DC GENERATOR

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DC Generator

Working principle
Construction
Working
Classification
Types of winding
Losses and efficiency
Armature reaction
Characteristics
Application

Working Principle

Faraday’s law of electromagnetic induction

First law

When a conductor moves in a magnetic field it cuts magnetic lines of force, which induces an electromagnetic force (EMF) in the conductor.

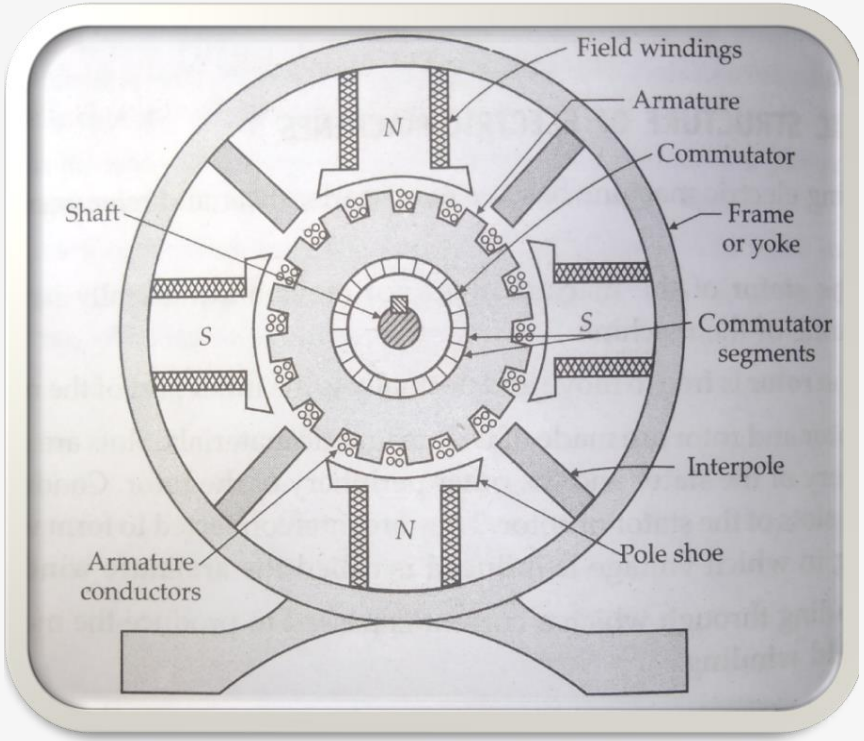
Second Law

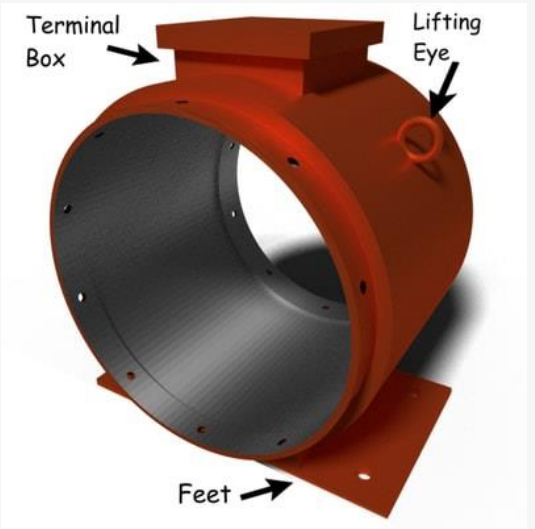
The magnitude of this induced EMF depends upon the rate of change of flux (magnetic line force) linkage with the conductor

Construction

Yoke or Frame

- Made of cast iron (small machine)
- cast steel or rolled steel (large machine)
- Mechanical support
- It carries magnetic flux





Pole cores

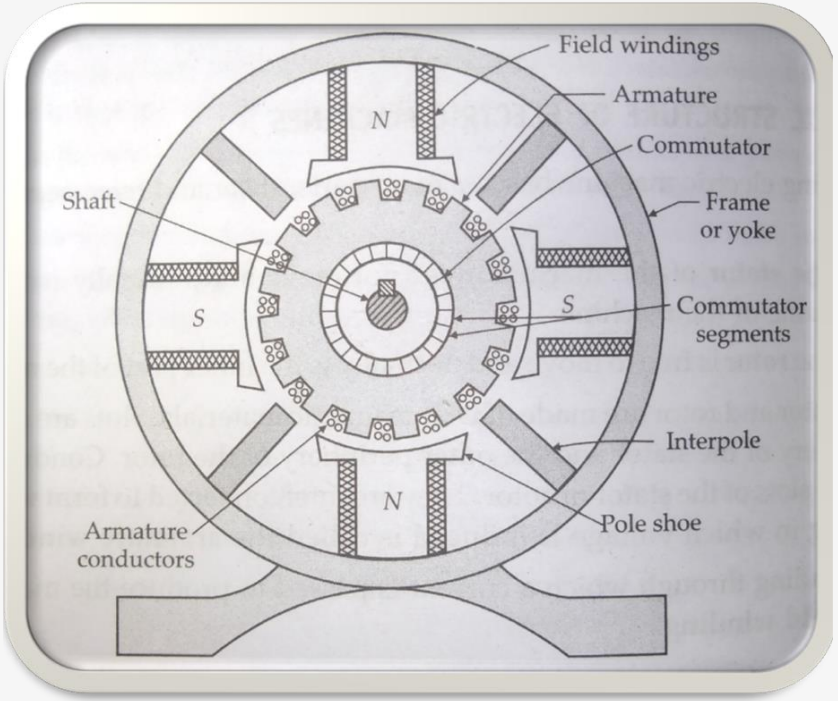
Pole cores

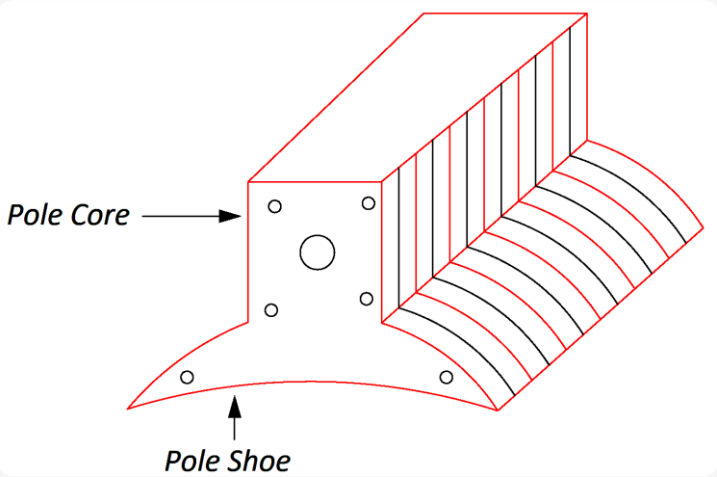
Pole core

- Laminated cast iron or cast steel
- Modern machine : Thin lamination of annealed steel
- Thickness of lamination = 0.25 to 1 mm

Pole Shoes

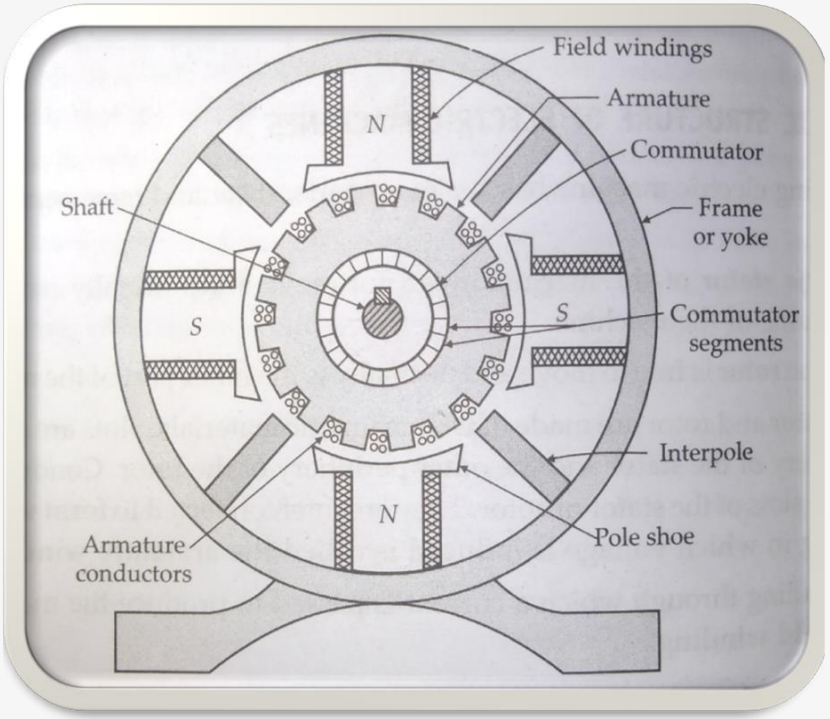
- Spread out the flux in the air gap
- Being large cross section , reduce the reluctance of the magnetic path.
- Support the exciting coil





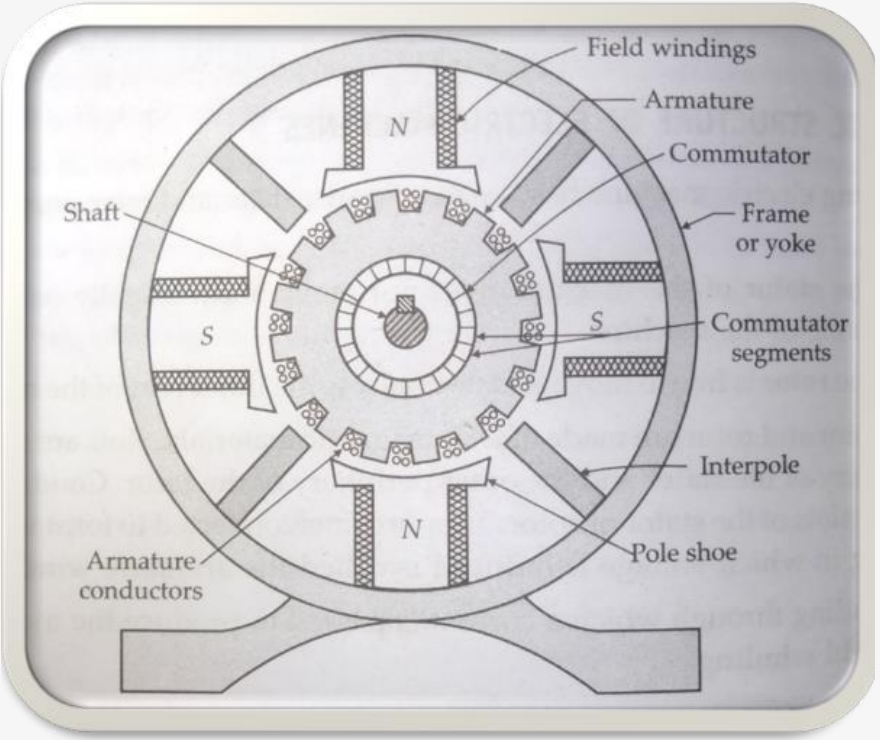
Pole Coil

- Consist of enameled copper coil
- usually finished off with an insulating varnish



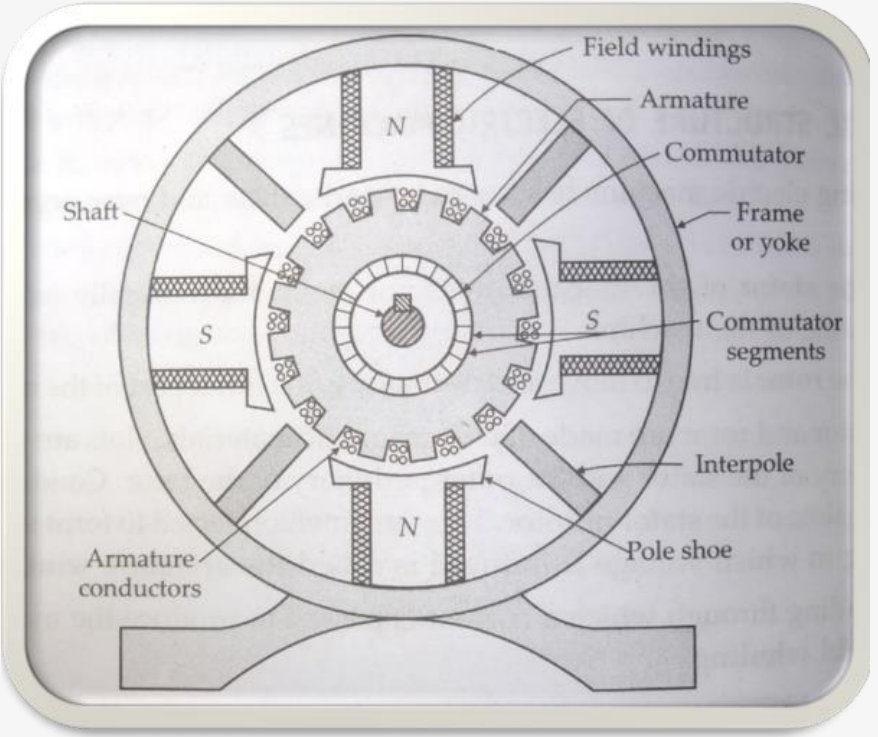
Armature core

- Houses the armature conductor
- It provides an easy path for the magnetic flux.
- silicon steel material is used
- laminated with a stamping of about 0.3 to 0.5 mm thickness
- Each lamination is insulated from the other by a coating of varnish.



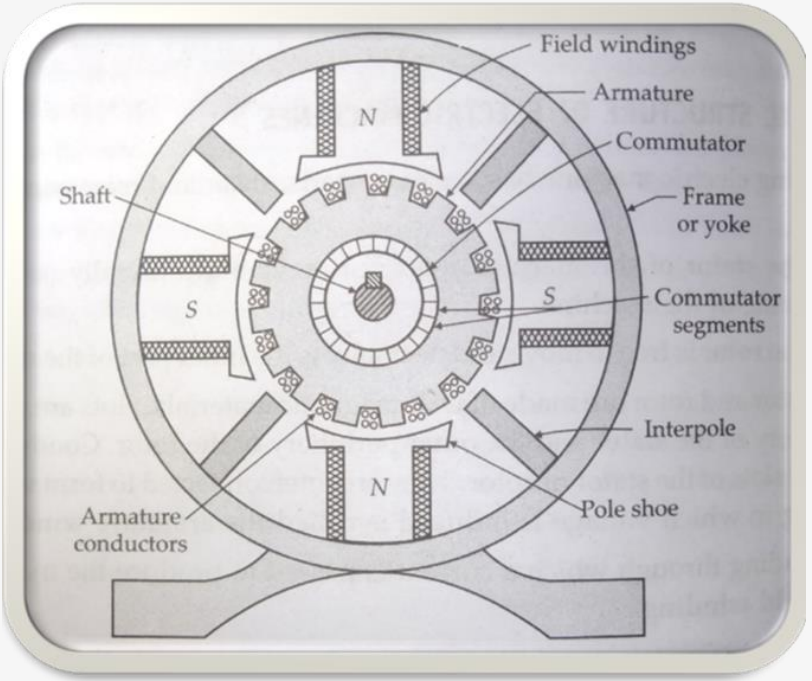
Armature winding

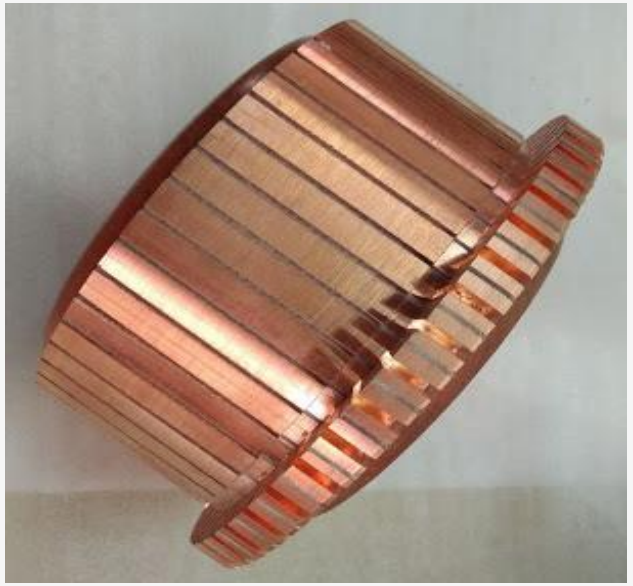
Consist of enameled copper coil



Commutator

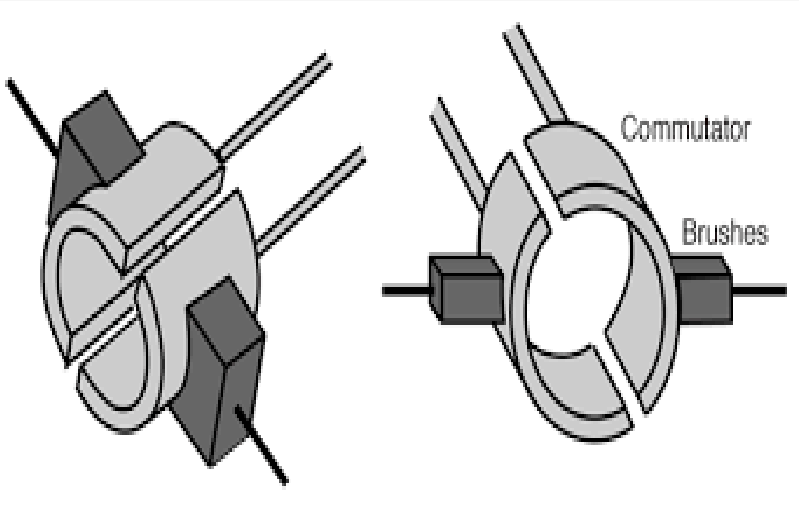
- Cylindrical in shape
- made from number of wedge-shaped hard drawn copper bars or segments insulated from each other and from the shaft.
- Each commutator segment is connected to the ends of the armature coils.
- It connects the rotating armature conductors to the stationary external circuit through brushes.
- It converts the induced alternating current in the armature conductor into the unidirectional current

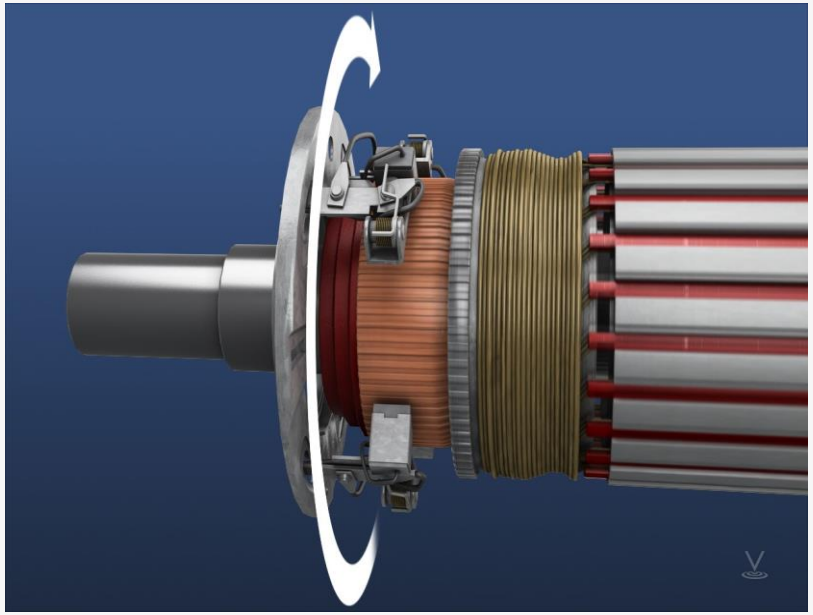




BRUSHES

- Carbon brushes are placed or mounted on the commutator
- They are usually made of high-grade carbon
- With the help of two or more carbon brushes current is collected from the armature winding.
- The brushes are pressed upon the commutator and form the connecting link between the armature winding and the external circuit.
- carbon is conducting material and at the same time in powdered form provides a lubricating effect on the commutator surface.





BEARINGS AND SHAFT

BEARINGS

- The ball or roller bearings are fitted in the end housings
- Mostly high carbon steel is used for the construction of bearings as it is a very hard material.

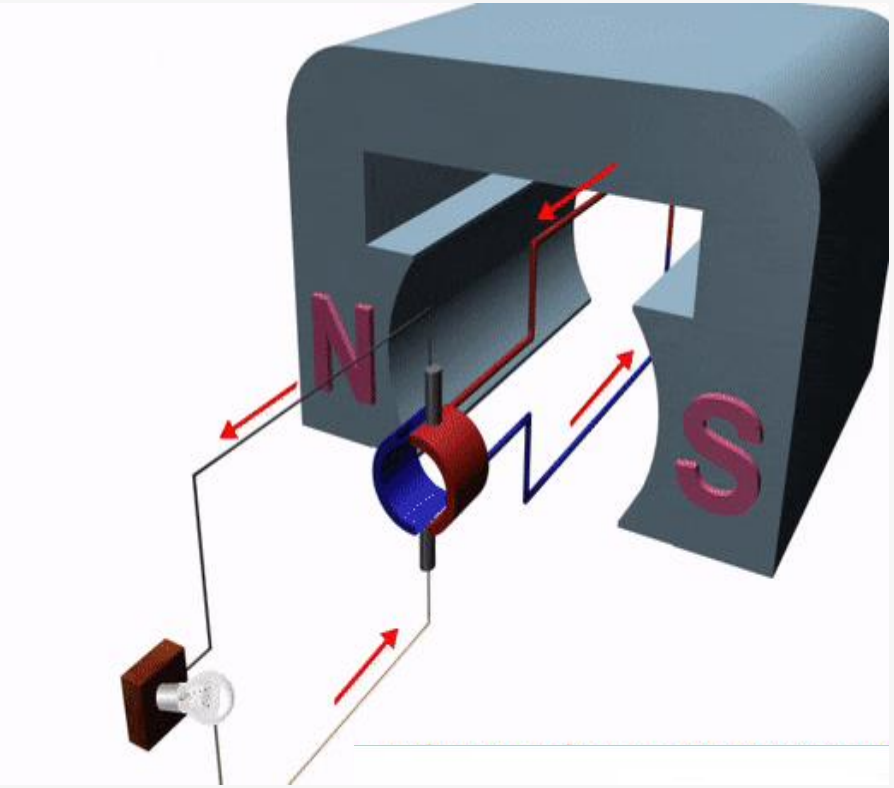
SHAFT

- Shaft is made of mild steel with a maximum breaking strength.

Working

The maximum emf is induced when the coil is perpendicular to the magnetic field.

The minimum emf is induced when the coil is parallel to the magnetic field



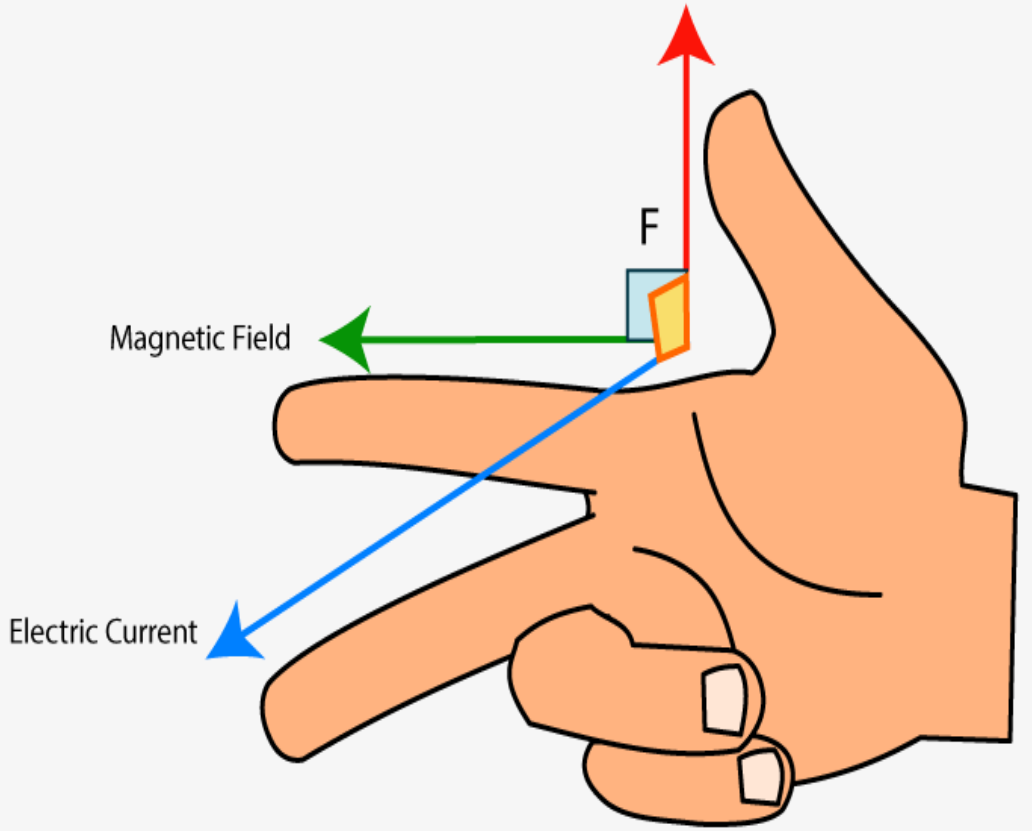
Fleming Right Hand Rule

To find the direction of induced EMF

Thumb – Direction force or rotation

For finger – magnetic field

Middle finger – direction of induced current



EMF EQUATION

$$E_g = \frac{\Phi ZN}{60} * \frac{P}{A}$$

Φ = flux per pole

Z = Total number of armature conductor = conductor per slots x number of slots

N = armature rotation in rpm

P = Number of poles

A = Number of parallel path

Types of winding

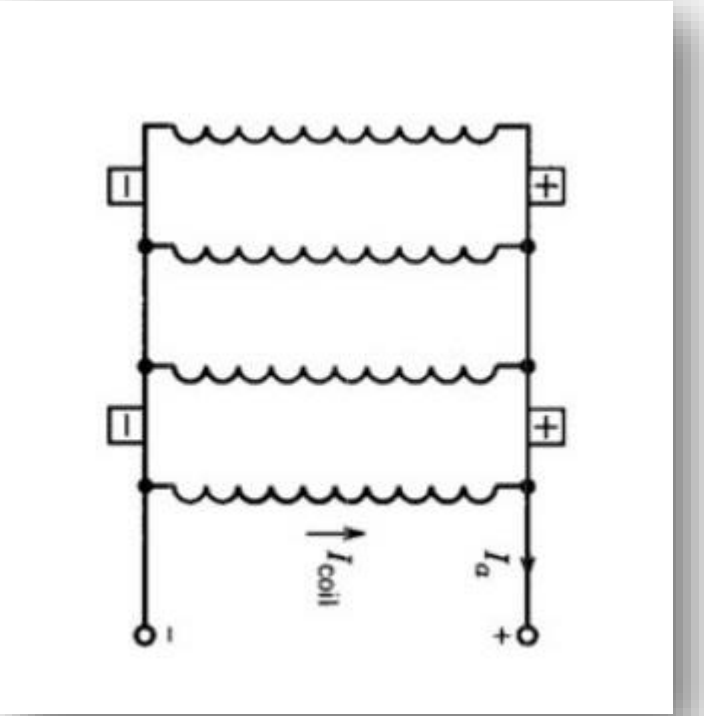
Lap winding

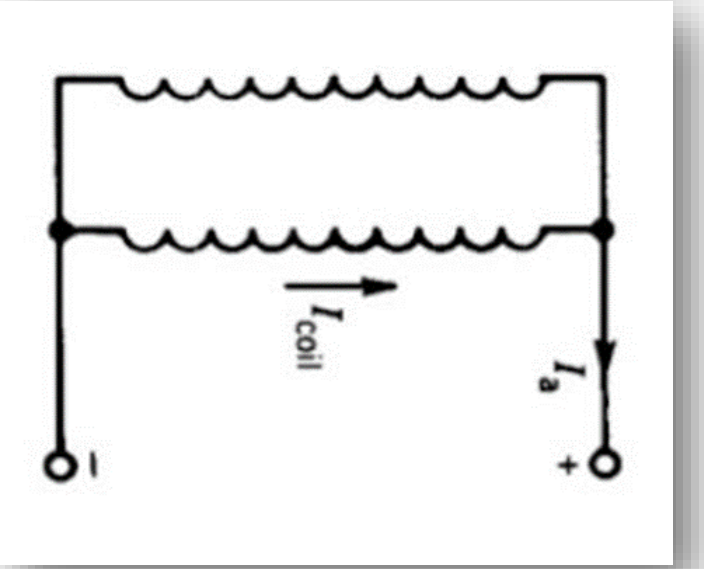
Number of parallel path = pole x m

Wave winding

Number of parallel path = 2 x m

m = multiplux
m = 1 for simplex
m = 2 for duplex
m = 3 for triplex
m = 4 for quadruplex





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Part 2 - Note

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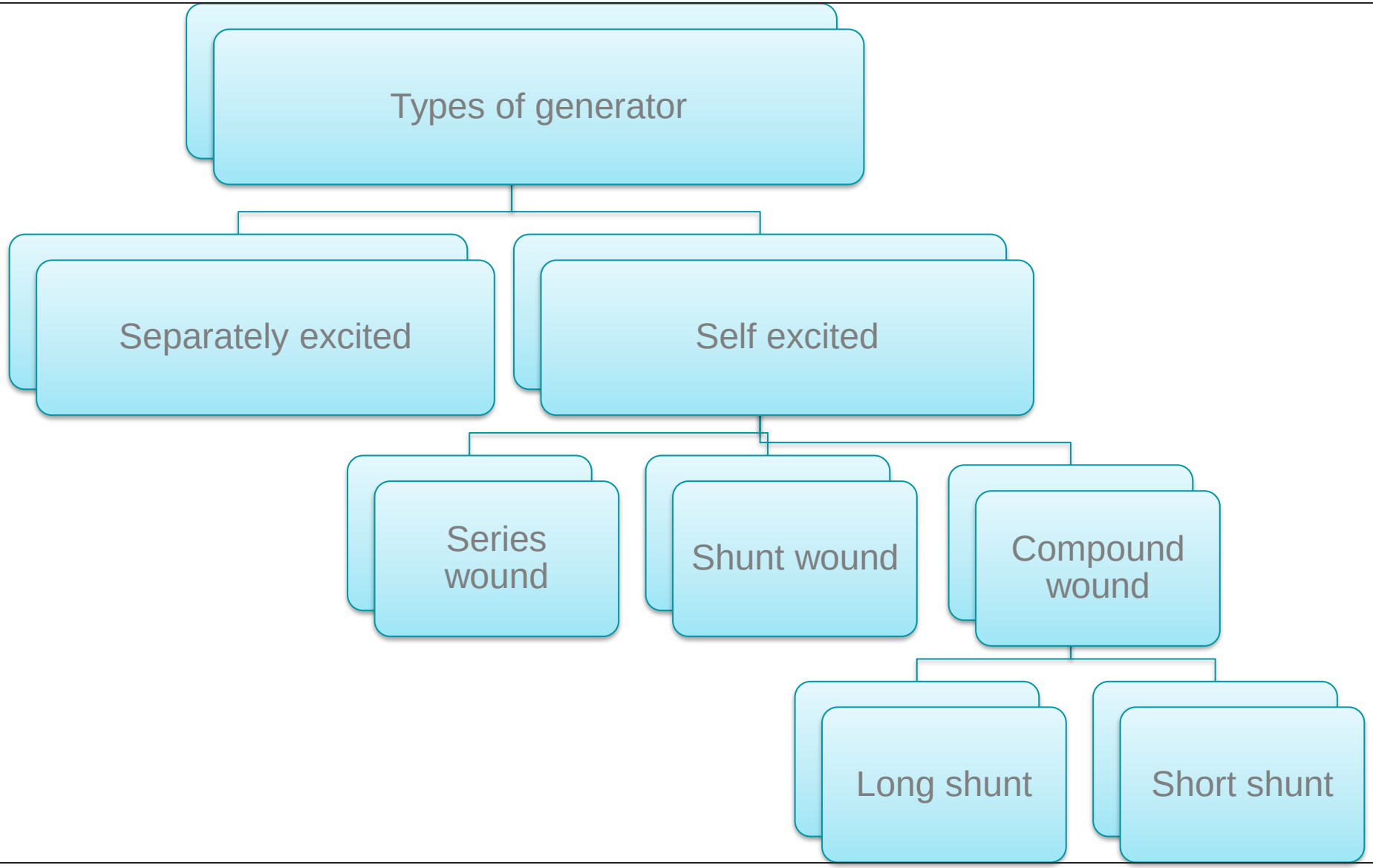
Types of Generator



Separately Excited

- Field magnets are energized by some external DC source

$$E_g = V + I_a R_a + 2V_b$$

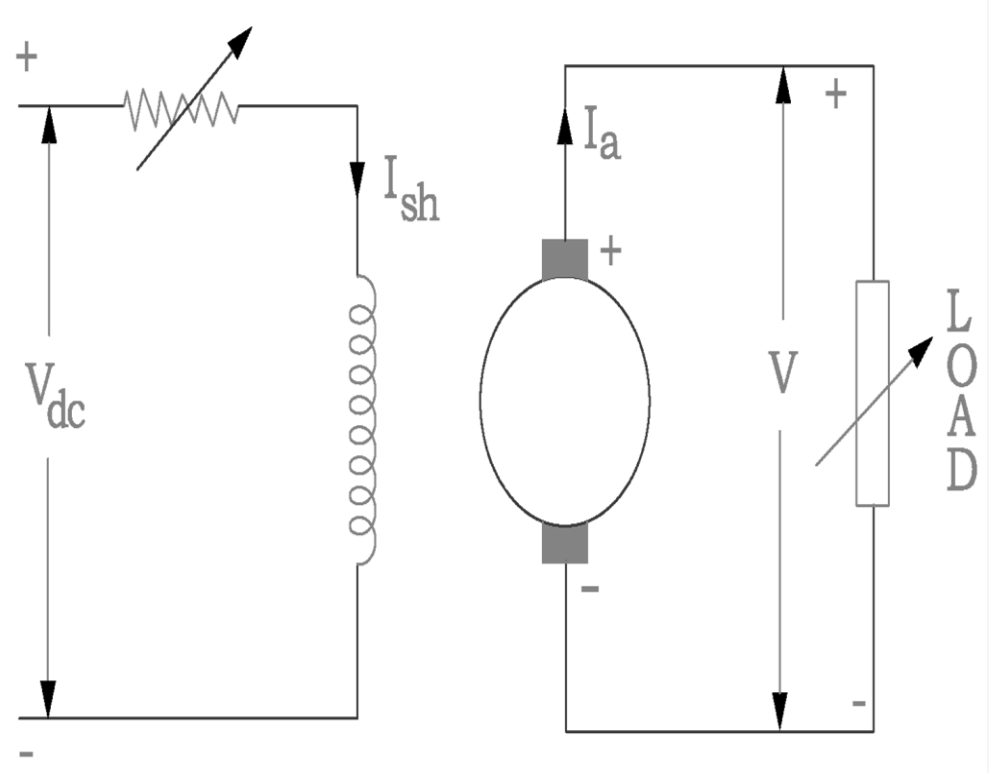
E_g = Generated voltage at armature

V = Terminal voltage

I_a = Armature current

R_a = Armature resistance

V_b = brush drop



$$P_{generated} = E_g I_a$$

$$P_{output} = V I_L$$

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Series Wound Generator

- Field coil connected series with armature winding
- Winding consist of thick wire of a few turns
- Normally resistance less than one ohm.

$$E_g = V + I_a (R_a + R_{se}) + 2V_b$$

E_g = Generated voltage at armature

V = Terminal voltage

I_a = Armature current

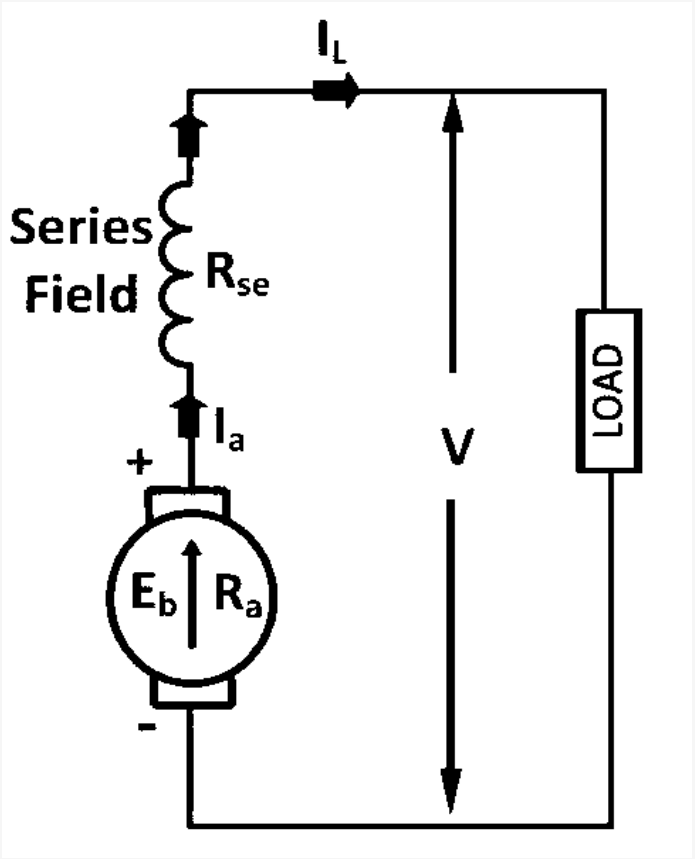
I_{se} = Series field current

$I_a = I_{se} = I_L$

R_a = Armature resistance

R_{se} = Series field resistance

V_b = brush drop



$$P_{generated} = E_g I_a$$

$$P_{output} = V I_L$$

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Shunt Wound Generator

- Field winding connected across the armature
- Full voltage applied across it
- Winding consist of thin wire of a many turns
- Resistance of the order of 100 ohm.

$$E_g = V + I_a R_a + 2V_b$$

E_g = Generated voltage at armature

V = Terminal voltage

I_a = Armature current

I_{sh} = Shunt field current

I_L = Load current

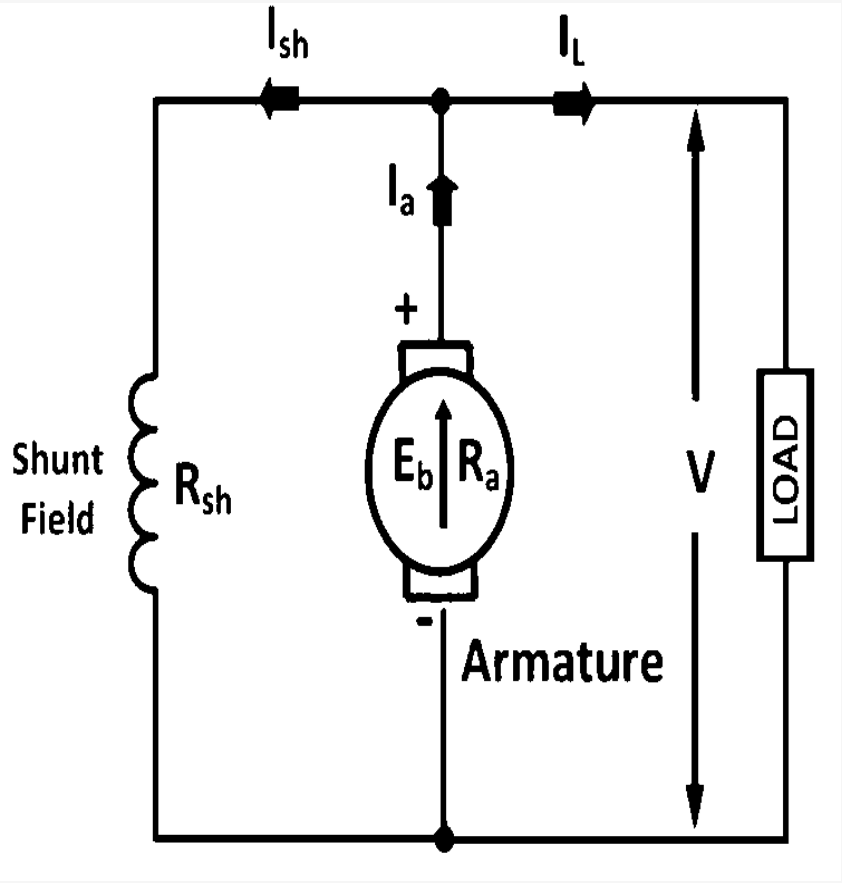
$I_a = I_L + I_{sh}$

R_a = Armature resistance

R_{sh} = Shunt field resistance

V_b = brush drop

$$R_{sh} = \frac{V}{R_{sh}}$$



$$P_{generated} = E_g I_a$$

$$P_{output} = VI_L$$

DC GENERATOR

Part 3 - Note

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Why Compound Generator

- In series wound generators, the output voltage is directly proportional with load current.
- In shunt wound generators, the output voltage is inversely proportional with load current.
- A combination of these two types of generators can overcome the disadvantages of both

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Long shunt Compound wound generator

- Shunt field winding parallel with both armature and series field winding

$$E_g = V + I_a (R_a + R_{se}) + 2V_b$$

E_g = Generated voltage at armature

V = Terminal voltage

I_a = Armature current

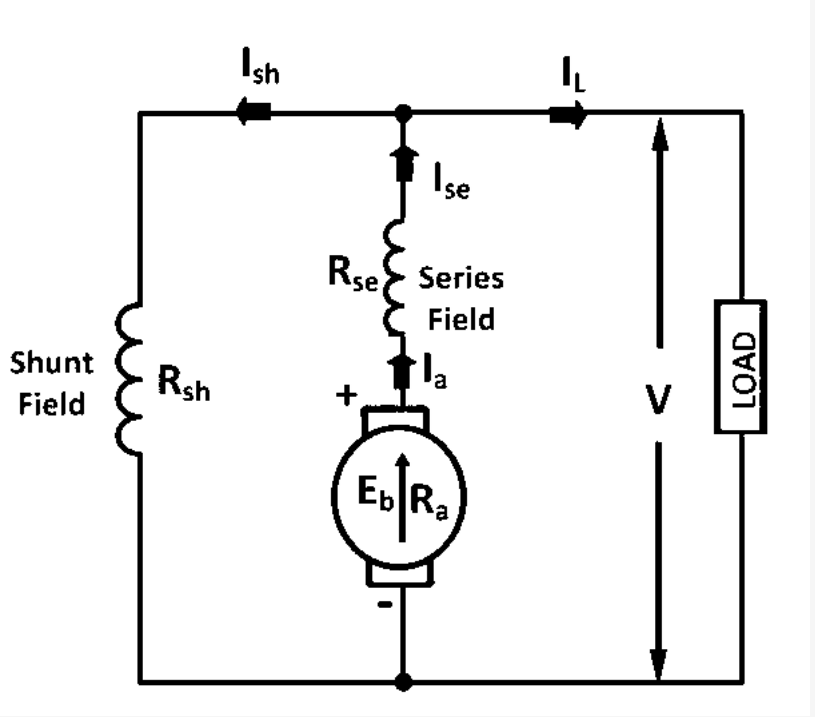
I_{se} = Series field current

$I_a = I_{se} = I_L + I_{sh}$

R_a = Armature resistance

R_{se} = Series field resistance

V_b = brush drop



$$P_{generated} = E_g I_a$$

$$P_{output} = V I_L$$

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Short shunt Compound wound generator

- Shunt field winding parallel with armature only

$$E_g = V + I_a R_a + I_{se} R_{se} + 2V_b$$

E_g = Generated voltage at armature

V = Terminal voltage

I_a = Armature current

I_{se} = Series field current

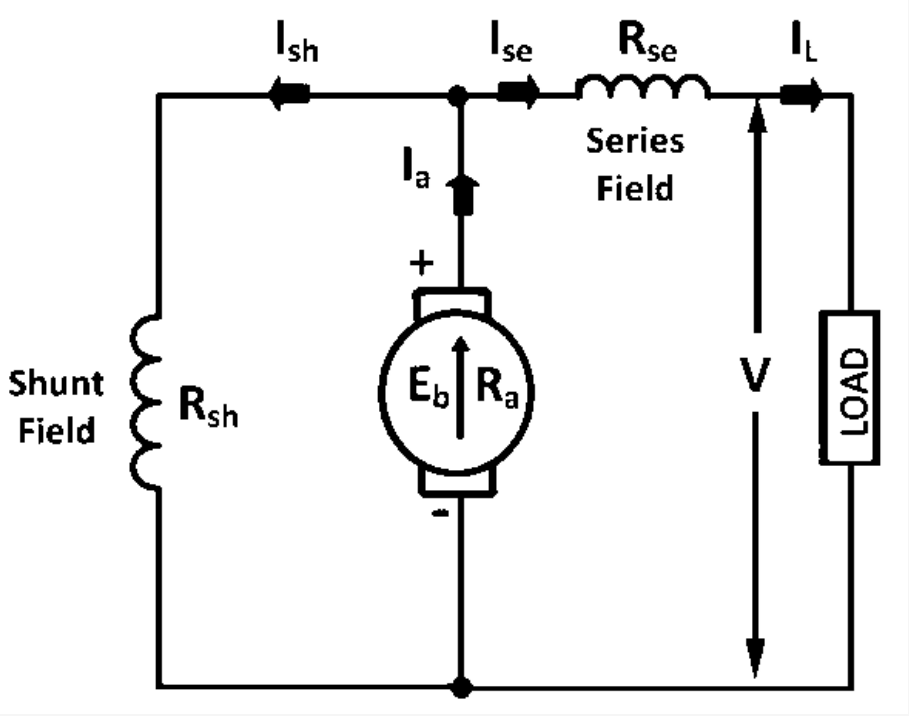
$I_a = I_L + I_{sh}$

$I_{se} = I_L$

R_a = Armature resistance

R_{se} = Series field resistance

V_b = brush drop



$$P_{generated} = E_g I_a$$

$$P_{output} = V I_L$$

Cumulative and Differential Compound Generator

Cumulative compound

- Magnetic flux produced by series winding assists the flux produced by shunt field winding
- **Total flux = $\varphi_{sh} + \varphi_{se}$**

Differential compound

- Series field flux opposes the shunt field flux
- **Total flux = $\varphi_{sh} - \varphi_{se}$**

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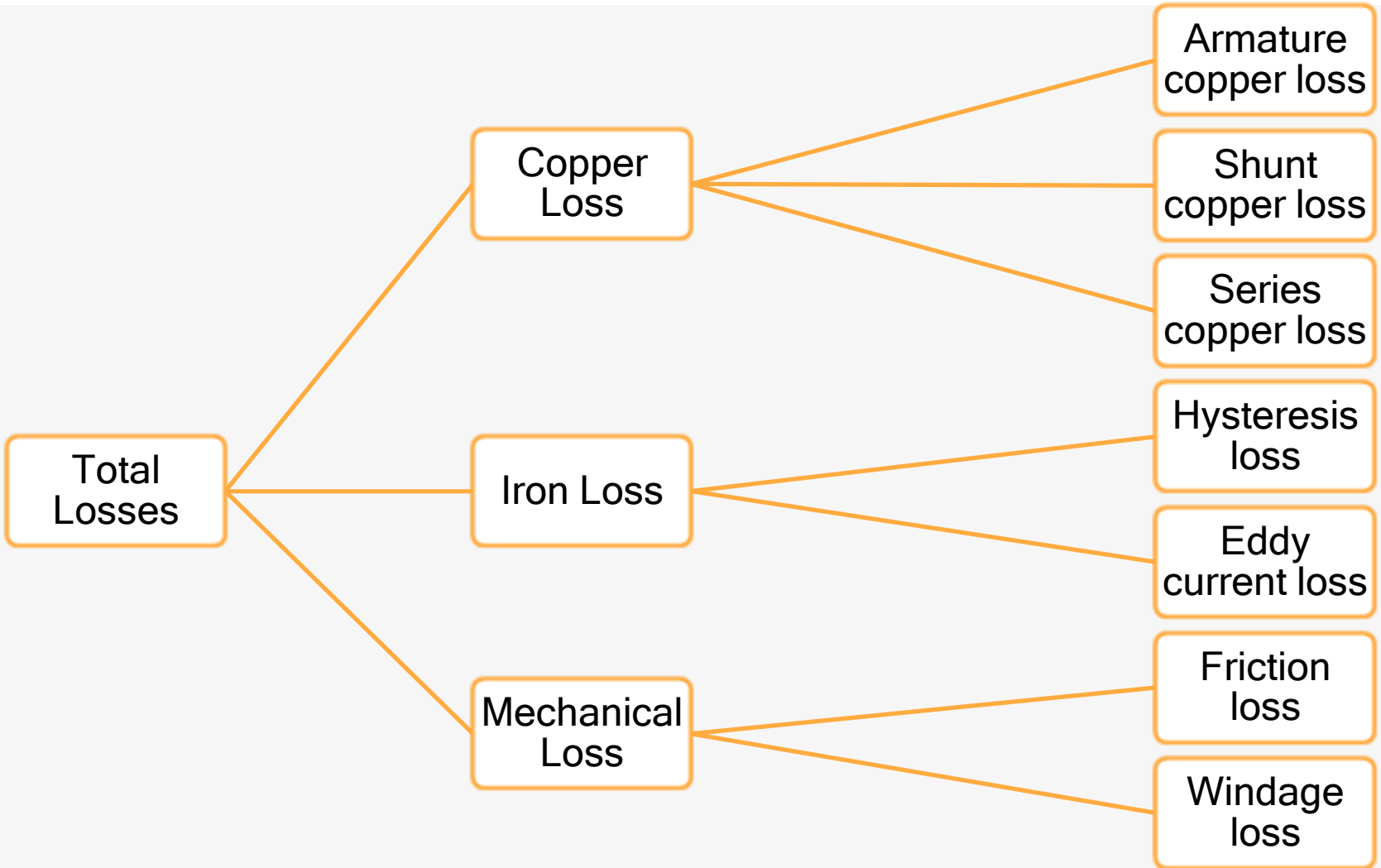
DC GENERATOR

Part 4 Note

Losses


Total Losses
Copper Loss
Iron Loss
Mechanical Loss
Armature copper loss
Shunt copper loss
Series copper loss
Hysteresis loss
Eddy current loss
Friction loss
Windage loss

Copper losses

Armature copper loss

- About 30 to 40% of full load loss

Field copper loss

- 20 to 30 % of full load loss

Loss due to brush contact resistance

Iron loss

- Losses at core
- Also known as core losses or magnetic losses
- 20 to 30 % of full load loss

Classified into two

- Hysteresis loss
- Eddy current loss

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Hysteresis loss

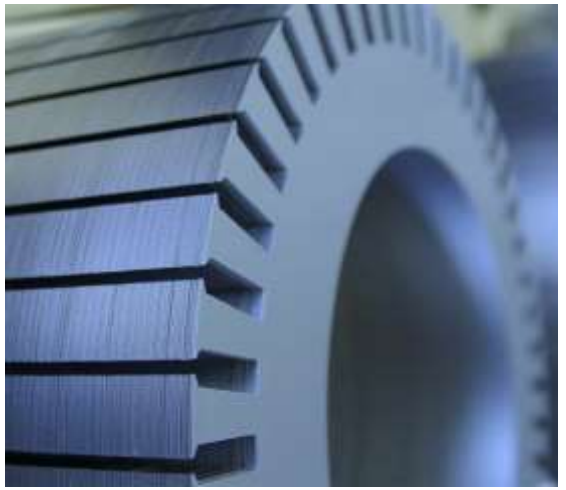
- This loss is due to the reversal of magnetization of the armature core.
- Energy wasted in the form of heat
- To reduce hysteresis loss, we are using silicon steel. silicon 3-4 %
- Losses calculated by Steinmetz formula.

$$W_h = \eta \; Bmax^{1.6} \; f \; V \text{ watts}$$

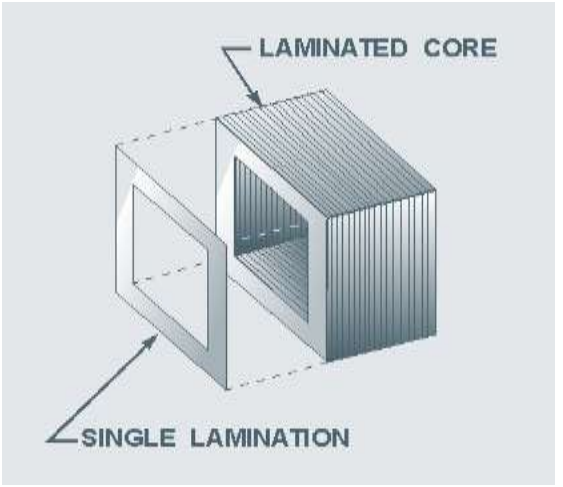
- η = Steinmetz hysteresis constant , unit = joule/m^2
- B_{max} = maximum flux density
- V = Volume of the core in m^3
- f = frequency
- Silicon steel = 191 joule/m^2 cast iron = 2700-4000 joule/m^2

Eddy current loss

- Armature cuts the magnetic flux and an emf will induce on it.
- Power loss due to flow of current through the armature core.
- By using laminated silicon steel , eddy current loss will reduce
- Power loss in the form of heat



$$W_e = K\ Bmax^2\ f^2\ t^2\ v^2 \text{ watts}$$



- K= eddy current constant
- B_{max} = maximum flux density
- V = Volume of the core in m^3
- f = frequency of magnetic reversal
- t = thickness of each lamination

- Magnetic losses are practically constant for shunt and compound generator.
    - Because field current approximately constant.

Mechanical losses

Friction loss

- At bearing and commutator

Windage loss

- Windage loss of rotating armature
- 10 to 20 % of full load loss

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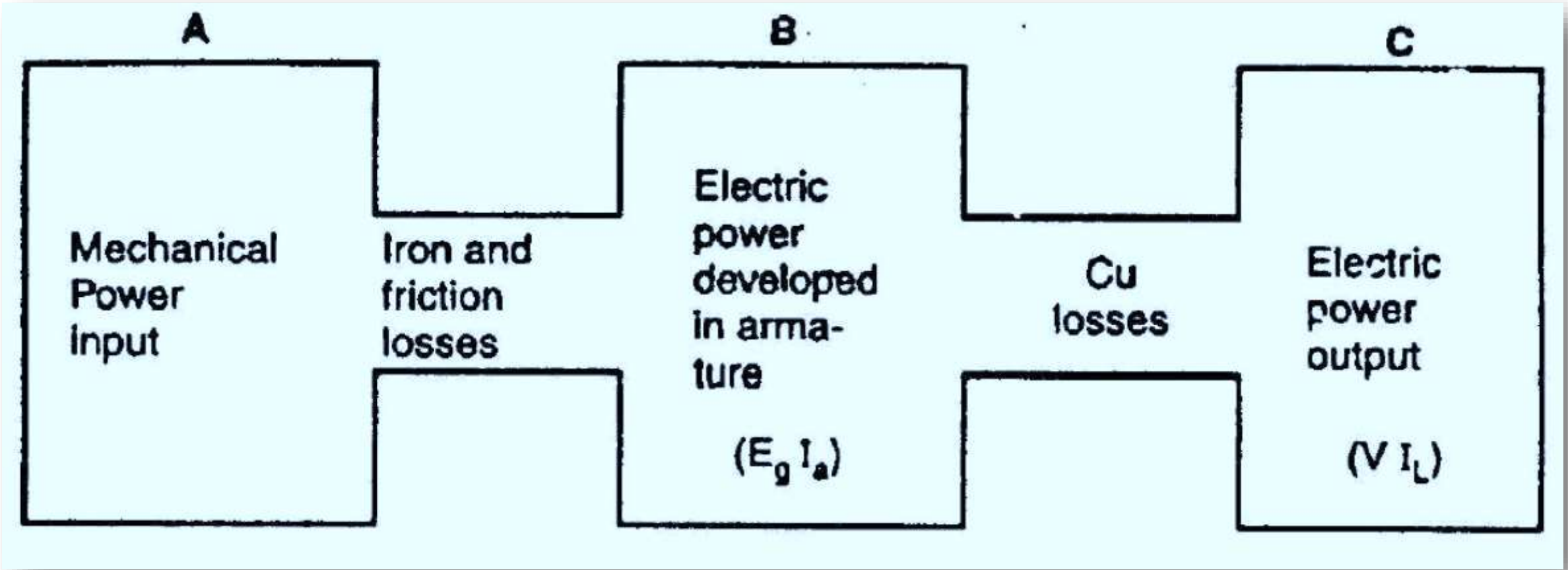
Stray losses

- Sum of magnetic and mechanical losses
- Also called rotational losses

Power stages of DC Generator



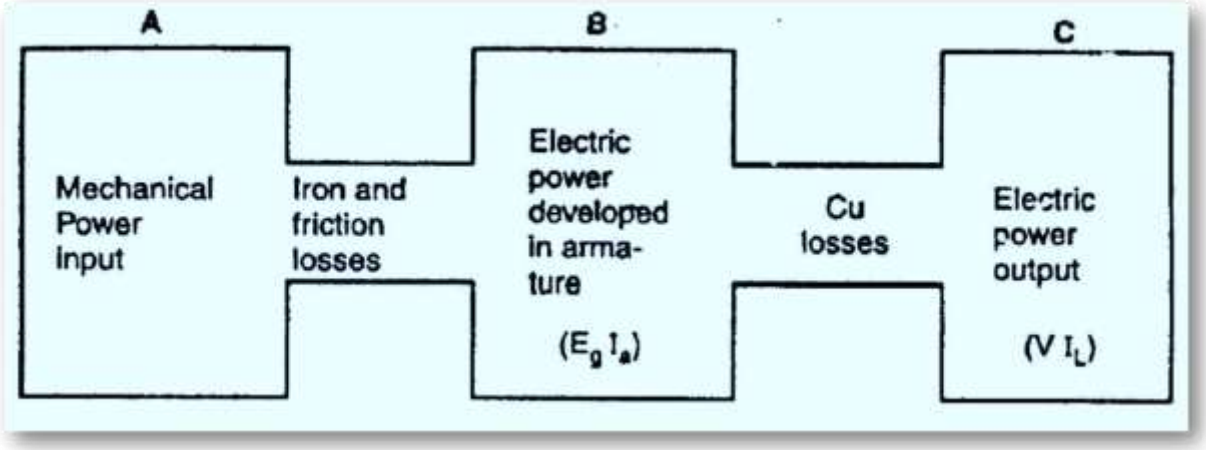
Generator Efficiency

- Mechanical efficiency

$$\eta = \frac{total\ watt\ generated\ in\ armature}{mechanical\ power\ supplied} = \frac{E_g I_a}{output\ of\ driving\ engine}$$

- Electrical efficiency

$$\eta = \frac{watts\ available\ in\ load\ circuit}{total\ watts\ generated} = \frac{VI}{E_g I_a}$$



- Overall efficiency

$$\eta = \frac{watts\ available\ in\ load\ circuit}{mechanical\ power\ supplied}$$

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Condition for maximum efficiency

- Copper loss = core loss
- $I^2 R_a = W_c$
- $I = \sqrt{\frac{W_c}{R_a}}$

DC GENERATOR

Part 5 Note

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Armature Reaction

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Armature Reaction

- Effect of magnetic field set up by armature current on the distribution of main flux produced by main pole.

  Mainly Two Types

- 1) de magnetizing or weakens the main flux

  After effect : reduction of generating voltage

- 2) cross magnetizing or distortion of main flux

  After effect : sparking at the brushes

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MNA

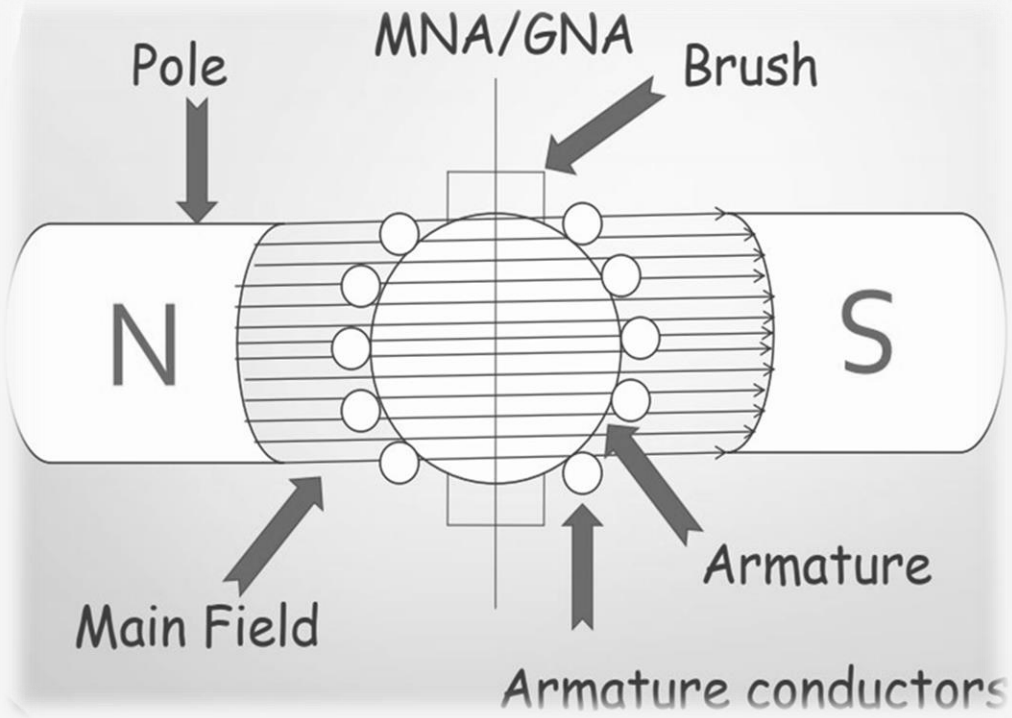
- Magnetic Neutral Axis
- axis along which no emf is induced in the armature conductor because they move parallel to line of flux
- Brushes are always placed M.N.A
- M.N.A is also called axis of commutation, reversal of current in armature conductor takes place.

GNA

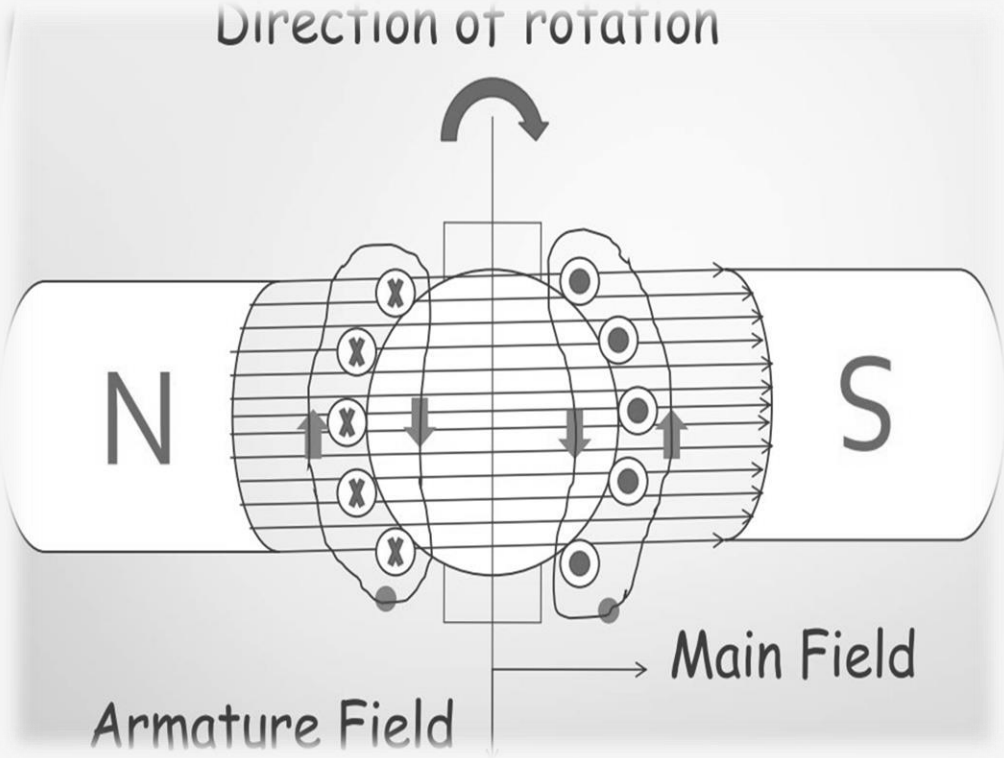
- Geometrical Neutral Axis
- It is the axis which divides the armature core in two equal parts.

Polar Axis

- It is the imaginary line which joins the center of NS poles.



- Now assume that there is current flowing through the armature conductors
- Direction of rotation is clock-wise.
- According to Fleming’s right-hand rule,
- The direction of current is inwards in conductors which are influence of N pole Outwards which are influence of S pole.
- Inward flow of current is represented by “cross ” whereas the outward flow is represented by “ dot” .
- Direction of flux produced by armature conductor can be found right hand palm rule.



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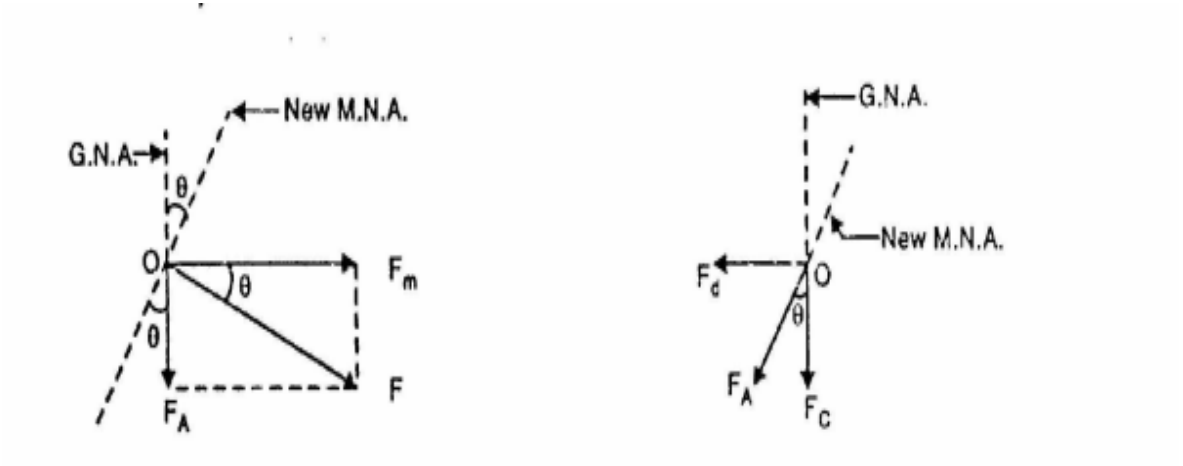
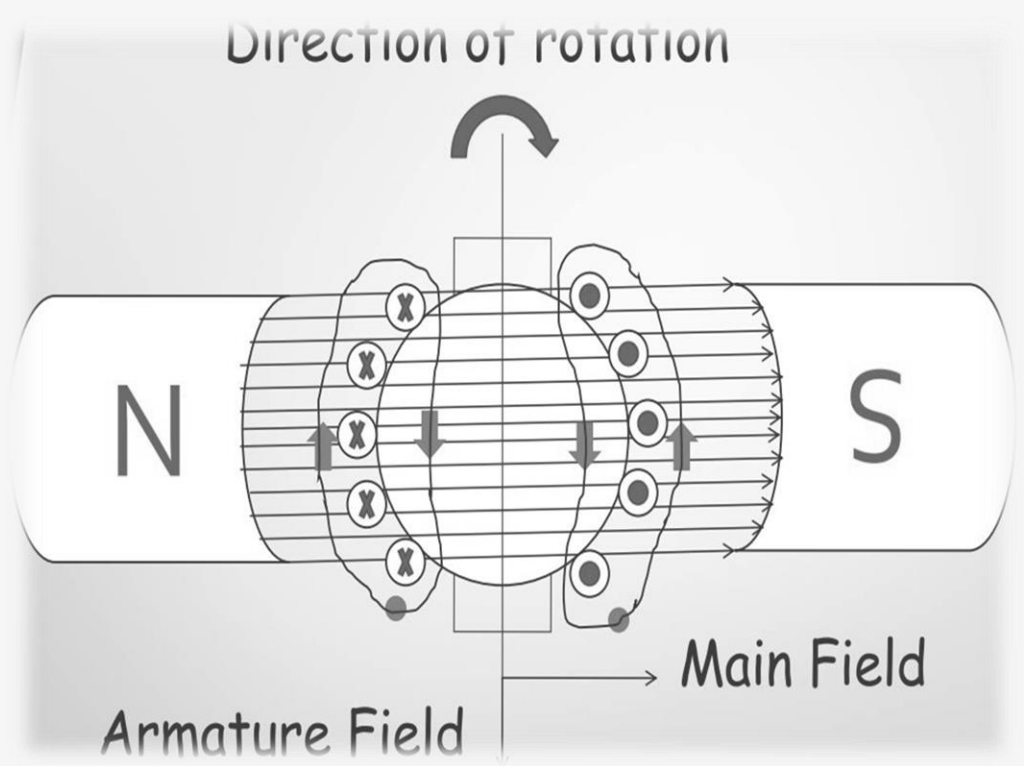
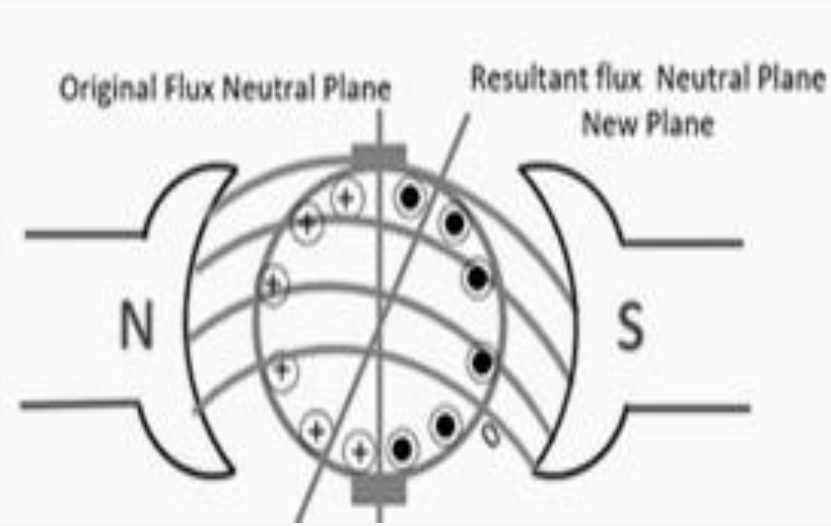
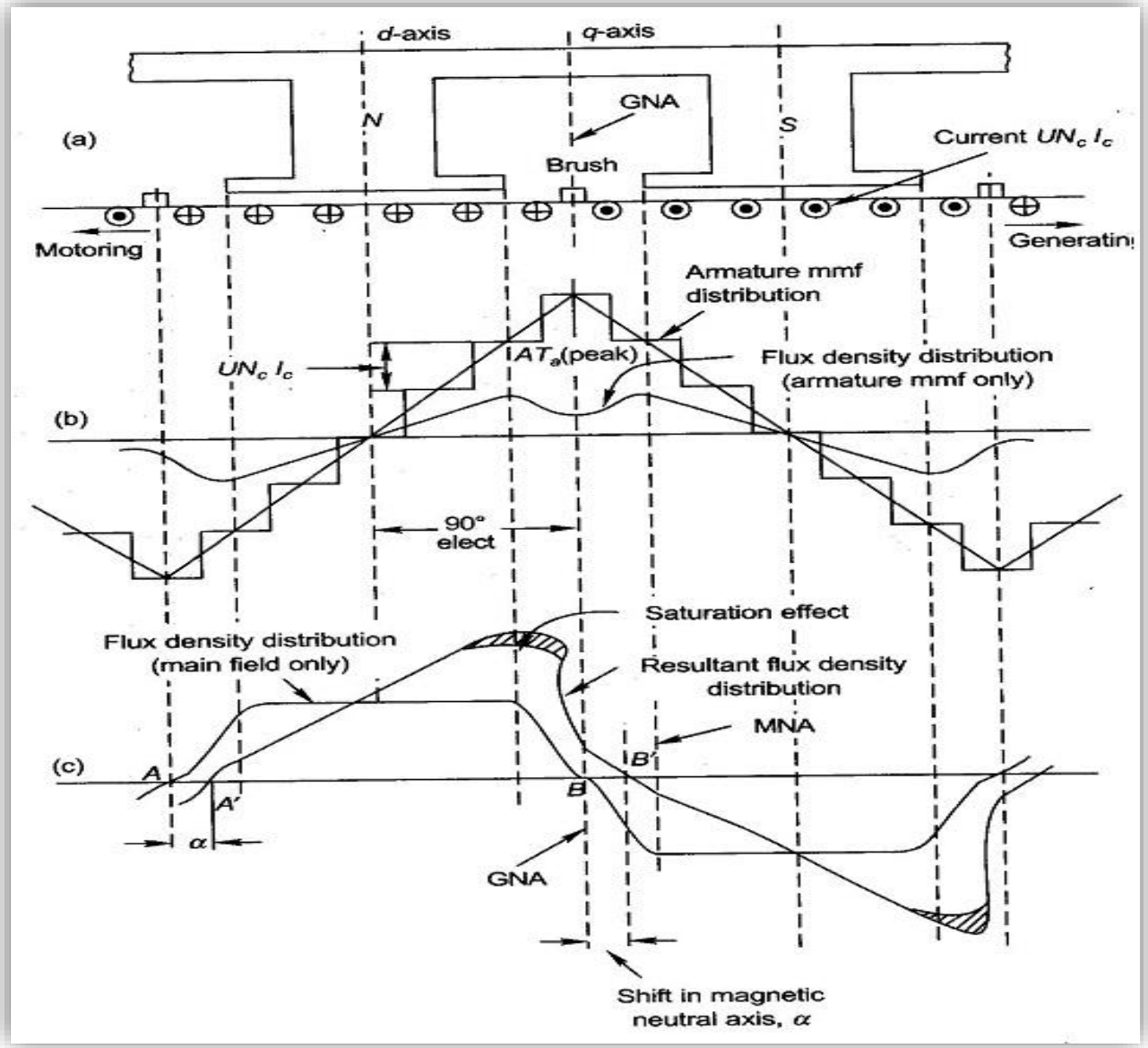
- Leading pole tip : pole tip which is first met during rotation by armature conductor.
- Trailing pole tip : pole tip which is last met during rotation by armature conductor.

- Crowded at Trailing pole Tips
- Weakened at leading pole Tips
- Brush position shift in the same direction of direction of rotation.









Shape of Armature MMF in air gap = Triangular

Shape of main field MMF and flux = Trapezoidal