductors





# Induction motor Working

- Now the situation is like a current carrying conductor (rotor conductor) placed in a magnetic field (produced by stator)
- Thus mechanical force acts on all rotor conductors. The sum of mechanical forces on all rotor conductors produces a torque which tends to move rotor in the same direction as that of rotating magnetic field



# Induction motor

- The flux from the stator cuts the short-circuited coil in the rotor. As the rotor coils are short-circuited, according to Faraday's law of electromagnetic induction, the current will start flowing through the coil of the rotor.
- When the current through the rotor coils flows, another flux gets generated in the rotor.
- Now there are two fluxes, one is stator flux, and another is rotor flux. The rotor flux will be lagging with respect to the stator flux.
- Because of that, the rotor will feel a torque which will make the rotor to rotate in the direction of the rotating magnetic field.



# Synchronous motor

- In this type of engine, the rotation of the rotor is synchronized with the frequency of the supply current and the speed stays constant under varying loads, making it suitable for moving equipment at a constant speed and used in high-precision positioning devices such as robots, instrumentation, machines and process control.
- Speed of the synchronous motor is controlled by the frequency of the applied current. The speed of a synchronous motor can be calculated as

$$N_s = 60f/P = 120f/p$$

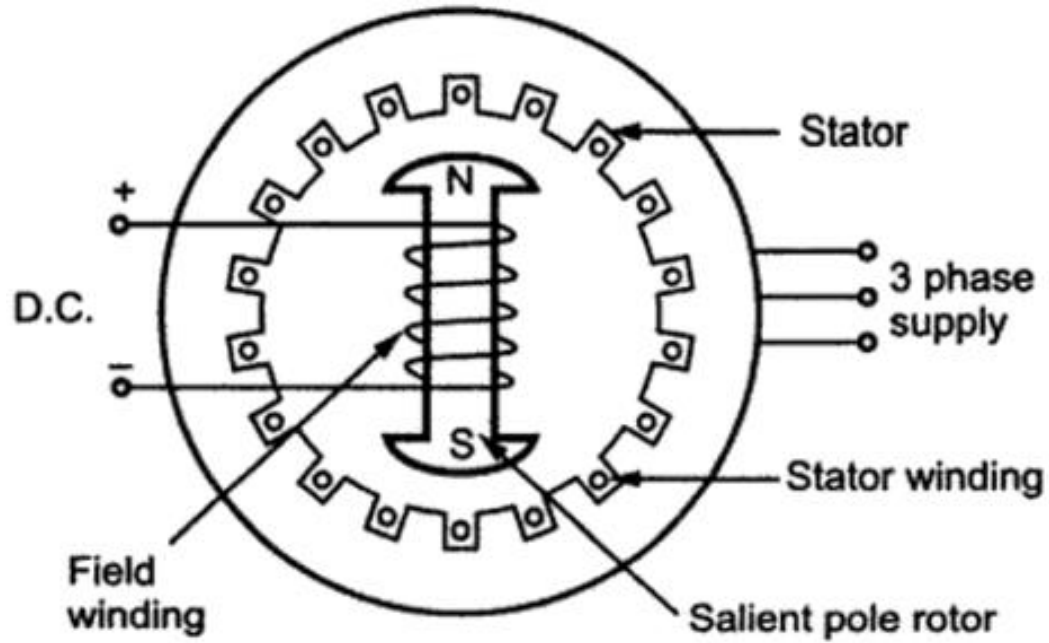
where,  $f$  = frequency of the AC current (Hz)

$p$  = total number of poles per phase

$P$  = total pair number of poles per phase.



# Synchronous motor





# Synchronous motor

- Working of synchronous motors depends on the interaction of the magnetic field of the stator with the magnetic field of the rotor.
- The stator contains 3 phase windings and is supplied with 3 phase power.
- Thus, stator winding produces a 3 phased rotating Magnetic- Field.
- DC supply is given to the rotor.
- The rotor enters into the rotating Magnetic-Field produced by the stator winding and rotates in synchronization.
- Now, the speed of the motor depends on the frequency of the supplied current.

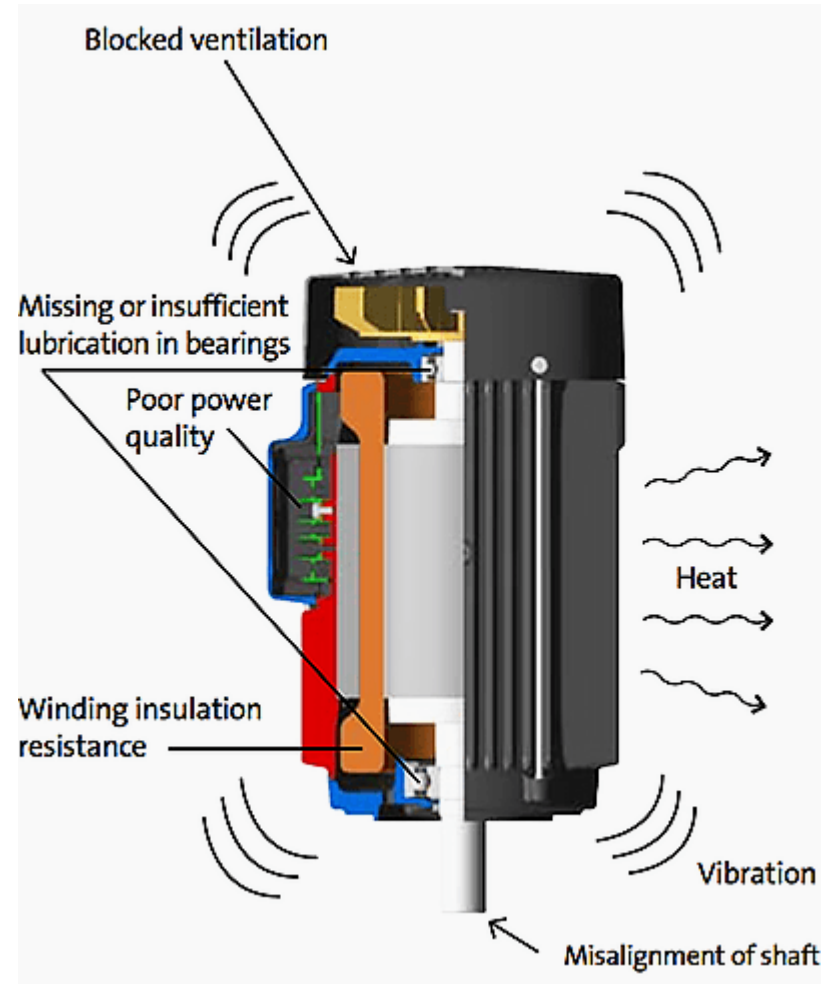


# Electric motors maintenance

- A well and carefully designed motor maintenance program, when correctly used, can be summed up as preventive maintenance, predictive maintenance and reactive maintenance. Inspection cycles depend upon the type of motor and the conditions under which it operates.
- Motors need maintenance regularly in order to avoid failure and prolong their lifespan. Generally speaking, should be maintained and tested at least every 6 months. Only then is it possible to maintain a motor's life and its efficiency.



# Electric motors maintenance





# Motor vibration

- Generally motor will run with very mild vibration.
- Vibration can be extremely damaging to electric motors, frequently causing premature failure.
- It is often caused by the motor being positioned on an uneven or unstable surface. However, vibration can also be a result of a misalignment or corrosion or bearing damage.
- Electric motors should be regularly inspected for vibration using a motor analysing tool.
- Ensure that electric motors are positioned on a flat and stable surface. If vibration still occurs, check for signs of wear, as well as misalignment or loose bearings. Any faulty item should be replaced.





# Temperature

- While running, the motor is warm.
- Overheating is generally caused by either a high temperature in the operating environment or poor power quality or bearing problems or winding insulation fault . Contaminants can damage the motor by blocking the cooling fan which causes the motor temperature to rise. Dirt can also affect the insulating value of the winding insulation if it settles on the motor windings.
- It is responsible for around 55% of insulating failures in electric motors. For every 10 degrees Celsius that the temperature of a motor rises, the insulation life is reduced by half.
- To avoid overheating, ensure that electric motors are kept as cool as possible. This can be done by maintaining as cool an operating environment as possible and regularly checking the temperature of the motor.



# Lubrication

- Bearings in standard motors are always lubricated with grease , they may be re lubricated via lubrication points. Lubrication will avoid friction between moving part ( shaft) and stationary part ( Stator).
- Lubricate the motors properly as over-lubrication or under-lubrication causes equal damage to the motors.
- Consider the frequency of the lubrication and the possible contaminants that the motors can be subjected to.
- Generally one in 6 months, motors to be lubricated.
- We can opt for anti-wear and oxidation resistance apart from consistency, viscosity and other factors if different materials are being mixed.



# Cleaning

- Electric motors frequently operate in environments where dust, dirt and chemicals are present, which may find their way inside the motor, leading to contamination and motor failure.
- These contaminants can dent bearing raceways and balls, leading to high levels of vibration and wear. They may also block the cooling fan, limiting the motor's ability to regulate its temperature and increasing the chances of overheating.
- As contamination is one of the leading causes of failure in electric motors, it is essential to prevent it from entering the motor.
- Ensure that work areas, tools and fixtures are kept as clean as possible at all times to help eliminate the chances of contamination entering the motor.
- When laying out the workspace, try to position motors away from applications such as grinding machines which produce large quantities of harmful contamination.
- Stop the motor and clean well once in an year.



# Ventilation

- While the motor is running, it generate heat. To cool the motor a cooling fan is fixed at one end of shaft.
- The cooler a motor operates, the longer lifetime it has. Therefore, the fan cover and the cooling fin always have to be as clean as possible.
- Even though motors are protected, it is important to install them in areas with constant ventilation so that high temperatures do not damage insulation and bearings.
- If the motors get overheated due to any reason, it may cause a number of performance issues.
- Overheating may occur when an electric motor is forced to operate in a high-temperature environment as it would cause the rate at which heat can be conducted to reduce at a significant rate.
- Every electric motor has a design temperature and if it starts off at a bad value, it will start operating in a much warmer condition than the design temperature.
- The motors should be matched with the ideal current values to prevent overheating. Make sure to check on the heat being dissipated to mitigate the damages caused by overheating.



# Overload of motors

- Electrical overload is also commonly referred to as overcurrent.
- It is caused by an excessive flow of current within the windings of the motor, which exceeds the design current that the motor is able to carry efficiently and safely.
- Motor overloading can be caused by an increase in the load being driven by the motor, bearing failure in the motor or the driven load, or an electrical problem such as a low input voltage or single phasing.
- Overcurrent is often the result of a low supply voltage, which results in the motor drawing in more current in an attempt to maintain torque.
- Electrical overload can also be caused by short-circuited conductors, or an excessive voltage supply.
- It is important to install effective overcurrent protection which is able to detect overcurrent and interrupt supply to protect the motor.



# D.C Generator - Principle

- Faraday's Laws of Electro magnetic Induction.

Whenever a conductor cuts the flux of a magnetic field, an emf is produced in the conductor. If the two ends of the conductor are connected to an outside circuit, the induced emf causes current to flow in the circuit.

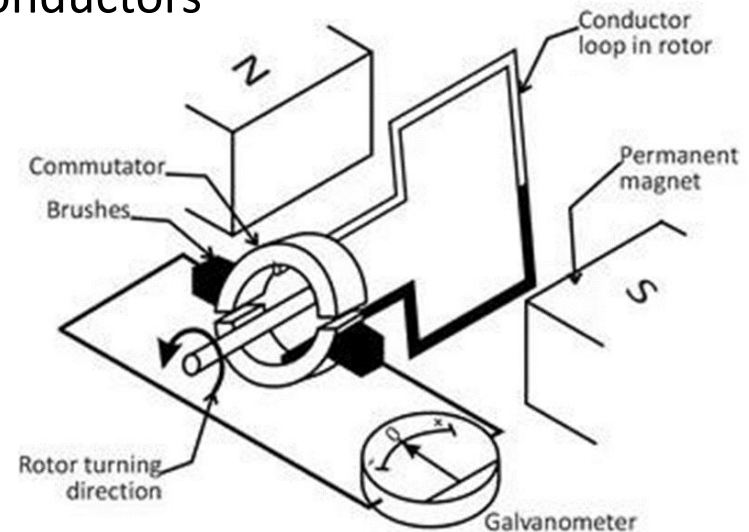
The direction of induced current is given by Fleming's right hand rule.



# D.C Generator - Construction

A DC machine essentially consists of two parts.

- Stator(Stationary Part) – Magnetic Field System
- Rotor(Rotating Part) – A system of conductors



Consider a single turn coil rotating about its own axis in a magnetic field.  
The two ends of the coil are connected to split rings(commutator)



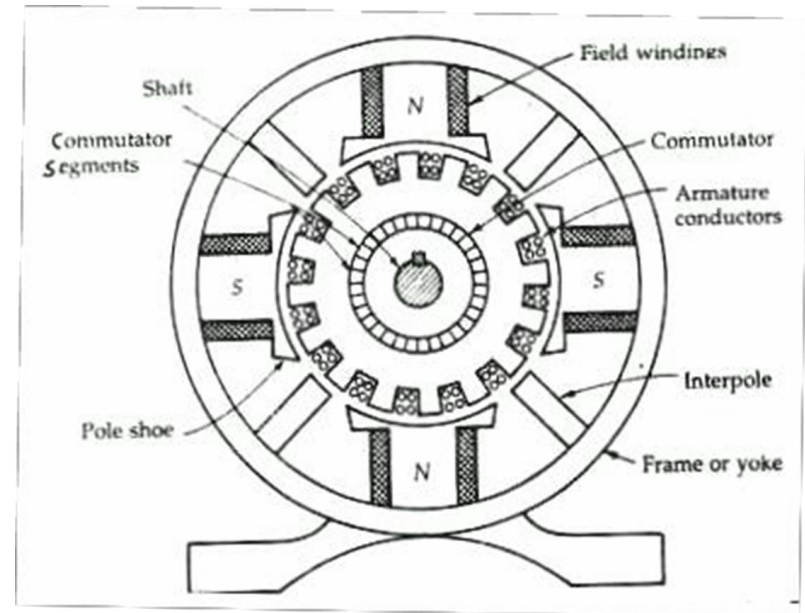
# D.C Generator - Construction

## Stator

1. Yoke
2. Pole Core
3. Pole Shoes
4. Field Coils
5. Interpoles

## Rotor

1. Shaft
2. Armature Core
3. Armature Windings
4. Commutator
5. Brushes





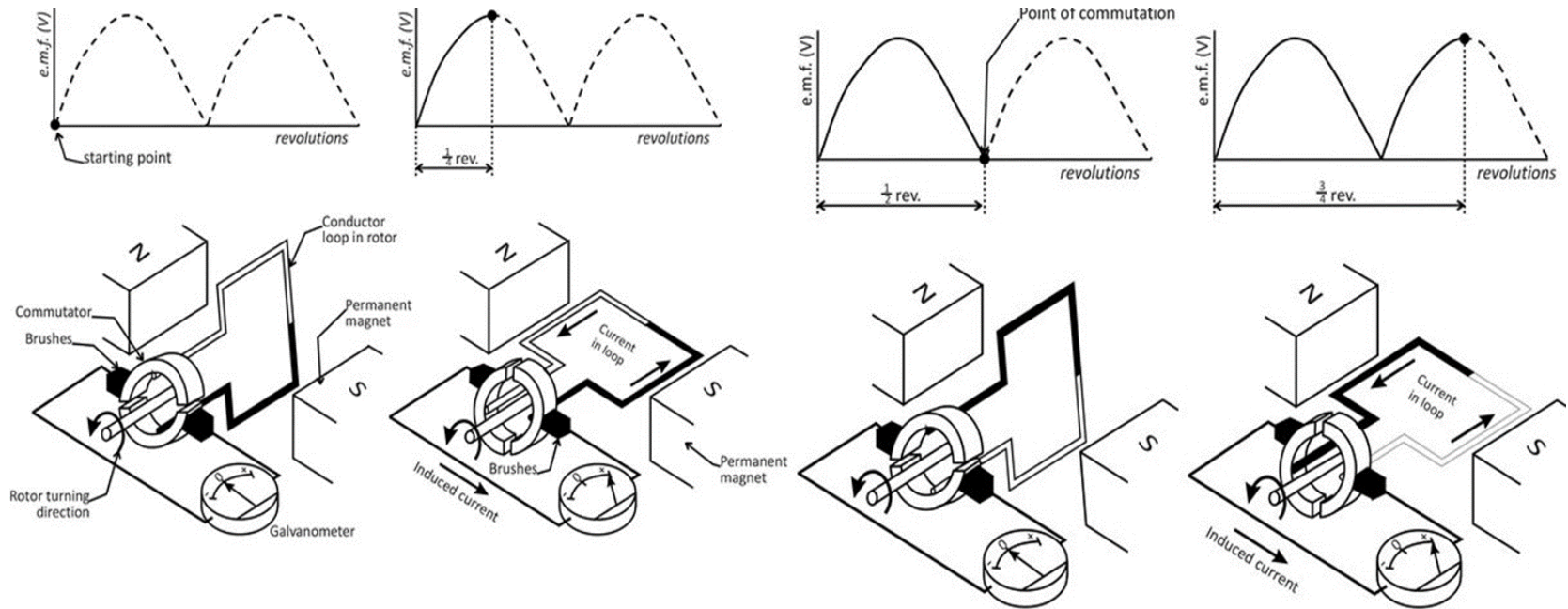


# D.C Generator - working

- EMF induced in coil is proportional to rate of change of flux.
- When the plane of coil is at right angles to the direction of field, flux linked with coil is maximum, but rate of change of flux is minimum. Hence induced EMF is minimum.
- When the plane of coil is at parallel to the direction of field, flux linked with coil is minimum, but rate of change of
- flux is maximum. Hence induced EMF is maximum.
- In order to get a unidirectional current in external circuit, a split ring arrangement is done.



# D.C Generator - working



(a): One-loop generator at start of revolution

(b): One-loop generator at 1/4 revolution

(c): One-loop generator at 1/2 revolution

(d): One-loop generator at 3/4 revolution



# DC Generator - EMF Equation

Let,

$\phi$  – useful flux per pole

Z – total number of conductors P – number of poles

N – speed in rpm

A – number of parallel paths in armature

Flux cut by one conductor in one revolution =  $P\phi$

N rotations in 60 seconds, Time for one revolution =  $60/N$

$$\text{EMF induced in one conductor} = \frac{d\phi}{dt} = \frac{P\phi}{60/N} = \frac{P\phi N}{60}$$

$$\text{EMF induced in one parallel path} = \frac{P\phi N}{60} \frac{Z}{A}$$



[Download the latest notes from www.ensolt.com](http://www.ensolt.com)