# DC GENERATOR

MUBARAK

- Kerala PSC Expert

# 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.

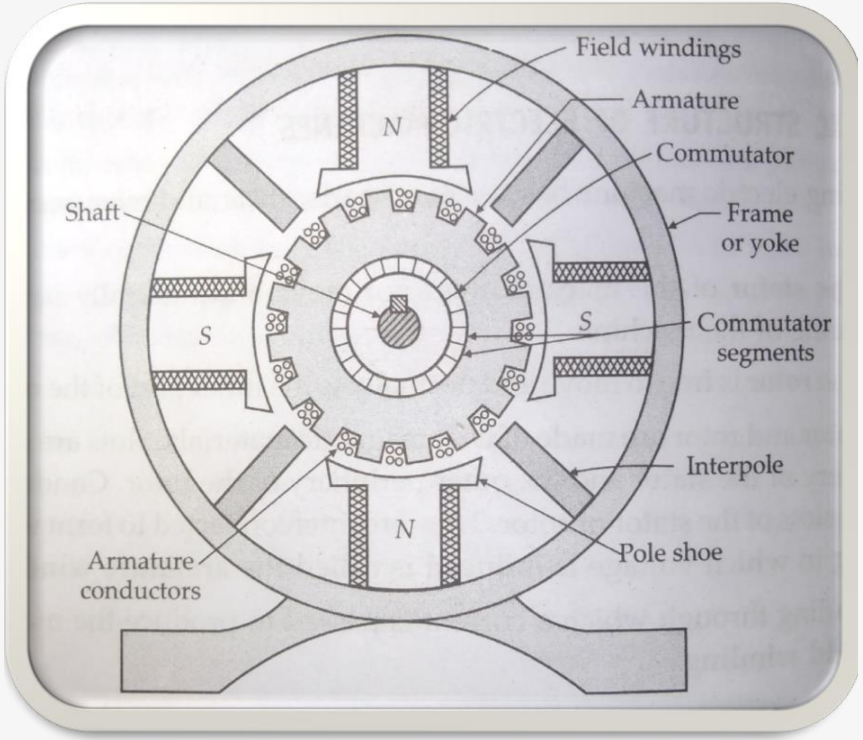
### Second Law

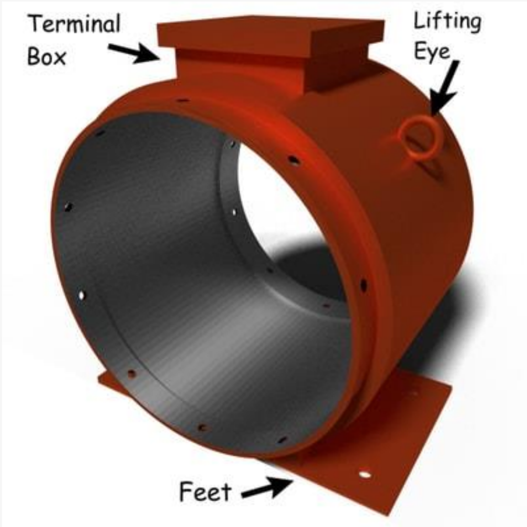
The magnitude of this induced EMF depends upon the rate of change of flux (magnetic line force) linkage with the conductor

# 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

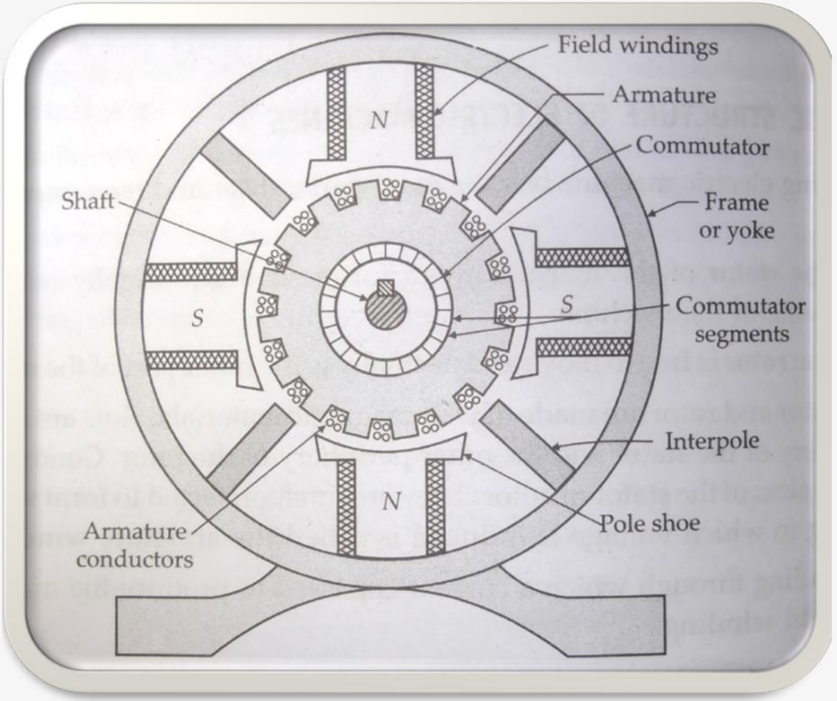
## Pole cores

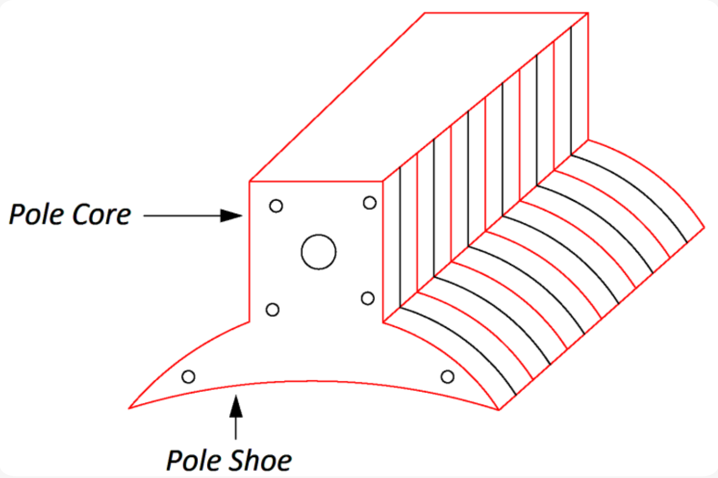
**Pole core**

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

**Pole Shoes**

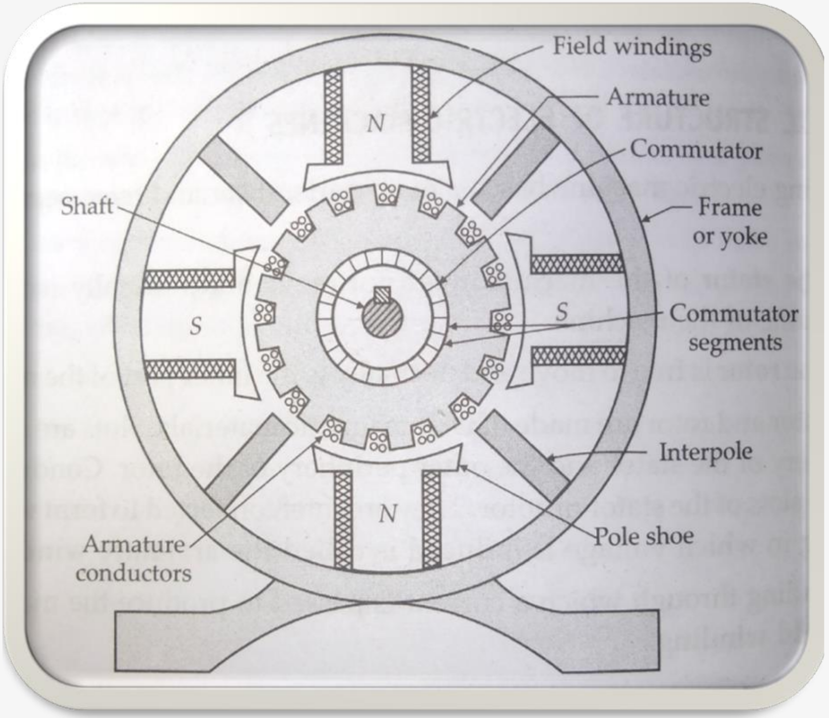
- Spread out the flux in the air gap
- Being large cross section , reduce the reluctance of the magnetic path.
- Support the exciting coil



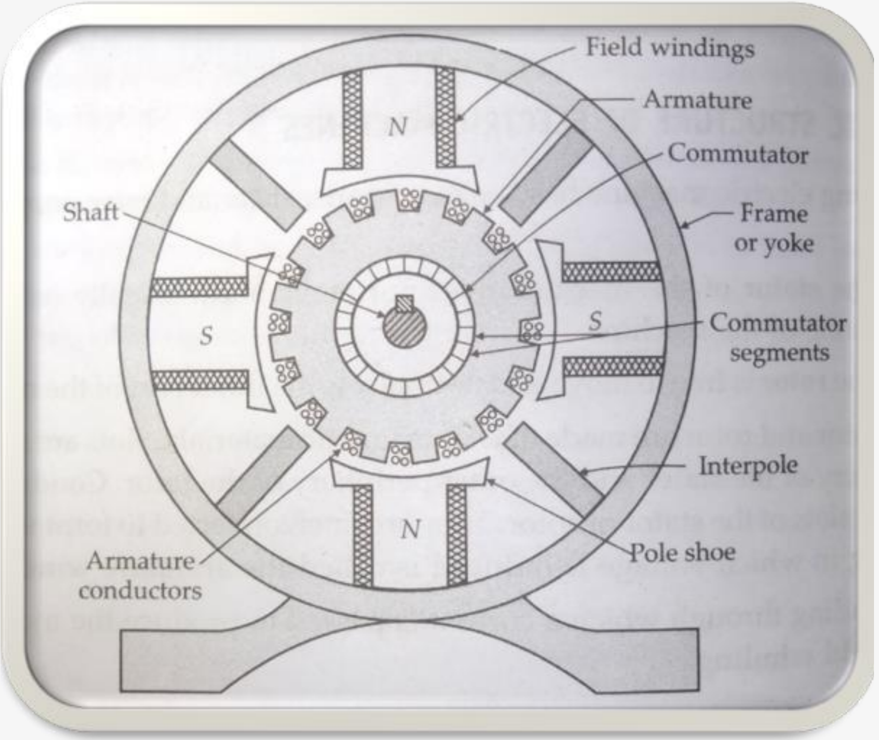
# Pole Coil

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



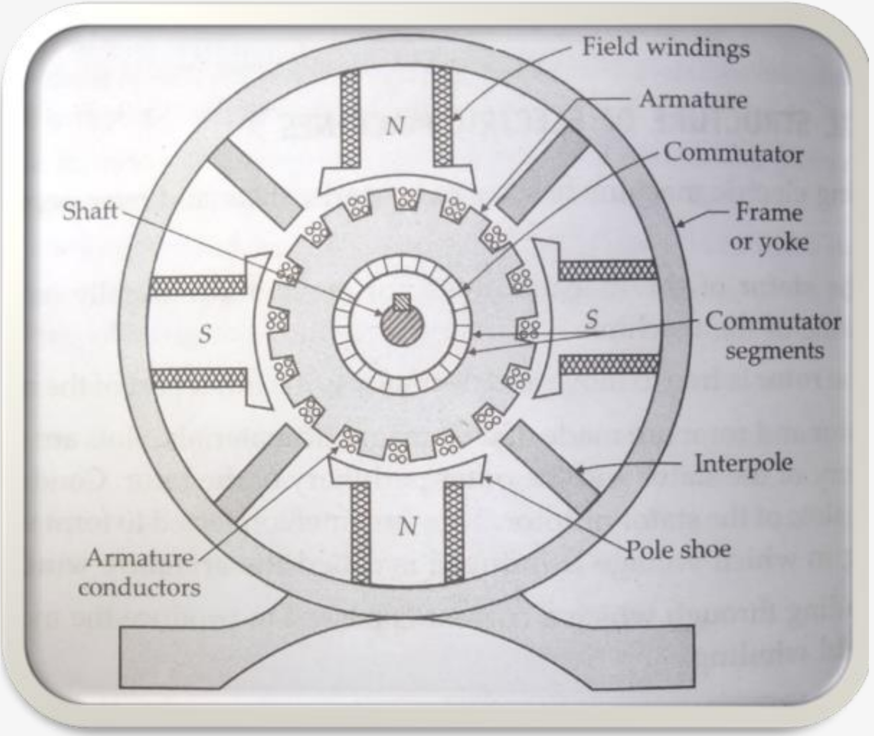

# Armature core

- 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.



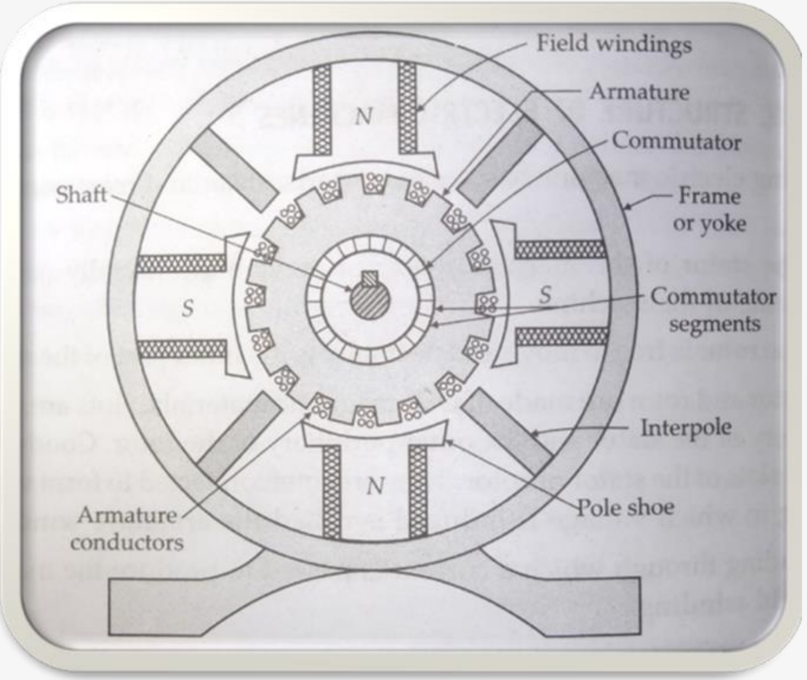

# Armature winding

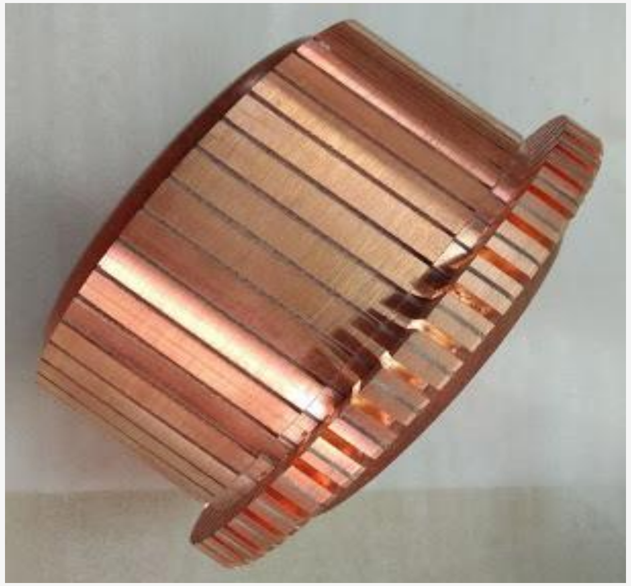
Consist of enameled copper coil




# Commutator

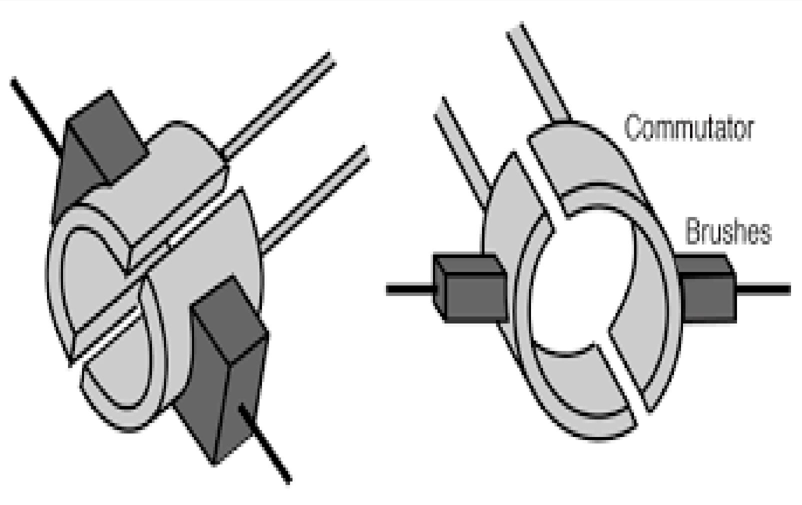
- Cylindrical in shape
- made from number of wedge-shaped hard drawn copper bars or segments insulated from each other and from the shaft.
- Each commutator segment is connected to the ends of the armature coils.
- It connects the rotating armature conductors to the stationary external circuit through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

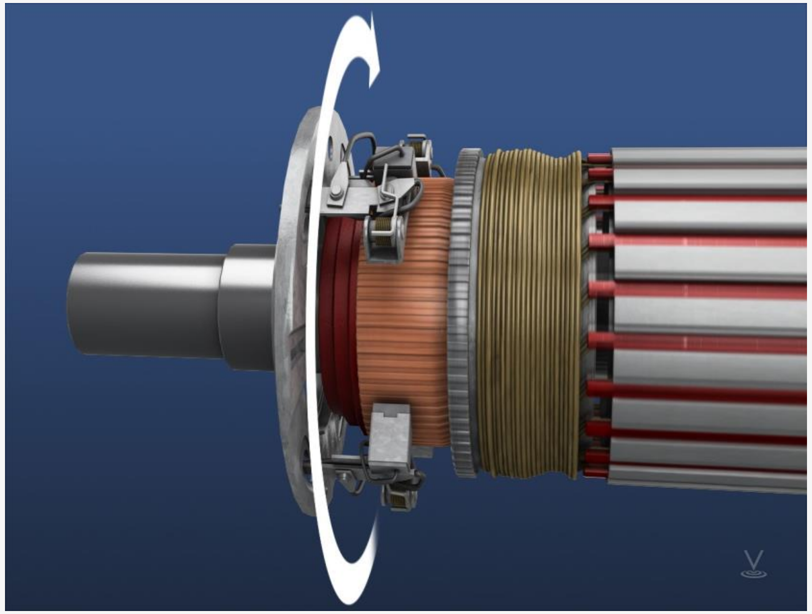


# BRUSHES

- 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.

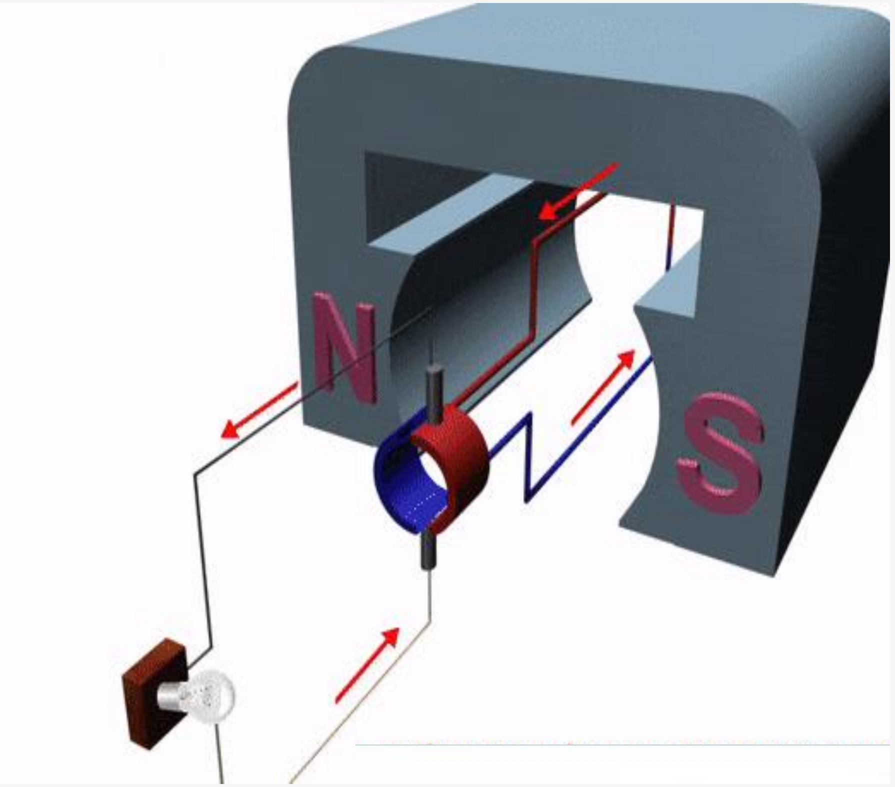
## SHAFT

- 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



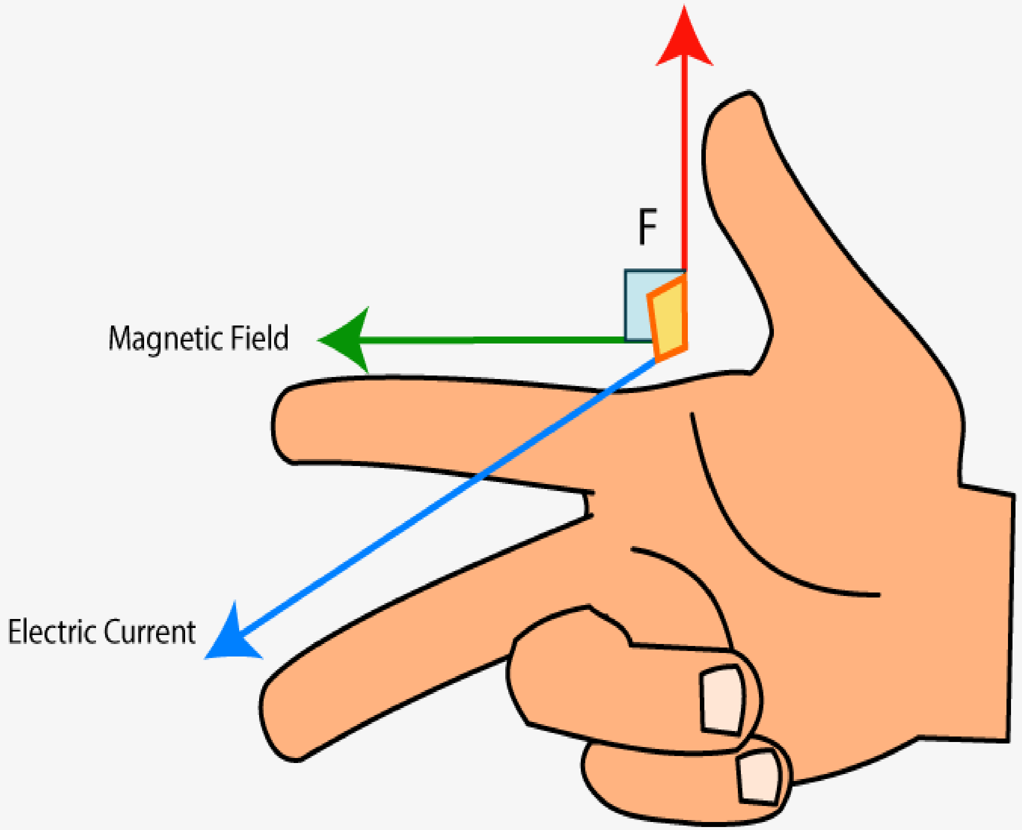
# Fleming Right Hand Rule

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

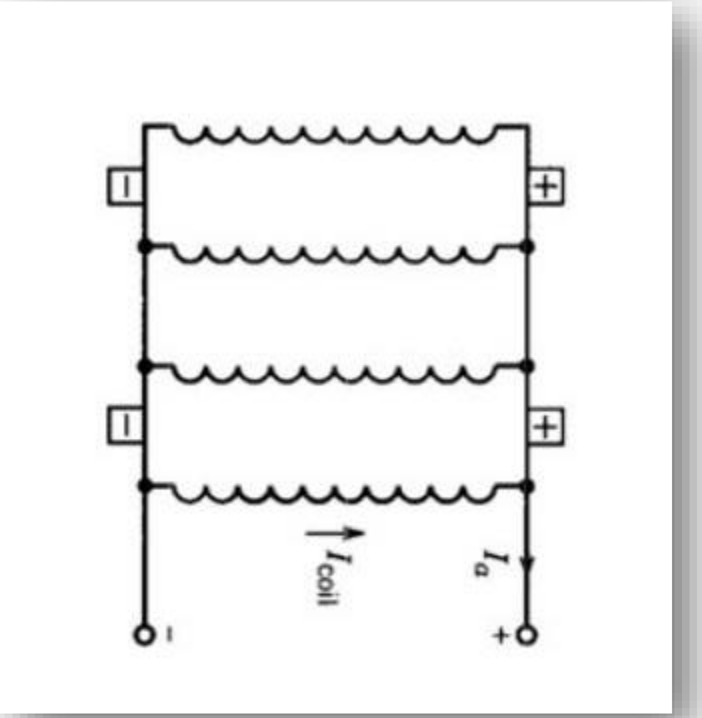
## Lap winding

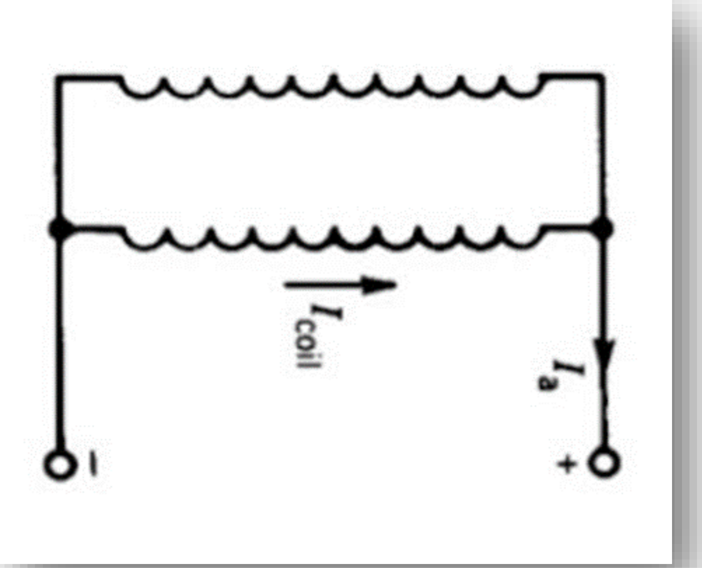
Number of parallel path = pole x m

## 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

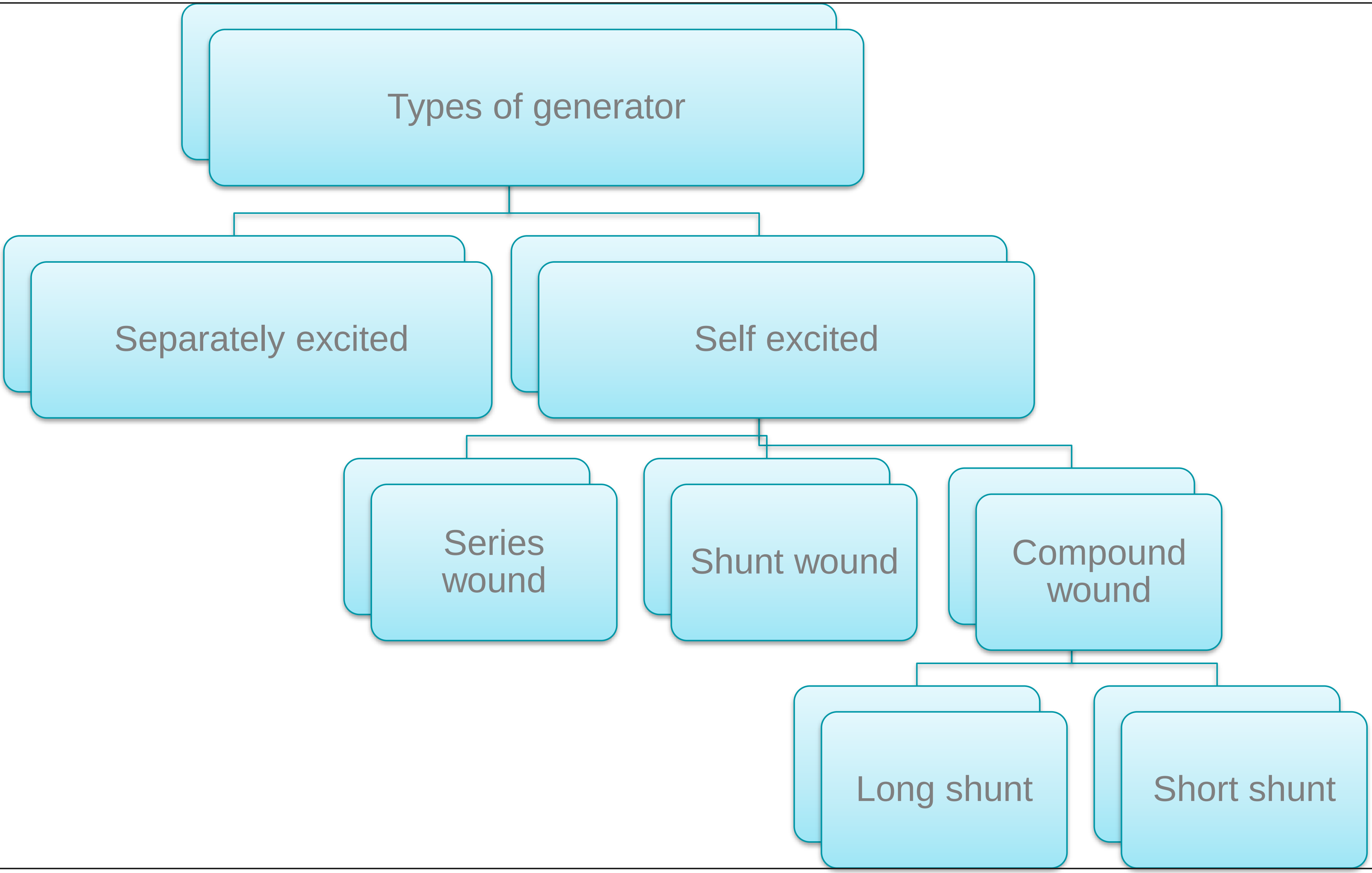


# DC GENERATOR

Part 2 - Note

# Types of Generator

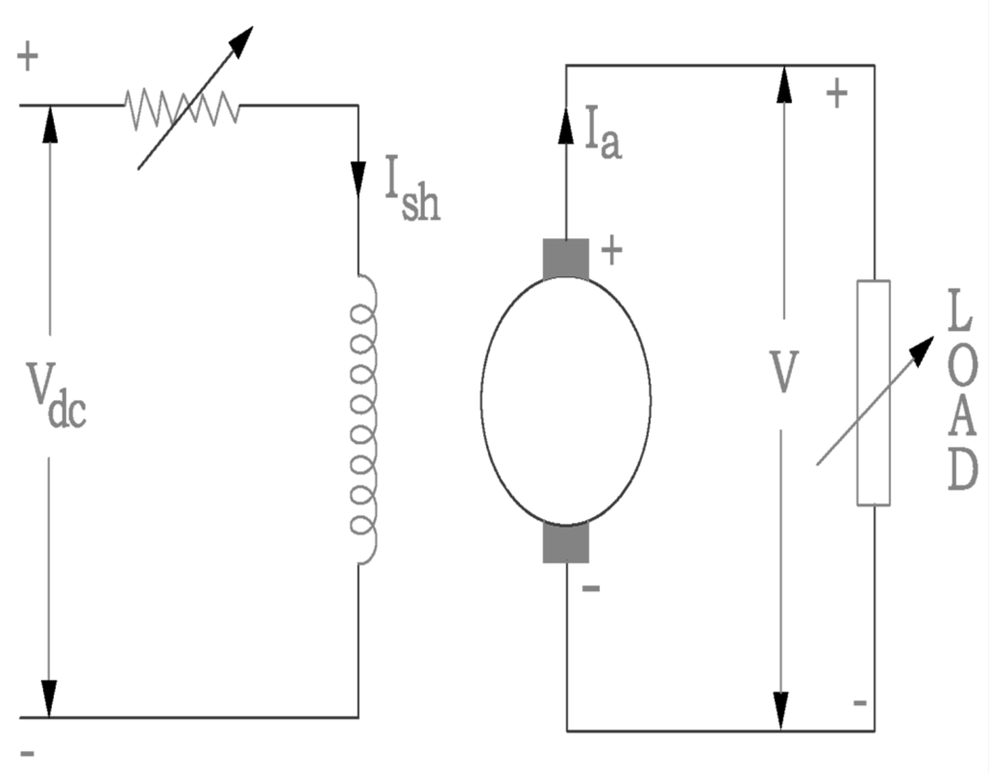


# Separately Excited

- Field magnets are energized by some external DC source

$$\boxed{E_g = V + I_a R_a + 2V_b}$$

**$E_g$ = Generated voltage at armature**
**$V$ = Terminal voltage**
**$I_a$ = Armature current**
**$R_a$ = Armature resistance**
**$V_b$ = brush drop**




$$P_{generated} = E_g I_a$$
$$P_{output} = VI_L$$

# 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

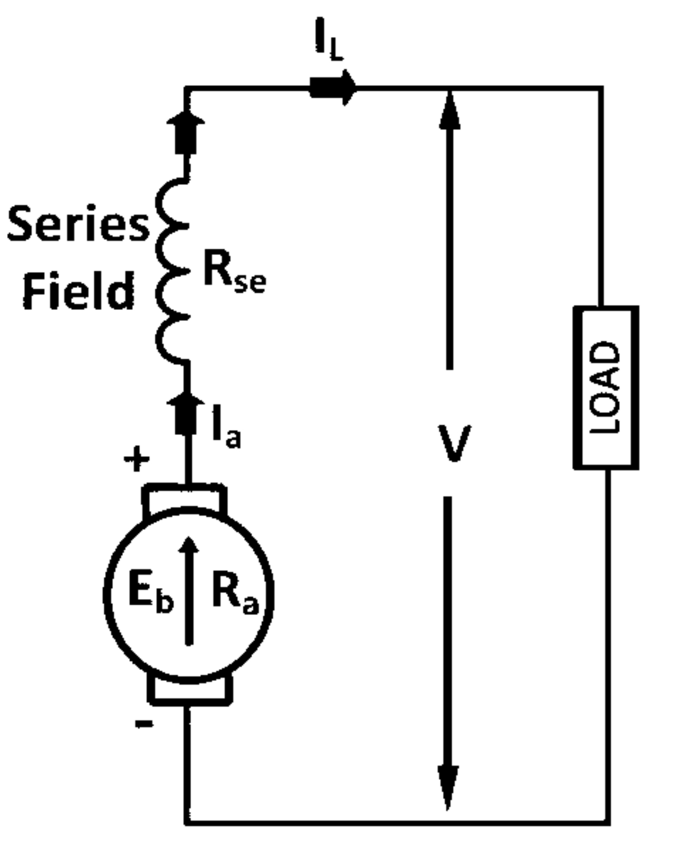
$I_{se}$ = Series field current

$I_a = I_{se} = I_L$

$R_a$ = Armature resistance

$R_{se}$ = Series field resistance

$V_b$ = brush drop




$$P_{generated} = E_g I_a$$
$$P_{output} = V I_L$$

# 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

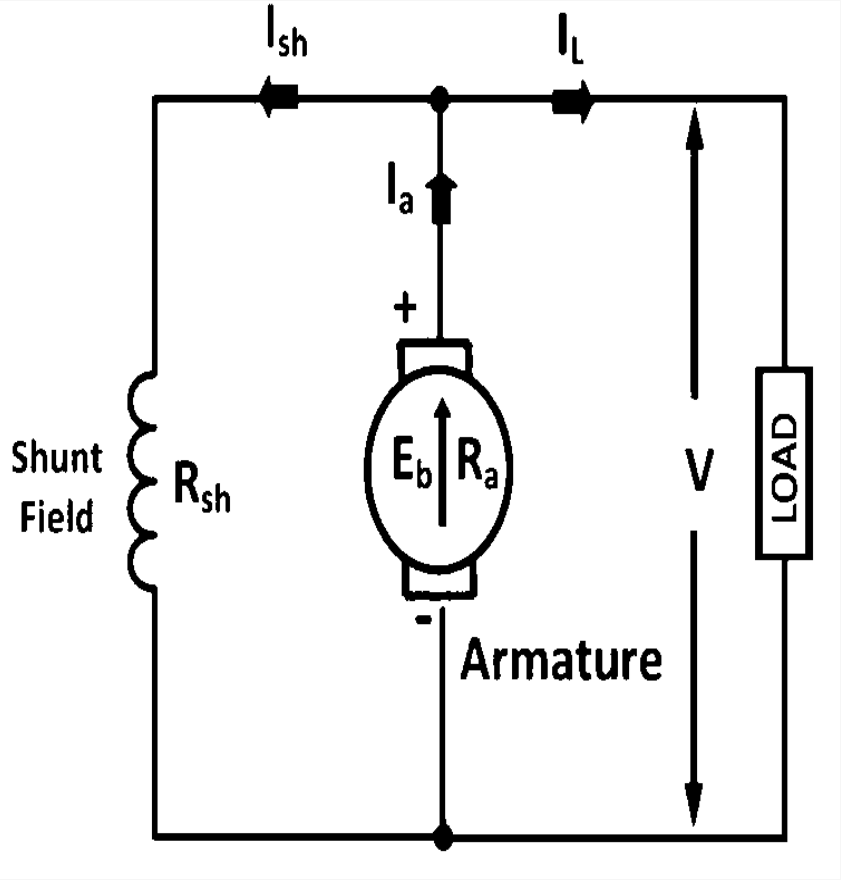
$I_a = I_L + I_{sh}$

$R_a$ = Armature resistance

$R_{sh}$ = Shunt field resistance

$V_b$ = brush drop

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




$$P_{generated} = E_g I_a$$
$$P_{output} = V I_L$$

# DC GENERATOR

Part 3 - Note

# 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

ENTRI

# Long shunt Compound wound generator

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

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

$E_g$ = Generated voltage at armature

$V$ = Terminal voltage

$I_a$ = Armature current

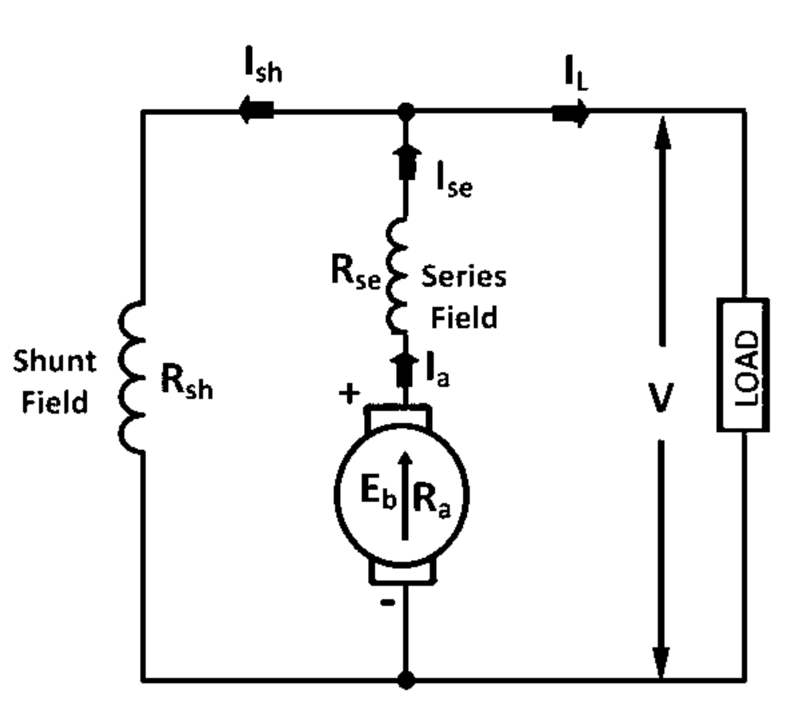
$I_{se}$ = Series field current

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

$R_a$ = Armature resistance

$R_{se}$ = Series field resistance

$V_b$ = brush drop




$$P_{generated} = E_g I_a$$

$$P_{output} = V I_L$$

# Short shunt Compound wound generator

- Shunt field winding parallel with armature only

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

$E_g$ = Generated voltage at armature

$V$ = Terminal voltage

$I_a$ = Armature current

$I_{se}$ = Series field current

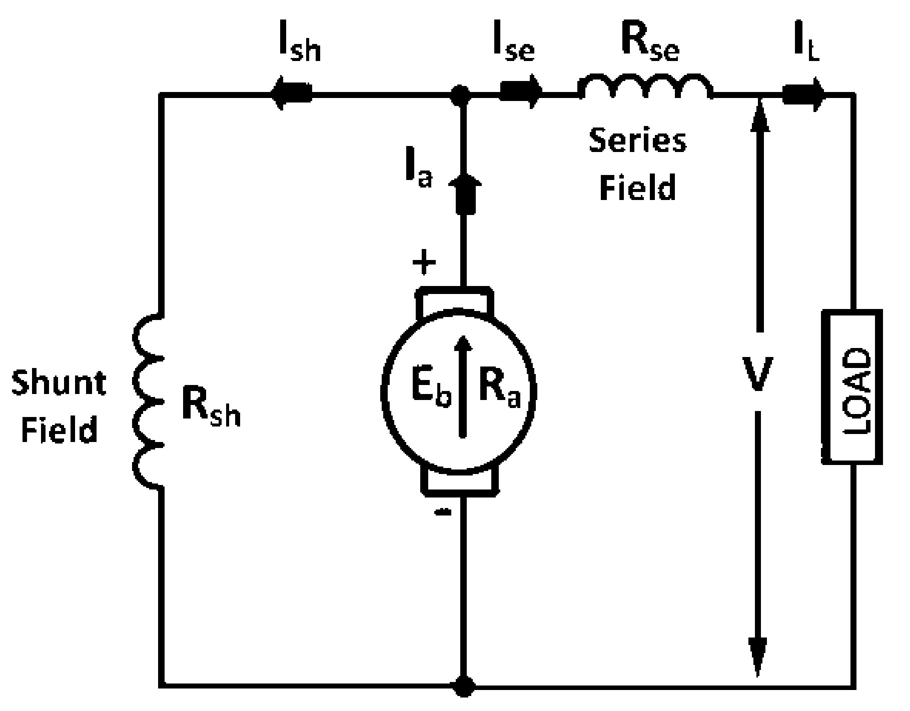
$I_a = I_L + I_{sh}$

$I_{se} = I_L$

$R_a$ = 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 =** $\varphi_{sh} + \varphi_{se}$

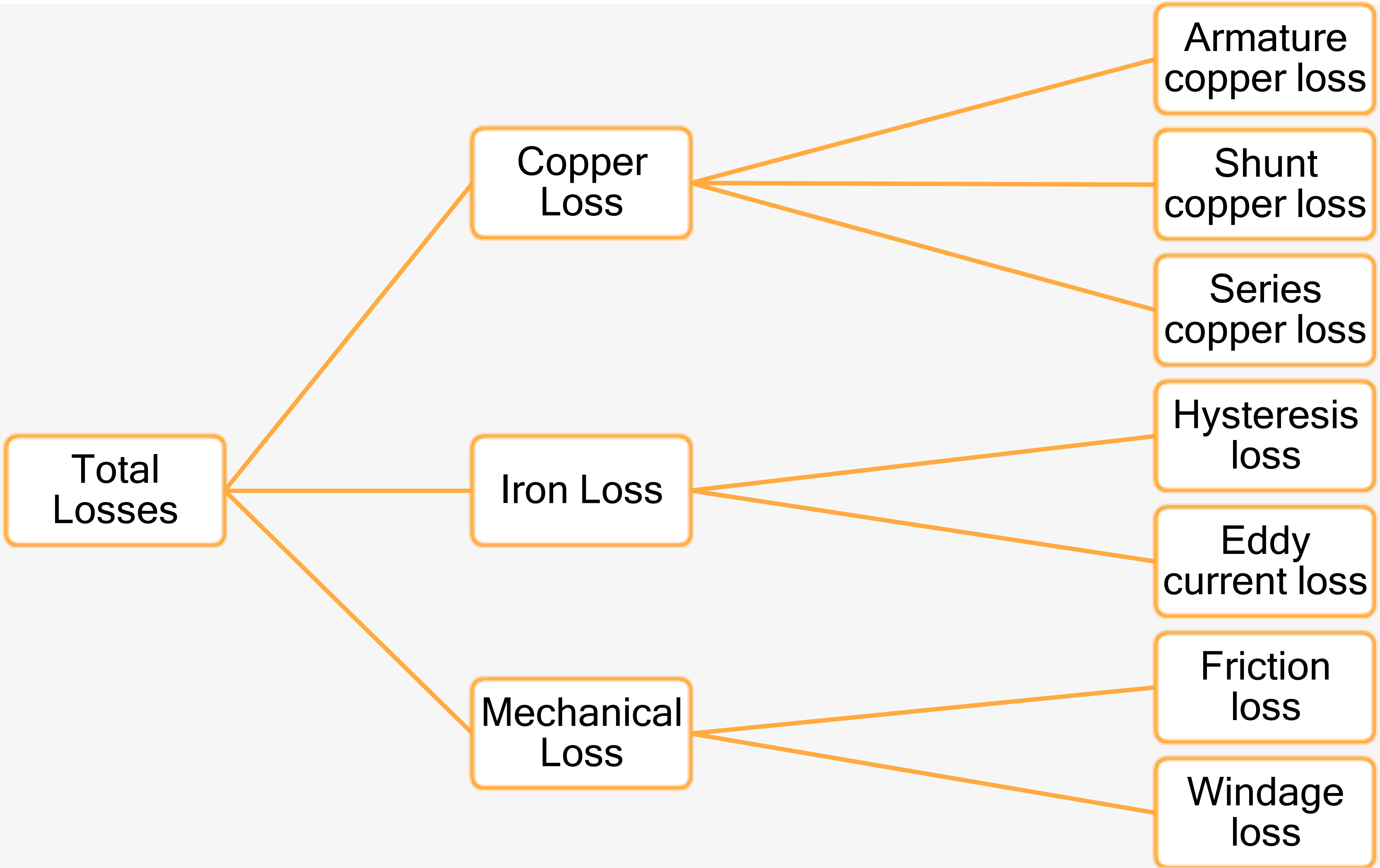
Differential compound

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

# 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

ENTRI

# Hysteresis loss

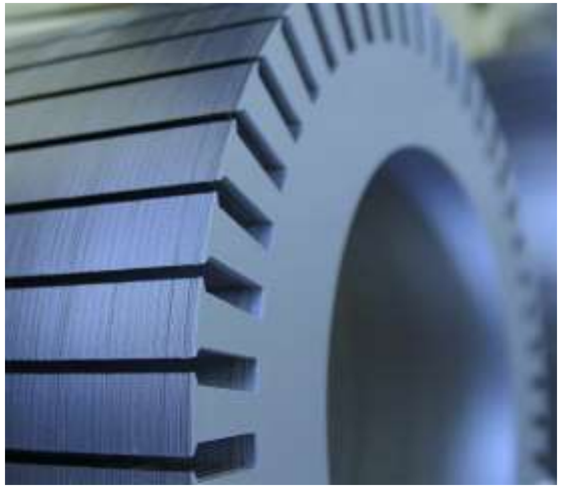
- This loss is due to the reversal of magnetization of the armature core.
- Energy wasted in the form of heat
- To reduce hysteresis loss, we are using silicon steel. silicon 3-4 %
- Losses calculated by Steinmetz formula.

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

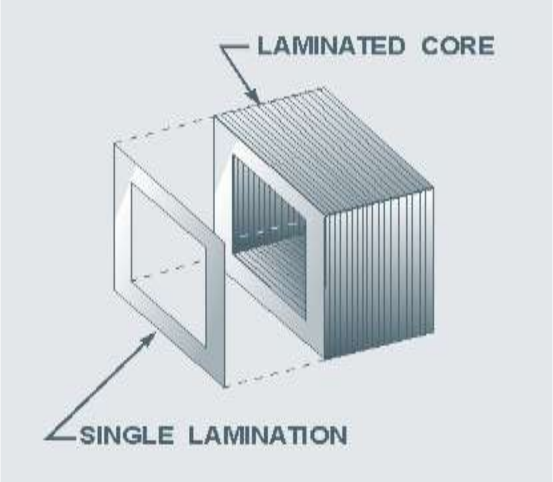
- $\eta$ = Steinmetz hysteresis constant , unit = joule/$m^2$
- $B_{max}$ = maximum flux density
- V = Volume of the core in $m^3$
- f = frequency
- Silicon steel = 191 joule/$m^2$ cast iron = 2700-4000 joule/$m^2$

# 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

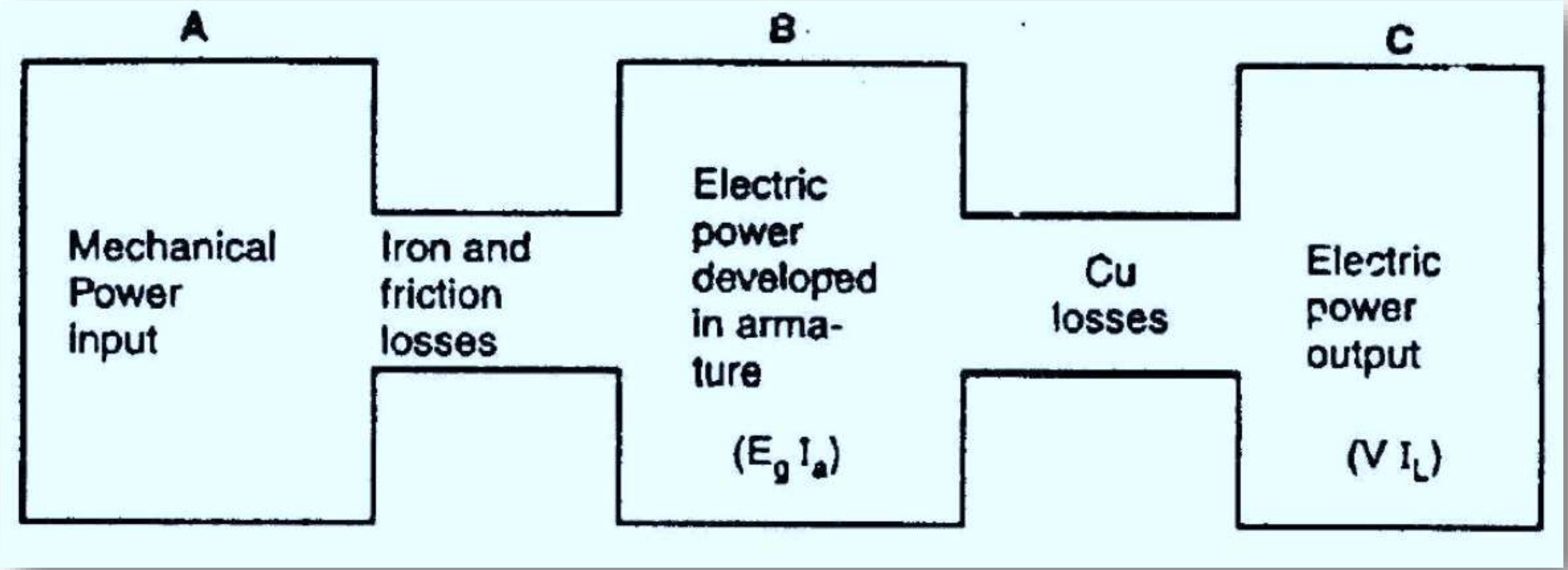
Windage loss

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

# Stray losses

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

# Power stages of DC Generator



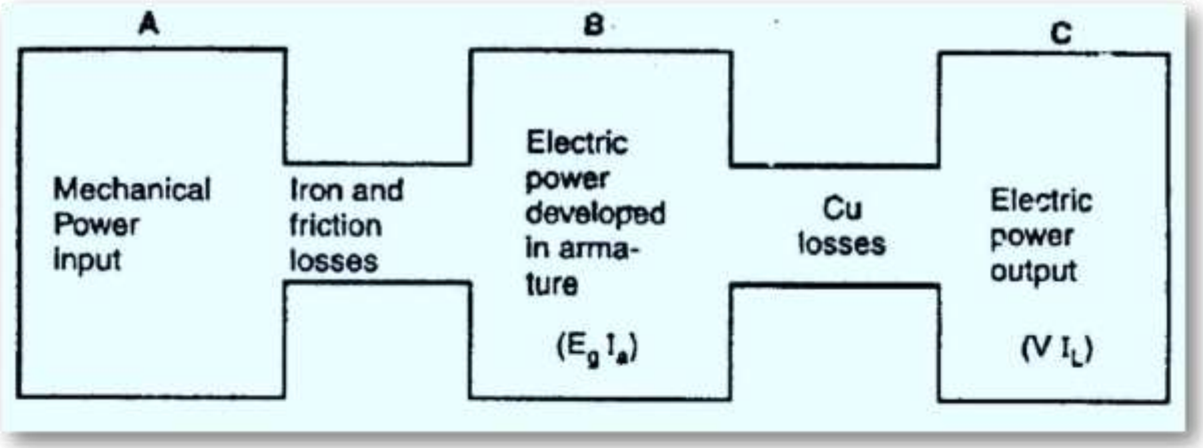
# Generator Efficiency

- 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

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

# Condition for maximum efficiency

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