Class Note of Energy Conversion-I

For 4^{Th} Semester

Faculty Name: Damayanti Bhatt

Government Polytechnic Nayagarh

Department : Electrical Engineering

CHAPTER-I

DC GENERATORS

* Faraday's Law Of Electromagnetic Induction :-

Faraday's 1st Law :-

Any change in the magnetic field of a coil of wire will cause an e.m.f to be induced in the coil. This is called induced e.m.f.

- If the conductor circuit is closed, the current will also circulate through the circuit and this current is called induced current.

Faraday's 2nd Law :-

It states that the magnitude of e.m.f induced in the coil is equal to the rate of change of flux that link with the coil.

$$E = -N \frac{d\phi}{dt}$$

Where, E = Induced E.M.F (volt)

N = Number of Turns

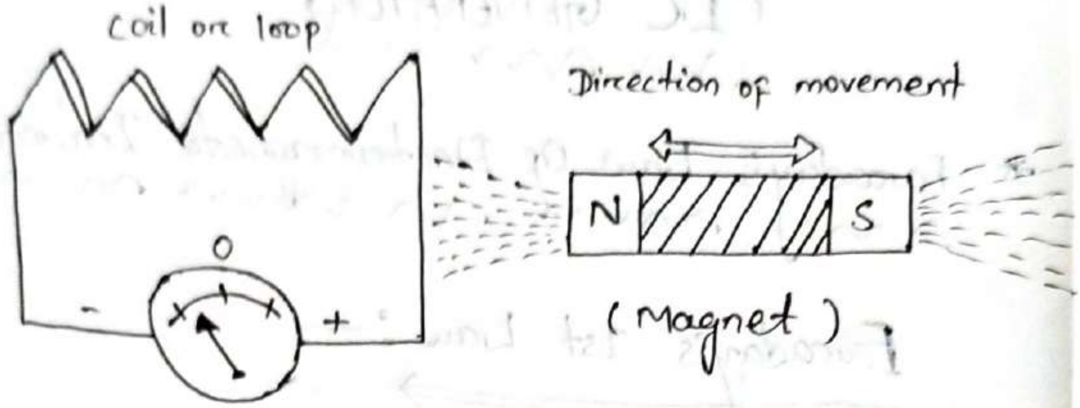
$\frac{d\phi}{dt}$ = Change in flux w.r.t Time

Unit of Flux is Webber.

→ It is used to explain the working principle of transformer, motor, generator & inductor.

Case-1

Conductor is at rest, Flux is at motion.



* Position Of Magnet	Deflection in Galvanometer	Induced E.M.F
1- Magnet at rest	No deflection in galvanometer	zero
2- Magnet moves towards the coil	Deflection in the galvanometer in one direction	Induced e.m.f will have finite value
3- Magnet is held stationary at same position (near the coil)	No deflection in the galvanometer	zero
4- Magnet moves away from the coil	Deflection in galvanometer but in the opposite direction	It has some finite value but in opposite direction
5- Magnet is held stationary at the same position (away from the coil)	No deflection in the galvanometer	Zero

* **Methods to change the magnetic Field :-**

(i) - By moving a magnet towards or away from the coil.

(ii) - By moving the coil into or out of the magnetic field.

(iii) - By changing the area of a coil placed in the magnetic field.

(iv) - By rotating the coil relative to the magnet.

* **How to Increase E.M.F Induced in a Coil :-**

$$E = -N\frac{d\phi}{dt}$$

→ By increasing 'N', E.M.F can be increased.

→ $B = \frac{\phi}{A}$

Where, B = Magnetic Flux Density (Wb/m^2)

ϕ = Flux

A = Area

→ If flux increases e.m.f induced will also increase.

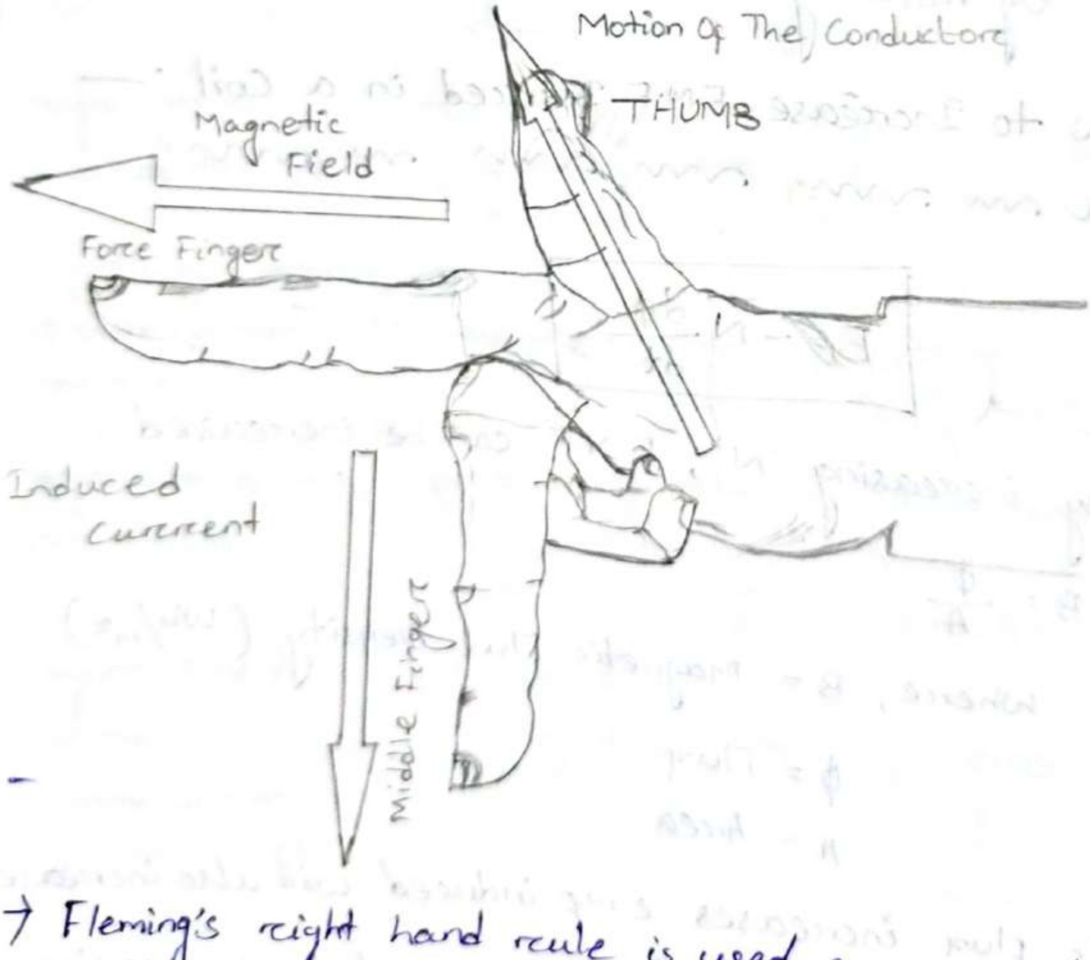
→ Induced e.m.f can be increased by increasing the speed of the relative motion between the coil and the magnet.

22.04.21

* Fleming's Right Hand Rule :—

In Fleming's right hand rule, the force finger, the middle finger & the thumb of the right hand are held at right angle to each other.

→ In the force finger represents the direction of the magnetic field, the thumb represents the direction of motion of the conductor, then the middle finger represents the direction of the induced current.



→ Fleming's right hand rule is used for generator to know the direction of induced e.m.f / induced current.

* Operating Principle of DC Generator :—

When conductor cuts the magnetic flux, e.m.f is induced in the conductor and direction of induced e.m.f is shown by fleming's right hand rule.

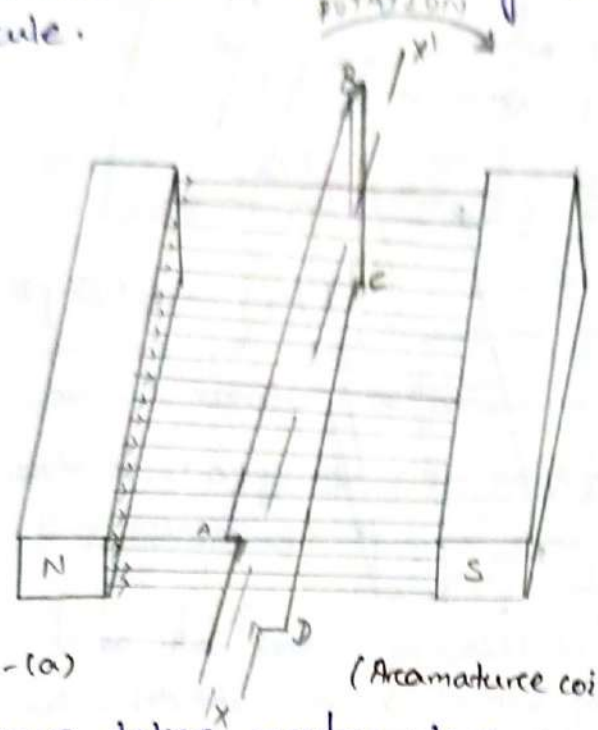


Fig - (a) (Armature coil in Neutral plane)

We have taken rectangular copper conductor single turn loop ABCD.

→ Loop ABCD is rotating in clock wise direction about it's own axis (XX') in the uniform magnetic field.

→ The conductor is rotated by means prime mover.

Induced e.m.f = rate of change of flux linkage

From the fig-(a) loop ABCD is parallel to the faces of field magnet north & south pole.

→ Loop ABCD is parallel to the faces of the field magnets north & south.

→ ~~Flux linking with loop is equal to maximum.~~

→ Flux linking with loop = Maximum

→ Rate of change of linking flux = 0

→ Induced e.m.f is 0.

→ This position of the loop neutral position or starting position.

→ Angle of rotation is measured from this position.

→ ABCD parallel to the magnetic field.

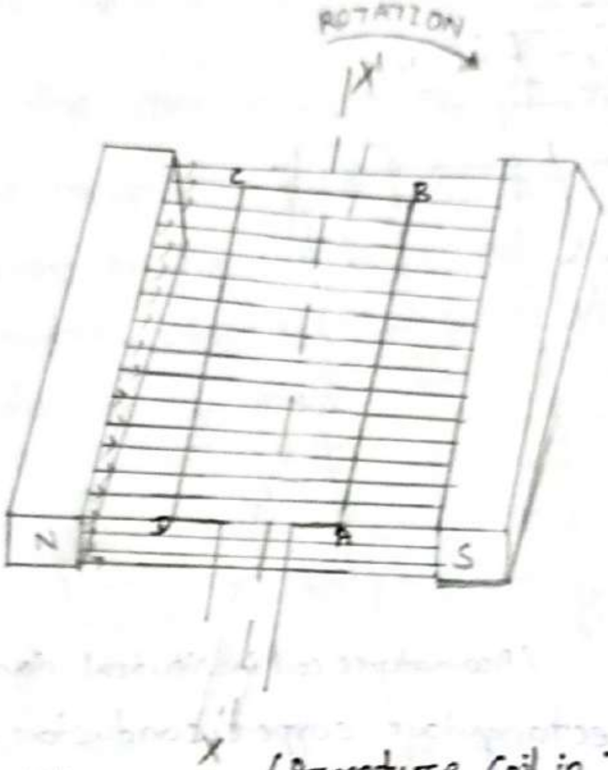


Fig-(b) (Armature Coil in The 90° position)

→ Coil is turned in clock wise direction at a constant speed.

→ It cuts the magnetic field slowly at first and then increases.

→ At 90° the rate of change of flux linkage is maximum and hence induced e.m.f is maximum.

→ By using Fleming's right hand rule direction of induced emf in the coil is form B to A & D to C.

→ Rate of change of flux linkage is maximum.

→ It follows the sign law.

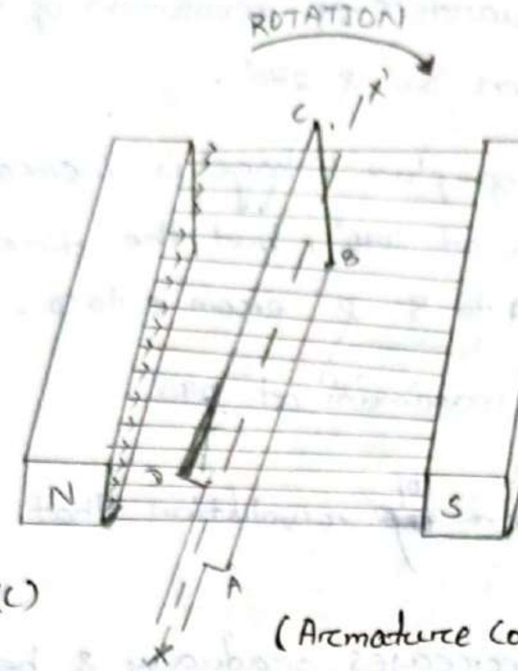


Fig-(c) (Armature Coil in The 180° Position)

→ The coil is rotated between 90°-180°.

→ The rate of change of flux linkage gradually decreases.

→ Hence magnitude of induced emf decreases and becomes zero.

→ Here face of the loop is parallel to the face of the magnetic field but with the change in the position of the sides AB & CD.

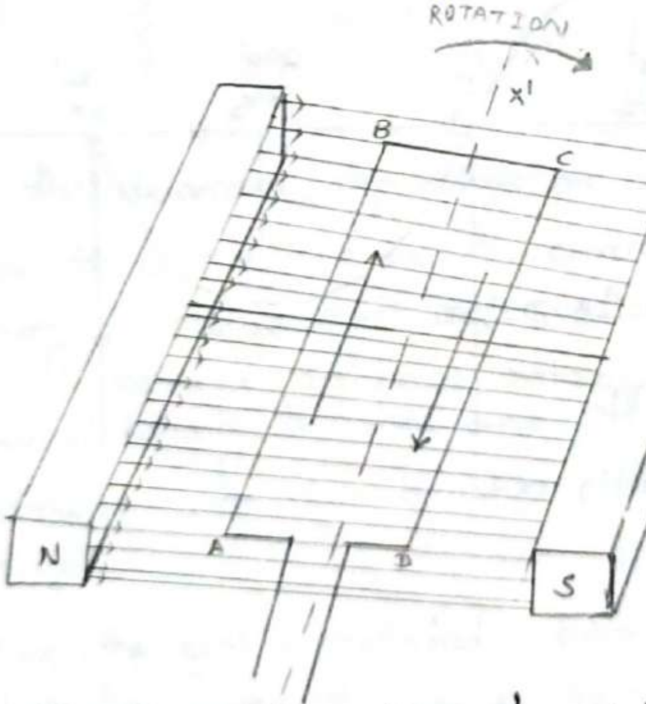
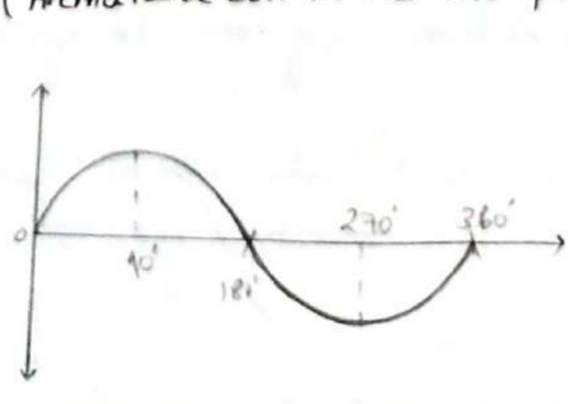


Fig-(d) X (Armature coil in the 270° position)



→ In the 3rd quarter of revolution of the loop that is between 180° & 270°.

→ Rate of change of flux linkage is increases gradually and it's maximum at 270°, but the direction of induced e.m.f A to B & from C to D.

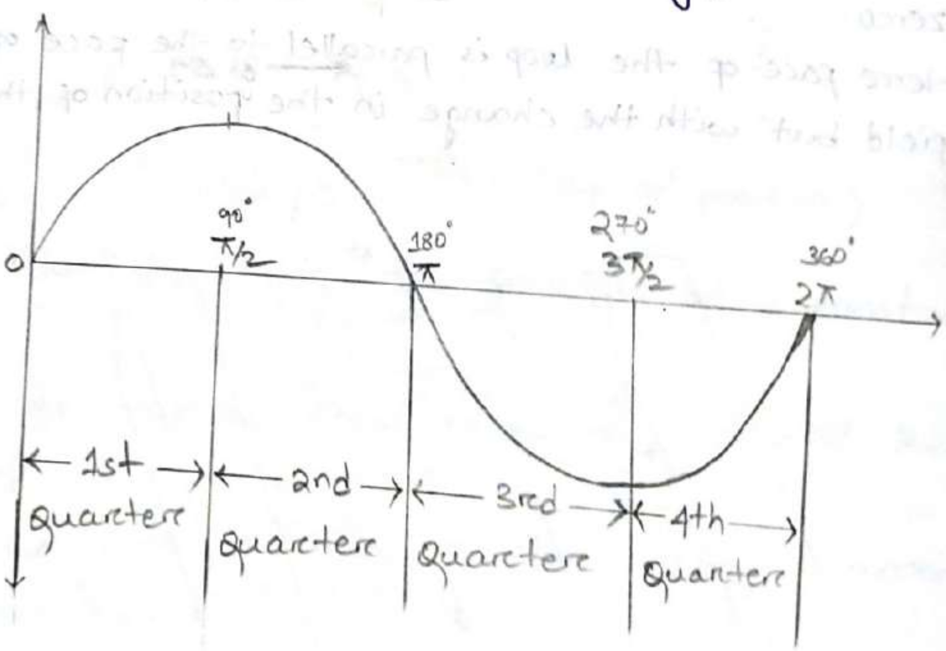
→ Induced e.m.f is maximum at 270°.

→ In the 4th quarter of revolution that is between 270° to 360°.

→ Induced e.m.f decreases gradually & becomes 0 at 360°.

→ Hence loop completes 1 cycle.

→ E.M.F generated in the loop is of pulsating nature, such an e.m.f is known as alternating e.m.f.



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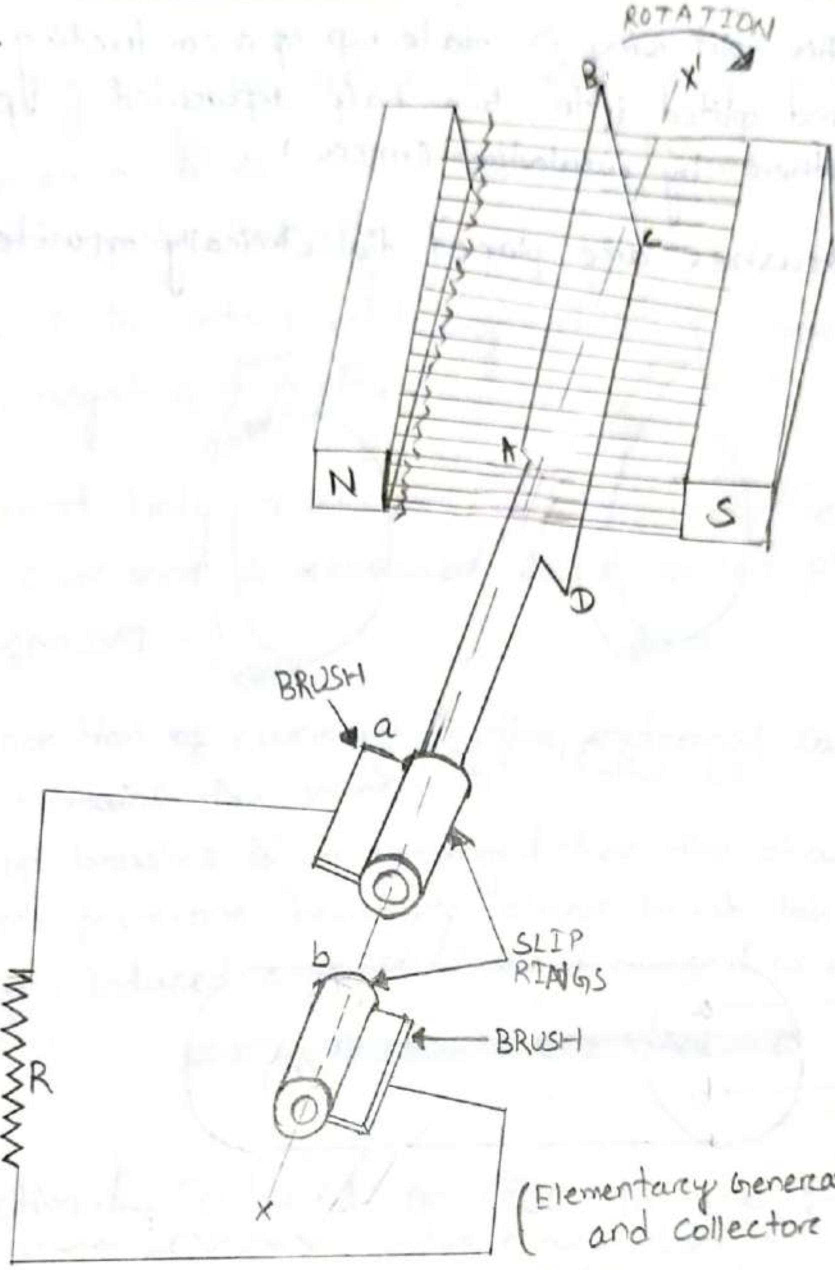


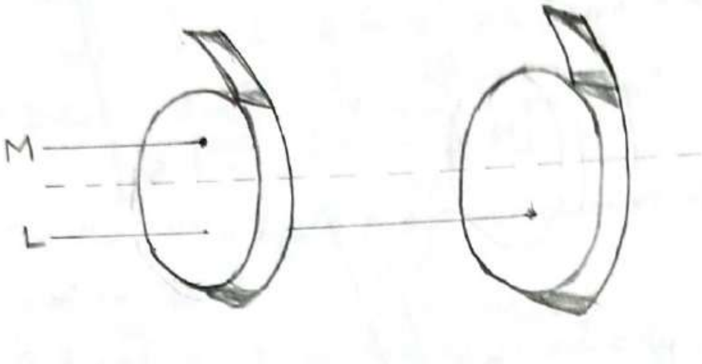
(Elementary Generator With Brushes and Collector Rings)

In the diagram, slip rings or collector rings are used to collect the induced current in the coil and convey to the ~~circuit~~ external load circuit.

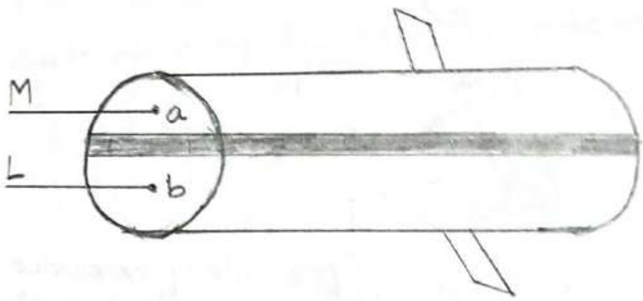
- Two stationary brushes are fitted in the slip rings, so there are two brushes fitted in the two slip rings.
- When the coil is rotated, alternating e.m.f produces alternating current through the coil and external circuit.
- Hence by using slip rings alternating current is conveyed to the load.
- To obtain direct current in the external load circuit, the slip rings are replaced by splitring.

→ This split ring is made up of a conducting matercial and splited into two half separated from each other by insulation (mica).

→ Brushes are placed diametrically opposite.



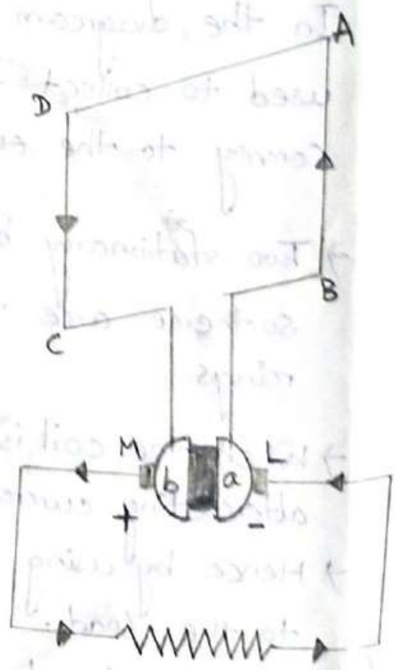
(a) SLIP RINGS



(b) SPLIT RING

Exterenal Load

(c)



Exterenal Load

(d)

In the fig-(c), current flows along ABMLCDA.
Here brush 'M' is in contact segment 'a' and segment 'a' acts as positive polarity.

→ Brush 'L' is in contact with segment 'b' & segment 'b' acts as negative polarity.

→ In the next half revolution, direction of the induced current is reversed i.e current flow along DCMLBAD.

→ Hence direction of current in the external load circuit remains the same.

→ Position of brushes is so arranged that the change of segments from one brush to other brush takes place when induced e.m.f or induced current is equal to zero.

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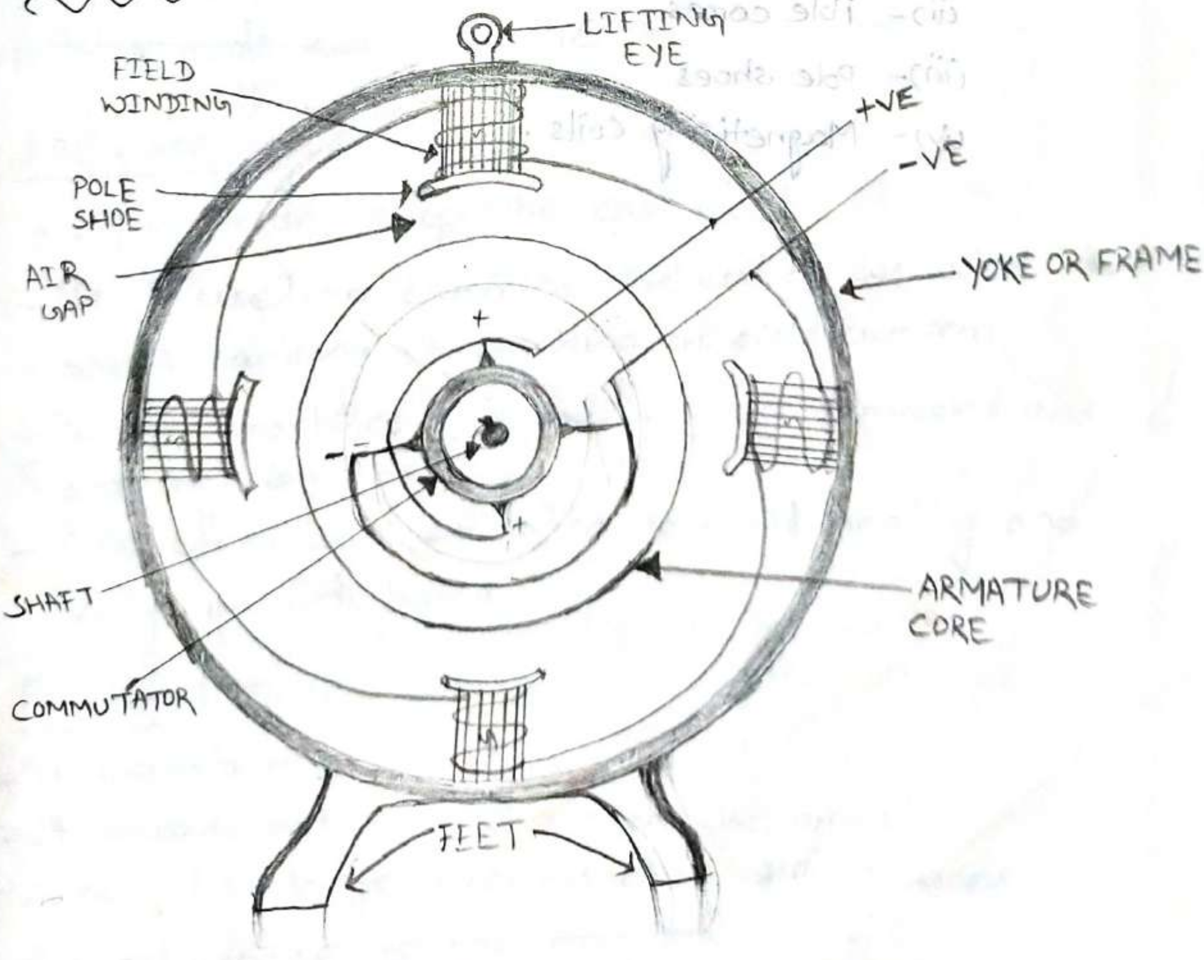
Constructional Features of DC Machine :—



DC Machine consists of,

(i)- Yoke

(ii)- Field Winding & Pole

(iii)- Armature

(iv)- Commutator

(V)- ~~Brass~~ Brush

(1)- Yoke :—

- It acts as a frame of the machine.
- It carries the magnetic flux produced by the poles.

(2)- Field System / Field Magnet :—

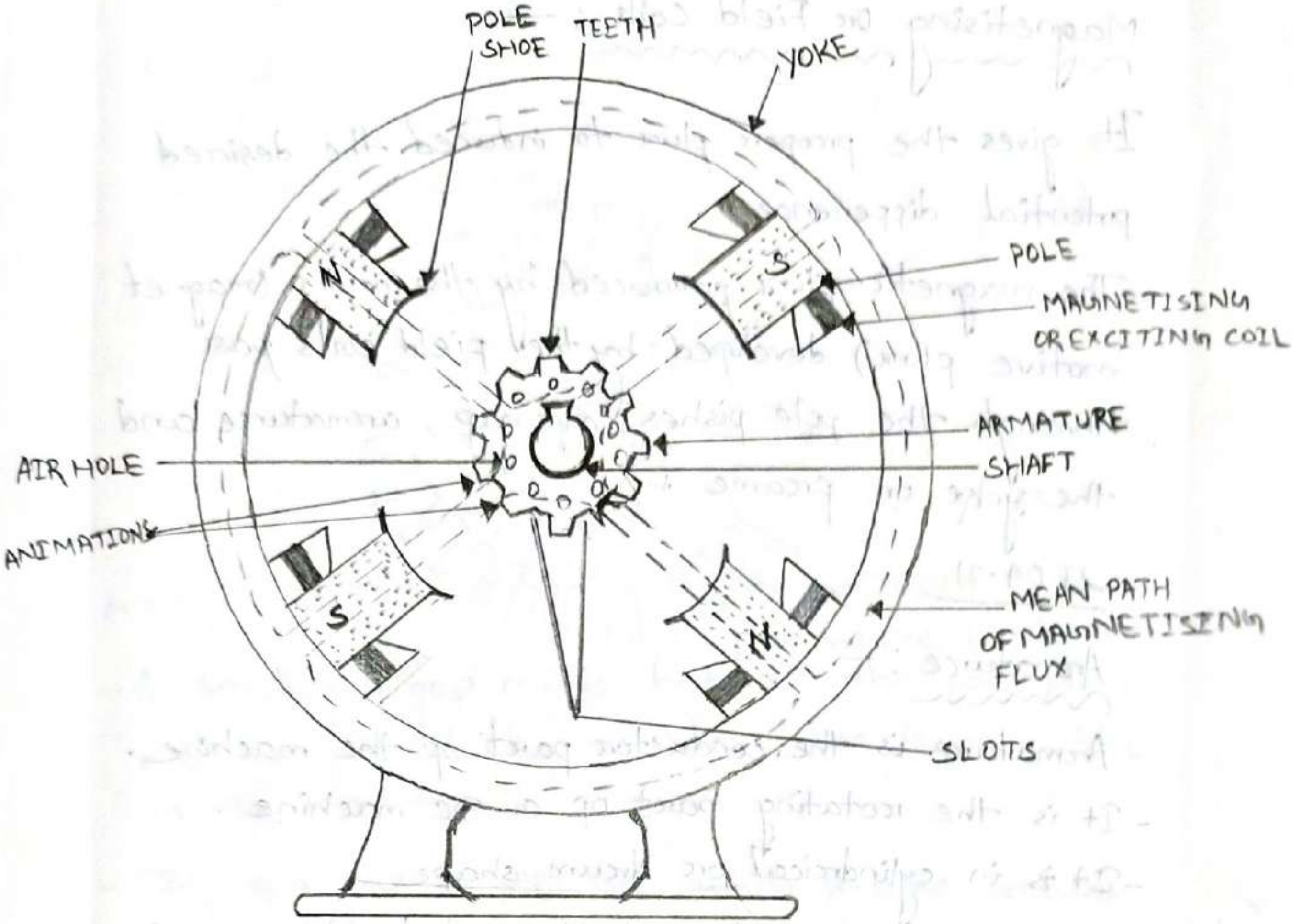
It's main aim is to create a uniform magnetic field with in which the armature rotates, so field consists of

(i)- Yoke or Frame

(ii)- Pole cores

(iii)- Pole shoes

(iv)- Magnetising coils.



[Cross Section Of Field System Of a DC Generator]

~~Pole Core~~ :—

~~It is made up off the~~

Pole Core :—

- It is made up of the cast steel.
- It is used to carries the coil of insulated wires carring the exciting or field current.
- In some machines pole ~~and~~ core are laminated and are not laminated.
- Pole cores are laminated to avoid heating and eddy current losses.

Pole shoe :—

- It supports the field coils.
- It spreads out the flux over the armature.
- Since it has large cross-section, ~~it~~ it reduces the reluctance of the magnetic path.

Magnetising or Field Coils :—

- It gives the proper flux to induced the desired potential difference.
- The magnetic flux produced by the m.m.f (magnet motive flux) developed by the field coils pass through the pole pishes, air gap, armature and the yoke or frame.

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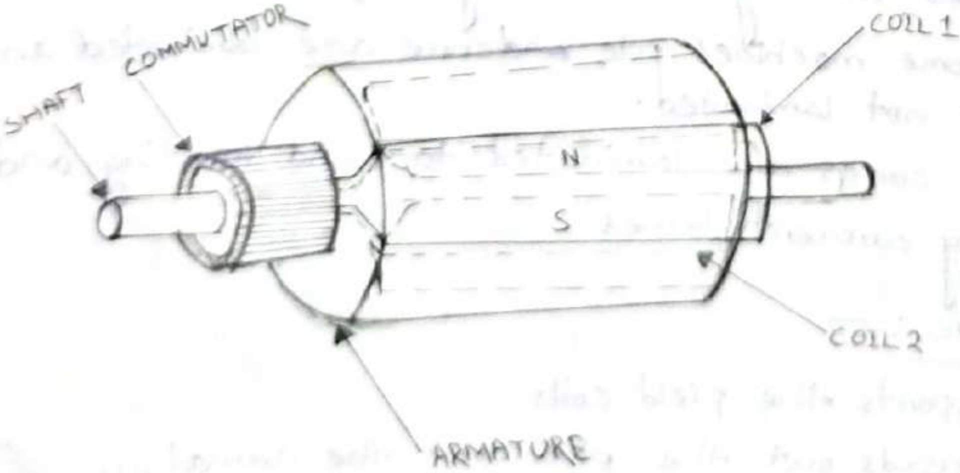
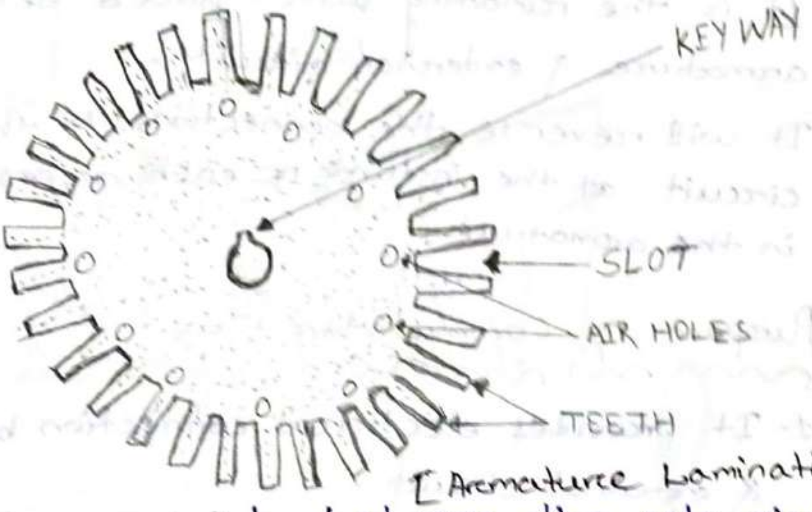
Armature :—

- Armature is the conductor part of the machine.
- It is the rotating part of a DC machine.
- It is in cylindrical or drum shape
- Aim of the armature is to rotate the conductors in the uniform magnetic field.
- It consists of coils of insulator wires wound around an iron.
- When armature rotates, currents are induced in these wires.
- It provides a path of very low reluctance to the magnetic flux.



[Longitudinal View Of Armature]



[Armature Lamination]

- A small air gap exists between the pole pieces and the armature so that there is no rubbing in the machine.

- This air gap is kept as small as possible because larger the air gap greater is the m.m.f required to create the required flux.

$$M.M.F = NI$$

Where, N = number of turns
& I = current

- For example, Air gap length of 1mm for 1 KW machine.
- 1.5 to 1.75mm for medium size machine.
- 6mm for 800 KW machines etc.

* Armature Core :—

It is made up of high grade steel 'y'.

- To keep Hysteresis loss low.
- To reduce the eddy current in the core.

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COMMUTATOR :—

It is the rotating switch placed between the armature & external circuit.

- It will reverse the connections to the external circuit at the instant of each reversal of current in the armature.

Purpose Of Commutator :—

1- It provides electrical connection between armature & external circuit.

2- As the armature rotates, commutator performs switching action by reversing the external circuit & armature coil.

3- It keeps rotor or armature ~~mmm~~ mmf stationary in space.

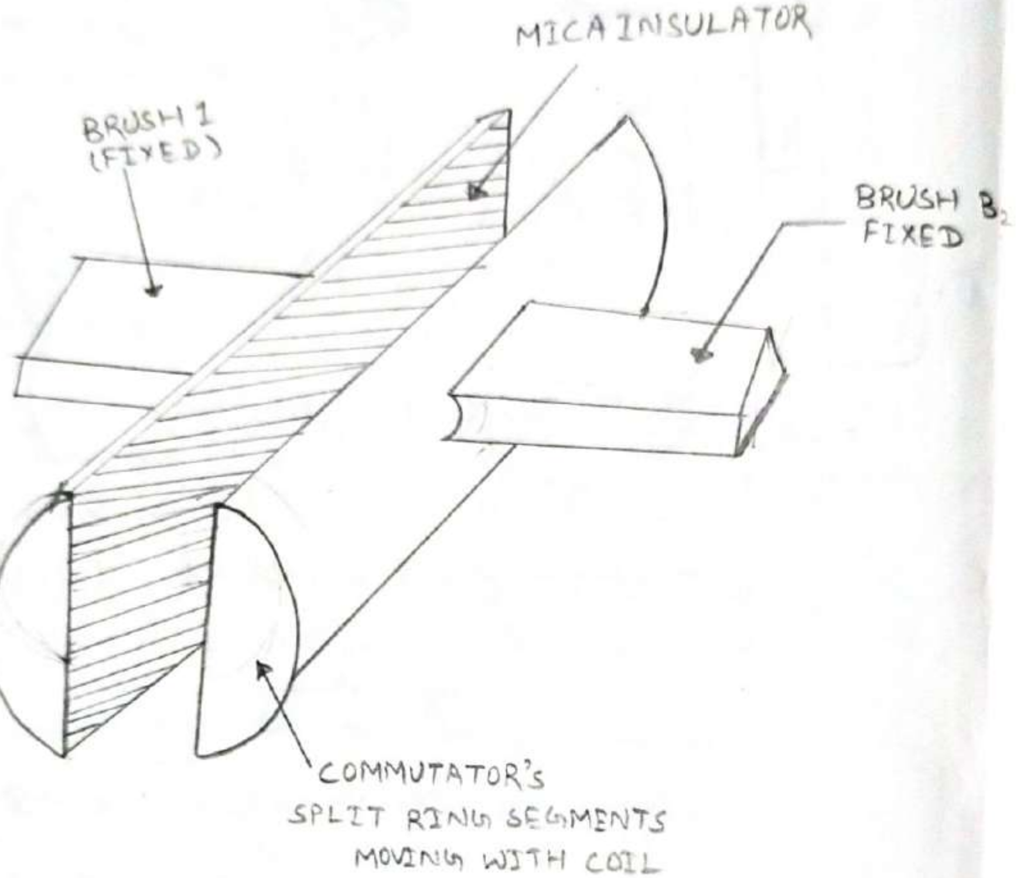
4- Commutator is the cylindrical structure. or It is of cylindrical structure.

5- It is built of wedge segments of high conductivity hard drawn copper.

6- These segments are insulated from each other by thin layers of mica.

Brushes :-

Function of brush is to collect current from the commutator & supply it to the external load circuit.



[BRUSHES]

- Brushes are rectangular in shape.
- Brushes are of different types,
  - (i) Carbon Brush
  - (ii) Carbon-Graphite Brush
  - (iii) Graphite Brush
  - (iv) Metal Graphite Brush
  - (v) Copper Brush.

Bearings :-

Bearings are used at driving end for larger machines (roller bearing).

- Ball bearings are used reduce friction at the moving parts.
- Ball bearings are used at the commutator end.

Shaft :—

It is used to transfer the mechanical power from one part to another, or from a machine which produces power to a machine which absorbs power.

- The rotating parts such as armature is connected with the shaft.

Dt:- 29.04.21

* ARMATURE WINDINGS :—

(1) - CONDUCTOR :—

Each individual length of wire line with in the magnetic field is called the conductor.

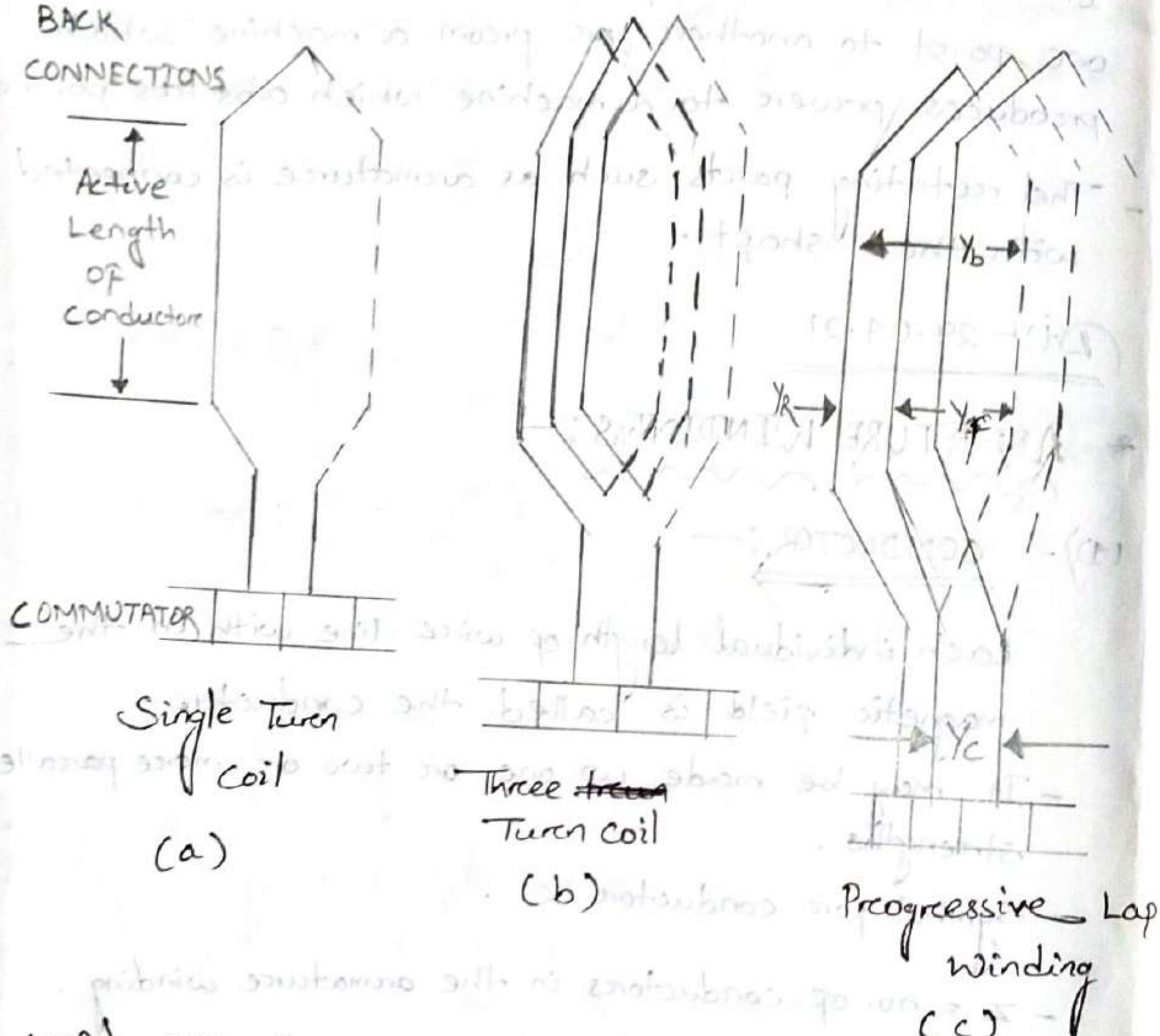
- It may be made up one or two or more parallel strengths.
- Symbol for conductor 'Z'.
- Z = no. of conductors in the armature winding.

(2) TURN :—

When two conductors laying in a magnetic field are connected in a series through that e.m.f induced in them

(2) TURN :—

When two conductors laying in a magnetic field are connected in a series through that e.m.f induced in them when each other, it is known as turn.



(3) COIL :—

When one or more turns are connected in series & the two ends of it are connected to adjacent commutator segments it is called a coil.

→ Coils may be

(i) Single Turn Coil

(ii) Multi Turn Coil

C - Total no. of coils in the armature winding.

(4) COIL SIDE :—

Each coil, single turn or multi turn has two sides called coil sides.

(5) COIL GROUP :—

A coil group may have one or more single coils.

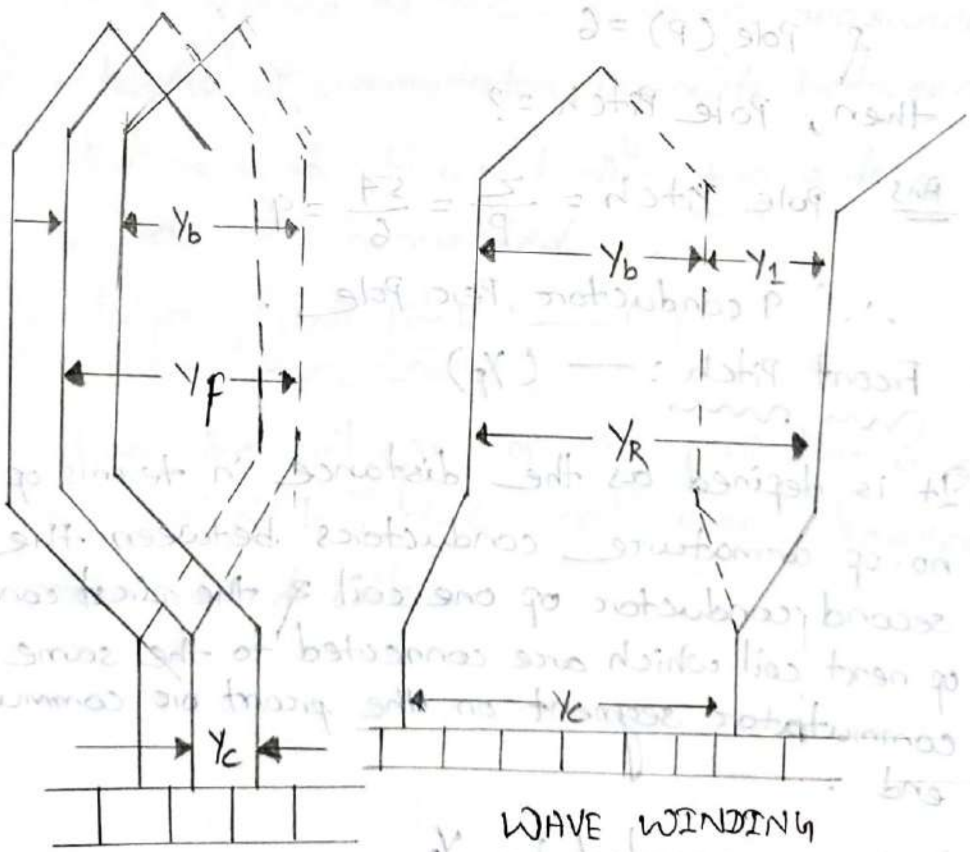
(6) WINDING :—

Number of coils arranged in coil groups is called winding.

(7) INDUCTOR :—

One of the wires making of the coil side is called the inductor.

→ Voltage is induced in the inductor.



RETROGRESSIVE LAP WINDING
(d)

WAVE WINDING
(e)

Dt:- 30.04.21

* Front End Connector :—

A wire that connects the end of a coil to a commutator segment is called front end connector.

- This is located nearest the commutator.

* Back End Connector :—

A wire that connects an inductor on one side of coil to an inductor on the other side of the coil is called back end connector.

- It is on the end opposite to that of commutator.

* Pole Pitch :—

It is defined as the number of conductors per pole.

If, there are 54 conductors,

$Z = 54$

& Pole $(P) = 6$

then, Pole Pitch = ?

Ans Pole Pitch $= \frac{Z}{P} = \frac{54}{6} = 9$

∴ 9 conductor per pole.

* Front Pitch :— (Y_F)

It is defined as the distance in terms of no. of armature conductors between the second conductor of one coil & the first conductor of next coil which are connected to the same commutator segment on the front or commutator end.

- It is represented by Y_F.

* Back Pitch :— (Y_b)

It is defined as the distance in terms of no. of armature conductors between the last & first conductor of the coil.

- It is also called coil span or coil spread.

- It is represented by 'Y_b'.

* Resultant Pitch :— (Y_R)

It is defined as the distance in terms of no. of conductors between the start of one coil & start of next coil to which it connected.

- It is represented by 'Y_R'.

* Commutator Pitch :— (Y_C)

It is defined as the distance measured interms of commutator segments between the segments to which the two ends of the coil are connected.

* Coil Span / coil Pitch :— (Y_S)

When the coil span of the winding is equal to pole pitch, the coils are called pole pitched coils.

09.05.21

* LAP WINDING :—

In a lap winding, finish end of one coil is connected to a commutator segment & to the start of the adjacent coil situated under the same pole & similarly all coils are connected.

- This winding is known as lap winding because the sides of successive coils over lap each other.

- Lap winding divides in to 2 types,

  (i) Simplex Winding (single Winding)

  (ii) Multiplex winding (Double / triple winding)

(i) - Simplex Winding :—

In simplex lap winding, there are many parallel paths or circuits through the winding as there are field poles on the machine.

(ii) - Multiplex Winding :—

Multiplex windings are designed for supply of large current at low voltage.

* Important Points Regarding Lap Winding :—

(i)- $Y_b = \frac{Z}{P}$

Where, Y_b = Back Pitch

Z = Total no. of conductors

P = No. of poles

(ii)- Back pitch sould be either lesser or greater than front pitch Y_f by 2m.

$$Y_b = Y_f \pm 2m$$

m = 1 for simplex winding

m = 2 for duplex winding

m = 3 for triplex winding & so on.

(iii)- Progressive Winding :—

When Y_b is greater than Y_f the winding progresses from left to right end & so known as progressive winding.

(iv)- Retrogressive Winding :—

When Y_b is lesser than Y_f the winding progress from right to left end & that is known as retrogressive winding.

- The back pitch & front pitch must be odd.

- Average Pitch = $\frac{Y_b + Y_F}{2} = \frac{Z}{P}$

& should be equal to Pole pitch i.e Z/P.

(V) - Resultant Pitch :—

The resultant pitch Y_R is always even, being the difference of two odd numbers & is equal to 2m.

$$Y_R = 2m$$

Where, 'm' is the multiplicity of the winding.

$Y_R = 2$ For Simplex Winding.

$Y_R = 4$ For Duplex Winding.

$Y_R = 6$ For Triplex Winding

(Vi) - Commutator Pitch :—

The commutator pitch, $Y_c = m$

i.e Y_c is equal to 1, 2, 3, 4 etc respectively for simplex, duplex, triplex, quadruplex etc. lap windings.

(Vii) - Number of parallel paths in lap winding = mP

i.e no. of parallel paths is equal to P, 2P, 3P, 4P etc respectively, For Simplex, duplex, triplex, quadruplex etc lap windings.

Q-1

Draw the developed winding diagram of progressive lap winding for 4 poles, 24 slots with one coil side per slot, single layer showing there in position of the poles, direction of motion, direction of induced emf & position of brushes.

Ans

No. of Poles (P) = 4

No. of coil sides, z = 24

Average pitch, $(Y_{av}) = \frac{Y_b + Y_F}{2} = \frac{Z}{P}$

$= \frac{24}{4} = 6$

Or, $Y_b + Y_F = 12$ —— (i)

For progressive simplex lap winding,

$Y_b = Y_F \pm 2m$

$Y_b = Y_F + 2 \times 1$

or, $Y_b = Y_F + 2$ —— (ii)

or, $Y_b - Y_F = 2$

solving eq^n (i) & (ii)

$Y_b + Y_F = 12$

$Y_b - Y_F = 2$

$2Y_b = 14$

$\Rightarrow Y_b = \frac{14}{2} = 7$

then, $Y_b - Y_F = 2$

$\Rightarrow 7 - Y_F = 2$

$\Rightarrow -Y_F = 2 - 7 = -5 \Rightarrow Y_F = 5$

* Characteristics of Simplex Lap Winding :-

1- Back pitch & front pitch of all the coils remains the same & odd number.

2- The total no. of brushes is equal to the total no. of poles.

3- The brushes are connected to the coil sides which lie between the poles & have no induced emf in them.

4- There are many parallel path in the armature as the number of poles.

5- The e.m.f between positive & negative brushes is equal to the emf generated in any of the parallel path.

6- If, I_a = Total armature current,

then current per parallel path, $I_c = \frac{I_a}{P}$

7- If 'l' is the length of each armature conductor.

& 'a' is the area of cross section

& 'ρ' is the resistivity of the material of conductor.

Then, Resistance of each conductor $= \rho \frac{l}{a}$

No. of conductors connected in series in each parallel path $= \frac{Z}{A}$.

Resistance of each parallel path $= \rho \frac{l}{a} \cdot \frac{Z}{A}$

Where, A = Total no. of parallel path

Equivalent armature resistance,

$$R_a = \frac{\rho \frac{l}{a} \cdot \frac{Z}{A}}{A} = \rho \frac{l}{a} \cdot \frac{Z}{A^2}$$

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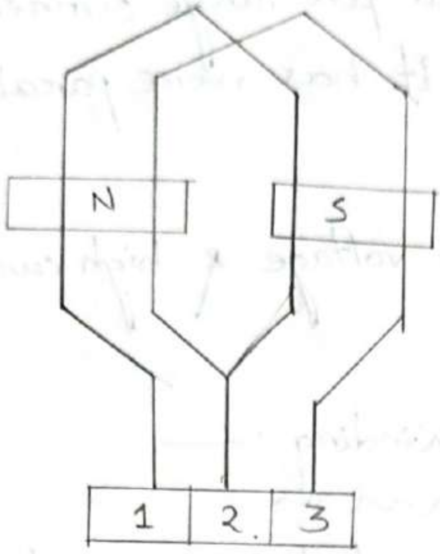
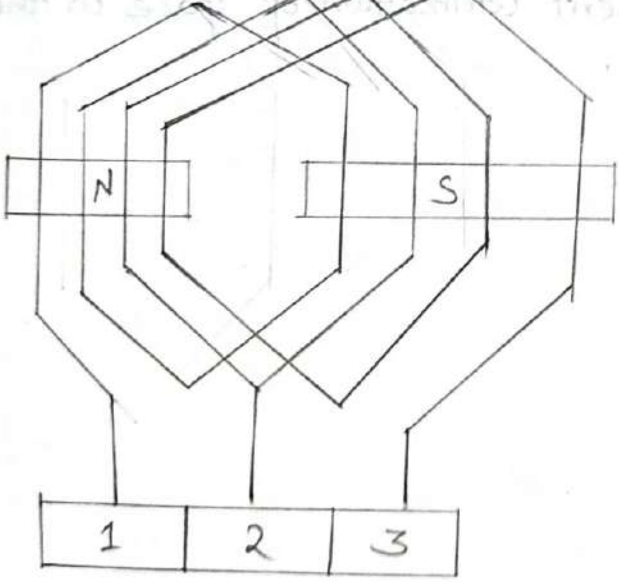


[SIMPLEX LAP WINDING]

No. of Parallel Paths = No. of Poles



[DUPLEX LAP WINDING]

- No. of parallel paths between the brushes is twice the no. of poles is called Duplex Lap Winding.

Advantages Of Lap Winding :—

1- This winding is required for large current applications because it has more parallel paths.

2- It is suitable for low voltage & high current generators.

Dis-advantages Of Lap Winding :—

1- It gives less e.m.f compared to wave winding.

2- This winding requires more number of conductors for giving the same e.m.f, which results in high winding cost.

3- It has less efficient utilization of space in the armature slots.

Dt:- 10.05.21

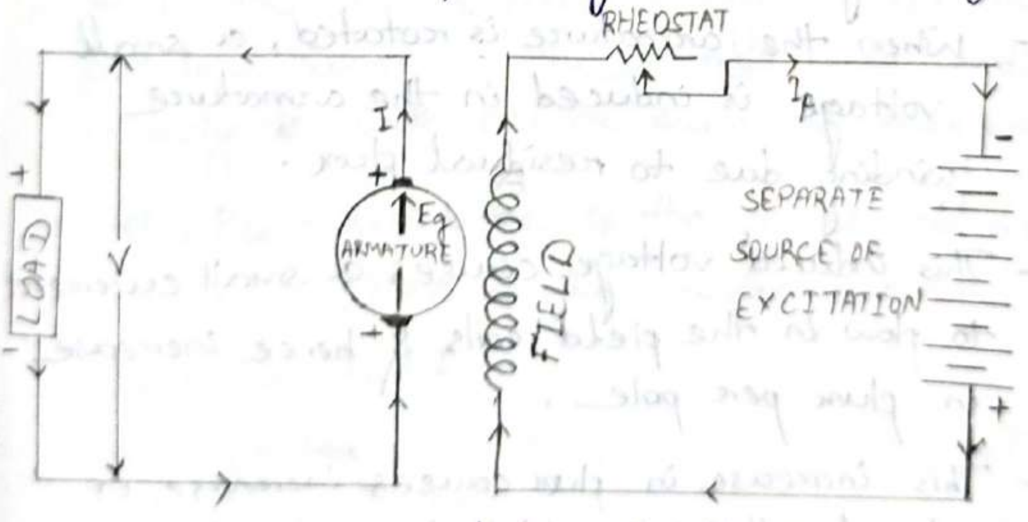
* TYPES OF DC GENERATORS :-

It is of two types,

(1) - Separately Excited DC Generators
(2) - Self Excited DC Generators
 (i) - Series Wound Generators
 (ii) - Shunt Wound DC Generators
 (iii) - Compund Wound Generator

(1) - Separately Excited DC Generators :-

A DC generator, whose field winding is excited from an independent external DC source such as battery, the generator is called a separately - excited DC generator.



Here, I_f = Current through the Field Winding
I_a = Armature Current
I_L = Load Current
R_a = Armature Resistance
E_g = Generated E.M.F
V = Terminal Voltage / Voltage across the load.

$I_a = I_L = I$ (Let)

By Using KVL,

$$V = E_g - IR_a$$

Rough
{ Input = Loss + Output
$E_g = IR_a + V$ }

Power developed,

$$P_g = E_g I$$

Rough
{(VI)}

Power delivered to external Load,

$$P_L = VI$$

(2) - Self Excited DC Generators :—

* Residual Magnetisim :—

- Due to residual magnetisim, some flux is always present in the poles.
- When the armature is rotated, a small voltage is induced in the armature winding due to residual flux.
- This induced voltage causes a small current to flow in the field coils & hence increase in flux per pole.
- This increase in flux causes increase in induced voltage, which increases the field current & so flux per pole.
- These events takes place rapidly & the generator builts up to the rated voltage.

Defn of Self Excited DC Generator :—

A DC generator whose field winding is excited by the current supplied by the generator itself is called a self excited generator.

- Here field coils are inter connected with the armature winding.

Dt:- 11. 05. 21

(1). Series Wound DC Generator :—

Here only one field winding is connected in series with the armature winding.

- So, total current flows through the field winding as well as load.
- Here current through armature winding, series field winding & load is the same.
- Since the series field winding carries the full load current, the series field winding is designed with fewer turns of thick wire.
- Let, R_{se} = Resistance of the series field winding. (It is of the order of 0.5Ω)

$I_a = I_{se} = I_L = I$

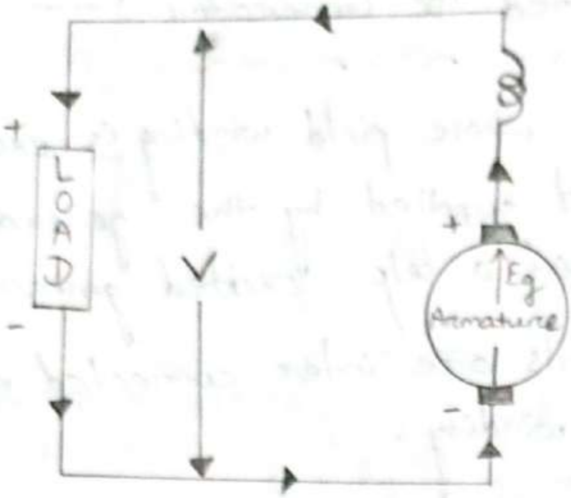
~~$V = E_g - IR_a$~~

$V = E_g - IR_a - IR_{se}$

$= E_g - I(R_a + R_{se})$

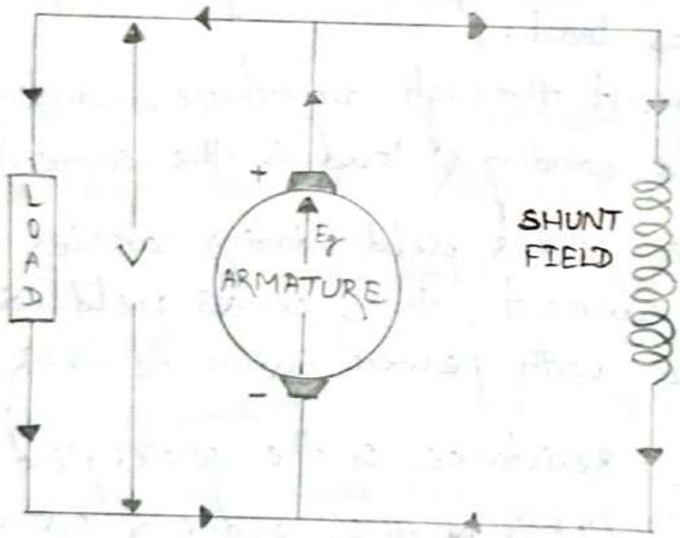
Power developed, $P_g = E_g I$

Power delivered, $P_L = VI$



(2). Shunt Wound DC Generators :—

Here the field winding is connected across the armature circuit forming a parallel or a shunt circuit.



- Terminal voltage, $V = E_g - I_a R_a$

  Armature current,

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

  Shunt field current,

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

  Power developed $= E_g I_a$

  Effective power / Power delivered,

~~$P_L = V \times I_L$~~

$$P_L = V I_L$$

- Effective power of a generator is proportional to the circuit delivered to the external load circuit.
- Therefore it is necessary to keep I_{sh} as small as possible.
- Resistance of the shunt field winding, R_{sh} will be high because the value of I_{sh} is small. Therefore R_{sh} is high.
- Since R_{sh} is high, area of cross section of the wire is small.
- Therefore shunt field coils are designed to produce the desired m.m.f, by means of large no. of turns of fine wire.
- R_{sh} is of the order of 100 Ω.

Dt:- 12.05.21

(3)- COMPOUND WOUND DC GENERATOR :-

Here, there are two sets of field windings on each pole one is in series & the other in parallel with the armature.

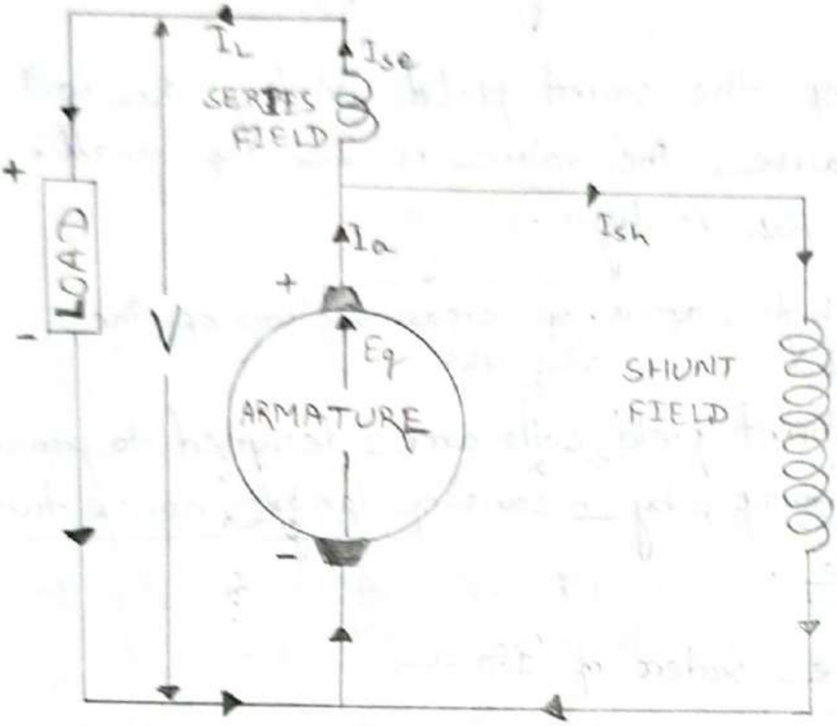
- A compound wound DC generator is of two types,

  (a)- Short shunt Compound wound Generator

  (b)- Long shunt Compound Wound Generator

~~(a) Short Woun~~

(a) - Short shunt Compound Wound Generator :-



- Here shunt field winding is in parallel with the armature winding.

Series field current, $I_{se} = I_L$

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

Terminal Voltage, $V = E_g - I_a R_a - I_{se} R_{se}$

Voltage across shunt field = Voltage across armature

$\Rightarrow I_{sh} R_{sh} = E_g - I_a R_a$

$$\Rightarrow \boxed{I_{sh} = \frac{E_g - I_a R_a}{R_{sh}}}$$

Terminal voltage,

$V = E_g - I_a R_a - I_{se} R_{se}$

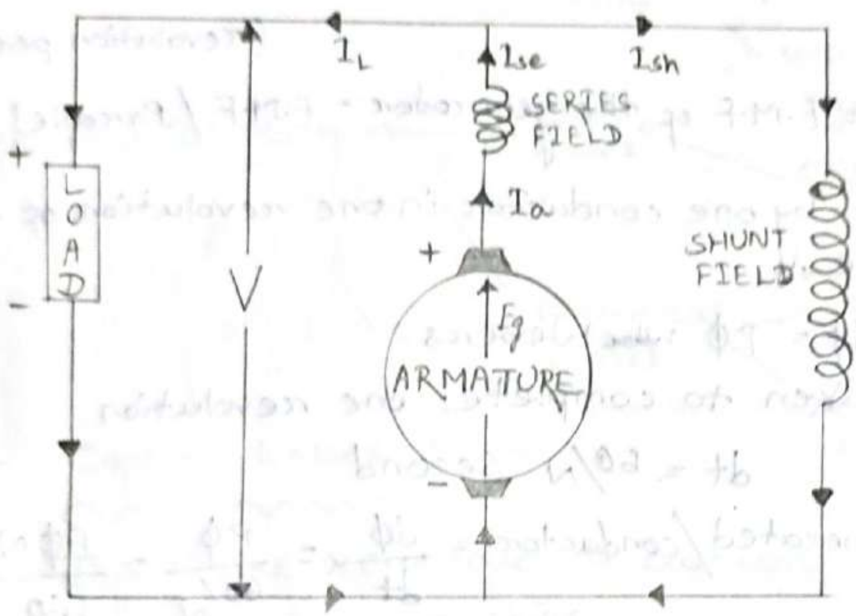
or, $E_g - I_aR_a = V + I_{se}R_{se}$

$$I_{sh} = \frac{V + I_{se}R_{se}}{R_{sh}}$$

Power developed in Armature = E_gI_a

Power delivered to Load = VI_L

(b) - Long shunt Compound Wound Generator :-



- Here, shunt field winding is in parallel with both series field and Armature winding.

$I_a = I_{se}$

Series field current,

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

shunt field current, $I_{sh} = \frac{V}{R_{sh}}$

- Terminal voltage, $V = E_g - I_a(R_a + R_{se})$

~~power delivered~~

Power developed in armature = E_gI_a

power delivered to Load = VI_L

Dt :- 13.05.21

* E.M.F Equation of DC Generator :—

Let, ϕ = Flux per Pole in Weber

Z = Total no. of Armature conductors.

P = No. of Poles

A = No. of Parallel paths

N = Speed of Armature in r.p.m (revolution per minute)

E_g = E.M.F of the generator = E.M.F / Parallel Path

- Flux cut by one conductor in one revolution of the armature,

$$d\phi = P\phi \text{ Webers}$$

Time taken to complete one revolution

$$dt = 60/N \text{ second}$$

$$\text{E.M.F generated/conductor} = \frac{d\phi}{dt} = \frac{P\phi}{60/N} = \frac{P\phi N}{60} \text{ volts}$$

E.M.F of generator, E_g = E.M.F per parallel path

= (E.M.F / conductor) × No. of conductor in series per parallel path

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

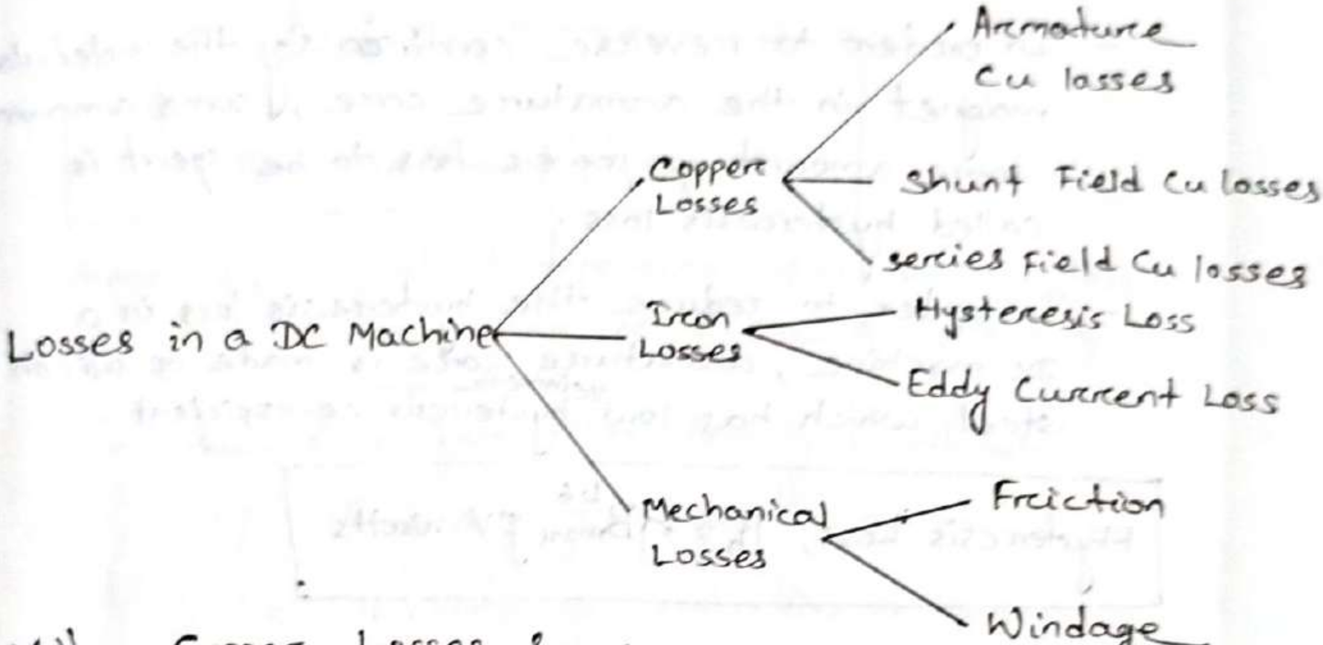
Hence,

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

$A = 2$, For Wave Winding

$A = P$, For Lap Winding

* LOSSES IN A DC MACHINE :—



(1)> - Copper Losses :—

This losses occur due to currents in various windings of the machine.

(i) - Armature Copper loss = $I_a^2 R_a$

(ii) - Shunt Field Copper loss = $I_{sh}^2 R_{sh}$

(iii) - Series Field copper loss = $I_{se}^2 R_{se}$

(2)> - Iron / Core Losses :—

This losses occur in the armature of a DC machine, these are due to the rotation of armature in the magnetic field of the pole.

- These are 2 types,

(i) - Hysteresis Loss.

(ii) - Eddy Current Loss.

(a)) - Hysteresis Loss :—

It occurs in the armature of the DC machine because the armature is subjected to magnetic field reversal, as it passes under successive poles.

- In order to reverse continously the molecular magnet in the armature core, some amount some amount of power has to be spent is called hysteresis loss.

- In order to reduce the hysteresis loss in a DC machine, armature core is made of silicon steel which has low steinmetz hysteresis co-efficient.

$$\text{Hysteresis Loss, } P_h = \eta B_{max}^{1.6} f V \text{ watts}$$

Where,

B_{max} = Maximum Flux density in Armature (Wb/m^2)

f = Frequency of Magnetic Reversals

= $NP/120$ where N is in r.p.m

V = Volume of Armature in m^3.

η = steinmetz hysteresis co-efficient.

(b)) - Eddy Current Loss :—

Voltage is also induced in the armature core, hence it will produce circulating current in the armature core, is called eddy current & power loss due to the flow of the eddy current is called eddy current loss.

- To minimize the eddy current loss, the current has to be reduced by increasing the resistance of the core.

- Core resistance can be increased by constructing the core of thin, round iron sheets called laminations.
- The laminations are insulated from each other with a coating of a varnish.

- Eddy current loss,

$$P_e = K_e B_{max}^2 f^2 t^2 V \text{ watts}$$

Where, K_e = Constant depending upon the electrical resistance of core & system of units used.

B_{max} = Maximum flux density in Wb/m^2

f = Frequency of magnetic reversals in Hz.

t = Thickness of lamination in m.

V = Volume of core in m^3.

Dt:- 17.05.21

* 3) Mechanical Losses :—

These losses are due to friction & windage.

(i) - Friction Loss :—

E.g - Brush friction, Bearing Friction

(ii) Windage :—

Air friction of rotating armature.

- These losses depend upon the speed of the machine.

* Constant & Variable Losses :—

The losses in a d.c generator is devided into two parts.

(i) - Constant Losses

(ii) - Variable Losses

(a) - Constant Losses :—

Those losses in a DC generator which remain constant at all loads are known as constant losses.

- The constant losses in a D.C generator are, (i) - Iron Losses
  (ii) - Mechanical Losses
  (iii) - Shunt Field Losses

Constant Loss = W_c

(b) - Variable Losses :—

Those losses which vary with load are called variable losses.

- The variable losses in a dc generator are,

(i) - Copper loss in armature winding = $I_a^2 R_a$

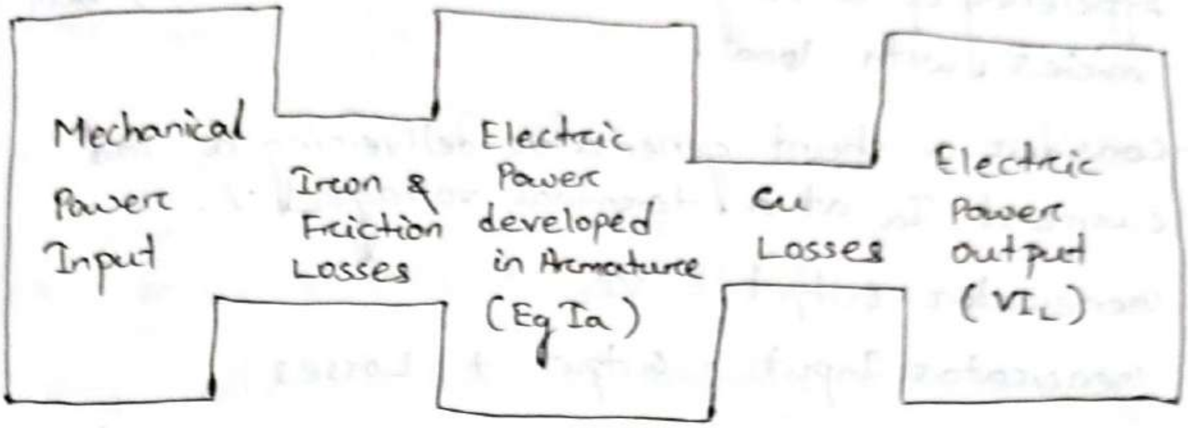
(ii) - Copper loss in series field winding = $I_{se}^2 R_{se}$

Total Losses = Constant Losses + Variable Losses

Note :-

Field copper loss is constant for shunt & compound generator.

* POWER STAGES :—



(i) - Mechanical Efficiency = $\eta_m = \frac{B}{A} = \frac{E_g I_a}{\text{Mechanical Power Input}}$

(ii) - Electrical Efficiency = $\eta_e = \frac{C}{B} = \frac{VI_L}{E_g I_a}$

(iii) - Commercial or overall Efficiency

$$= \eta_c = \frac{C}{A} = \frac{VI_L}{\text{Mechanical Power Input}}$$

$$\Rightarrow \eta_c = \eta_m \times \eta_e$$

- Commercial Efficiency,

$$\boxed{\eta_c = \frac{B}{A} \times \frac{C}{B}}$$

Commercial efficiency $(\eta_c) = \frac{C}{A}$

$$= \frac{\text{OutPut}}{\text{Input}}$$

$$= \frac{\text{Input} - \text{Losses}}{\text{Input}}$$

<u>Extra</u>

$$\boxed{\text{Input} = \text{Loss} + \text{Output}}$$

* Condition For Maximum Efficiency :- Dt:- 18.05.21

Efficiency of a dc generator is not constant, but varies with load.

- consider a shunt generator delivering a load current I_a at a terminal voltage V.
- Generator Output $= VI_L$

Generator Input = Output + Losses

$= VI_L +$ variable losses + constant losses

$= VI_L + I_a^2 R_a + W_c$

$= VI_L + (I_L + I_{sh})^2 R_a + W_c$

$[\because I_a = I_L + I_{sh}]$

Since I_{sh} is smaller than I_L, therefore I_{sh} can be neglated.

Generator Input $= VI_L + I_L^2 R_a + W_c \quad [I_{sh} = 0]$

We know that efficiency,

$$\eta = \frac{\text{Output}}{\text{Input}}$$

$$= \frac{VI_L}{VI_L + I_L^2 R_a + W_c} = \frac{VI_L}{VI_L\left(1 + \frac{I_L R_a}{V} + \frac{W_c}{VI_L}\right)}$$

$$= \frac{1}{1 + \left(\frac{I_L R_a}{V} + \frac{W_c}{VI_L}\right)} \quad \text{——— (i)}$$

- The efficiency will be maximum when the denominator of eqⁿ (i) is minimum i.e,

$$\frac{d}{dI_L}\left(\frac{I_L R_a}{V} + \frac{W_c}{VI_L}\right) = 0$$

or $$\frac{d}{dI_L} \times \frac{I_L R_a}{V} + \frac{d}{dI_L} \times \frac{W_c}{VI_L} = 0$$

or, $\frac{R_a}{V} - \frac{W_c}{VI_L^2} = 0$

or, $\frac{R_a}{V} = \frac{W_c}{VI_L^2}$

or, $\boxed{I_L^2 R_a = W_c}$

or, $\boxed{\text{Variable Loss} = \text{Constant Loss}}$

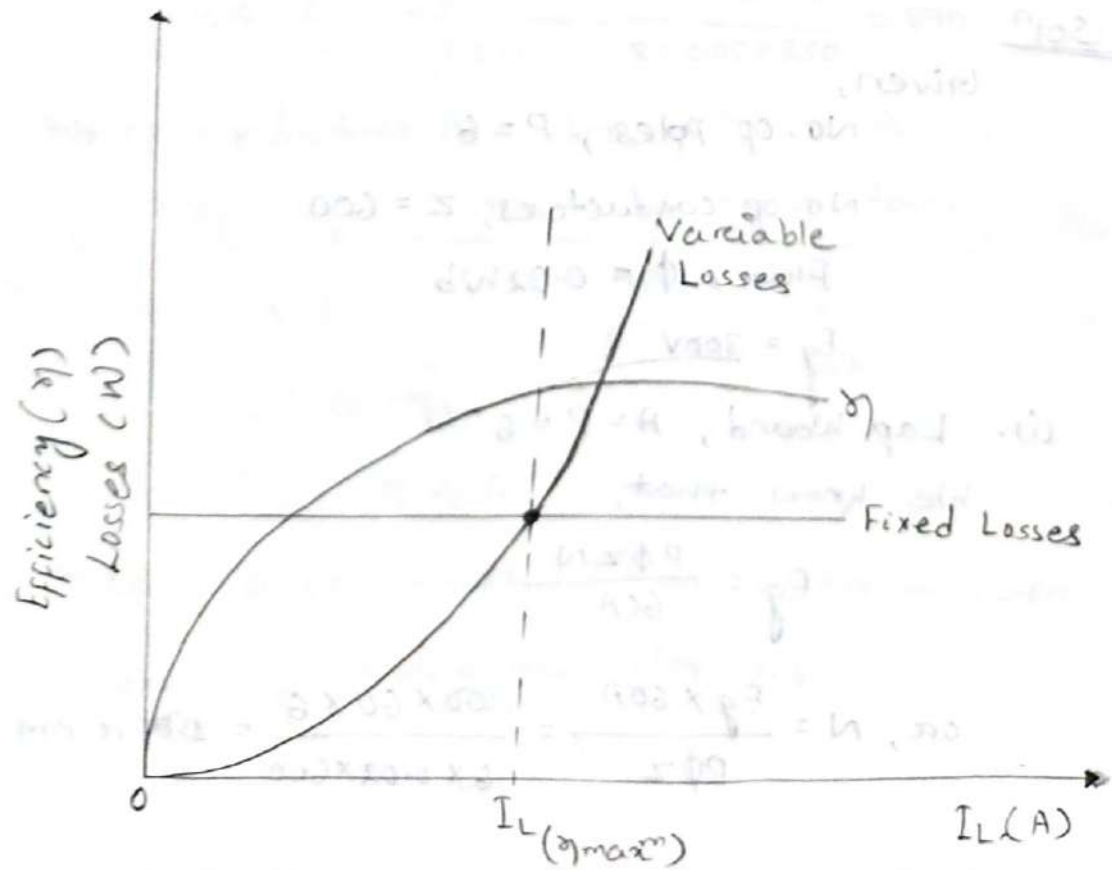
The load current corresponding to maximum efficiency is given by,

$$I_L^2 R_a = W_c$$

$$\text{or, } I_L^2 = \frac{W_c}{R_a}$$

$$\text{or, } \boxed{I_L = \sqrt{\frac{W_c}{R_a}}}$$

- Efficiency of a DC generator will be maximum, when the load current is such that, Variable loss is equal to the constant loss.



From the Graph,

(i)- Fixed loss / constant loss is represented by a horizontal line parallel to load current axis.

(ii)- The variable losses vary with load current.

(iii)- The point at which the variable losses determine the maximum efficiency.

(iv)- The value of load current corresponding to maximum efficiency can be determined from the graph.

Dt:- 19.05.21

NUMERICALS

(1)- A 6-Pole lap wound dc generator has 600 conductors on its armature. The flux per pole is 0.02 wb. Calculate.

(i) - The speed at which the generator must be run to generate 300V.

(ii) - What would be the speed, if the generator were wave wound.

Soln

Given,

No. of Poles, $P = 6$

No. of conductors, $Z = 600$

Flux, $\phi = 0.02 Wb$

$E_g = 300V$

(i). Lap Wound, $A = P = 6$

We know that,

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

$$or, \ N = \frac{E_g \times 60A}{P\phi Z} = \frac{300 \times 60 \times 6}{6 \times 0.02 \times 600} = 1500 \ r.p.m$$

(ii) Wave Wound, A = 2

$$N = \frac{E_g \times 60A}{P\phi Z} = \frac{300 \times 60 \times 2}{6 \times 0.02 \times 650} = 500 \text{ r.p.m}$$

(2) - An 8-Pole, Lap wound armature rotated at 350 r.p.m is required to generate 260V. The useful flux per pole is 0.05 Wb. If the armature has 120 slots, calculate the number of conductors per slot.

Soln Given,

$P = 8$

$A = P = 8$ (Lap Wound)

$N = 350$ r.p.m

$E_g = 260V$

Flux = 0.05 Wb

No. of slots = 120

We know that,

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

$$\text{or} \quad Z = \frac{E_g \times 60A}{P\phi N} = \frac{260 \times 60 \times 8}{8 \times 0.05 \times 350} = 890$$

No. of conductors per slot,

$$= \frac{\text{Total no. of conductors}}{\text{Total no. of slots}}$$

$$= \frac{890}{120}$$

$$= 7.416$$

This value must be an even number,

Hence, conductors/slot = 8 .

(3) - The armature of a 6-pole, 600 r.p.m lap wound generator has 90 slots. If each coil has 4 turns, calculate the flux per pole required to generate an e.m.f of 288 volts.

Sol^n

Given,

$P = 6$

$A = P = 6$ (Lap wound)

slots = 90

$N = 600$

No. of turns per coil = 4

$E_g = 288$ volts

Each turn has two active conductors & 90 coils are required to fill 90 slots.

Then,

No. of conductor = Total no. of slots × No. of turns per coil × No. of conductors per turn

$Z = 90 \times 4 \times 2$

$= 720$

$\Rightarrow Z = 720$

We know that,

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

$$\phi = \frac{E_g \times 60A}{PZN} = \frac{288 \times 60 \times 6}{6 \times 720 \times 60}$$

$= 0.04\,Wb$

(4)) - A 30KW, 300V dc shunt generator has armature & field resistance of 0.05 Ω & 100 Ω respectively. Calculate the total power developed by the armature when it delivers full load output.

Given, DC shunt generator,

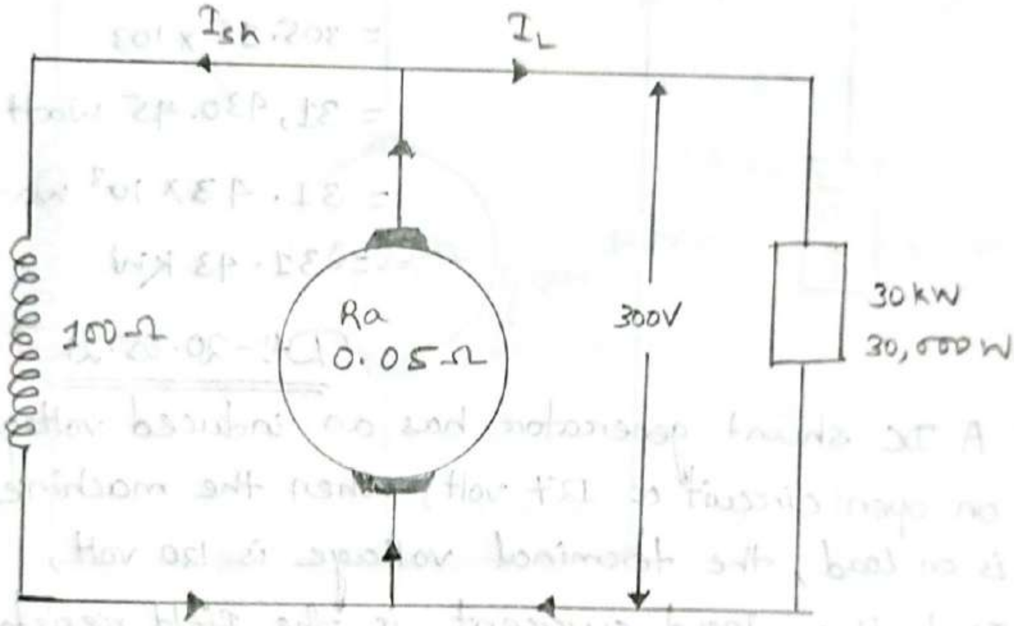
Terminal voltage, $V = 300V$

Power delivered to the load $= 30KW$

$= 30,000$ Watt

$R_a = 0.05 \Omega$

Field Resistance, $R_{sh} = 100 \Omega$



$P_L = V I_L$

$I_L = \frac{P_L}{V} = \frac{30,000}{300} = 100$ Ampere

$I_L = 100$ Ampere

We know that,

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

$= \frac{300}{100}$

$= 3$ Ampere

$I_{sh} = 3$ Ampere

$I_a = I_L + I_{sh}$

$= 100 + 3$

$= 103$ Ampere

$I_a = 103$ Ampere

$E_g = V + I_a R_a$

$= 300 + 103 \times 0.05$

$= 305.15$ volt

Power developed in Armature, $= E_g I_a$

$= 305.15 \times 103$

$= 31,430.45$ Watt

$= 31.43 \times 10^3$ watt

$= 31.43$ kW

Dt:- 20.05.21

(5)- A DC shunt generator has an induced voltage on open circuit of 127 volt, when the machine is on load, the terminal voltage is 120 volt, Find the load current, if the field resistance be 15Ω & the armature resistance 0.02Ω.

Solⁿ Given, $E_g = 127$ volt

$V = 120$ volt

$R_{sh} = 15\Omega$

$R_a = 0.02\Omega$

$I_L = ?$

We know that,

$E_g = V + I_a R_a$

$\Rightarrow I_a R_a = E_g - V = 127 - 120$

$= 7V$

$$I_a = \frac{7}{R_a} = \frac{7}{0.02} = 350\,A$$

$$I_{sh} = \frac{V}{R_{sh}} = \frac{120}{15} = 8A$$

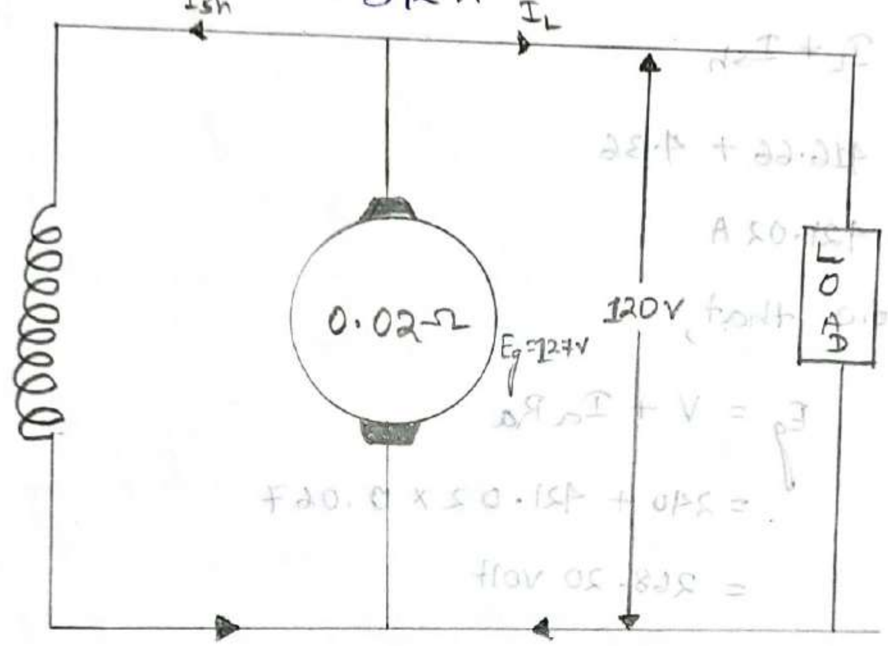
We know that,

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

$$\Rightarrow I_L = I_a - I_{sh}$$

$$= 350 - 8$$

$$= 342\,A$$



(Q) - A 100KW, 240 volt shunt generator has a field resistance of 55Ω & armature resistance of 0.067Ω. Find the full load generated voltage.

Sol^n Given,

DC shunt Generator

Power delivered to the load (P_L) = 100KW

$= 100 \times 10^3\,W$

Terminal voltage (V) = 240 volt

$R_{sh} = 55\Omega$

& $R_a = 0.067\Omega$

$E_g = ?$

We know that,

$$P_L = VI_L$$

$$\Rightarrow I_L = \frac{P_L}{V} = \frac{100 \times 10^3}{240}$$

$$= 416.66\ A$$

We know that,

$$I_{sh} = \frac{V}{R_{sh}} = \frac{240}{55}$$

$$= 4.36\ A$$

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

$$= 416.66 + 4.36$$

$$= 421.02\ A$$

We know that,

$$E_g = V + I_a R_a$$

$$= 240 + 421.02 \times 0.067$$

$$= 268.20\ \text{volt}$$

Dt:- 21.05.21

* APPLICATIONS OF DC GENERATOR :-

(1)- Separately Excited DC Generator :-

- Since it requires separate source of supply, it is more expensive than self excited generators.
- It got very accurate speed.
- It is suitable for applications which needs speed variation from low speed to higher speed (speed control).
- It gives a more quicker & more presize response to changes of the resistance of the field circuit.

Applications of Excited DC Generator :-

(i)- They are used for testing purpose in the labrotaries.

(ii)- Separately excited generators operate in a stable condition with any variation in field excitation. They are used as supply source of DC motors. Whose speeds are to be controlled for various applications.

Example :- Ward Leonard Systems of Speed Control.

(2)- Applications of Shunt Wound DC Generator :-

(i)- They are used for general lighting.

(ii)- They are used to charge battery because they can be made to give constant output voltage.

(iii)- They are used for giving the excitation to the alternators.

(iv)- They are also used for small power supply (such as a portable generator).

(3)- Applications of Series Wound DC Generator :-

- They can't be used for power supply on account of their rise in voltage characteristics.
- They can be employed as a constant current source by making use of the dropping portion of the voltage - current characteristics.

(i)- They are used for supplying field excitation current in DC locomotives for generative breaking.

(ii)- It is used as boosters to compensate the voltage drop in the feeder line in variation distribution system such as railway service.

(iii)- It is used in series arc lightening.

(4)- Commulative compound Wound DC Generators :-

It is used for lighting & power services.

(5)- Differential compound Wound DC Generator :-

It is used as an arc welding generator.

Numericals

Dt:- 26.05.21

(1)- A 10 KW, 250V DC, 6 pole shunt generator runs at 1000 rpm, when delivering full load. The armature 534 lap connected conductors. Full load copper loss is 0.64 KW. The total brush drop is 1 volt. Determine the flux per pole. Neglect shunt current.

Given,

Power delivered to the Load = 10KW

Terminal Voltage (V) = 250 volt

No. of Pole (P) = 6

P = A = 6 (Lap connected)

Speed (N) = 1000 rpm

No. of conductors • Z = 534

Full load Copper loss = 0.64 KW

Total brush drop = 1 volt

Since, $I_{sh} = 0$

There is no shunt copper loss.

Copper loss occurs only in the armature.

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

$$E_g = V + I_aR_a + \text{Brush Drop}$$

$$I_L = I_a = \frac{P_L}{V} = \frac{10,000}{250}$$

$$= 40 \text{ Ampere}$$

$$I_a^2R_a = 0.64 \times 10^3$$

$$\Rightarrow (40)^2 \cdot R_a = 0.64 \times 10^3$$

$$\Rightarrow R_a = \frac{0.64 \times 10^3}{(40)^2} = \frac{0.64 \times 10,000}{1600}$$

$$= \frac{6400}{1600} = 0.4\Omega$$

$$\Rightarrow R_a = 0.4\Omega$$

$$I_aR_a \text{ drop} = 40 \times 0.4 = 16 \text{ volt}$$

$$E_g = V + I_aR_a + \text{Brush Drop}$$

$$= 250 + 16 + 1$$

$$= 267 \text{ volt}$$

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

$$\Rightarrow \phi = \frac{E_g 60 A}{PZN} = \frac{E_g 60 P}{PZN} = \frac{267 \times 60}{534 \times 1000}$$

$$= \frac{16020}{534,000}$$

$$= 0.03 \text{ Wb}$$

Dt:- 29·05·21

ARMATURE REACTION AND COMMUTATION IN DC MACHINE

* ARMATURE REACTION :—

The effect of magnetic field set up by the armature current on the distribution of flux under the main poles of a dc machine is known as armature reaction.

It affects →

(i) - Change the direction of main flux.

(ii) - Reduce the

* WHEN THERE IS NO LOAD :—

Polar Axis :—

Line joining the ~~centores~~ centres of North-South pole.

GNA :— (Geometrical Neutral Axis)

It is the axis i.e. geometrically 90° to the main flux.

MNA :— (Magnetic Neutral Axis) / (Axis of the commutations)

It is the axis which is perpendicular to the flux passing through the armature.

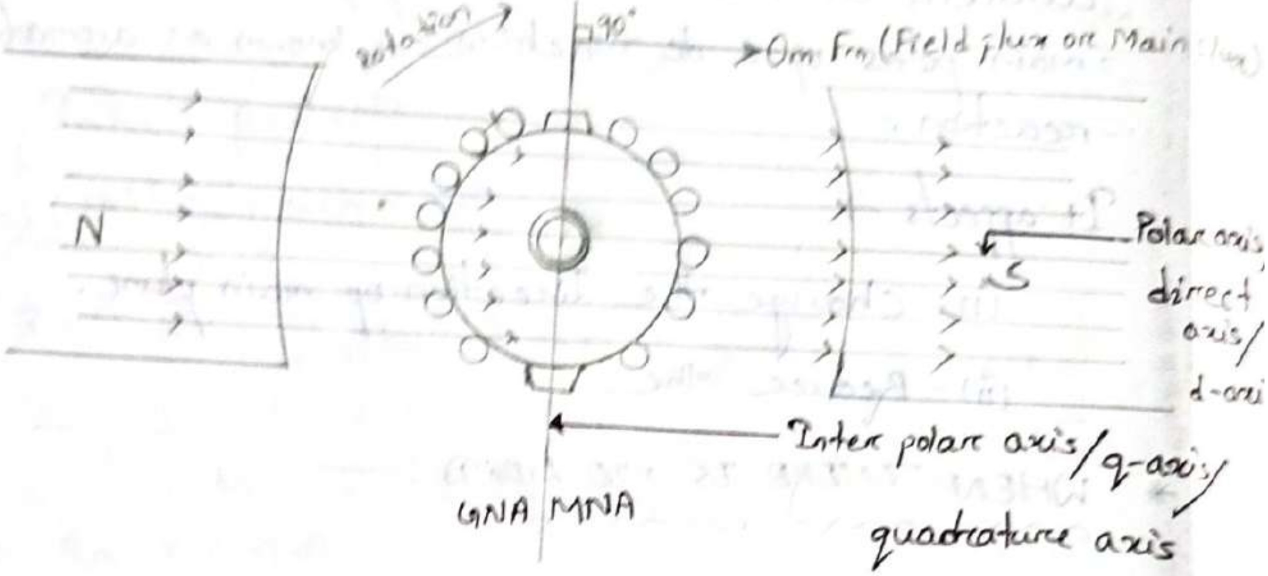
OR

It is the axis along which no. of emf is produced in the armature conductors because armature conductors move parallel to the lines of flux.

- Field winding is energised and the generator is supplying no load, the field flux is distributed uniformly across polar axis.

- MNA will coincide with GNA.

- Brushes will be in MNA.



* **When There Is Load :—**

- When armature is connected with the load, induces current will flow the

- Direction of current will be found by using Fleming's Right-Hand Rule.

- Current direction is downwards (x) in the conductor under N-pole.

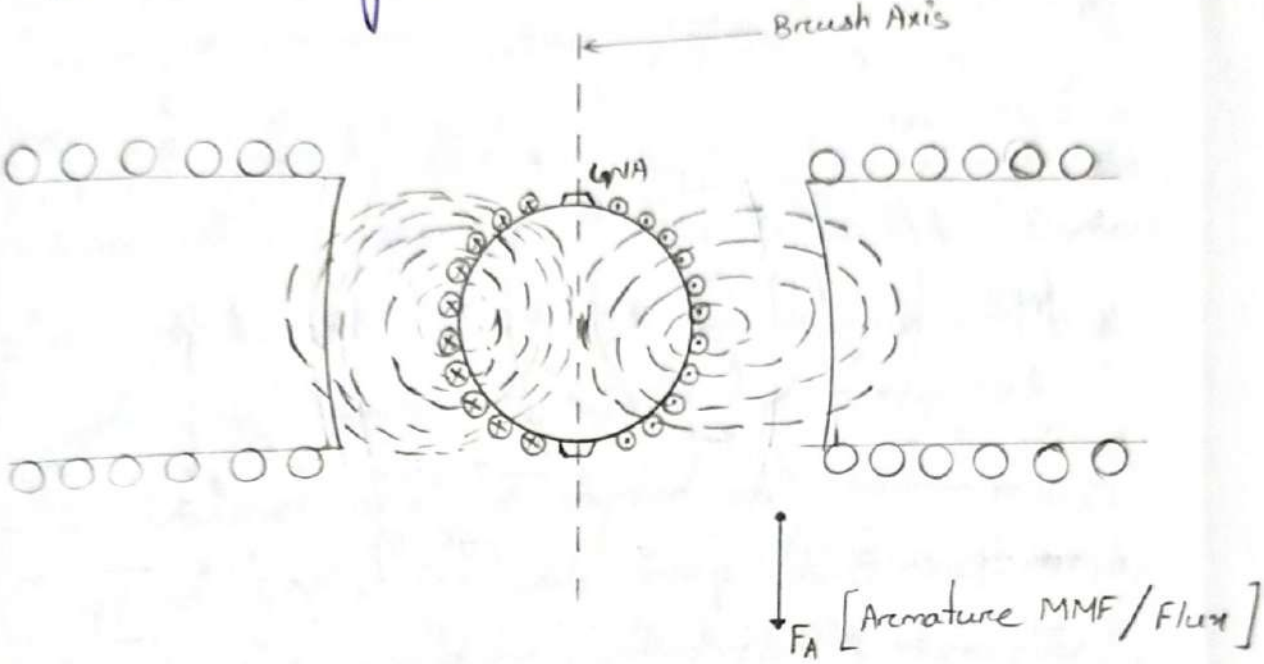
- Current direction is upwards(.) in the conductor under S-pole.

- Armature MMFs combined to send flux downward.

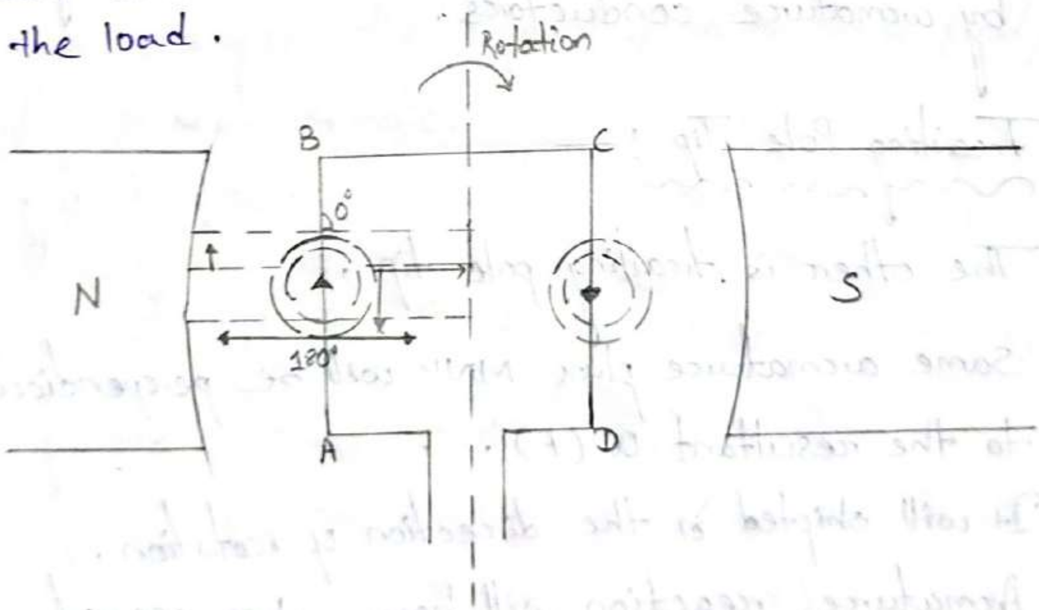
- Direction of the lines of forces can be found by applying (Cork Screw Rule).

- Armature MMF depends on the strength of armature current.

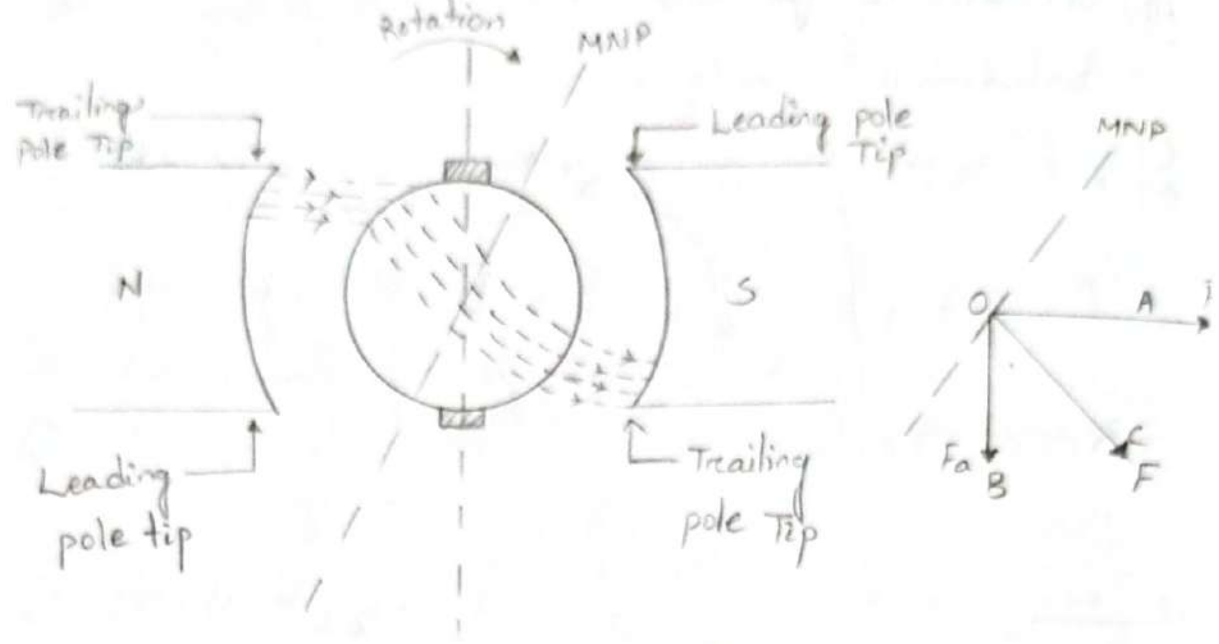
- It is shown by ϕ_a.



- It is assumed the field flux / main flux = 0, Only distribution of flux due to current in armature current conductor is shown, when it is connected with the load.



- In practical condition, the main flux & armature flux occur in the armature conductor simultaneously.



Leading Pole Tip :—

The pole tip which is first ~~which~~ met during rotation by armature conductors.

Trailing Pole Tip :—

- The other is trailing pole tip.
- Same armature flux MNP will be perpendicular to the resultant OC (F).
- It will shifted in the direction of rotation.
- Armature reaction will have two effects,-

(1) - Cross Magnetising Effect :—

- Here the armature flux is perpendicular to the main flux.
- ~~It distores~~
- It distorts the main flux.

- The flux through the armature & in the air gap is no longer uniform.

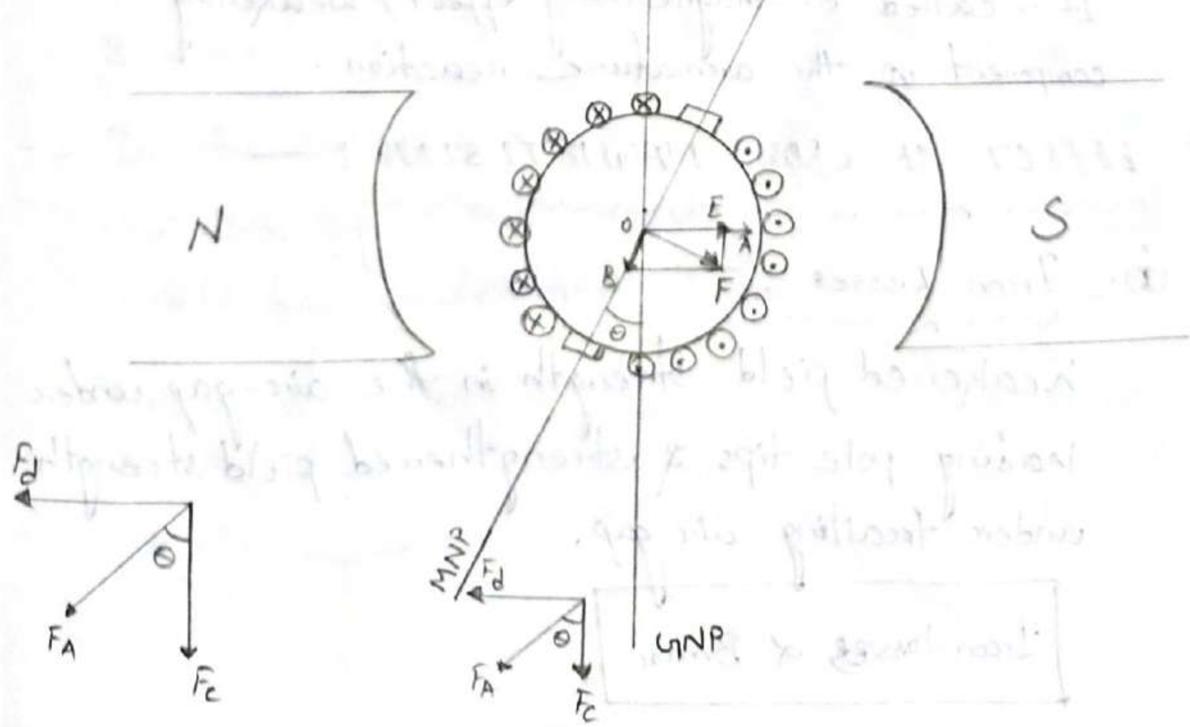
- If the brushes are not shifted along MNP, then there will be sparking at the commutator segments.

- MNP is the axis along which emf is equal to 0 & thats why brushes are attached along MNP.

- If brushes are not shifted along MNP and are kept at GNP, the coils being short circuited by the brushes would be cutting flux & therefore, have an emf generated in them causing an arc to be formed as the commutator segments move under brushes.

- As load changes, the amount of distortion of field/shifting of MNA varries.

- To get secure sparkless commutation brushes are to be shifted to the new MNP.



- Some conductors under to S-pole earlier come under N-pole & vice-versa.
- Total armature MMF lie along the new MNP which is no longer at 90° to the main field.
- Partly of armature MMF → Cross Magnetizing.
  Partly of armature MMF → Demagnetizing.
- Due to shifting of brushes along new MNP through an ∠θ (angle θ), distribution of current in armature conductor is changed.
- Now armature MMF (F_A is no longer perpendicular to F_m). It is inclined at an angle θ (∠θ) to the left of GNA.
- F_A is resolved into two parts.
  (i) - F_c (at perpendicular (⊥r) to F_m main flux)
  - It is called cross-magnetising or distorting component of the armature reaction.
  (ii) F_d (at 180° or direct opposite to F_m, Main flux)
  It is called de-magnetising effect / weakening component of the armature reaction.

* EFFECT OF CROSS-MAGNETISING :—

(i) - Iron Losses :—

Weakened field strength in the air-gap under leading pole tips & strengthened field strength under trailing air gap.

Iron losses ∝ B_{max}

- Increase in iron losses due to increase in flux density under ~~under~~ trailing pole tips is more than the decrease in iron losses due to decrease in flux density in the leading pole tip.

∴ Iron losses at load are more than those on no load.

(iii) Commutation :—

- For good commutation, the coils short-circuited by the brushes should have 0 emf induced in them.
- Due to cross-magnetisation, magnetic field is created in the interpolar region where brushed are placed for commutation.
- Brushes should be placed along the interpolar region / axis.
- Now, the coils under going commutation do not have 0 emf induced in them.
- B wave is shifted from the inter polar axis.
- In the coil under the brushes, the emf & the direction of the current is opposite to what would be under the approaching pole.

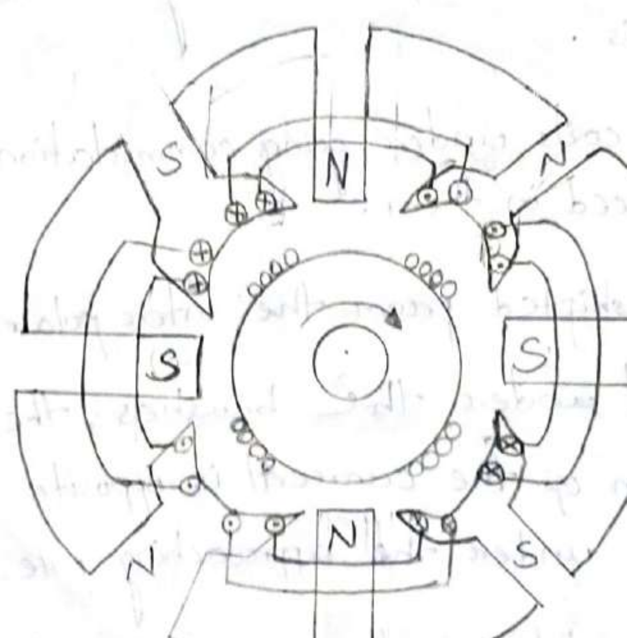
∴ There is a delay in the reversal of the current is the short-circuited coil is which cause sparking at the brushes.

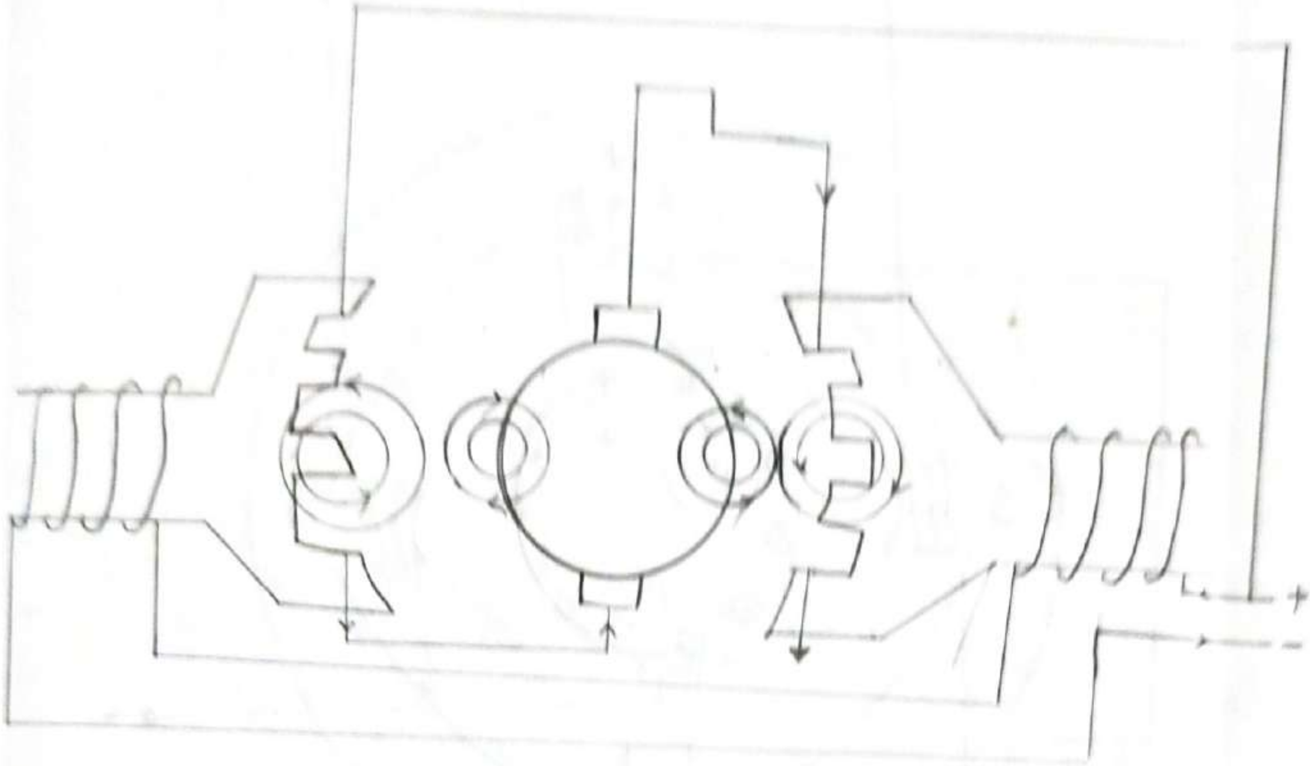
(2). Demagnetising Effect :—

- It reduces the total flux per pole / main flux as it is 180' out of phase to the main flux.
- Reduction in the main flux reduce & the generated emf decreases.

* COMPENSATING WINDINGS :—

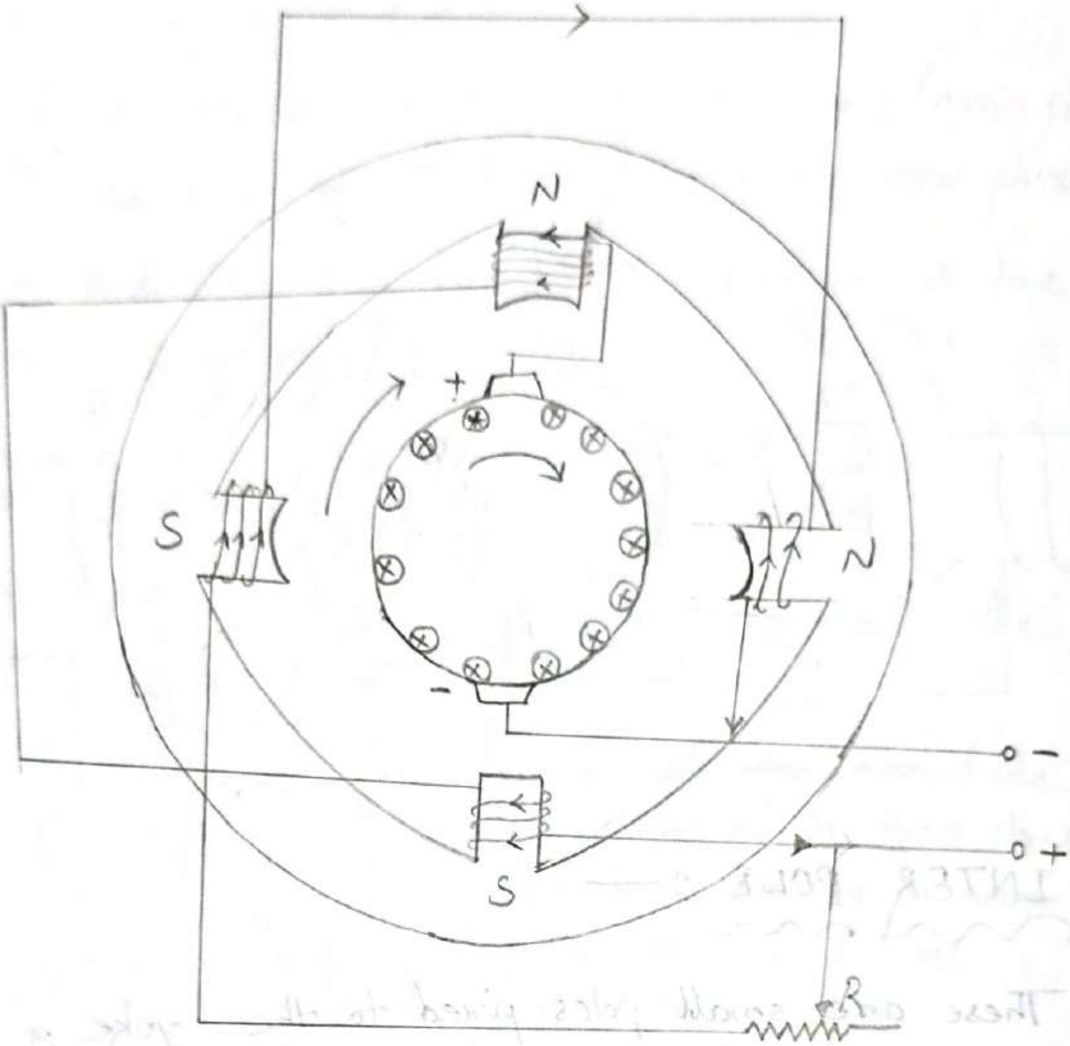
- These windings are embeded in slots in the pole shoes.
- It is connected in series with the armature in such a way that the current in them flows in opposite direction to that flowing in armature conductors directly below the pole shoes.





* INTER POLE :—

- These are small poles fixed to the yoke & spaced in between the main poles.
- They are wound with comparatively few heavy gauge copper wire turns.
- They are connected in series with the armature, so that they carry full armature current
- ~~There are~~
- Their polarity is the same as that of the main pole ahead in the direction of rotation.



→ The flux produced due to the inter pole is equal & opposite to that of the armature conductors under it.

→ Hence this leads to the cancelation of the flux.

→ In this way armature reaction is reduced & generated emf is constant.

(RH:- 04.06.21)

* CHARACTERSTICS OF DC GENERATOR :—

(1)- Open Circuit Characterestics :—

It is the graph drawn between generated emf at no load i.e E_0.

- It is the graph between E_0 & I_f at a fixed speed.

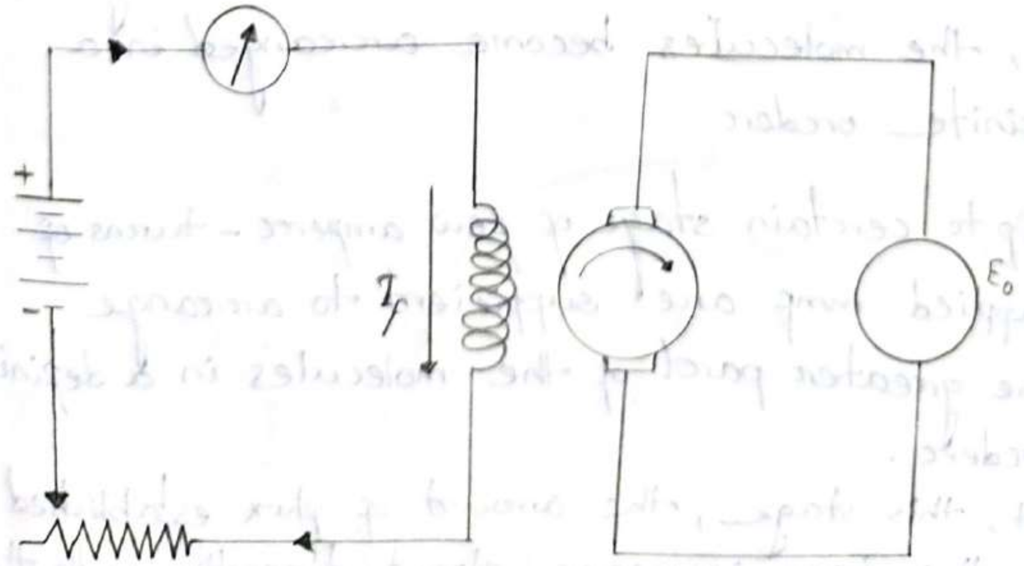
(2)- Internal or Total Characterestics :—

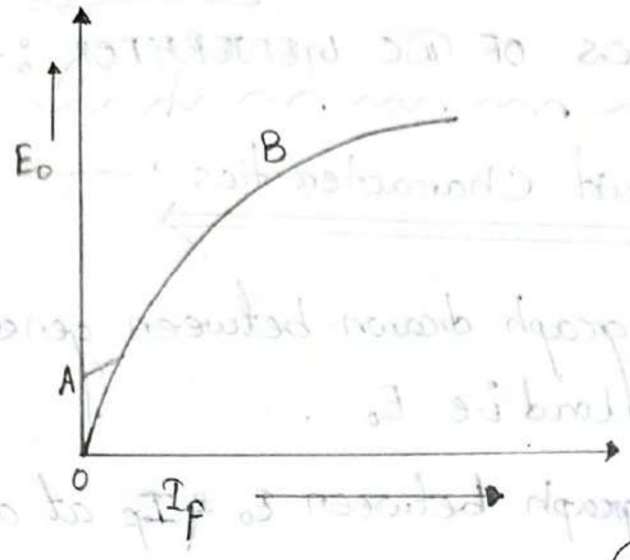
It is the relation between E, emf actually induces in the armature considering the demagnetising effects of armature reaction.

- It is the relation between E & I_a.

(3)- External Characterestics :—

It is the relation between that terminal voltage V & the load current I.





DT:- 08.06.21

* D.C GENERATOR CHARACTERISTICS :—

It gives the relation between terminal voltage & load current.

Based upon this, it is judged for its ~~suitability~~ it suitability for a particular purpose.

* Saturation Point :—

When a current is passed through a coil placed around the iron, in order to magnetise it, the molecules become arranged in a definite order.

- Up to certain stage of few ampere-turns of applied mmf are sufficient to arrange the greater part of the molecules in a definite order.
- At, this stage, the amount of flux established in the iron increase almost directly with the increase A-T applied.

- Above this point, saturation point, at this point, it becomes increasingly difficult to magnetise the iron further since the unmagnetised molecules becomes fewer & fewer.

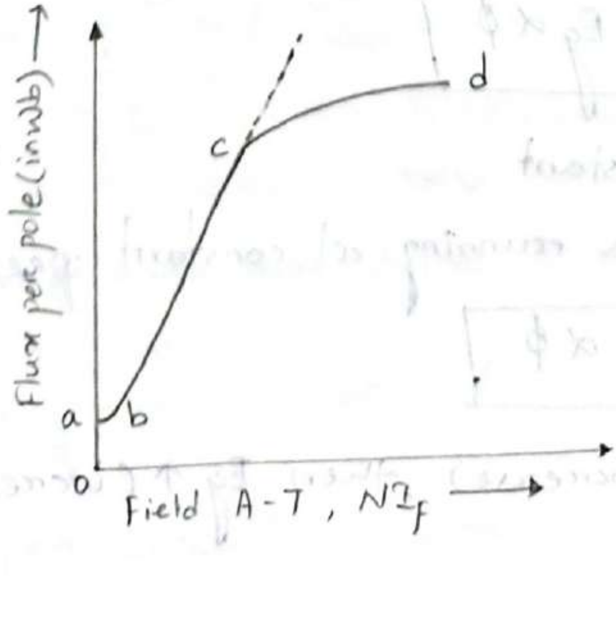
Above the saturation point,

When much larger increase in A-T are required for corresponding increase in the iron, the iron is said to be saturated.

- After saturation it does not mean that a further increase in magnetism is impossible.
- But very large increase in A-T is required for a more increase in magnetisim.

Magnetisation Curve / saturation Curve :-

The curve giving the relation between flux per pole & field ampere-turns per pole is known as magnetisation or saturation curve.



- It does not start from 0, due to residual (ab) magnetisim.

- For lower values of field A-T (NI_f),

$$\text{Flux} \propto NI_f$$

∴ It is straight line (bc)

- At point c → saturation occurs

- After c → curve falls away from straight line due to varying permeability.

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

$$E_g = \phi N\left(\frac{ZP}{60A}\right)$$

$$E_g \propto \phi N$$

For given machine Z, P, A are constant.

If 'N' is constant

$$E_g \propto \phi$$

N = constant

Machine is running at constant speed.

$$E_g \propto \phi$$

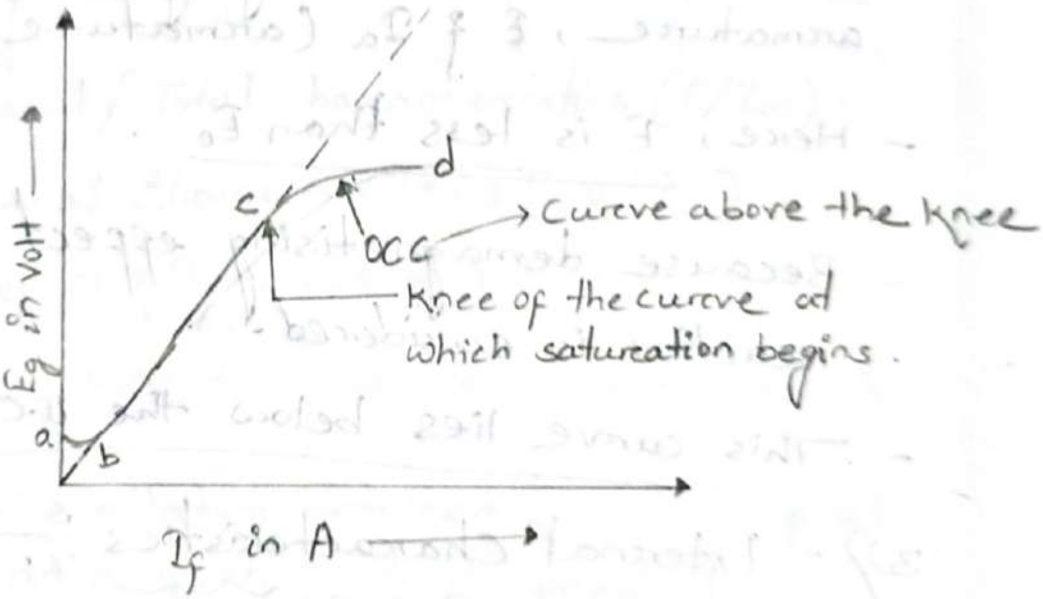
If ϕ ↑ (increase), then E_g ↑ (increase)

- ϕ depends on AT of field

AT of field i.e. I_f

AT of field $\propto I_f$

- When a curve is drawn between E_g at no load & I_f (field current), when the machine is running at a constant speed (N) the curve obtained is called saturation curve / Magnetic characteristics / open circuit characteristics:- (O.C.C)



Mag / OCC

* Characteristis of DC Generator :-

(1) - No-load saturation characteristics.

OR

Magnetic characteristics

OR

Open circuit characteristics (O.C.C)

- It shows the relation between the generated emf at no load i.e E_0 & I_F (field current) at a given speed (N = constant)

- shape of this O.C.C is same for all types of generators (separately excited & self excited)

(2)- Internal / Total Characteristics (E/I_a) :—

It is a curve which gives the relation between the emf actually generated in the armature, E & I_a (armature current).

- Here, E is less than E_0 .

- Because demagnetising effect of armature reaction is considered.

- This curve lies below the O.C.C .

(3) - External Characteristics :— [V & load current]

It gives the relation between terminal voltage V & the load current I under given conditions of speed & excitation.

- The terminal voltage V is less than E .
[due to voltage drop in armature]

$$\boxed{V = E - I_a R_a}$$ voltage drop in armature.

- It is very important for determining the suitability of a generator for a particular service.

* There are 3 characteristics of a DC generator

1 - O.C.C
2 - Internal Characteristics
3 - External characteristics

* CHARACTERISTICS OF SEPARATELY EXCITED DC GENERATOR

(1) - O.C.C [E_0/I_f] at no load & fixed N (speed)
(2) - Internal / Total characteristics (E/I_a)
(3) - External characteristics [V/I_L]
(keep N & I_f constant)

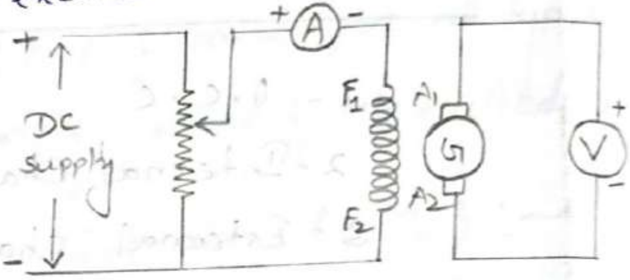
(1) - O.C.C :—

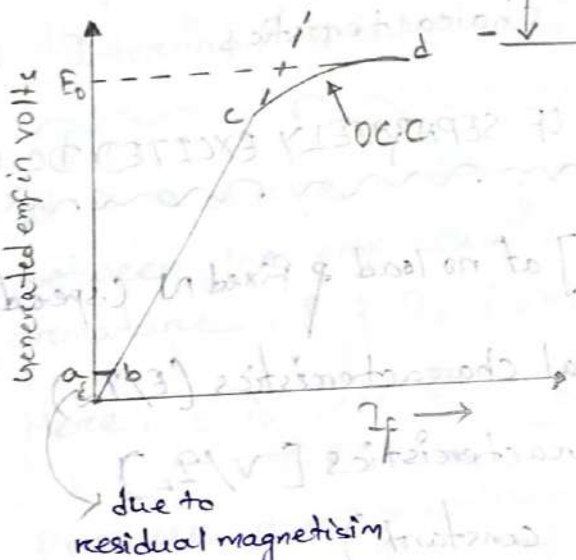
It shows the relation between I_f & E_0 [Emf at no-load at a given constant speed].

- To draw OCC, I_f is increased from 0 to max^m & reading of terminal voltage across armature at no load, E_0 are taken.
- Speed is kept constant.
- $E_0 \propto \phi$ & $H \propto I_f$

$\phi \propto I_f$

- It is similar to magnetization curve or B - H curve for the materials of electromagnets.
- O.C.C is same for all generators whether separately excited / self excited.





$$E_g = \frac{P\phi N}{60}\left(\frac{Z}{A}\right)$$

N = constant

$E_g \propto K\phi N$

$$\boxed{E_g \propto K\phi}$$

(2) - Internal / Total characteristics (E/I_a) :-

- Voltage at terminals of armature is always less than E_0 because of the
  - (i) voltage drop in armature ($I_a R_a$)
  - (ii) Armature reaction (Demagnetising Effect)

→ E = actually induced in the armature considering the demagnetising effect of armature reaction.

$E = E_0$ - Voltage drop due to armature reaction.

- $\boxed{E < E_0}$

- This characteristics shows the relationship between E & I_a.
- It is of interest mainly to designer/manufacture & it can't be obtained directly by performing experiment because it is not possible to measure E with voltmeter.
- It gives slightly a dropping characteristics curve - II.
- The straight line OA → I_aR_a drops at different I_a.

(3) External Characteristics :— (V/I_L)

It gives the relation between terminal voltage V & the load current I_L.

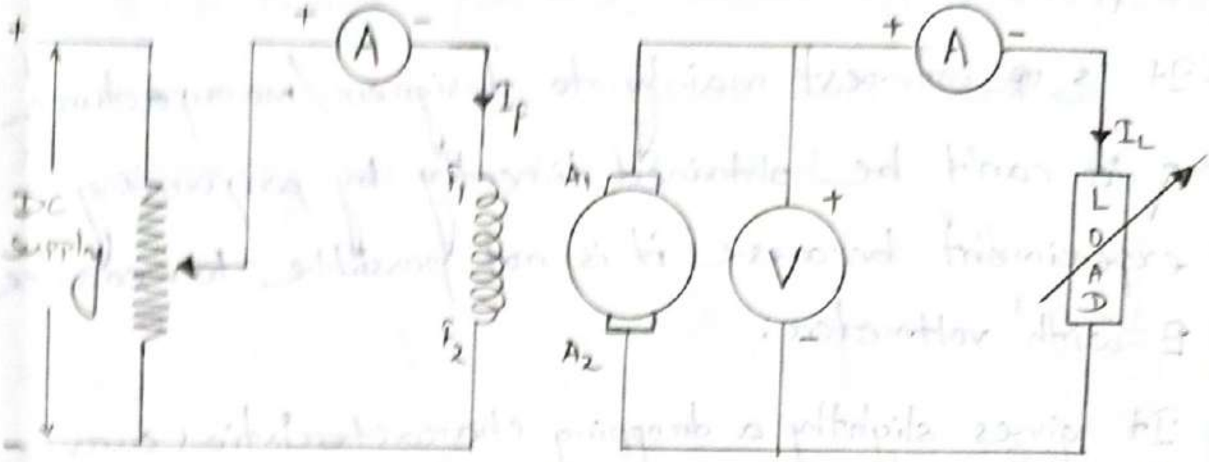
$$V = E - I_aR_a$$

→ $V < E$, so external characteristics lies between internal characteristics.

→ $V < E < E_0$

→ It is most important while selecting appropriate generator for specific purpose/application.

→ It can be plotted by actually loading the generator & taking reading of the terminal voltage V & I_L.



Generator is run with the primeover at a constant speed (rated speed).

N = constant

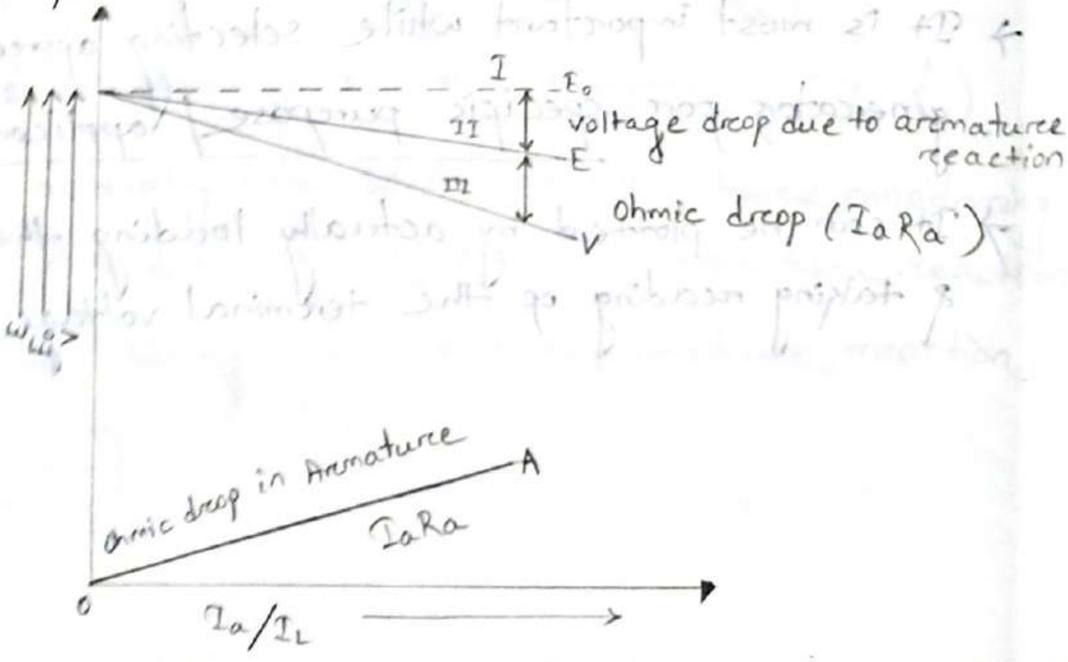
I_f = constant

ϕ/pole = constant

- The load is increased in steps from no load to full load.

∴ V can be noted for various values of load current I_L.

- External characteristics can be plotted I_f is independent of I_L.



Curve - I

I_f / exciting current / field current is independent of I_L or I_a.

- It is drawn between E_0 & I_L/I_a.
  neglecting armature reaction, armature drop & keeping I_f constant.

Curve - II

Due to armature reaction, the curve is slightly droping.

It is the internal characteristics.

Curve - III

$$V = E - I_a R_a$$

Line OA → $I_a R_a$

Line OA is deducted from curve - III

we get curve - III → external characteristics.

[This decrease in V can be neutralised by increasing field current slightly & ∴ constant V can be maintained]

$$\boxed{\text{curve III} = \text{curve II} - I_a R_a}$$

Advantages :—

It operates in a stable condition with any field excitation. ∴ a wide range of O/P can be obtained. ∴ It is used for experimental & testing laboratories.

* CHARACTERISTICS OF SERIES WOUND DC GENERATOR

Series field winding in series with DC generator

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

$$E_g = V + I(R_a + R_{se})$$

$$V = I_L R_L$$

$$E_g = V + IR_a + IR_{se}$$

$$E_g = I_L R_L + IR_a + IR_{se}$$

$$E_g = I_L(R_L + R_a + R_{se}) \quad [\because I_a = I_{se} = I_L]$$

$$I_L = I_a = I_{se} = \frac{E_a}{R_a + R_{se} + R_L}$$

$$\phi \propto I_{se} = I_a = I_L$$

∴ ϕ depends on I_L.

Under no Load condition :-

$I_L = 0$

If $I_L = 0$, $I_{se} = I_a = 0$

There will be no flux,

There will be no drop, $I_a R_a = 0$

$I_{se} R_{se} = 0$

$$\boxed{E_g = V = E_{gr}}$$

E_{gr} → residual flux emf.

In series generator, voltage build up process under lightly loading condition.

Magnetisation Curve :-

$I_L = I_{se} = I_a$

- Here a light load is taken,
  R_L is fixed.

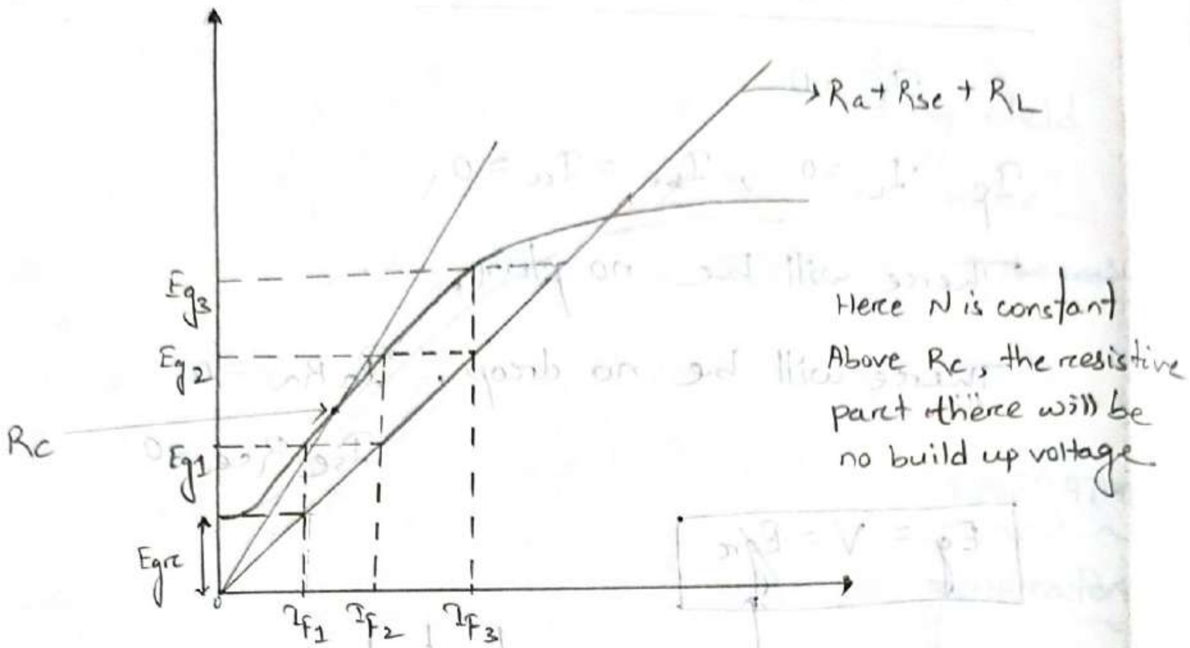
- When the switch is ON, the load is connected load current flows due to E_{gr}, then mmf (NI_{se}) ~~will~~ will be created ϕ will generate.

$$\boxed{I_L = I_a = I_{se} = \frac{E_g}{R_a + R_{se} + R_L}}$$

($R_a + R_{se} + R_L$) → are fixed

So, I_L depends on E_g.

If $E_g \uparrow$, then $\uparrow I_L$



This voltage build up process when the field resistance line crosses it.

$$E_g = I_a \times (R_a + R_{se} + R_L)$$

$(R_a + R_{se} + R_L)$ max. value up to R_c.

up to which one can developed build up voltage.

$$\boxed{E_g = K\phi N} \quad (\because N = \text{Fixed})$$

External & Internal characteristics :—

Value of R_{se} is very small as it has to carry load current so no. of turns is less with thick wire.

- so there is not so large effect on drop i.e $I_L(R_{se} + R_a)$.
- When $I_L \uparrow$, ϕ through field winding increases,

$\therefore E_g \uparrow$

$$\uparrow \boxed{V = \uparrow\uparrow E_g - \downarrow I_L (R_a + R_{se})}$$

- The increase in E_g is greater that the drop.
- Upto saturation of field winding the external characteristics is straight / linear.
- But after saturation, the curve terminal voltage decreases with increase in I_L & fall to 0.

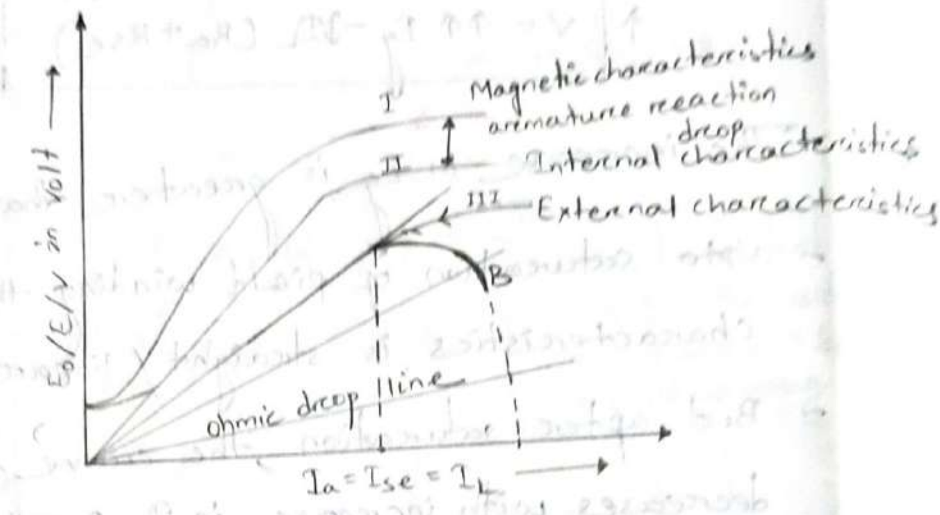
External Characteristics

- Straight portion
  - It gives voltage approximate proportional to I.
  - Here load is varied.
- Drooping portion (Because ϕ becomes constant)
  - It gives constant current irrespective of load ckt R.
  - N is constant.

- After saturation,

  ϕ is constant

  So, E_g will be constant



Curve-I,

Magnetic characteristics - (E_0 Vs I_{se})

Curve-II,

Internal characteristics (E Vs I_a)

Curve-III

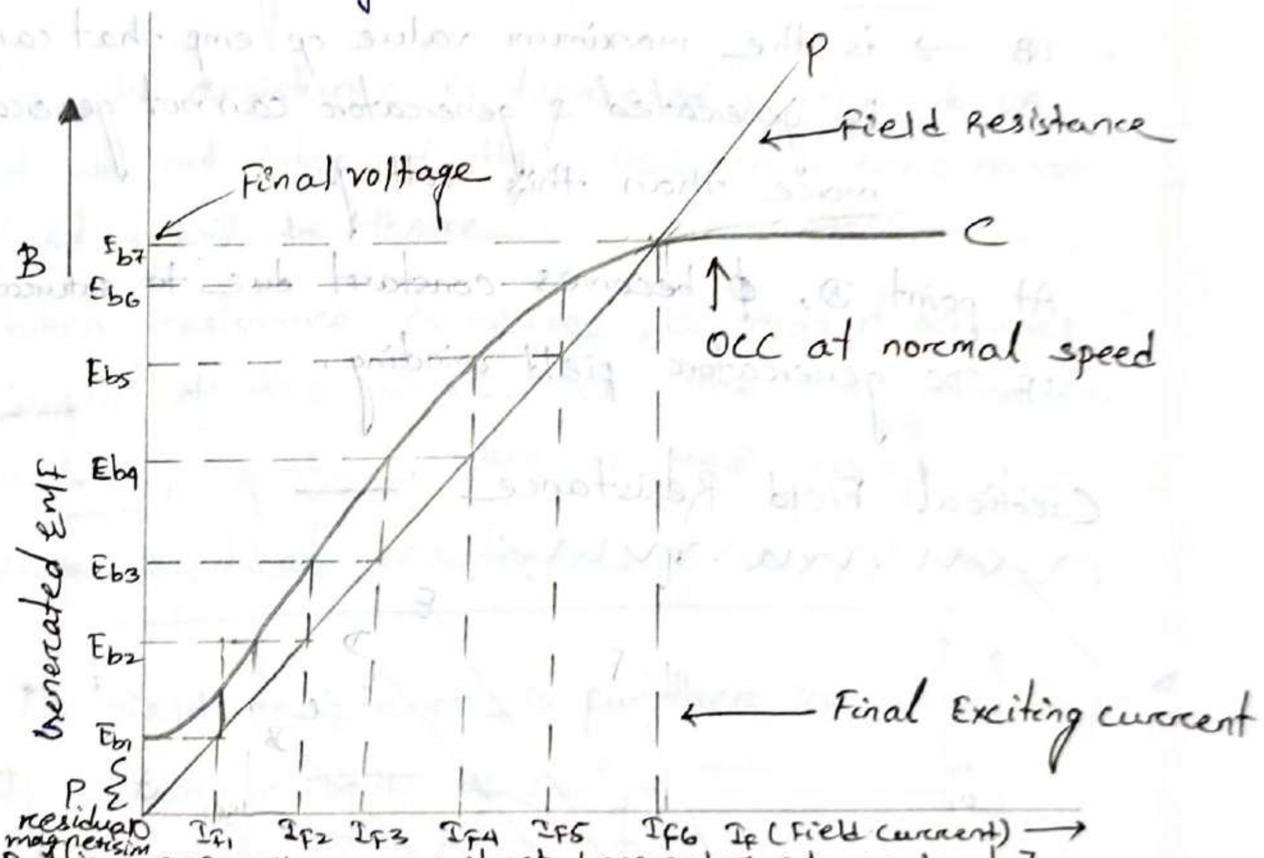
External characteristics (V Vs I_L)

Dt:- 29.06.21

* CHARACTERISTICS OF SHUNT WOUND DC GENERATOR :-

Build Up Of Voltage Of A Shunt Generator At No Load :-

- Curve plotted between the generated emf and shunt field current.
- Generator excites itselfs due to residual magnetisim & develops voltage.



[Building up of voltage of a shunt generator at no load]

- OP - shunt field resistance.
- The armature is rotated at the rated speed (at a fixed speed) with no load.
- N = constant
  no load.
- A small emf E_{gr} is induced due to residual magnetisim.

- This E_{g2} causes I_{f_2} to flow in the field circuit.

- When field current is I_{f_2}, the generated emf is E_{g2}.

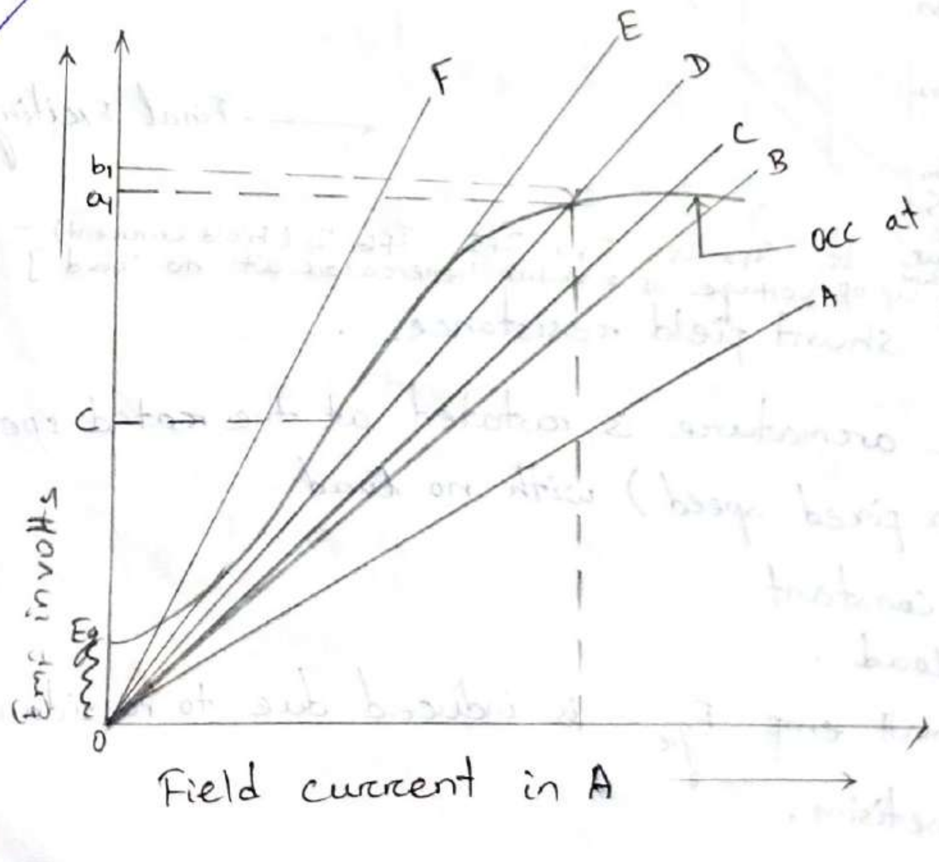
- Thus, the effect is cumulative & value of induced emf & field current increases until these reach point D.

- Point D → Point of intersection of the shunt field resistance line & O.C.C obtained.

- OB → is the maximum value of emf that can be generated & generator can not generate more than this voltage.

- At point D, ϕ becomes constant due to saturation of DC generator field winding.

Critical Field Resistance :—



- Maximum voltage which a generator can generate is given by point of intersection of field resistance line with the O.C.C.

- If line OD intersects OCC, it represents the field resistance line.

∴ OO_1 → Max^m. emf generated.

- If field resistance is decreased to OC, the max^m. generated emf will be Ob_1.

- If the resistance is decreased further to OA, it will not intersect the OCC, it means no voltage build up will be there.

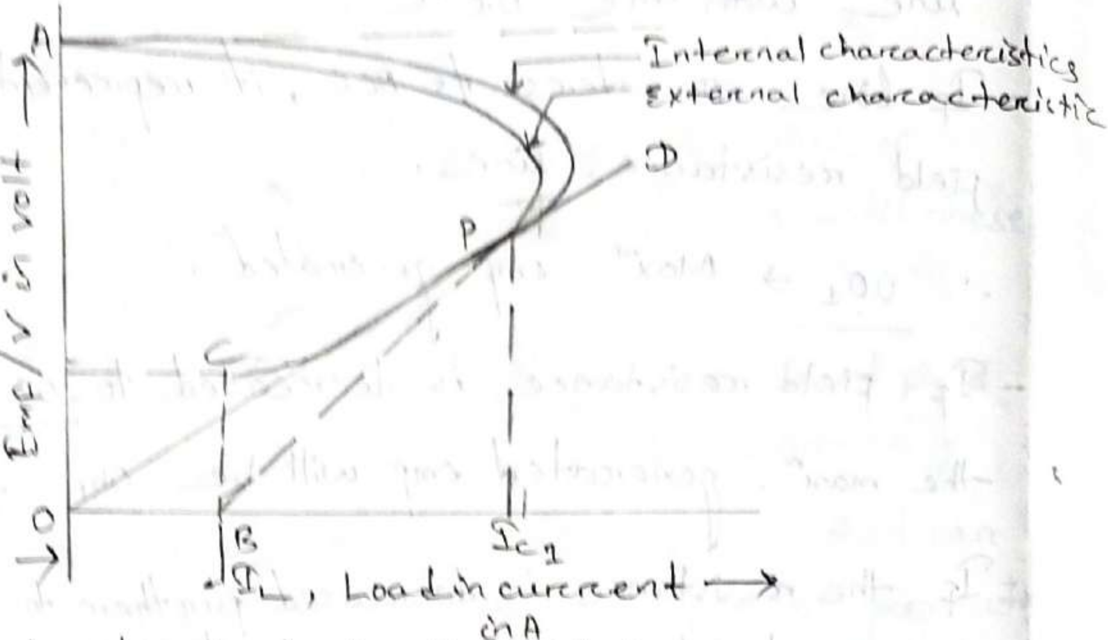
- When resistance increases, so that it becomes tangent to the curve OCC, the emf generated is OC_1, & the value of resistance is called ~~critic~~ critical resistance (R_c) → OE.

- If field resistance is further increased to OF, the voltage build up ≃ E_{gr}.

- It is not sufficient to voltage build up.

- For voltage build up, the field resistance must be less than R_c.

External & Internal Characteristics :—



Current under short circuit condition.
(Here, V=0, but $I_L = I_a = \frac{E_g}{R_a}$)

- terminal voltage at no load;

$$\boxed{V = E_0} = OA$$

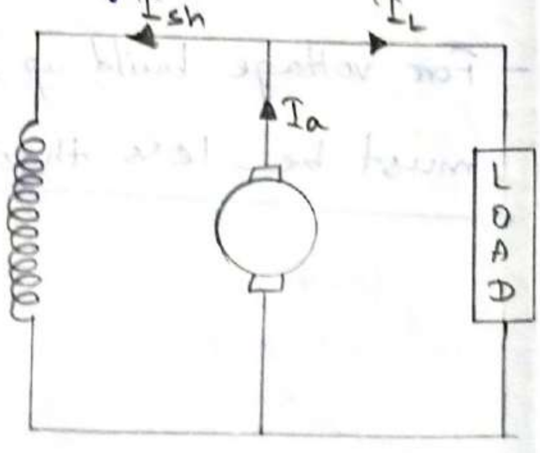
- I_L depends upon R_{sh}.

$$\boxed{\uparrow I_L = \frac{V}{R_{sh}\downarrow}}$$

- I_L is increased by decreasing R_{sh}.

$$\boxed{\uparrow I_a = \uparrow I_L + I_{sh}}$$

- $$\boxed{\downarrow V = E_0 - \uparrow I_a R_a}$$



- With increases in I_{a_1}, voltage drop across armature winding & the contact resistance of the brushes.
- Upto I_{L_1} V decreases with increases in I_{L_1}.
- After I_{L_1}, the effect of armature reaction is significant.
- So, due to the demagnetising effect of armature reaction, the field is ~~weakend~~ & weakened & value of induced emf reduces & there by terminal voltage falls.

$$(\downarrow\downarrow)(\uparrow) I_L = \frac{\downarrow\downarrow V}{\downarrow R_{sh}}$$

∴ Reduction is terminal voltage is dominating, after I_{L_1}, the I_L reduces, & after some time V reduces to 0.

- Effects are cumulative.
- In the beginning, the effect of decrease in resistance predominates over the effect of V (terminal voltage).
- But, when the load current reaches a certain value (I_{L_1}) the demagnetising effect predominates, so further decrease in load resistance causes a decrease in current rather than increase.

∴ characteristics turns back.

(1) - Why the shunt generators are self - protective against accidental short - circuit ?

Ans When terminal voltage becomes 0, the terminals are short circuited, we know that, $I_{sh} = \frac{V}{R_{sh}} = \frac{0}{R_{sh}} = 0$

$$\boxed{I_{sh} = 0}$$

- The shunt winding becomes inactive.

If $I_{sh} = 0$, Flux $= 0$

Only residual magnetisim is left.

so emf generated = $E_{gr} = BC$

- The external characteristics meets the current axis at point B.

Short - circuit current = OB

(2) - Why shunt generator often fail to build up after they have been shut down through a severe type of short - circuit ?

Ans At short - circuit, V=0 & Short - circuit I = OB

Actually emf generated due to residual magnetisim = BC = E_{gr}

- This E_{gr} is completely neutralisation by armature reaction.

- Sometimes it may even be reversed.

* Critical Load Resistance :—

When demagnetising effect of armature reaction ~~is ionis ionc ionsider~~ is considered, then ~~it~~ internal characteristics is obtained between E & I_a.

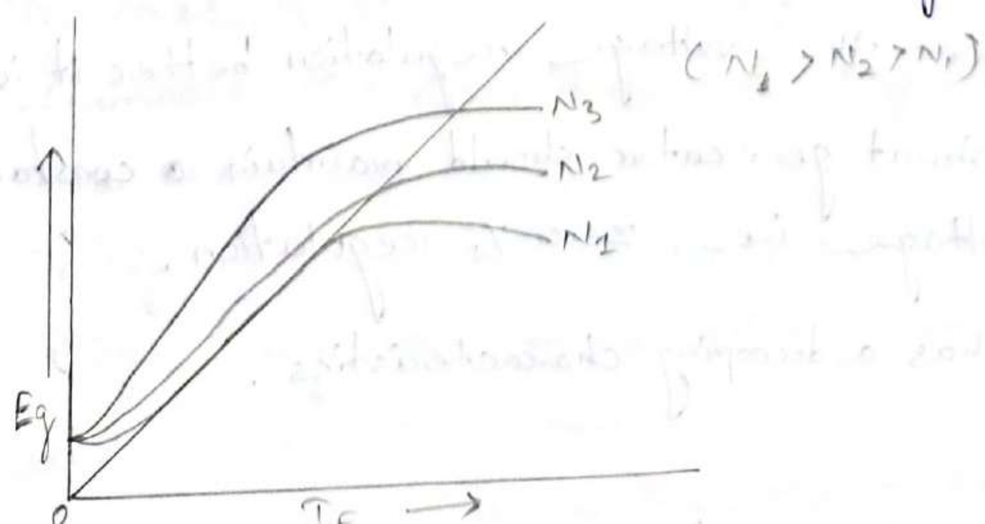
$$E = E_0 - \text{Armature Reaction Drop}$$

- If a line from the origin 0 is drawn tangential to internal characteristics curve, the gradient of this line will give the minimum value of the external load.

* Determination of ~~Crid~~ Critical Speed :—

Critical speed of shunt wound DC generator is that speed for which the given shunt field resistance will represents the critical field resistance.

- Below, N_c, there will be low emf generated.



We know that,

$$E_g \propto \phi N$$

$$E_g \propto N$$ (ϕ is fixed)

- Value of R_{sh} is tangent to the OCC having speed N_1. Up to that N can be varied speed N_1 is called N_c.

---

* Voltage Regulation :—

It means the change in its terminal voltage from full load to no-load as a percentage of the terminal voltage at full load.

i.e,

$$\% \text{ voltage Regulation} = \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100$$

- It is used for determining the performance of the generator.
- Lower the voltage regulation better it is.
- A shunt generator should maintain a constant voltage i.e, zero % regulation.
- It has a drooping characteristics.

* There are 3 main reason for the drop in terminal voltage of a shunt generator when under load —

(i) - Armature R drop :—

As $I_L \uparrow$, more & more V is consumed in the Ra.

∴ $V = E - I_a R_a \uparrow$ is decreased where

E = induced emf in the armature under load condition.

(ii) - Armature Reaction Drop :—

Due to demagnetising effect of armature reaction, pole flux is weakened & so the induced emf in the armature is decreased.

(iii) - Drop in V due to (i) & (ii) results in, Increase is I_f which further reduces E.

* CONTROL OF TERMINAL VOLTAGE OF DC SHUNT GENERATOR :

It should maintain a constant voltage across its terminals irrespective of the magnitude of load being supplied by it.

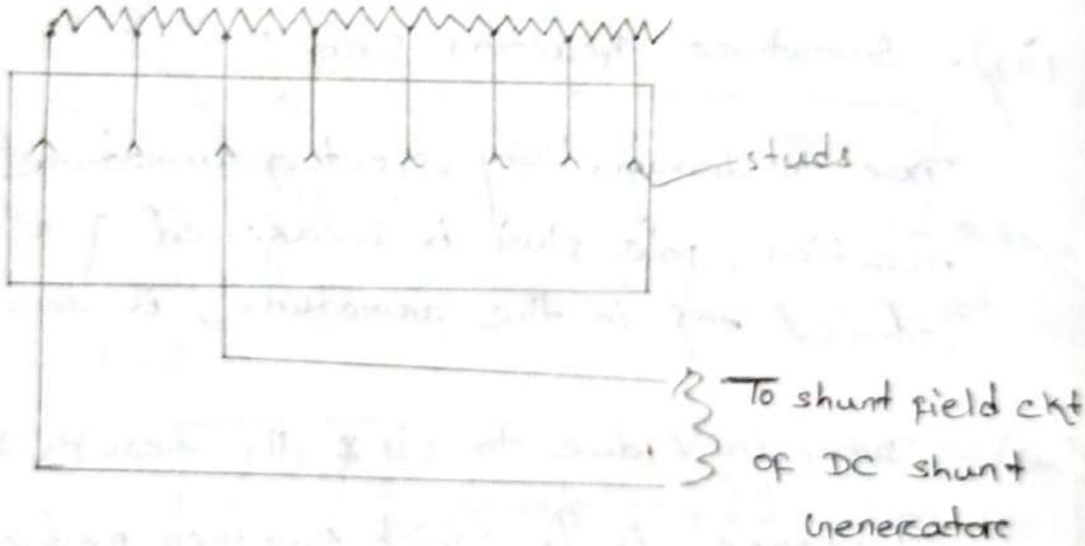
- To regulate the voltage o/p of a generator

(1) by using the speed (it is undest

(2) " " the magnetic flux

↓ This is the only method.

- It can be done by inserting an adjustable resistance in series with shunt field ckt.
- Value of adjustable resistance is approx equal to the resistance of field coils. [to obtain a wide range of control of the I_f & thereby a wide range of control of E]
- This adjustable resistance is called the shunt field regulator.



- It is remote from generator.
- It is placed in some easily accessible position.
- It is easily accessible consists of wire spirals mounted in a metal frame.

* CHARACTERISTICS OF DC COMPOUND WOUND GENERATOR :-

- Electrical appliances are designed to operate at constant voltage.
- A shunt generator is undesirable, because its terminal voltage decreases as the load on it increases [drooping voltage characteristics]
- It can't even used for the transmission of the power —
  1- Voltage drop in line E.
  2- Greater the load, greater the volt drop in the line.
- A shunt generator may be mades to supply substantially constant voltage or (even a rise in voltage as the load increases) by adding to it a few turns joined in series with either the armature or the load.

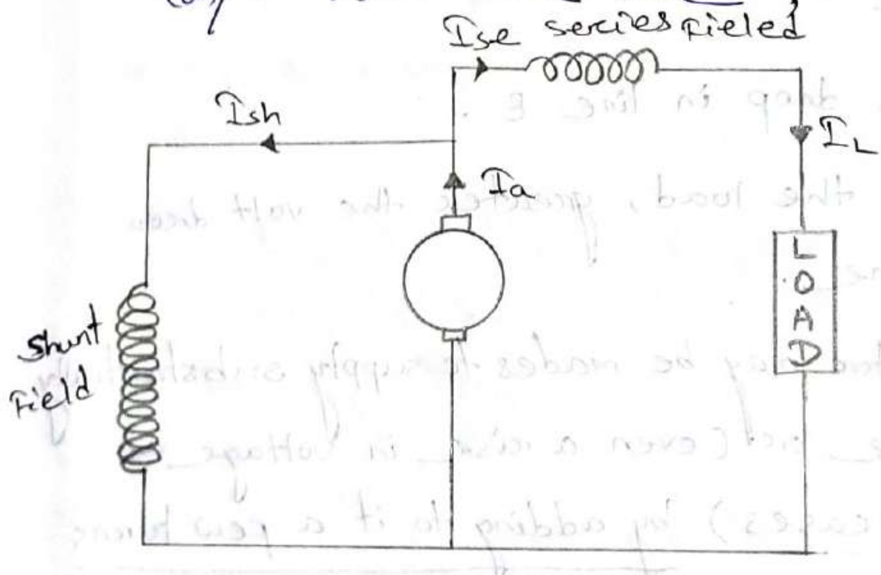
- As the load current (I_L) ↑, (current series field winding) I_{se} ↑ & there by ϕ ↑ & E ↑.
- By adjusting the no. of series turns or series ATs, this increase in emf can be made to balance the combined voltage drop in the generator due to armature reaction & armature drop.

- Hence, V remains practically constant.
- It means I_f is almost unchanged.

Cumulative Compound Wound DC Generator :-

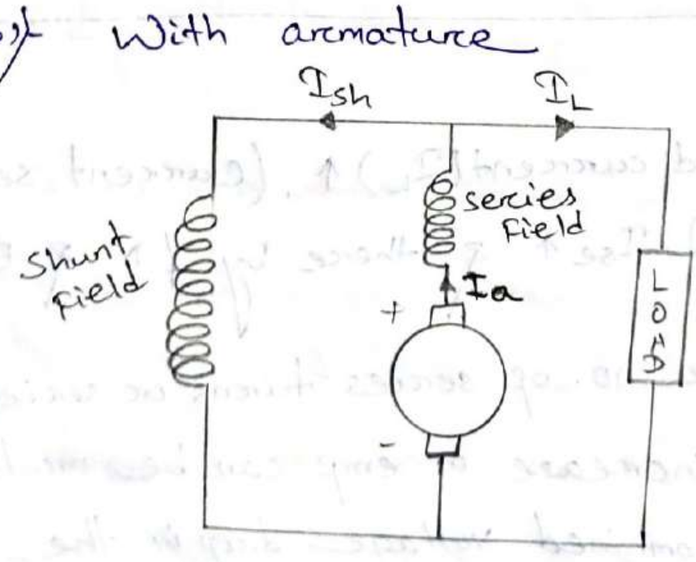
It has an additional wdg - series field winding connected in series either

(a) - With the line



Short - shunt compound wound Generator

(b) - With armature



$I_a = I_{se}$
Here I_{se} is greater long shunt.

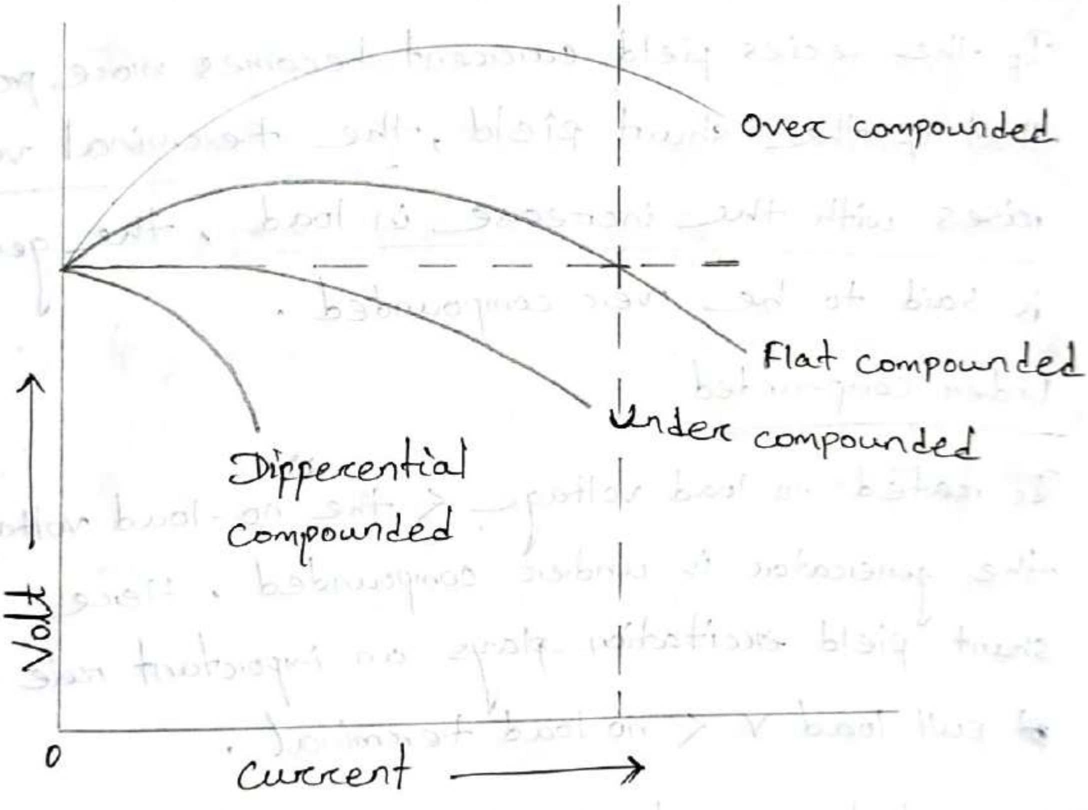
Cumulative $\longrightarrow \phi_{sh} + \phi_{se}$

- Flux due to I_{se} add to the flux due to I_{sh} to compents for fall in V due to

(1) - Armature Reaction

(2) - Armature ckt drop.

- I_{se} in long shunt > I_{se} in short shunt
- It combines the characteristics of both series & shunt.



* Flat Compound :-

At no load the shunt field winding provides all the field flux.

- With the increases in load in the generator, the series field adds an increasing amount of field flux to that of shunt field.
- Here if the series excitations is such that the terminal voltage of the generator on full load that

on no-load, the generator is said to be level or flat compound.

* Here, the v is not constant for all loads from no loads to full loads.

- From the diagram, at half full load, V is more that no load (or full load) terminal voltage.

[It is used for loads at short voltages]

Over compounded

If the series field current becomes more prominent that of the shunt field, the terminal voltage rises with the increase in load, the generator is said to be over compounded.

Under compounded

If rated no load voltage < the no-load voltage, the generator is under compounded. Here shunt field excitation plays an important role & full load V < no load terminal.

Differential Compound Wound Generator :—

- $\phi_R = \phi_{sh} - \phi_{se}$

- Here, Flux produced by series field opposes flux produced by shunt field winding.

- This is accomplished by interchange the connections of series field winding.

- Here,

(a) - The E on no-load would be the same as for the shunt field generator because series field does not create any flux.

(b) - When the generator is loaded, load current or armature current flows through the series field windings creating magnetic flux that opposes that flux created by shunt field.

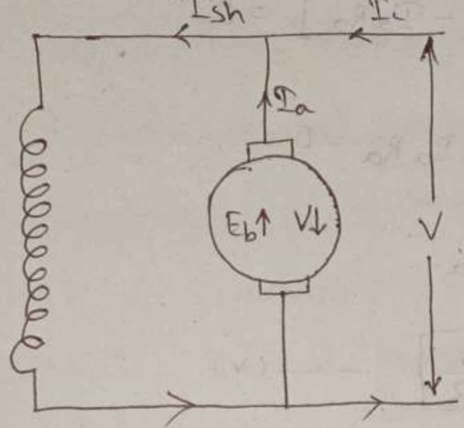
∴ E↓ & V↓ with increase in I_L (Load current)

∴ A short-circuit can not cause any damage to it.

Dt:- 18.06.21

DC MOTOR

* Voltage Eq^n of a DC Motor :—



$V = E_b + I_a R_a$ ——— (i)

$V I_a = E_b I_a + I_a^2 R_a$ ——— (ii)

Motor Efficiency $= \frac{E_b I_a}{V I_a} \times 100$ ——— (iii)

Higher the value of E_b, more is the efficiency.

* Condition For Max^m power :—

$E_b I_a = P_m$ = gross much power

$V I_a = P_m + I_a^2 R_a$

$\Rightarrow P_m = V I_a - I_a^2 R_a$ ——— (iv)

(Differencenting eq^n -IV w.r.t I_a

$$\frac{dP_m}{dI_a} = 0$$

$$\Rightarrow \frac{d}{dI_a}\left[VI_a - I_a^2 R_a\right] = 0$$

$$\Rightarrow V - 2I_aR_a = 0$$

$$\Rightarrow V = 2I_aR_a$$

$$\Rightarrow \boxed{I_aR_a = \frac{V}{2}} \quad \text{——— (v)}$$

$$V = E_b + I_aR_a$$

$$\Rightarrow V = E_b + \frac{V}{2} \quad (\text{From eq}^n \text{ (v)})$$

$$\Rightarrow E_b = V - \frac{V}{2}$$

$$\Rightarrow E_b = \frac{2V - V}{2}$$

$$\Rightarrow \boxed{E_b = \frac{V}{2}} \quad \text{——— (vi)}$$

$\because P_m$ will be maximum.

* Types Of DC Motors :—

(1)- Permanent Magnet Motor

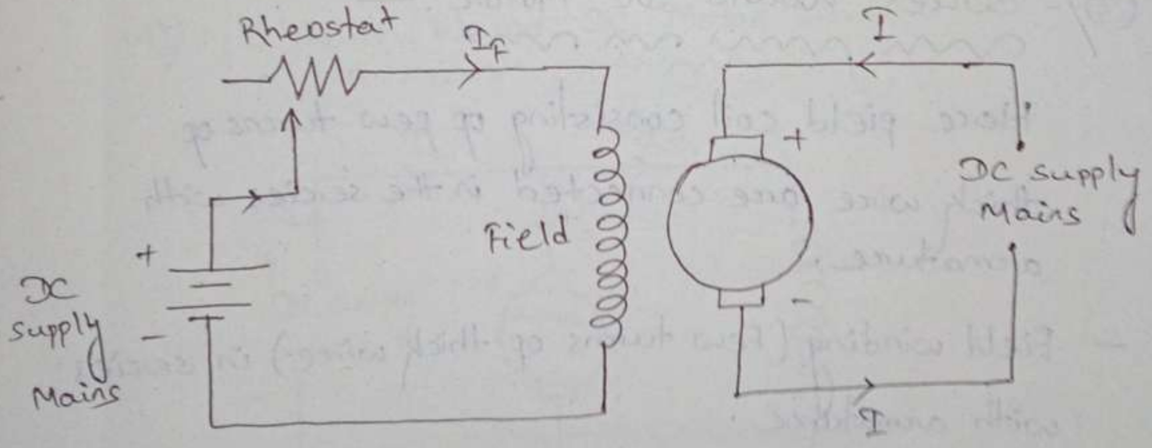
(2)- Separately excited Motor

(3)- Series Wound Motor

(4)- Shunt Wound Motor

(5)- Compound Wound Motor

(2)- Separately Excited Motor :—



- Separately excited DC motor, these motors have field coil.
- The armature & field coils said from different supply source.
- Armature current (I_a) = Line current (I_L)

Back emf here developed.

We know that, $V = E_b + IR_a$

or $E_b = V - IR_a$

Power drawn from supply mains, $P = VI$

V= Supply voltage

Mechanical power developed (P_m) =

Power input to Armature - Power loss in Armature

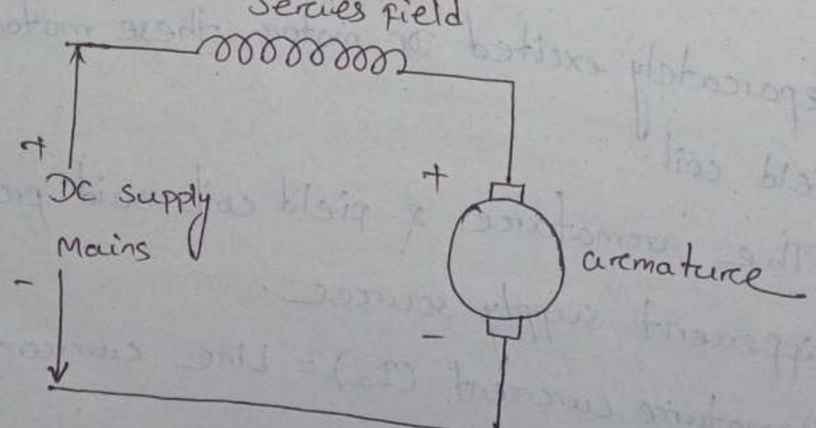
$\Rightarrow P_m = VI - I_a^2 R_a$

$\Rightarrow \boxed{E_b I_a = VI - I_a^2 R_a}$

(3) - Series Wound DC Motor :—

Here field coil consisting of few turns of thick wire are connected in the series with armature.

- Field winding (Few turns of thick wire) in series with armature.



$$I_a = I_{se} = I_L = I \quad (\text{assume})$$

I_L = Line Current

Back emf developed, $E_b = V - I(R_a + R_{se})$

Power drawn from supply mains, $P = VI$

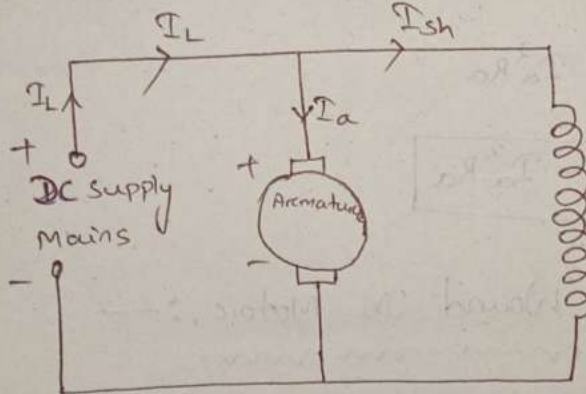
Mechanical Power developed,

P_m = Power input armature − Loss in armature

$= VI - I^2(R_a + R_{se})$

$$\Rightarrow E_b I = VI - I^2(R + R_{se})$$

(4) - Shunt Wound DC Motor :—



Here field coils are connected in parallel with the armature.

- Field winding → Large no. of turns & thin wires, so as to provide larger resistance.

Input current, $I_L = I_a + I_{sh}$

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

V = Supply Voltage

$V = E_b + I_a R_a$

$\Rightarrow \boxed{E_b = V - I_a R_a}$

Power drawn from the supply mains, $P = VI_L$

Mechanical power developed, P_m =

P_m = Power input to armature − Losses in armature & shunt field

$\Rightarrow P_m = VI_L - I_a^2 R_a - VI_{sh}$

$\Rightarrow P_m = V(I_L - I_{sh}) - I_a^2 R_a$

$= VI_a - I_a^2 R_a$

$\Rightarrow \boxed{E_b I_a = VI_a - I_a^2 R_a}$

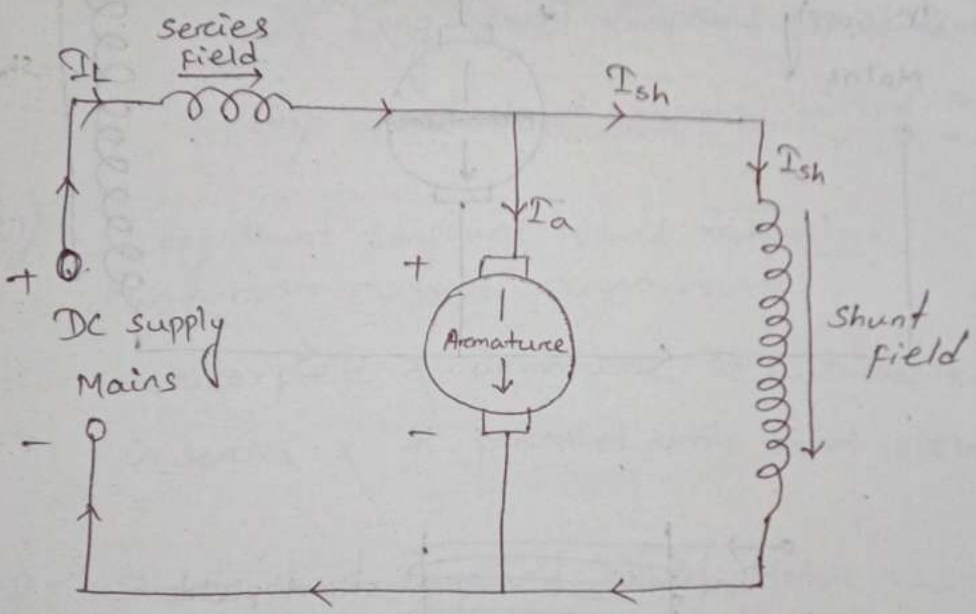
(5) - Compound Wound DC Motor :—

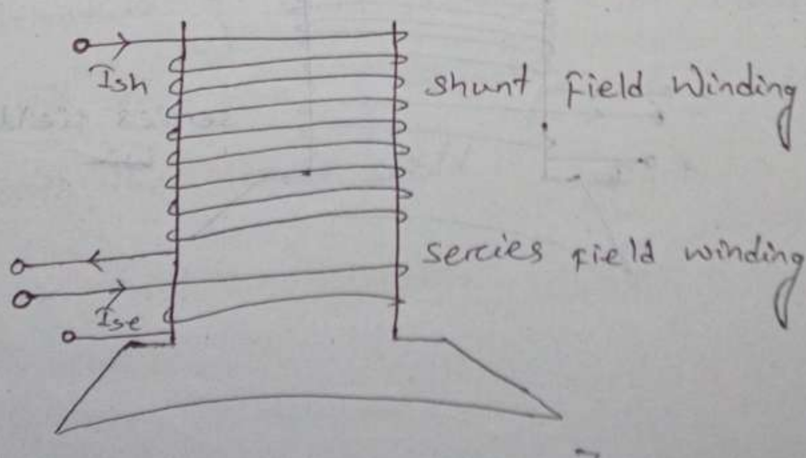
- It has both series & shunt field coils.
- Basically it is of 2 types;
  - (a) - Cumulative Compound Wound Motor
  - (b) - Differential compound Wound Motor

(a) - Cumulative Compound Wound Motor :-

Here field windings are connected in such a way that the direction of flow of current is same in both of the field windings.

- Here flux due to series field winding strengthens the field due to the shunt field winding.

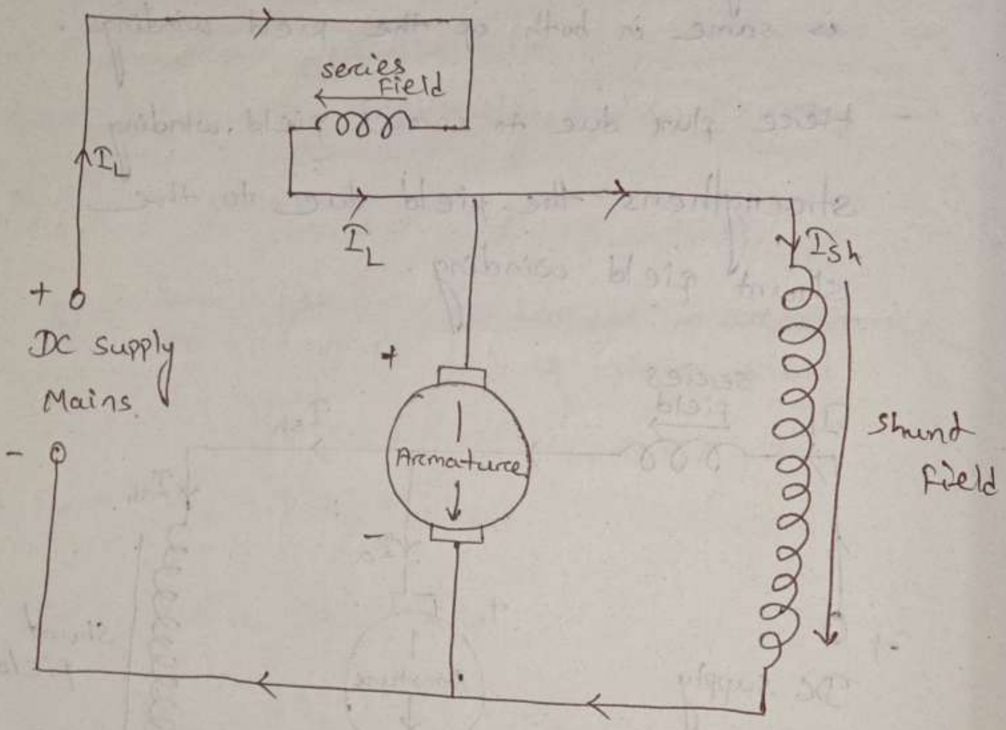


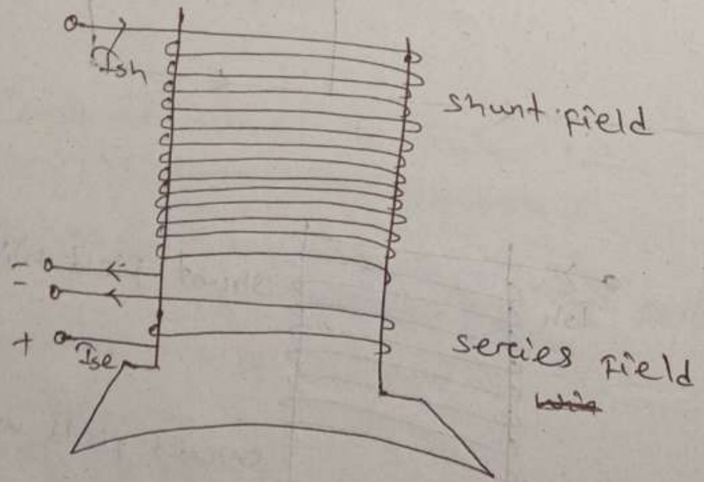


[Winding Connection diagram]

~~(b) Diffe~~

(b) - Differential Compound Wound DC Motor :—





Here the field windings are connected in such a way that the direction of flow of current is opposite to each other in the two field winding.

- Hence flux due to series field winding weakens the field due to shunt field winding.

- Compound wound DC motor, it can also be classified into,

(i) Long shunt Compound Wound Motor

(ii) Short shunt compound Wound Motor

(i) - Long Shunt Compound Wound Motor :-

series field & armature are connected in series & in parallel with shunt field.

(ii) - Short shunt Compound Wound Motor :-

Armature & shunt field are in parallel with each other & the pair is in series with the series field.

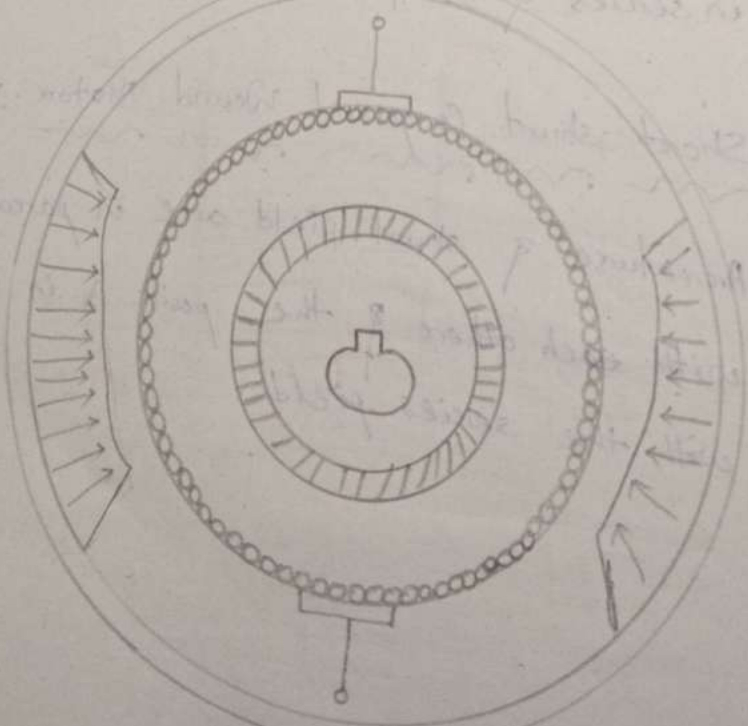
(1) - Permanent Magnet DC Motor :— (PMDC)

It is a DC motor whose poles are made of permanent magnets i.e field flux is required in the air gap of a PMDC motor is developed by set of permanent magnet fixed to the stator.

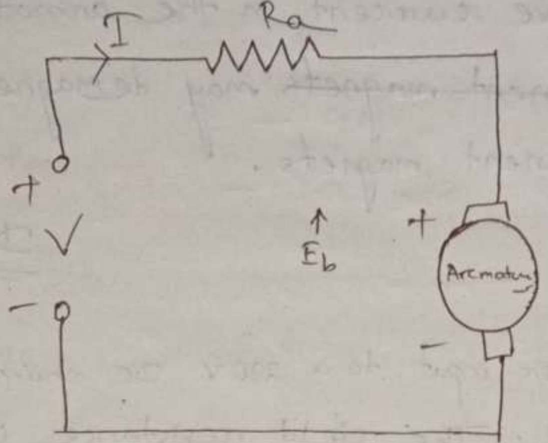
- The permanent magnets are radially magnetisied & are mounted on the periphery of the cylindrical steel stator.

- The stators serve as a return path for the magnetic flux. Here field coils are not required.

- It consists of armature core, armature winding, commutator, brushes.



A two Pole PMDC Motor



[Equivalent Circuit of a PMDC Motor]

Since field flux is developed by permanent magnets, the field winding is not shown in the equivalent circuit.

- It operates on 6V, 12V or 24V dc supply obtained from batteries or rectifiers.
- Here the torque is developed by interaction between current carrying rotor conductor & the magnetic flux setup by the permanent magnets.

Advantage :-

- They don't have any field winding so they require no excitation current.
- There is no contineous loss of energy in the field.

Dis-Advantages :-

Excessive current in the armature winding ~~permanent magnets~~ may demagnetised the permanent magnets.

Problem-1 — Dt:- 24.06.21

The power input to a 230 V DC shunt motor is 8.477 kW. The field resistance is 230 Ω & armature resistance is 0.28 Ω. Find the input current, armature current & back emf.

Given,

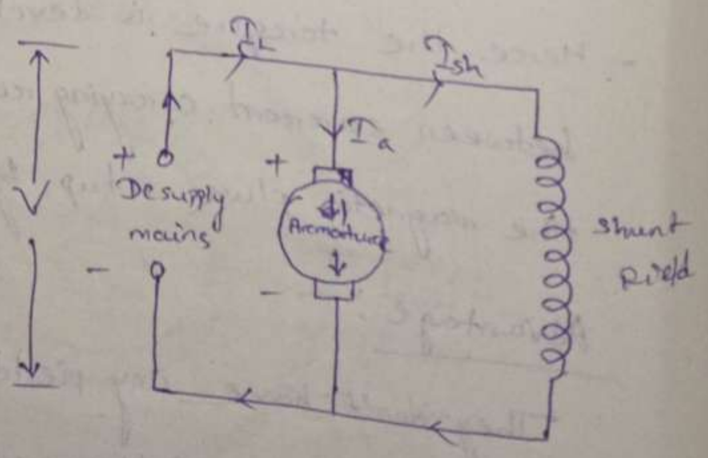
Power input, $P = 8.477$ kW

$= 8477$ W

Supply voltage, $V = 230$ V

$R_{sh} = 230\,\Omega$

$R_a = 0.28\,\Omega$



Soln

$P = VI_L$

$\Rightarrow I_L = \frac{P}{V} = \frac{8{,}477}{230}$

$= 36.86$ A

We know that,

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

$$I_{sh} = \frac{V}{R_{sh}} = \frac{230}{230} = 1A$$

$$I_a = I_L - I_{sh}$$

$$= 36.86 - 1 = 35.86\ A$$

Back emf, $V = E_b + I_a R_a$

$$E_b = V - I_a R_a$$

$$\Rightarrow E_b = 230 - 35.86 \times 0.28$$

$$= 230 - 10.04$$

$$\Rightarrow E_b = 219.96\ V$$

Problem-2

A 230 V series motor is 50 A. Resistance of armature & series field winding is 0.2 Ω & 0.1 respectively. Calculate (1). Brush voltage

(2). Back emf

(3). Power wasted in armature

& Mechanical power developed.

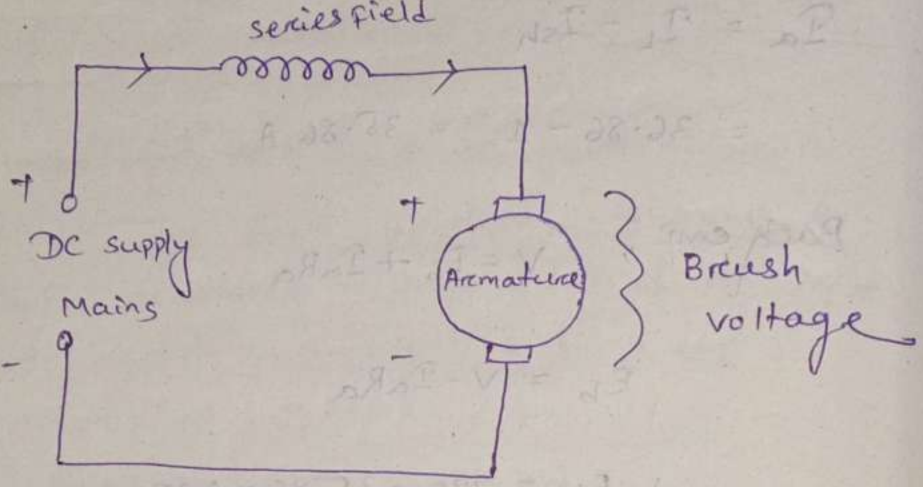
Given,

Supply voltage, $V = 230V$

Supply current / Input current $= 50A$

$R_a = 0.2\Omega$

$R_{se} = 0.1\Omega$ $\quad I_L = I_{se} = I_a = I$



We know that,

(1) V = Brush voltage + Voltage drop in series field winding

$\Rightarrow$ Brush Voltage $= V - IR_{se}$

$= 230 - 50 \times 0.1$

$= 225V$

(2) - Back emf, E_b.

Brush voltage $= E_b$ + Voltage drop in Armature

$\Rightarrow E_b =$ Brush voltage $- IR_a$

$= 225 - 50 \times 0.2$

$= 215V$

(3) - Power Wasted in Armature

$$I^2 R_a$$

$$= (50)^2 \times 0.2$$

$$= 500W$$

(4) - Mechanical powe Developed, $P_m = E_b I$

$$= 215 \times 50$$

$$= 10,750 \text{ W}$$

$$= \frac{10,750}{1000}$$

$$= 10.75 \text{ kW}$$

* **Torque :—**

The measure of causing the rotation of a wheel or the turning or twisting moment of a force about the axis is called the torque.

- It is measured by the product of a force & the radius at which this force acts.

- consider a wheel of radius,

Let r = Radius of the wheel

F [in Newton (N)] = Circumferential Force

Let, the F cause the wheel to rotate at n rps.

n = revolution per second.

Torque, $T = F \times r$ newton × meter

Workdone per revolution = F × Distance Moved

$= F \times 2\pi r$

Workdone Per second = $F \times 2\pi r \times n$

$= F \times r \times 2\pi n$ Joules/second

$F \times r$ = Torque (T)

$2\pi n = \omega$ = angular speed in radians/second

⇒ Workdone per second = $T\omega$ Joules/second

Power developed, $P = T\omega$

$= T(2\pi n)$

$= T\left(2\pi \frac{N}{60}\right)$ $\left[n = \frac{N}{60}\right]$

$= \frac{2\pi}{60}(TN)$

$= 0.105\, NT$ Watt

* **Armature Torque :—**

Let, T_e = Electro magnetic Torque developed in N-m by the motor running at n rps.

Power developed = Workdone per second

$= T_e \omega$

$= T_e \times 2\pi n$ Watt ——— (i)

Electrical equivalent of mechanical power developed by the armature $= E_b I_a$ ——— (ii)

comparing eq^n (i) & (ii) we get,

$$T_e \times 2\pi n = E_b I_a$$

$$\Rightarrow T_e = \frac{E_b I_a}{2\pi n}$$

$$\Rightarrow T_e = \frac{1}{2\pi}\left[\frac{E_b I_a}{n}\right] \text{ N-m}$$

$$= 0.159 \frac{E_b I_a}{n} \text{ N-m} \quad \text{——— (iii)}$$

Revolution per minute, 'N',

$$T_e = \frac{E_b I_a}{2\pi n} = \frac{E_b I_a}{2\pi\left(\frac{N}{60}\right)} \quad \left[n = \frac{N}{60}\right]$$

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

$$= 9.55 \frac{E_b I_a}{N} \text{ N-m} \quad \text{——— (iv)}$$

Substituting,

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

Putting E_b in eqn (iv),

$$T_e = 9.55 \frac{E_b I_a}{N}$$

$$= 9.55 \frac{\left(\frac{P\phi ZN}{60A}\right) I_a}{N}$$

$$= 9.55 \frac{P\phi ZN I_a}{60A N}$$

$$= \left(\frac{9.55}{60}\right)\left(\frac{P\phi Z I_a}{A}\right)$$

$$\Rightarrow T_e = 0.159 \left(\frac{P\phi Z I_a}{A}\right)$$

~~Te or Ta~~

$$\boxed{T_a \text{ or } T_e = 0.159 \left(\frac{P\phi Z I_a}{A}\right)}$$

Dt:- 25.06.21

$$n = \frac{N}{60}$$

$$T_e = 0.159\left(\frac{\phi Z P I_a}{A}\right)$$

For a particular machine, Z, P, A are constant.

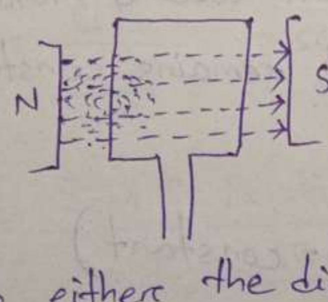
$$T_e = 0.159\,\frac{ZP}{A}\,(\phi I_a)$$

$$\Rightarrow T_e = K\phi I_a$$

$$\Rightarrow \boxed{T_e \propto \phi I_a}$$

From this eq^n, It may be concluded that electro-magnetic torque developed by the armature is proportional to the product of flux per pole & armature current.

- Direction of Te depends upon direction of flux (ϕ), direction of flow of the current in armature (I_a).



- If either the direction of ϕ or I_a is reversed then the direction of rotation is changed.

- If both the direction ϕ & I_a are reversed, then the direction of torque or rotation will not changed.

- In case of DC series motor,

The motor flux, $\phi \propto I_a$ [Before Saturation]

because the series wound motor field winding & armature winding currents are same.

$$[I_{se} = I_a]$$

We know that,

$T_e \propto \phi I_a$ — DC series motor develops highest starting Torque.

$\phi \propto I_a$

$$\boxed{T_e \propto I_a^2}$$

- In case of PMDC & shunt wound motors the field strength i.e, ϕ remains constant.

$T_e \propto \phi I_a$

$\Rightarrow \boxed{T_e \propto I_a}$ (ϕ = constant)

∴ Produces the least starting torque.

* SHAFT TORQUE :—

The armature torque is the gross torque (developed by the armature).

- The total torque is not available at the pully, because sertain percentage of the torque developed by the armature is lost to overcome the iron & friction loss.

- Net Torque/shaft Torque = Gross/total torque developed at the armature − Torque lost in iron & Friction losses

Let,

T_a = Torque developed by armature in N-m.

T_F = Torque lost in iron & friction losses.

T_{sh} = shaft Torque / Useful Torque

$$T_a = \frac{E_b I_a}{\frac{2\pi N}{60}} = 9.55 \frac{E_b I_a}{N} \text{ N-m}$$ [N = speed of armature]

$$T_F = \frac{\text{Iron \& Friction losses in Watts}}{\frac{2\pi N}{60}}$$

$$= \frac{9.55}{N}$$ [Iron & friction losses in Watts]

$$T_{sh} = T_a - T_f$$

$$= \frac{E_b I_a - \text{Iron \& Friction losses in Watts}}{\frac{2\pi N}{60}} \; N\text{-}m$$

$$T_{sh} = \frac{\text{Output in Watts}}{\frac{2\pi N}{60}} = \frac{9.55 \times \text{output in watt}}{N} \; N\text{-}m$$

* **Break Horse Power :— (BHP)**

In case of AC / DC motors, the mechanical power available at the shaft in horse power is known as Break horse power.

T_{sh} = Shaft torque in N-m

N = Speed in r.p.m.

$$\text{Output in BHP} = \frac{2\pi N T_{sh}}{60 \times 735.5}$$

$$1 HP = 735.5$$

Dt:- 28.06.21

* Speed Of a DC Motor :—

$$E_b = V - I_a R_a$$

$$E_b = \frac{P\phi Z N}{60A} = \left(\frac{PZ}{60A}\right)\phi N$$

$$= K\phi N \qquad \left(\text{Let, } K = \frac{PZ}{60A}\right)$$

$$\Rightarrow N = \frac{E_b 60A}{PZ\phi}$$

$$\Rightarrow N = \left(\frac{60A}{PZ}\right)\frac{E_b}{\phi}$$

$$\Rightarrow N = K\frac{E_b}{\phi}$$

$$\Rightarrow \boxed{N \propto \frac{E_b}{\phi}}$$

It shows that,

(i) - Speed is directly proportional to E_b,

$$N \propto E_b$$

(ii) - Speed is inversly proportional to ϕ,

$$N \propto \frac{1}{\phi}.$$

For a series motor upto saturation $\phi \propto I_a$.

Let,

N_1 = Speed in 1st case

I_{a1} = Armature current in the first case

ϕ_1 = Flux per pole in the 1st case.

N_2 = Speed in 2nd case

I_{a2} = Armature current in the 2nd case.

ϕ_2 = Flux per pole in the 2nd case.

Corresponding quantities in the 2nd case, using the above relation.

$$N_1 \propto \frac{E_{b1}}{\phi_1}$$

$E_{b1} = V - I_{a1}R_a$ (supply voltage, V = constant)

$$N_2 \propto \frac{E_{b2}}{\phi_2}$$

$E_{b2} = V - I_{a2}R_a$ (supply voltage, V = constant)

Upto saturation of magnetic poles,

$$\phi \propto I_a$$

$$\frac{N_2}{N_1} = \frac{E_{b2}}{E_{b1}} \times \frac{\phi_1}{\phi_2}$$

$$\Rightarrow \boxed{\frac{N_2}{N_1} = \frac{E_{b2}}{E_{b1}} \times \frac{I_{a1}}{I_{a2}}}$$

For Shunt Motor, ~~ϕ~~

ϕ is constant

$$\frac{N_2}{N_1} = \frac{E_{b2}}{E_{b1}} \times \frac{\phi_1}{\phi_2} \quad [\phi_1 = \phi_2]$$

$$\Rightarrow \boxed{\frac{N_2}{N_1} = \frac{E_{b2}}{E_{b1}}}$$

* Speed Regulation :—

It refers to the change in speed of a motor with change in applied load torque, other conditions remaining constant.

- Here, change in speed means change which occurs under these conditions due to inherent properties of the motor itself & not those changes which are affected through manipulation of rheostats or others speed controlling devices.

Defn

It is defined as the change in speed when the load on the motor is reduced from rated value to zero, expressed as percent of the rated load speed.

$$\% \text{ Speed Regulation} = \frac{\text{No load speed} - \text{Full load speed}}{\text{Full load speed}} \times 100$$

* Torque & speed of a DC Motor :—

$$N = K \frac{E_b}{\phi} \quad \text{—— (i)}$$

$$N = K \frac{V - I_a R_a}{\phi} \quad \text{—— (ii)}$$

$$T_a \propto \phi I_a \quad \text{—— (iii)}$$

From the above eq^n,

If flux increases would decrease the speed. ($\phi\uparrow, N\downarrow$), but torque decrease, ($\phi\uparrow, T\uparrow$).

- ($N\downarrow, T\uparrow$), It can't be show because torque always tends to produce rotation.
- If torque increases, motor speed increases. ($T\uparrow, N\uparrow$)
- Let flux of a motor decreased by decreasing the field current.

Back emf, E_b ($E_b = \frac{N\phi}{K}$) drops instantly,

(speed remains constant, because of inertia of heavy armature.).

- Due to decrease in E_b (back emf) I_a increases due to decrease in E_b & increase in I_a.

$$\left[I_a = \frac{V - E_b}{R_a} \right]$$

- A small reduction of flux produces a proportionaly a large increase in armature current.

- Due to increase in I_a, T_a increase.

$$I_a \uparrow, \ T_a \uparrow \quad [T_a \propto \phi I_a]$$

- This increase in T_a, produces an increase in motor speed.

- With the applied voltage V, held constant, motor speed varies inversly flux.

V = constant.

$$\boxed{N \propto \frac{1}{\phi}}$$

- It is possible to increase flux & at the same time increase the speed provided I_a is held ~~constat~~ constant.

(It is done in DC servomotor.).

Dt:- 01.07.21

Problem-3

A 25 KW, 250V DC shunt generator has armature & field resistance of 0.06-Ω & 100-Ω respectively. Determine the total armature power developed when working,

(i)- As generator delivering 25 KW output.

& (ii)- As a motor taking 25 KW input.

Sol^n

Given, DC shunt generator

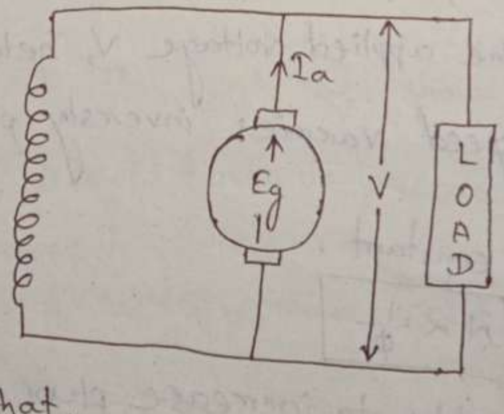
$V = 250V$

$R_{sh} = 100\Omega$

$R_a = 0.06\Omega$

Shunt field current, $I_{sh} = \frac{V}{R_{sh}} = \frac{250}{100} = 2.5A$

(i)- As generator,



We know that,

$$P = VI_L$$

$$I_L = \frac{P}{V} = \frac{25000}{250} = 100A$$

$$I_a = I_{sh} + I_L = 2.5 + 100 = 102.5A$$

$E_g = V + I_a R_a$

$= 250 + 102.5 \times 0.06$

$= 256.15V$

Power developed,

$P_g = E_g I_a$

$= 256.15 \times 102.5$

$= 26,255.375$ Watt

$= \frac{26,255.375}{1000} = 26.25 KW$

(ii) - As Motor,

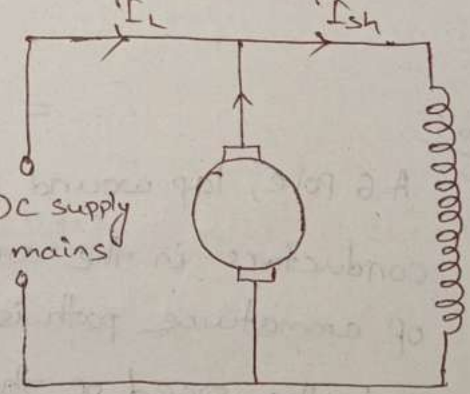
Line current, $I_L = \frac{25000}{250} = 100A$

$I_L = I_a + I_{sh}$

or, $I_a = I_L - I_{sh}$

$= 100 - 2.5$

$= 97.5A$



$E_b = V - I_a R_a$

$= 250 - 97.5 \times 0.06$

$= 244.15$ volt

$P_m = E_b I_a$

$= 244.15 \times 97.5$

$= 23,804.625$ Watt

$= \frac{23,804.625}{1000} = 23.8KW$

Problem-4

(27)- A 25 KW, 250V shunt generator delivers rated current at rated voltage, on removal of load the terminal voltage rises to 275V. Determine the voltage regulation.

Soln

Full load terminal voltage, $V_{FL} = 250V$

No load terminal voltage, $V_{NL} = 275V$

We know that,

$$\% \text{ Voltage Regulation} = \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100$$

$$= \frac{275 - 250}{250} \times 100$$

$$= \frac{25}{250} \times 100$$

$$= 10\%$$

Problem-5

(28)- A 6 Pole, lap wound shunt motor has 500 conductors in the armature, the resistance of armature path is $0.05\,\Omega$, $R_{sh} = 25\,\Omega$, Find the speed of the motor when it takes 120A from DC mains of 100V supply. Flux per pole $= 2 \times 10^{-2}$ Wb.

Soln Given, Pole, $P = 6$ Lap Wound Motor

$Z = 500$

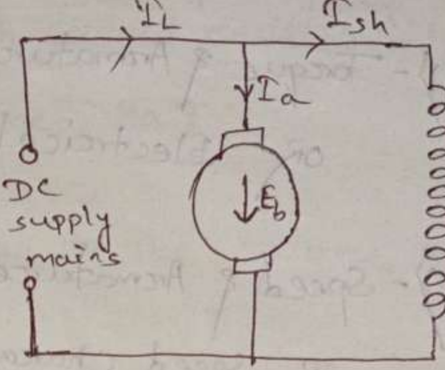
$R_a = 0.05\,\Omega$ $I_L = 120A$

$R_{sh} = 25\,\Omega$ $\phi = 2 \times 10^{-2}$ Wb/pole

$V = 100V$

To find N,

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



$$E_b = V - I_a R_a$$

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

$$= \frac{100}{25} = 4A$$

$$I_a = I_L - I_{sh}$$

$$= 120 - 4 = 116 A$$

$$E_b = V - I_a R_a$$

$$= 100 - 116 \times 0.05$$

$$= 100 - 5.8$$

$$= 94.2 \text{ volt}$$

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

$$= \frac{6 \times 2 \times 10^{-2} \times 500 \times 94.2}{60 \times 6}$$

$$= 565.2 \text{ rpm}$$

$$= 565 \text{ rpm}$$

* Motor Characteristics :—

(i) - Torque & Armature current (T_a/I_a Characteristics)
OR Electrical characteristics

(ii) - Speed & Armature current (N/I_a Characteristics)
OR Speed Characteristics.

(iii) - Speed & Torque (N/T_a characteristics)
(Mechanical characteristics)

$T_a \propto \phi I_a$

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

I.M.P Formula

Dt:- 05.07.21

* Power Losses :—

There are two types,

(i) - Closed due to flow of electric current in various path of DC motor (electrical/copper loss)

(ii) - Caused due to rotation of armature, (rotational losses)

* Copper Loss :—

(1) Armature Copper loss ($I_a^2 R_a$)

I_a = Armature current

R_a = Armature Resistance

- Here brush constant loss in taken in account (by including the brush contact resistance in the armature resistance Ra)

- This loss is proportional to the square of armature current.

$$\text{Loss} \propto I_a^2$$

- It is about 30% to 40% of full load losses.

(2) - Field Copper loss :—

- This loss divided into 4 types,
  - (i) - shunt field loss $= I_{sh}^2 R_{sh}$
  - (ii) - Interpole field loss $= I_a^2 R_i$
  - (iii) - compensating winding field loss $= I_a^2 R_{com}$
  - (iv) - series loss $= I_{se} R_{se}$

(3) - Rotational Losses :—

- These are also called core losses it varies with the change in speed & strength of field of a DC machine.

- It divided into
  - (i) - Iron / magnetic losses (core loss)
  - (ii) - Mechanical losses.

(i) - Iron Magnetic loss :—

These are also called core loss.

→ It is 2 types

(a) - Hysteresis Loss

(b) - Eddy current Loss

(a) Hysteresis Loss :—

→ It occurs the revolving armature core.

→ It is directly proportional to the no. of reversals per second.

Hysteresis loss $\propto$ speed $\left(speed = \frac{120F}{P}\right)$

$P_h = n(B_{max})^{1.6} FV$. joules/second or Watt

$P_h \propto F$

→ It can be reduced by using laminated armature core & silicon steel.

(b) - Eddy Current Loss :—

$$P_e = K_e B_{max} F^2 V t^2$$

When armature core rotate in the magnetic field of the poles & emf is induced in with circulates eddy current in the armature core.

- The power loss due to this eddy current is called as the eddy current loss.
- It occurs in the armature core & pole faces.

* Mechanical Losses :—

Power loss due to friction of bearing air friction of windage.

→ caused by the motion of moving paths through the air.

→ Friction between brushes & commutator or slip rings.

→ Improve bearing reduced ammount of energy consumed also bearing wear.

→ Proper in lubrication reduced the bearing friction.

* Mechanical Loss :—

(a). Windage Loss :—

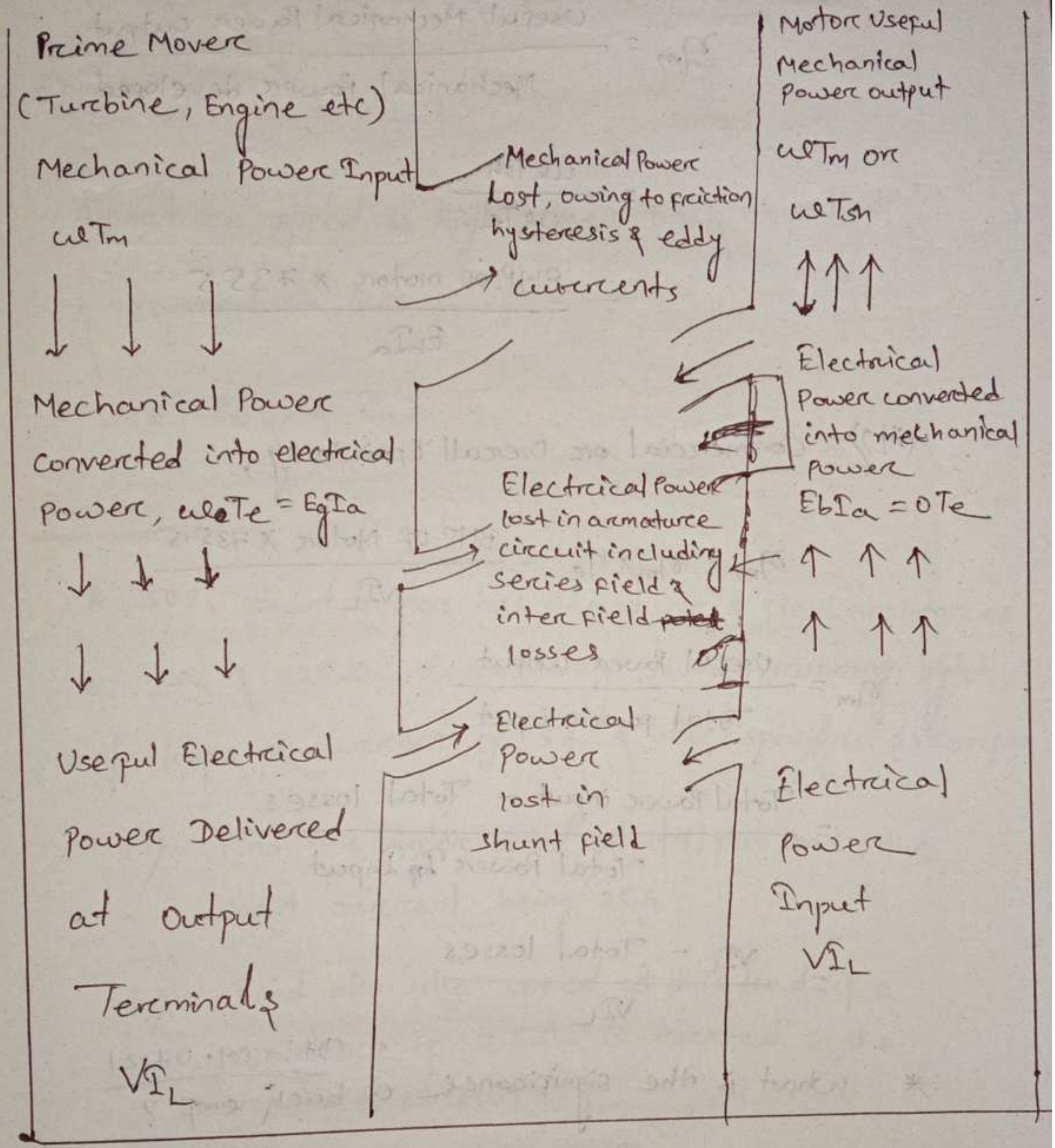
The power required to move the air about the armature greater quantity of air moved greater the power consumed.

- Are constant loss.
- 10 to 20% Full load losses

(b) - Stray load loss

- Due to distortion of the flux owing to armature reaction.
- Lack of uniform division of the current in the armature winding through various paths.
- short circuit current in the coils under going commutation.
- It is difficult to the determine stray loss.
- 1% of the output of the machine.

Dt:- 08.07.21



* Motor Efficiency :-

(i)- Electrical Efficiency =

$$\eta_e = \frac{\text{Mechanical Power developed}}{\text{Total electrical Power input}}$$

$$= E_b I_a / VI_L$$

(ii) - Mechanical Power Efficiency,

$$\eta_m = \frac{\text{Useful Mechanical Power Output}}{\text{Mechanical Power developed}}$$

$$= \frac{\omega T_{sh}}{\omega T_e}$$

$$= \frac{\text{BHP of motor} \times 735.5}{E_b I_a}$$

(iii) - Commercial or Overall Efficiency,

$$\eta_m = \eta_m \times \eta_e = \frac{\text{BHP of Motor} \times 735.5}{V I_L}$$

$$\eta_m = \frac{\text{Useful Power Output}}{\text{Total power input}}$$

$$= \frac{\text{Total Power input} - \text{Total losses}}{\text{Total Power Input}}$$

$$= \frac{V I_L - \text{Total losses}}{V I_L}$$

DT:- 09.07.21

* What is the significance of back emf ?

OR

How back emf makes the DC motor a self regulating machine ?

Ans $E_b = \frac{P \phi Z N}{60 A}$ ——— (i)

$I_a = \frac{V - E_b}{R_a}$ ——— (ii) [V is fixed & R is fixed]

From eq^n (i) & (ii), E_b depends upon speed (N).

I_a depends upon E_b.

~~I_f, speed increases, & back emf increase~~

I_f $N\uparrow$, $E_b\uparrow$, $I_a\downarrow$

Armature speed is high, then back emf high & current is less.

$N\downarrow$, $E_b\downarrow$ & $I_a\uparrow$

Problem-6

A 250V, shunt motor has armature & field resistances of 1Ω & 125Ω respectively. When running light, it takes a current of 5A & the speed is 1550 rpm.

(i) - Find the motor speed at it's full load, the input current being 25A.

(ii) - Find also the speed at this load if a resistance of 2.5Ω is inserted in the armature circuit.

Given,

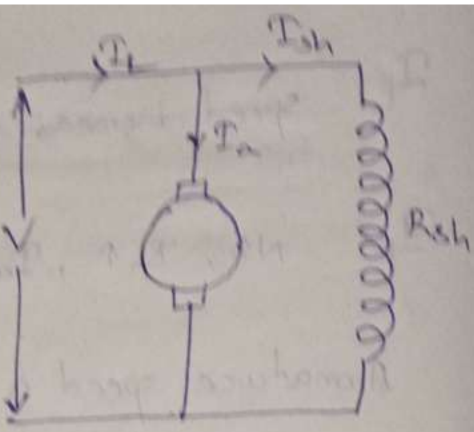
Supply Voltage, $V = 250V$

No load armature current, $I_{a0} = I$

No load line current, $I_{L0} = 5A$

$$I_{sh} = \frac{V}{R_{sh}} = \frac{250}{125}$$

$$= 2A$$



$I_{a0} = I_{L0} - I_{sh}$

$= 5 - 2$

$= 3A$

No load back emf,

$E_{b0} = V - I_{a0} R_a$

$= 250 - 3 \times 1$

$= 247V$

No load speed, $N_0 = 1500$ rpm

(ii) - At full load speed,

$I_{Lf} = 25A$

$I_{sh} = 2A$

Armature current at full load,

$I_{af} = I_{Lf} - I_{sh}$

$= 25 - 2 = 23A$

At full load back emf,

$E_{bf} = V - I_{af} R_a$

$= 250 - 23 \times 1$

$= 227V$

Assume flux constant,

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

$$E_b \propto N$$

$E_{bo} \rightarrow N_o$

$247V \rightarrow 1500 rpm$

$E_{bf} \rightarrow N_f$

$227V \rightarrow ?$

$$\frac{E_{bo}}{E_{bf}} = \frac{N_o}{N_f}$$

$$\Rightarrow N_f = N_o \frac{E_{bf}}{E_{bo}}$$

$$\Rightarrow N_f = 1500 \times \frac{227}{247} = 1378 \text{ rpm}$$

(iii) - When a resistance of 2.5 is inserted in the armature circuit.

$R_a' = R_a + R$

$R_a = 1\Omega$

$R = 2.5\Omega$

$R_a' = 1 + 2.5 = 3.5\Omega$

Back emf, $E_{bf} = V - I_{af} R_a'$

$= 250 - 23 \times 3.5$

$= 250 - 80.5$

$= 169.5V$

$E_{bo} \rightarrow N_o$

$E_{bf}' \rightarrow N_f' = ?$

$$\boxed{E_b \propto N}$$

$$\frac{E_{bo}}{E_{bf}'} = \frac{N_o}{N_f'}$$

$$\Rightarrow N_f' = N_o \frac{E_{bf}'}{E_{bo}}$$

$$= 1500 \times \frac{169.5}{247}$$

$$= 1500 \times 0.686$$

$$= 1029 \text{ rpm}$$

Problem-7

A 120V, DC shunt motor has an armature of resistance 0.2 Ω & ~~af~~ a field resistance of 60Ω. The full load line current is 60A, & Full load speed is 1800 rpm. If the brush contact drop is 3V, find the speed of the motor at half load?

Given, supply voltage, V = 120V

$R_a = 0.2\ \Omega$

$R_{sh} = 60\ \Omega$

$$I_{sh} = \frac{V}{R_{sh}} = \frac{120}{60} = 2A$$

At full load,

Line current, $I_{LF} = 60A$

$I_{sh} = 2A$

$I_{af} = I_{LF} - I_{sh}$

$= 60 - 2$

$= 58A$

$E_{bF} = V - I_{af} R_a$ − Brush contact drop

$= 120 - 58 \times 0.2 - 3$

$= 105.4V$

We know that,

$E_b \propto N$

At full load, $N_F = 1800$ rpm

At half load,

Line current at half load

$I_{LH} = \frac{60}{2} = 30A$

$I_{sh} = 2A$

$I_{ah} = I_{Lh} - I_{sh} = 30 - 2 = 28A$

$E_{bh} = V - I_{ah} R_a$ − Brush Drop

$= 120 - 28 \times 0.2 - 3$

$= 111.4V$

$E_{bF} \rightarrow N_F$

$E_{bh} \rightarrow N_h$

$$\frac{E_{bf}}{E_{bh}} = \frac{N_f}{N_h}$$

$$\Rightarrow N_h = N_f \frac{E_{bh}}{E_{bf}}$$

$$= 1800 \times \frac{111.4}{105.4}$$

$$= 1800 \times ~~105.6~~ 1.056$$

$$= 1902 \text{ rpm}$$

Problem-8

A 230V, DC motor takes no load armature current of 2A & runs at a speed of 1200 rpm in the full load current of 40 A.

(i) - Find the speed on Full load

(ii) - % speed Regulation

[Assume that the flux remains constant & Armature Resistance $(R_a) = 2.5\,\Omega$]

Given, supply voltage, $V = 230V$

No load armature current, $I_{a0} = 2A$

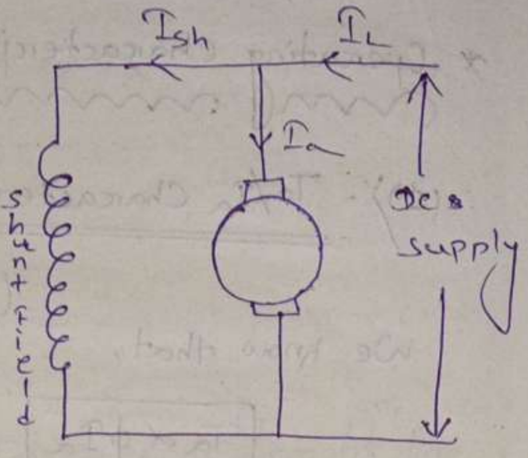
Full load current, $I_{af} = 40A$

At no load speed, $N_0 = 1200$ rpm

& also given the flux remains constant

ϕ = constant.

~~(i) Ebo~~



(i) - $E_{b0} = V - I_{a0} R_a$

$= 230 - 2 \times 2.5$

$= 225\ V$

$E_{bf} = V - I_{a2} R_a$

$= 230 - 40 \times 2.5$

$= 130 V$

~~$\frac{N_2}{N_1} = \frac{E_{b2}}{}$~~

$\frac{N_f}{N_0} = \frac{E_{bf}}{E_{b0}}$

$\Rightarrow N_f = N_0 \times \frac{E_{bf}}{E_{b0}}$

$\Rightarrow N_f = 1200 \times \frac{130}{225}$

$= 693.33$

$\Rightarrow N_f = 693$

(ii) - % speed Regulation $= \frac{\text{No load speed} - \text{Full load speed}}{\text{Full load speed}} \times 100$

$= \frac{1200 - 693}{693} \times 100$

$= \frac{505}{693} \times 100 = 0.72 \times 100$

$= 72.87\ \%$

2

Dt:- 13.07.21

* Operating Characteristics of DC Series Motor:

(1) - Ta/Ia Characteristics :-

(Electrical Characteristics)

We know that,

$$T_a \propto \phi I_a$$

Here,

Field windings also carry the armature current.

$$\phi \propto I_a$$ (up to saturation)

$T_a \propto \phi I_a$

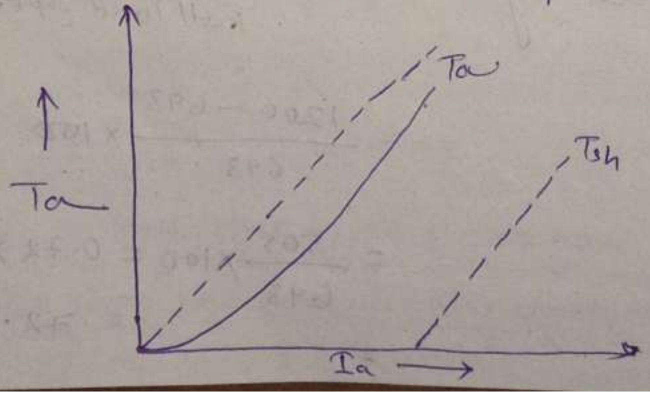
$$T_a \propto I_a^2$$ (Before saturation)

At light loads,

I_a & ϕ is small

As I_a increases T_a increases as the square of current.

- Hence, T_a/I_a curve is a parabola.



After saturation,

ϕ is independent of I_a

$T_a \propto \phi I_a$

ϕ = constant

$$\boxed{T_a \propto I_a}$$

- characteristics will become a straight line.

The shaft torque (T_{sh}) is less than the armature torque due to stray losses.

$T_{sh} < T_a$ due to stray losses.

Conclusion

Upto magnetic saturation on heavy loads, a series motor exhausts a torque proportional to square of armature current.

$$\boxed{\text{Torque} \propto I_a^2}$$

Example
So, DC series motors are used where high starting torque is required for accelerating heavy masses quickly.

& in hoists electric trains.

(2) - Speed & Armature Current (N/I_a) Characteristics

(speed characteristics)

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

- Change in E_b for various load currents is small & it can be neglected.
- With increased I_a, ϕ also increase.

$$N \propto \frac{1}{\phi}$$

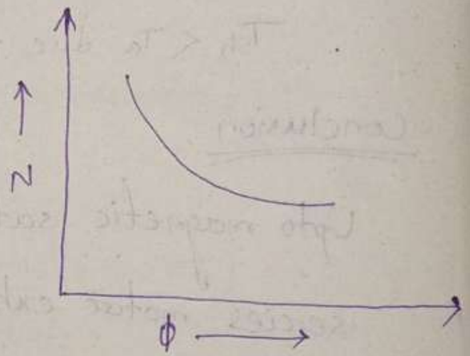
- When load is heavy

I_a is large

Hence, ϕ is increases,

speed(N) is decreases

& also E_b decrease.



$$\uparrow I_a = \frac{V - E_b \downarrow}{R_a}$$

When load current decreases to a small value,

- Here speed becomes dangerciously high.

Note

A series motor should never be started without some mechanical load.

- Because it may developed excess speeds & get damage due to heavy centripulgal forces produced on it.

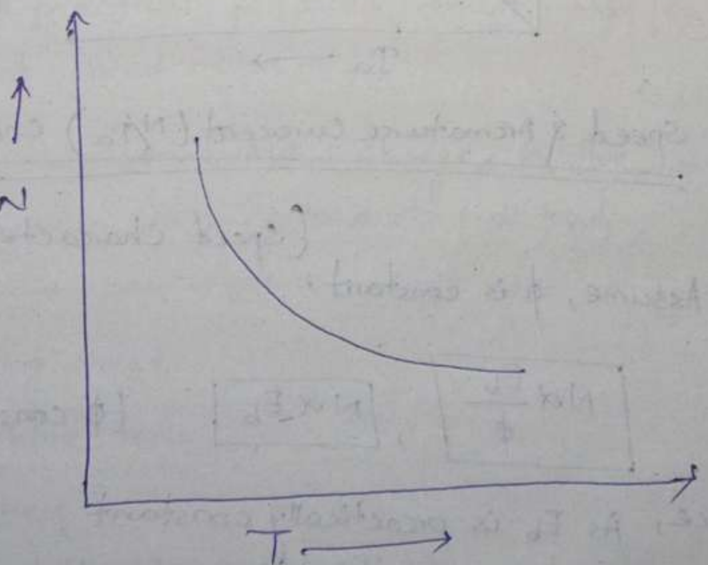
- Hence series Motor is a variable speed Motor.

(3) - Speed & Torque (N/T_a) Characteristics :—

(Mechanical Characteristics)

From the above two characteristics we conclude that, when speed is high, torque is low.

- When speed is low, torque is high.
- At higher loads, the speed decreases linearly, but slowly with increase in torque.
- It is best suited for the services, where the motor is directly coupled to the load, such as fans, whose speed falls with the increase in load torque.



* Operating Characteristics Of DC shunt Motor :-

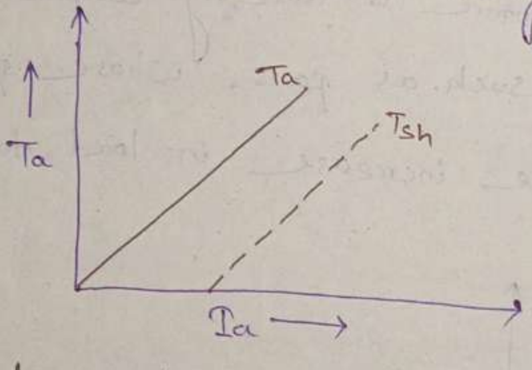
(1) - T_a/I_a Characteristics :-

(Electrical characteristics)

Assume, flux (ϕ) to be practically constant.

$$T_a \propto I_a$$

- Electrical characteristics will be straight line to the origin.
- shaft torque (T_{sh}) is shown in dotted.
- Hence a heavy starting load will need a heavy starting current. Therefore a shunt motor never be started on heavy load.



(2) - Speed & Armature Current (N/I_a) characteristics :-

(Speed Characteristics)

Assume, ϕ is constant.

$$N \propto \frac{E_b}{\phi}, \quad N \propto E_b \quad (\phi \text{ constant})$$

Hence, As E_b is practically constant,

speed is constant for most purposes.

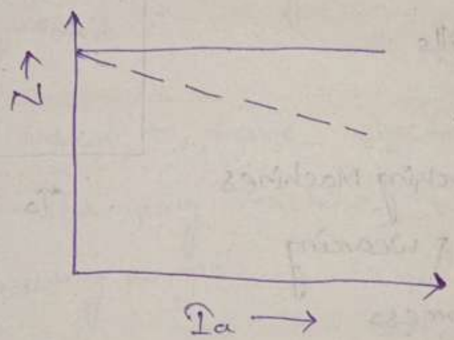
- E_b & ϕ, both are decrease with increase in load.

- E_b decrease in slightly more than ϕ.

  ∴ There is decrease in N.

- The drop varies from 5 to 15 % of full load speed.

- The drop is dependent on saturation, armature reaction & brush position.



- The actual speed torque is drooping characteristics.
- For all practical purposes shunt motor is taken as a constant speed motor.
- There is no appreciable change in the speed of a shunt motor from no load to full load.

Uses

① Driving shaft.

(2) Machine tools.

(3) Lathes

④ Wood working machines etc.

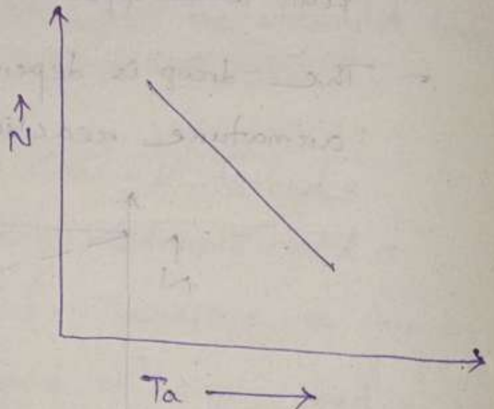
(3) - Speed & Torque (N/Ta) characteristics :—

(Mechanical characteristics)

This characteristics can be drawn from the above two characteristics.

- DC shunt motor is used where medium starting torque is required like,

(i) Centrifugal pumps
(ii) Blowers
(iii) Fans
(iv) Conveyors
(v) Boring mills
(vi) shapers
(vii) Wood working Machines
(viii) Spinning & Wearing
(ix) Printing press
(x) Machine tools etc



* Operating characteristics of DC compound wound Motor :—

These motors have both series & shunt windings.

- If the series excitation helps shunt excitation i.e series flux is in the same direction, then the motor is said to be cumulative compound wound motor.
- If series field opposes shunt field, then it is called differential compound wound motors.

(1) - Cumulative Compound Motors :—

This machines are used where series characteristics are required & where the load is lightly to be removed totally such as coal cutting machines or driving heavy machines tools.

- Due to shunt windings, speed will not become excessively high & due to series windings it will be able to take heavy loads.
- It is used where high starting torque & pulsating load.

(i) There used, to, drive electric shovel.
(ii) Metal - stamping machines.
(iii) Reciprocating pumps
(iv) Hoists
(v) Compressors etc.

(2) - Differential Compound Motors :—

Here series field opposes the shunt field flux decreases as the load is applied to motor.

- So, this results in the motor speed remaining almost constant.

OR

Even increases with increase in load.

$$\left(N \propto \frac{E_b}{\phi} \right).$$

- So, there is a decrease in the rate at which the motor torque increases with load.

- In practical purpose they have no used.

- They are used for experimental & research work.

Demerit :-

When load increases, flux decrease & speed is increase, this will leads to be speed instability, motor running away.

Torque

Dt:- 16.07.21

Problem - 1

A DC motor takes an armature current of 110A at 480V. The armature circuit resistance is 0.2Ω. The machine has 6 poles & the armature is lap connected with 864 conductors. The flux per pole is 0.05 Wb. Calculate

(i) The speed

(ii) The brush developed by the armature.

Given, $I_a = 110A$

Supply voltage = 480V

$R_a = 0.2\Omega$

No. of pole (P) = 6

no. of conductors (Z) = 864

ϕ/per = 0.05 Wb

Lap connected, A = P = 6

$E_b = V - I_a R_a$

$= 480 - 110 \times 0.2$

$= 458V$

We know that,

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

$$\Rightarrow N = \frac{E_b 60A}{P\phi Z} = \frac{458 \times 60 \times 6}{6 \times 0.05 \times 864}$$

$$= \frac{164,880}{259.2}$$

$$= 636 \text{ rpm}$$

$$T_a = 0.159 \times \frac{P\phi Z I_a}{A}$$

$$= 0.159 \times \frac{6 \times 0.05 \times 864 \times 110}{6}$$

$= 755.568$ N-m.

Problem-2

A 250 V, 4 pole wave wound DC series motor has 782 conductors on its armature. It has armature & series field resistance of 0.75Ω. The motor takes a current of 40 A. Estimate its speed & gross torque developed if it has flux per pole 25mWb.

Given, supply voltage (V) = 250V

Pole, (P) = 4

Wave wound, A = 2

no. of conductor = Z = 782

R = 0.75Ω

I = 40 A. & ϕ per pole = 25mWb = $\frac{25}{1000}$ = 0.025Wb

$E_b = V - IR$

$= 250 - 40 \times 0.75$

$= 220V$

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

$= \frac{220 \times 60 \times 2}{2\ 4 \times 0.025 \times 782}$

$= \frac{13,200}{39.1}$

$= 337.59$

$= 337$ rpm

$T_a = 0.159 \times \frac{P\phi Z I_a}{A}$

$= 0.159 \times \frac{4 \times 0.025 \times 782 \times 40}{2}$

$= 248.676$ N-m.

(37) Problem-3

Determine developed torque & shaft torque of 220V of 4 pole, series motor with 800 conductors wave connected supplying a load 8.2KW by taking 45A from the mains. The flux per pole is 25 mWb & its armature circuit resistance is 0.6Ω.

Given,

$V = 220V$

Pole, $(P) = 4$

no. of conductors $(Z) = 800$

Wave connected, $(A) = 2$

$I_a = 45A$

ϕ per pole $= 25 = \frac{25}{1000} = 0.025$

$R_a = 0.6\Omega$

Output power $= 8.2KW = 8.2\times10^3 W$

$E_b = V - I_a R_a$

$= 220 - 45\times0.6$

$= 193V$

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

$N = \frac{E_b\, 60A}{P\phi Z} = \frac{193\times60\times2}{4\times0.025\times800}$

$= 289.5$ rpm

$n = \frac{289.5}{60}$ rps $\quad \left[n = \frac{N}{60} \text{ rps} \right]$

$= 4.825$ rps

$T_a = 0.159\times\frac{P\phi Z I_a}{A}$

$= 0.159\times\frac{4\times0.025\times800\times45}{2}$

$= 286.2$ N-m

$T_{sh} = \frac{o/p}{2\pi n} = \frac{8.2\times10^3}{2\times\pi\times4.825} = 270.48$ N-m.

Dt:- 19.07.21

* Speed Control Of DC Motor :—

Speed control means, intentional change of the drive speed to a value required for performing the specific work process.

- Any industrial equipment may have it's speed changed or adjusted mechanically by means of
  - (i)- stepped pulleys.
  - (ii)- sets of change gear
  - (iii)- Variable speed friction clutch mechanisim etc

- some drives may require contineous variation speed for the whole of the speed range from 0 to full speed. or over a portion of this range & some require two or more fixed speeds.

* Percentage (%) Speed Regulation :—

$$\% \text{ Speed Regulation} = \frac{\text{No Load speed} - \text{Full load speed}}{\text{Full load speed}} \times 100 \quad \text{—(i)}$$

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

$$E_b = K\phi N \quad \text{—— (ii)}$$

$$E_b = V - I_a R_a$$ —— (iii)

$$K\phi N = V - I_a R_a$$ —— (iv)

$$\Rightarrow N = \frac{V - I_a R_a}{K\phi}$$ —— (v)

If, R = Resistance of external circuit,

then,

$$N = \frac{V - I_a (R_a + R)}{K\phi}$$ —— (vi)

$$N = K\left[\frac{V - I_a (R + R_a)}{\phi}\right]$$ —— (vii)

From the above expression we noted that,

The speed can be controlled by adjusting any of the 3 factors appearing in the RHS of the eq^n (vii),

(1) - Applied voltage to the armature terminals (V).
(2) - External Resistance in the armature circuit, R. } Armature
(3) - Flux per pole, ϕ → Field or magnetic Field.

Broadly speed Control methods,

(a) - Armature control

(b) - Field control.

Dt:- 23.07.21

* Speed Control Of Shunt Motors :—

(a) Field Control Methods :—

We know that,

$$N = K\left[\frac{V - I_a(R_a + R)}{\phi}\right] \qquad \uparrow N \propto \frac{E_b}{\phi \downarrow}$$

If, weakening of field ($\phi\downarrow$) causes increase in speed of motor.

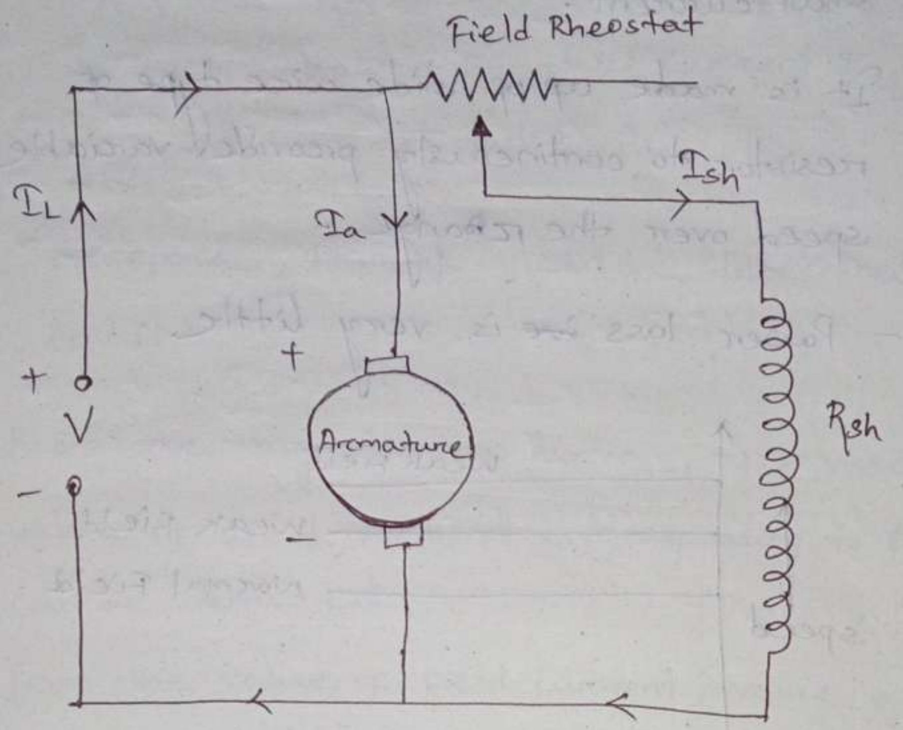
- strengthing of field ($\phi\uparrow$) it leads to decrease in speed ($\downarrow N$).
- Speed adjustment of DC shunt motor by field control can be obtained by any one of the following methods,

(i)- Field Rheostat Control → Variation of flux by means a field rheostat.

(ii)- Reluctance Method → Variation of the reluctance of the magnetic circuit of the motor.

(iii)- Field Voltage control → Variation of the voltage applied to the field circuit keeping the applied voltage to the armature constant.

(i) Field Rheostat control :—



→ Field Rheostat means variable resistance is inserted in series with the shunt field.

→ Increase in controlling resistance, field current decrease & flux also decrease and thereby increase in speed.

Advantages :—

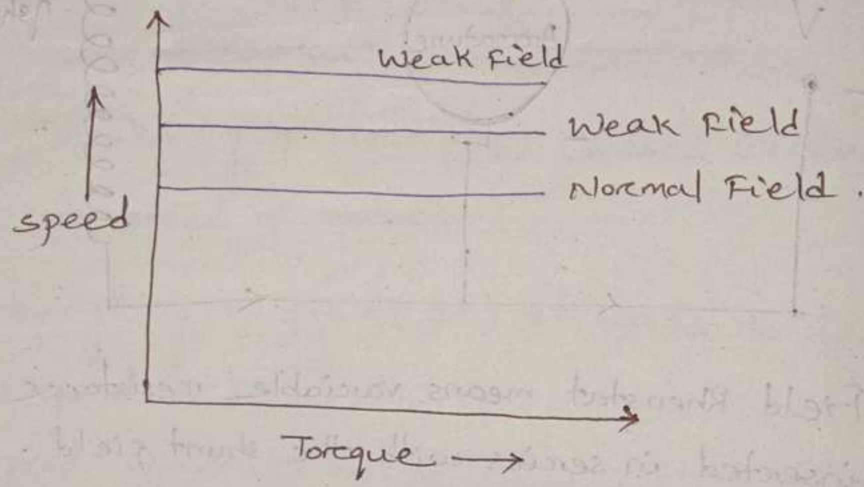
→ This method is simple, convenent, most economical, extensively used in electrical devices.

→ It is independent of load on the motor & permits remote control of speed.

* The controlling resistance has to carry small current.

- It is made up of slide wire type of resistor to contineously provide variable speed over the range.

- Power loss is very little.



- Let, Initial value of back emf, flux & speed be E_{b1}, ϕ_1 & N_1 respectively.

- Let the back emf & speed be E_{b2} & ϕ_2 respectively at the new speed N_2.

→ since, $N \propto \frac{E_b}{\phi}$

$$\frac{N_2}{N_1} = \frac{E_{b2}}{E_{b1}} \times \frac{\phi_1}{\phi_2}$$

$$\Rightarrow \phi_2 = \frac{E_{b2}}{E_{b1}} \times \frac{N_1}{N_2} \times \phi_1 \quad \text{——(i)}$$

→ Since,

E_{b1} & E_{b2} can be calculated from the value of supply voltage, Armature current I_{a1} & I_{a2} & Armature resistance R_a.

→ Therefore, Flux ϕ_2, can be determined from eqⁿ (i).

→ From the magnetisation curve of the machine value of field current corresponding to ϕ_2 can be obtained.

→ From the value of field current, value of controlling resistance can be obtained.

→ From this graph, the flux can only view reduced & not increased hence speed above the normal can be obtained.

DT:— 26·07·21

(ii) - Reluctance Control :—

Here, reluctance of the magnetic circuit can be changed.

- In this way, the motor should be designed.

Dis Advantages :—

It makes the motor,

(a) More Expensive

(b) same results can be obtained much more simply by means of a field rheostat.

(c) It is seldom used.

(iii) - Field Voltage control :—

It requires a variable voltage supply for the field circuit, which is separate from the main power supply to which armature is connected.

- Such a variable supply can be obtained by means of control generator or an adjustable electronic rectifier.

Numericals—

Problem-1

A 500V shunt motor runs at it's speed of 250 rpm, when the armature current is 200A & $R_a = 0.12\Omega$ calculate the speed when a resistance is inserted in the field, reducing the shunt field to 80% of normal value, & $I_a = 100A$.

Sol^n

Case - 1

Let, Flux $= \phi_1$

$V = 500V$

$R_a = 0.12\Omega$

$I_{a1} = 200A$

$N_1 = 250$ rpm

$E_{b_1} = V - I_a R_a$

$= 500 - 200 \times 0.12$

$= 476\ V$

Case-2

Flux, $\phi_2 = 80\%\ \phi_1$

$= 0.8\ \phi_1$

$I_{a_2} = 100\ A$

$R_a = 0.12\ \Omega$

$E_{b_2} = V - I_{a_2} R_a$

$= 500 - 100 \times 0.12$

$= 488\ V$

$$\frac{N_2}{N_1} = \frac{E_{b_2}}{E_{b_1}} \times \frac{\phi_1}{\phi_2}$$

$$\Rightarrow N_2 = \frac{488}{476} \times \frac{\phi_1}{0.8\ \phi_1} \times 250$$

$$= \frac{488 \times 250}{476 \times 0.8} = \frac{122,000}{380.8}$$

$= 320.37$

$= 320.4\ rpm$

Problem-2

A 220V, DC shunt motor runs at 760 rpm & takes $I_a = 48A$. Find the resistance to be added to the field circuit to increase the speed to 950 rpm at an armature current of 78A. Assume flux is proportional to the field current.

[$R_a = 0.15\Omega$ & $R_{sh} = 240\Omega$]

Soln

Case-1

$V = 220V$

$N_1 = 760$ rpm

$I_{a1} = 48A$

$R_a = 0.15\Omega$

$R_{sh} = 240\Omega$

$E_{b1} = V - I_{a1} R_a$

$= 220 - 48 \times 0.15$

$= 212.8V$

Case-2

$V = 220V$

$N_2 = 950$ rpm

$I_{a2} = 78A$

$R_a = 0.15\Omega$

$R_{sh} = 240\Omega$

$$E_{b_2} = V - I_{a_2} R_a$$

$$= 220 - 78 \times 0.15$$

$$= 208.3 V$$

We know that,

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

$$\Rightarrow \frac{N_2}{N_1} = \frac{E_{b_2}}{E_{b_1}} \times \frac{\phi_1}{\phi_2}$$

$$\Rightarrow \frac{\phi_2}{\phi_1} = \frac{E_{b_2}}{E_{b_1}} \times \frac{N_1}{N_2}$$

$$= \frac{208.3}{212.8} \times \frac{760}{950}$$

$$= 0.783$$

$$\Rightarrow \boxed{\phi_2 = 0.783 \phi_1}$$

Shunt field current,

Case-1

$$I_{sh_1} = \frac{V}{R_{sh_1}} = \frac{220}{240}$$

$$= 0.9167 A$$

We know that,

Flux, $(\phi) \propto$ Field current (I_{sh})

$$\boxed{\phi \propto I_{sh}}$$

$$\frac{\phi_1}{\phi_2} = \frac{I_{sh1}}{I_{sh2}}$$

$$\Rightarrow I_{sh_2} = I_{sh_1} \times \frac{\phi_2}{\phi_1}$$

$$= 0.9167 \times 0.783$$

$$= 0.7178\ A$$

$$I_{sh_2} = \frac{V}{R_{sh_2}}$$

$$= \frac{220}{0.7178} = 306.48\ \Omega$$

$$R_{sh_1} = 240\ \Omega$$

$$R_{sh_2} = 306.48\ \Omega$$

Additional Resistance in field circuit,

$$R = R_{sh_2} - R_{sh_1}$$

$$= 306.48 - 240$$

$$= 66.48\ \Omega$$

* Speed Control Of DC Shunt Motor :—

(b) - Armature Control Method :—

It is speed adjustment of DC shunt motor by armature control may be obtained by any one of the methods -

(i) - Armature Resistance Control →

It involves variation of voltage applied to the armature terminals by means of variable resistance connected in series with the armature.

(ii) - Shunted Armature Control :→

Variation of voltage applied to the armature terminals by means of a combination of a variable R shunting the armature & a variable R in series with the shunted armature.

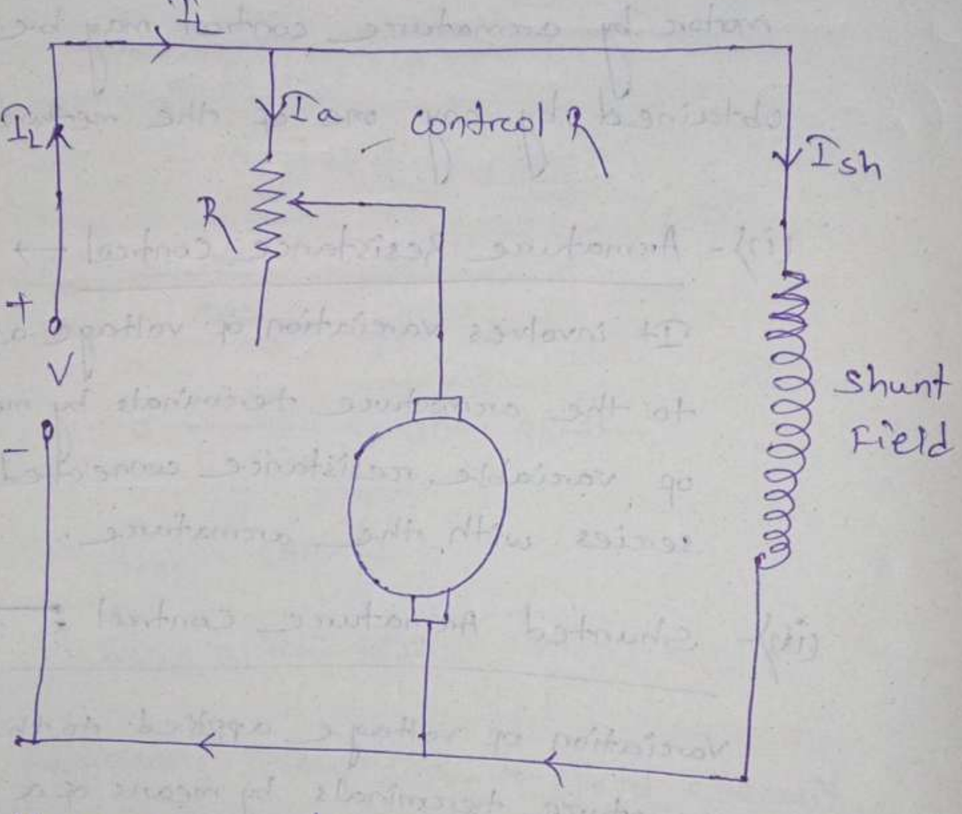
(iii) - Armature terminal Voltage Control :→

Variation of voltage impressed upon the armature circuit.

Dt:- 27.07.21

(ii) - Armature Resistance Control :—

Consist of a variable resistance connected in series with the armature.



- Here, current passes through the series resistance & voltage across the armature drops.
- Remaining voltage applied to the armature is less than the applied voltage.
- Hence, speed is reduced in direct proportional to the voltage drop at armature terminals,

$$N \propto \frac{E_b}{\phi} \propto \frac{V - I_a R}{\phi}$$

- Field current (I_{sh}) will remain unaffected because field is directly connected across the supply mains.

- For a constant torque load, the armature current (I_a) remains the same, so input to the motor remains the same but the output decreases in proportion to speed (N).

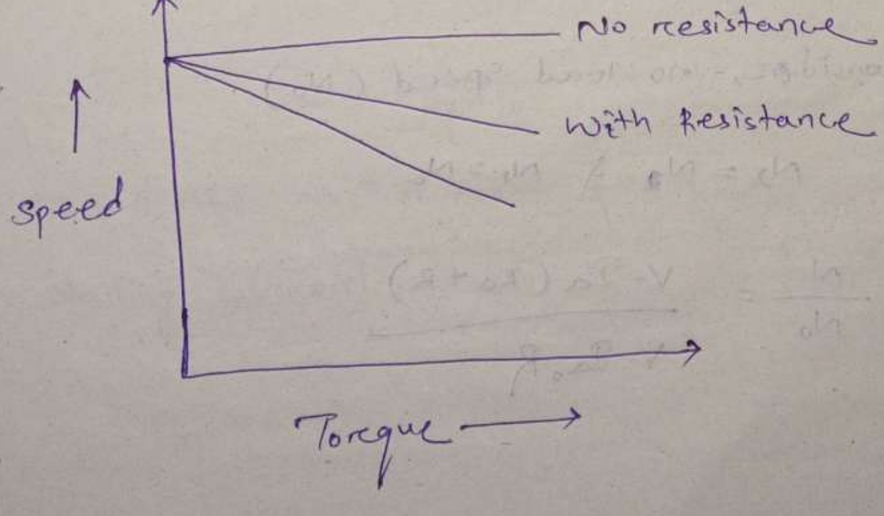
- In case of fans & centrifugal pumps, where the load torque decreases with the decrease in speed, losses are low.

- Because of its low initial cost & simplicity, this method is,

(1) - Quiet convenient

(2) - Economical for short time or intermittent slows - downs.

(3) - wide range of speed can be obtained.



- Let, E_{b1} be the backemf at N_1, with armature current I_{a1}, no extra resistance in the armature circuit, (R_a).

- After insertion of extra resistance R in the armature circuit,

E_{b2}, N_2, I_{a2} (flux ~~remaining~~ remaining the same) ($R_a + R$)

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

$\because$ Flux is constant.

So, $\boxed{N \propto E_b}$

$$\frac{N_2}{N_1} = \frac{E_{b2}}{E_{b1}}$$

$$\Rightarrow \frac{N_2}{N_1} = \frac{V - I_{a2}(R + R_a)}{V - I_{a1}(R_a)}$$

Knowing the values of V, I_{a1}, I_{a2}, R_a, N_1 & N_2, the value of additional resistance (R) can be determined.

- Consider, no-load speed (N_0)

$N_2 = N$ & $N_1 = N_0$

$$\frac{N}{N_0} = \frac{V - I_a(R_a + R)}{V - I_{a_0} R}$$

If armature drop is neglected then the above eqⁿ,

$$\frac{N}{N_0} = \frac{V - I_a(R_a+R)}{V}$$

$$\Rightarrow \frac{N}{N_0} = \frac{V}{V} - \frac{I_a(R_a+R)}{V}$$

$$\Rightarrow \frac{N}{N_0} = \left[1 - \frac{I_a(R_a+R)}{V}\right]$$

$$\Rightarrow \boxed{N = N_0\left[1 - \frac{I_a(R_a+R)}{V}\right]} \quad \text{——— (i)}$$

From this eqⁿ,

For a given (R_a+R) in the armature circuit, then the speed is a linear function of armature current (I_a).

- The motor speed will be zero, or motor will be stalled, when

$$I_a = \frac{V}{R_a+R} \quad \text{——— (ii)}$$

This is the max^m current & is known as stalling current.

Putting eqⁿ (ii) ~~& (iii)~~ in eqⁿ (i),

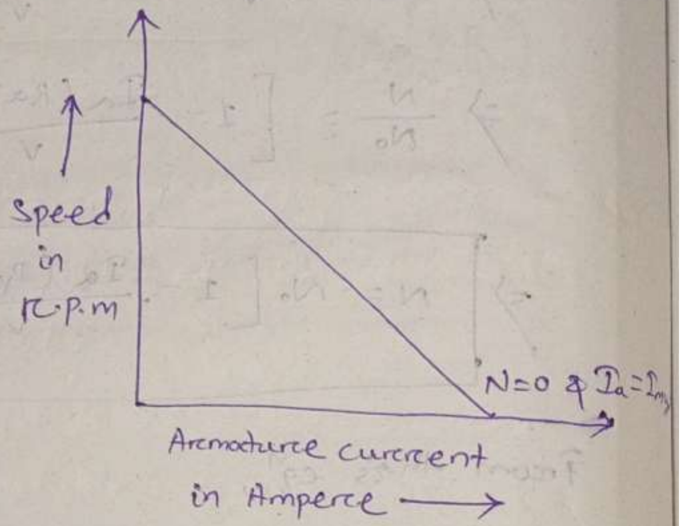
$$N = N_0 \left[1 - \frac{V}{(R_a + R)} \frac{(R_a + R)}{V} \right]$$

$$= N_0 [1 - 1]$$

$$= N_0 \times 0$$

$$= 0$$

$$\Rightarrow \boxed{N = 0}$$



→ This method is used, where speeds lower than the rated speed are required for a short - period only.

→ This type of machine is required in

(1) - Printing Machines

(2) - Cranes

(3) - Hoists

[Here motor is frequently started & stopped]

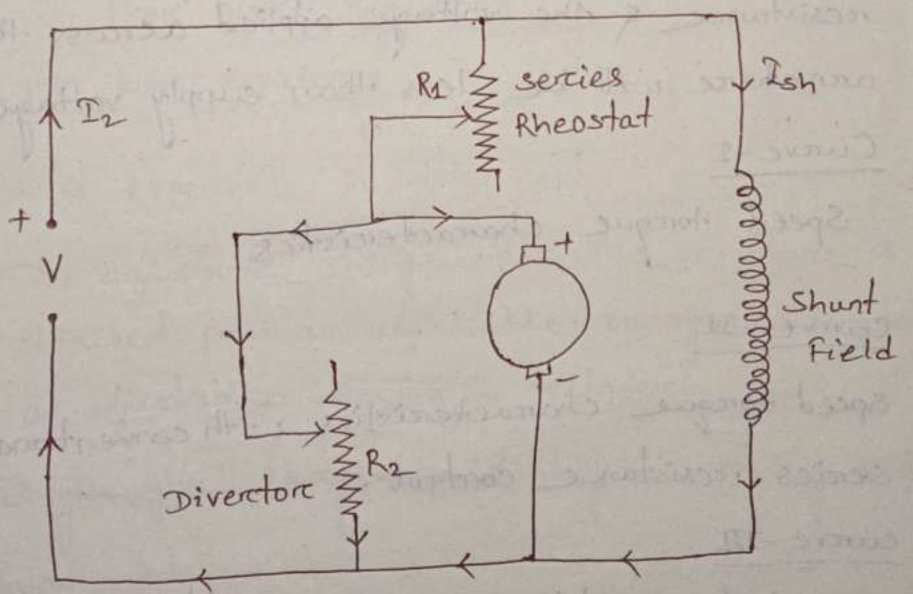
Dt:- 04.08.21

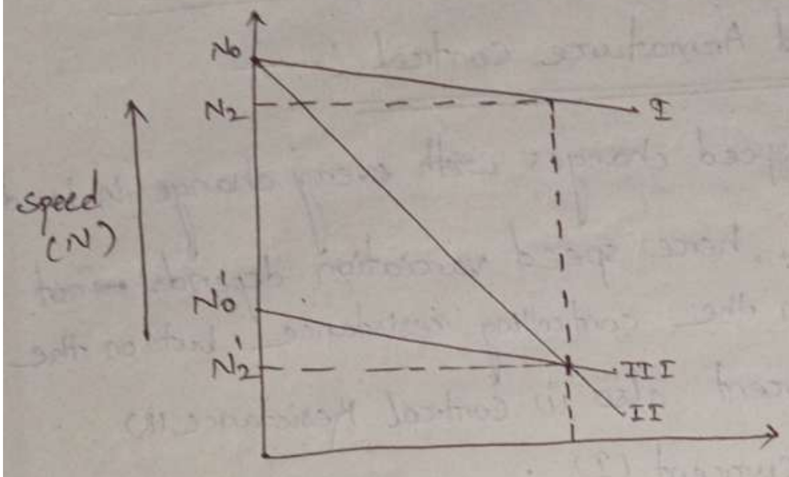
(ii) - Shunted Armature control :—

Here speed changes with every change in load because, here speed variation depends not only upon the controlling resistance but on the load current also (i) Control Resistance (R)
(ii) Load Current (I).

- This double dependance makes it impossible to keep the speed sensible constant on rapidly changing load.

- A divertor across the armature in addition to series resistance (R) is connected.





- In this method ideal no-load speed of the motor will be less than that obtained with conventional series resistance control.
- If there is no current in the motor armature, there is a current in the series resistance & diverter, so there is a voltage drop in series resistance & the voltage applied across the armature will be less than supply voltage.

Curve - I

Speed torque characteristics

Curve - II

speed torque characteristics with conventional series resistance control.

curve - III

Shunted armature control.

- shunted armature control has a distinct advantage over the series resistance control.

→ A speed N_2' is required at a load torque T_2, then sufficient resistance can be placed in series with the armature so that the characteristics passes through the required point.

→ Hence, it is difficult to the load but with the shunting method a provide stable operation.

- It is use in case of low power rating drives.

(iii) - Armature Voltage Control :—

Here, speed control requires a variable source of voltage, separate from the source supplying the field current.

- It avoids the disadvantages of
  - (i)- Poor speed Regulation
  - (ii)- Low Efficiency.

- It is expensive in initial cost.

- The adjustable voltage for the armature is obtained from an adjustable voltage generator or adjustable electronic rectifier.

- It ~~give~~ give large speed range with any no. of speed points.

- It is a constant torque system because the output delivered by the motor decreases with a decrease in applied voltage & a corresponding decrease in speed.

→ It has excellent starting characteristics because by changing the genrated voltage gradually up from zero, starting & bringing the motor up to speed with a comparetively slowly increasing voltage.

- It is used for modern high-speed elevators.

Disadvantages :—

If the voltage across armature terminals higher than the rated value for a long duration of time, the armature winding insulation may get damaged.

* Speed Control Of DC Series Motor :—

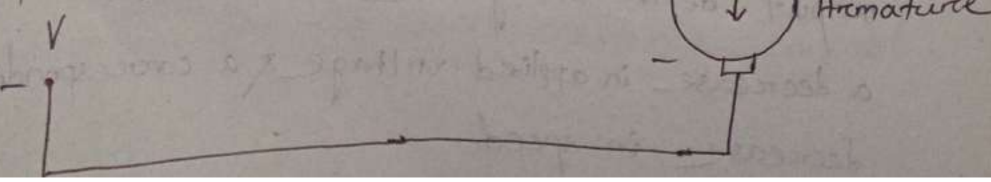
(1) - Armature Control Method.
(2) - Field control Method.
(3) - Series - parallel control.

(1) - Armature Control Method :—

(i) - Armature Resistance Control.
(ii) - Shunted Armature Control.
(iii) - Armature terminal voltage.

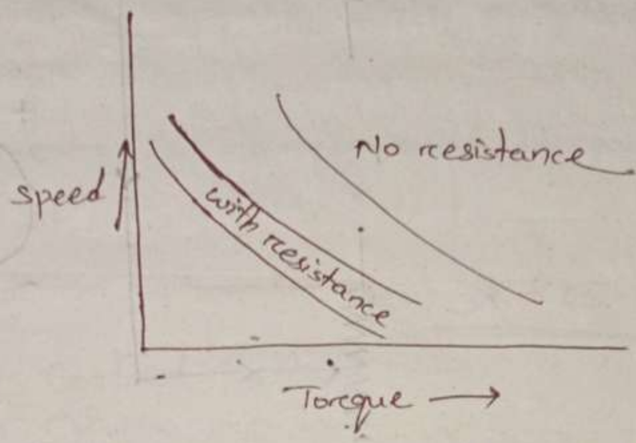
(i) - Armature Resistance Control :—

This is the most common method employeed.



→ Here control resistance is connected direct series with the supply to the complete motor.

→ Control of armature voltage for the series motor is the same as the voltage applied to the complete motor.



→ DC series motor has poor speed regulation, but it has no significance for the control of DC series motors.

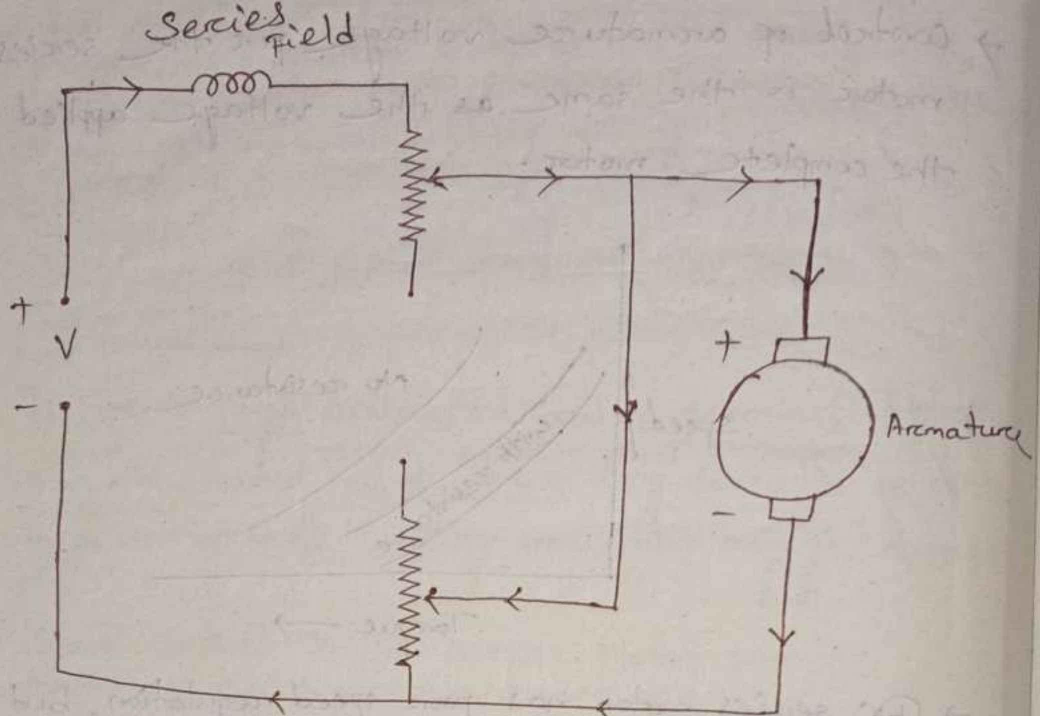
→ The speed characteristics of DC series motors is a rapidly drooping curve.

→ The power loss in the control resistance is not too serious.

→ It is most economical for constant torque drives.

→ It is used in driving, crane, hoist etc.

(iii) - Shunted Armature control :-



- It is used to give slow speed at light load.

→ Here speed control is achieved by

(i) - Lowering the voltage applied to motor armature (By varying the R_1)

(ii) - By varying the flux (exciting current can be varried by varrying the R_2 for the same current I_a.

→ For a given constant load torque if I_a decrease due to armature divertor, then flux (ϕ) must increase because torque developed by the armature

→ It is obtained over a wide range but below normal speed.

→ This method is not economical due to considerable power loss in the speed control resistances R_1 & R_2.

(iii) - <u>Armature Terminal Voltage Control</u> :—

It is achieved by supplying the power to the motor from a separated variable voltage supplying.

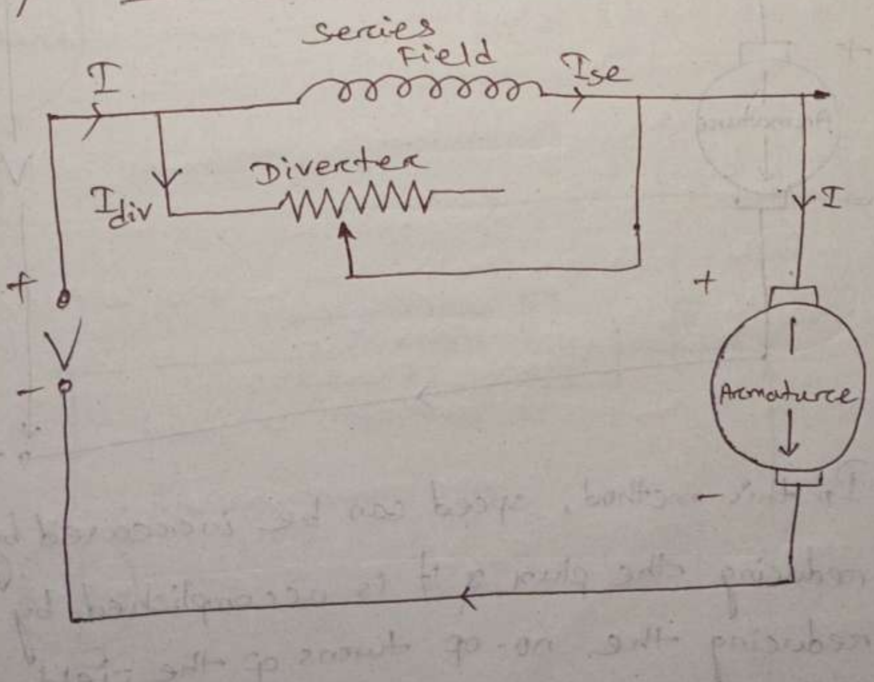
- This method is rarely used because it is high cost.

Dt:- 05-08-21

(2) - Field Control Method :—

Here, speed of a DC series motor can be controlled by varying the flux.

(i) - <u>Field Diverter Method</u> :—



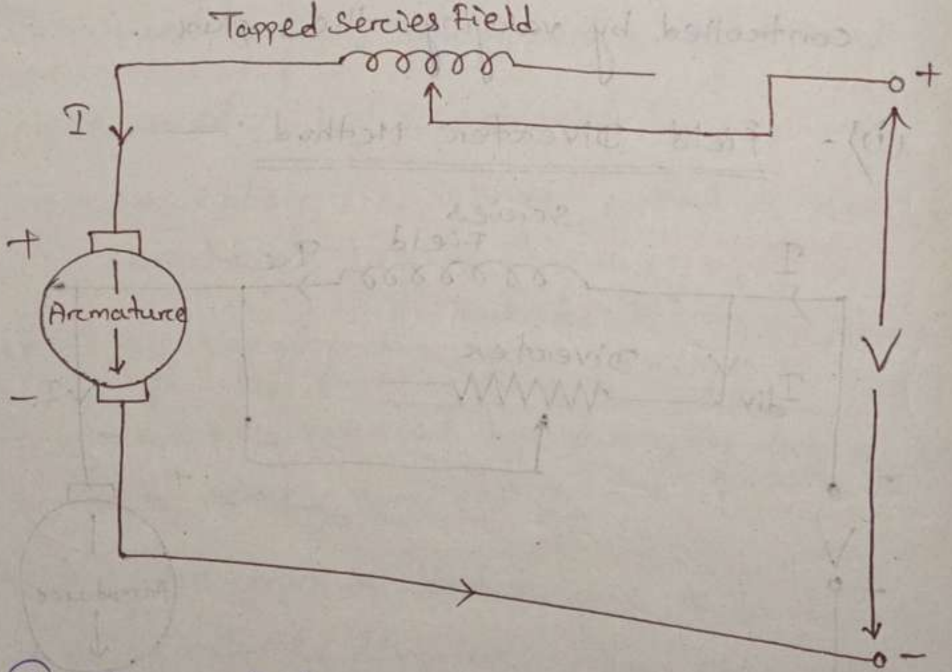
- The series winding is shunted by a variable resistance known as field diverter.

- Any desired amount of current can be passed through the diverter by adjusting it's resistance.

- Hence, lesser the diverter resistance less the field current, less the flux & more the speed. $\left[N \propto \frac{1}{\phi} \right]$.

- This method is convenient economical, it is used in electric drives.

(iii) - Tapped Field Control :-



- In this method, speed can be increased by reducing the flux & it is accomplished by reducing the no. of turns of the field winding through, which current flows.

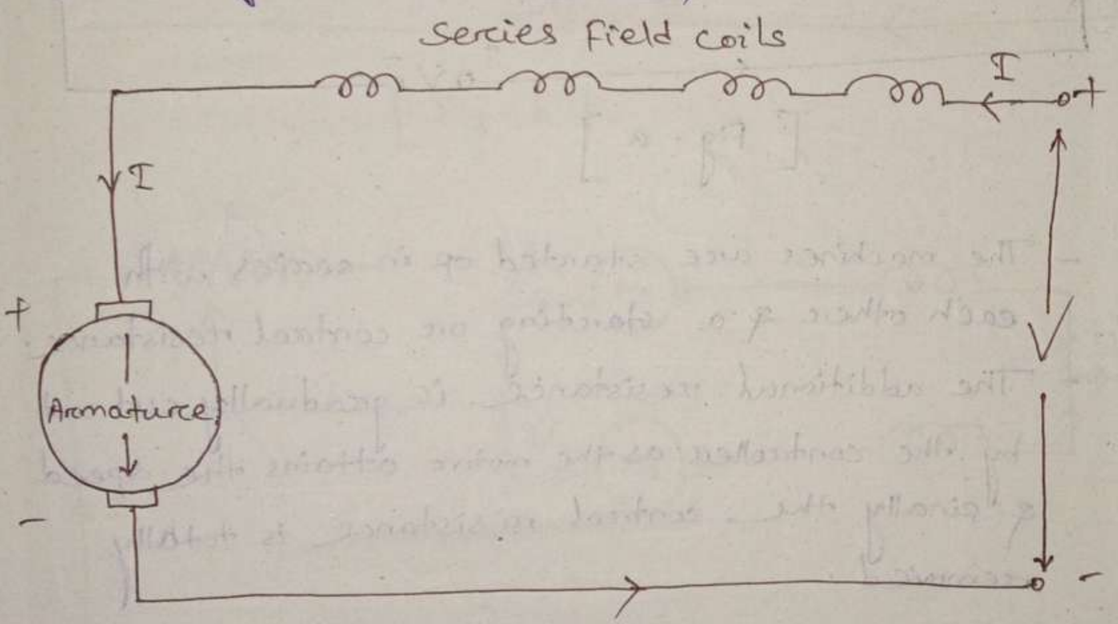
→ Here, there are a no. of tappings from the field windings which are brought outside.

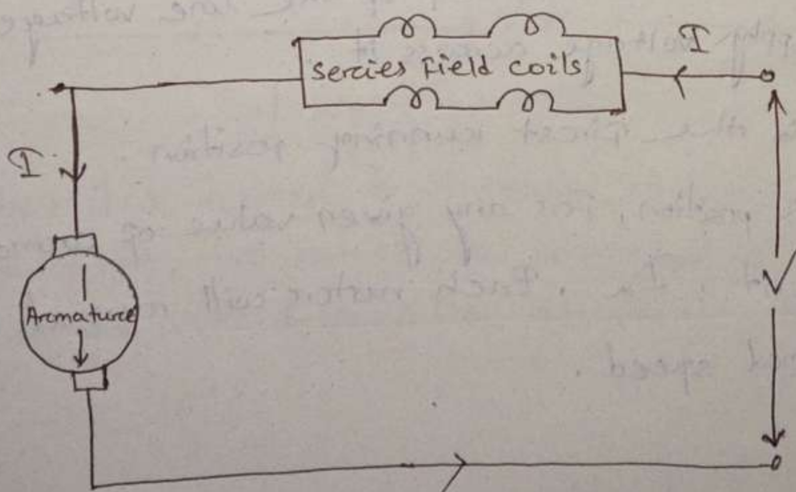
→ A no. of series field turns can be short-circuited according to the requirement.

→ When all field turns are in circuit, the motor runs at lowest speed.

→ So, to increase the speed cutting out of series field turns is done.

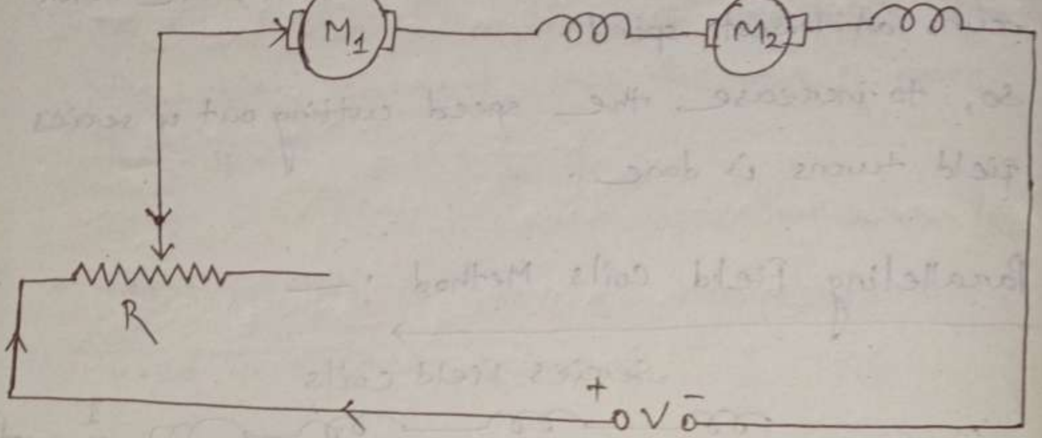
Paralleling Field Coils Method :—





→ This method is used in fan motor.

→ By doing such arrangments or regrouping of field coils.

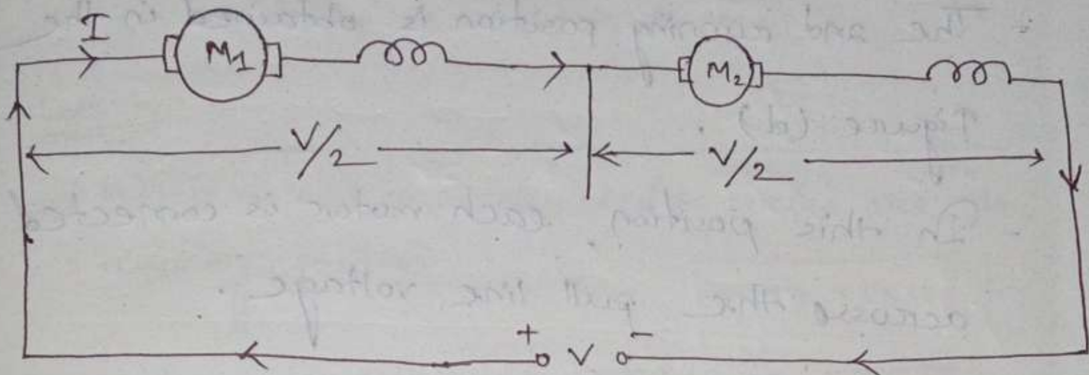


[Fig - a]

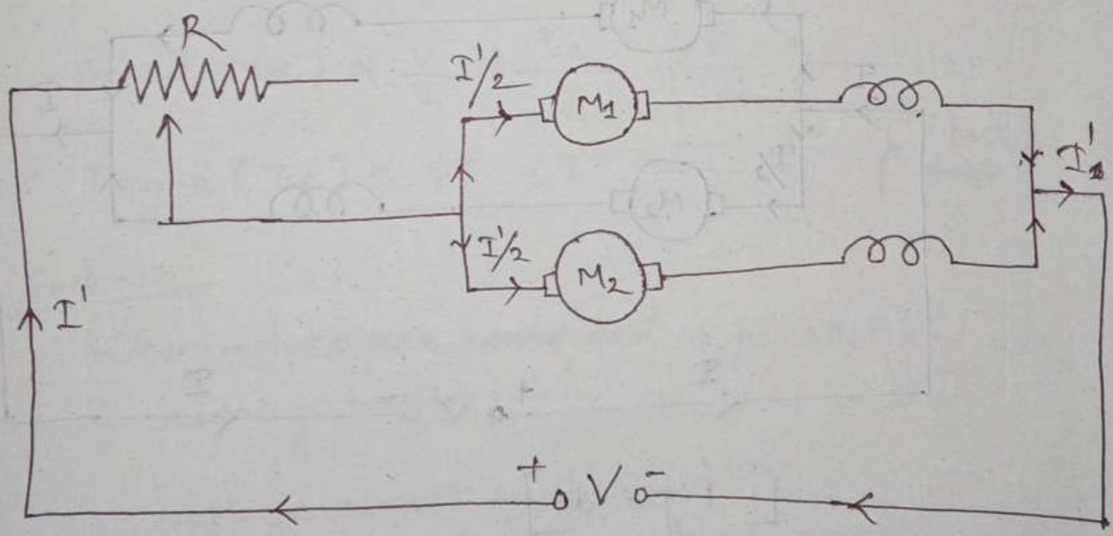
- The machines are started of in series with each other & a starting or control resistance.
- The additional resistance is gradually cut out by the controller as the motor attains the speed & finally the control resistance is totally removed.
- Each motor has one half of the line voltage or supply voltage across it.
- This is the first running position.
- In this position, for any given value of armature current, I_a. Each motor will run at half of normal speed.

→ Here, there is no external resistance circuit, there is no wasteage of energy.

→ Here motors operate at a very good efficiency.



[Fig - b]

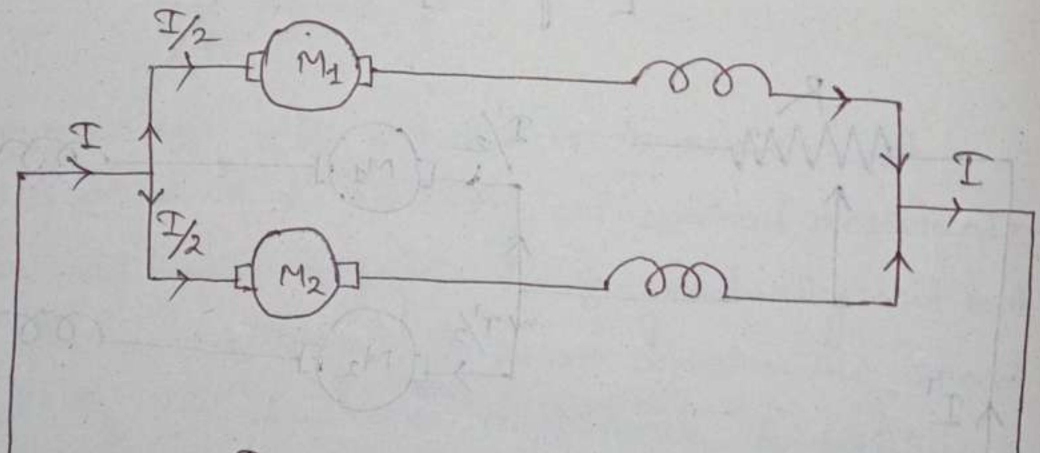


[Fig - c]

- When it is desired to increase the speed of the combination, two motors are connected in parallel & in series with a variable resistance 'R'.

- This resistance is gradually ~~cut off~~ cut-out as the motor attains the speed & finally this resistance is totally removed from the circuit.

- The 2nd running position is obtained in the Figure-(d).
- In this position, each motor is connected across the full line voltage.



[Fig - d]

(Dt:- 06.08.21

We know that,

$$V = E_b + I_a R_a$$

Let, V = Line voltage in volt.

I = Line current in Ampere.

Case-I

When motors are connected in series are in running position.

Voltage across each motor = $\frac{V}{2}$

Current through each motor = I

$$\text{Speed } (N_{se}) \propto \frac{V}{I} \propto \frac{V/2}{I} \propto \frac{V}{2I} \text{ ——— (i)}$$

$$\text{Torque } (T_{se}) \propto \phi I \propto I^2 \text{ ——— (ii)} \quad [\phi \propto I]$$

Case-II

When motors are connected in parallel and are in running position.

Voltage across each motor = V

current through each motor = $I/2$

$$\text{Speed } (N_{sh}) \propto \frac{V}{I/2} \propto \frac{2V}{I} \text{ ——— (iii)}$$

$$\text{Torque } (T_{sh}) \propto \phi I \propto I^2 \propto \left(\frac{I}{2}\right)^2 \propto \frac{I^2}{4} \text{ ——— (iv)}$$

$$N_{se} \propto \frac{V}{2I} \quad \text{——(i)}$$

$$T_{se} \propto I^2 \quad \text{——(ii)}$$

$$N_{sh} \propto \frac{2V}{I} \quad \text{——(iii)}$$

$$T_{sh} \propto \frac{I^2}{4} \quad \text{——(iv)}$$

$$\frac{N_{se}}{N_{sh}} = \frac{V/2I}{2V/I} = \frac{V}{2I} \times \frac{I}{2V} = \frac{1}{4}$$

$$\Rightarrow \boxed{N_{sh} = 4N_{se}}$$

$$\frac{T_{se}}{T_{sh}} = \frac{I^2}{I^2/4} = I^2 \times \frac{4}{I^2} = 4$$

$$\Rightarrow \boxed{T_{se} = 4T_{sh}}$$

→ We observe that, speeds of the motor when running in the parallel is 4 times that while running in series.

→ Torque of the motor when running in series in 4 times that while running in parallel.

* **Advantages** :—

(1) It is more economical than providing each motor with a separate or different starting resistance, or by connecting the motor permanently in parallel with only in the single - starting resistance.

(2) - It reduces the starting & breaking time by reducing the overall moment of inertia because in this control system two motors each rated for half the required load capacity are used.

(3) - It provides higher reliability of operation.

(4) - It is convenient to used two motors of smaller size than of larger size.

(5) - It provides to speeds without wastage of powers.

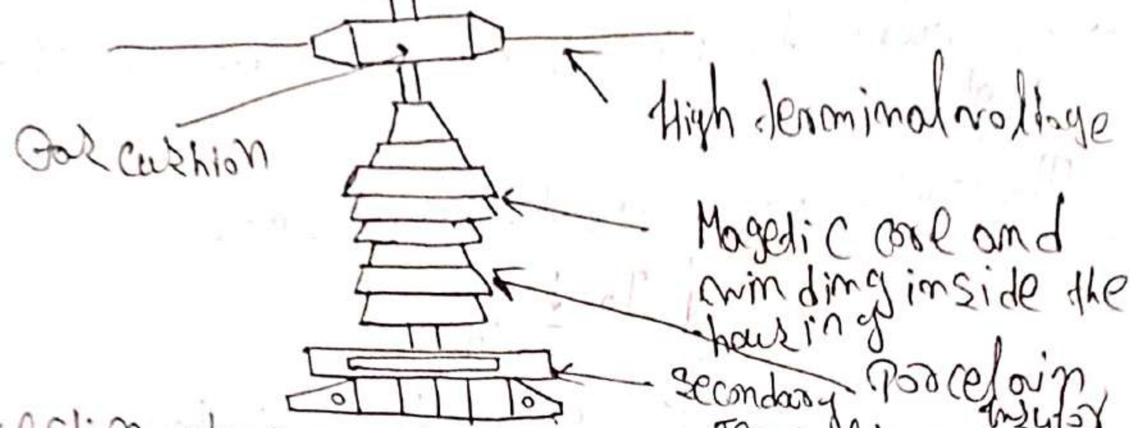
C.T. & P.T.

→ It is always used in AC operation.
→ It is one of the type of transformer.
→ It is used to measured of current & voltage.

★ Current Transformer :→

→ A current transformer is a device that used for the transformer of current from a higher value into a proportional current to a lower value.
→ The current transformer is used with the AC instrum
→ The primary & secondary current of the current transformer are potential to each others.
→ The current transformer is used for measuring the high voltage current because of the difficulty of indequate insulation in the meter itself.
→ The current transformer is used in meter for measuring the current up to 100 Amperes.

(Current Transformer)



Construction of Current Transformer :-

→ The core of the current transformer is built up with transformer is built up with lamination of Silicon Steel.

→ For getting a high degree of accuracy of the permalloy.

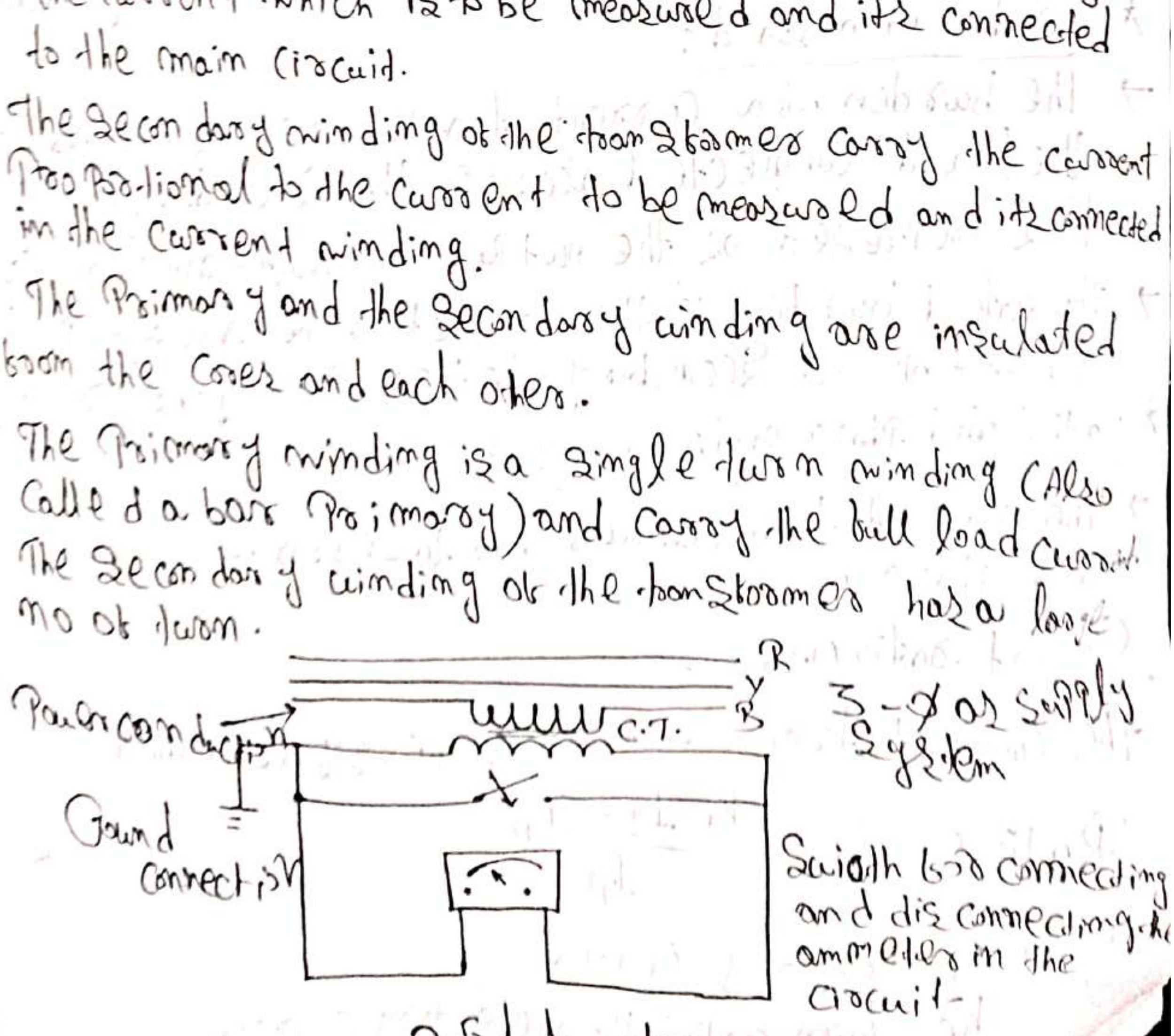
→ The Primary winding of the current transformer carry the current which is to be measured and its connected to the main circuit.

→ The secondary winding of the transformer carry the current proportional to the current to be measured and its connected in the current winding.

→ The Primary and the Secondary winding are insulated from the cores and each other.

→ The Primary winding is a single turn winding (Also called a bar Primary) and carry the full load current.

→ The Secondary winding of the transformer has a large no of turn.

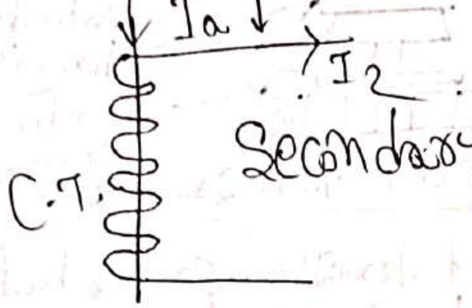


O.S.A. Ammeter

→ The ratio of the Primary current and the secondary current is known as current transformer ratio of the circuit.

→ The current ratio of the transformer is usually high.

The symbol of current transformer



→ The current transformer the load impedance on burden on the secondary has slightly differed from the Power transformer.

→ The current transfer operate on secondary circuit.

★ **Burden on a load:**

→ The burden of a current transformer is the value of the load connected accross the secondary transformer

→ It is expressed as the output in volt-amperes (VA).

→ The rated burden is the product of the voltage and current on the secondary when the CT supply the instrument

★ **Ratio and Phase Angle Errors of CT:**

→ The current transformer has two errors :- Ratio error and Phase angle error.

Current ratio error :-

The current transformer is energy component

$$\text{Ratio error} = \frac{K_E I_s - I_P}{I_P}$$

where, I_P = Primary current

K_E = turn ratio the secondary current.

* Phase angle error :-

* Potential Transformer

In an ideal current transformer the ... is exactly between the primary and reversed secon... ctly in is zero.

Construction of Potential transformer :-

→ The Potential transformer is made with high quality core operating at low flux density so that the magnetising current is small.

→ The primary winding has a large no of turn, and the secondary winding has much small no of turn.

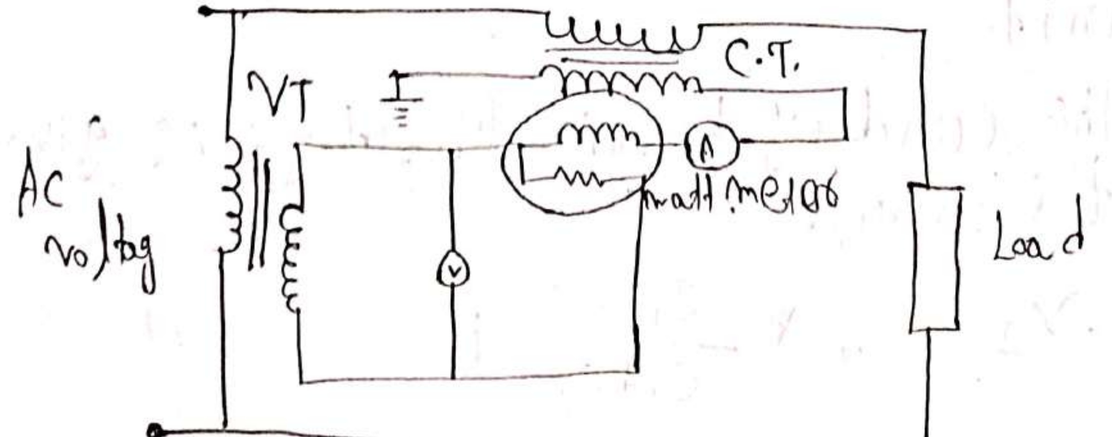
Connection of Potential Transformer :-

→ The Potential transformer is connected in parallel with the circuit.

→ The primary winding of the potential transformer are directly connected to the power circuit whose voltage is to be measured.

→ The secondary terminal of the potential transformer are connecting to the measuring instrument like the voltmeter, wattmeter.

→ The secondary winding of the potential transformer are magnetically coupled through the magnetic circuit of the primary winding.



* Type of Potential transformer :-

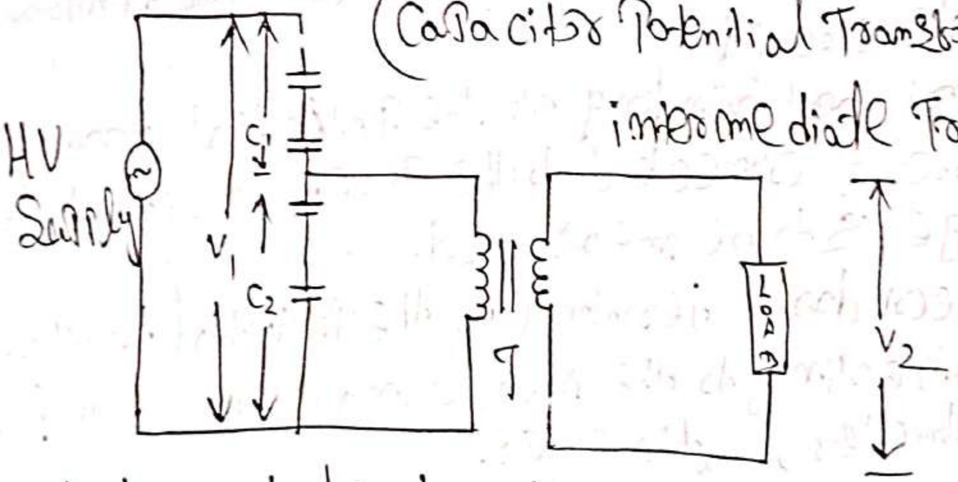
The Potential transformer mainly classified into two type
① conventional wound type (electro magnetic type)
② capacitor voltage Potential transformer.

→ Conventional wound type transformer is very expensive because of the requirement of the insulation.

→ Capacitor Potential transformer is a combination of capacitor Potential divider and magnetic Potential transformer.

→ The circuit diagram of the capacitor Potential transformer.

(Capacitor Potential Transformer circuit)



The intermediate transformer must be of very small ratio error and Phase angle gives the satisfactory performance of the complete unit.

→ The secondary terminal voltage is given by the formula

$$V_2 = V_1 \times \frac{C_1}{C_1 + C_2}$$

* Radio and Phase Angle Errors of Potential Transformer

The Primary & the secondary voltage is exactly proporsal to the primary voltage and exactly in phase opposition.

→ Both the primary & secondary voltage is introdused in the system.

Voltage radio error:

The voltage radio error is expressed is regarding measure voltage and it is given by formula.

$$\text{Radio Error} = \frac{K_E - I_S - I_P}{I_P}$$

K_n is the nominal radio

Phase angle error :-

→ The secondary terminal voltage which is exactly in phase opposition with the primary terminal voltage.

→ The number of instrument in the relay connected to the secondary of the potindial transformer will increase in the error in the potential transformer.

* Burden of a Potidial Transformer:

→ Total enternal volt-Amp load on the secondary at rated secondary voltage.

→ The rated burden of the PT is a VA burden which must not be enceeded if the transformer is to operate which its rated accuraly.

→ This burden is several time greater then the rated burden.

★ <u>uses of C.T & P.T :→</u>

C.T. & P.T are called the instrument transformer because those are used to asist the measuring instrument for the measurement of electrical parameter like current, voltage, frequency, power factor, active power (MW), reactive power (MVAR) etc of high voltage system.

★ ~~Armature reaction~~ :