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Gateway Classes

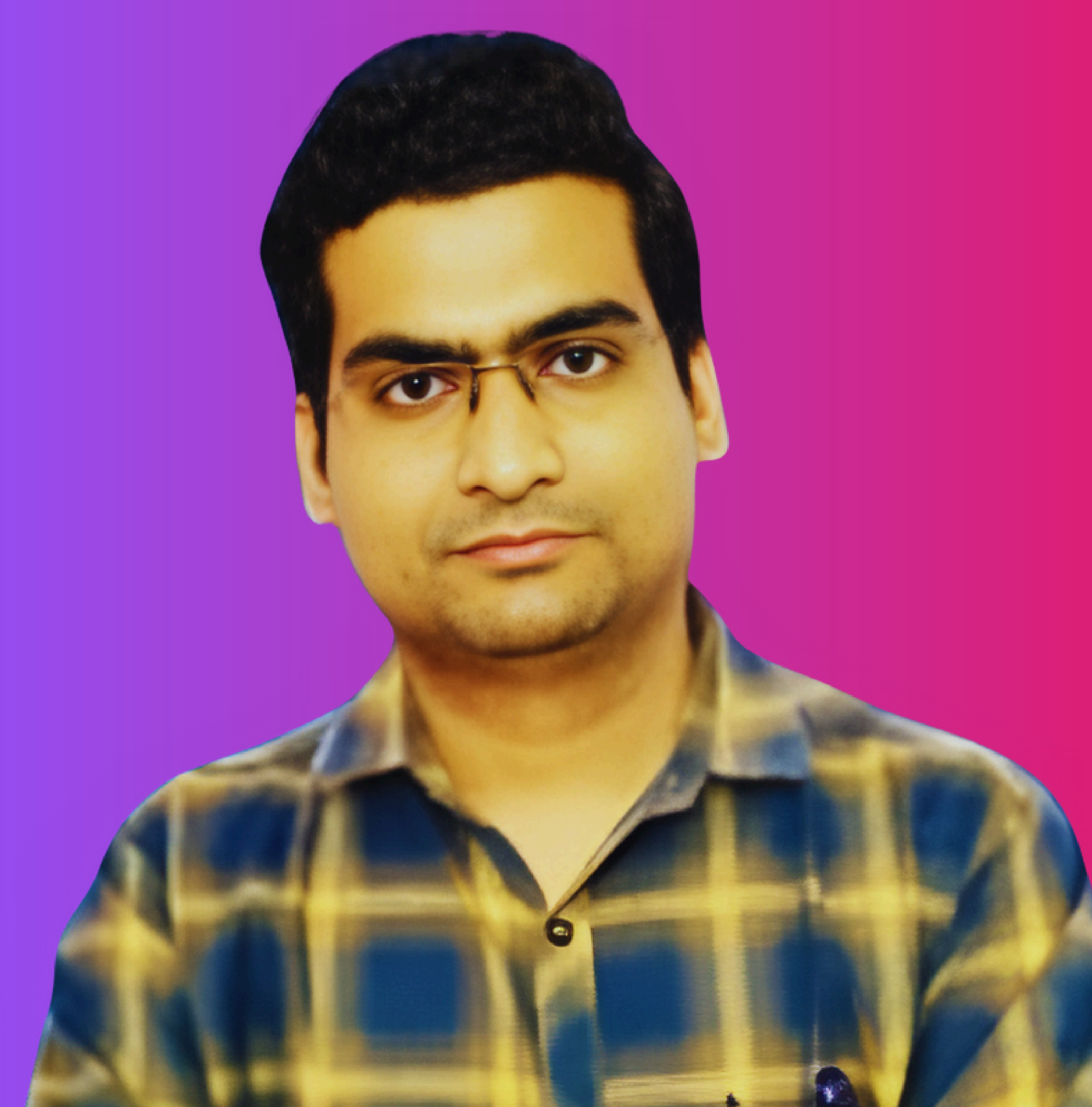
GATEWAY CLASSES

Semester -I & II

Common to All Branches

BEE101/201: FUNDAMENTALS OF ELECTRICAL ENGG.

UNIT-4 ONE SHOT : : Electrical machines



Gateway Series for Engineering

- Topic Wise Entire Syllabus
- Long - Short Questions Covered
- AKTU PYQs Covered
- DPP
- Result Oriented Content

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Gateway Classes

GATEWAY CLASSES

BEE101 / BEE201: FUNDAMENTALS OF ELECTRICAL ENGINEERING

Unit-4

Introduction to : Electrical machines

Syallbus

DC machines: Principle & Construction, Types, EMF equation of generator and torque equation of motor, applications of DC motors (simple numerical problems) Three Phase Induction Motor: Principle & Construction, Types, Slip-torque characteristics, Applications (Numerical problems related to slip only) Single Phase Induction motor: Principle of operation and introduction to methods of starting, applications. Three Phase Synchronous Machines: Principle of operation of alternator and synchronous motor and their applications.

As per New Syllabus

AKTU

GATEWAY CLASSES

Electrical Engg

One Shot

UNIT - IV

Syllabus BEE-201/101

- **Unit-4 : (Electrical machines)**
- DC Machine:- Principle & Construction, Types, EMF equation of generator and torque equation of motor, applications of DC motors (simple numerical problems)
- Three Phase Induction Motor: Principle & Construction, Types, Slip-torque characteristics, Applications (Numerical problems related to slip only)
- Single Phase Induction motor: Principle of operation and introduction to methods of starting, applications.
- Three Phase Synchronous Machines: Principle of operation of alternator and synchronous motor and their applications.

1

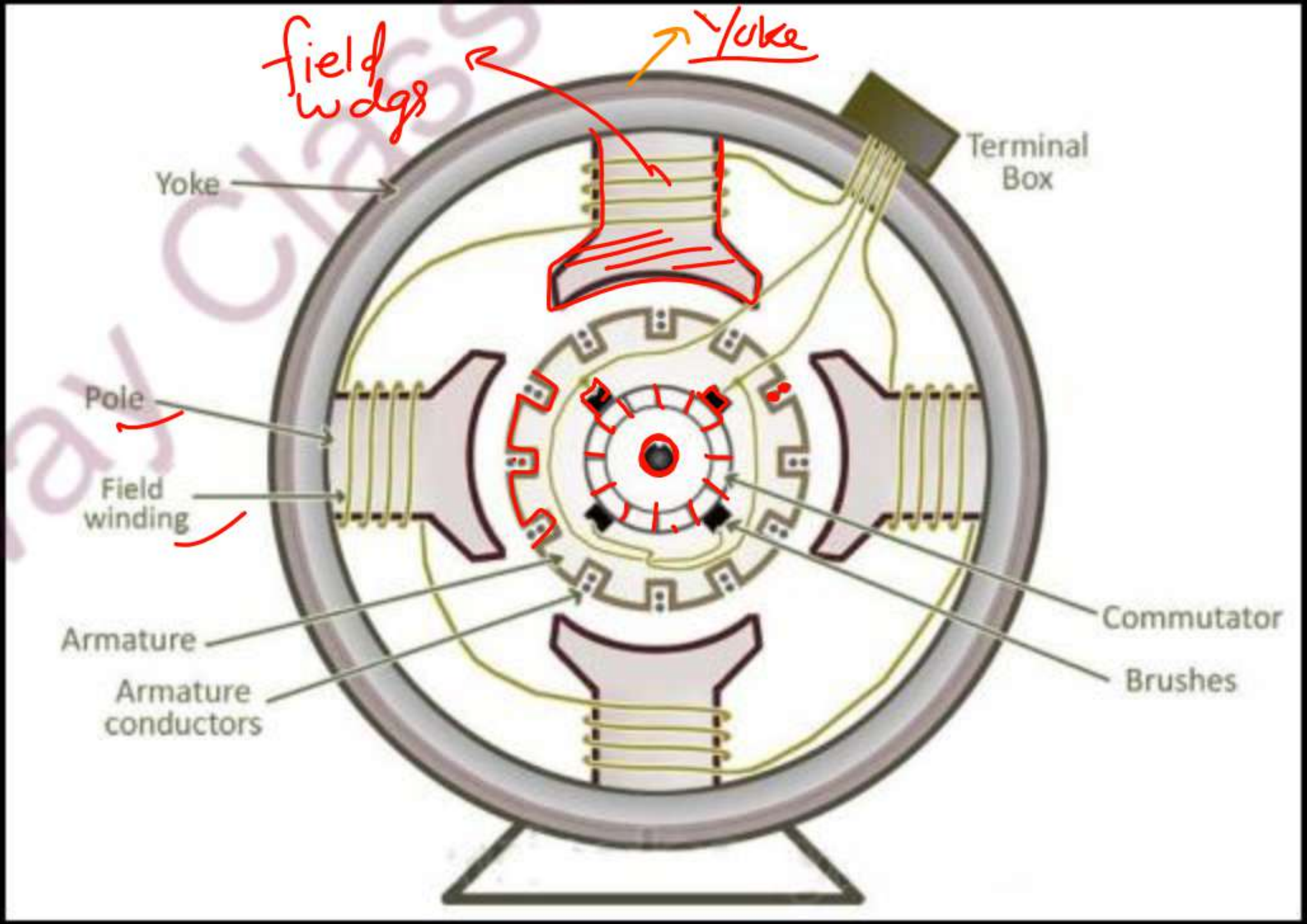
1

2

Construction of DC Machine

DC generator can be used as a DC motor without any constructional changes and vice versa is also possible. So we called both as DC Machine. Basic constructional parts of a DC machine are described below.

1. Magnetic frame or Yoke
2. Pole Cores and Pole Shoes
3. Field windings
4. *Armature core*
5. *Armature Winding*
6. *Commutator*
7. *Brushes and Bearings*



Construction of DC Machine

Stator Parts

1. **Magnetic frame or Yoke:-** The outer frame of a dc machine is called as yoke. It is made up of cast iron or steel. It not only provides mechanical strength to the whole assembly but also carries the magnetic flux produced by the field winding.
2. **Poles and pole shoes:** Poles are joined to the yoke with the help of bolts or welding. They carry field winding and pole shoes are fastened to them. Pole shoes serve two purposes; (i) they support field coils and (ii) spread out the flux in air gap uniformly.
3. **Field coil or winding:-** The field coil or winding is made up of copper wire. The field winding is former wound and inserted around the pole core. When field windings are excited by DC supply, they become electromagnets and produce magnetic flux in the machine.

Rotor Parts

1. **Armature core:** Armature core is the rotor of a dc machine. It is cylindrical in shape with slots to carry armature winding. The armature is built up of thin laminated circular steel disks for reducing eddy current losses. It may be provided with air ducts for the axial air flow for cooling purposes.

Construction of DC Machine (Rotor Parts)

2. Armature winding :- The armature winding is placed on the slots of the armature core. It is made up of copper. The armature winding links with the magnetic flux and induce a rotating magnetic flux.

According to the connections, there are two types of windings; Lap winding and Wave winding

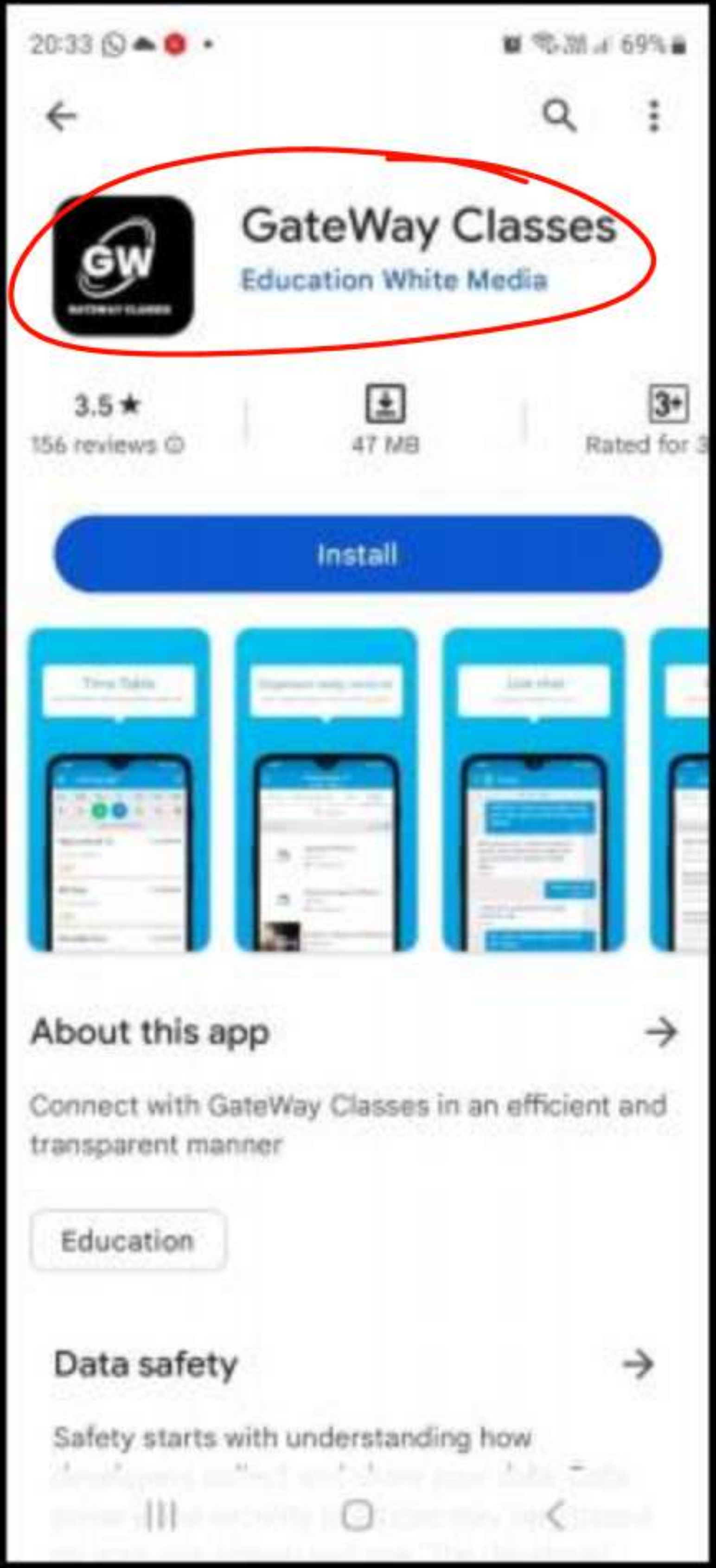
Imp

3. Commutator:- The commutator is one of the important parts of the DC machine. It is basically mechanical rectifier. It is a cylindrical shaped device and is made up of copper. The commutator is made of copper segments insulated from each other by mica sheets and mounted on the shaft of the machine. The commutator is mounted on the shaft of the DC machine on one side of the armature. The commutator converts the alternating current of the armature into unidirectional current in the external circuit with the help of brushes, and *vice-versa*.

Imp

4. Brushes:- Brushes are used to make an electrical connection with the rotating commutator. These collect (or supply) current from (or to) the moving commutator. Brushes are usually made up of carbon.

5. Bearings:- Bearings are used in the DC machine to reduce the frictional losses. Thus, the main function of bearings in the DC machine is to support the machine shaft with minimum friction.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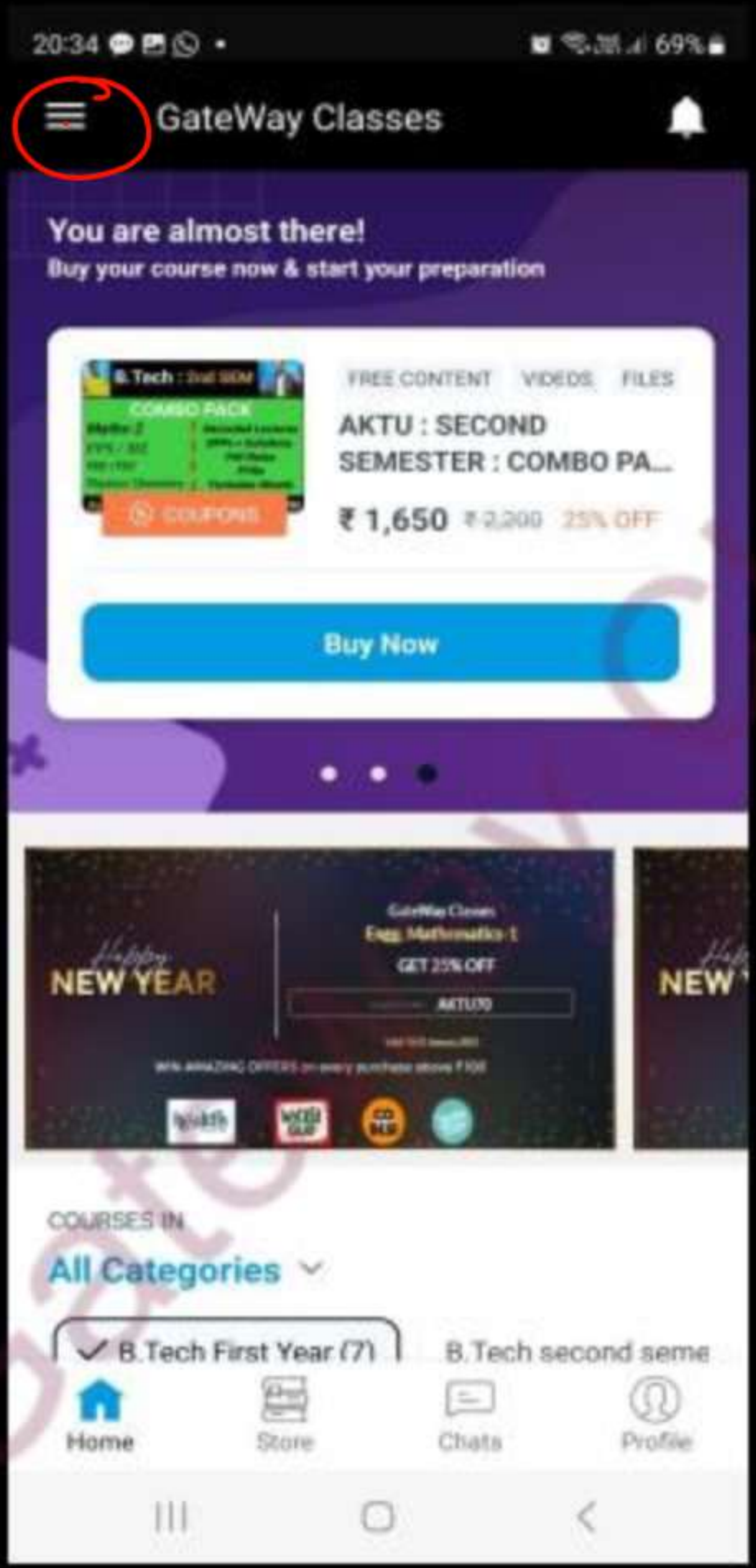
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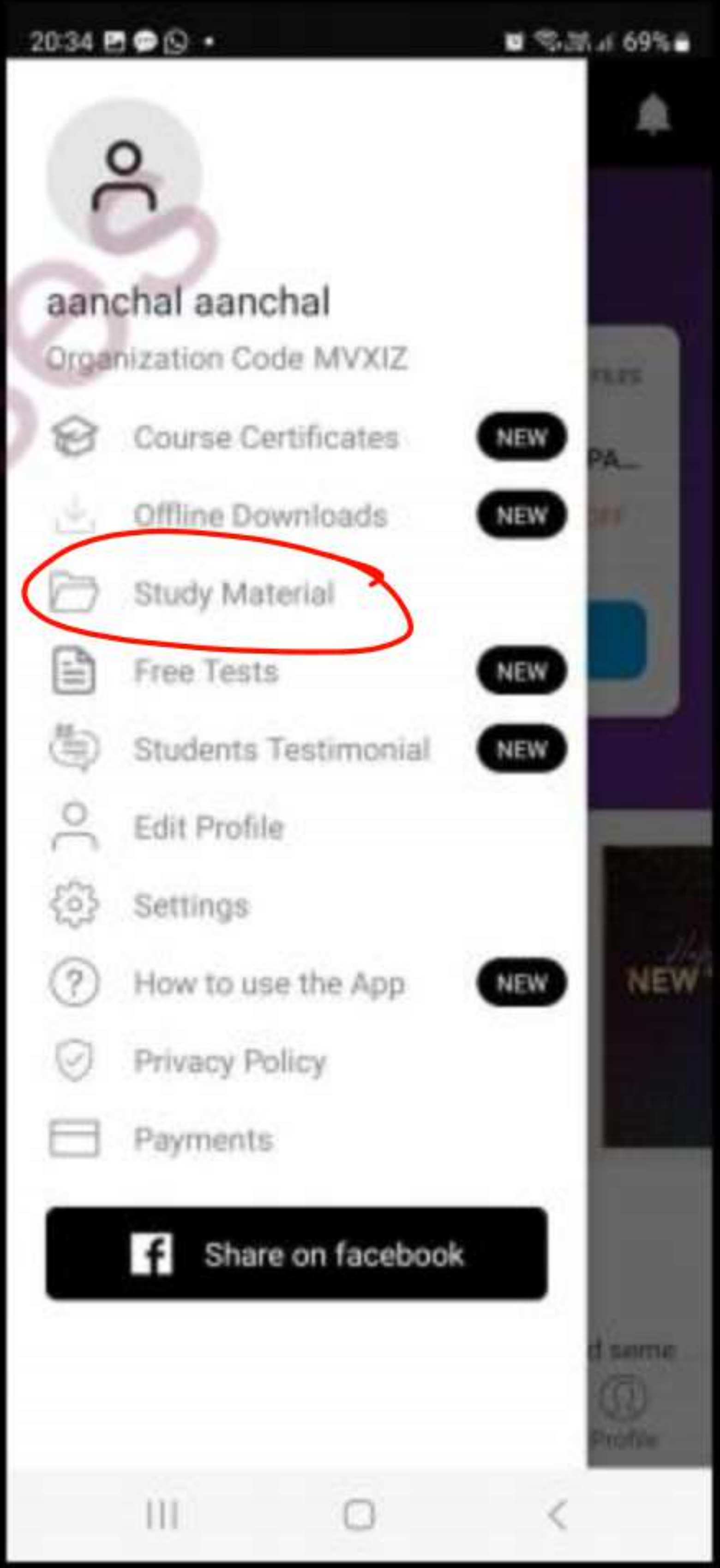
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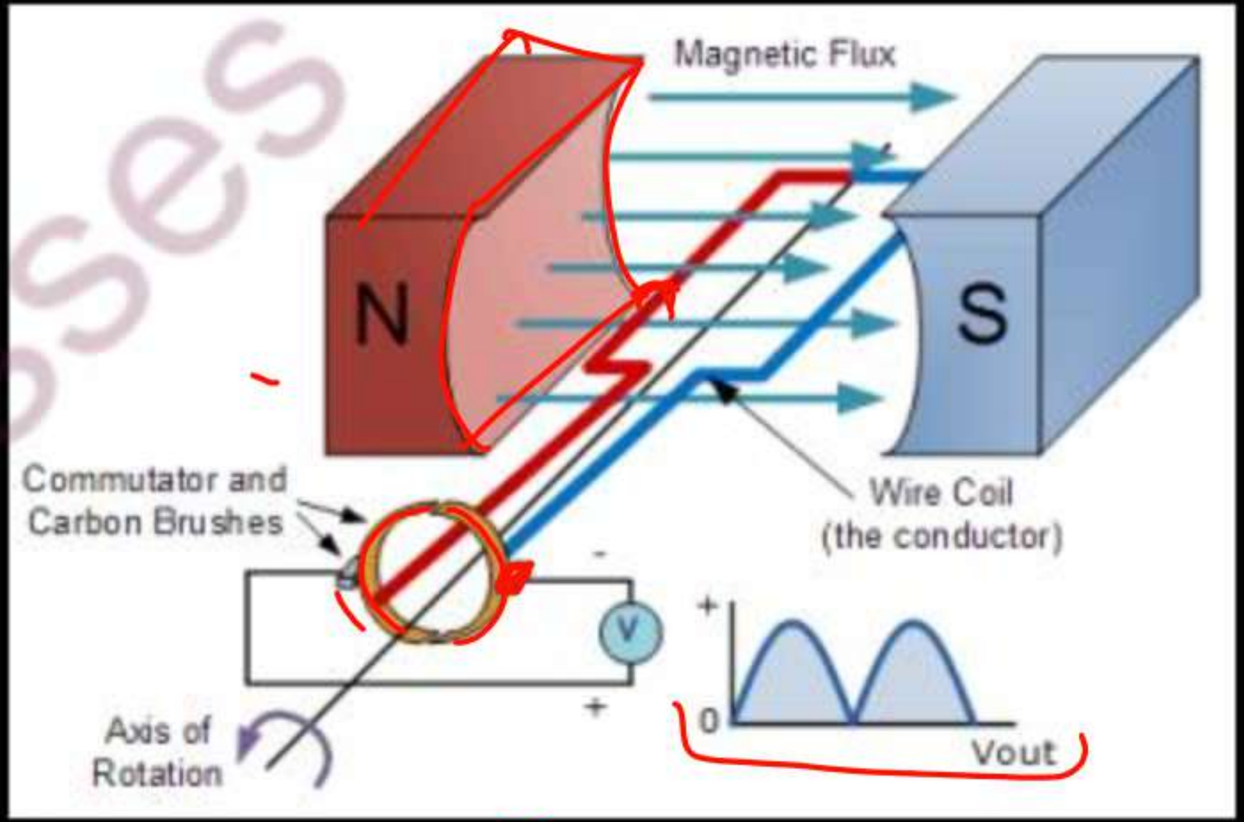
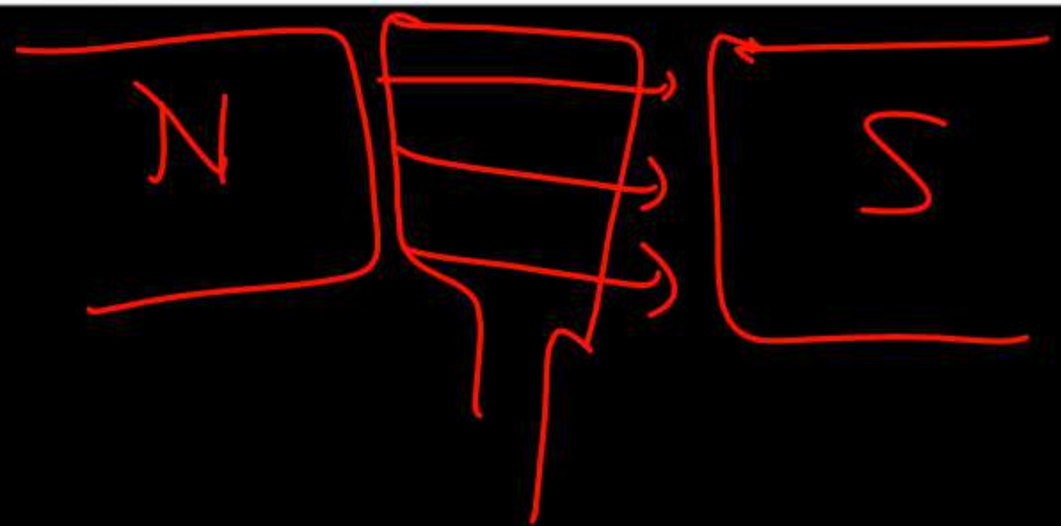
Working of DC generator

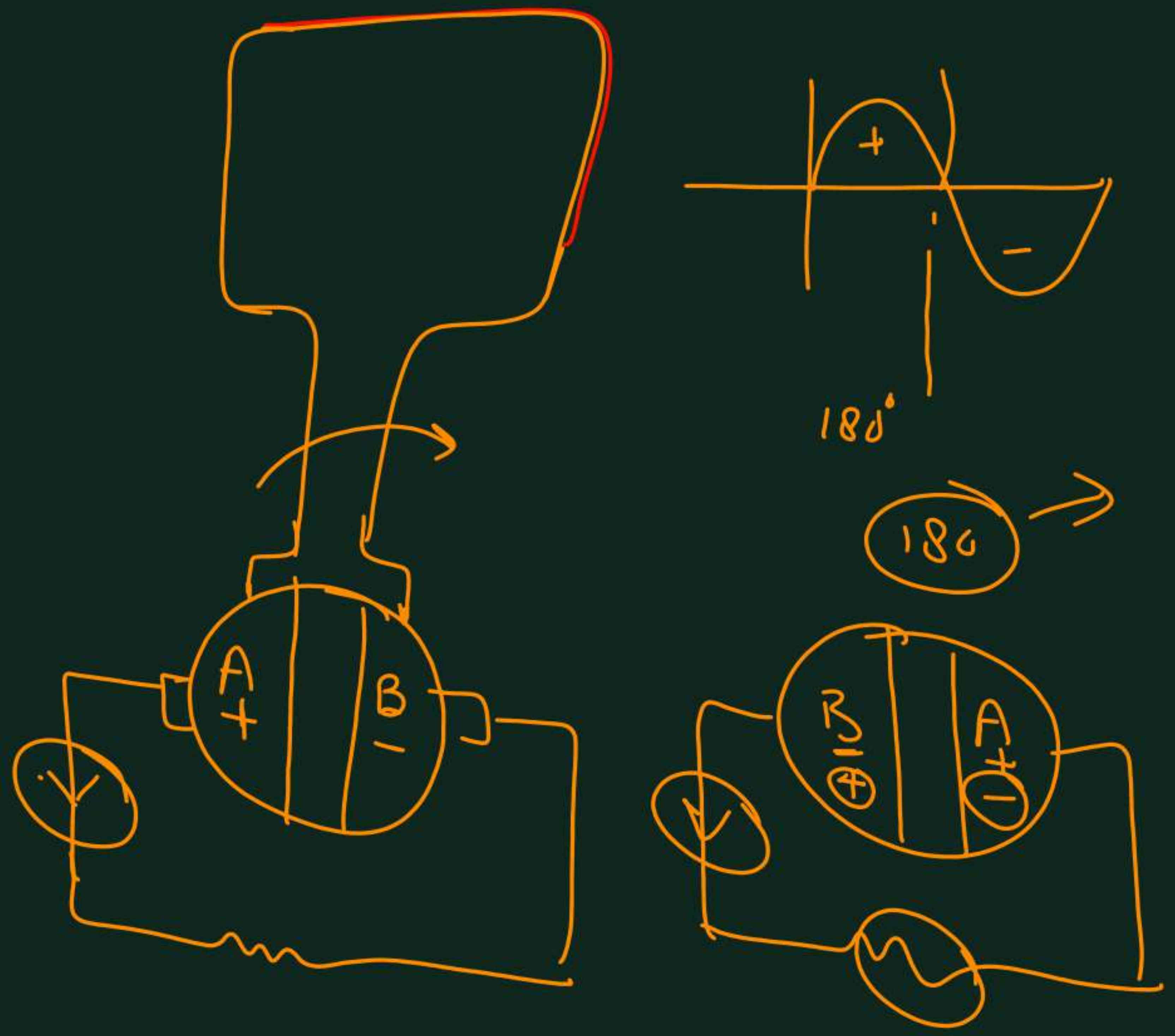
- According to Faraday's laws of electromagnetic induction, whenever a conductor is placed in a varying magnetic field (OR a conductor is moved in a magnetic field), an emf (electromotive force) gets induced in the conductor.
- If the conductor is provided with a closed path, the induced current will circulate within the path.
- In a DC generator, field coils produce an electromagnetic field and the armature conductors are rotated into the field.
- Thus, an electromagnetically induced emf is generated in the armature conductors.
- The direction of induced current is given by Fleming's right hand rule.





Need of a Split ring commutator:

- the direction of current in every armature conductor will be alternating
- with a split ring commutator, connections of the armature conductors also gets reversed when the current reversal occurs. Thus we get unidirectional current at the terminals.


A
+
B
−
V
+
−
180°
180
B
A
V

E.M.F. Equation of Generator

Let, **P** – number of poles of the machine,

φ – Flux per pole in Weber.,

Z – Total number of armature conductors.

N – Speed of armature (r.p.m),

A – number of parallel paths in the armature winding.

Lap $A = P$

wave $A = 2$

In one revolution of the armature, the flux cut by one conductor is given as:

$$\text{Flux cut by one conductor} = P\varphi \ \text{wb} \ \dots\dots(1)$$

Time taken to complete one revolution is given as:

$$t = \frac{60}{N} \ \text{seconds} \quad \dots\dots(2)$$

Therefore, the average induced e.m.f in one conductor will be:

$$e = \frac{P\varphi}{t} \quad \dots\dots(3)$$

Putting the value of (t) from Equation (2) in the equation (3) we will get

$$e = \frac{P\varphi}{60/N} = \frac{P\varphi N}{60} \ \text{volts} \quad \dots\dots(4)$$

The number of conductors connected in series in each parallel path = Z/A.

Therefore, the average induced e.m.f across each parallel path or the armature terminals is given by the equation shown below:

$$E_g = \frac{P\varphi N}{60} \times \frac{Z}{A} = \frac{PZ\varphi N}{60\,A} \ \text{volts} \quad \text{or}$$

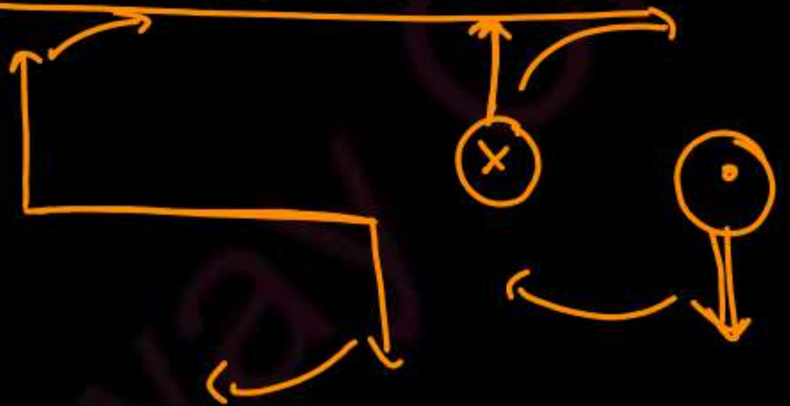
$$E = \frac{PZ\varphi n}{A} \quad \dots\dots(5)$$

Where, n=N/60 in r.p.s

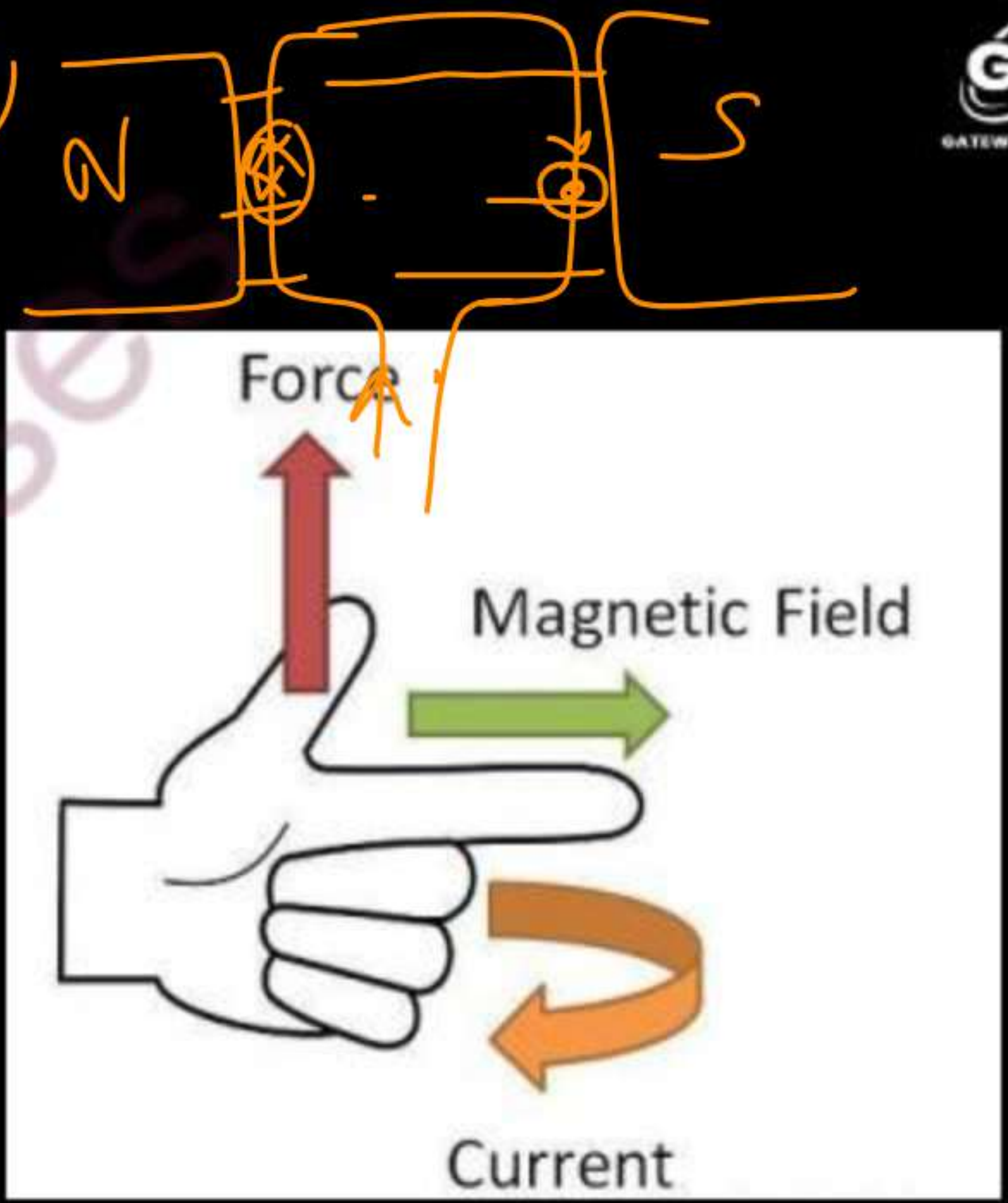
This equation is for generated emf and in case of dc motor this emf is called as **back emf**

Working Principle of DC Motor

- A machine that converts DC electrical power into mechanical power is known as a Direct Current motor.
- DC motor working is based on the principle that when a current carrying conductor is placed in a magnetic field, the conductor experiences a mechanical force.
- The direction of this force is given by Fleming's left-hand rule and magnitude is given by;



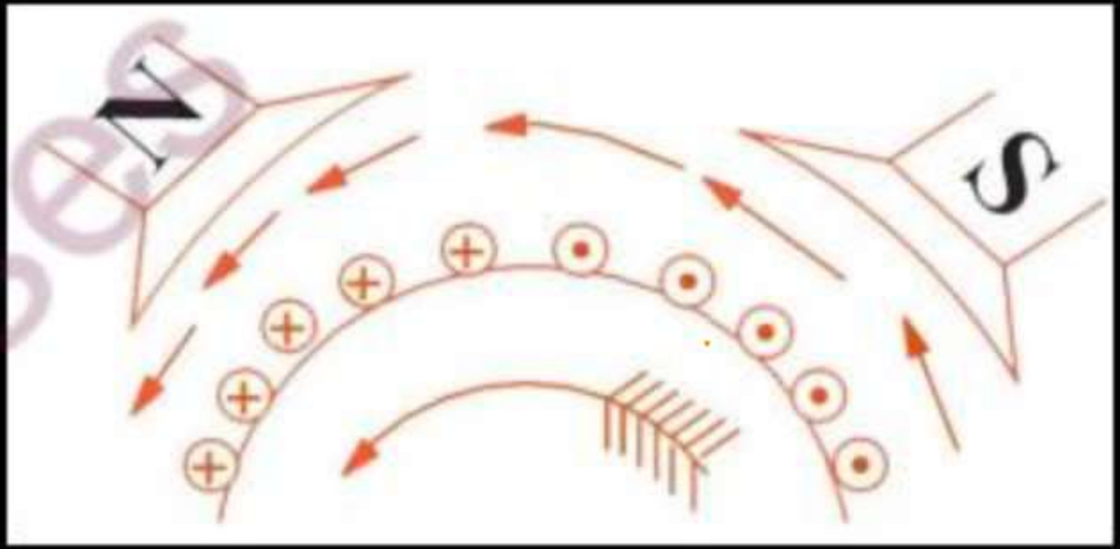
F = BIL Newtons



- *According to Fleming's left-hand rule when an electric current passes through a coil in a magnetic field, the magnetic force produces a torque that turns the DC motor.*
- The direction of this force is perpendicular to both the wire and the magnetic field.

Working of DC Motor

- When the terminals of the motor are connected to an external source of DC supply:
- All conductors under North-pole carry currents in one direction while all the conductors under South-pole carry currents in the opposite direction.
- Since each armature conductor is carrying current and is placed in the magnetic field, a mechanical force acts on it.



- On applying Fleming's left-hand rule, it is clear that force on each conductor is tending to rotate the armature in the anticlockwise direction. All these forces add together to produce a driving torque which sets the armature rotates.
- When the conductor moves from one side of a brush to the other, the current in that conductor is reversed. At the same time, it comes under the influence of the next pole which is of opposite polarity. Consequently, the direction of the force on the conductor remains the same.
- It should be noted that the function of a commutator in the motor is the same as in a generator. By reversing current in each conductor as it passes from one pole to another, it helps to develop a continuous and unidirectional torque.

Significance of back emf

- Magnitude of back emf is directly proportional to speed of the motor.
- Consider the load on a dc motor is suddenly reduced. In this case, required torque will be small as compared to the current torque. Speed of the motor will start increasing due to the excess torque. Hence, being proportional to the speed, magnitude of the back emf will also increase. With increasing back emf armature current will start decreasing. Torque being proportional to the armature current, it will also decrease until it becomes sufficient for the load. Thus, speed of the motor will regulate.

In case of load decr eas ed

d torq ue will be sma ll as com par ed to curr

d of the moto r will start incre asing due to the exces s

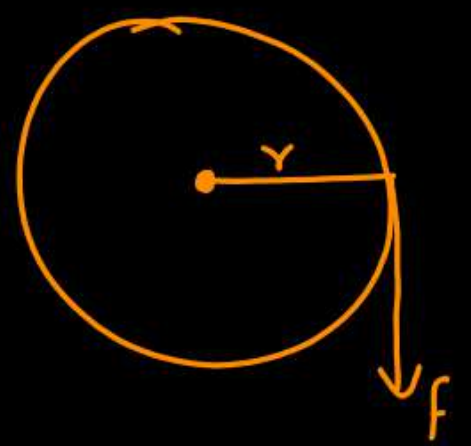
propo rtional to the speed, magni tude of the back emf will also

with incre asing back emf arma ture curre nt will start decre

ional to the armatu re current , it will also decreas e until it becom es

- On the other hand, if a dc motor is suddenly loaded, the load will cause decrease in the speed. Due to decrease in speed, back emf will also decrease allowing more armature current. Increased armature current will increase the torque to satisfy the load requirement. Hence, presence of the back emf makes a dc motor 'self-regulating'.

Torque equation of Motor



Torque

Mech. Power = Electrical power

$$T \times \omega = E_b \cdot I_a$$

$$T = \frac{E_b \cdot I_a}{\omega} = \frac{E_b \cdot I_a}{\left(\frac{2\pi N}{60}\right)}$$

$$= \left(\frac{Z\phi \cancel{N} P}{\cancel{60} A} \cdot I_a\right) \times \frac{\cancel{60}}{2\pi \cancel{N}}$$

$$\boxed{T = \frac{Z\phi P I_a}{2\pi A}}$$

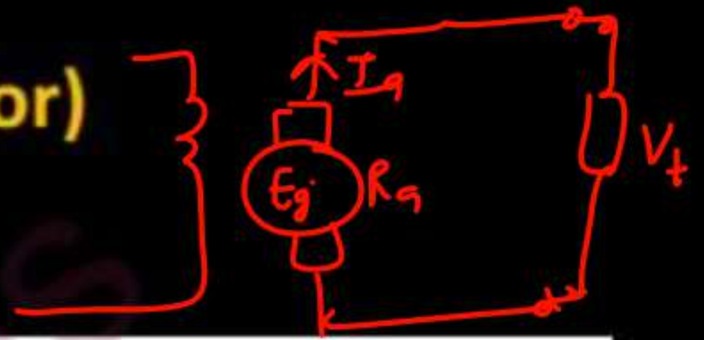
Types of DC Machine (Generator / Motor)

Separately excited (field winding is fed by external source)

Self-excited -

- Series wound (field winding is connected in series with the armature)
- Shunt wound (field winding is connected in parallel with the armature)
- Compound wound -
  - Long shunt
  - Short shunt

Types of DC Machine (Generator / Motor)



Separately excited (field winding is fed by external source)

Motor :→ $I_L = I_a$

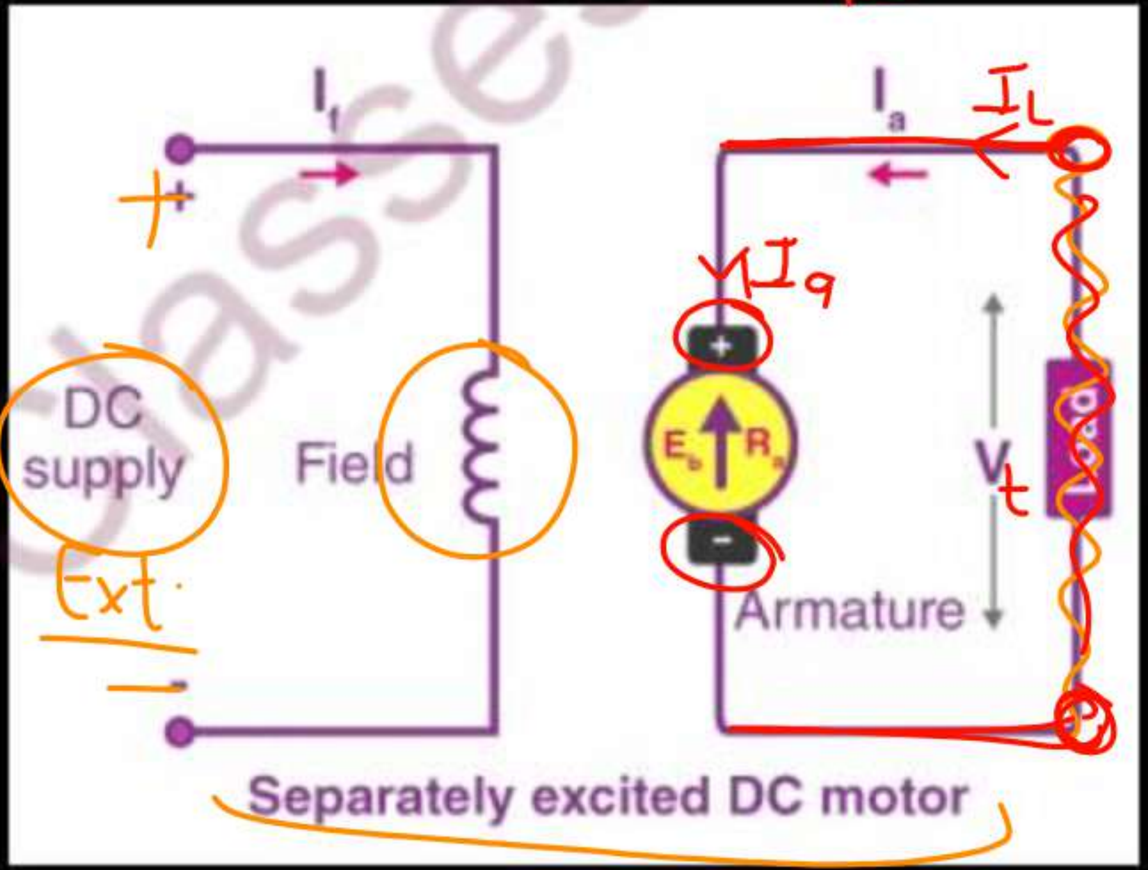
$V_t - \text{Brush drop} - I_a R_a = E_b$

$$\boxed{E_b = V_t - I_a R_a - \text{Brush drop}}$$

Generator: $I_a = I_L$

$E_g - I_a R_a - \text{Brush drop} = V_t$

$$\boxed{E_g = V_t + I_a R_a + B.D.}$$



Separately excited DC motor

Types of DC Machine (Generator / Motor)

GW GATEWAY CLASSES

Motor

Shunt Generator:-

$I_L = I_a + I_{sh}$

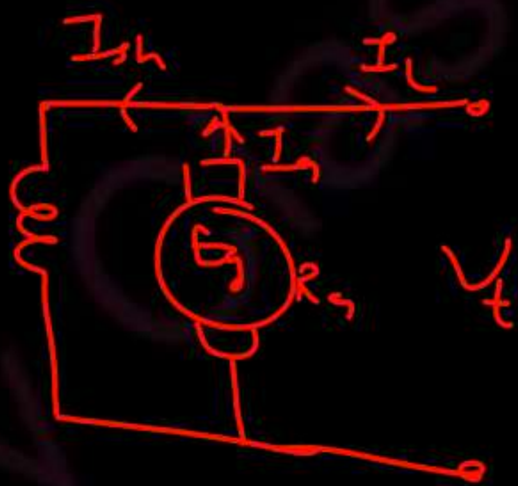
$$\boxed{V_t - I_a R_a - B.D = E_b}$$

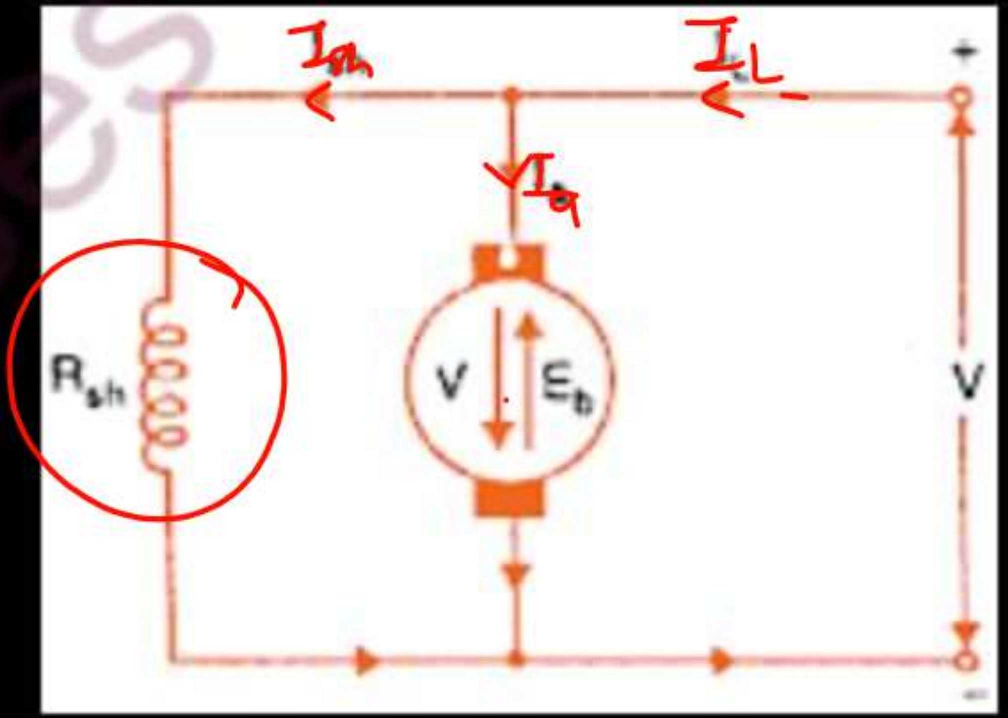
Generator:

$I_a = I_L + I_{sh}$

$E_g - I_a R_a - B.D = V_t$

$$\boxed{V_t + I_a R_a + B.D = E_g}$$





Types of DC Machine (Generator / Motor)

Series Generator:-

Motor

$I_a = I_L = I_{se}$

$V_t - I_a R_{se} - I_a R_a - B.D = E_b$

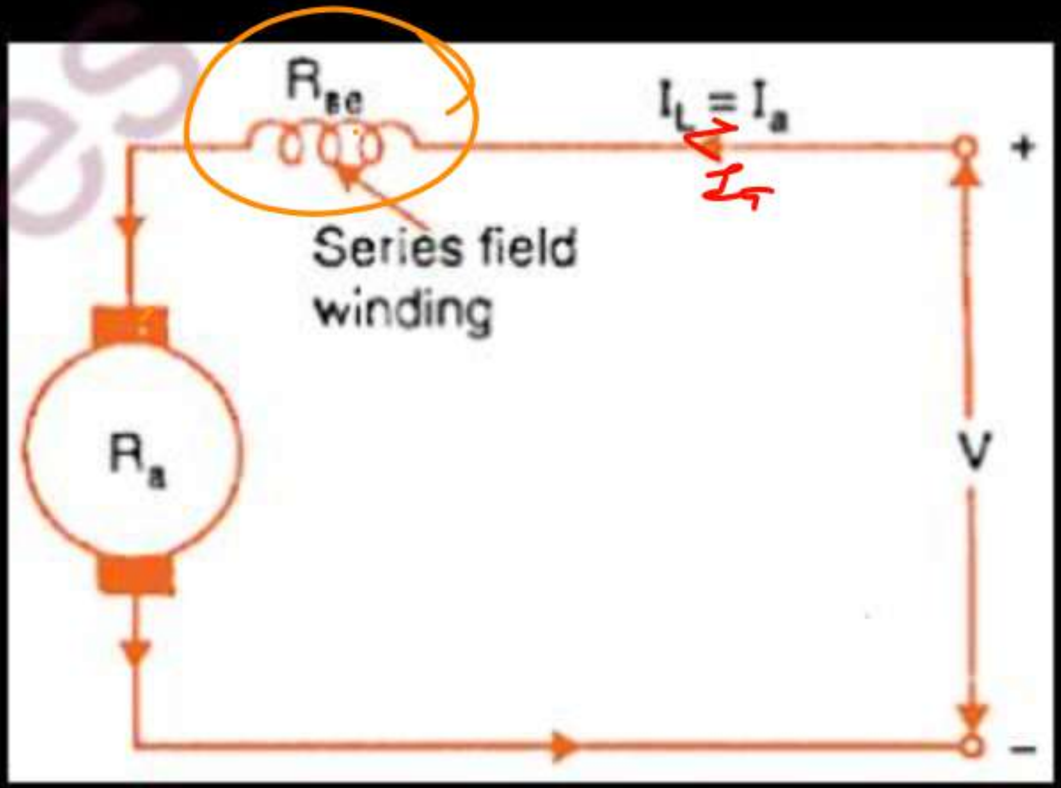
$$\boxed{E_b = V_t - I_a(R_a + R_{se}) + B.D.}$$

Generator

$I_a = I_L = I_{se}$

$E_g - I_a R_a - B.D - I_a R_{se} = V_t$

$$\boxed{E_g = V_t + I_a(R_a + R_{se}) + B.D}$$

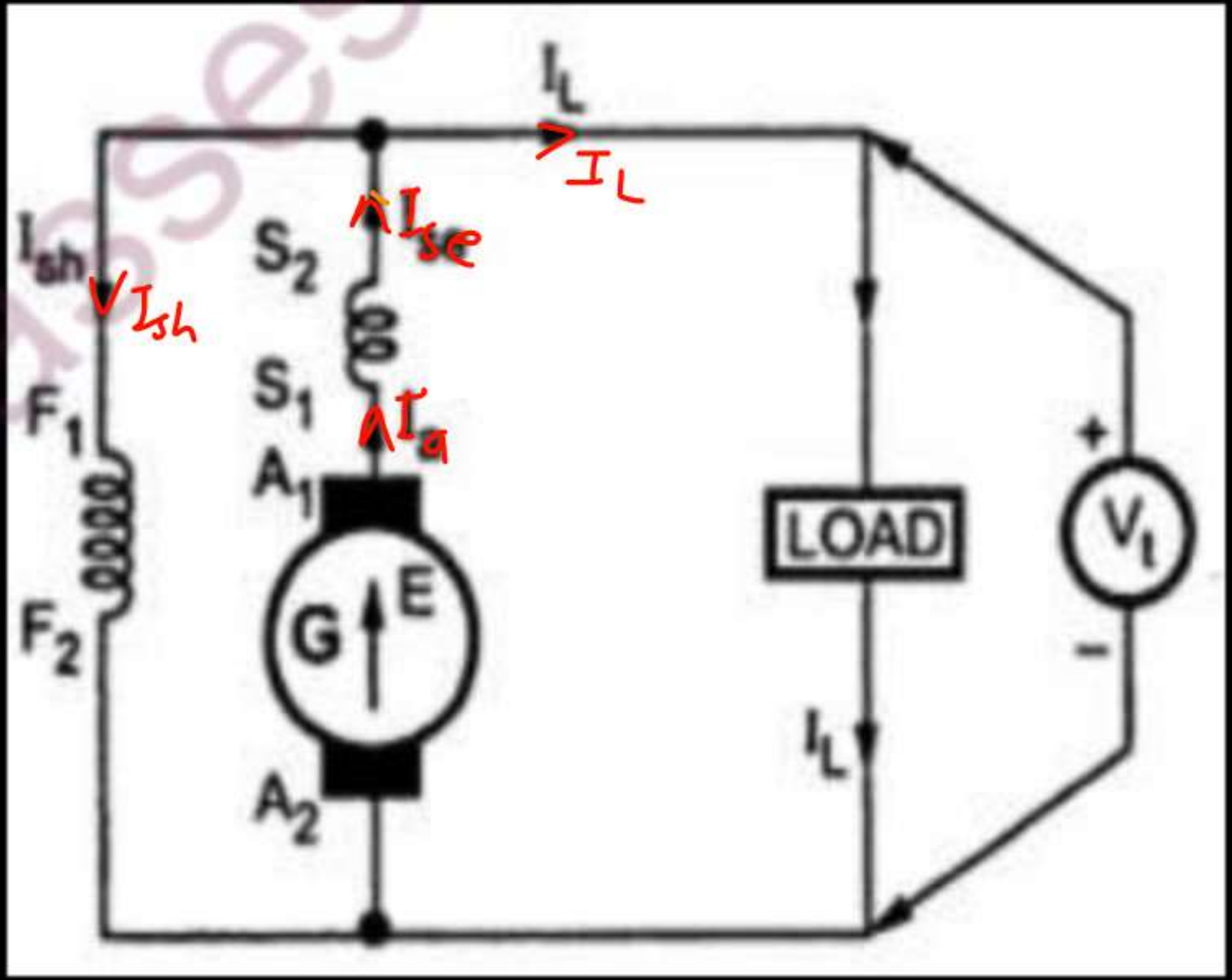


Compound Generator (Long Shunt) :-

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

$$E_g - I_a R_a - I_a R_{se} - B.D = V_t$$

$$\boxed{E_g = I_a(R_a + R_{se}) + B.D + V_t}$$

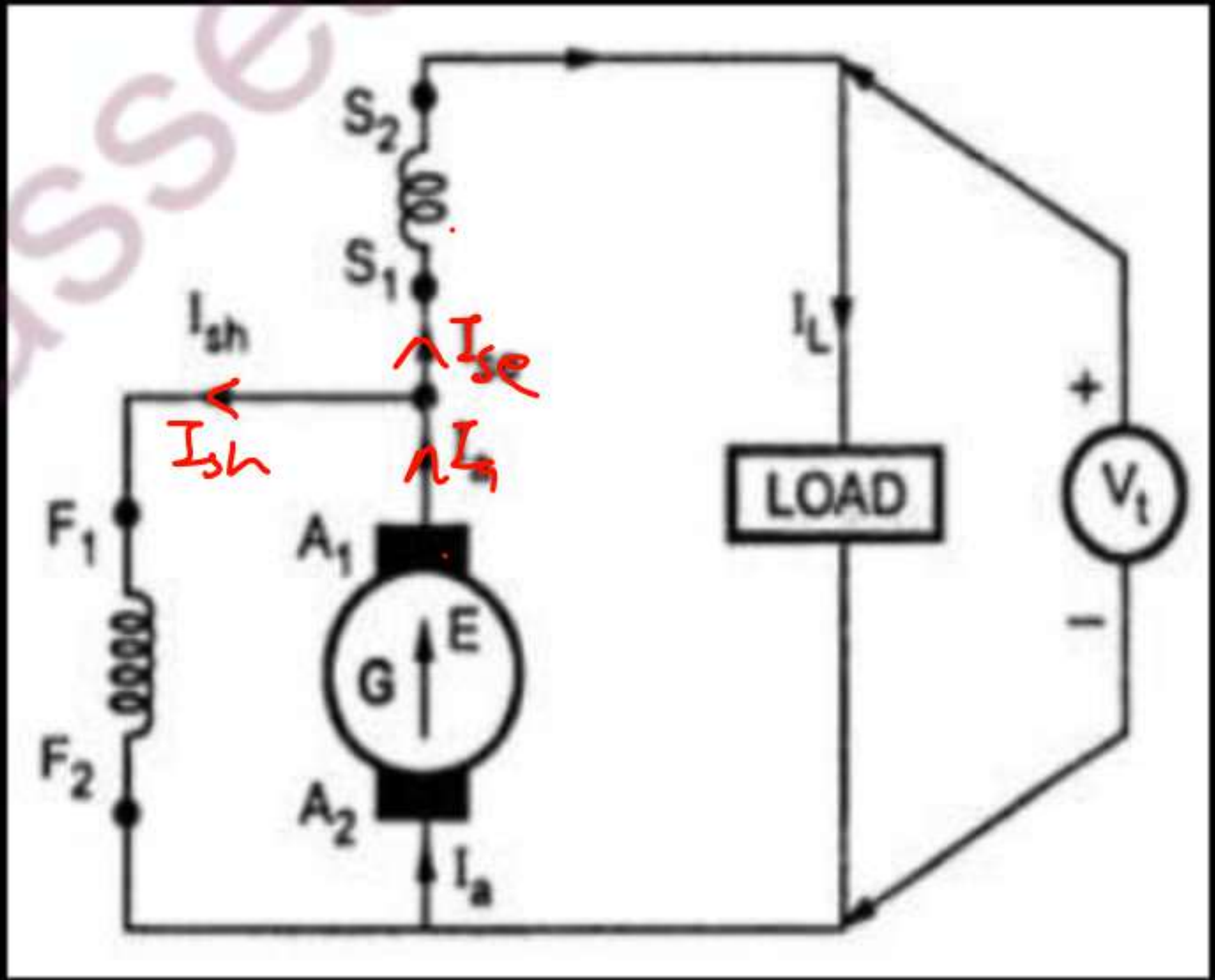


Compound Generator (Short Shunt) :-

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

$$E_g - I_a R_a - B.D - I_{se} R_{se} = V_t$$

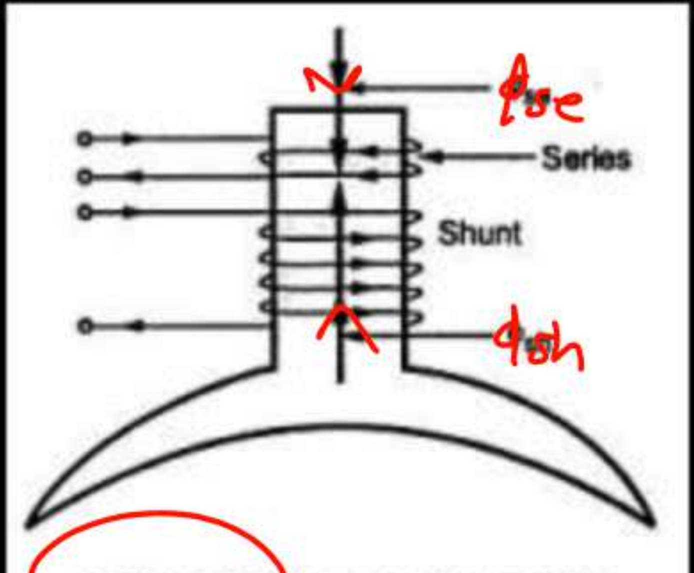
$$\boxed{E_g = V_t + I_a R_a + I_{se} R_{se} + B.D}$$



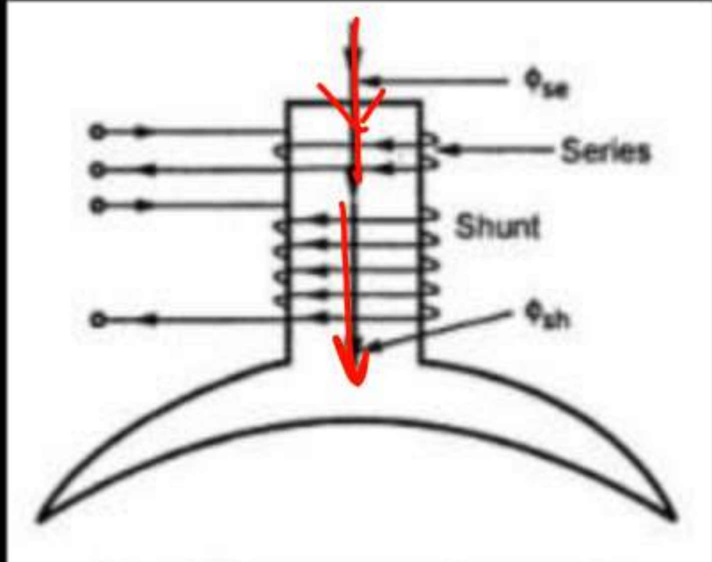
Differentially and cumulative Compound Generator :-

Both field add

Both field subtract



Differential compound generator



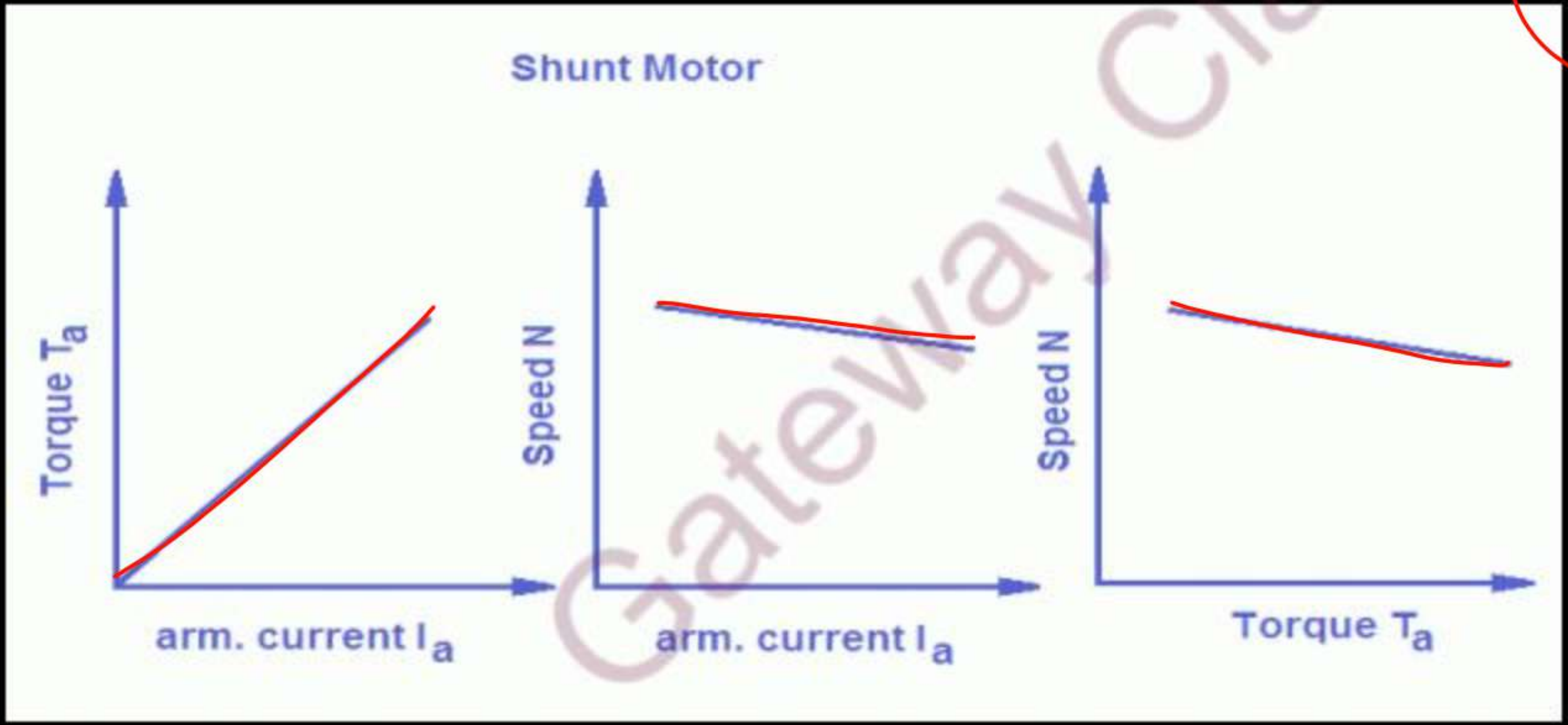
Cumulative compound generator

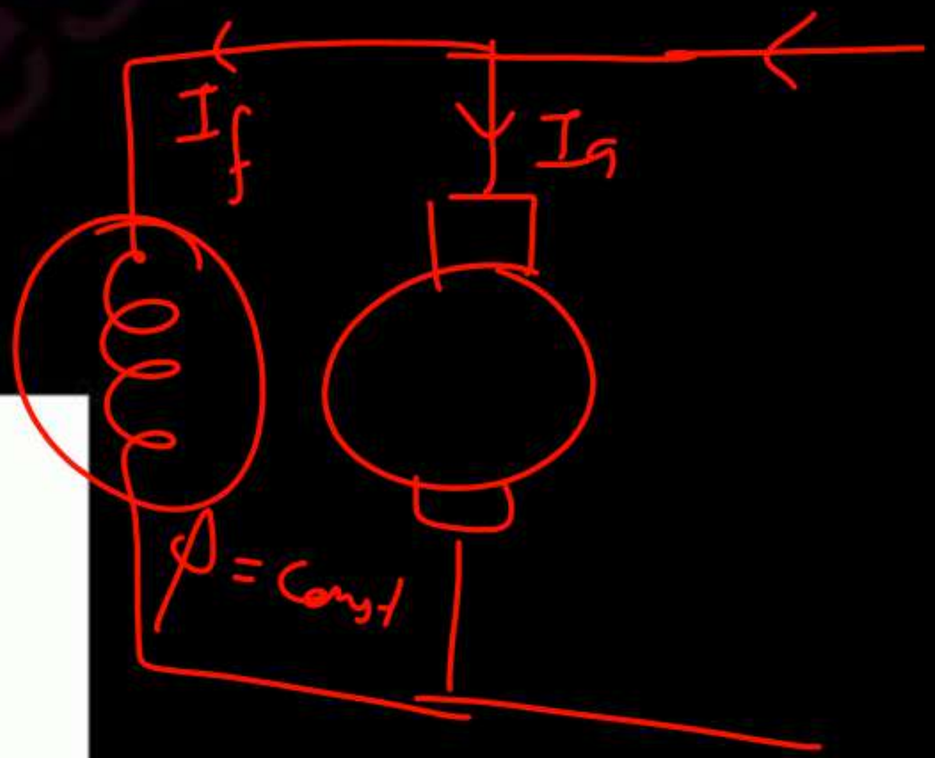
Characteristics of DC Shunt motor

(i) Torque Vs Armature Current (T Vs Ia) :- $T_a \propto \Phi I_a$, *Rsh and V is constant so Ish is also constant so flux is also constant so* $T_a \propto I_a$,

(ii) Speed Vs Armature Current (N Vs Ia) :- $N \propto V - I_a R_a / \Phi$ $\frac{E_b}{\phi}$

(iii) Speed Vs Torque (N vs T) :-



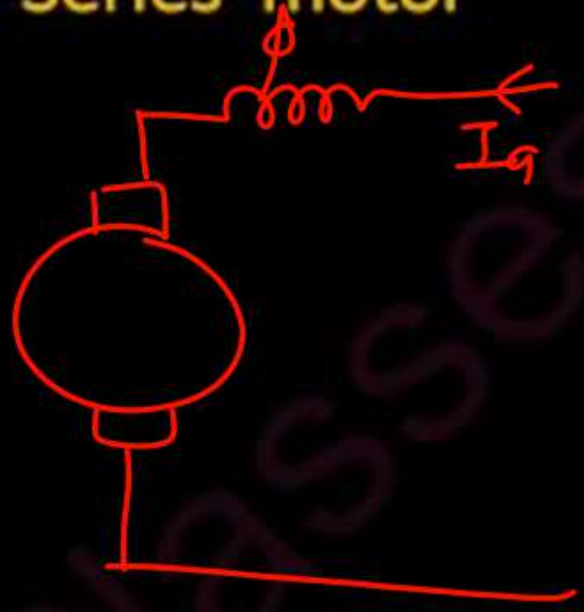


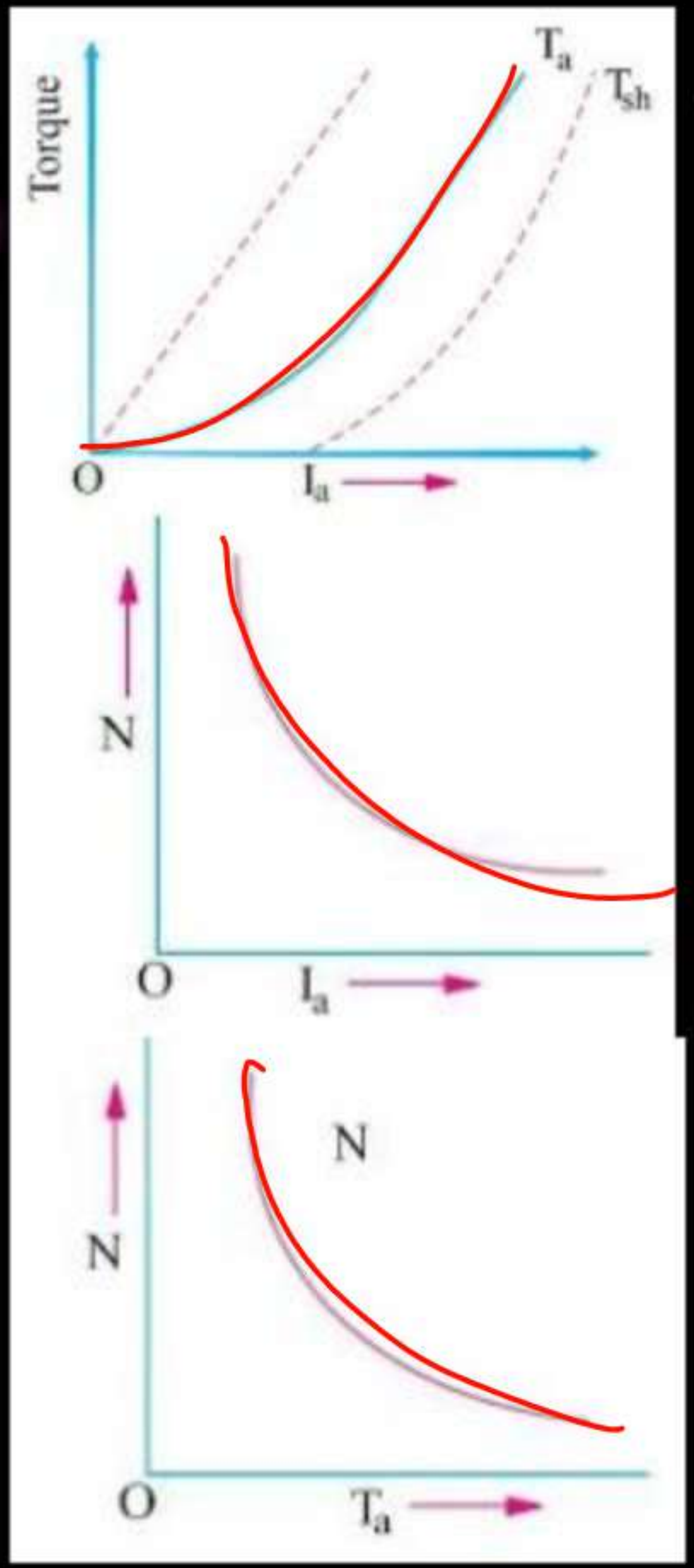
Characteristics of DC Series motor

(i) Torque Vs Armature Current (T Vs Ia) :-

$T_a \propto \Phi I_a$ So $T_a \propto I_a^2$

$\Phi \to I_a$





(i) Speed Vs Armature Current (N Vs Ia) :-

$N \propto Eb/\Phi$

and $N \propto (V\text{-}IaRa)/\Phi$

$N \propto 1/Ia$

(i) Speed Vs Torque (N vs T) :-

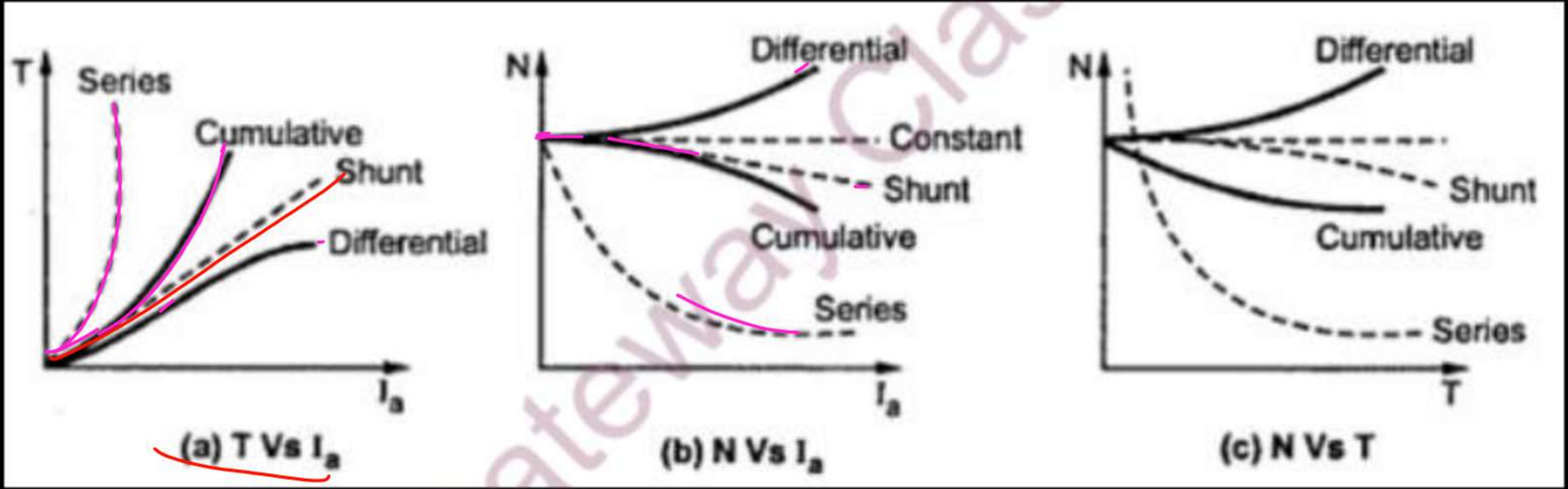
$N \propto 1/\sqrt{T}$

Characteristics of DC Compound motor

(i) Torque Vs Armature Current (T Vs Ia) :-

(ii) Speed Vs Armature Current (N Vs Ia) :-

(iii) Speed Vs Torque (N vs T) :-



Application of DC motor

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

Numericals

GW GATEWAY CLASSES

Q.1 A 4 pole, lap wound d.c. motor has 540 conductors. Its speed is found to be 1000 r.p.m. when it is made to run light. The flux per pole is 25 mWb. It is connected to 230 V d.c. supply. The armature resistance is 0.8 Ohm. Calculate i) Induced e.m.f ii) Armature Current iii) Stray losses iv) Lost torque

$P = 4$, $A = P = 4$, $Z = 540$, $N = 1000$, $\phi = 25\,mWb$

$V_t = 230V$, $R_a = 0.8$

$$\boxed{E_b = \frac{Z\phi NP}{60A}} = \frac{540 \times 25 \times 10^{-3} \times 1000 \times \cancel{4}}{60 \times \cancel{4}} = 225 \text{ volt}$$

$\cancel{I_a} =$ $\boxed{V_t = E_b + I_a R_a}$

$$I_a = \frac{V_t - E_b}{R_a} = \frac{230 - 225}{0.8} = 6.25 \text{ amp}$$

(iii) $\text{Loss} = E_b I_a$

$= 225 \times 6.25$

$= 1406.25$ watt

(iv) $\text{Torque} = \frac{E_b I_a}{\omega}$

$$= \frac{1406.25}{\frac{2\pi 1000}{60}}$$

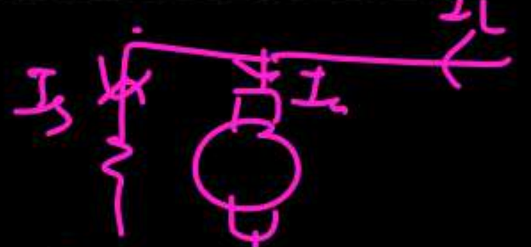
$= 13.42\,N\text{-}m$

Numericals

GATEWAY CLASSES

Q.2 A d.c. shunt genrator running at 1200 r.p.m. supplies a load of 60 kW at 250 volts. Find the speed at which it runs as a shunt motor when taking 60 kW from 250 volts supply. Take armature resistance at 0.1 ohm and field winding resistance as 50 ohm. Neglect brush drop.

Gen $N = 1200$, $P_{out} = 60\,kW$, $V_t = 250\,V$, $R_a = 0.1\,\Omega$, $R_f = 50\,\Omega$



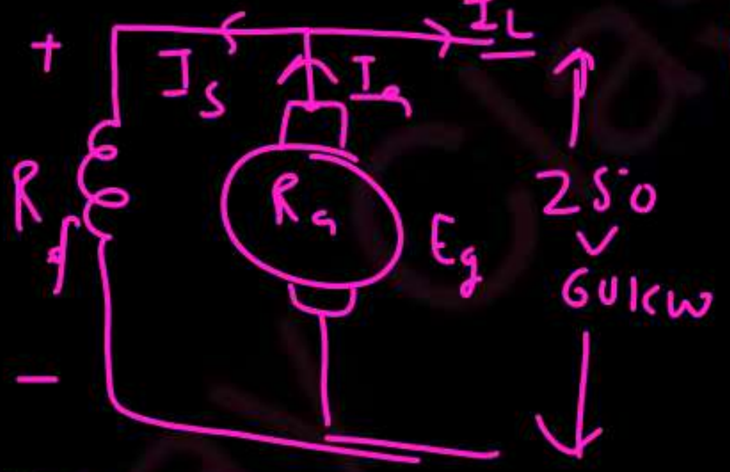
$$I_L = \frac{60\times10^3}{250} = 240\,A$$

$$I_a = I_s + I_L$$

$$I_s = \frac{250}{50} = 5\text{ amp}$$

$$I_a = 240+5 = 245\text{ amp}$$

$$E_g = V_t + I_a R_a = 250 + 245\times0.1 = 274.50\text{ Volt}$$



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

$$\frac{N_g}{N_m} = \frac{E_g}{E_b} = \frac{274.5}{226.5}$$

$$N_m = \frac{1200\times226.5}{274.5} = 990.1\text{ rpm}$$

$$I_L = \frac{60\times10^3}{\cancel{250}\ 250} = 240\,A$$

$$I_L = I_a + I_s \Rightarrow I_a = I_L - I_s$$

$$I_s = \frac{250}{50} = 5\text{ amp}$$

$$I_a = 240-5 = 235\text{ Amp}$$

$$E_b = V_t - I_a R_a = 250 - 235\times.1 = 226.5\text{ Volt}$$

Numericals

GW GATEWAY CLASSES

Q.3 A 4 pole, d.c. shunt motor working on 220 V D.C. supply takes a line current of 3 A at no load while running at 1500 r.p.m. Determine the speed when the motor takes a line current of 50 A. Assume armature and field resistance as 0.2 ohm and 400 ohm respectively.

$P = 4$, $V_t = 220V$, $I_{L_0} = 3A$, $N_0 = 1500$ rpm, $I_L = 50A$, $N = ?$, $R_a = 0.2$, $R_f = 400\Omega$

At No load.

$$I_{a_0} = I_{L_0} - I_{sh} = 3 - \left(\frac{220}{400}\right) = 2.45A$$

$$E_{b_0} = V_t - I_{a_0}R_a = 220 - (2.45 \times 0.2) = 219.51V$$

at load

$$I_a = I_L - I_{sh} = 50 - 0.55 = 49.45A$$

$$E_b = V_t - I_a R_a = 220 - (49.45 \times 0.2) = 210.11V$$

$$\frac{N}{N_0} = \frac{E_b}{E_{b_0}} = \frac{210.11}{219.51}$$

$$N = \frac{210.11}{219.51} \times 1500$$

$$= 1435.76 \text{ rpm}$$

Ans

Construction of Three Phase Induction Motor

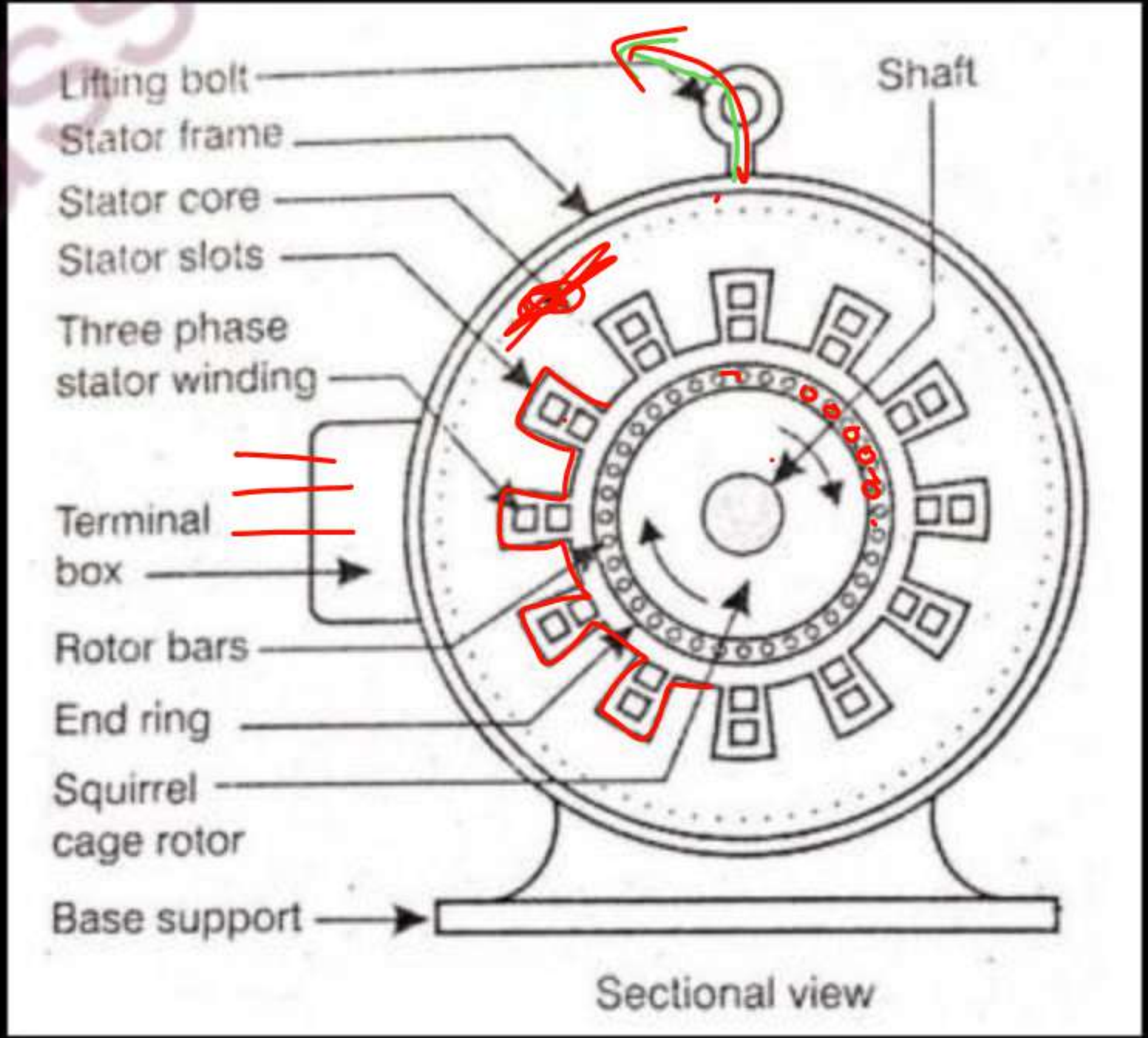
A 3-phase induction motor has **a stator and a rotor**. The stator carries a **3-phase winding** (called stator winding) while the rotor carries a **short-circuited winding** (called rotor winding).

Stator Parts:-

Frame or Yoke:- It is the outer part of the three phase induction motor. Its main function of the frame is to support the stator core & stator winding. It acts as a covering, and it provides protection & mechanical strength to all the inner parts of the three phase induction motor.

Stator core :- The main function of stator core is to carry the alternating flux. In order to reduce the eddy current loss, the stator core is laminated. The core is made up of thin silicon steel laminations. These are insulated from each other by varnish, the slots are cut on inner periphery of core stampings.

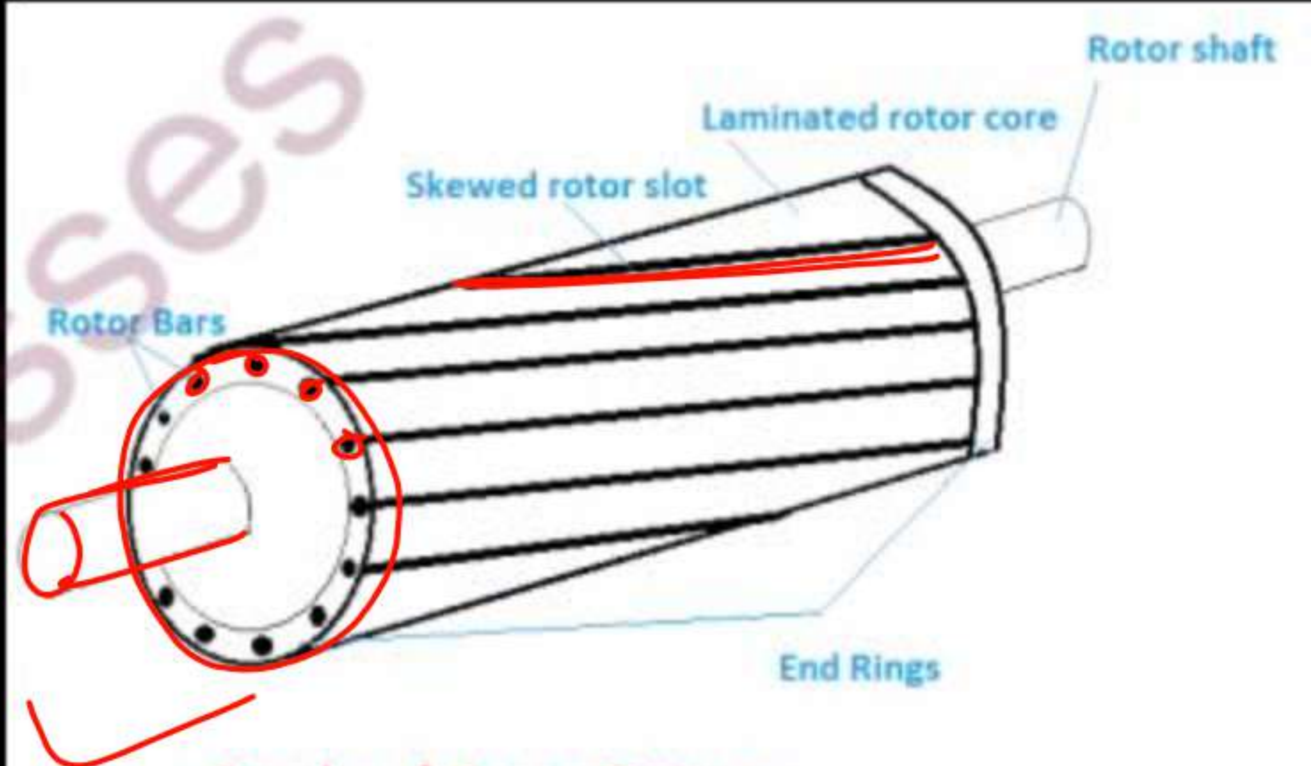
Stator windings:- Stator winding is made up of super enameled copper wire. Three phase windings are placed in the stator core slots & six terminals are brought out. They may be star connected or may be delta connected. The windings are connected in star at starting.



Construction of 3 Phase Induction Motor (Rotor)

Depending upon the type of rotor construction used the **three phase induction motor** are classified as:

- Squirrel cage induction motor
- Slip ring/ wound / phase wound induction motor.
- The squirrel cage rotor consists of a cylindrical laminated core having slots on its outer periphery which are nearly parallel to the shaft axis or *skewed*. An uninsulated copper or aluminium bar (rotor conductor) is placed in each slot.
- At each end of the rotor, the rotor bar conductors are short-circuited by heavy end rings of the same material (see the figure). This forms a permanently short circuited winding which is indestructible. This entire arrangement resembles a cage which was once commonly used for keeping squirrels and hence the name.

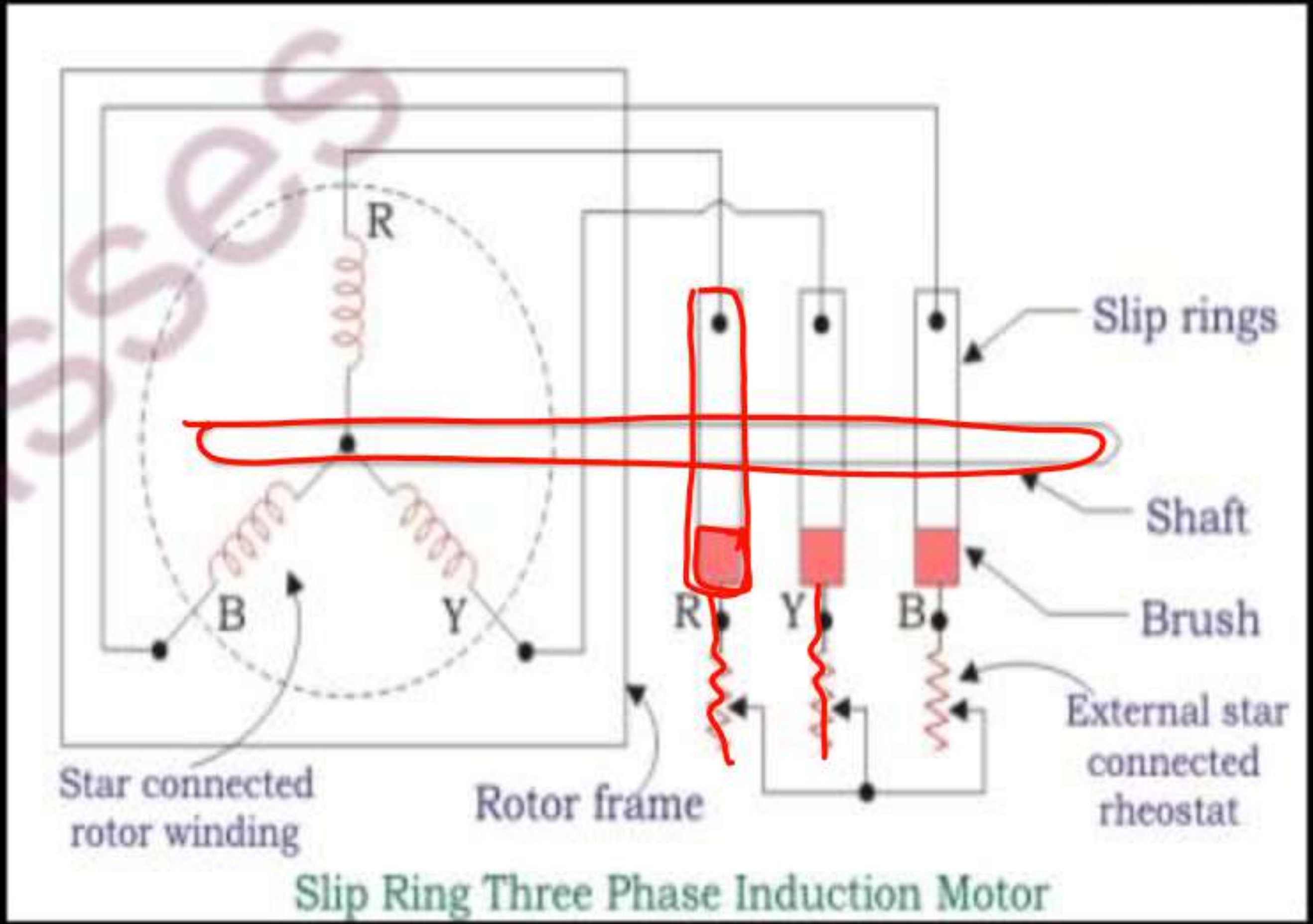


Squirrel Cage Rotor

- **Advantages of Squirrel Cage Induction Rotor :- Its construction is very simple and rugged.**
  As there are no brushes and slip ring, these motors requires less maintenance.
- **Applications of Squirrel Cage Induction Rotor:- We use the squirrel cage induction motors in lathes, drilling machine, fan, blower printing machines, etc**

Construction of 3 Phase Induction Motor (Rotor)

- **Slip ring/ wound / phase wound induction motor.:-**
- The rotor consists of numbers of slots and rotor winding are placed inside these slots. The three end terminals are connected together to form a star connection. As its name indicates, three phase slip ring induction motor consists of slip rings connected on the same shaft as that of the rotor.



- The three ends of three-phase windings are permanently connected to these slip rings. The external resistance can be easily connected through the brushes and slip rings and hence used for speed controlling and improving the starting torque of three phase induction motor. The brushes are used to carry current to and from the rotor winding. These brushes are further connected to three phase star connected resistances.

- At starting, the resistance is connected to the rotor circuit and is gradually cut out as the rotor pick up its speed. When the motor is running the slip ring are shorted by connecting a metal collar, which connects all slip ring together, and the brushes are also removed.

Advantages of Slip Ring Induction Motor :- high starting torque and low starting current, Possibility of adding additional resistance to control speed.

Application of Slip Ring Induction Motor:- Slip ring induction motor are used where high starting torque is required i.e in hoists, cranes, elevator etc.

Difference between Slip Ring and Squirrel Cage Induction Motor

Slip ring or phase wound Induction motor	Squirrel cage induction motor
Construction is complicated due to presence of slip ring and brushes	Construction is very simple
The rotor winding is similar to the stator winding	The rotor consists of rotor bars which are permanently shorted with the help of end rings
We can easily add rotor resistance by using slip ring and brushes	Since the rotor bars are permanently shorted, its not possible to add external resistance
Due to presence of external resistance high starting torque can be obtained	Staring torque is low and cannot be improved
Slip ring and brushes are present	Slip ring and brushes are absent
Rotor copper losses are high and hence less efficiency	Less rotor copper losses and hence high efficiency
Speed control by rotor resistance method is possible	Speed control by rotor resistance method is not possible
Slip ring induction motor are used where high starting torque is required i.e in hoists, cranes, elevator etc	Squirrel cage induction motor is used in lathes, drilling machine, fan, blower printing machines etc

Generation of Rotating Magnetic Field

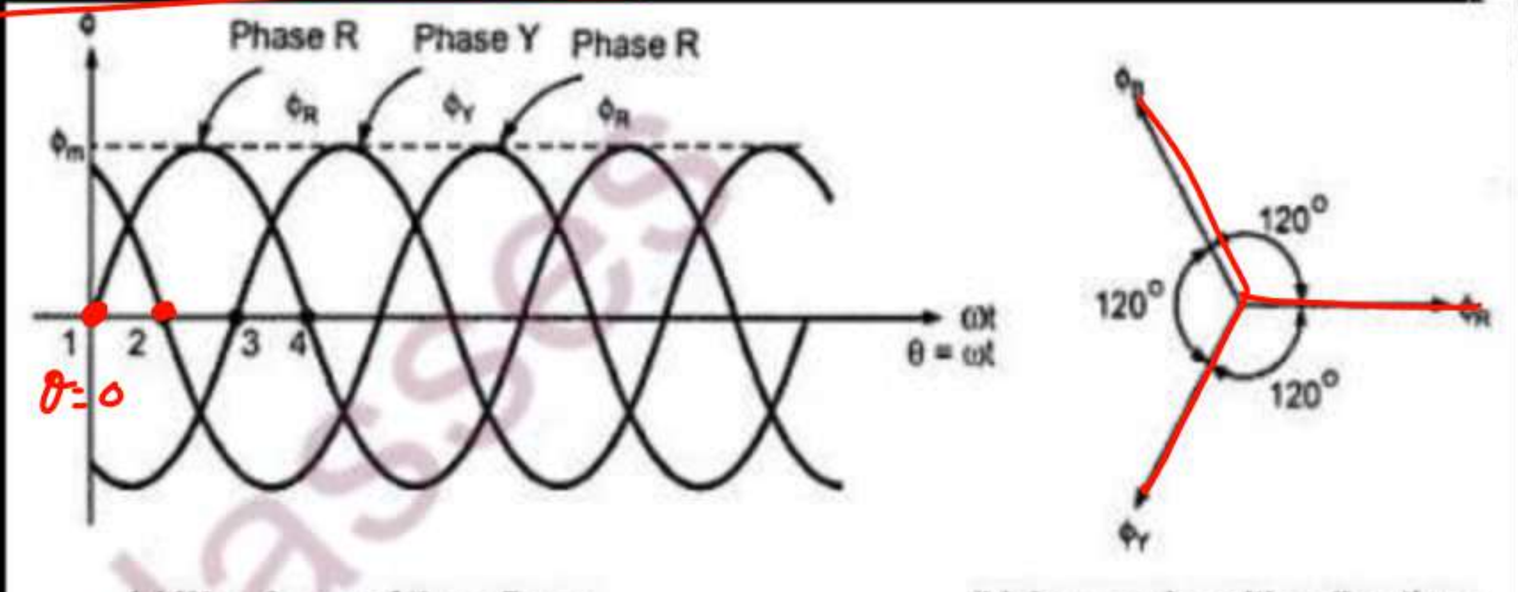
all three fluxes are sinusoidal and are separated from each other by 120°. If the phase sequence of the windings is R-Y-B, then

$N_s = \frac{120f}{P}$

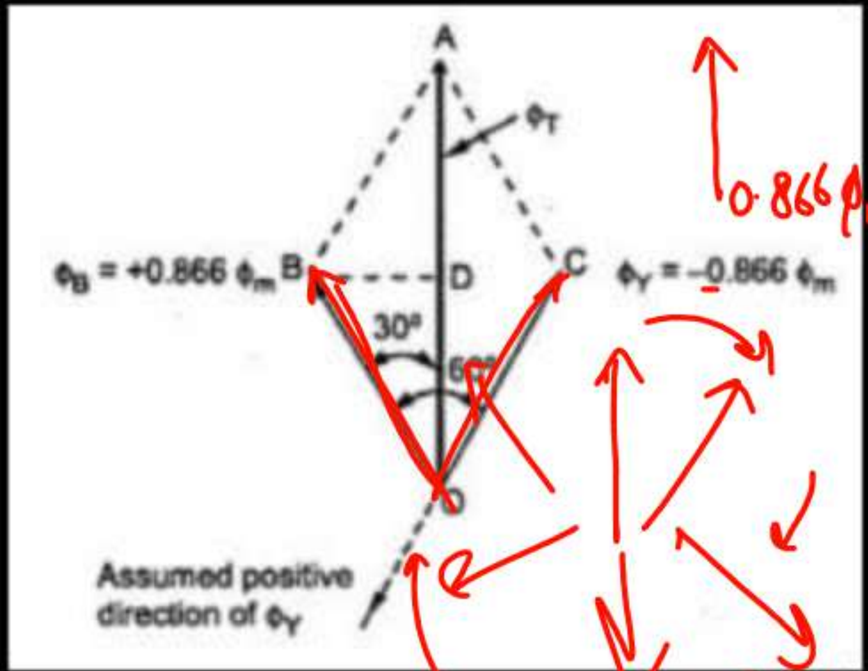
$$\Phi_R = \Phi_m \sin(\Phi t) = \Phi_m \sin \Phi \qquad \text{............(1)}$$

$$\Phi_Y = \sin(\Phi t - 120^o) = \Phi_m \sin(\Phi - 120^o) \qquad \text{............(2)}$$

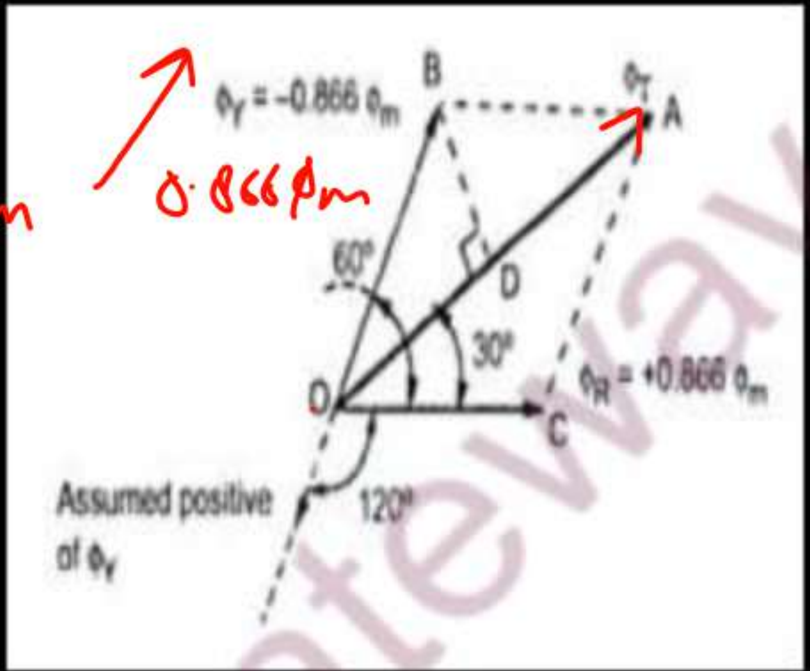
$$\Phi_B = \Phi_m \sin(\Phi t - 240^o) = \Phi_m \sin(\Phi - 240^o) \qquad \text{............(3)}$$



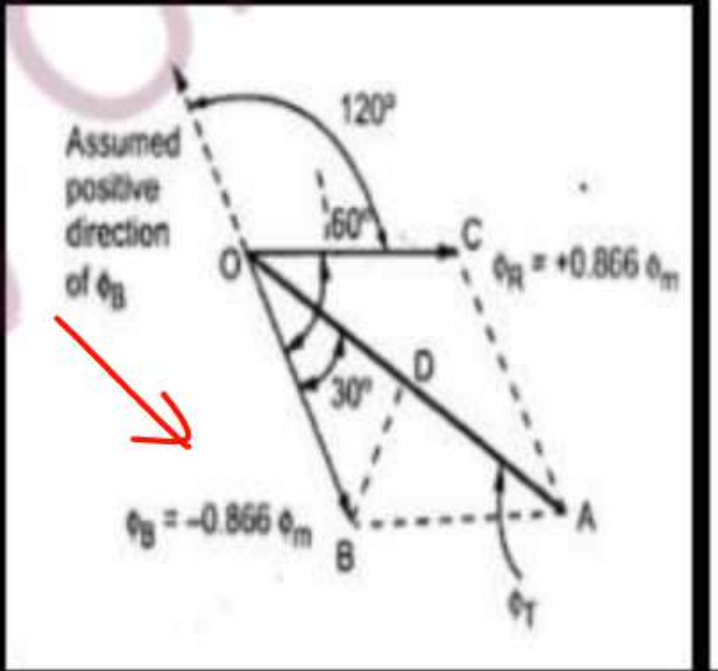
(a) Waveforms of three fluxes (b) Assumed positive directions



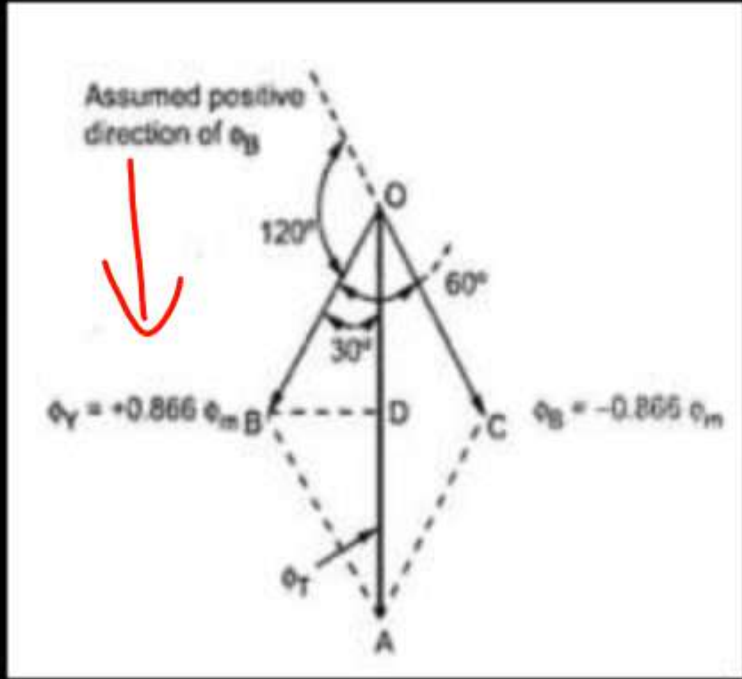
Φ = 0°



Φ = 60°



Φ = 120°



Φ = 180°

$(N_s - N_r) \rightarrow$ E.m.f. $\rightarrow I \rightarrow$ force $\rightarrow$ Torque

Working Principle of 3 Phase Induction Motor

field N_s
Rotal $N_r \rightarrow 0$

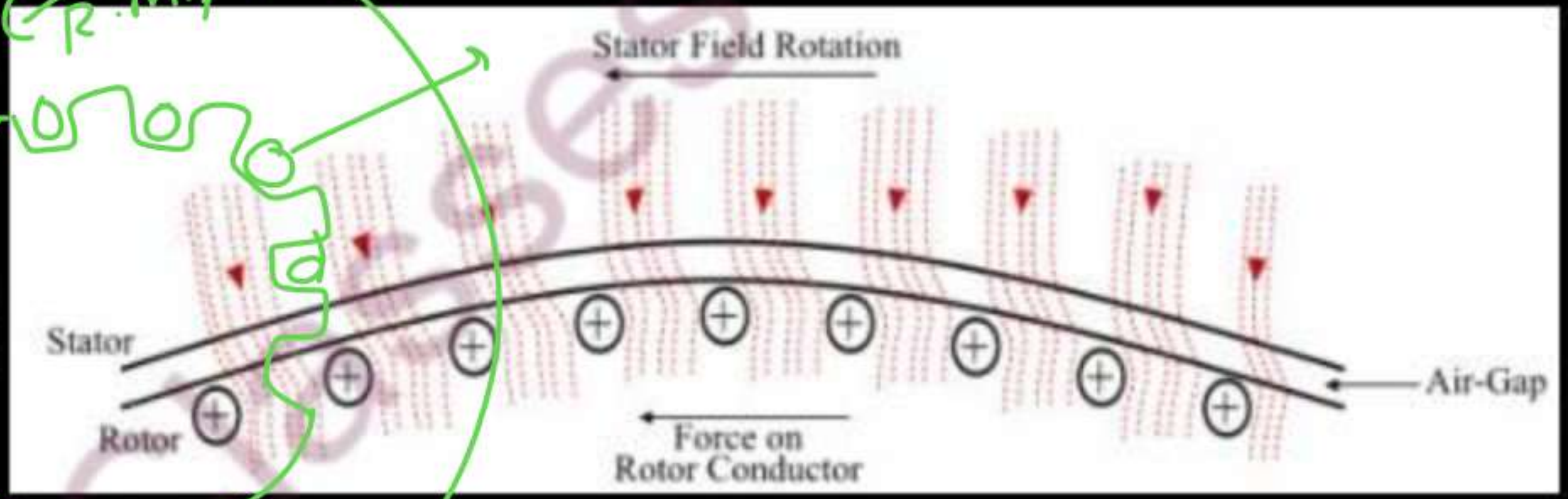
$N_r \uparrow$

The working principle of a 3-phase induction motor is fundamentally based on *electromagnetic induction*.

Consider a portion of a three phase induction motor (see the figure). Therefore, the working of a three phase induction motor can be explained as follows –

$(N_s - N_r\uparrow)\downarrow$

R.m.f



- When the stator winding is connected to a balanced three phase supply, a rotating magnetic field (RMF) is setup which rotates around the stator at synchronous speed (N_s). Where, $N_s = 120f/P$
- The RMF passes through air gap and cuts the rotor conductors, which are stationary at start. Due to relative motion between RMF and the stationary rotor, an EMF is induced in the rotor conductors. Since the rotor circuit is short-circuited, a current starts flowing in the rotor conductors.
- Now, the current carrying rotor conductors are in a magnetic field created by the stator. As a result of this, mechanical force acts on the rotor conductors. The sum of mechanical forces on all the rotor conductors produces a torque which tries to move the rotor in the same direction as the RMF.
- Hence, the induction motor starts to rotate. From, the above discussion, it can be seen that the three phase induction motor is self-starting motor.
- The three induction motor accelerates till the speed reached to a speed just below the synchronous speed.

Slip on Induction Motor

In Induction Motor, a slip is a speed among the rotary magnetic flux as well as rotor expressed in terms of for every unit synchronous speed. It is dimensionless & the value of this motor cannot be zero. It is denoted by s.

$$S = (Ns - Nr) / Ns$$

$$\% S = (Ns - Nr) / Ns * 100$$

In terms of slip, The actual speed of Motor Nr can be given by

$$Nr = Ns (1-s)$$

At starting motor is at rest so Nr is zero and slip at starting is,

$$s = 1$$

When S = 0, Nr= Ns which is not possible so slip can not be zero for a induction motor.

$\% S = \frac{N_s - N_r}{N_s} \times 100$ $(N_s - N_r)$ $N_r \to N_s$

0

E.m.f

↓

I

↓

force

↓

Torque

Effect of Slip on the rotor Frequency

Imp

The frequency of current and voltage in the stator of a 3-phase induction motor must be same as the supply frequency and is given by, $f = \frac{N_S P}{120} \ldots (1)$

But, *the frequency of the current and EMF in the rotor circuit* of the 3-phase induction motor is variable and depends upon the difference between the synchronous speed *(N_S)* and the rotor speed *(N_r)*, i.e., on the slip. Thus, the rotor frequency is given by, $f_r = \frac{(N_S - N_r)P}{120} \ldots (2)$

Now, from the equations (1) and (2), we get,

$$\frac{f_r}{f} = \frac{N_S - N_r}{N_S}$$

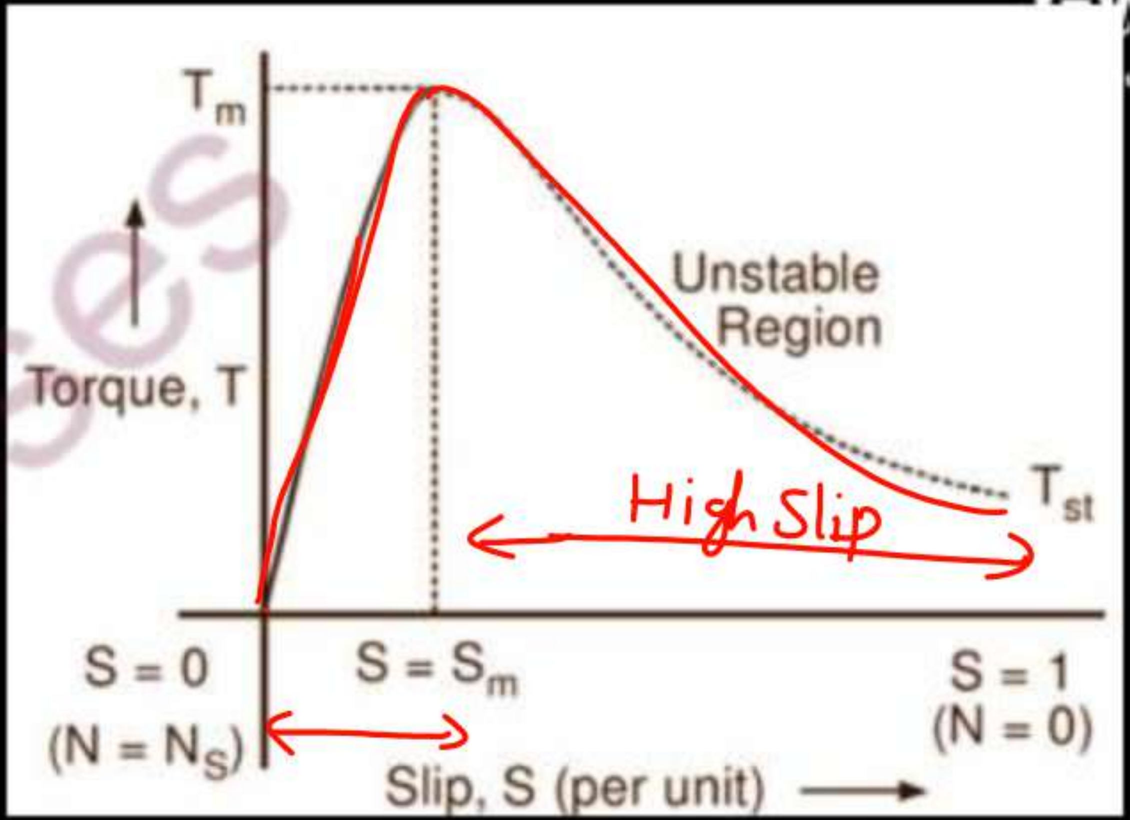
$$\because \text{Slip, } s = \frac{N_S - N_r}{N_S}$$

$$\boxed{\therefore f_r = sf \ldots (3)}$$

Rotor Current Frequency = Per unit slip × Supply frequency When the rotor is stationary, i.e., $N_r = 0$, then

V.V. Imp

Torque Slip Characteristics



The torque slip characteristic curve is divided roughly into three regions. They are as follows:

- Low slip region, High slip region

The torque equation of the induction motor is given below

$$T \propto \frac{SR_2}{R_2^2 + (SX_2)^2} \dots (1)$$

$$T \propto \frac{SR_2}{S^2X_2^2}$$

$$T \propto \frac{1}{S}$$

Low Slip Region (Stable region)

0

At the synchronous speed, s = 0, the torque is zero. When the speed is very near to synchronous speed, the slip is very low, and $(sX_2)^2$ is negligible in comparison with R_2.

Therefore,

$$T \propto \frac{S}{R_2} \propto S \dots (2)$$

It is clear that the torque is proportional to slip.

High Slip Region (Unstable Region) :- As the slip increases, the speed of the motor decreases with the increase in load. The term $(sX_{20})^2$ becomes large. The term R_2^2 may be neglected in comparison with the term $(sX_2)^2$ and the torque equation becomes as shown :

$$T \propto \frac{R_2}{SX_2^2} \propto \frac{1}{S} \dots (3)$$

the torque is inversely proportional to the slip.

Difference between Transformer and Induction Motor

Induction Motor	Transformer
it is a rotating electrical machine.	it is a static electrical machine.
It consists of two main components namely stator and rotor.	Transformer has magnetic core, primary and secondary winding.
In case of induction motor, the frequency of secondary winding (rotor winding) emf is variable and it depends on the load on the motor.	In a transformer, the frequency of induced emf in the secondary winding remains constant and it does not depend on the load.
The input of an induction motor is electrical energy. Whereas, the output is the mechanical energy.	The input of a transformer is electrical energy, while the output is also electrical energy.
The magnetic field in case of an induction motor is a rotating magnetic field.	The magnetic field in a transformer is an alternating magnetic field.
An air gap exists between stator and rotor of an induction motor.	There is no air gap in case of transformer.
The power factor of an induction motor is always predefined by the manufacturer and it is always lagging.	The power factor of a transformer is determined by the load. Hence, a transformer can operate at any kind of power factor like lagging, leading or unity.
Induction motor is always rated in kilowatt (kW).	The rating of a transformer is specified in KVA.
The efficiency of an induction motor is always less than that of a transformer.	Transformer has relatively high efficiency due to absence of moving parts.

Numericals

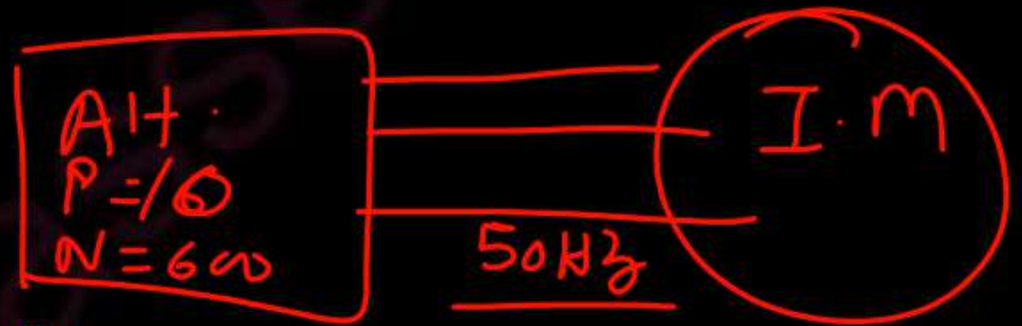
Ex.-1 A 6-pole, induction motor is supplied by a 10 pole alternator which is driven at 600 r.p.m. If the motor running at 970 r.p.m., determine the percentage slip.

$P = 6, \; N_r = 970 \text{ rpm}$

$$N_s = \frac{120f}{P} = \frac{120 \times 50}{6} = 1000$$

$$\% s = \frac{N_s - N_r}{N_s} = \frac{1000 - 970}{1000} = \frac{30}{1000} = .03 \times 100$$

$$= 3\% \text{ Ans}$$



$$N_s = \frac{120f}{P}$$

$$f = \frac{N_s \cdot P}{120} = \frac{600 \times 10}{120} = 50 \text{ Hz}$$

Numericals

GW GATEWAY CLASSES

2Hz

Ex.-2 In a three phase slip ring, , 4 pole induction motor, the rotor frequency is found to be 50 Hz, while connected to 400 V, 3-phase, 50 Hz supply, motor speed in r.p.m.

$P = 4, \; f_r = 2\,Hz, \; f = 50\,Hz$

$N_s = \frac{\overset{30}{\cancel{120}} \times 50}{\cancel{4}} = 1500\ rpm.$

$S = \frac{f_r}{f} = \frac{2}{50} = 0.04$

$N_r = (1-S)N_s = (1-0.04)\,1500$

$= 1440\ rpm.$

Numericals

Ex-3 A 3-phase, 50 Hz induction motor has 6 poles and operates with a slip of 5 % at a certain load. Determine (i) the speed of the rotor with respect to the stator (ii) the frequency of rotor current (iii) the speed of the rotor magnetic field with respect to rotor.

.05

.5

$P = 6, \; f = 50, \; s = .05$

$N_s = \frac{120f}{P} = \frac{\cancel{120}^{2}0 \times 50}{\cancel{6}} = 1000 \text{ rpm}$

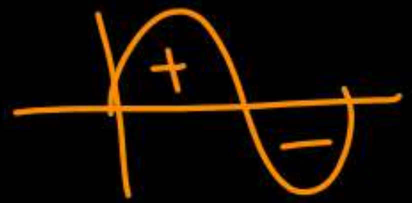
(i) $N_r = (1-s)N_s = (1-0.05)1000 = 950 \text{ rpm.}$

(ii) $f_r = sf = .05 \times 50 = 2.5 \text{ Hz}$

(iii) $N_r = \frac{120 f_r}{P} = \frac{\cancel{120}^{20} \times 2.5}{\cancel{6}} = 50 \text{ rpm}$

Principle of Single Phase Induction Motor

A single phase induction motor consists of a stator & a rotor. Single phase winding is placed in the stator slots & cage winding on the rotor. When A.C. single phase supply is given to the stator winding, a pulsating field is produced. In the pulsating field, the rotor does not rotate due to inertia. Therefore a single phase induction motor is not self starting & requires some special starting means.



Double Revolving Field Theory

According to double revolving field theory, the magnetic field produced by the stator winding when an alternating supply is given is equal to the sum of the two revolving fields rotating at synchronous speed in the opposite direction of equal magnitude.

Each revolving magnetic field is equal to one-half of the maximum value of the alternating field, i.e., $\phi_1 m/2$, where $\phi_1 m$ is the maximum value of the alternating field.

Let ϕf = forward component rotating in anti-clockwise direction

ϕb = is the backward component rotating in clockwise direction.

The resultant of these two components at any instant gives the instantaneous value of the stator flux at the instant. So, resultant of these two is the original stator flux.

At start, both the components are shown opposite to each other. Thus, the resultant $\phi R = 0$. This is nothing but the instantaneous value of the stator flux at start.

Double Revolving Field Theory

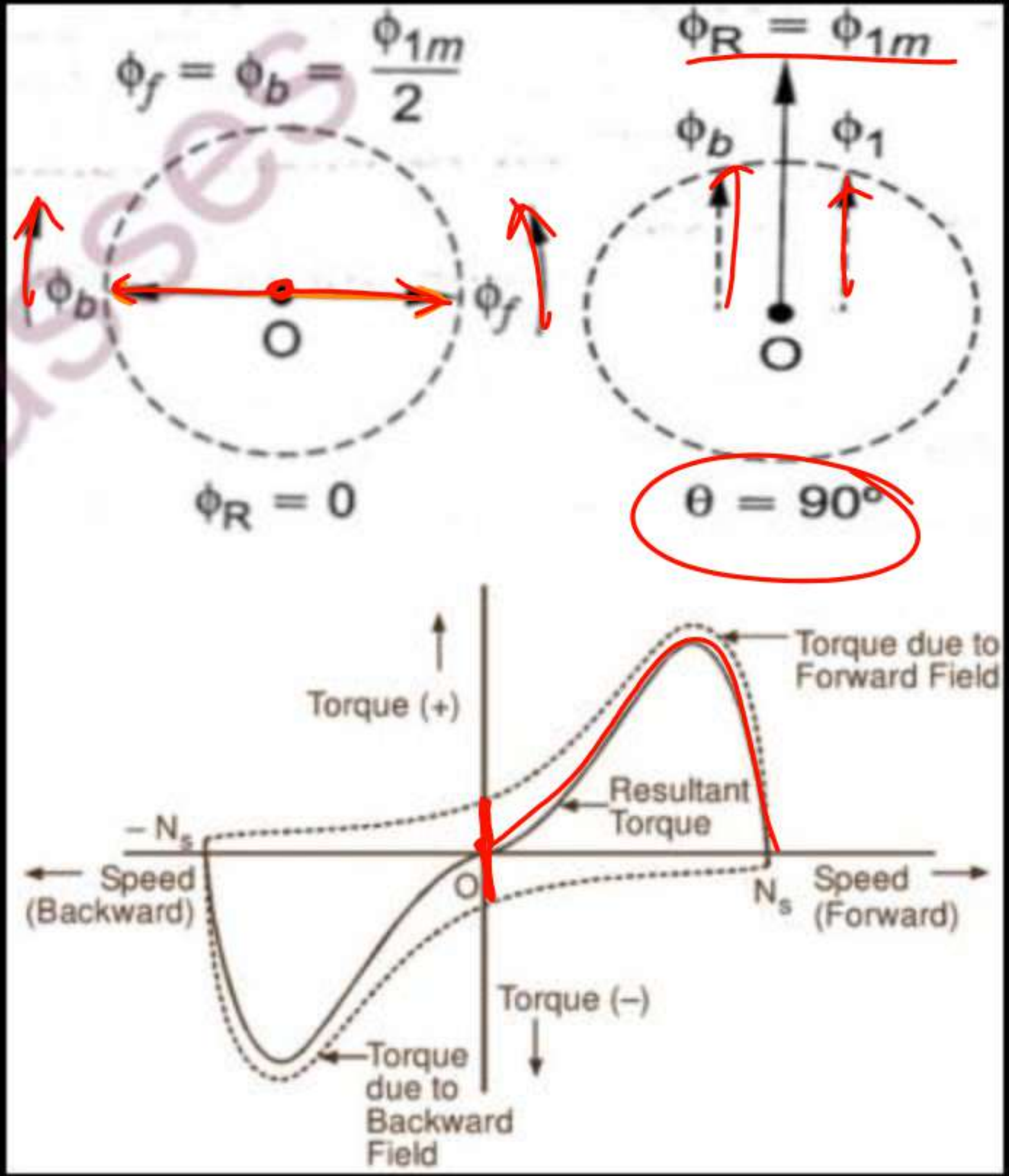
After 90° , the two components are rotated in such a way that both are pointing in the same direction. Hence, the resultant ϕR is the algebraic sum of the two components.

So, $\phi R = (\phi_1 m/2) + (\phi_1 m/2)$

$\phi R = \phi 1m$

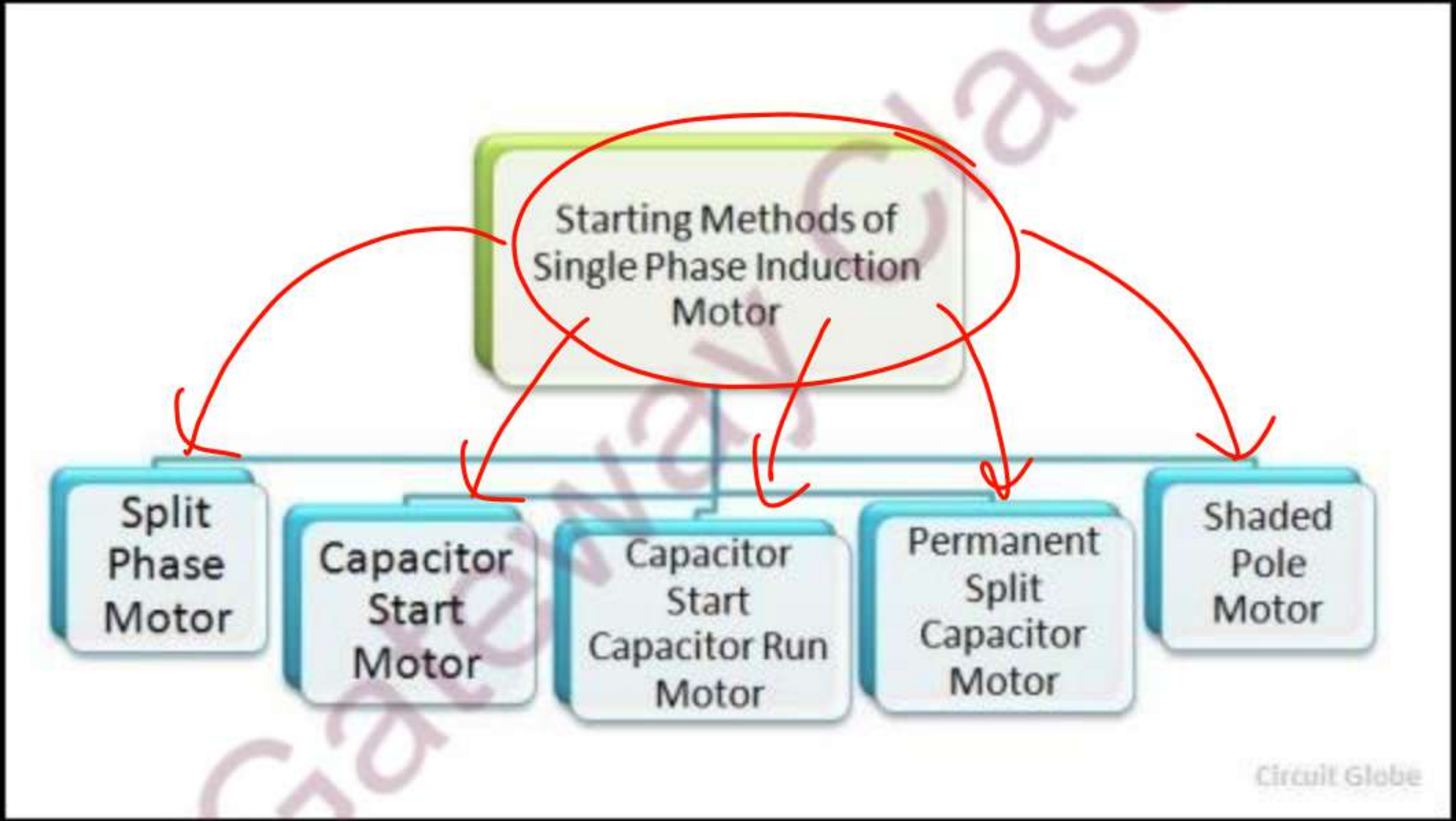
Both the components are rotating and hence, get cut by the rotor conductors. Due to cutting of flux emf get induced in rotor conductors which circulate in the rotor current. The rotor current produces rotor flux.

At start, these two torques are equal in magnitude but opposite in direction. Each torque tries to rotate the rotor the rotor in its own direction. Thus, net torque experienced by the rotor is zero at start. ***And hence the single-phase induction motors are not self starting.***



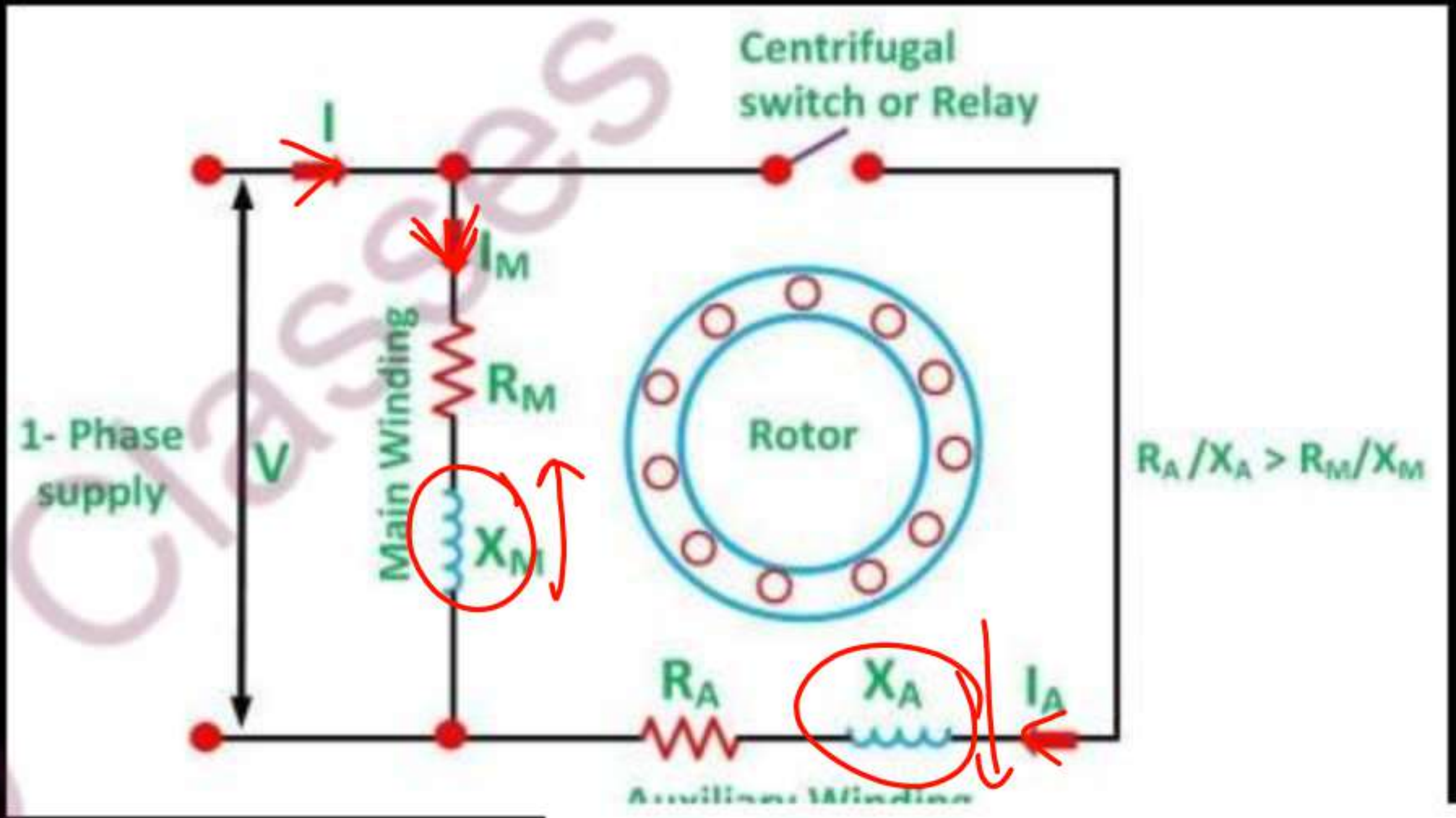
Self Starting of Single Phase Induction Motor

- By producing a rotating stator magnetic field, the 1-phase induction motor can be made self-starting. This may be accomplished by converting a single supply into two-phase supply through the use of an additional winding or auxiliary winding.



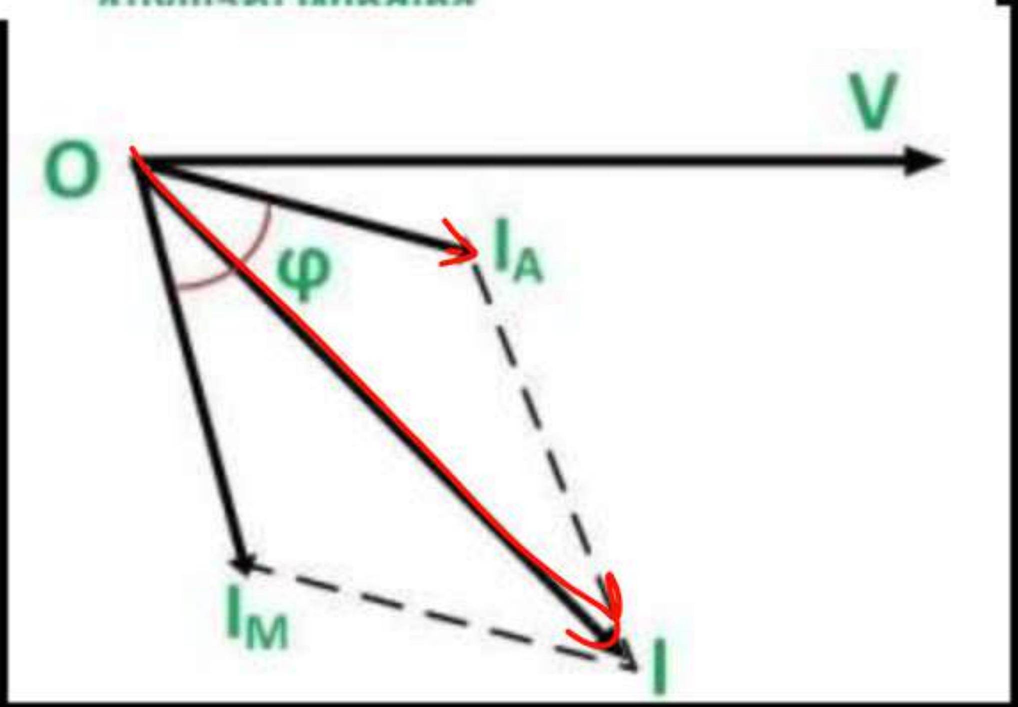
Split Phase Motor

The Split Phase Motor is also known as a **Resistance Start Motor**. Its stator has two windings known as **main winding and starting winding**. Both the windings are displaced 90 degrees in space. The **main winding has very low resistance** and a **high inductive reactance** whereas the **starting winding has high resistance and low inductive reactance.**



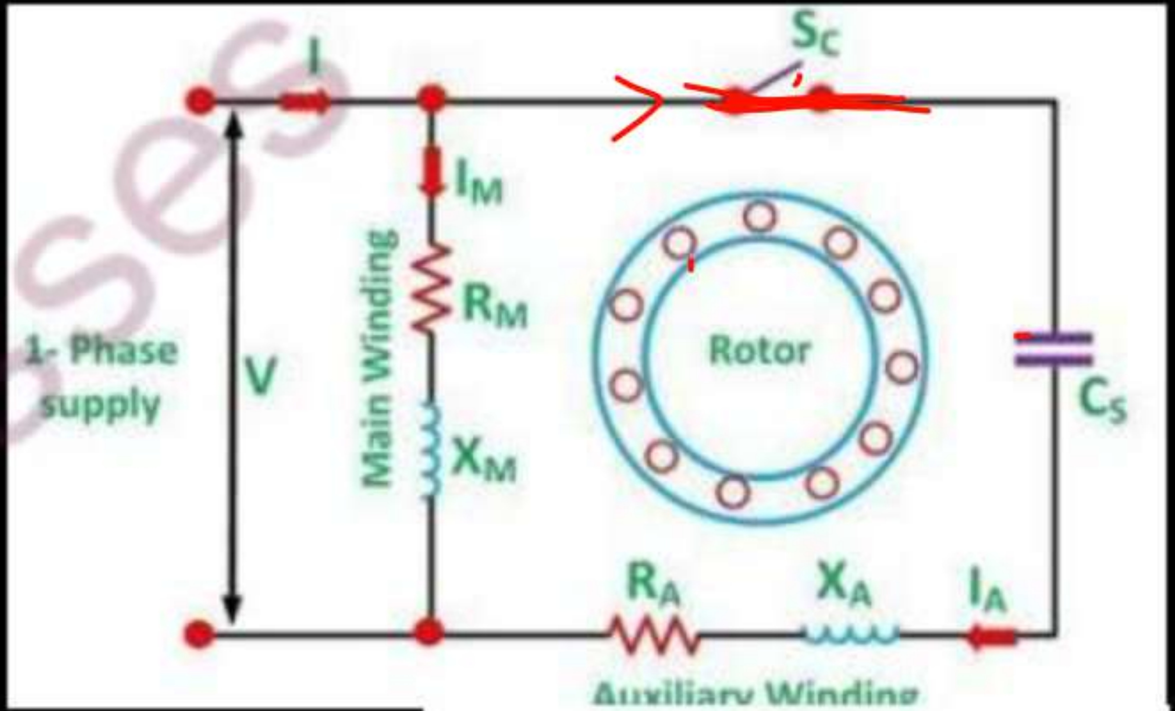
A resistor is connected in series with the auxiliary winding. The current in the two windings is not equal as a result, the rotating field is not uniform. Hence, the starting torque issmall, of the order of **1.5** to **2** times the stated running torque. At the starting of the motor both the windings are connected in parallel.

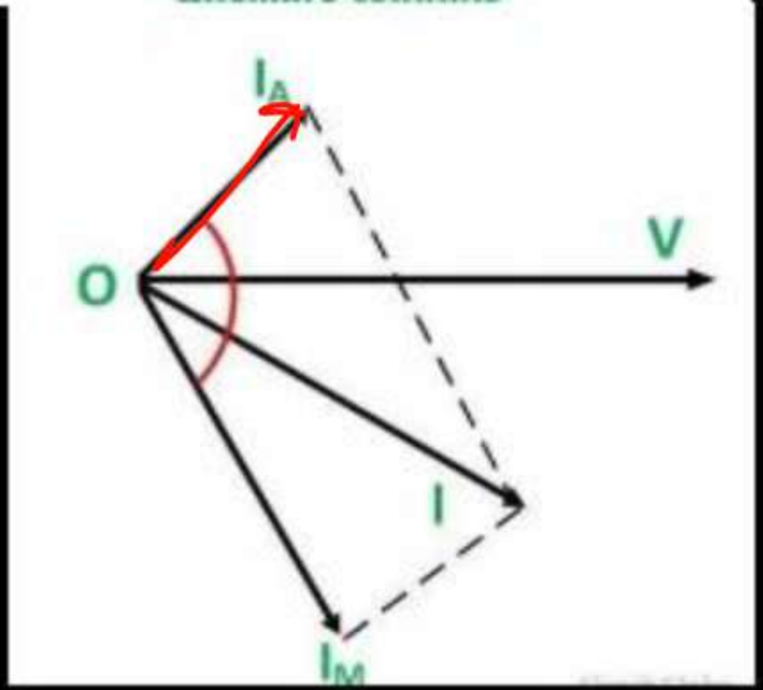
As soon as the motor reaches the speed of about **70 to 80 %** of the synchronous speed the starting winding is disconnected automatically from the supply mains.



Capacitor Start Induction Motor

The capacitor start motor has a cage rotor and has two windings on the stator. They are known as the main winding and the auxiliary or the starting winding. The two windings are placed 90 degrees apart. A capacitor C_S is connected in series with the starting winding. A centrifugal switch S_C is also connected to the circuit.



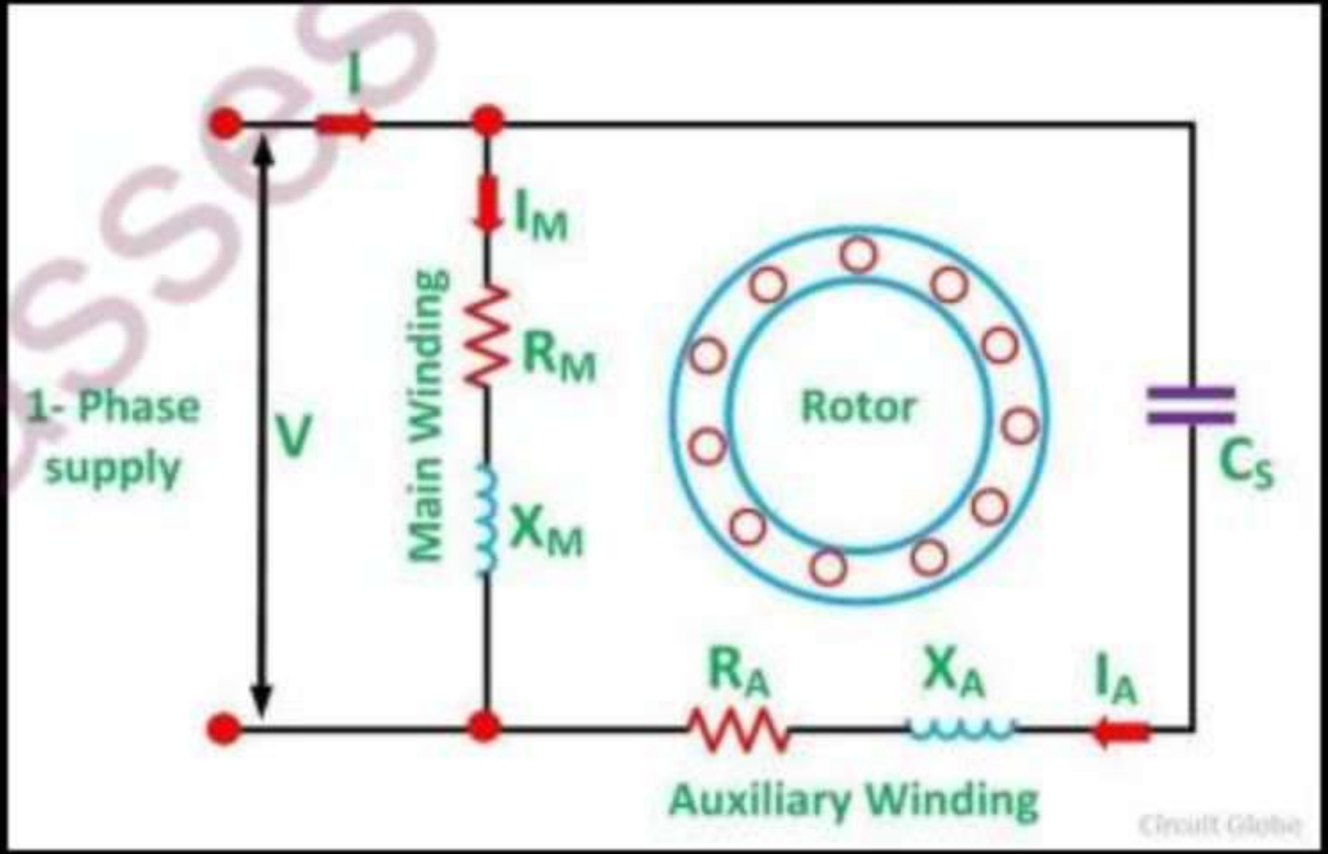


I_M is the current in the main winding which is lagging the auxiliary current I_A by 90 degrees as shown in the phasor diagram above. Thus, a single-phase supply current is split into two phases. The two windings are displaced apart by 90 degrees electrical, and their MMF's are equal in magnitude but 90 degrees apart in the time phase.

The motor acts as a balanced two-phase motor. As the motor approaches its rated speed, the auxiliary winding and the starting capacitor are disconnected automatically by the centrifugal switch provided on the shaft of the motor.

Capacitor Start Capacitor Run Motor

Capacitor is always in the circuit and thus this type of motor does not contain any starting switch. The auxiliary winding is always there in the circuit. Therefore, the motor operates as the balanced two-phase motor. The motor produces a uniform torque and has a noise-free operation.



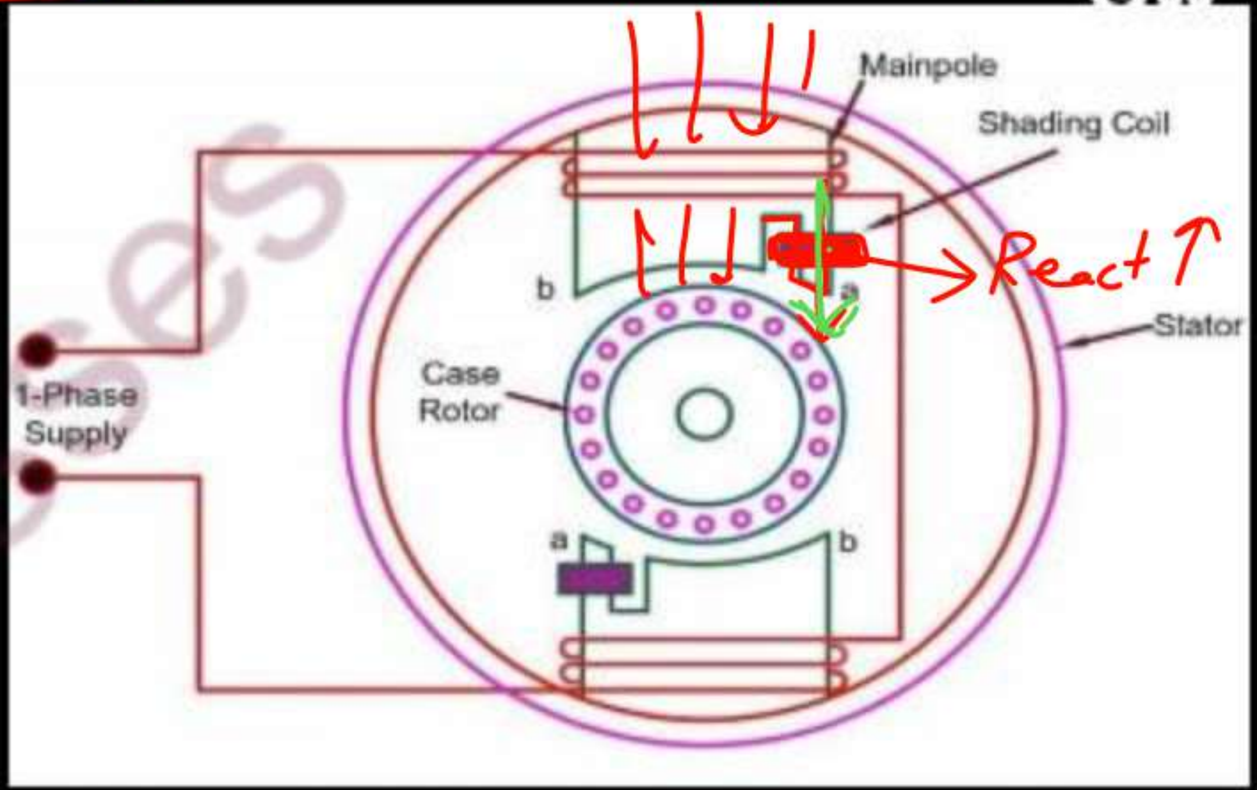
This type of motor is quiet and smooth running. They have higher efficiency than the motors that run on the main windings only.

Advantages of Capacitor Motor:-

- No centrifugal switch is required.
- Efficiency is high.
- As the capacitor is connected permanently in the circuit, the power factor is high.
- It has a higher pullout torque.

~~Capacitor Start Capacitor Run Motor~~
Shaded Pole I.M.

This motor is made up of stator and a rotor which is cage type. The stator has projected poles also called main poles in it. The supply winding on the main poles forms the main winding. The poles in this motor are unequally divided into two halves where the smaller portion is shaded portion that carries a copper band. Copper ring, which is a single turn is fitted on the smaller part. This ring is also known as a shading coil. The shading coil fitted on the main pole is called shading pole.



When power is supplied to the stator, flux is induced in the main part of the pole. This flux induces a voltage in the shading coil. This acts as a secondary winding. By Lenz's law, the current direction should be in such a way that, is opposing the flux entering into the coil. This acts as a secondary winding of a transformer.

In the core, when a single phase is applied an alternating flux is generated. This flux links with the shaded coil in fraction amounts. Then voltage gets induced in the coil due to the variation in the flux linking. Hence, the shaded portion is short-circuited due to which it produces the circulating current in it. In such a way, the direction is opposing the main flux

The main core flux is opposed by the flux in the ring that is developed by the circulating current. Hence, flux is induced in the shaded portion of the motor along with the unshaded portion with a phase difference, which is lagging behind the unshaded pole flux. Due to this Phase Difference, a rotating magnetic field is produced which leads to a torque on the cage motor.

Application of single phase Induction Motor

Applications of Split Phase Induction Motor:0- This type of motor is cheap and is suitable for easily starting loads where the frequency of starting is limited. This type of motor is not used for drives that require more than 1 KW because of the low starting torque. The various applications are as follows:

Used in the washing machine, and air conditioning fans.

The motors are used in mixer grinders, floor polishers.

Blowers, Centrifugal pumps.

Drilling and lathe machine.

2 marks

Applications of the Capacitor Start Motor:- The various applications of the motor are as follows:

These motors are used for the loads of higher inertia where frequent starting is required.

Used in pumps and compressors

Used in the refrigerator and air conditioner compressors.

They are also used for conveyors and machine tools.

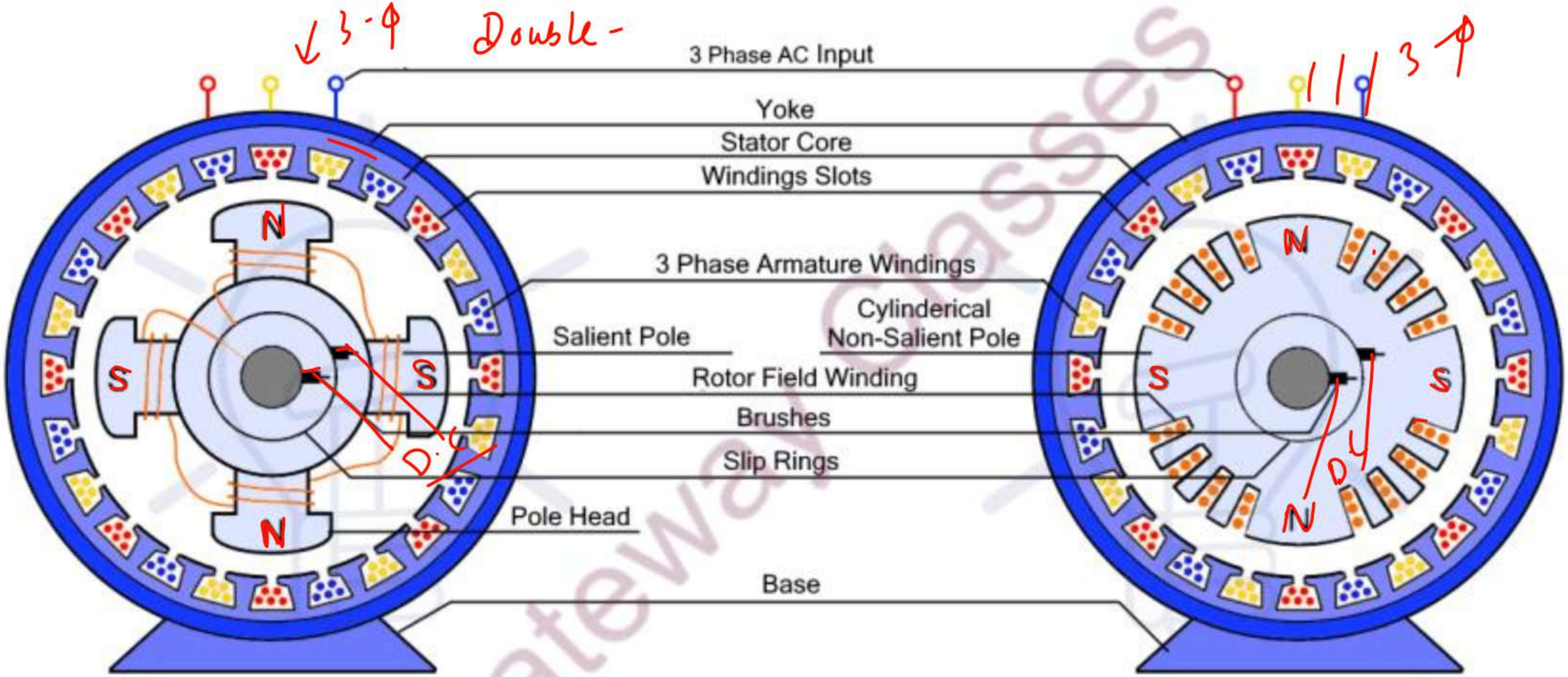
Applications of Permanent Split Capacitor Motor:- The various applications of the split motor are as follows:

Used in fans and blowers in heaters and air conditioners.

Used in refrigerator compressors.

Used in office machinery.

Construction of Synchronous Motor



Salient Pole

Cylinderical Pole

Construction of Synchronous Motor

Working of Synchronous Motor

- The stator winding produces a rotating magnetic field which revolves around the stator at synchronous speed. The DC voltage applied to the rotor sets up a two-pole field which is stationary so long as the rotor is not running. Hence, under this condition, there exists a pair of revolving stator poles (N_S-S_S) and a pair of stationary rotor poles (N_R-S_R).

- Now, suppose at any instant, the stator poles are at positions as shown in Figure-2. From Figure-2, it is clear that poles N_S and N_R repel each other and so do the poles S_S and S_R. Hence, the rotor experiences a torque in the anticlockwise direction.

- After a period of half-cycle of the AC supply, the polarities of the stator poles are reversed but the polarities of the rotor poles remain the same as shown in Figure-3. Under this condition, the poles S_S and N_R attract each other and so do the poles N_S and S_R. Due to this, the rotor tends to move in the clockwise direction.

- Since the stator poles change their polarities rapidly, they tend to pull the rotor first in one direction and then after a period of half cycle in the other direction. But the rotor has high inertia, consequently, the rotor does not move and we say that the starting torque is zero. In other words, *a synchronous motor is not self starting.*

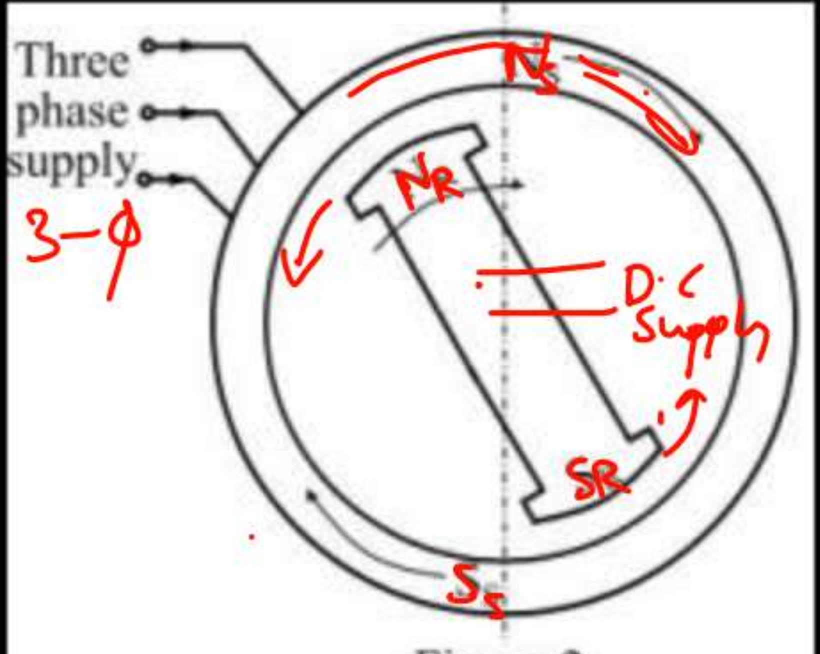


Figure-2

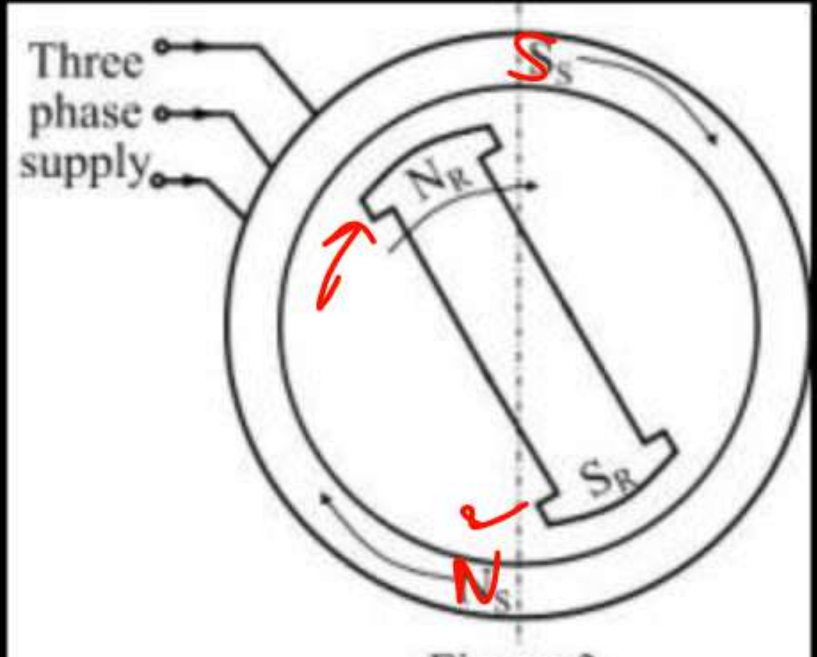


Figure-3

Starting of Synchronous Motor

- **Motor starting with an external prime Mover:-** Synchronous motors are mechanically coupled with another motor. It could be either 3 phase induction motor or a DC shunt motor. Here, we do not apply DC excitation initially. It rotates at speed very close to its synchronous speed, and then we give the DC excitation. After some time when magnetic locking takes place supply to the external motor is cut off.

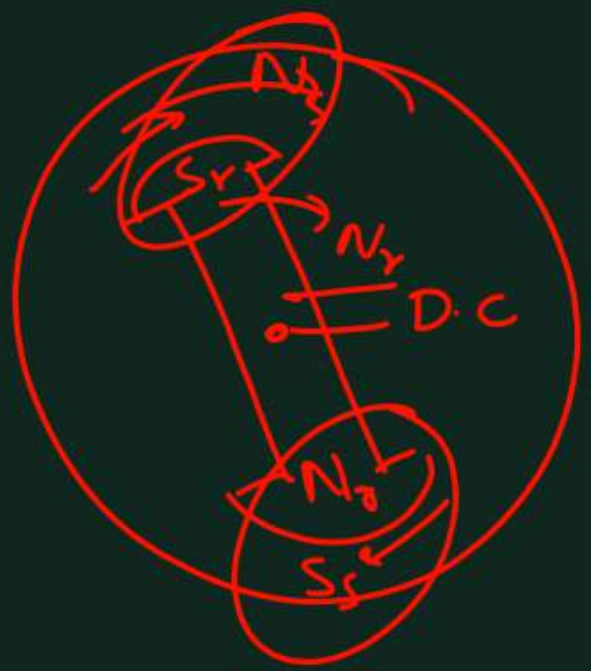
- **Damper winding:-** In this case, the synchronous motor is of salient pole type, the additional winding is placed in the rotor pole face. Initially, when the rotor is not rotating, the relative speed between damper winding and rotating air gap flux is large and an emf is induced in it which produces the required starting torque. As speed approaches synchronous speed, emf and torque are reduced and finally when magnetic locking takes place; torque also reduces to zero. Hence, in this case, the synchronous motor first runs as three phase induction motor using additional winding and finally it is synchronized with the frequency.

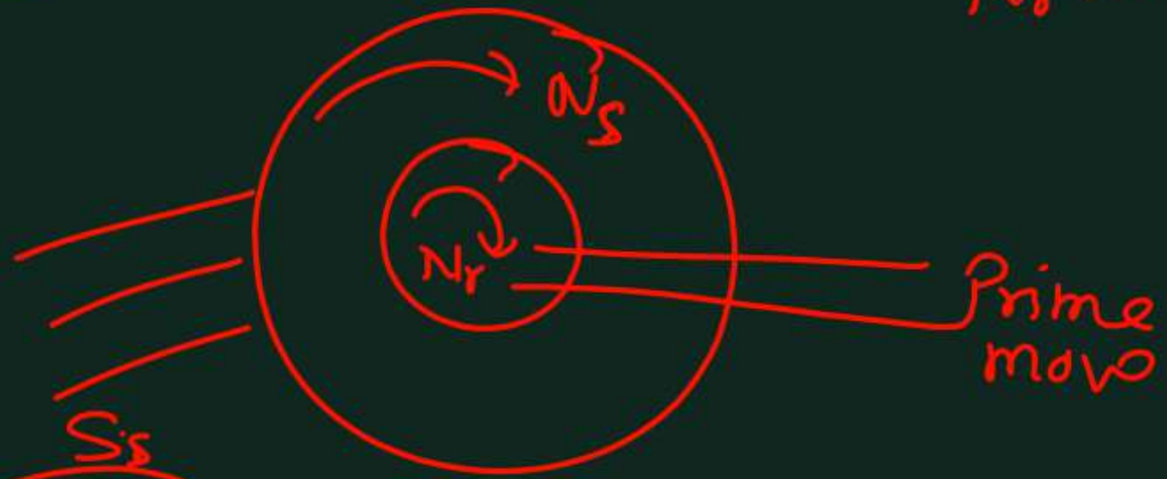
Applications of Synchronous Motors:-

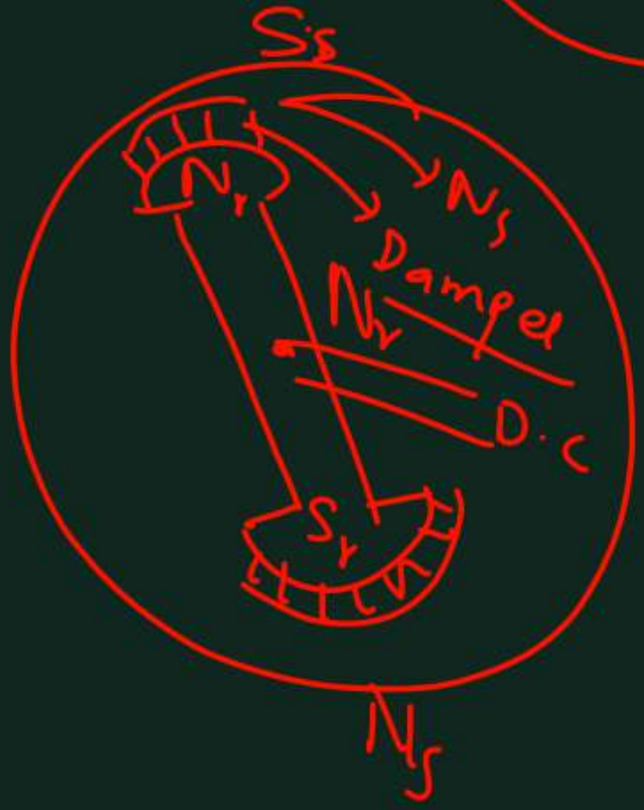
- A synchronous motor having no load connected to its shaft is used for power factor improvement. Owing to its characteristics to behave at any electrical power factor, it is used in power systems in situations where static capacitors are expensive.
- Synchronous motor finds applications where operating speed is less (around 500 rpm) and high power is required. For power requirements from 35 kW to 2500 KW, the size, weight and cost of the corresponding three-phase induction motor are very high. Hence these motors are preferably used. Ex- Reciprocating pump, compressor, rolling mills etc.

$$N_r = N_s$$

$$N_r \cong N_s$$







Working of Alternator

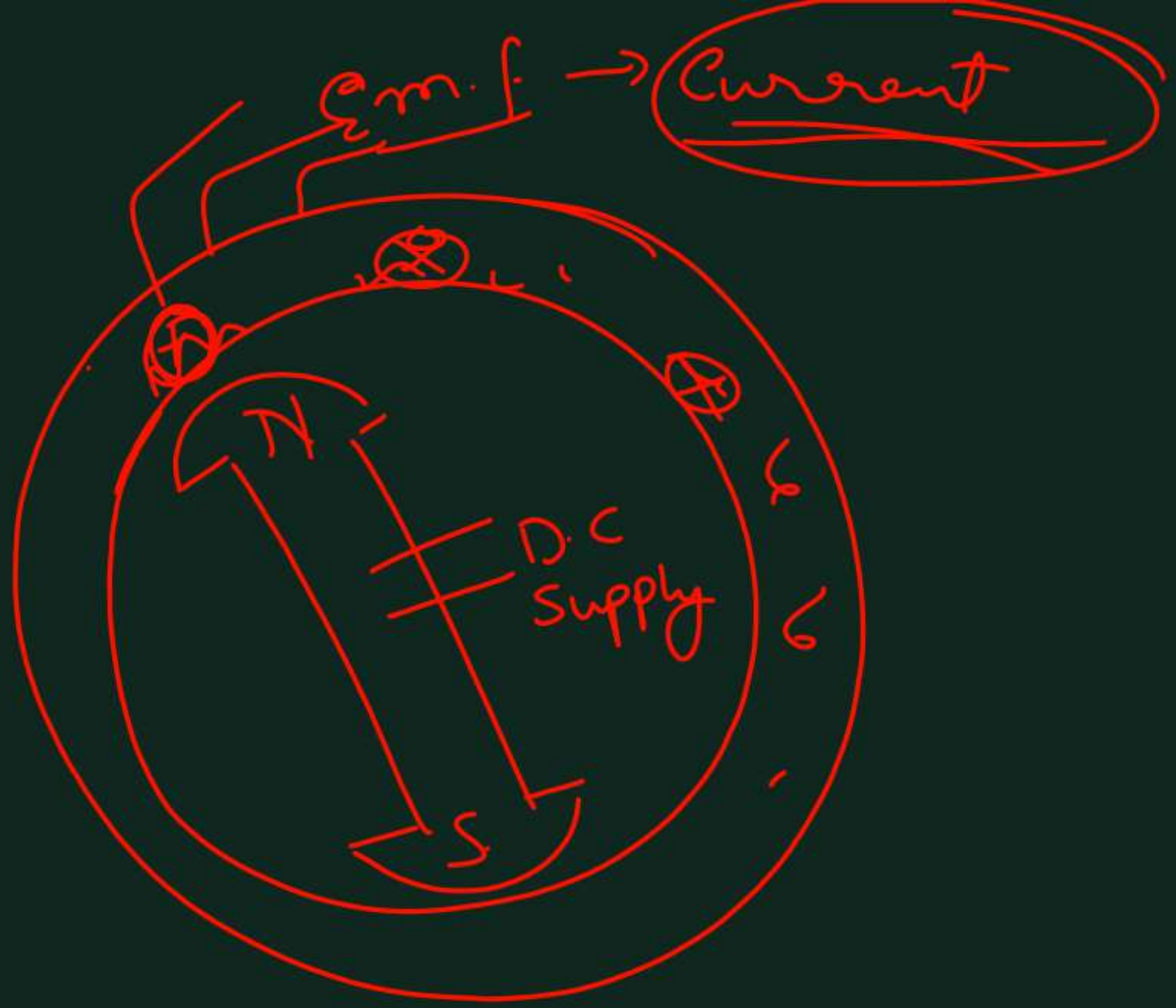
- An alternator operates on the same fundamental principle of electromagnetic induction as a DC generator.
- Like a DC generator, an alternator also has an armature winding and a field winding. But there is one important difference between the two.

- In a DC generator, the armature winding is placed on the rotor in order to provide a way of converting alternating voltage generated in the winding to a direct voltage at the terminals through the use of a rotating commutator.
- The field poles are placed on the stationary part of the machine. Since no commutator is required in an alternator, it is usually more convenient and advantageous to place the field winding on the rotating part (i.e., rotor) and armature winding on the stationary part (i.e., stator).

- An alternator has 3,-phase winding on the stator and a DC field winding on the rotor. This DC source (called exciter) is generally a small DC shunt or compound generator mounted on the shaft of the alternator.
- The rotor winding is energized from the DC exciter and alternate N and S poles are developed on the rotor.

- When the rotor is rotated in the anti-clockwise direction by a prime mover, the stator or armature conductors are cut by the magnetic flux of rotor poles. Consequently, e.m.f. is induced in the armature conductors due to electromagnetic induction.

- The induced e.m.f. is alternating since N and S poles of rotor alternately pass the armature conductors. The direction of induced e.m.f. can be found by Fleming right-hand rule and frequency is given by; $f = PN / 120$



e.m.f → Current
N
S
D.C
Supply

Applications of Alternator:-

An alternator is mainly used for converting mechanical energy into electrical energy in various applications such as:

- In automobiles
- In locomotives
- Power generation plants
- In Marine and navy boats
- Radiofrequency transmission

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Thank You