BEE402 Electrical Machines - I

Date

Unit-1 :- Principle of Electro Mechanical Energy Conversion :-

Introduction, Review of magnetic system, Energy in magnetic system, Force and torque in magnetic field system, Energy balance equation, Energy conversion via electrical field. Energy in a singly excited system, Determination of the force and Torque from energy and co-energy, Generation of EMF in Machines, Torque in machine with cylindrical air gap.

Unit-2 :-

DC Machines :- Armature winding (Concentrated and Distributed).

Winding factor, Armature reaction, communication, Interpoles and compensating windings, Performance characteristics of DC generators, Applications.

Unit-3 :-

DC Machines :- (Contd): Performance characteristics of DC motors,

Starting of DC motors; 3 point and 4 point starters, speed control of D.C motors; Field control, Armature control and voltage control (Ward Leonard method); Efficiency and Testing of DC machines (Hopkinson's and Swinburne's Test). Application, stepper motor and DC servo motor and their Applications.

Unit-4 :-

Single Phase Transformer :- Efficiency and voltage regulation, all day efficiency, Excitation phenomenon and harmonics in Transformer.

Date

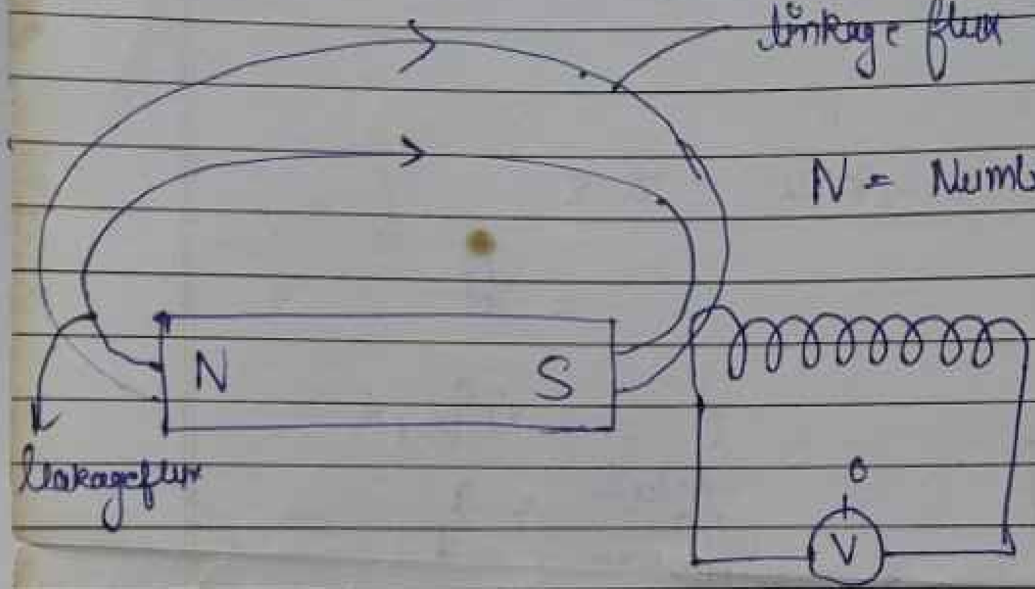
Auto Transformer :- Single phase and three phase Transformers. Volt-ampere relation, copper saving in autotransformer Efficiency, Merits & demerits and applications.

Testing of Transformers :- OC and SC tests, Polarity test, Sumpner's test.

Unit-5 :-

Three phase Transformer :- Construction, Three phase transformer, phasor groups and their connections, open delta connection, three phase to 2 phase and their applications, Three winding transfo-rmers. Parallel operation of single phase transformers and load sharing.

Transformer :-



N = Number of turns

$R_v = \infty\ \Omega$

$$\boxed{e \propto \frac{d\psi}{dt}}$$

ψ = flux linkage

$$\psi = N\phi$$

$$e \propto \frac{d(N\phi)}{dt} \Rightarrow e = 1 \cdot \frac{d(N\phi)}{dt}$$

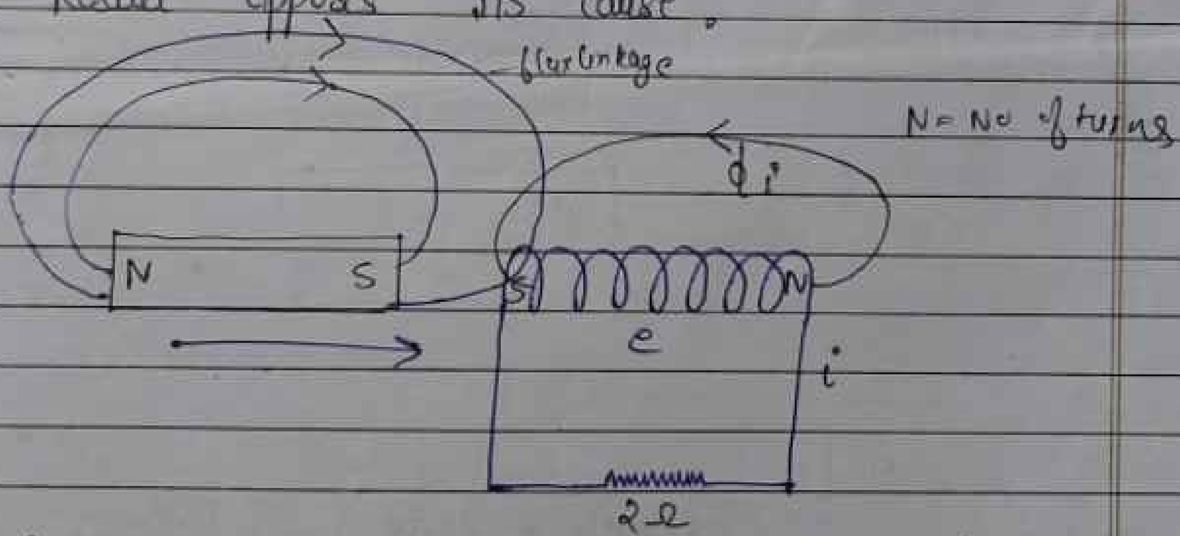
$$\boxed{e = N \cdot \frac{d\phi}{dt}}$$

(1) if magnet → stationary, conductor → motion } Dynamically induced emf

(2) if magnet → motion, conductor → stationary } statically induced emf

Lenz law :-

" Result opposes its cause ".



(without opposition no energy conversion)

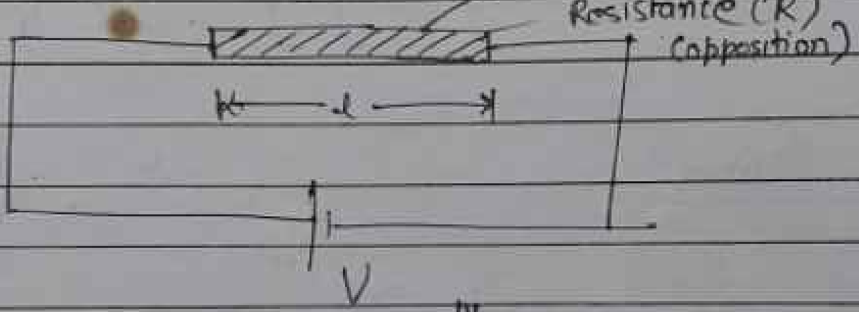
$$\phi_i \xrightarrow[\text{from}]{\text{came}} i \xrightarrow[\text{from}]{\text{came}} e \xrightarrow[\text{from}]{\text{came}} \phi$$

oppose

$$\boxed{e = (-N \cdot \frac{d\phi}{dt}}$$

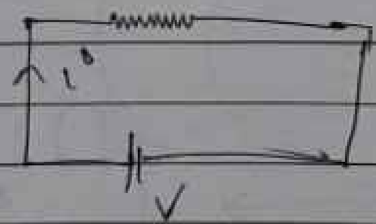
represents opposition

<u>Electrical circuit</u> :- A closed path followed by current is known as electrical circuit.



electric → Heat

|||



emf (electromotive force) → Driving force

$$R \propto \frac{l}{A}$$

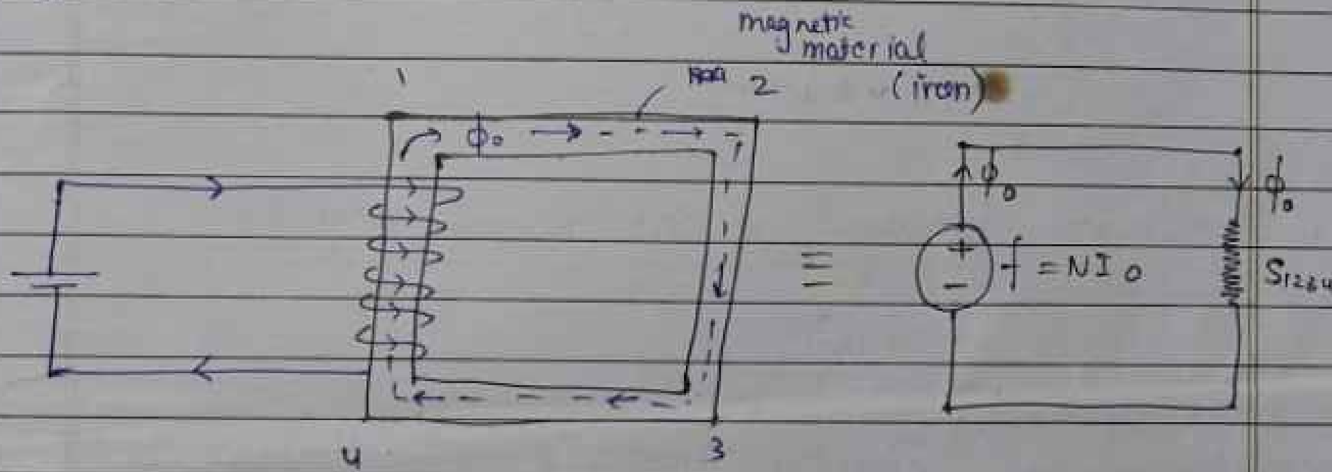
$$\boxed{R = \frac{\rho l}{A}}$$

ρ = resistivity

Ohm's law :-

$$\boxed{V = IR}$$

Magnetic circuit :- A closed path followed by flux is ~~to~~ known as magnetic circuit.



MMF (f) = NI_o

↓

magnetomotive force

↓

(Driving force)

$V = IR$

↓

$$\boxed{NI_o = \phi_o \cdot S_{1234}}$$

$\therefore R = \frac{\rho l}{A}$

$S \propto \frac{l}{A}$ — mean length of core (कोर की लंबाई)

$$\boxed{S = \frac{\rho_r \cdot l}{A}}$$

ρ_r → Reluctivity

Similarities between electrical and magnetic circuit

Parameter	Electrical circuit	Magnetic ckt
(1) Driving force	emf (e/V) volt	m.m.f ($\mathcal{F}$) $\mathcal{F} = NI_0$ (Ampere . Turns / ATs / Amperes)
(2) Response	current (Ampere)	Flux (weber / Wb)
(3) Oppose	Resistance (R) (Ω)	Reluctance (S) (ATs/wb)
(4) Proportanility		

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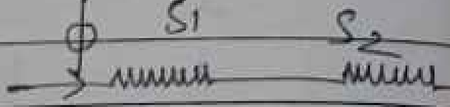
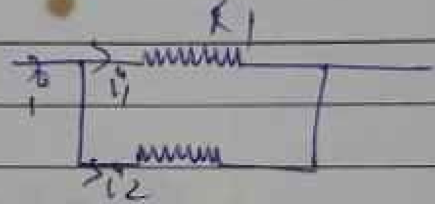
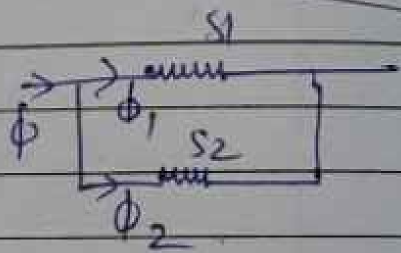
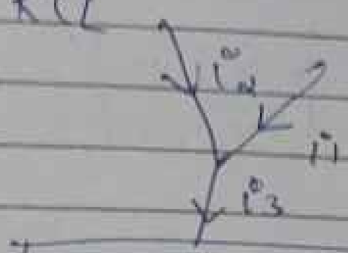
Transformer ...

(5) Admittance	Conductance (G) $G = 1/R \cdot (\Omega)^{-1}$	Permeance (Λ) $\Lambda = \frac{1}{S}$ Wb/ATs
(6)	Conductivity (σ) $\boxed{\sigma = \frac{1}{\rho}}$ $(\Omega \times m)^{-1}$	Permeability (μ) $\boxed{\mu = \frac{1}{\rho L}}$ $\mu = \mu_0 \mu_r$ μ_r = Relative permeability μ_0 = Permeability of free space $\mu_0 = 4\pi \times 10^{-7}$ H/m
(7) ~~Density~~ Density	current density (J) $\boxed{J = \frac{I}{A}}$ (A/m2)	Flux density (B) $\boxed{B = \frac{\phi_0}{A}}$ (Wb/m² or Tesla)
(8) Intensity	Electric field intensity (E) $E = \frac{V}{l}$ (V/m)	magnetic field intensity (H) $H = \frac{NI_0}{l}$ (ATs/m)

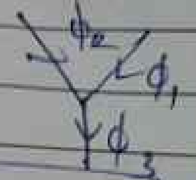
Law	ohm's law	Hopkinson law
	$J = \sigma E$	$\boxed{B = \mu . H}$
Series combination	 $\boxed{R_{eq} = R_1 + R_2}$	 $\boxed{S = S_1 + S_2}$
Parallel combination	 R $\boxed{\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}}$	 $\boxed{\frac{1}{S} = \frac{1}{S_1} + \frac{1}{S_2}}$
Drop	~~emf D~~ emf Drop $\boxed{V = IR}$	mmf drop $\boxed{f = \phi_0 \cdot S}$
	KVL $\boxed{\Sigma V_{Drop} + \Sigma V_{Rise} = 0}$	K(MMF) law $\boxed{\Sigma f_{drop} + \Sigma f_{rise} = 0}$

KCL



$$\boxed{i_3 = i_1 + i_2}$$

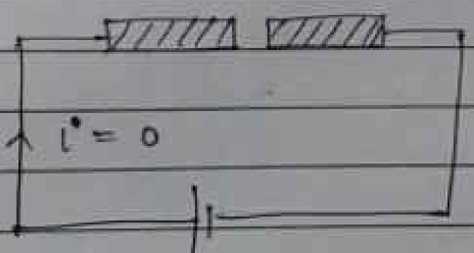
K(flux)L

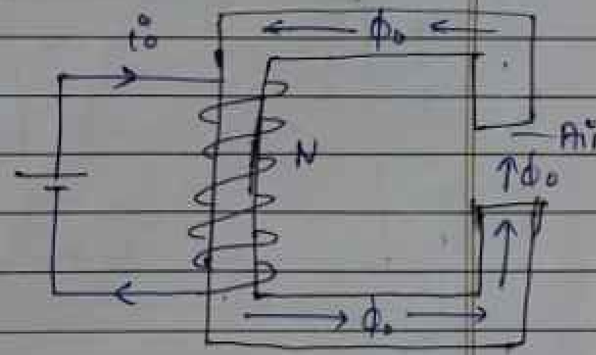


$$\boxed{\phi_3 = \phi_1 + \phi_2}$$

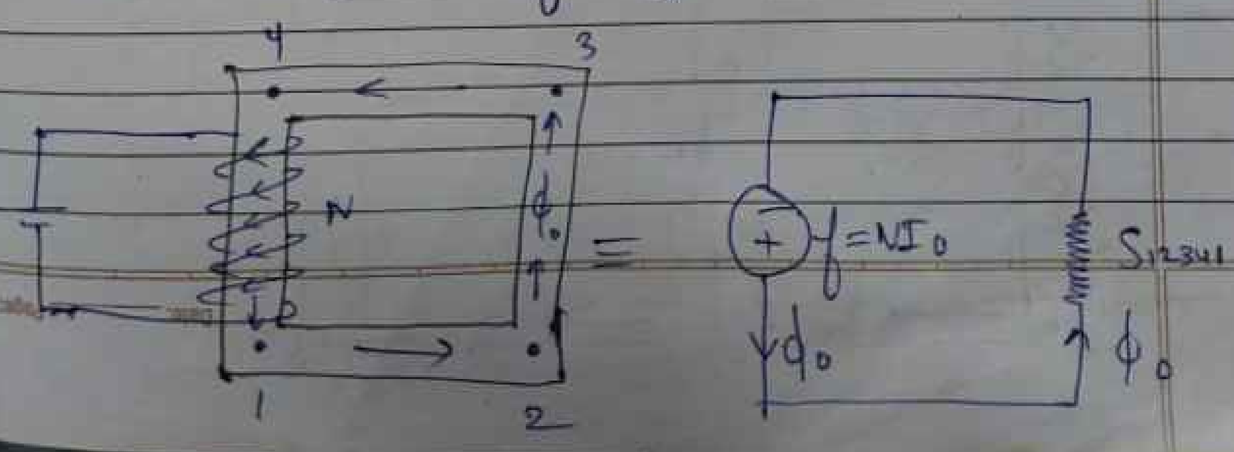
Dissimilarities

(1) In case of electrical circuit air act as insulator but in case of magnetic circuit it does not act as insulator. even in air flux can be created.

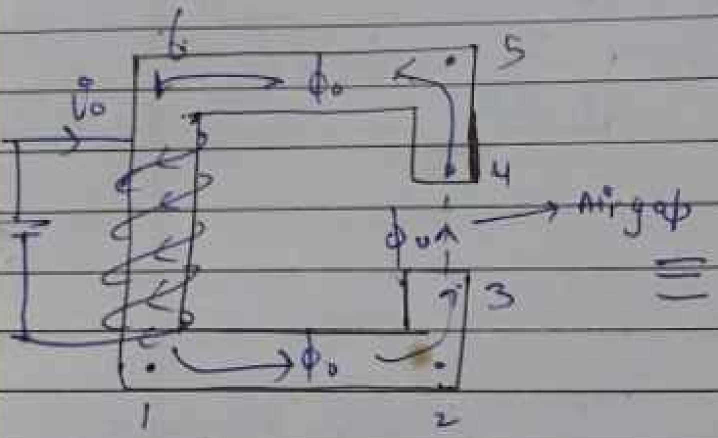


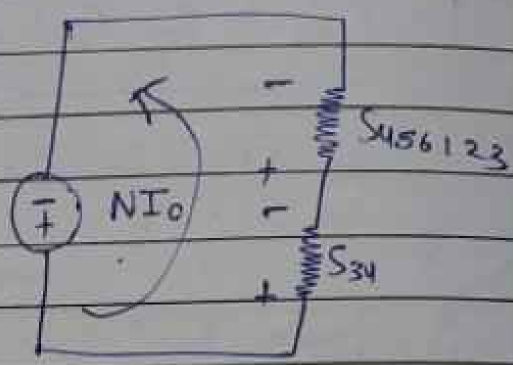


(2) Electrical equivalent of magnetic circuit



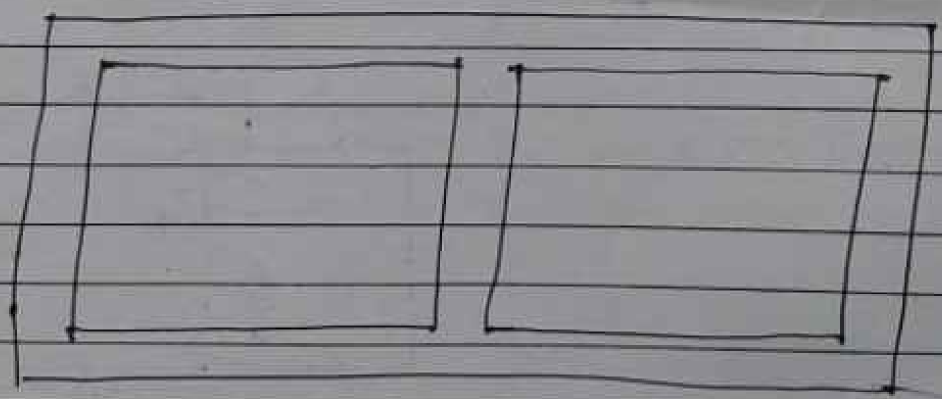
$$\Rightarrow \boxed{NI_0 = \phi_0 S_{12341}}$$

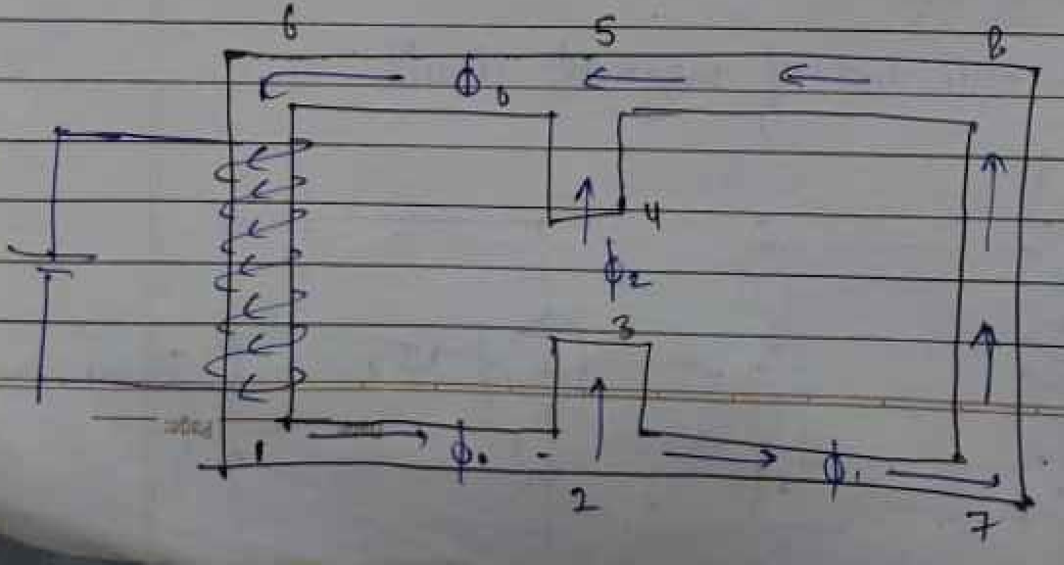


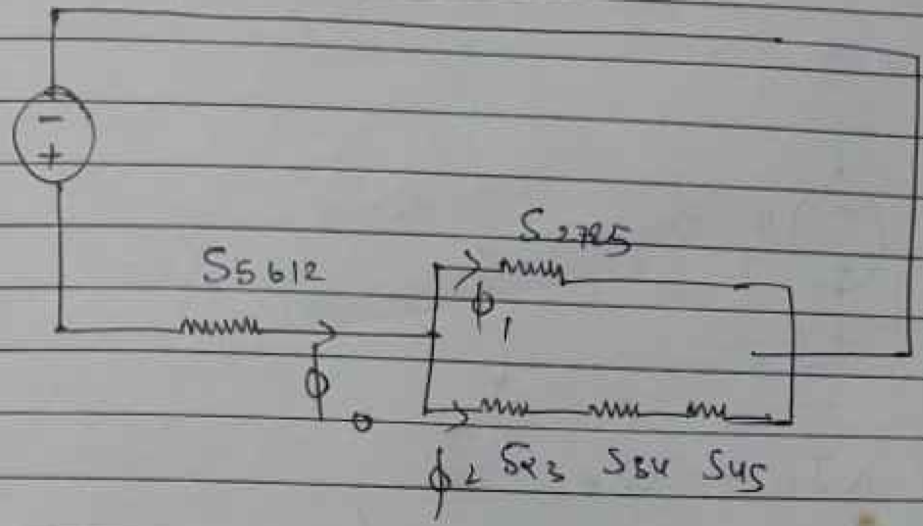


$$\boxed{NI_0 = \phi_0 (S_{34} + S_{456123})}$$

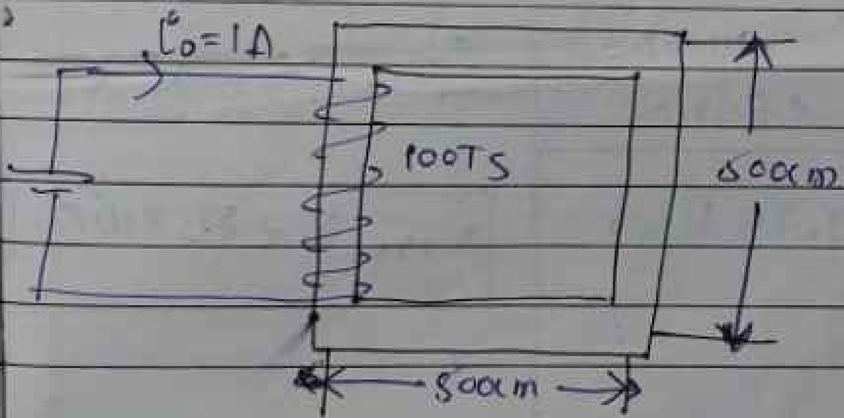
3







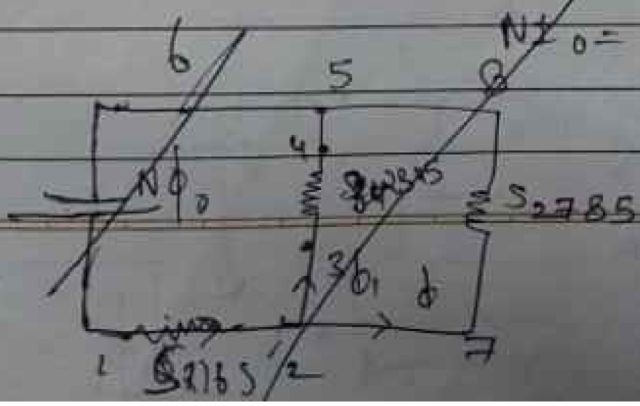
Q. Find the value of operating flux for the given magnetic circuit if relative permeability of core is 2500 and cross sectional area of core is $25 \times 10^{-4} m^2$.



$\mu_r = 2500$

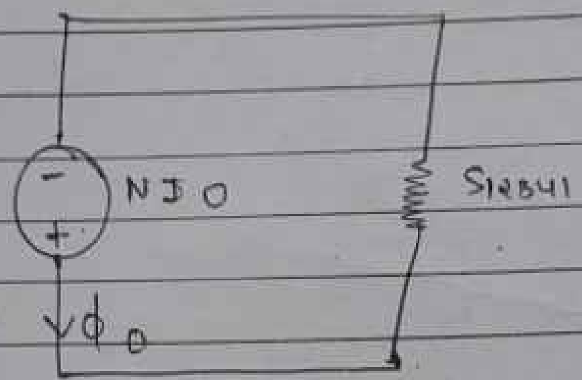
$A = 25 \times 10^{-4} m^2$

$i_0 = 1A$



$N i_0 =$ $\phi_0(S_{2165})$ + $\phi_0 \left(\frac{1}{\frac{1}{S_{34}} + \frac{1}{S_{2785}}} \right)$

(iii)



$$NI_0 = \phi_0 \cdot S_{12341}$$

$$\phi = \frac{NI_0}{S_{12341}}$$

$$\phi_0 = \frac{100 \times 1}{2.55 \times 10^6}$$

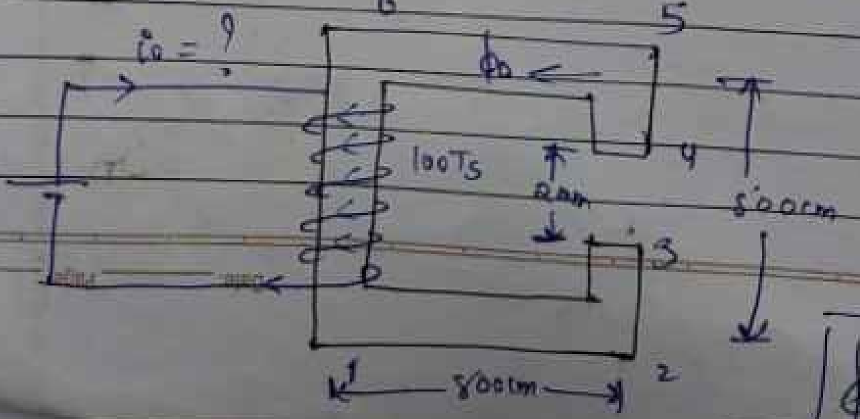
$$\boxed{\phi_0 = 39.25\ \mu Wb}$$

$$S_{12341} = \frac{1}{\mu_0 \mu_r} \frac{l_{12341}}{A}$$

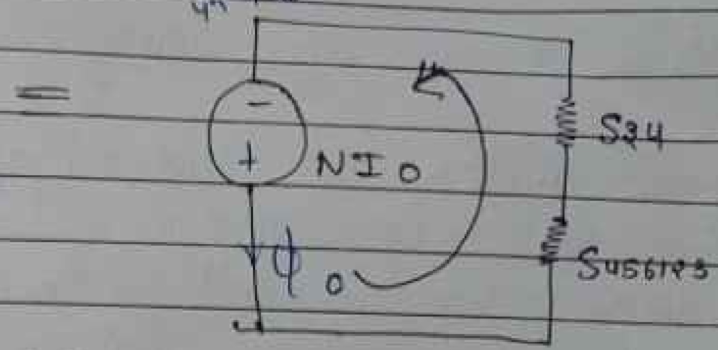
$$= \frac{1}{4\pi \times 10^{-7} \times 2500 \times 25 \times 10^{-4}} \times 20$$

$$\boxed{S_{12341} = 2.55 \times 10^6\ ATS}$$

Q If in above question some air gap is present as shown then find the value of coil current to create 39.25 μWb of flux.



$$\phi_0 = 39.25\ \mu Wb$$



$$NI_0 = \phi_0 \left[\frac{S_{456123} + S_{34}}{} \right]$$

$$= \phi_0 \left[\frac{S_{456123} + S_{34}}{N} \right]$$

$$I_0 = 39.25 \times 10^{-6} \left[\frac{S_{456123} + S_{34}}{100} \right]$$

$$\boxed{I_0 = 1.25\,A}$$

$$S_{456123} = \frac{1}{\mu_0 \mu_r} \cdot \frac{l_{456123}}{A}$$

$$= \frac{1}{4\pi \times 10^{-7} \times 2500} \times \frac{19.998}{25 \times 10^{-4}}$$

$$= 2.55 \times 10^{6} \frac{ATs}{Wb}$$

$$S_{34} = \frac{1}{\mu_0 \mu_0} \times \frac{.002}{A}$$

$$=$$

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~~Note~~ Result :- ~~In case of transformer~~

In a magnetic circuit as the airgap increases then to maintain the same amount of flux the current drawn by the coil increases excessively. In case of transformer their is no air gap present. so, its noload current is minimum which is only 2-5% of full load current.

⇒ In case of induction machine this noload current becomes (30-40)% of full load current due to presence of air gap.

⇒ In case of motor and generator air gap is present for mechanical clearance.

Transformer :-

"Transformer is a static device which transfer electrical energy from one electrical circuit to another electrical circuit through the medium of magnetic field without change in frequency"

→ Transformer is an electromagnetic energy conversion device.

① electro magnetic energy conversion

Electrical energy ⇌ magnetic energy.

Eg (x)mer, inductor.

② Electromechanical energy conversion

electrical ⇌ mechanical.

Eg :- Motor, generator.

③ Electrochemical energy conversion

Electrical ⇌ chemical.

Eg battery.

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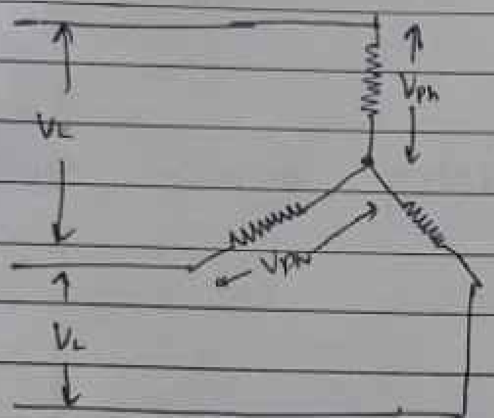
former under

What happens with power loss when one of the wire of branch of 3-ϕ load get breaked.

Star connected load



$\therefore$ Power loss in each resistor $= \frac{V_{ph}^2}{R}$

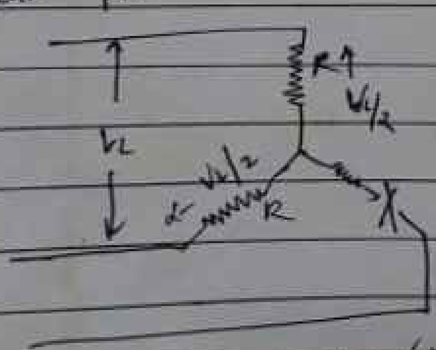
In 3 resistor $= \frac{3V_{ph}^2}{R}$

$\because V_{ph} = \frac{V_L}{\sqrt{3}}$

$\therefore \frac{\cancel{3} V_L^2}{\cancel{3} R}$

$P_{eq} = \frac{V_L^2}{R}$

If 1 of the branch get break then



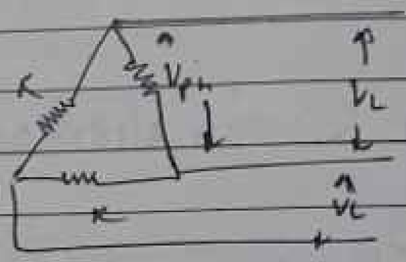
$\therefore$ Power loss $= 2 \times \left(\frac{V_L}{2}\right)^2 R$

$$\boxed{P_{eq}' = \frac{V_L^2}{2R}}$$

$$\boxed{P_{eq}' = 50\% \text{ of } P_{eq}}$$

Reduction in loss $= 50\%$

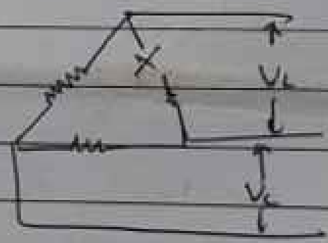
Δ connected load



Power loss in each $= \frac{V_L^2}{R} = \frac{V_{ph}^2}{R}$

$P_{eq} = \frac{3V_L^2}{R}$

If one brach get bred



$P_{eq}' = \frac{2 \times V_L^2}{R}$

$$\frac{P_{eq}'}{P_{eq}} = \frac{\frac{2V_L^2}{R}}{\frac{3V_L^2}{R}}$$

$\frac{P_{eq}'}{P_{eq}} \times 100 = \frac{2 \times 100}{3}$

$$\therefore \boxed{P_{eq}' = 66.6\% \text{ of } P_{eq}}$$

reduction in loss $= 33\frac{1}{3}\%$

Ideal Transformer analysis :-

For ideal transformer analysis following assumptions are taken :-

① The resistance of both primary and secondary assumed to be zero.

(i.e Cu losses = 0, resistive voltage drop = 0)

② Leakage flux between primary and secondary assumed to be zero.

③ Reluctance of core assumed to be zero.

$\therefore \boxed{i_\mu = 0}$

$$\phi_0 = \frac{N_1 I_\mu}{S}$$

$$I_\mu = \frac{\phi_0 S}{N_1} = 0 \quad \because \phi_0 S = 0$$

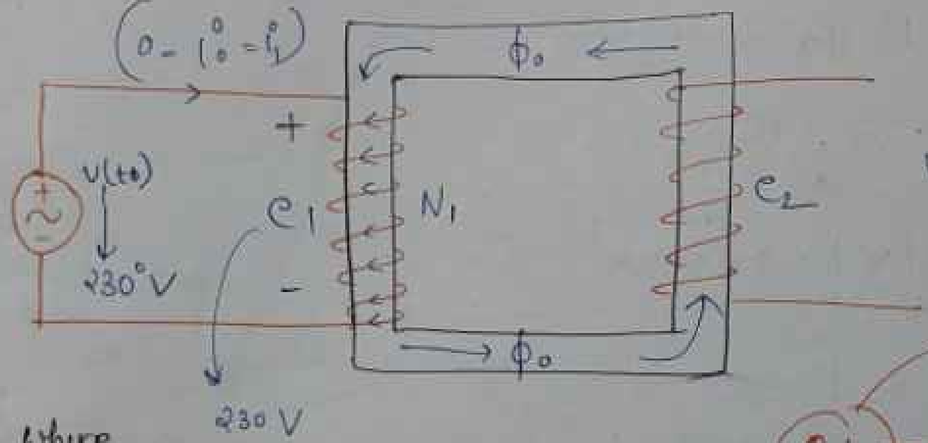
④ The hysterisis and eddy current losses are assumed to be zero.

i.e $\boxed{i_w = 0}$ i.e transformer assumed to be linear

$\boxed{\phi \propto i}$ – linear

Case - I :-

Ideal transformer under noload condition :-



$V_2 \rightarrow$ No load.

$e_1 \rightarrow \phi_0 \rightarrow N_1 i_0 \rightarrow i_0 \rightarrow V_1$

oppose

where

e_2 = secondary induced emf

e_1 = primary induced emf

V_2 = secondary terminal voltage

V_1 = Primary terminal voltage

~~By KVL~~

According to lenz law (always used for phasor)

$$\boxed{V_1 = (-)e_1}$$

it represents opposition

$$\boxed{V_2 = e_2}$$

Let $\phi_0 = \phi_m \sin \omega t$

supply frequency

$$\boxed{e_1 = -N_1 \frac{d\phi_0}{dt}}$$

$$= -N_1 \frac{d\,\phi_{max}\sin\omega t}{dt}$$

$$= -N_1 \phi_m \frac{d \sin\omega t}{dt}$$

$$= -N_1 \phi_m\, \omega \cos\omega t$$

$$= -2f\pi N_1 \phi_m \cos\omega t$$

$$\boxed{e_1 = \underbrace{2f\pi N_1 \phi_m}_{E_{1max}} \sin(\omega t - \pi/2)}$$

$\because \sin(\pi/2 - \phi) = \cos\phi$

$$\boxed{E_{1max} = 2f\pi N_1 \phi_{max}}$$

max / Peak value of primary induced emf.

$$E_{1rms} = \frac{E_{1max}}{\sqrt{2}}$$

$$= \frac{2f\pi N_1 \phi_{max}}{\sqrt{2}}$$

$$\boxed{E_1 = 4.44\, \phi_{max} \cdot f \cdot N_1}$$

EMF equation of Transformer

$$\boxed{e_2 = \underbrace{2\pi f N_2 \phi_{max}}_{E_{2max}} \sin(\omega t - \pi/2) \Rightarrow E_2 = 4.44\, \phi_{max}\, f \cdot N_2}$$

By KVL (used in numerical)

$$\overline{V_1} - \overline{e_1} = 0$$

$$\boxed{\overline{V_1} = \overline{e_1}}$$

Result :-

① $$\boxed{\frac{E_1}{N_1} = \frac{E_2}{N_2} = E_t = 4.44\, \phi_{max} f}$$

Primary induced emf per turn

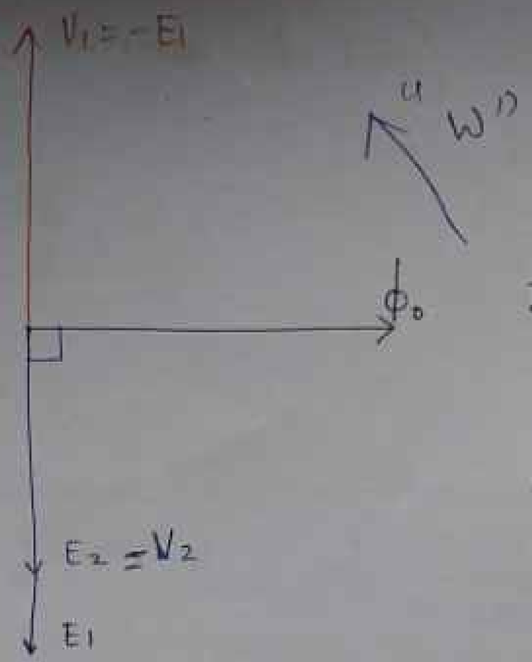
Secondary induced emf / turn

induced emf / turn

② If rated D.C is applied to the primary of the transformer then its primary will definitely burn because their is no back emf.

③ Always induced emf e_1 and e_2 lags 90° with respect to corresponding operating flux ϕ_0.

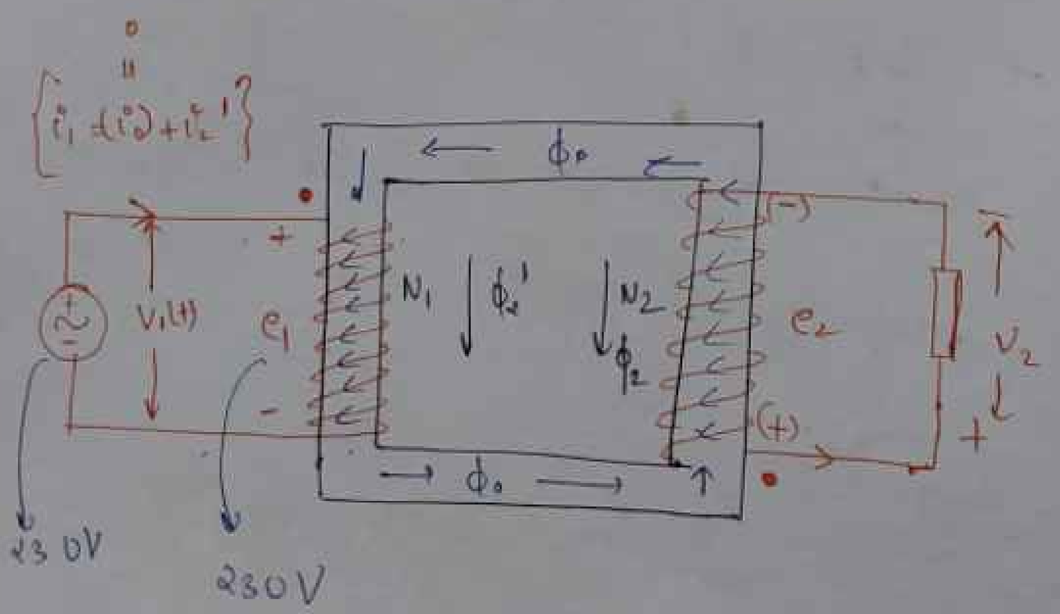
Phasor diagram :-



Let transformer is Step down
$$\left[E_2 < E_1\right]$$

$\because$ E_1 & E_2 lag ϕ_0 by $90°$

Case → 2 :- Ideal transformer under loading condition :-



$$\phi_0 \longrightarrow e_2 \longrightarrow i_2 \longrightarrow N_2 i_2 \longrightarrow \phi_2$$

(ϕ_2 oppose ϕ_0 so ϕ_0 reduces so i_2' will flow to maintain ϕ_0 flux so ϕ_2' is produced which is equal to & oppo to ϕ_2. So flux remains constant

$$\boxed{\phi_0 - \phi_2 + \phi_2' = \phi_0 = \text{constant}}$$

As load ↑ i_2 ↑, ϕ_2 ↑, ϕ_2' ↑, i_2' ↑

load component of primary current.

$$\boxed{e_2 = V_2}$$

$$\boxed{\bar{\phi}_2 = -\bar{\phi}_2'}$$

$$\bar{\phi}_2 = -\bar{\phi}_2'$$

$$\frac{N_2 \bar{I}_2}{S} = -\frac{N_1 \bar{I}_2'}{S}$$

$$\boxed{I_2' = -\frac{N_2}{N_1} \bar{I}_2}$$

$$\boxed{\bar{I}_1 = \bar{I}_2' = -\frac{N_2}{N_1} I_2}$$

$\cancel{\phi_2' = \phi_2}$ $\cancel{NI = S\phi}$

$\cancel{\frac{N_1 i_2'}{S} = \frac{N_2 i_2}{S}}$ $\cancel{i_2' = \frac{N_2}{N_1} i_2}$

Result :-

1) $$\boxed{\frac{E_1}{E_2} = \frac{N_1}{N_2} = \frac{I_2}{I_1} = \frac{V_1}{V_2}}$$

2) $\boxed{V_1 I_1 = V_2 I_2}$

$V_1 I_1$ ↓ I/P VA, $V_2 I_2$ ↓ O/P VA

∴ In transformer

VI = constant

$I \propto \frac{1}{V}$

3) $N_1 I_1 = N_2 I_2$

$N_1 I_1$ ↓ Primary MMF, $N_2 I_2$ ↓ Secondary MMF

∵ P. MMF = S. MMF So; from primary to secondary power is transformed through induction.

4) Conductor size $\propto$ current

5) Insulation $\propto$ Voltage

6) H V side ⇌ L.V side.

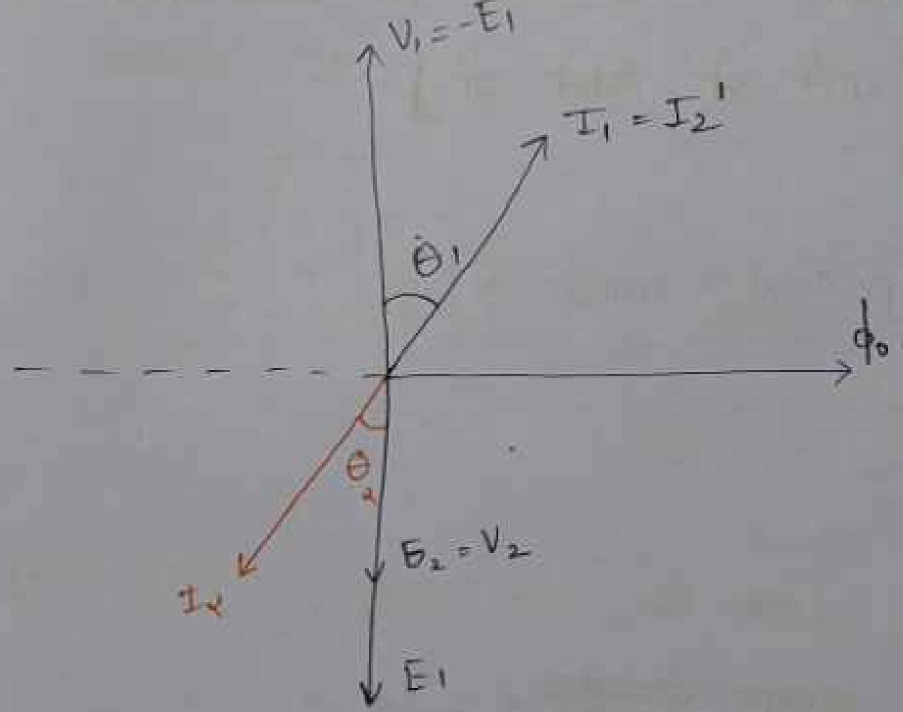
HV side	LV side
V ↑, insulation ↑	V ↓, insulation ↓
I ↓, conductor thin	I ↑, Thick wire.

Phasor diagram :-

$i_1 = e_2'$

Parameters V_1 , I_1 , ϕ_0 , E_2 , V_2 , I_2

$I_1 = I_2'$



∵ ϕ_0 is linking to both so it is taken as reference

If load is R-L i_2 lags V_2 by angle (θ_2)

θ_1 = angle B/w V_1 and i_1

θ_2 = ~~p/f~~ I/P p.f angle of T/F

$$\boxed{\theta_1 = \theta_2}$$

$$\therefore \boxed{\cos\theta_1 = \cos\theta_2}$$

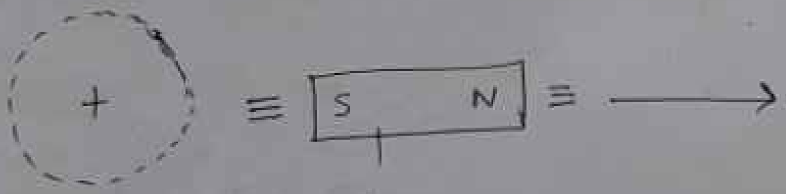
Note :-

If in a transformer current enter in dot on primary side then current must leave from the dot on secondary side or vice versa.

(ये नही दिखने वाले wire से enter से enter करेगी then नही दिखने वाले से निकलेगी)

Analysis of practical transformer :-

(1) B-H curve :-



Diple

Normal material

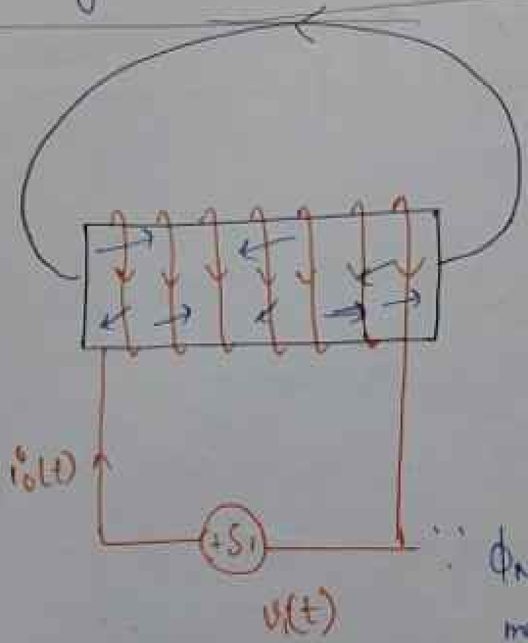
(wood, plastic)

has n number of random dipoles

$$\therefore \boxed{\Sigma \phi_d = 0}$$

(2) Non-magnetic material :- (saturation not occurs)

When non-magnetic materials are placed in external magnetic feild the dipoles remains random and does not change their position ~~at~~ because non magnetic materials provide high a reluctance path. so, net flux due to dipoles becomes zero and we gets flux only due to current.



$$\boxed{\Sigma \phi_d = 0}$$

$$\boxed{\phi_{Net} = \phi_i}$$

$\because$ ϕ_{Net} is only due to i ~~so~~ becauz material have high ~~ret~~ reluctance

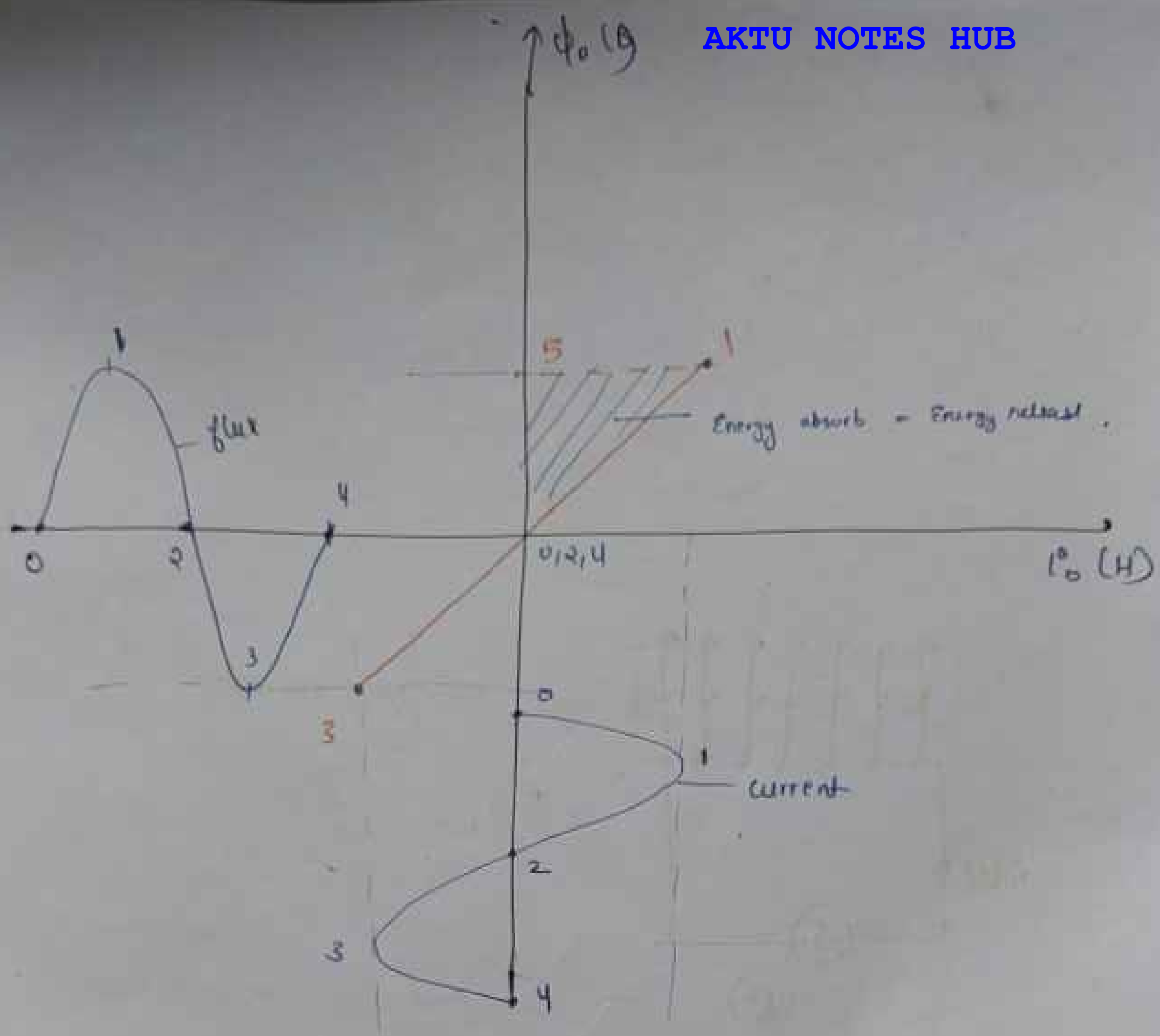
reluctanc $\uparrow$

eg wood, plastic, $\boxed{\text{Aluminium, air}}$

non magnetic

$\boxed{\phi_i \propto i}$ — linear

Permiability of air = 1 " " iron ≈ 1000



$$E = \frac{1}{2} L I^2$$

$$\vec{I_0} \longrightarrow \phi_0$$

From 0 to 1 :-

$i_0 \uparrow$, system absorb energy
area of $\Delta 015$

From 1 to 2 :- $i_0 \downarrow$, system release energy
area of Δ 015

So, there is no hysterissis loss.

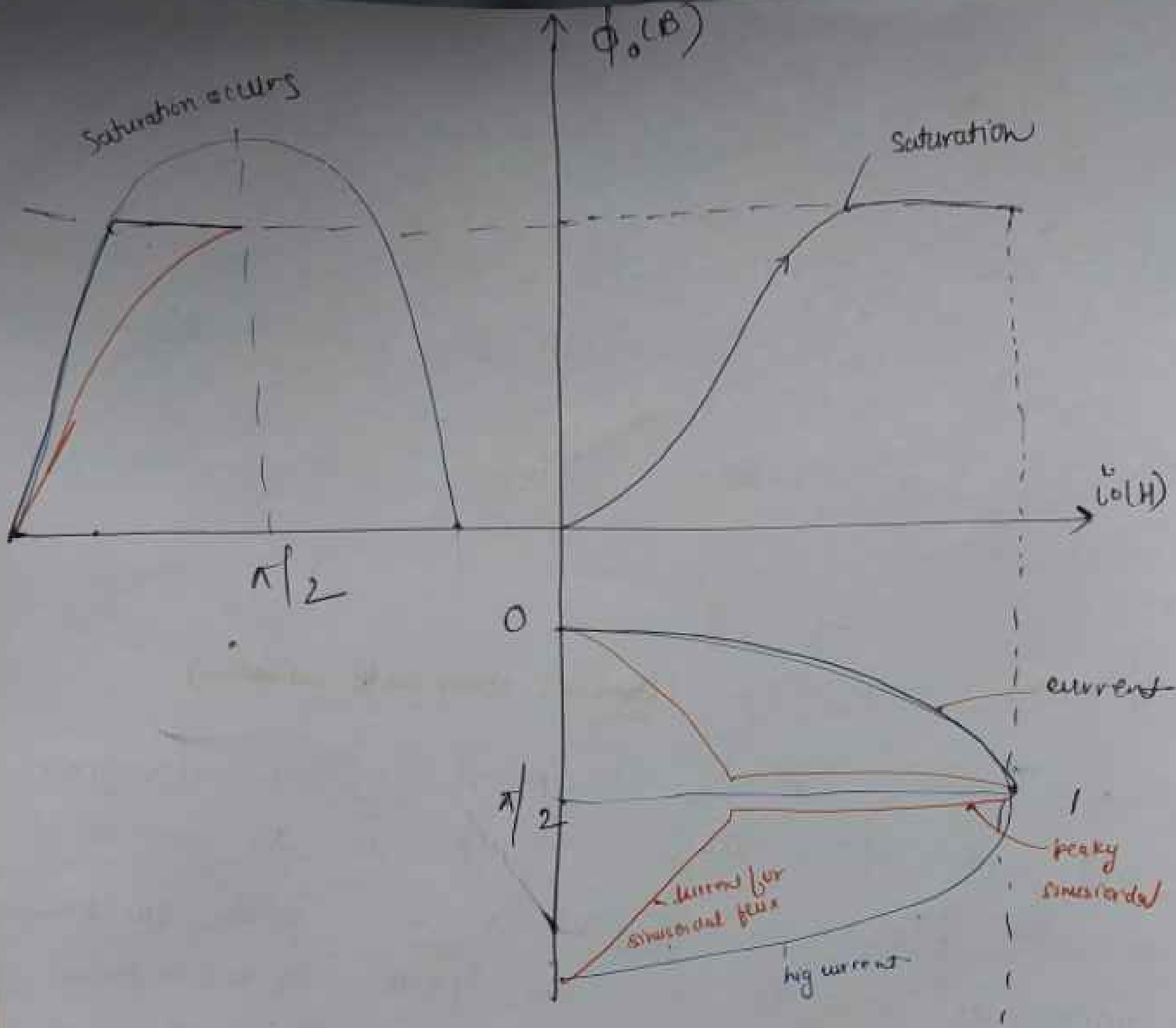
loss due to magnetisation & demagnetisation.

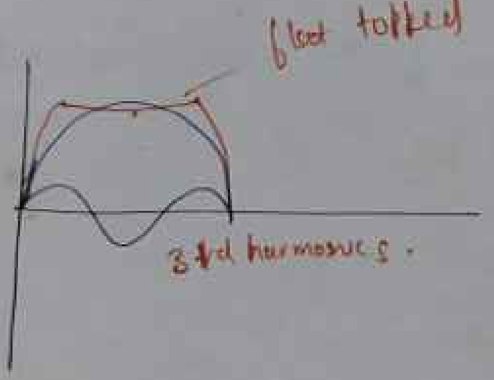
(3) In case of of non magnetic material their is no saturation So, if current is sinusoidal then flux will also sinusoidal

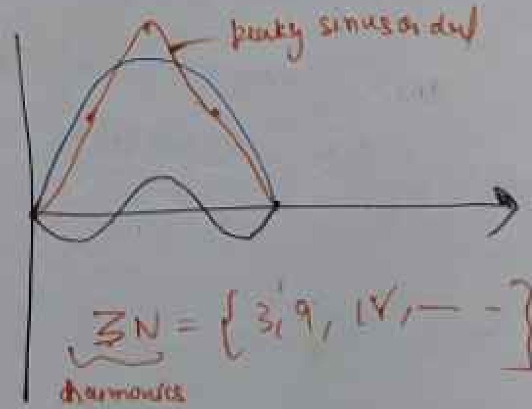
(4) Their is no harmonics injection in case of non-magnetic material.

Magnetic materials:- (Harmonics comes due to saturation)

When magnetic materials are placed in external magnetic field the dipoles start arranging in the direction of magnetic field. So, we gets the magnetic field due to current as well as due to dipoles. So, the B-H curve is non linear. Once all the dipoles are arranged in the direction of magnetic feild then material goes into saturation region.







case 1

$\underbrace{\Sigma N}_{\text{harmonics}} = \{3, 9, 15, \text{---}\}$

N = always odd

case 2

Diamagnetic material $\mu_r < 1$

Pararamagnetic material $\mu_r > 1$

Feromagnetic material $\mu_r >> 1$

$\boxed{\mu_{dia} < \mu_P < \mu_F}$

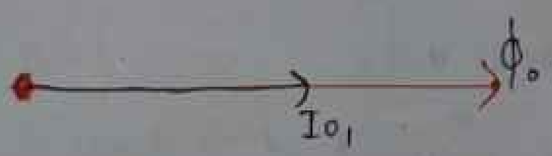
Results :-

① In case of magnetic material if current is sinusoidal then flux becomes flat topped or if flux is sinusoidal then current becomes peaky sinusoidal. So, their is harmonic injection due to saturation of the core (with dominant the 3rd order harmonics).

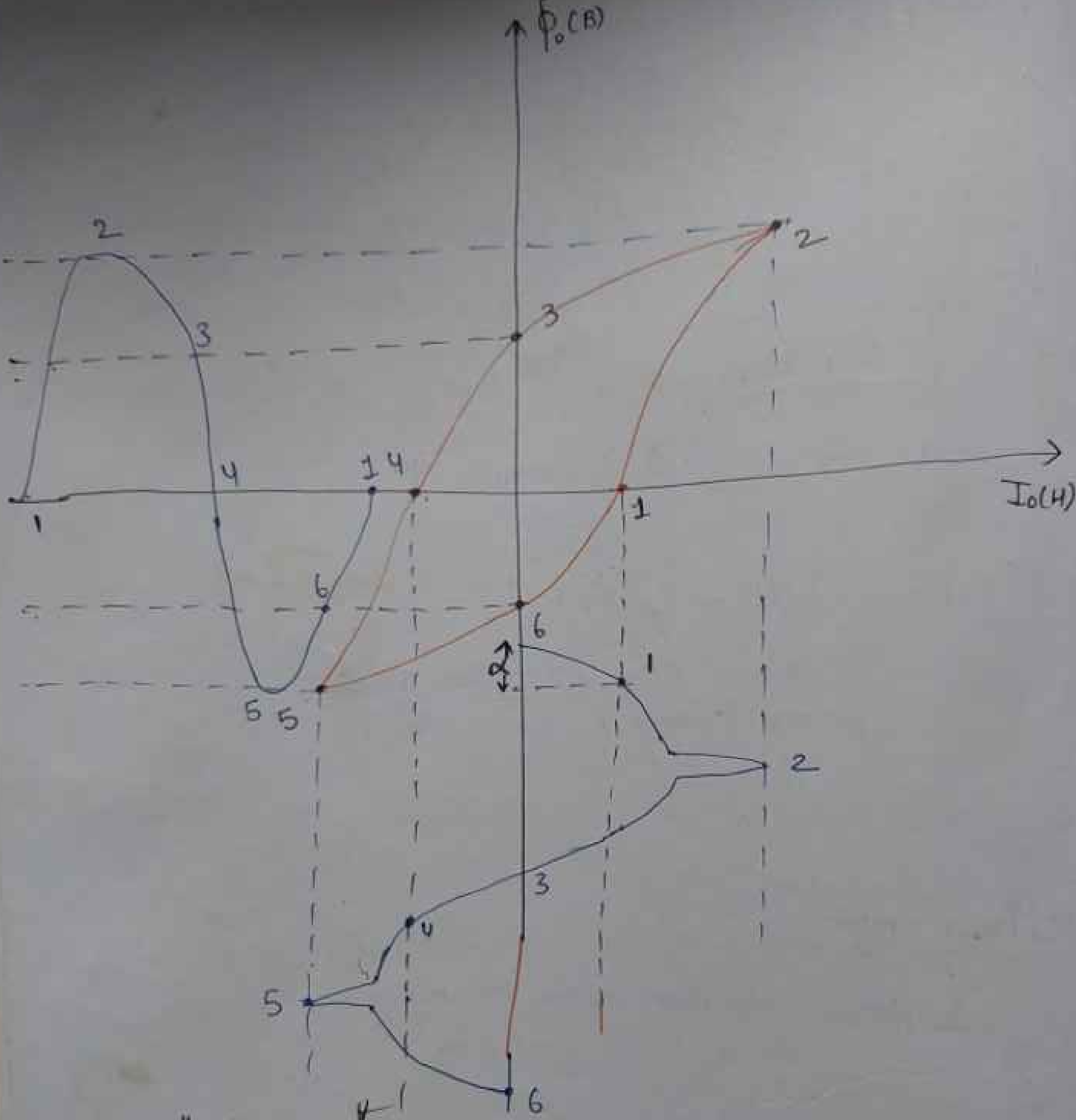
$$i_o(t) = \underbrace{i_{o_1}(t)}_{\substack{\text{fundamental component} \\ (f)}} + \underbrace{i_{o_3}(t)}_{\substack{\text{3rd order harmonics} \\ (3f)}} + \cdots\cdots$$

② Phasor diagram :-

∵ In phasor all have same frequency.



③ Magnetic material with cyclic magnetic feild :-

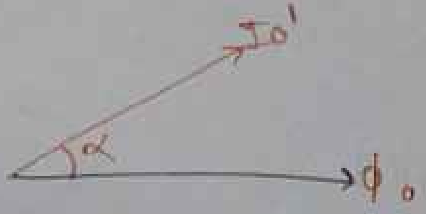


$\boxed{\alpha = \text{hysterisis angle}}$

$\therefore$ the fundamental component of i_o leads ϕ_o by angle α

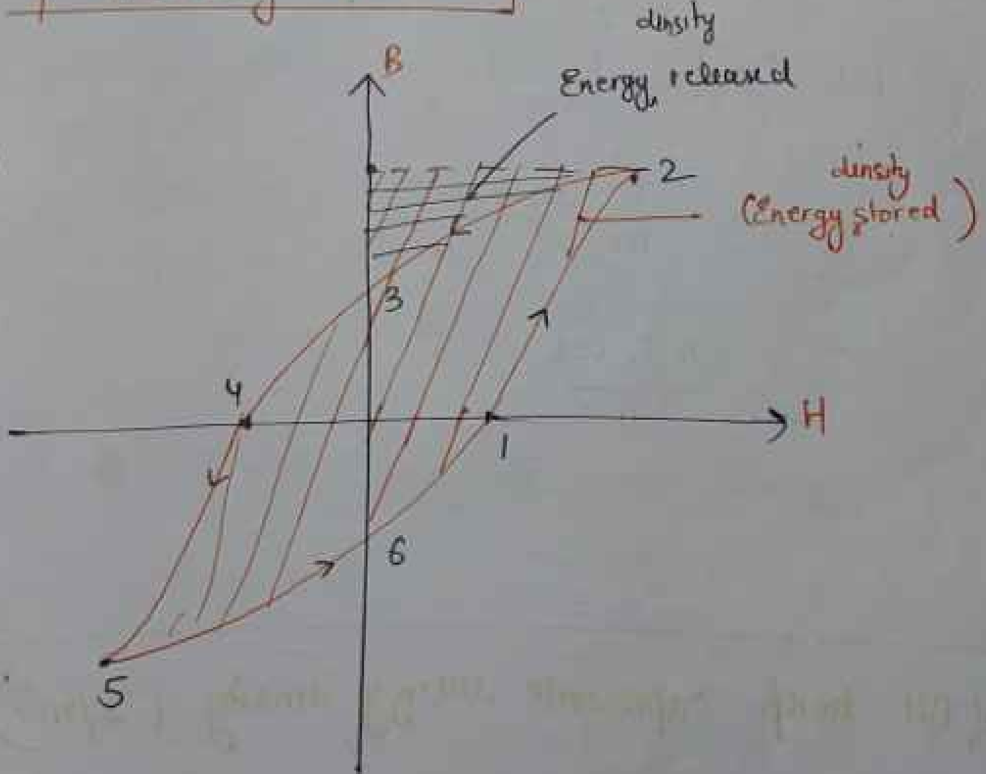
Results :-

(1)



$$\boxed{\text{Practically } \alpha = 15^\circ}$$

(2)



(3)

$\psi \propto i$

$\psi = Li$

$N\phi = Li$

$$\boxed{L = \frac{N\phi}{i}}$$

$\therefore \quad E = \frac{1}{2} L i^2$

$$= \frac{1}{\alpha} \times \frac{N\phi}{i} \times i^2$$

$$\boxed{E = \frac{1}{\alpha} N \phi i}$$ —— (3)

Joule (Ts, wb A)

$$\text{area of BH Loop} = B \times H$$

$$\frac{wb}{m^2} \times \frac{ATs}{m}$$

$$= \frac{ATs\, wb}{m^3} =$$

from equation (3)

$$= \frac{J}{m^3}$$

area of BH loop represents energy density (J/m^3)

(4) hysterisis loss per cycle = area of BH loop (J/m^3)

(5) hysterisis loss per cycle = area of BH loop x Volume of core

(6) Total hysterisis Loss = area of BH loop x volume of core x operating frequency

$W = J/sec$

Watt

Area of BH loop = ~~50 cm²~~ for a magnetic material = $50 cm^2$

when two axes are scalled as

$$1cm = 50\ mWb \text{ — } y$$
$$1cm = 20\ ATs \text{ — } x$$

If operating frequency is 50 Hz then find the total hysterisis loss.

area of BH curve $= 50\ cm^2$

$$= 50\ (\underset{x\text{-axis}}{1cm} \times \underset{y\text{-axis}}{1cm})$$

$$= 50 \times (50 \times 20)\ m\,Wb\,ATs$$

$$= 50 \times 10^{+3}\ mWb\,ATs$$

area $= 50\ J$

Total hysterisis loss $= 50J \times 50Hz$

$$= 2500\ W$$

① **Steinmetz formula for hysterisis loss :-**

$$\boxed{W_h \propto B_m^x \cdot f}$$

B_m = maximum flux density (T)

f = operating frequency (Hz)

x = Steinmetz constant

$$\left\{ \begin{array}{l} \text{By default} \\ x = 1.6 \text{ for } \cancel{\text{GRO}} \text{ CRGO steel} \end{array} \right\}$$

Cold Rolled Grain oriented

$$\boxed{B_m = \frac{\phi_{max}}{A}}$$

$$\boxed{\phi_{max} \propto \frac{V}{f}}$$

$\because E \approx V$ and $E = N \frac{d\phi}{dt}$

$\boxed{t = \frac{1}{f}}$

$V_1 = E_1$

$V_1 = 4.44 \, \phi_{max} N_1 f$

$\phi_{max} \propto \frac{V_1}{f}$

Case - I If $\frac{V}{f}$ = constant

i.e ϕ_{max} = const i.e B_m = const

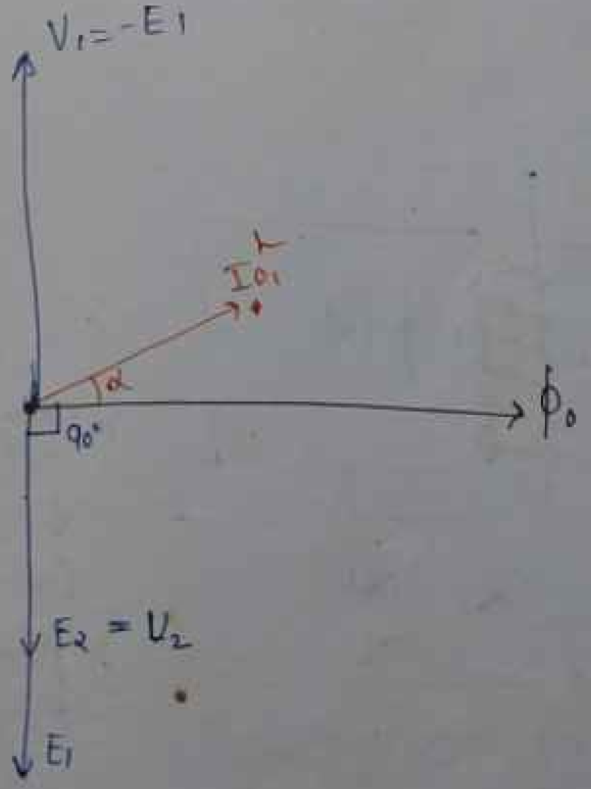
$\cancel{B_m}$ $\boxed{W_h \propto f}$

Case → 2 If $V/f \neq$ constant, $\phi_{max} \neq$ const, $B_m \neq$ const

$$\therefore W_h \propto \left(\frac{V}{f}\right)^x \cdot f$$

$$\boxed{W_h \propto \frac{V^x}{f^{x-1}}}$$

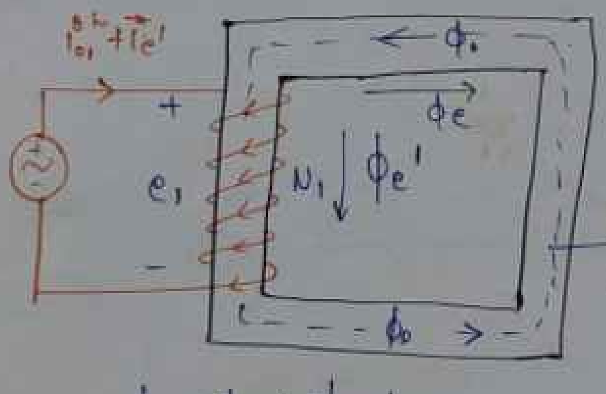
(5) Phasor diagram of practical transformer with only hysterisis loss :-



Eddy current loss:-

The main disadvantage of magnetic material is they are well (good) conductor of electricity. Since the alternating flux also link with core. So, an emf is induced in the core which is known as eddy induced emf.

⇒ Since the core is always closed so, a current start flowing threw it and due to resistance power losses occurs.



e_e eddy induced emf

↓

i_e = eddy current

↓

ϕ_e produce

(So i_e' start flowing in primary due to which a flux ϕ_e' produce to cancel flux ϕ_e)

$$\phi_o - \phi_e + \phi_e'$$

$$= \phi_o = \text{constant}$$

$$\therefore \boxed{\phi_e' = -\phi_e}$$

$$\frac{N_1 I_e'}{S} = -\frac{(1) I_e}{S}$$

$$\boxed{I_e' = -\frac{I_e}{N_1}}$$

$$\boxed{E_e = 4.44\,\phi_{max} f}$$

$$L = \frac{N\phi}{i}, \quad \phi = \frac{Ni}{S}$$

$$L = \frac{N \times Ni}{i\; S} = \frac{N^2}{S}$$

$$\therefore \boxed{L = \frac{N^2}{S}}$$

$$\cancel{\phi_e = -\phi_e'}$$

$$\cancel{\frac{NI_e}{S} = \frac{N_1 I_e'}{S}}$$

$$\cancel{\boxed{I_e' = \frac{I_e}{N_1}}}$$

Since core having only 'one' turn.

$$L = \frac{(1)^2}{255 \times 10^6} \Rightarrow L = 0.5 \times 10^{-6} H$$

$$L = 0$$

Core can be assumed pure resistive.

$$\therefore \boxed{W_e = i_e^2 R} \qquad \boxed{W_e = \frac{E_e^2}{R}}$$

R = resistance of core.

∵ E_e cannot be reduced bec of E_2 reduces ~~and~~ and it is only reduced by reducing f & ϕ_m

$\therefore$ $\boxed{R = \frac{\rho \uparrow l}{A \downarrow}}$ → const (~~both~~ otherwise size of T/F ↑) (to Increase R)

max 4% silicon
To increase resistivity

area is reduced by using laminated core.

$\boxed{\text{thicknes of strips} = t = 0.35\,mm \text{ to } 0.50\,mm}$

$\boxed{W_e \propto t^2}$ thickness of core

Result →

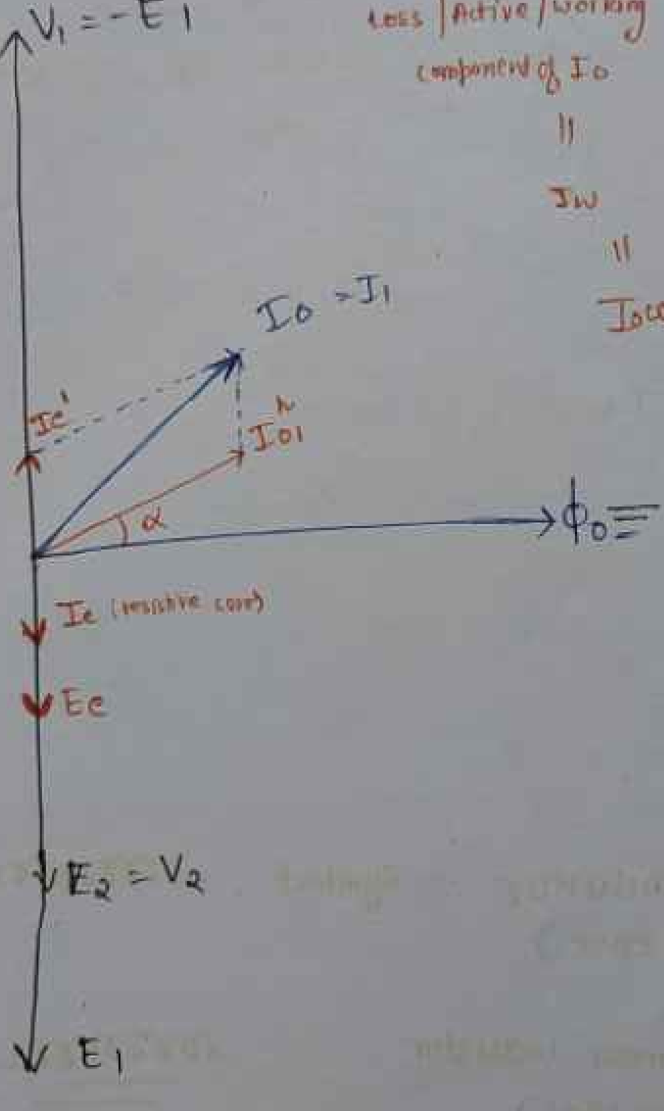
(1) Eddy current loss can be minimised by making the core with thin lamination due to laminations effective cross sectional area of core gets reduced

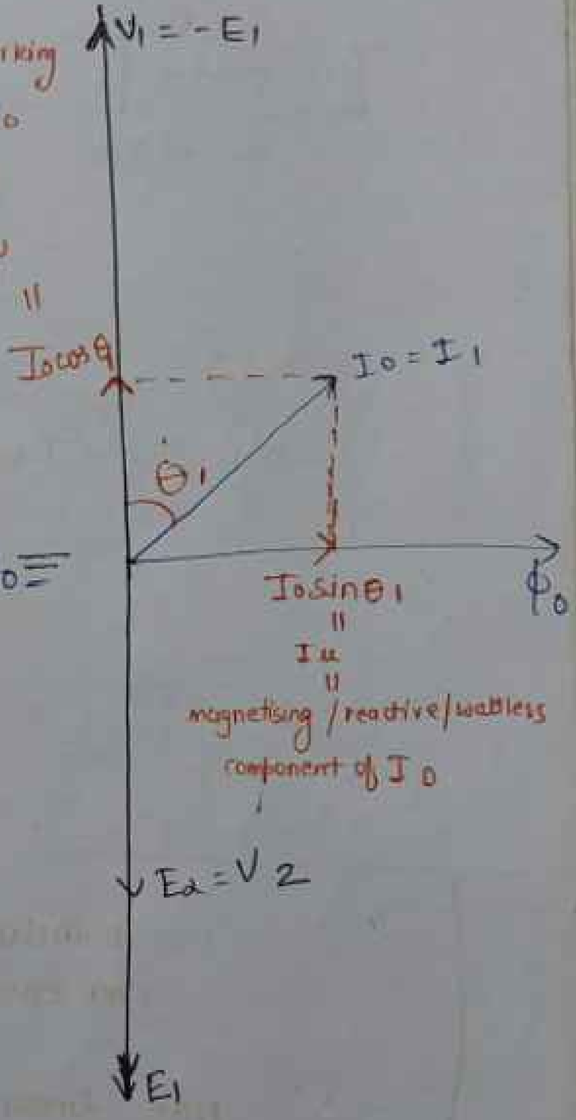
(2) To increase the resistivity of the core a controlled quantity of silicon will be added. Too much addition of silicon is not preferred because it reduces the magnetic property of the core and also make the core ~~m~~ mechanically brittle.

(3) The laminations are insulated by varnish or red oxide

(4) Eddy current and hysterisis loss combined by known as iron loss as ~~Am~~ core loss.

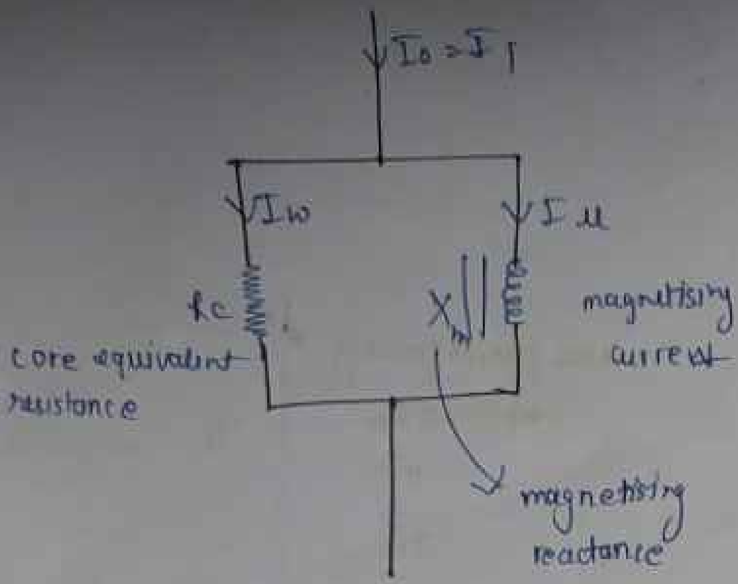
Phasor diagram of practical transformer which only core loss





$$\boxed{\overline{I_0} = \overline{I_w} + \overline{I_\mu}}$$

current divided in parallel connection



$$\boxed{W_c = I_w^2 R_c = V_1 I_0 \cos\theta_1}$$

$$\boxed{L = \frac{N^2}{S}}$$

For Linear inductor (Air core) · symbol

· Non linear inductor (Iron core)

for transformer $\theta_1 = 75^\circ$
b/w V_1 and I_1 or I_0

Steimetz formula for eddy current loss :-

$$\boxed{W_e \propto B_m^2 \cdot f^2}$$

Case-I if $\frac{V}{f}$ = constant

$$\boxed{W_e \propto f^2}$$

Case→II if $V/f \neq$ constant.

$$W_e \propto \frac{V^2}{f^2} \times f^2$$

$$\boxed{W_e \propto V^2}$$

A 220 V, 60Hz single ~~fase~~ phase transformer having hysterisis loss of 340 watt and eddy current loss of 120W find the total core loss of the transformer is operated at

(1) 110V, 30Hz

(2) 200 V, 50Hz

$V = 220$ V, $f = 60$Hz.

$W_h = 340$ W, $W_e = 120$ W.

$$\frac{V}{f} = \frac{220}{60} = \frac{11}{3}$$

for case - 1

$V_1 = 110$V, $f' = 30$Hz

$$\frac{V_1}{f_1} = \frac{110}{30} = \frac{11}{3} = \frac{V}{f}$$

$\therefore \frac{V}{f}$ is constant.

$\therefore W_H \propto f$

$$\frac{W_H'}{W_H} = \frac{f'}{f}$$

$$W_H' = W_H \frac{f'}{f}$$

$$= 340 \times \frac{30}{60}$$

$$\boxed{W_H' = 170 \text{ watt}}$$

for constant V/f

$$\boxed{W_e \propto f^2}$$

$$\therefore \frac{W_e'}{W_e} = \frac{f_1^2}{f^2}$$

$$W_e' = W_e \frac{f_1^2}{f^2}$$

$$= 120 \left(\frac{30}{60}\right)^2$$

$$\boxed{W_e' = 30 \text{ watt}}$$

$$\boxed{W_{core}' = W_e' + W_H'}$$

$$= 30 + 170$$

$$\boxed{W_{core}' = 200\,watt}$$

(2) $V'' = 200$, $f'' = 50\,Hz$

$$\frac{V''}{f''} = \frac{200}{50} = 4 \neq \frac{V}{f}$$

$\therefore \frac{V}{f}$ is not constant

$\therefore$ $W_H \propto B_m^x f$

$$W_H \propto \left(\frac{V}{f}\right)^x f$$

$$W_H \propto \frac{V^x}{f^{x-1}}$$

$$\frac{W_H''}{W_H} = \frac{V_{11}^x}{V^x} \times \frac{f^{x-1}}{f_{11}^{x-1}}$$

$$= \left(\frac{V_{11}}{V}\right)^x \times \left(\frac{f}{f''}\right)^{x-1}$$

$$\frac{W_h''}{340} = \left(\frac{200}{220}\right)^{1.6} \times \left(\frac{60}{50}\right)^{.6}$$

$$\boxed{W_H'' = 325.55\,W}$$

If $\frac{V}{f}$ is not const

$W_e \propto f^2$

$$\frac{W_e''}{W_e} = \frac{f''^2}{f^2}$$

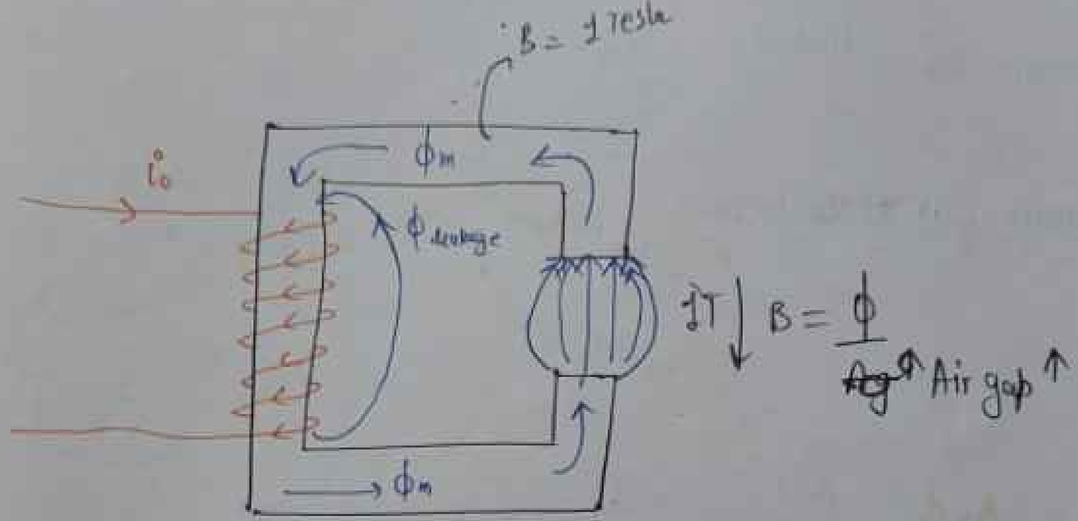
$$\boxed{W_e'' = \left(\frac{80}{60}\right)^2 \times W_e}$$

$$\boxed{W_e'' = 99\,W}$$

$$\therefore \boxed{W_e'' = 42555\,W}$$

Fringing effect :-

As the flux crosses the air gap flux buldge out at the end of the core this is known as fringing due to fringing effective cross sectional area of the air gap increases. so, flux density decreases.



ϕ_l = leakage flux

ϕ_m = usefull / mutual flux.

$$\boxed{\bar{\phi}_0 = \bar{\phi}_m + \bar{\phi}_l}$$

total operating flux.

ideally $\boxed{L \cdot F = 1}$

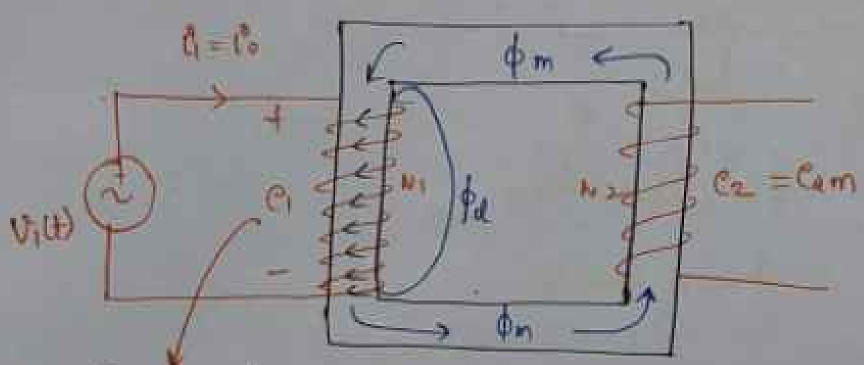
Practically $\boxed{L \cdot F > 1 \, , \; L \cdot F = 1.2}$

$$\boxed{\text{Leakage factor} = \frac{\text{Total operating flux}}{\text{useful flux}}}$$

$$\boxed{L \cdot F = \frac{\phi_0}{\phi_m}}$$

Leakage flux :- The flux which link only with primary or only with secondary but not both. Is known as leakage flux

Case I Leakage flux at No load



$(e_{1m} + e_{1l})$

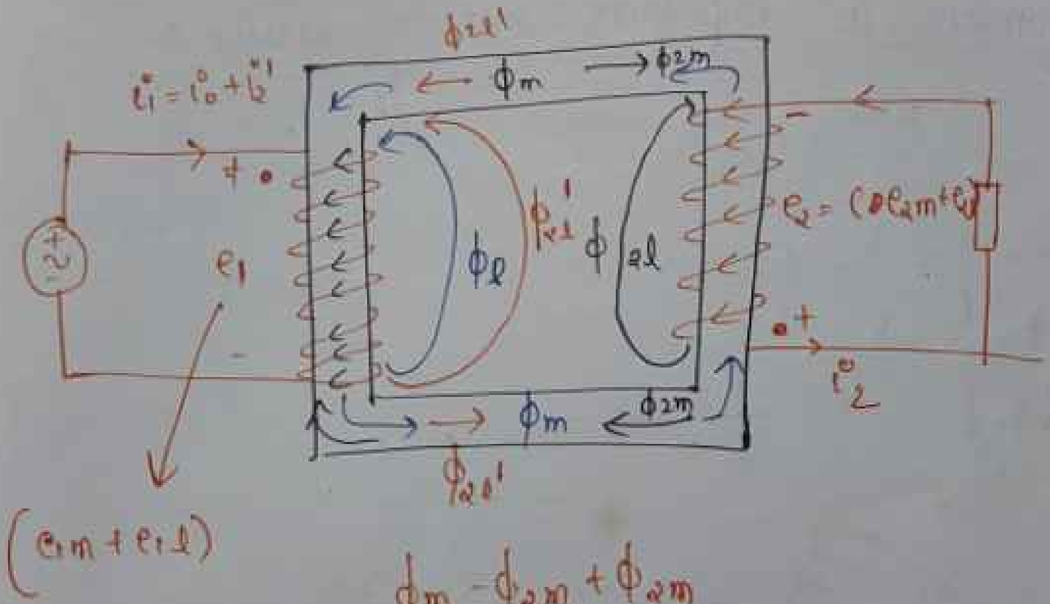
$\boxed{V_1 = -e_1}$, $e_1 = (e_{1m} + e_{1l})$

$\boxed{V_2 = e_2}$, $e_2 = e_{2m}$

Primary leakage flux $= \phi_l$

Secondary leakage flux $= 0$

Case → II   leakage flux at load



$\phi_m - \phi_{2m} + \phi_{2m}$

$\therefore \phi_m = \text{const}$

$\phi_2 = (\phi_{2m} + \phi_{2l})$

$$\boxed{\overline{\phi_{2m}'} = -\overline{\phi_{2m}}}$$

$\phi_2' = \phi_{2m}' + \phi_{2l}'$

$e_2 = e_{2m} + e_{2l}$

$e_1 = e_{1m} + e_{1l}$

$v_1 = -e_1$

$v_2 = e_2$

Primary leakage flux $\phi_l + \phi_{2l}'$

Sec leakage " ϕ_{2l}

AKTU NOTES HUB

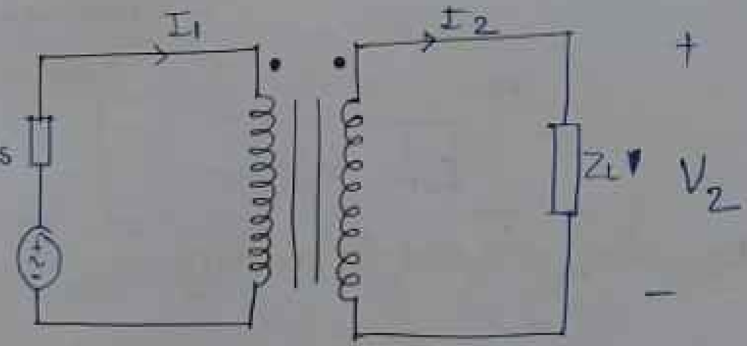
As the load increases leakage flux also increases and it is minimum at no load.

Transformer as impedance matching device :-

$HV \rightleftharpoons L.V$

$V\uparrow, I\downarrow$	$V\downarrow, I\uparrow$
$\uparrow Z_{HV} = \frac{V\uparrow}{I\downarrow}$	$Z_{LV} = \frac{V\downarrow}{I\uparrow}$

Let transformer is ideal.



$N_1 : N_2$

Here Z_s = Source impedance

Z_L = Load impedance

→ Transformation ratio. (K)

$$\boxed{K = \frac{V_2}{V_1} = \frac{I_1}{I_2} = \frac{N_2}{N_1}}$$

$$Z_s = \frac{V_1}{I_1} \quad , \quad Z_L = \frac{V_2}{I_1}$$

$$\because \boxed{\frac{V_1}{V_2} = \frac{I_2}{I_1} = \frac{N_1}{N_2} = \frac{1}{K}}$$

$$Z_S = \frac{V_2}{K \times K I_2}$$

$$\boxed{Z_S = \frac{Z_L}{K^2} = Z_L'}$$

Z_L' = Load impedance referred to primary.

&

$$\boxed{Z_L = K^2 Z_S = Z_S'}$$

condition for maximum power transfer.

Z_S' = Source impedance reffered to secondary.

<u>Example :-</u> 4. Q1 = Q

<u>Page = 72</u>

$N_2 = 40$, $N_1 = ?$

$Z_L = 2\Omega$

$Z_S = 8\Omega$

$Z_S = Z_L'$

$$Z_s = \frac{Z_L}{K^2}$$

$$K^2 = \frac{Z_L}{Z_s}$$

$$= \frac{2}{8}$$

$$K^2 = \frac{1}{4}$$

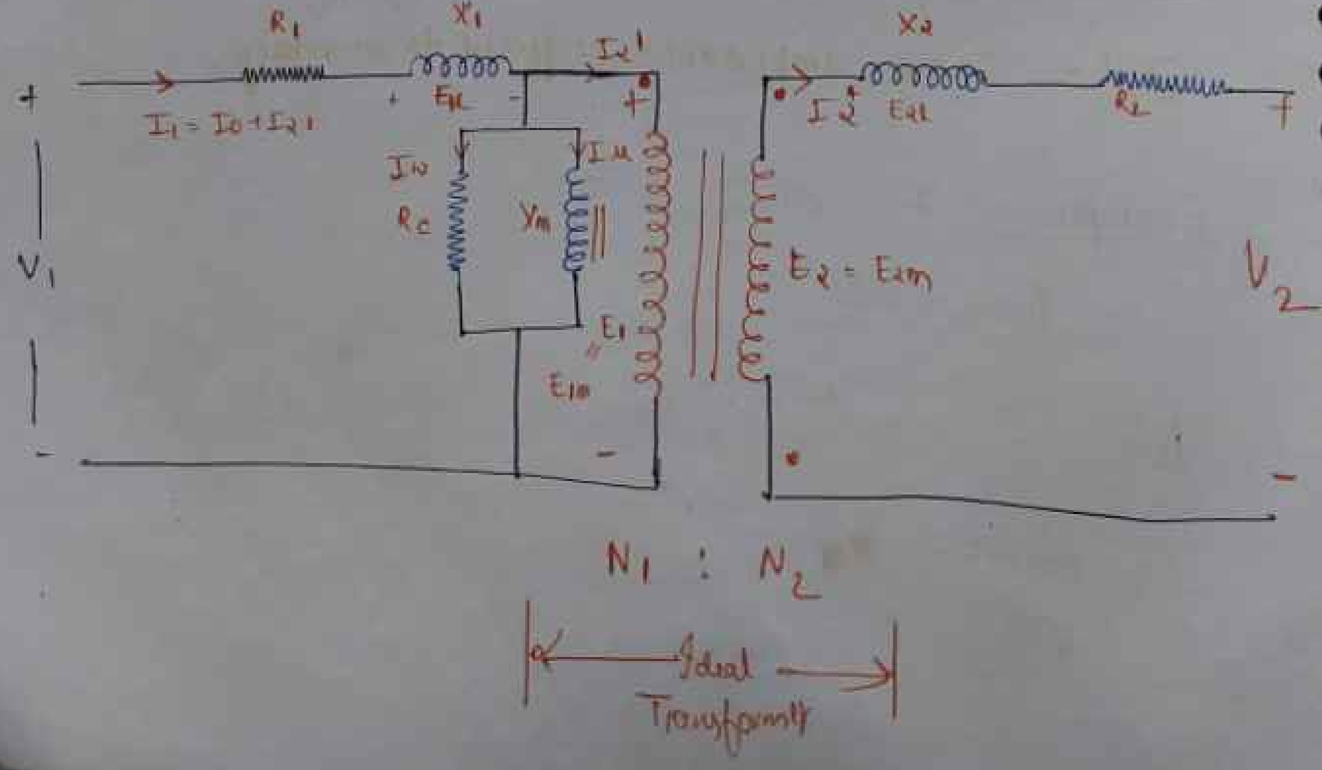
$$K = \frac{1}{2} = \frac{N_2}{N_1}$$

$$N_1 = 2N_2$$

$$N_1 = 2 \times 40$$

$$\boxed{N_1 = 80 \text{ turns}}$$ Ans

Exact equivalent circuit of transformer:-



By KVL

$$\boxed{\overline{V_1} = \overline{E_1} + \overline{I_1}R_1 + j\overline{I_1}X_1} \rightarrow \text{Numericals.}$$

lenz law

$$\boxed{\overline{V_1} = -\overline{E_1} + \overline{I_1}R_1 + j\overline{I_1}X_1} \text{ — Phasor diagram}$$

oppose

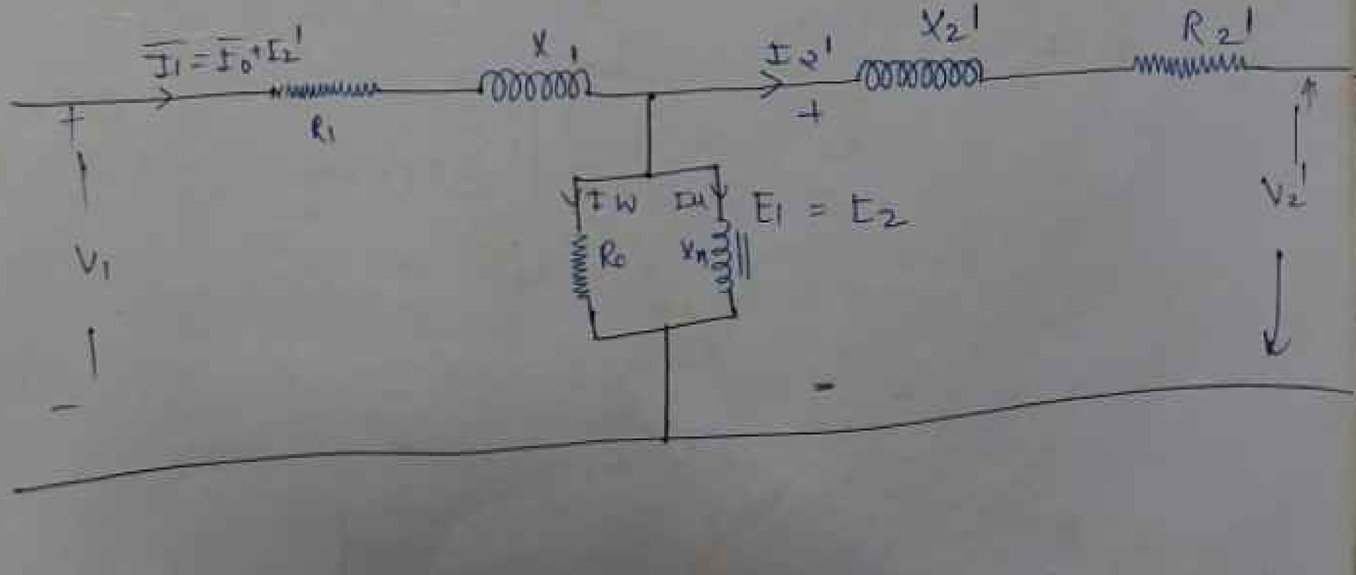
KVL

$$\boxed{\overline{E_2} = \overline{V_2} + \overline{I_2}R_2 + j\overline{I_2}X_2}$$

R_1 = Primary winding resistance

X_1 = Primary leakage reactance.

<u>Equivalent circuit of transformer reffered to primary :-</u>



$R_2' = \frac{R_2}{K^2}$ = Sec resistance reffered to primary.

$X_2' = \frac{X_2}{K^2}$

$$\boxed{I_2' = \frac{N_2}{N_1} I_2 = K I_2}$$

$$\boxed{V_2' = \frac{V_2}{K}}$$

$$\boxed{E_2' = \frac{E_2}{K} = E_1}$$

$\because \frac{E_1}{E_2} = \frac{N_1}{N_2} = \frac{1}{K}$

$\therefore \boxed{E_1 = \frac{E_2}{K}}$

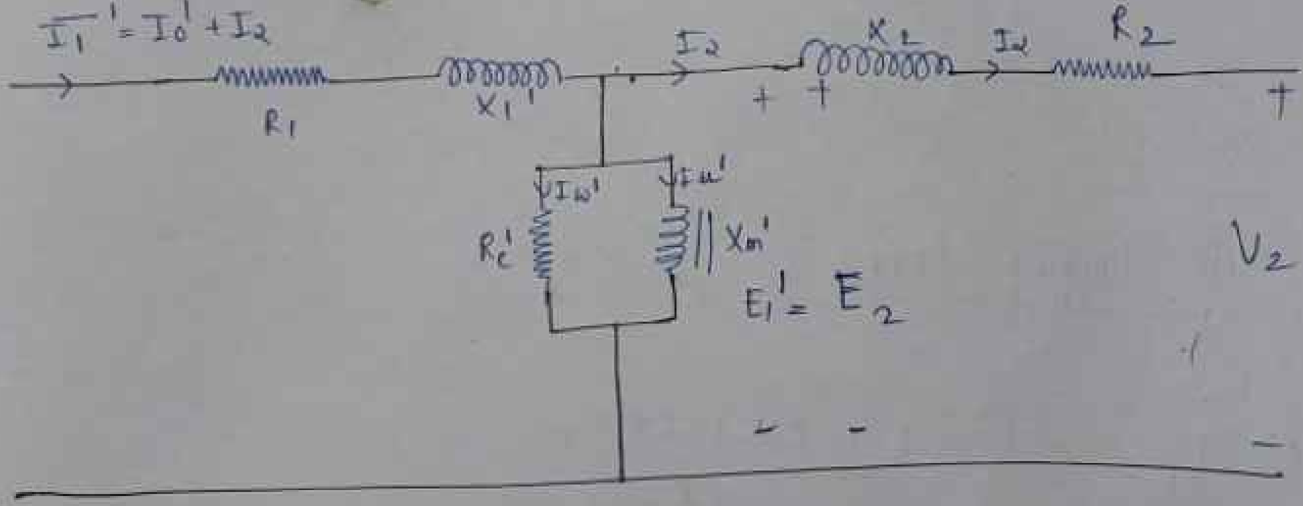
$\cancel{\frac{I_1}{I_2} = K}$

$\cancel{I_1 = K I_2 = I_2'}$

$\cancel{\frac{V_1}{V_2} = \frac{1}{K}}$

$\cancel{\boxed{V_1 = \frac{V_2}{K}}}$

Equivalent circuit of transformer reffered to secondary :-



$R_1' = K^2 R_1$

$X_1' = K^2 X_1$

$\boxed{I_2 = \frac{I_2'}{K}}$

$V_1' = K V_1$

$\boxed{E_1' = K E_1 = E_2}$

$\boxed{I_1' = \frac{I_1}{K}}$

$\boxed{I_0' = \frac{I_0}{K}}$

$\boxed{I_\mu' = \frac{I_\mu}{K}}$

$\boxed{X_m' = K^2 X_m}$

$\boxed{R_c' = K^2 R_c}$

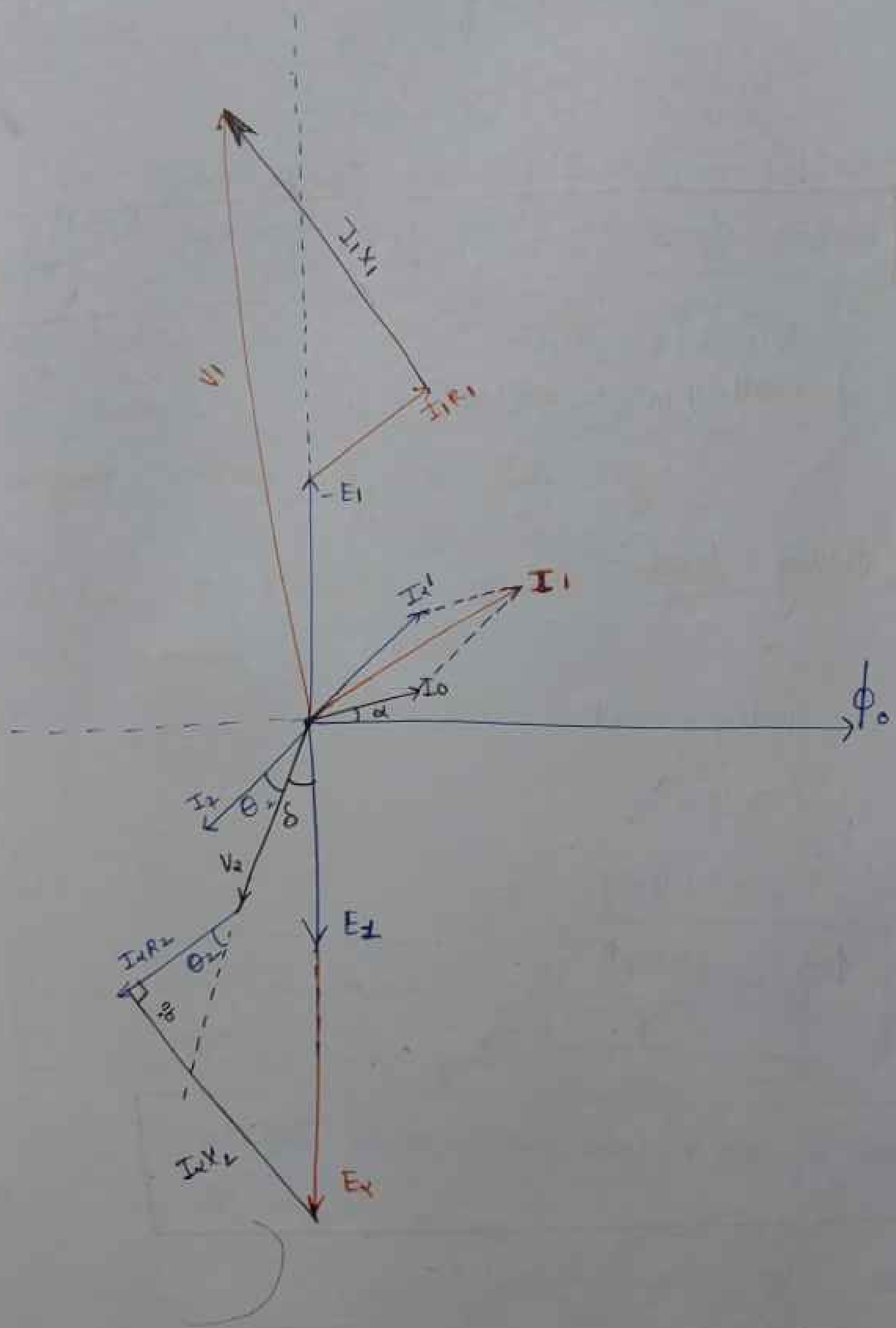
Phasor diagram of practical transformer at loading condition

Case 1 :

At lagging load :

$$\bar{V_1} = -\bar{E_1} + \bar{I_1}R_1 + j\bar{I_1}X_1$$

$$\bar{E_2} = \bar{V_2} + \bar{I_2}R_2 + j\bar{I_2}X_2$$



ⓐ lagg load

$|E_1| < |V_1|$

$$E_1 = 4.44\, \phi_{max} f$$

$$\boxed{\phi_{max} \propto \frac{E_1 \downarrow}{f}}$$

In case of lagg load flux decreases slightly

Ex $\left\{ \begin{array}{l} \text{No load} = 1\,w \\ \text{Lod } \phi_m = .99\, wb \end{array} \right\}$

At leading load :-

at leading load

$$|E_1| > |V_1|$$

$$E_1 = 4.44\, \phi_m f$$

$$\boxed{\uparrow \phi_{max} \propto \frac{E_1 \uparrow}{f}}$$

Similar in T/M lines ferranti effect

In case of leading load flux increases slightly

at No load = 1 wb

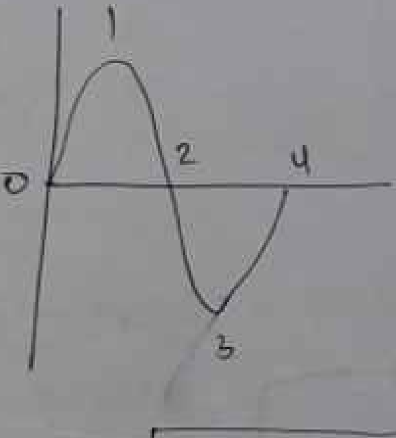
load = 1.01 Wb.

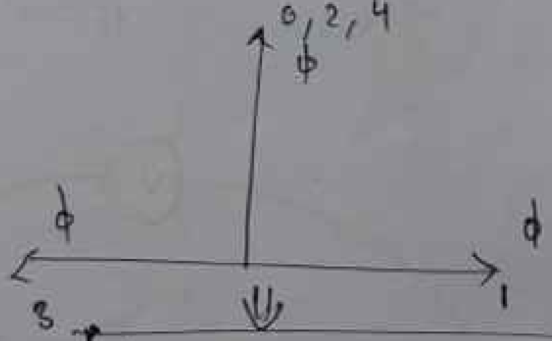
Magneto striction effect :-

(only occurs in ferromagnetic material)

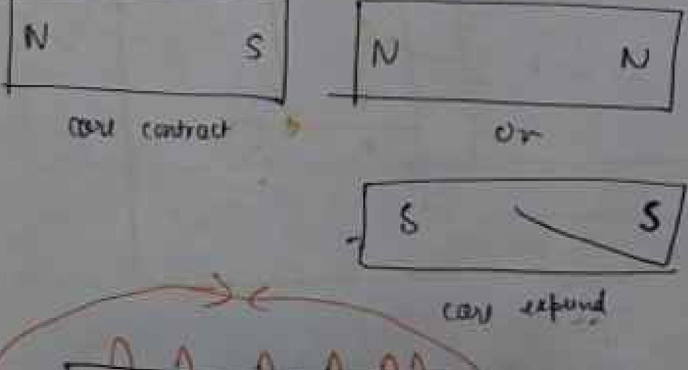
① When ferro magnetic materials undergoes in an alternating magnetic field the dipoles start vibrating arounds its mean position. So, effective length of the core increases or decreases (10^{-6} m) this is known as magneto striction effect or joule effect.

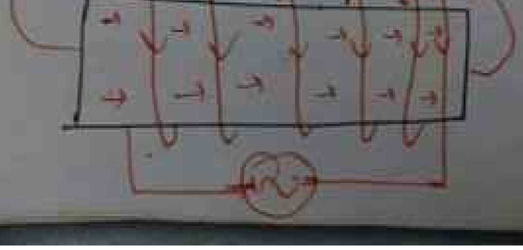
② Due to vibrations of the dipole their is a noise humming





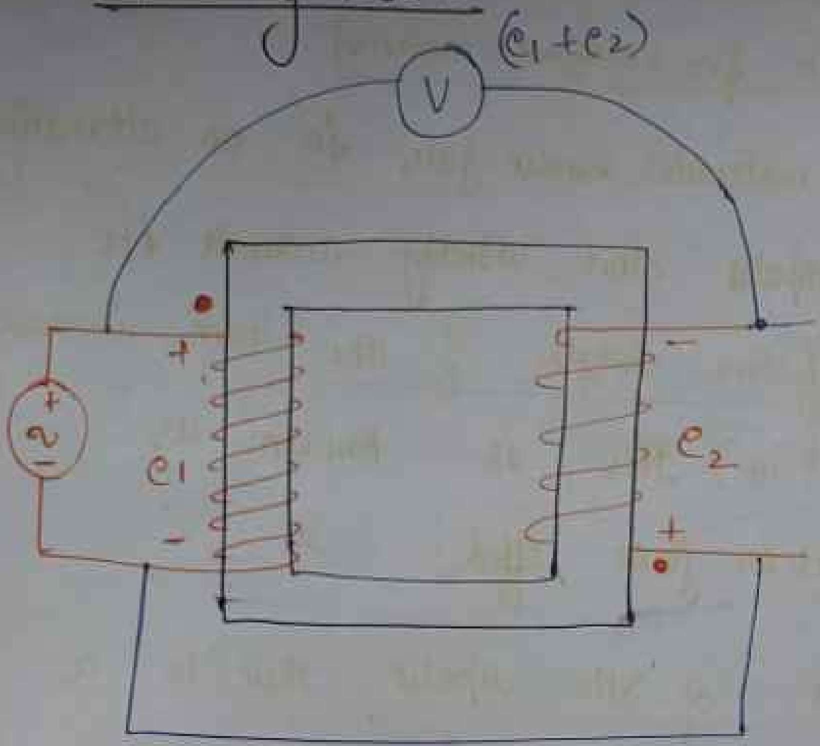
f magneto = 2 f supply





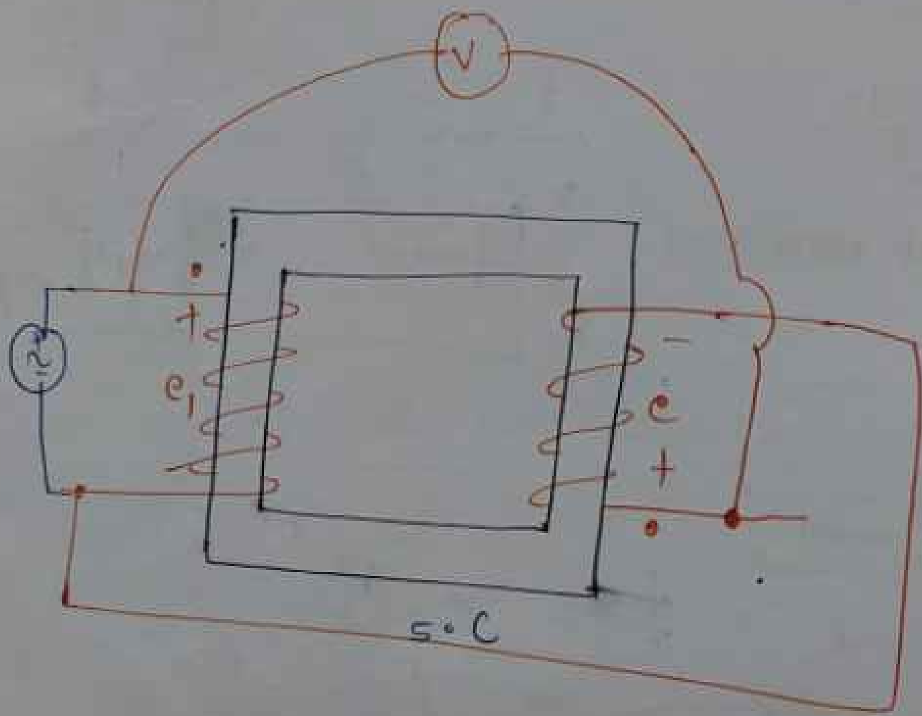
Polarity test :-

(use in ||^{l} operation)



Short circuit

Additive polarity

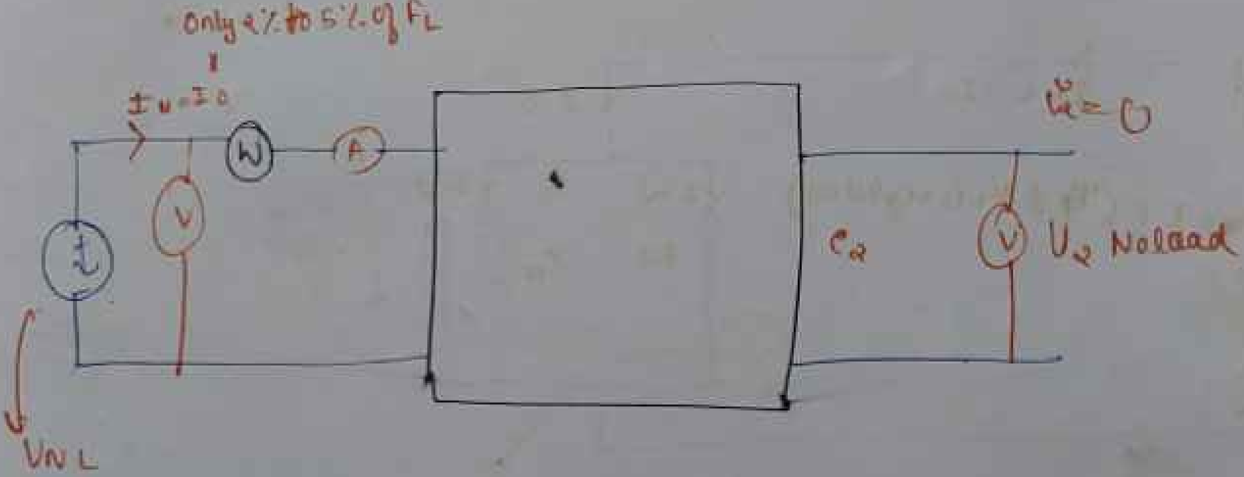


Subtractive polarity

② Open circuit test (No load test) (OC test)

⇒ Open circuit test is perform to find out shunt branch parameters, core losses, turn ratio.

⇒ It is better to conduct OC test on L-V side with open circuited H-V with low power factor watt meter.



Rated voltage at rated frequency

$P_i = P_{out} + Loss$

$\because (I_2 = 0 \therefore P_{out} = 0)$

$W_{NL} = 0 + Loss$ — Cu loss = 0 — $I_2^2 R_2 = 0$; $I_1^2 R_1 = I_0^2 R_1$ ∵ i_0 is (2–5)% of full load current so it can be neglected

— Core loss ⟶ $(W_h + W_e) \propto (B_m^x f + B_m^2 f^2)$

at $x = 2$

$\propto (B_m^2 f + B_m^2 f^2)$ at $B_m = \frac{V}{f}$

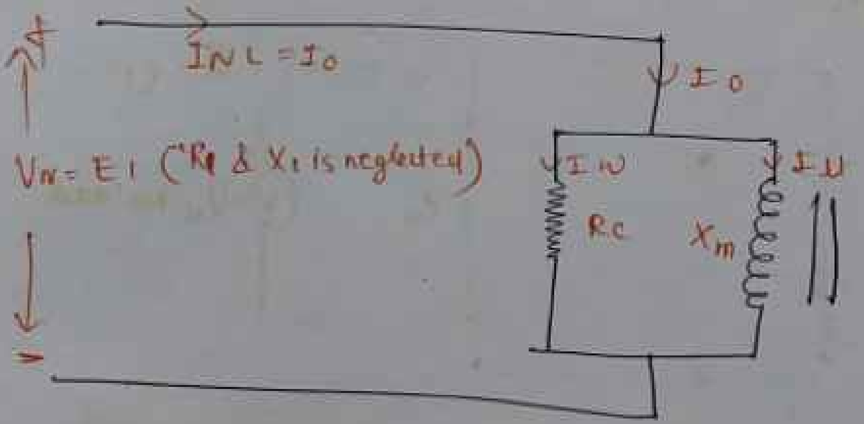
$$\propto \left(\frac{V^2}{f} + V^2 \right) \Longrightarrow$$ So rated core loss occurs.

rated voltage

rated frequency

$$\boxed{W_{NL} = \text{core loss}}$$

$\Downarrow$



~~equal~~ equivalent ckt of T/F under Open circuit condition

H.V ⟶ L.V (O.C)

V↑, I↓ ✗ (So, test is not ~~co~~ done)

High ratting volt meter required

Ammeter cannot read (2-5)% of very small current

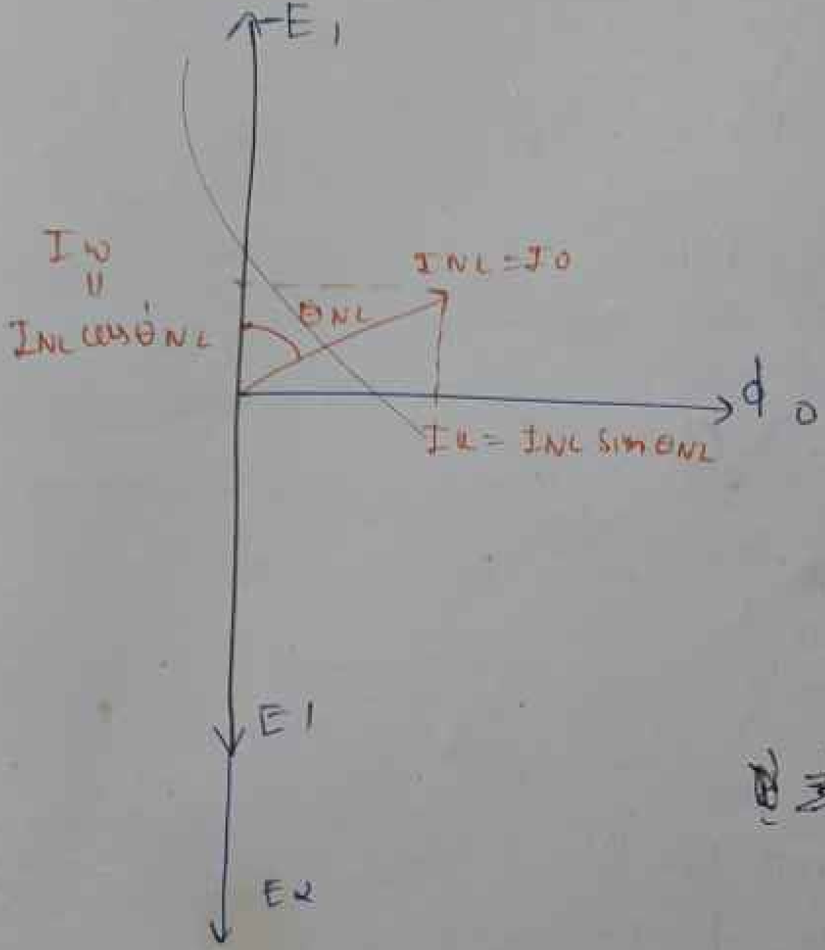
L.V ⟶ H.V (O.C)

V↓, I↑ (Test is done)

Low ratting volt meter available

Ammeter read current

$V_{NL} = -E_1$



core loss = $V_{NL} I_{NL} \cos\theta_{NL}$

$$\boxed{W_{NL} = V_N I_{NL} \cos\phi_{NL}}$$

Known (K/N) (K/N) (K/N) Calculated by this formula

$$\boxed{I_W = I_{NL} \cos\phi\theta_{NL}}$$

Calculater K/N K/N (just above)

$$\boxed{I_\mu = I_{NL} \sin\theta_{NL}}$$

Calculated K/N K/N

K/N

$$\boxed{R_c = \frac{V_{NL}}{I_w}}$$

K/w

K/w

$$\boxed{X_m = \frac{V_{NL}}{I_\mu}}$$

K/w

K/N

$$\boxed{\frac{N_1}{N_2} = \frac{V_{NL}}{V_2}}$$

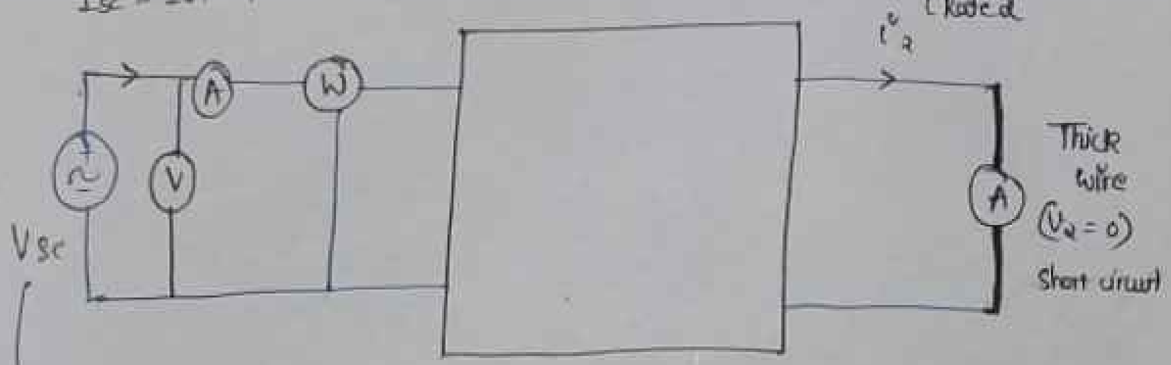
K/N

Short circuit test :-

⇒ Short circuit test is conducted to find out rated copper loss, series branch parameters, turn ratio.

⇒ It is better to conduct short circuit test on H-V side with short circuited L-V with high power factor watt meter

$\overline{I_{sc}} = \overline{I_0} + \overline{I_1'}$ = Rated



V_{sc} = supply voltage required to produce ratted current ~~require~~ on both primary and secondary. It is only 6% to 12% of rated voltage at rated frequency.

$P_i = P_0 + \text{Loss}$

$W_{sc} = 0 + \text{Loss}$

$\because (V_2 = 0)$

- Core Loss $\propto (V^2)$ — Since V is less so, core loss are very low
- Cu Loss $[I_{sc}^2 R_1 + I_2^2 R_2]$

So, compare to rated cu loss core loss can be neglected

(3) HV ⟶ LV (SC)

$V\uparrow, I\downarrow$ — $V\downarrow, I\downarrow$ ✓ So ~~test is ce~~ supply is given to H-V side

L.V ⟶ H (SC) ✗

$V\downarrow, I\uparrow$

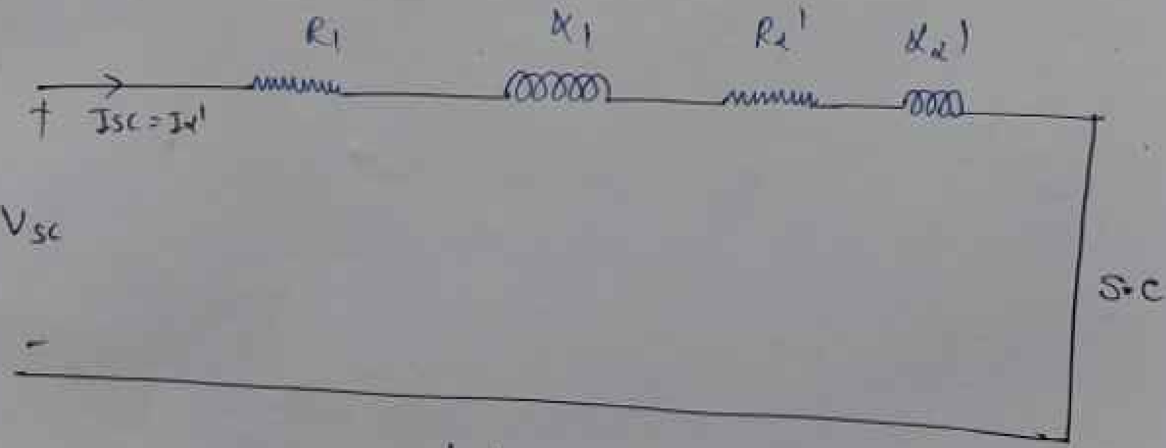
W_{sc} = Cu loss of transformer

Here $\overline{I_{sc}} = \overline{I_0} + I_2'$

I_0 = 2% to 5% of I_1

$I_0 <<<< I_2'$

$\therefore \boxed{\overline{I_{sc}} \approx I_2'}$



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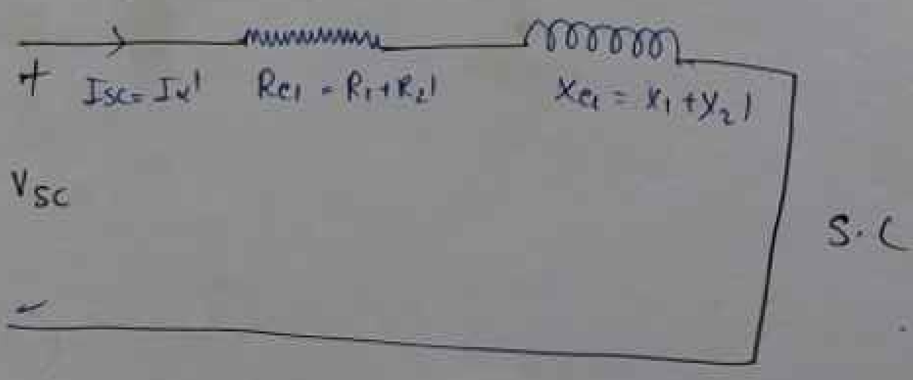


$R_{e1} = R_1 + R_2' =$ equivalent resistance of transformer reffered to primary.

$X_{e1} = X_1 + X_2' =$ equivalent reactance of transformer reffered to primary

Cu loss of transforme $= I_{sc}^2 R_{e1}$

$$\boxed{\underbrace{W_{sc}}_{K/n} = \underbrace{I_{sc}^2}_{K/n} \underbrace{R_e}_{Cal}}$$

$$R_{e1} = R_1 + R_2'$$

let $\boxed{R_1 \approx R_2' = \frac{R_{e1}}{2}}$

$$\overline{Z_{sc}} = R_{e1} + jX_{e1}$$

$$\overline{Z_{sc}} = \sqrt{R_{e1}^2 + X_{e1}^2} \angle \tan^{-1}\frac{X_{e1}}{R_{e1}}$$

$\overline{Z_{sc}} = |Z_c| \angle\beta$ (impedance angle) of T/F

$$\boxed{\underbrace{|Z_{sc}|}_{K/n} = \sqrt{\underbrace{R_{e1}^2}_{K/n} + \underbrace{X_{e1}^2}_{Cal}}}$$

$$\boxed{|Z_{sc}| = \frac{V_{sc}}{I_{sc}}}$$

$$X_{e1} = X_1 + X_2'$$

let

$$\boxed{X_1 \approx X_2' = \frac{X_{e1}}{2}}$$

let , Re is Vsc

$$\overline{V_{sc}} = V_{sc} \angle 0^\circ$$

$$\overline{I_{sc}} = I_{sc} \angle -\theta_{sc}$$

Isc lags Vsc by angle θ_{sc}

$$\overline{Z_{sc}} = \frac{\overline{V_{sc}}}{\overline{I_{sc}}}$$

$$Z\angle\beta = \frac{V_{sc}\angle 0^\circ}{I_{sc}\angle -\theta_{sc}}$$

$$Z_{sc}\angle\beta = Z_{sc}\angle\theta_{sc}$$

$$\boxed{\theta_{sc} = \beta = \tan^{-1}\left(\frac{X_{e1}}{R_{e1}}\right) = \text{p.f angle of T/F under s.c condition}}$$

$$\boxed{Z_{sc} = \frac{V_{sc}}{I_{sc}}}$$

$$\boxed{Z_{sc\,(Base)} = \frac{V_{Rated}}{I_{Rated}} = \frac{V_{Rated}}{I_{sc}}}$$

Let

$V_{sc} = x\%$ of V_{rated}

$$V_{sc} = \frac{x\, V_{rated}}{100}$$

$$\boxed{(Z_{sc})_{pu} = \frac{Z_{sc}}{(Z_{sc})_{Base}} = \frac{\frac{V_{sc}}{I_{sc}}}{\frac{V_{Rated}}{I_{sc}}}}$$

$$(Z_{sc})_{pu} = \frac{V_{sc}}{V_{rated}}$$

$$\boxed{\begin{aligned}(Z_{sc})_{pu} &= \frac{x}{100} \\ \%(Z_{sc}) &= x\%\end{aligned}}$$

Q-14 Page → 72

$S = 10\,KVA$

$V_1 = 400\,V$

$V_2 = 200\,V$

$Z_{pu} = 0.10$

$V_{sc} = 10\%$ of $400\,V$

$= 40$

~~$V_1 I_1 =$~~

$$\boxed{V_{sc} I_{sc} = 10\,KVA}$$

$$I_{sc} = \frac{10000}{40} = 250$$

Result :-

1. $\theta_2 = \tan^{-1}\left(\frac{X_{e1}}{R_{e1}}\right)$

2. $\cos\theta_2 = \frac{R_{e1}}{\sqrt{R_{e1}^2 + X_{e1}^2}}$

$f\uparrow$, $X_{e1}\uparrow$, $\cos\theta_2\downarrow$

2. $\phi \propto V/f$

3. $\phi = \frac{N_1 I_\mu}{S}$

$\phi \propto I_\mu$

$$\boxed{I_\mu \propto V/f}$$

Page 78
Q = 45

$V_{sc} = 30V$, $f = 50Hz$, $I_{sc} = 20A$, $\cos\theta_{sc} = .2$ lagg

$V_{sc}' = 30V$, $f' = 25Hz$, $I_{sc}' = ?$ $\cos\theta_{sc} = ?$

Objective :-

$\uparrow I_{sc} = \frac{V_{sc}}{\sqrt{R_{e1}^2 + X_{e1}^2}\downarrow}$, $I_{sc}\uparrow$

$\uparrow \cos\theta_{sc} = \frac{R_{e1}}{\sqrt{R_{e1}^2 + X_{e1}^2}\downarrow} > 0.2$

Solution :-

$$\overline{Z_{sc}} = \frac{V_{sc} \angle 0^\circ}{I_{sc} \angle -\theta_{sc}}$$

$$\overline{Z_{sc}} = \frac{30 \angle 0^\circ}{20 \angle -\cos^{-1}(0.2)} = 1.5 \angle 78.46^\circ = 1.5 \left[\cos 78.46 + j\sin(78.46)\right]$$

$$= R_{e_1} + jX_{e_1}$$

$\therefore$

$$\therefore R_{e1} = 0.3\,\Omega$$
$$X_{e1} = 1.46\,\Omega$$

$$\overline{Z_{sc}'} = \frac{V_{sc}' \angle 0}{I_{sc}' \angle \theta_{sc}'}$$

$$\overline{Z_{sc}'} = \frac{30}{I_{sc}'} \frac{\angle 0^\circ}{\angle -\theta_{sc}'}$$

$$I_{sc}' \angle -\theta_{sc} = \frac{30 \angle 0^\circ}{\overline{Z_{s0}'}}$$

$$\overline{Z_{s1}} = R_e + jX_{e1}'$$
$$\therefore \overline{Z_{s1}}' = 0.3 + jX_{e1}'$$

$$\because X \propto f$$

$$\therefore \boxed{\frac{X_{e1}'}{X_{e1}} = \frac{f'}{f}} \Rightarrow \frac{X_{e1}'}{1.46} = \frac{25}{50} \Rightarrow \boxed{X_{e1}' = .73}$$

$\therefore \boxed{Z_{s1}' = .3 + j.73\,\Omega}$

$\boxed{Z_{sc}' = .784 \angle 67.66^\circ}$

$$I_{sc}' \angle -\theta_{sc}' = \frac{V_{sc} \angle 0^\circ}{Z_{sc}'}$$

$$I_{sc}' \angle \theta_{sc}' = \frac{30 \angle 0^\circ}{.784 \angle 67.66}$$

$\therefore \boxed{I_{sc}' \angle \theta_{sc}' = 38.02 \angle -67.66}$

$\therefore \boxed{I_{sc}' = 38.02}$

$\boxed{\theta_{sc} = 67.66}$

(4) Sumpners back to back test / regenerative test / Heat run test

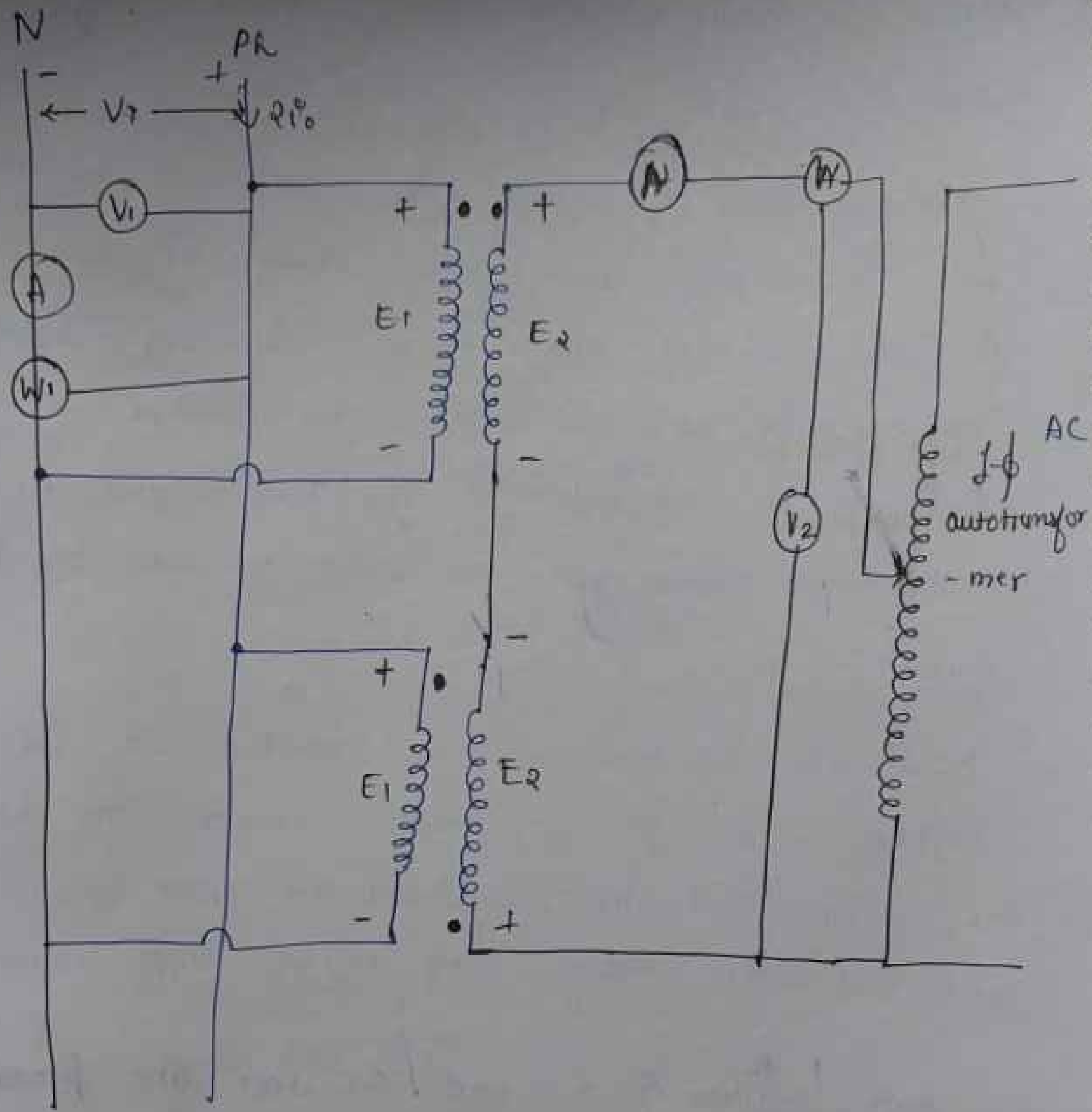
→ This test is perform for finding temperature rise for large rating transformer, core losses, copper losses and efficiency

⇒ In this test two identical transformers primaries are connected in parallel and the secondaries are connected in such a way their induced emf cancel out each other.

⇒ When primaries of both the transformer is connected with the supply the current drawn by the primary is only no-load current because secondary induced emf cancel out each other. This condition of transformer is equivalent to O.C test and the watt meter reading gives core losses of both the transformers.

⇒ Now, the auto transformer is connected to the supply which produces rated current on transformer windings and this is equivalent to short circuit test. and watt meter reading gives rated copper losses.

→ So, both condition of O.C and S.C test are produced simaltaniously. And rise in temp can be calculated.



W_1 = Rated core losses of both transformers

Rated core loss of 1 T/F = $\frac{W_1}{2}$

W_2 = Rated copper losses of both transformers

Rated cu loss of 1 T/F = $\frac{W_2}{2}$

Ratting of transformer :-

Q $10\,KVA$, $220\,KV / 100\,V$, $3-\phi$, $Y-\Delta$, $50\,Hz$, T/F ---?

$10\,KVA$ → Total (3-ϕ) Rated Full load power

$220\,KV$ → Rated H-V voltage (line voltage)

$100\,V$ → Rated L-V voltage (line voltage) (V_{2L})

$50\,Hz$ → Operating frequency.

$$\boxed{S = 3V_1 I_1 = 3V_2 I_2}$$

V_1 → Rated primary voltage (phase value)

I_1 → Rated primary current (phase value)

$$\boxed{S = \sqrt{3}\,V_L I_{1L} = \sqrt{3}\,V_{2L} I_{2L}}$$

V_L → Rated Primary voltage (line value)

I_{1L} → Rated Primary current (line value)

$$S = 3V_1 I_1$$

$$10\,KVA = 3 \times \frac{220000}{\sqrt{3}} \times I_1$$

$$\boxed{I_1 = 0.026\,A}$$

Voltage regulation :-

$$\boxed{V.R = \text{p.u voltage drop} \mid \text{Rise}}$$

$$V.R = \frac{|V_{NL}| - |V_L|}{|V_{rated}|}$$

→ Transformer , $|V_{Rated}| = |V_{NL}|$

→ Alternator , transmission $|V_{Rated}| = |V_{FL}|$

→ Motor $|N_{rated}| = |N_{FL}|$

∴ For transformer

$$V_R = \frac{|V_{NL}| - |V_L|}{|V_{NL}|}$$

$$\boxed{V_R = \frac{|E_2| - |V_2|_{nth}}{|E_2|}}$$

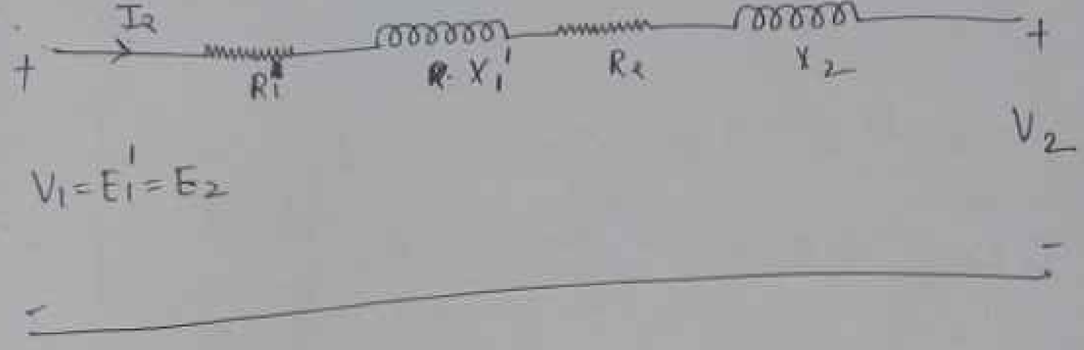
$|E_2|$ = Secondary terminal voltage at no load

$|V_2|_{nth}$ = Secondary terminal voltage at n^{th} loading of full loading.

$$\boxed{\text{Loading} = \frac{\text{Present loading}}{\text{Full} \mid \text{Ratted} \mid \text{Loading}} \Rightarrow n = \frac{I_{2n}}{I_2}}$$

$$\therefore \boxed{I_{2n} = nI_2}$$

Where, I_{2n} = Secondary current at nth loading of F.L (full load)



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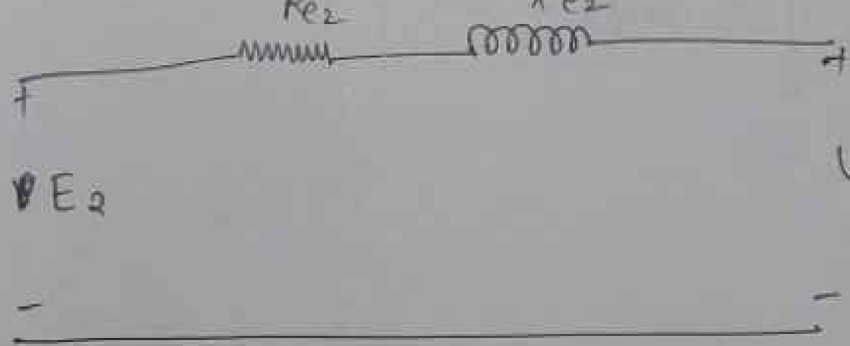


$$\boxed{\overline{E_2} = \overline{I_2} Re_2 + j\,\overline{I_2} X_{e_2} + \overline{V_2}}$$

$$V.R = \frac{|E_2| - |V_2|}{|E_2|}$$

Case-1 If load is lagg load :-

I_2 lags V_2 by angle 'θ_2'

$Re_2 = R_1' + R_2$ = equivalent resistance of T/F secondary

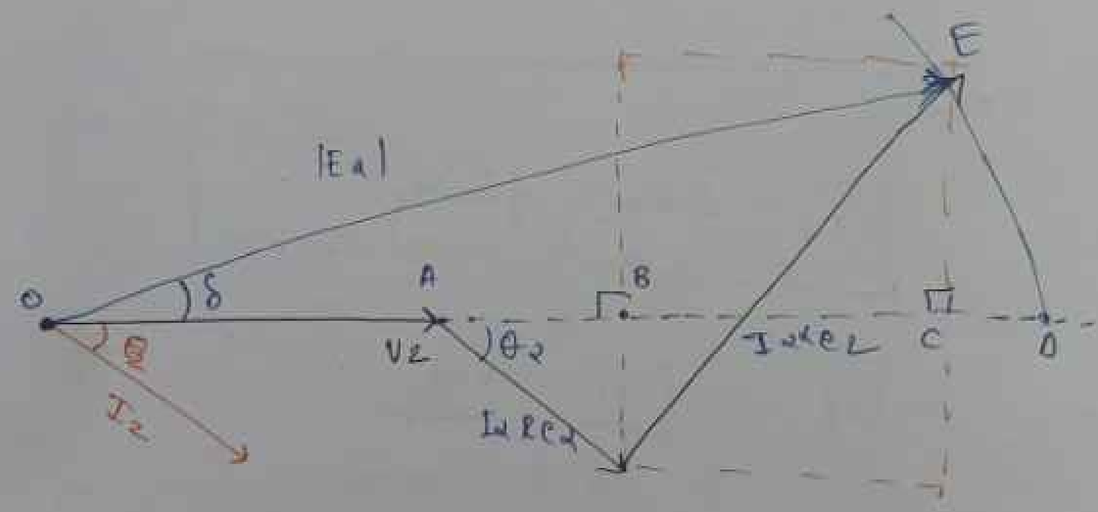
$Xe_2 = X_1' + X_2$ = equivalent reactance of T/F reactance

Case - III If load is leading I_2' leads V_2 by angle 'θ_2'

$$\theta_2 \longrightarrow -\theta_2$$

$$\boxed{V.R = \frac{I_2 R_{e_2}}{E_2} \cos\theta_2 - \frac{I_2 X_{e_2}}{E_2} \sin\theta_2}$$

Derivation of formula :-



$OE = OD$

$|E_2| = OC + CD$

$OC >>>> CD$

$|E_2| = OC$

$|E_2| = OA + AB + BC$

$$|E_2| = |V_2| + I_2 R_{e2} \cos\theta_2 + I_2 X_{e2} \sin\theta_2$$

$$|E_2| - |V_2| = I_2 R_{e2} \cos\theta_2 + I_2 X_{e2} \sin\theta_2$$

$$\boxed{\frac{|E_2| - |V_2|}{|E_2|} = \frac{I_2 R_{e2}}{E_2} \cos\theta_2 + \frac{I_2 X_{e2}}{E_2} \sin\theta_2}$$

for lagging

(1) $$(V.R)_{nth} = n \left[\frac{I_2 R_{e2}}{E_2} \cos\theta_2 \pm \frac{I_2 X_{e2}}{E_2} \sin\theta_2 \right]$$

$+ \rightarrow$ Lagg

$- \rightarrow$ Leading

(2) $$\frac{I_2 R_{e2}}{E_2} = \frac{\text{Resistive Drop}}{\text{Rated voltage}} = \text{P.u resistive Drop} = \frac{R_{e2}}{E_2/I_2} = \frac{\text{Resistance}}{Z_{Base}}$$

$= \text{P.u resistance of 'x'mer } (R_e)_{pu}$

(3) $$\frac{I_2 X_{e2}}{E_2} = \text{P.u } \cancel{\text{resist}}\text{reactive drop} = \text{P.u reactance of 'T/F'} = (X_e)_{pu}$$

$$\boxed{(V.R)_{nth} = n \left[(R_e)_{pu} \cos\theta_2 \pm (X_e)_{pu} \sin\theta_2 \right]}$$

$\Rightarrow$ V.R $\downarrow$, Better V.R

$\Rightarrow$ V.R $\uparrow$, Poor V.R

③ Cond^n ~~maxi~~ maximum V.R :-

max V.R occurs at lagg p.f load.

$$\frac{d (V_R)_{nth}}{d\theta_2} = 0$$

$$\boxed{\tan\theta_2 = \frac{(X_e)_{pu}}{(R_e)_{p.u}}}$$

④ Cond^n for zero V.R :- It occurs at leading pf load or near to ~~U.P.~~ unit p.f load.

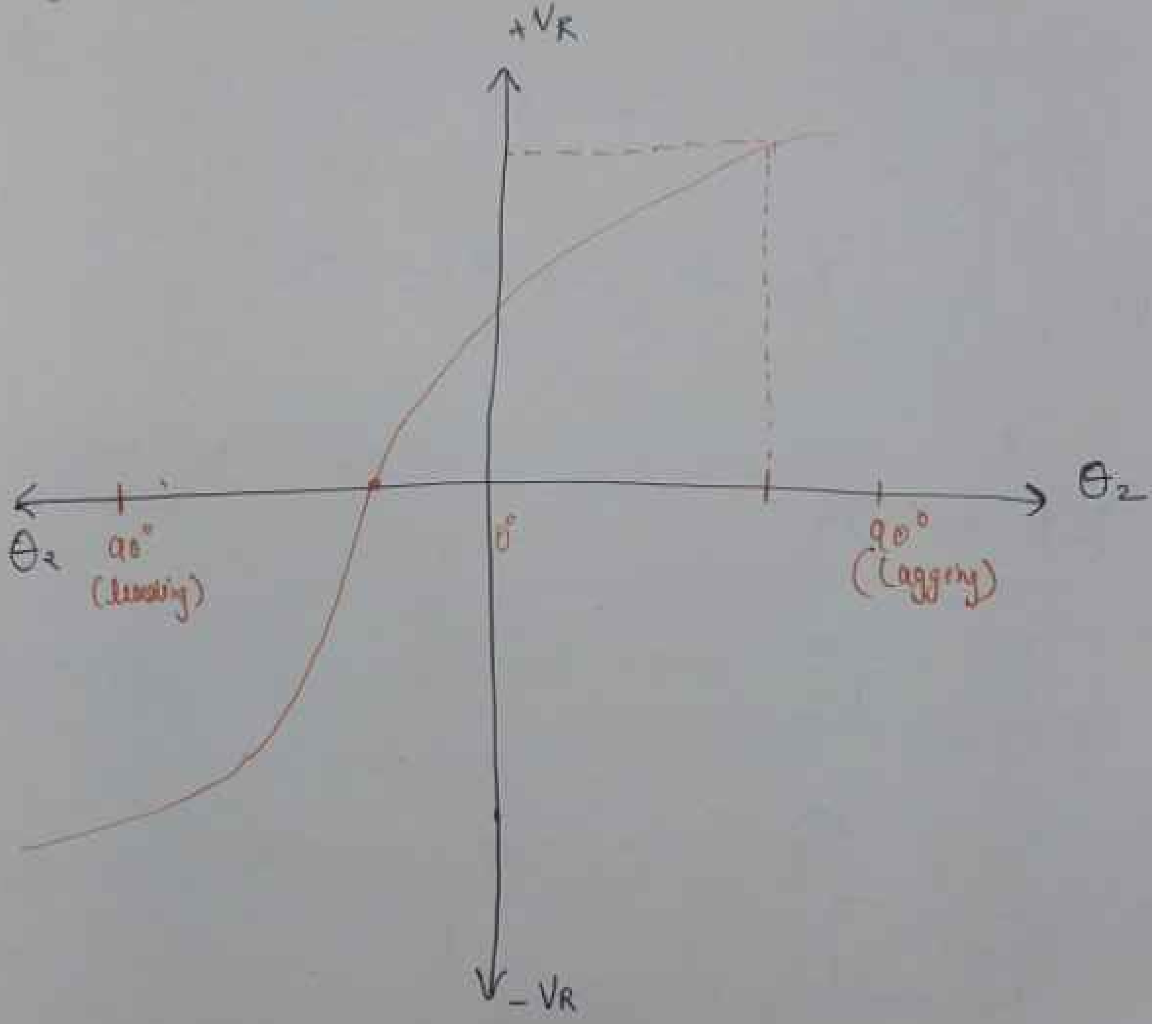
$$\boxed{(V.R)_{nth} = n\left[(R_e)_{pu}\cos\theta_2 - (X_e)_{pu}\sin\theta_2\right]}$$

$$(V_R)_{nth} = 0$$

$$\boxed{\tan\theta_2 = \frac{(R_e)_{pu}}{(X_e)_{pu}}}$$

⑤ ~~If load is~~ If voltage regulation is positive then load is lagging load but if ~~load is lagging then voltage regulation may be positive or negative.~~ voltage regulation is positive then load may be lagging or leading.

(6) If voltage regulation is negative then load is leading load. But, if load is leading then voltage regulation may be positive, negative or zero.



(5) If load is lagging then voltage regulation is positive but if voltage regulation is positive then load may be lagging or leading.

(16) 10KVA, 400/200V

$\%(R_e) = 3\% \Rightarrow (R_e)_{pu} = .03$

$\%(X_e) = 6\% \Rightarrow (X_e)_{p.u} = .06$

$I_{2n} = 50A$

$(V_2)_{nth} = ?$

$$V.R = n\left[R_{pu}\cos\theta_2 \pm X_{pu}\sin\theta_2\right]$$

$I_{2}n = I_{2n}$

$n = \frac{I_{2n}}{I_2}$

$= \frac{50}{50}$

$\boxed{n = 1}$

$I_2 = \frac{10000}{200}$

$I_2 = 50$

load = resistive = $\theta_2 = 0°$

$\therefore V.R = \frac{|E_2| - |V_2|_{nth}}{|E_2|} = n\left[.03 \times 1\right]$

$\frac{200 - |V|_{2nth}}{200} = .03$

no load voltage $\boxed{E_2 = 200}$

$\boxed{|V_2|_{nth} = 194\ V}$

Effiancy and losses :-

losses :-

~~Full load~~

core losses : (W_c)

$$W_c = W_e + W_h$$

$$W_c \propto \left[\frac{V^2}{\cancel{f^2}} \cdot \cancel{f^2} + \frac{V^2}{f^{\cancel{2}}} \cdot \cancel{f}\right]$$

$$\boxed{W_c \propto \left[V^2 + \frac{V^2}{f}\right]}$$

From No load to full load. V and f remains constant so, core loss also remains constant. So, these are known as constant loss.

② Full load / Rated cu Loss (W_{cu})

$$W_{cu} = (I_1^2 R_1 + I_2^2 R_2)$$

$$= I_1^2 \left(R_1 + \frac{I_2^2}{I_1^2} R_2\right)$$

$$= I_1^2 \left(R_1 + \frac{R_2}{K^2}\right)$$

$$= I_1^2 (R_1 + R_2')$$

$$\boxed{W_{cu} = I_1^2 (R_1 + R_2')} = \boxed{W_{cu} = I_1^2 R_{e1}}$$

$$\cancel{(W_{cu})_{nth} = (n I_2)^2}$$

$$W_{cu} = I_2^2 \left[\frac{I_1^2}{I_2^2} R_1 + R_2 \right]$$

$$= I_2^2 \left[K^2 R_1 + R_2 \right]$$

$$= I_2^2 \left[R_1' + R_2 \right]$$

$$\boxed{W_{cu} = I_2^2 R_{e2}}$$

Copper loss of transformer at full load remains constant

at n^{th} load of full load

$$(W_{cu})_{nth} = I_{2n}^2 R_{e2}$$

$I_{2n} = n I_2$

$$= n^2 I_2^2 R_{e2}$$

$$\boxed{(W_{cu})_{nth} = n^2 W_{cu}}$$

$$\boxed{(W_{cu})_{nth} \propto n^2}$$

represent parabolic relation

variable loss

Condition for maximum efficiency :-

Case → 1 if n = constant
θ_2 = variable

$$\frac{d\eta^{n\cdot m}}{d\theta_2} = 0$$

$$\therefore \boxed{\cos\theta_2 = 1}$$

unity powerfactor

Power o/p at maximum η condition

$= n_m \times$ Rated Power

$= \sqrt{\frac{W_c}{W_{cu}}} \times$ Rated power

Case - 2 if n = variable
θ_2 = const

On putting,

$$\frac{d\eta^{n\cdot m}}{dn} = 0$$

$$\boxed{n^2 W_{cu} = W_c}$$

variable loss = constant loss

$$\boxed{n_m = \sqrt{\frac{W_c}{W_{cu}}}}$$

It is the load at which maximum η occurs.

Efficiency (η)

$$\therefore \text{eff} = \frac{o/p}{o/p + \text{loss}}$$

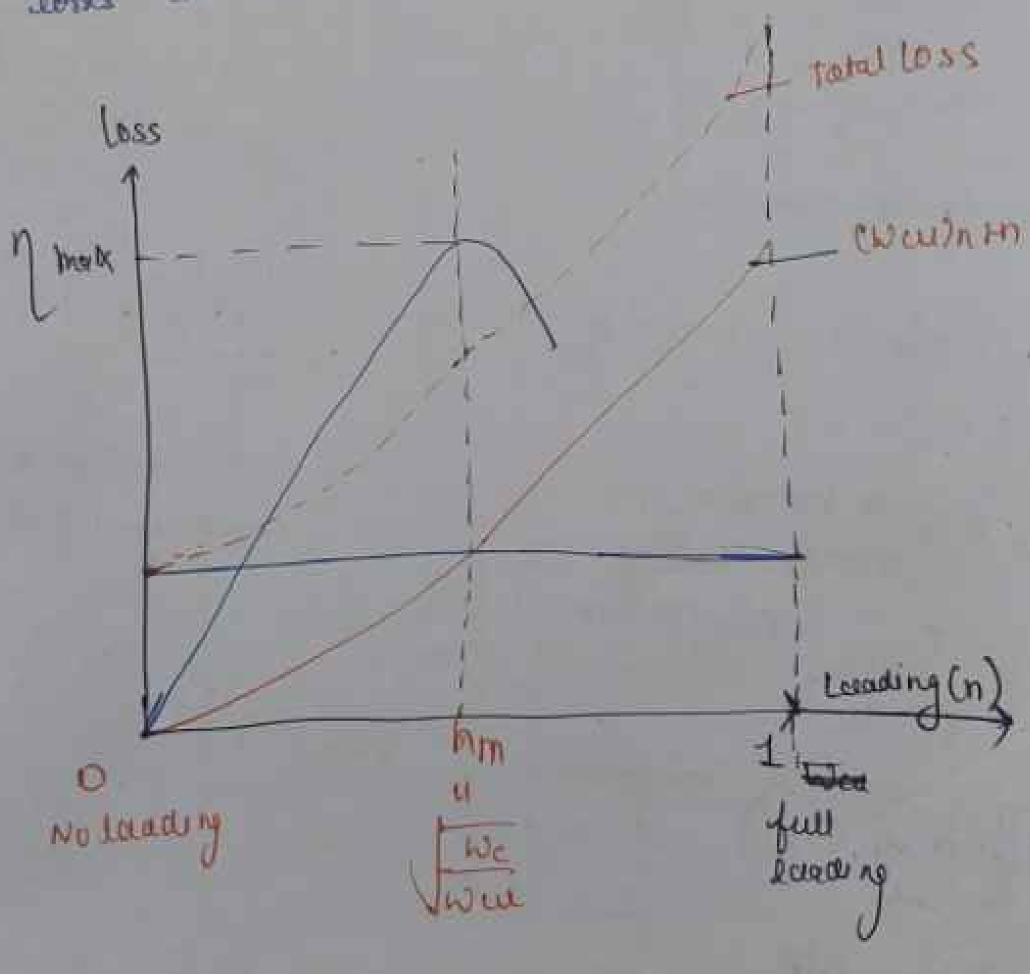
$$\eta_{n\cdot m} = \frac{V_2 I_{2n} \cos\theta_2}{V_2 I_{2n}\cos\theta_2 + (W_{cu})_{n\cdot m} + W_c}$$

$$\eta_{n\cdot m} = \frac{n V_2 I_2 \cos\theta_2}{n V_2 I_2 \cos\theta_2 + n^2 W_{cu} + W_C}$$

Result :-

1. Loading below n_m efficency is low because core losses are more in percentage with respect to output

2. Efficency is low loading above n_m because percentage copper losses are more with respect to output.



3. In case of distribution transformer avg loading in a day is approximately 70% of full loading. So distribution transformer are design maximum efficiency at 70% of full loading and power transformer are designed maximum efficiency at nearly

equal to full loading.

Distribution Transformer	Power Transfer
$\eta_m = 70\%$	$\eta_m = 100\%$
$\sqrt{\frac{W_c}{W_{cu}}} = 0.7$	$\sqrt{\frac{W_c}{W_{cu}}} = 1$
$\boxed{W_{cu} = \alpha W_c}$	$\boxed{W_{cu} = W_c}$
$\boxed{W_{cu} > W_c}$	

Note :-

1) → Voltage ratting $\propto f$

→ KVA ratting $\propto f$

→ Size of Transformer $\propto \frac{\text{Power O/P}}{f}$

① A single phase 50Hz transformer having max η of 90% @ full load unity P.f then find the efficiency at half load unity for power factor.

$$\eta = \frac{n V_2 I_2 \cos\theta_2}{\quad}$$

$$\eta_{max} = \frac{n_m \cdot V_2 I_2 \cos\theta_2}{n_m V_2 I_2 \cos\theta + \cancel{n_m} n_m^2 W_{cu} + W_c}$$

given

$$\eta_{max} = \frac{9}{10}$$

$$n_m = 1$$

$$\cos\theta_2 = UPF = 1$$

$$\sqrt{\frac{W_c}{W_{cu}}} = 1$$

$$\boxed{W_c = W_{cu}}$$

$$\frac{9}{10} = \frac{(1)\, V_2 I_2 (1)}{(1)\, V_2 I_2 (1) + (1)^2 W_c + W_c}$$

$$\frac{9}{10} = \frac{V_2 I_2}{V_2 I_2 + 2 W_c}$$

$$\boxed{18 W_c = V_2 I_2}$$

$$\eta_{1/2} = \frac{\frac{1}{2} V_2 I_2 \cos\theta_2}{\frac{1}{2} V_2 I_2 \cos\theta_2 + \left(\frac{1}{2}\right)^2 W_c + W_c}$$

$$\eta_{1/2} = \frac{\frac{1}{2} V_2 I_2}{\frac{1}{2} V_2 I_2 + \frac{W_c}{4} + W_c}$$

$\eta_{1/2} = .878$

$\therefore \boxed{\eta_{1/2}\% = 87.8\%}$

Q

All day effiancy :-

On a distribution transformer loading is variable so for distribution transformer we define all day efficency which is calculated for 24 hours

$$\boxed{\text{All day effiancy} = \frac{\text{energy o/p (Kwh)}}{\text{energy o/p (Kwh)} + \text{loss (Kwh)}}}$$

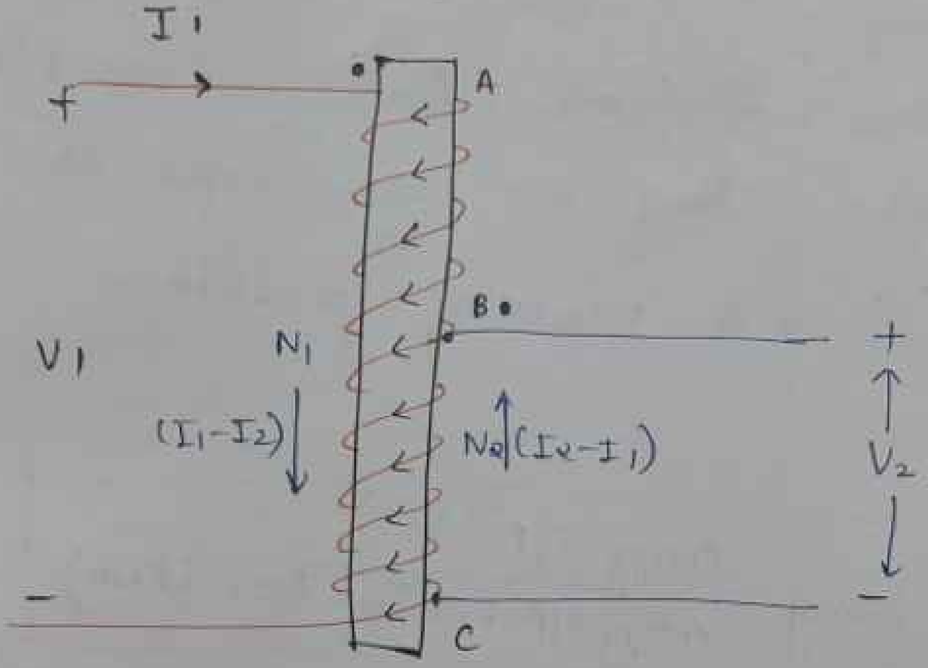
$\boxed{\text{Commercial efficeny } (\eta) > \text{All day effiany } \eta}$ — In distribution

Auto transformer :-

(1) Auto transformer is a transformer in which a parth of primary will act as secondary and power is transfer threw both induction and conduction.

(2) In Autotransformer both primary and secondary

are electrically connected but in two winding transformer both are electrically isolated.



$\therefore$ $$\boxed{\frac{N_1}{N_2} = \frac{V_1}{V_2} = \frac{I_2}{I_1} = \frac{1}{K}}$$, Here $N_2 < N_1$

$K < 1$

① MMF of AB = $(N_1 - N_2) I_1$

$= N_1 I_1 - N_2 I_1$

$= N_2 I_2 - N_2 I_1$

$= N_2 (I_2 - I_1)$

= MMF of BC

So, power transferred from A-B to BC is through induction only

② Power transferred inductively

$= (V_1 - V_2) I_1$

$= V_1 I_1 - V_2 I_1$

$= V_1 I_1 - K V_1 I_1$

$= (1-K) V_1 I_1$

$\boxed{= (1-K) \text{ input VA}}$

Power transferred conductively $= V_1 I_1 - (1-K) V_1 I_1$

$\boxed{= K V_1 I_1}$

Advantages :-

Volume of Cu Required

$V_{cu} \propto A \cdot l$

$V_{cu} \propto I N$

$\boxed{V_{cu} \propto mmf}$

$(V_{cu})_{2\,wdg} \propto (N_1 I_1 + N_2 I_2)$

$(V_{cu})_{2\,wdg} \propto 2 N_1 I_1$ —— ①

$(V_{cu})_{Auto} \propto$ (MMF of AB + mmf of BC)

$(V_{cu})_{Auto} \propto 2(N_1 - N_2) I_1 \longrightarrow$ ② By adjusting as load MMF

$$\frac{(V_{cu})_{Auto}}{(V_{cu})_{2\,wdg}} = \frac{2(N_1 - N_2) I_1}{2 N_1 I_1} = \frac{N_1 - N_2}{N_1}$$

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$$\boxed{(V_{cu})_{auto} = (1-K)\,(V_{cu})_{2\,winding}}$$

~~$K = .2$ $(V_{cu})_{auto} = 80\%$~~

Cu losses :-

$$\boxed{W_{cu} \propto I^2 R}$$

$$W_{cu} \propto I^2 \frac{l}{A} \propto I^2 \cdot \frac{N}{I}$$

$$\boxed{W_{cu} \propto N I}$$

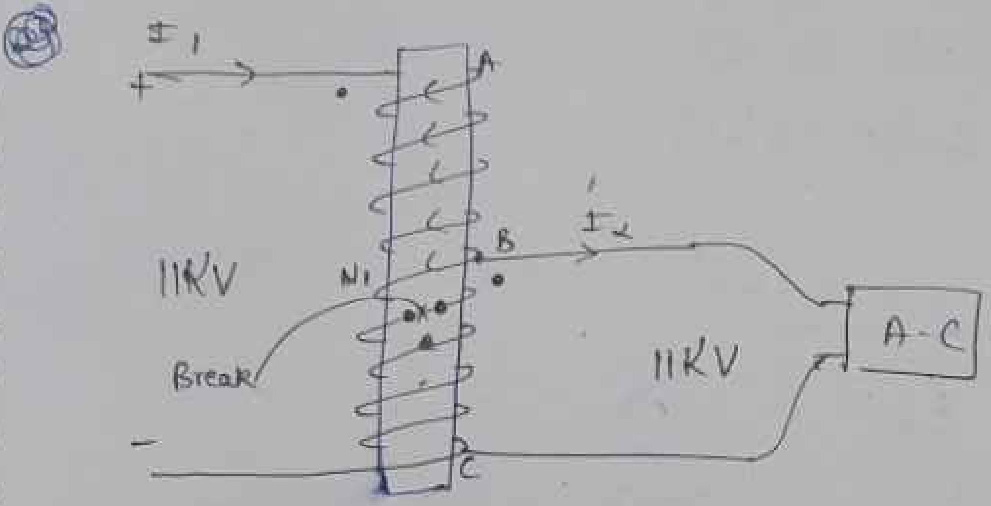
$$\boxed{(W_{cu})_{auto} = (1-K)(W_{cu})_{2\,winding}}$$

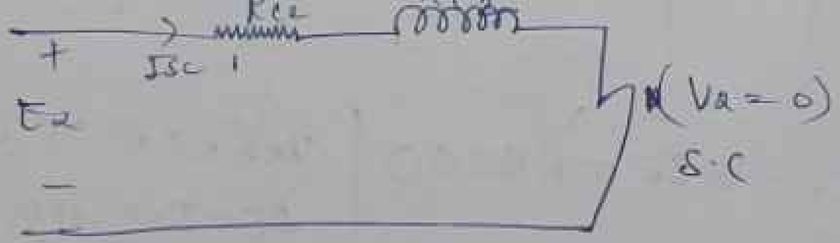
3. Leakage flux ↓, X ↓, VR ↓ better.
4. Core less required, core loss ↓, η increases, cost reduces

Disadvantage :-

1. In case of step-down transformer if their is any break in the conductor of winding BC then L-V terminal will hit by ~~H-V~~ high voltage. so, all

the connected load get damage.



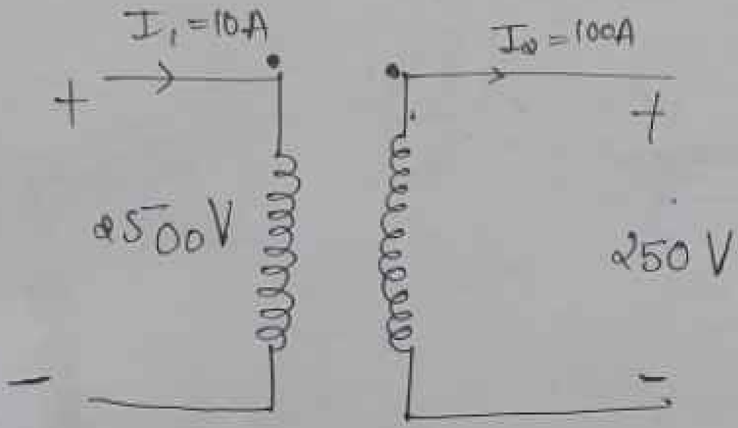


$$I_{SC} = \frac{E_2}{\sqrt{R_{e_1}^2 + X_e^2}} \downarrow$$

So, its S.C current are greater than 2 winding T/F

Additive → Valid ($K \to 1$) near but small
→ Invalid ($K \to 0$) near to zero

Subtractive → Valid ($K \to 1$)
→ invalid ($K \to 0$)



$V_1 I_1 = V_2 I_2 = 25000$

$V_1 I_1 = 25000$

$= \frac{\cancel{25000}}{\cancel{2500}}$ 10

$\boxed{I_1 = 10A}$

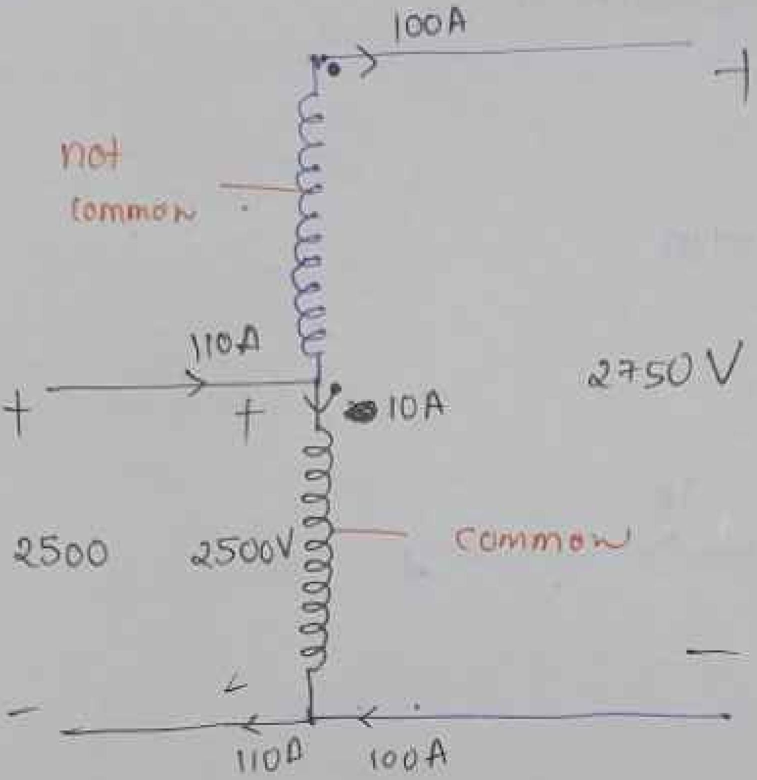
$V_2 I_2 = 28000$

$250 I_2 = 28000$

$\boxed{I_2 = 100A}$

Additive polarity :-

first find current of which coil is not common



$$\text{Ratting} = 2750 \times 100 = 275\,KVA$$

$$K = \frac{V_2}{V_1} = \frac{2750}{2500} = \frac{11}{10}$$

$$\boxed{K' = \frac{1}{K} = \frac{10}{11} = .999}$$

Valid case.

Power transferred inductively $= (1-K')\,V_1 I_1$

$$= \left(1 - \frac{10}{11}\right) 2500 \times 110$$

$$= \frac{1}{11} \times 2500 \times 110$$

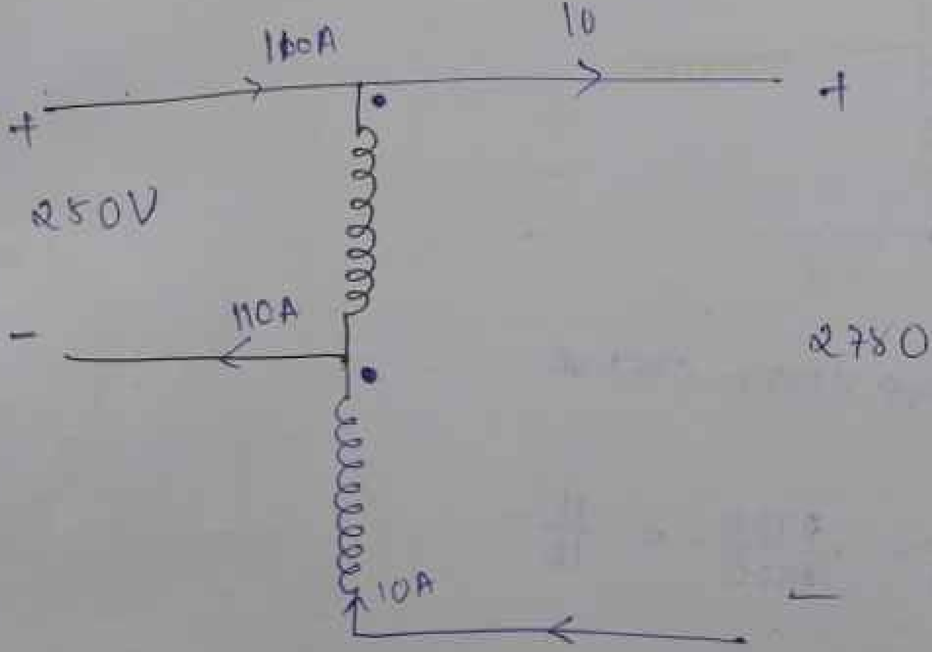
$$= 25000\,VA$$

Power transferred conductively.

$= K' \cdot V_1 I_1$

$= \frac{10}{11} \times 2300 \times 110$

$= 250 KVA$



Rating $= 2750 \times 10$

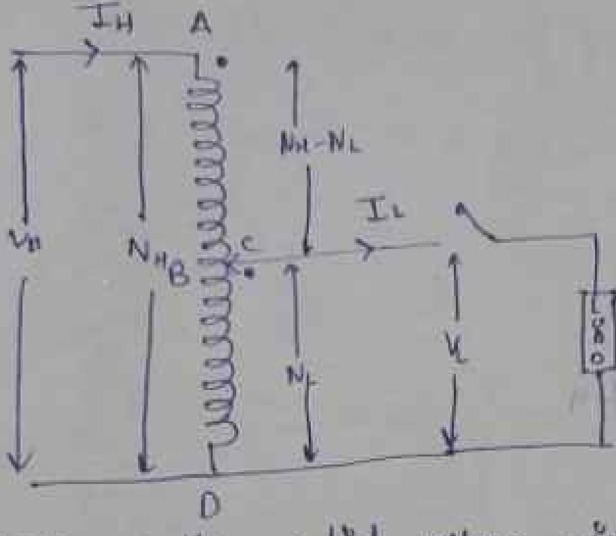
$K = \frac{2750}{250} = 11$

$K' = \frac{1}{11} = .09$

Inductive Power transfer $= (1-K') V_1 I_1 = 25 \times 10$

Conductive $= K' V_1 I_1$

Auto transformer :-



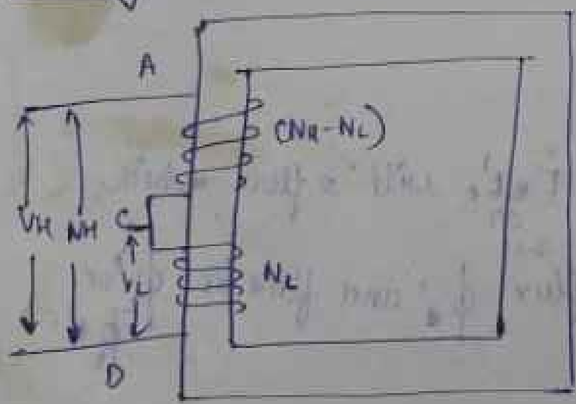
ABD ⟶ N_H ⟶ high voltage winding

BC ⟶ Common shortcircuited

CD ⟶ N_L ⟶ Low voltage winding

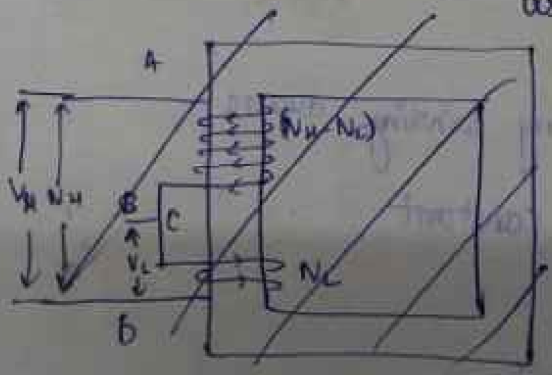
AB ⟶ $(N_H - N_L)$ ⟶ Series winding

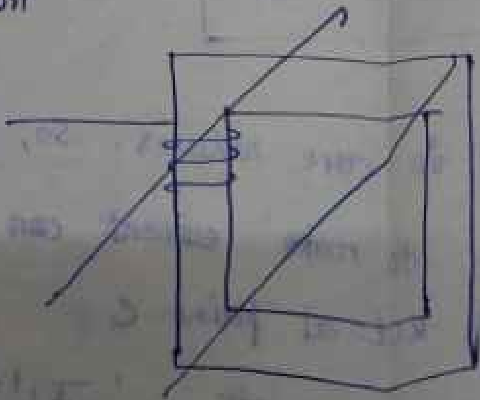
Working auto transformer :-

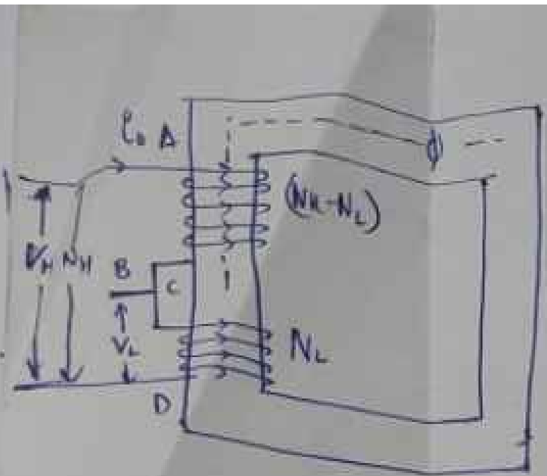


At no load :-

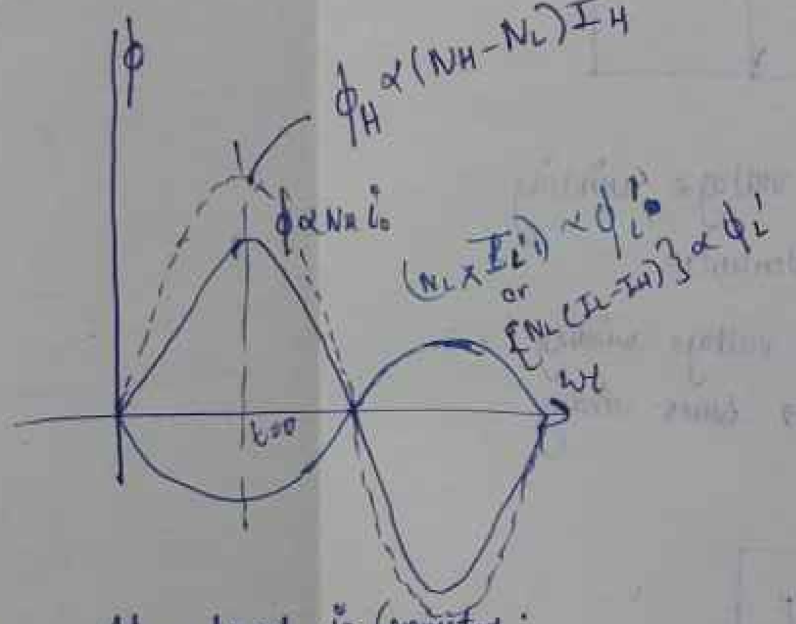
At no load a current flow from A to D as shown





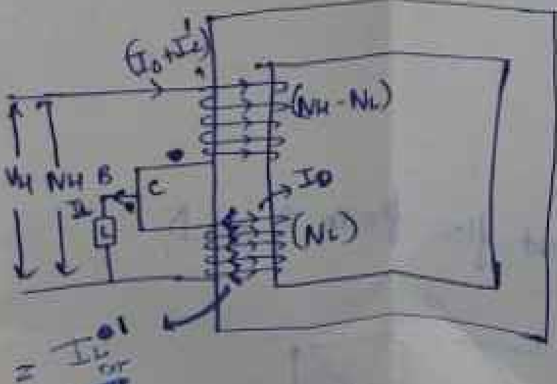


So a flux is setup in core



~~So a~~ If a load is connected :-

In this condition a current I_L' or I_H' will flow which opposes the flux ϕ_0 and flux is ϕ_2' or ϕ_2'



→ Now flux ϕ in core reduces. So, primary winding draws current I_H to make ~~current~~ core flux constant

so, apply KCL at point C

$\therefore I_L' + I_H = I_L$

∴ $\boxed{I_L' = I_V - I_H}$

For common flux Enduced emf per turn must be same.

$$E = \sqrt{2}\pi f \phi_m N \quad \text{i.e} \left(\frac{E}{N} \propto \phi\right)$$

$$\therefore \frac{V_H}{N_H} = \frac{V_L}{N_L}$$

$$\boxed{\frac{V_H}{V_L} = \frac{N_H}{N_L} = K_{auto}}$$ turn ratio of auto transformer

~~(on ignoring I_0)~~

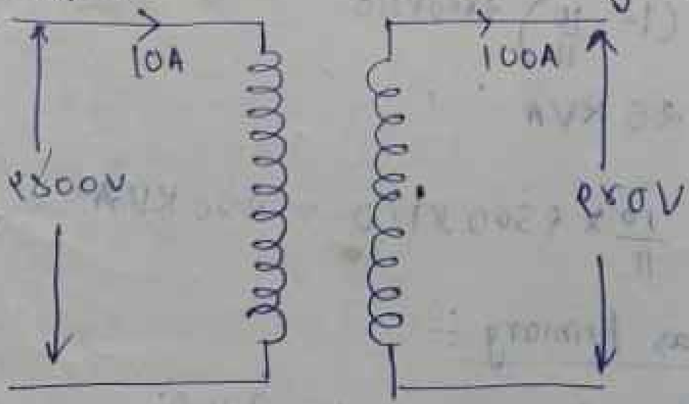
Conversion of two winding transformer into auto transformer

It can be converted into two ways :-

① Additive (voltage) < valid $K \to 1$; invalid $K \to 0$

② Subtractive (voltage) < valid $K \to 1$; invalid $K \to 0$

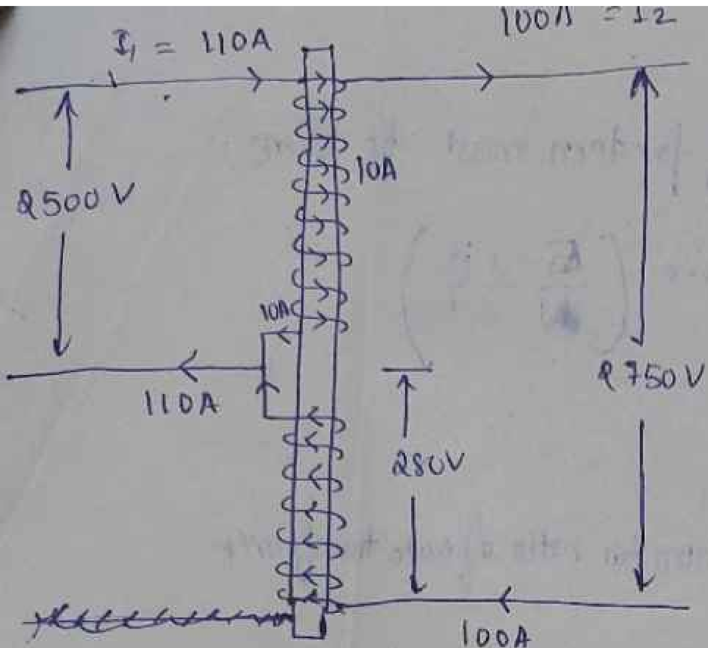
Suppose their is two winding T/F



Additive polarity :-

Case -1

$\boxed{\text{First find current of coil which is in not common}}$



Due to additive polarity turns in both winding coiled in same direction.

$$K = \frac{V_2}{V_1} = \frac{2750}{2500} = \frac{11}{10}$$

$$\boxed{K' = \frac{10}{11} = .99}$$ valid case ∵ K is near 1

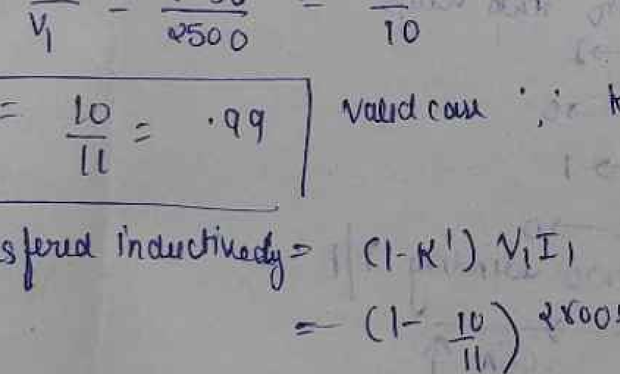
Power transfered inductively $= (1-K')\,V_1 I_1$

$$= \left(1-\frac{10}{11}\right) 2500 \times 110$$

$$= 25\ \text{KVA}$$

conductively $= K' V_1 I_1 = \frac{10}{11} \times 2500 \times 110 = 250\ \text{KVA}$

Case → II make 250V as primary :-



$$K = \frac{2750}{250}$$

$$K_1 = \frac{250}{2750}$$

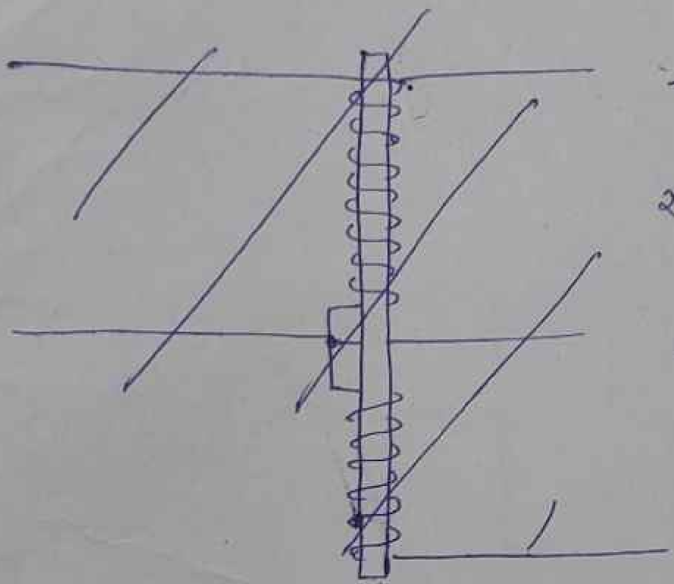
$$\boxed{K_1 = .09}$$

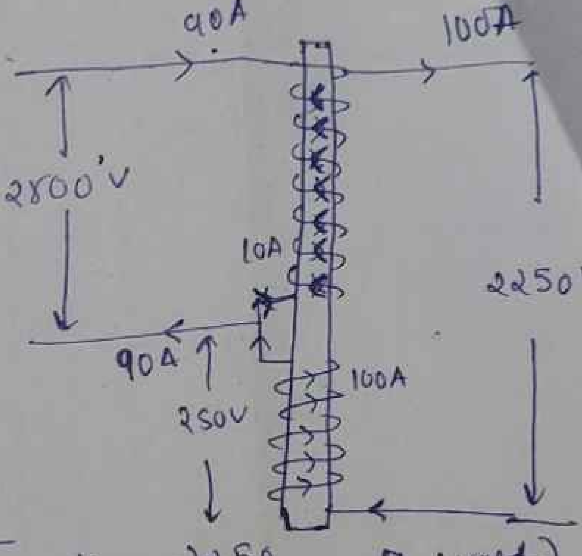
Since 0 comes so, invalid.

Inductive power transfer $= (1-K')V_1I_1 = 25KVA$

conductived $= K'V_1I_1 = \frac{1}{11} \times 280 \times \frac{110}{8} = 2.5KVA$

<u>Subtractive polarity</u> :- It means both coil with coiled in opposite direction :-



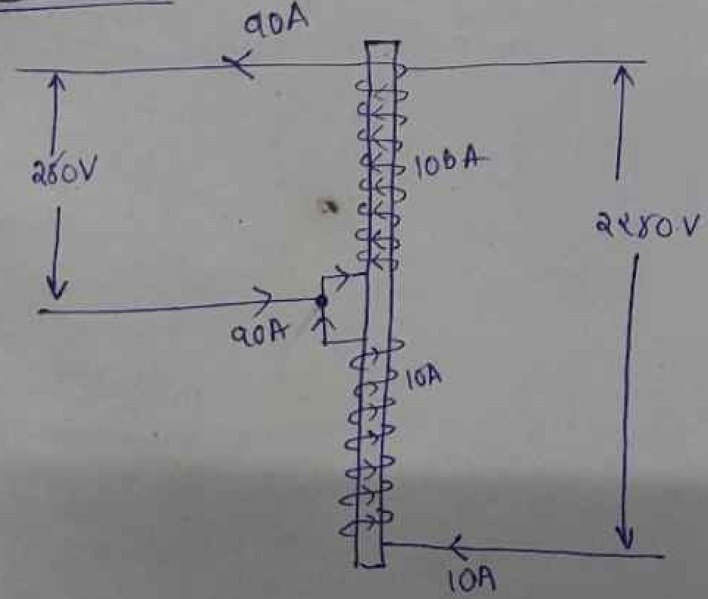


$K = \frac{2250}{2500} = .9$ (valid)

Inductively $= (1-K)V_1I_1 =$

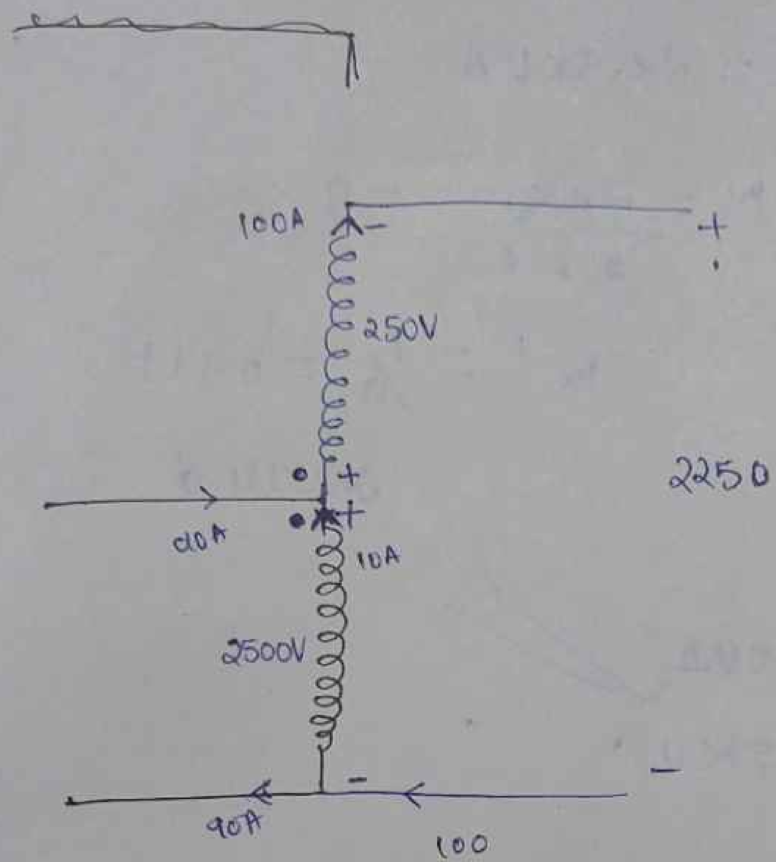
Conductively $= K V_1 I_1$

<u>Case - 4</u>



$K = \frac{225\cancel{0}}{25\cancel{0}}$

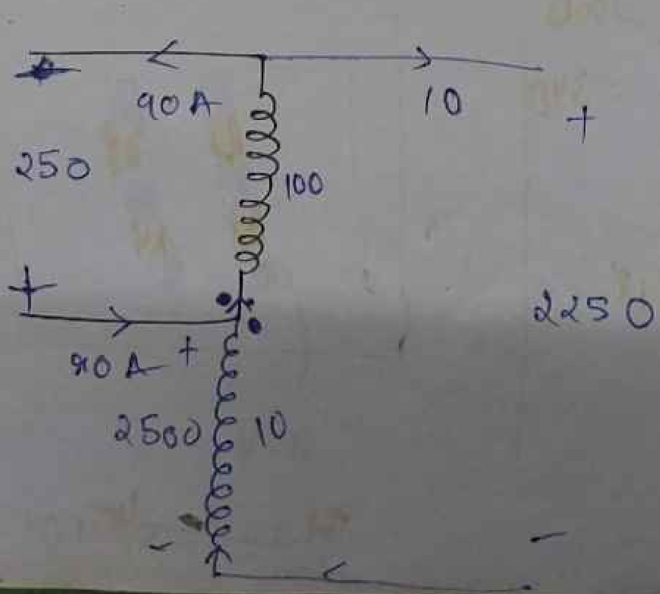
$K_1 = \frac{\cancel{25}}{\cancel{225}} = .1$ (valid)



$$KVA = \text{Rating} = 225\,KVA = 2250 \times 100$$

$$\alpha = \frac{2250}{2500}$$

$$= \frac{45}{50} = .9 \text{ valid case.}$$



$$KVA = \frac{2250 \times 10}{}$$

$$= 22.5\,KVA$$

$$K = \frac{2250}{250} = 9$$

$$K' = 1/9 = 0.111$$

invalid

Valid :-

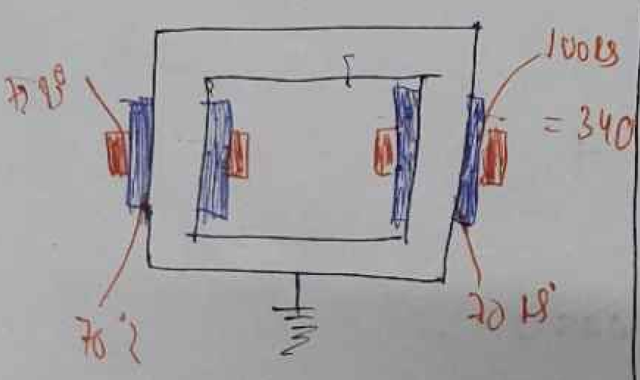
275 KVA

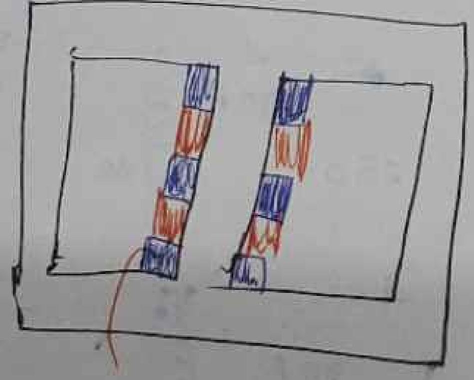
225 KV.

Types of transformer :-

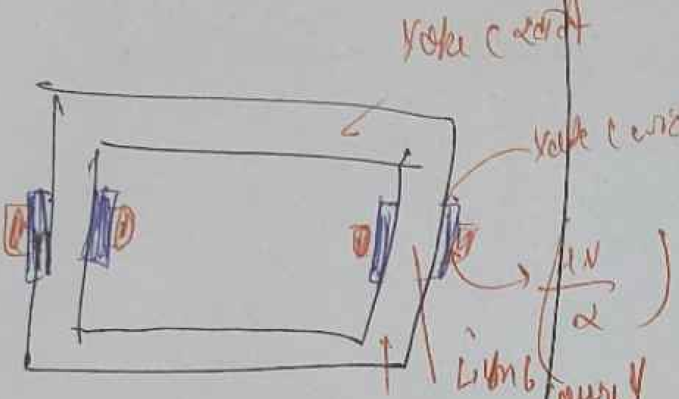
(i) According to construction :-

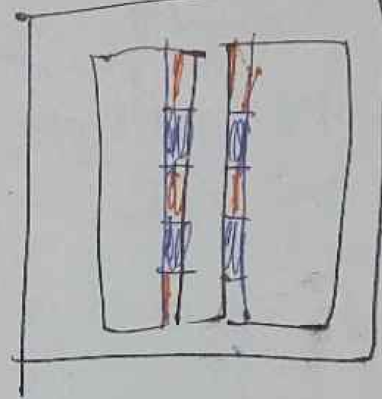
(i) core type	shell type





H-V





100 to 1020 ~~sheet~~

Windings around a part of the core

~~a part of the core~~ The core surrounds a part of the winding.

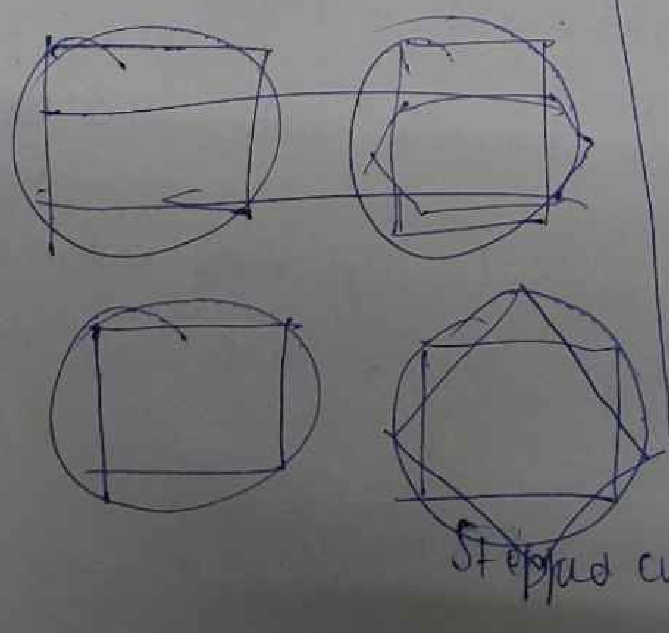
C-V-V-C can in ter-leave to reduce leakage flux. Half the primary and 1/4 the secondary have been placed ~~size~~ and concentric ~~relay~~ cylindrical on each limb. It drawing

→ It have 3 - limb and 2 yoke. Middle limb is provided with winding circular cylindrical windings are used.

wo limb and 2 yoke: ~~It is a series magnetic circuit which ha~~

(9) Sandwitch ~~is~~ are ~~sect~~ alternate windings are used.

(10) In square core, larg amount of ~~CA~~ space is wasted so stepped core are used which give max ~~to~~ ~~max~~ stack factor, reduce mean length and I^2R loss.



Stepped core.

(1) It is a series magnetic which having more leakage	→ It is a parallel magnetic ckt which having less leakage
→ Providing insulation & cooling is easy.	→ Difficult in ~~cutting~~ cooling and insulation
→ Economical for high voltages	Economical for low voltage.
→ In this stepped core is used to reduce copper losses.	
→ Low voltage winding is inside or near to core due to which :-	
→ Reduce in insulation requirement.	
→ Reduce the risk of shock in case of insulation breakdown.	

3-ϕ Transformer :-

3-ϕ transformer can be constructed by 2 ways

① **Three phase transformer bank :-** When a three phase transformer is constructed by three identical single phase transformer then it is called as three phase transformer bank.

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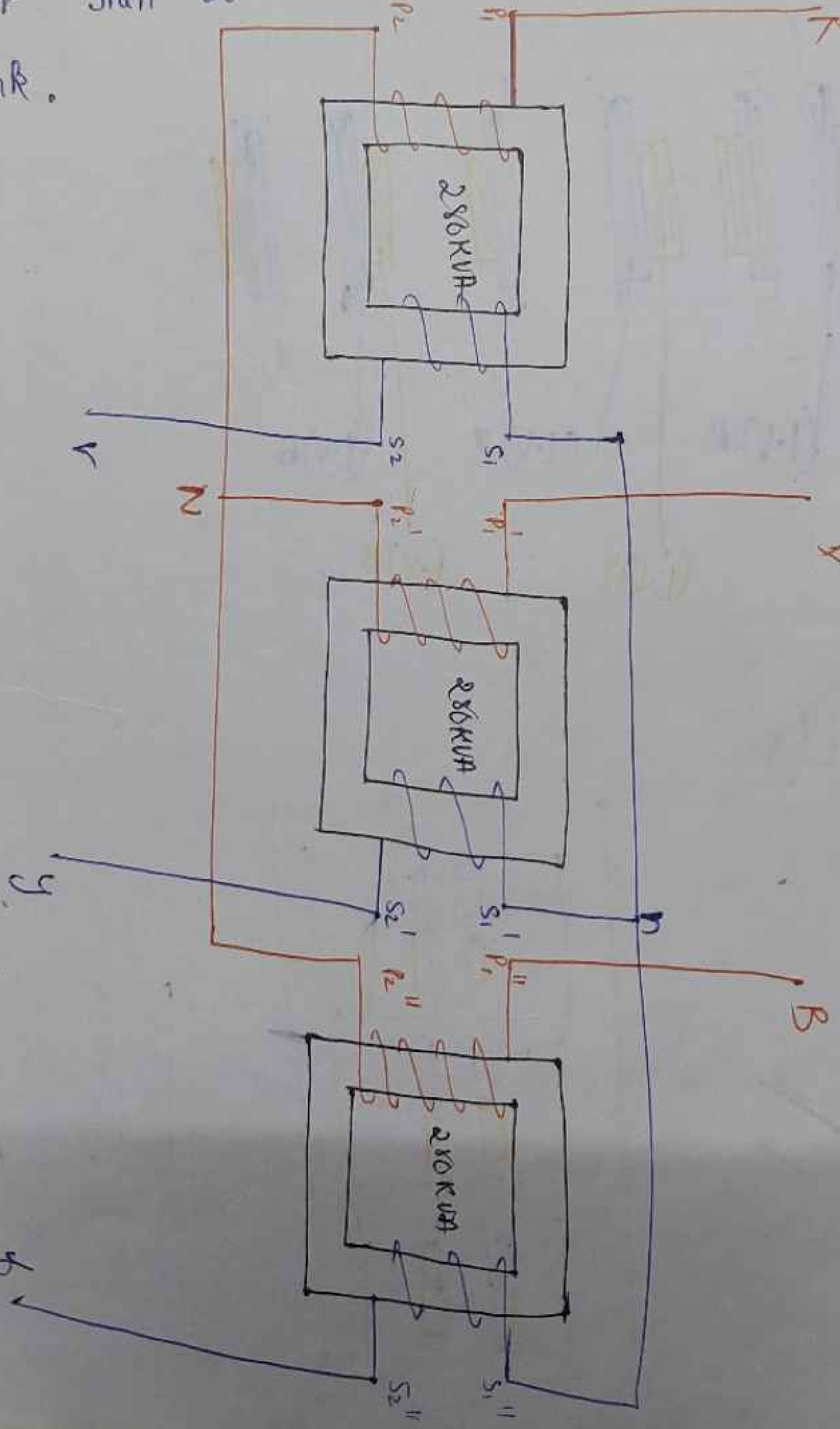
Class = 38

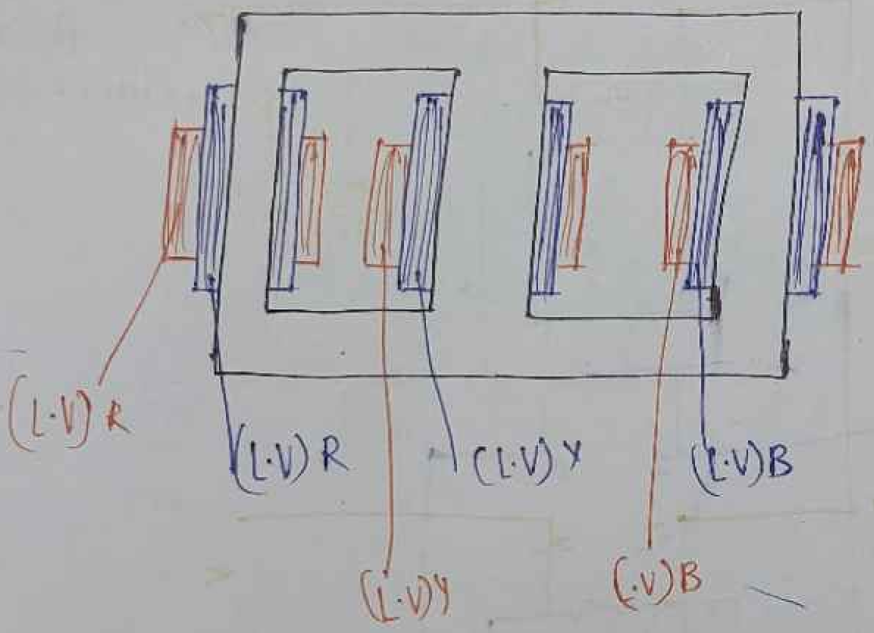


Equivalent rating = 250×3 = 750 KVA

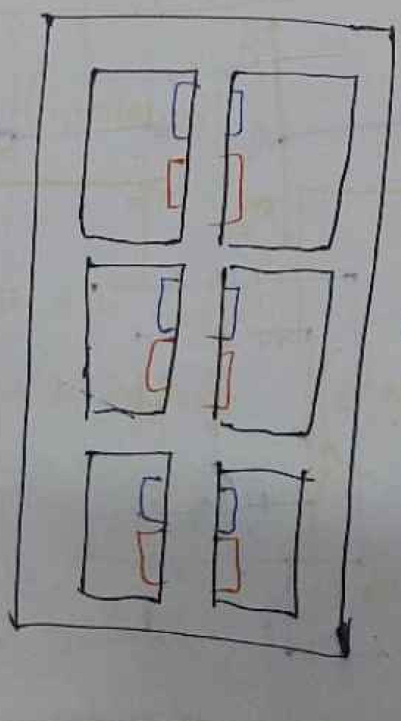
3-ϕ transformer :-

When a single unit of 3-ϕ transformer is constructed then it is known as 3-ϕ transformer. These are of two types :-

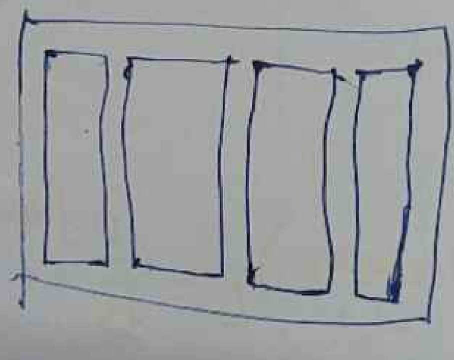
① Core :-



② Shell type :-



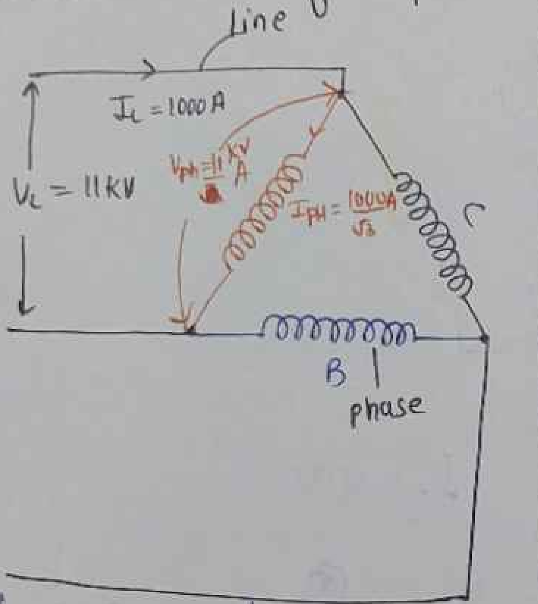
or

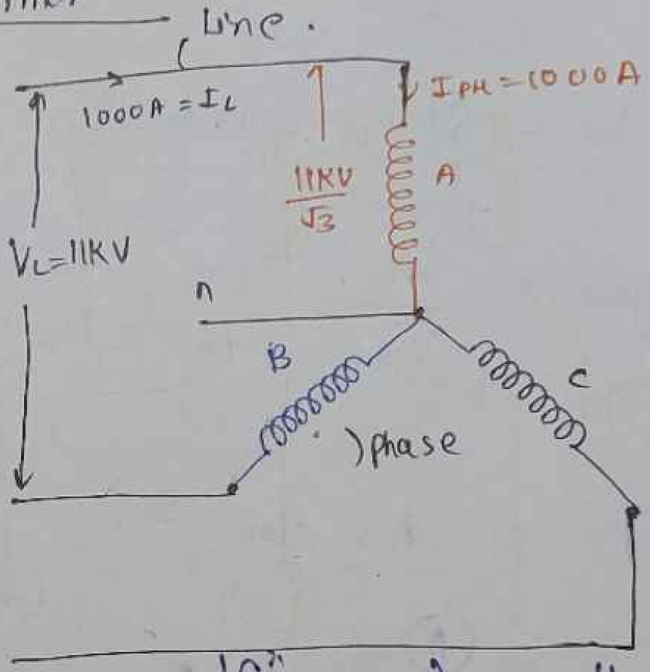


Result :-

(1) Cost of the 3-ϕ transformer is lesser, efficiency is higher than a three phase transformer bank.

Connection of 3-ϕ transformer :-





$V_L = V_{PH}$

$I_L = \sqrt{3} I_{ph}$

$(\text{insulation})_\Delta \propto 11KV$

$\begin{pmatrix}\text{conductor}\\ \text{size}\end{pmatrix}_\Delta \propto \frac{1000}{\sqrt{3}}$

Conductor

$V_L = \sqrt{3} V_{ph}$

$I_L = I_{PH}$

$(\text{Insulation})_Y \propto \frac{11}{\sqrt{3}}$

$$\boxed{(\text{Insulation})_Y = \frac{1}{\sqrt{3}} (\text{insulation})_\Delta}$$

$\therefore$ for H-V side Y connection is preffered.

$$\begin{pmatrix}\text{conductor}\\ \text{size}\end{pmatrix}_\Delta = \frac{1}{\sqrt{3}} (\text{conductor size})_Y$$

$\therefore$ for ~~H-V size~~ high current side Δ - connection is preffered

Down

H·V ⟶ L·V

Y ⟶ Δ

UP

L·V ⟶ H·V

Δ   Y

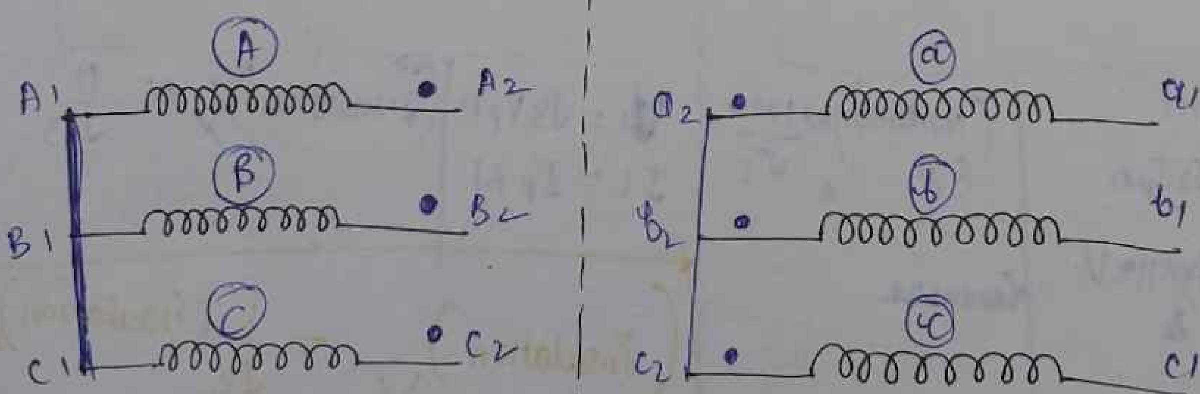
$\frac{V_{L1}}{\sqrt{3}V_{ph1}}$

$\sqrt{3}V_{ph2}$

Star - star connection :-

given = $\boxed{\frac{V_{ph1}}{V_{ph2}} = \frac{I_{ph2}}{I_{ph1}} = \frac{N_1}{N_2} = \frac{1}{K}}$

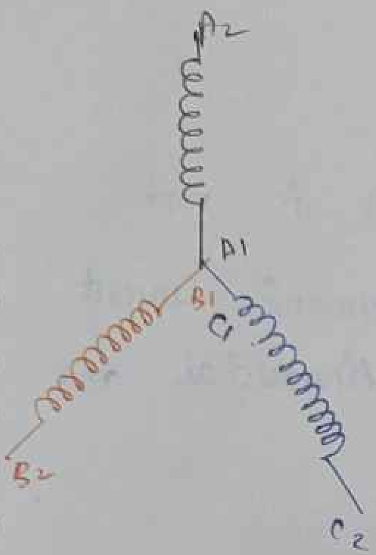
h-v side | l-v side



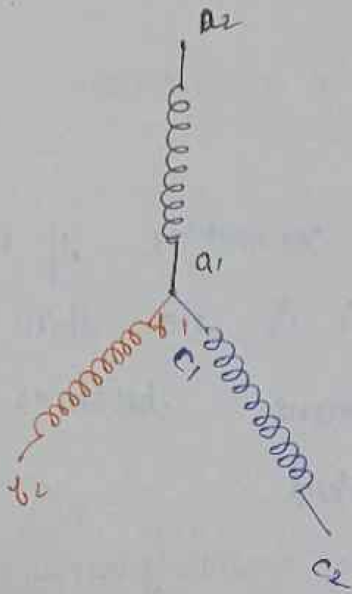
find $\boxed{\frac{V_{L1}}{V_{L2}} = \frac{\sqrt{3}V_{ph1}}{\sqrt{3}V_{ph2}} = \frac{1}{K}}$

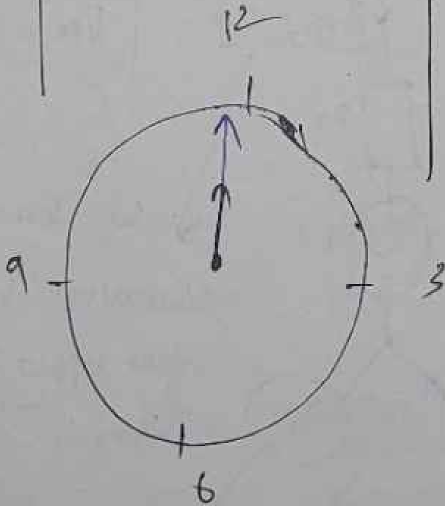
$\boxed{\frac{I_{L2}}{I_{L1}} = \frac{I_{ph2}}{I_{ph1}} = \frac{1}{K}}$

~~0° phase group~~

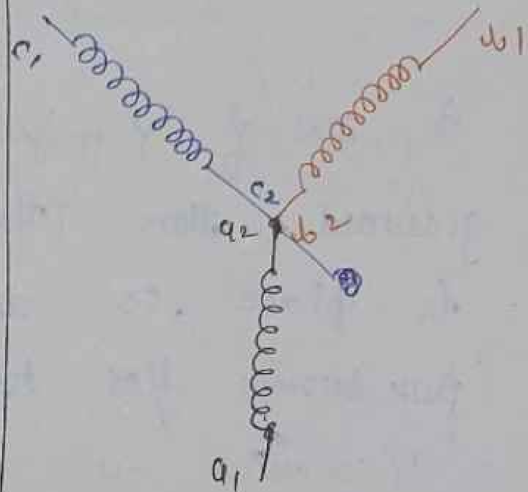


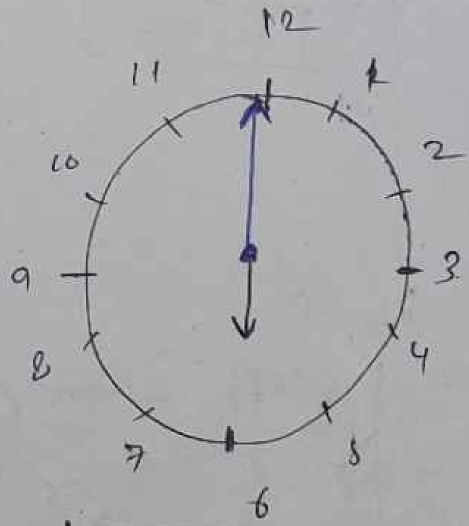
0° phase group





180° phase group





H.V – by minute hand

L.V – by hour hand

$\boxed{Yy0 \text{ or } Yy12}$

$\boxed{Yy6}$

H-V star

L.V star

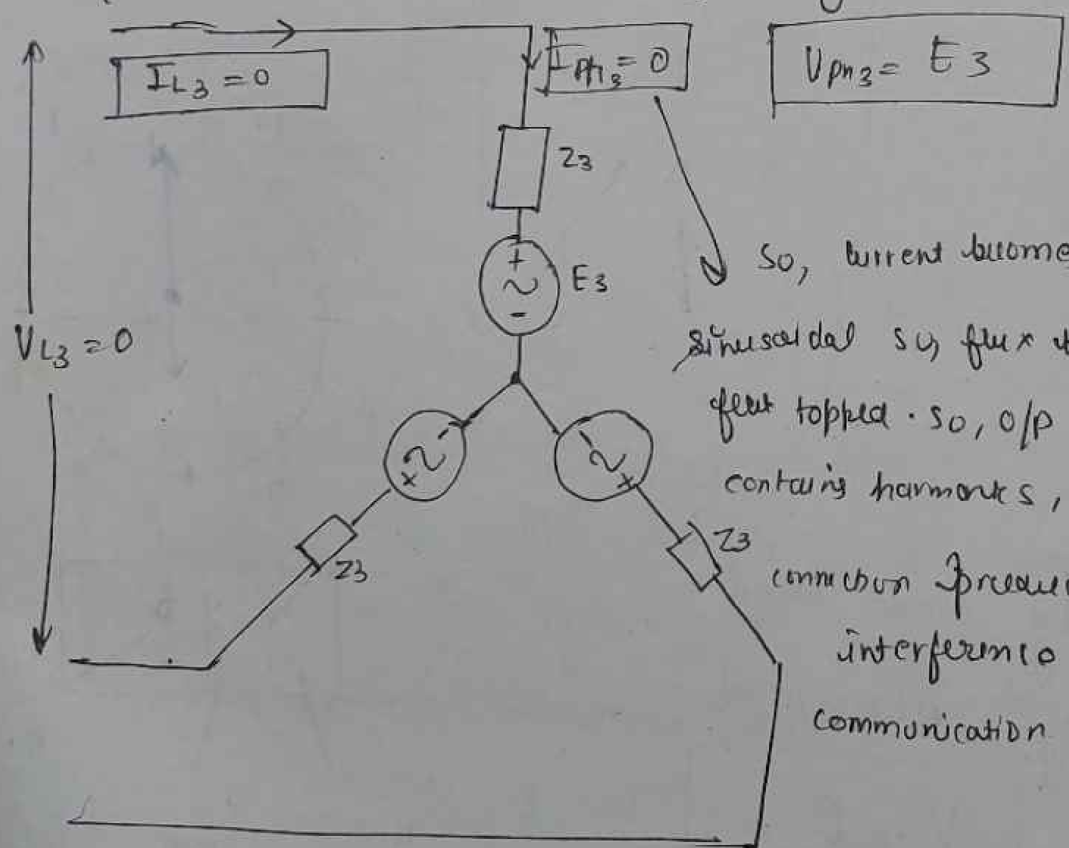
[illegible]

Star - star connection is not generally used.

⇒ Problem with Y - Y connection :-

In case of Y - Y connection if neutral is not grounded, then their is no third harmonic current in phase, so, current becomes sinusoidal and flux becomes flat topped

Y connection with no neutral grounding :-

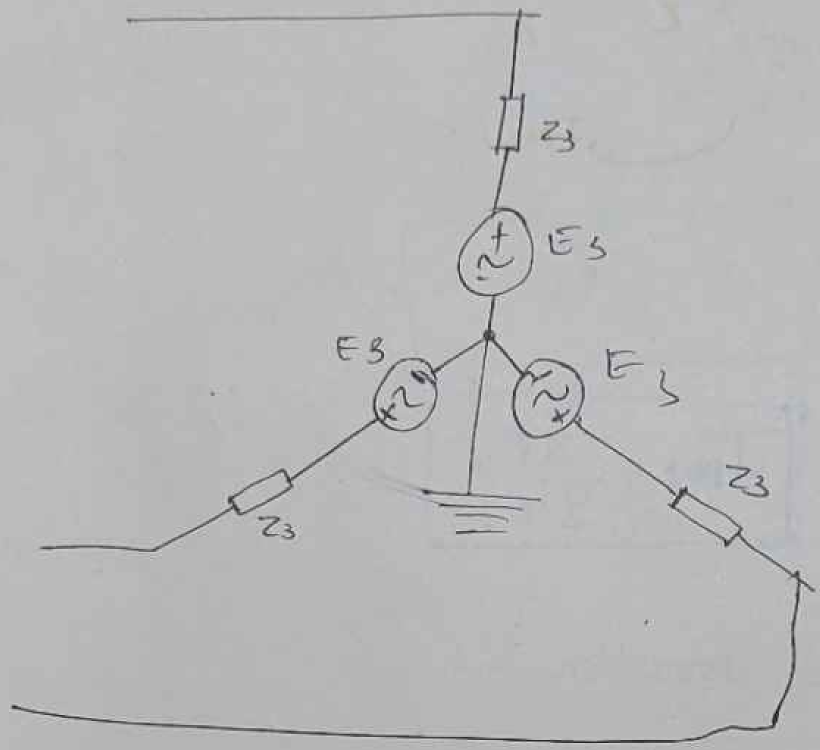


So, current becomes sinusoidal so flux becomes flat topped. so, o/p voltage contains harmonics, so, Y-Y connection produces an interference with communication line.

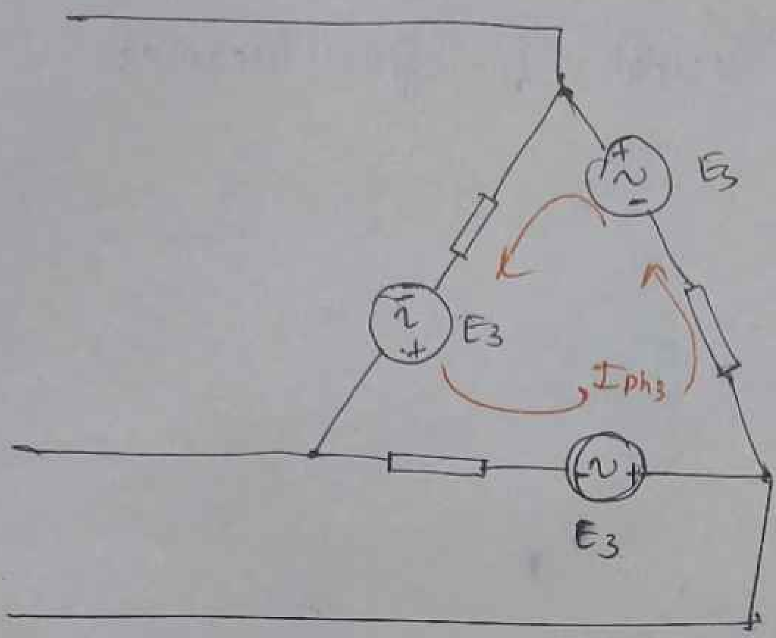
~~Interference with transmission line~~ :-

(2) If in star connection neutral is grounded then third order current harmonics can flow. so, current

becomes peaky sinusoidal & flux becomes sinusoidal.

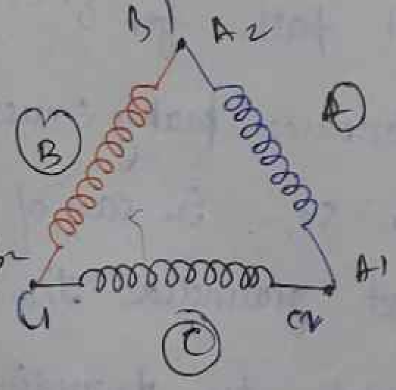


Since, Δ connection provides the closed path for 3rd harmonics current. So, current becomes peaky sinusoi-dal and flux becomes sinusoidal. So, In case of Y–Y connection if neutral is not grounded then third harmonics current can be obtained by providing a third winding known as tertiary. Tertiary is always connected in delta



$$\boxed{I_{ph3} = \frac{3E_3}{3Z_3}}$$

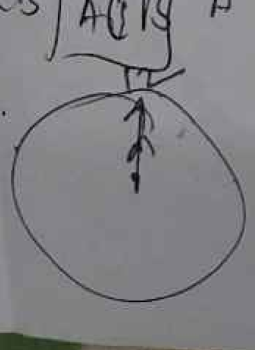
⊙ Delta - Delta connection :-

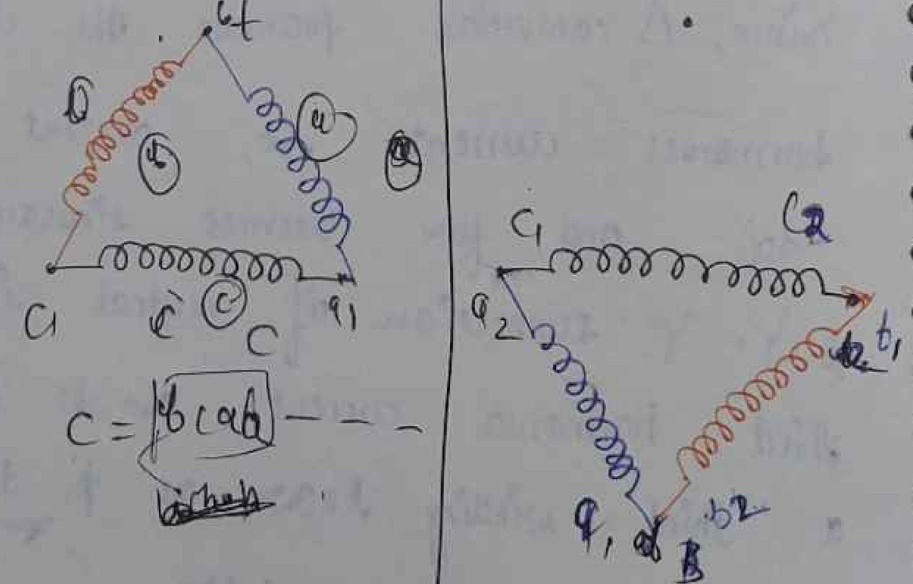


sequence =

~~CBA CB5 A~~ CBA CBA

CB $\boxed{ACB}$ A - -

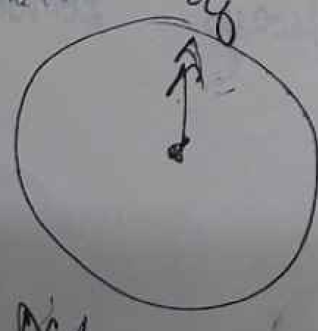




$C = \boxed{bcab}$ - - -

D d_{12}, Dd0

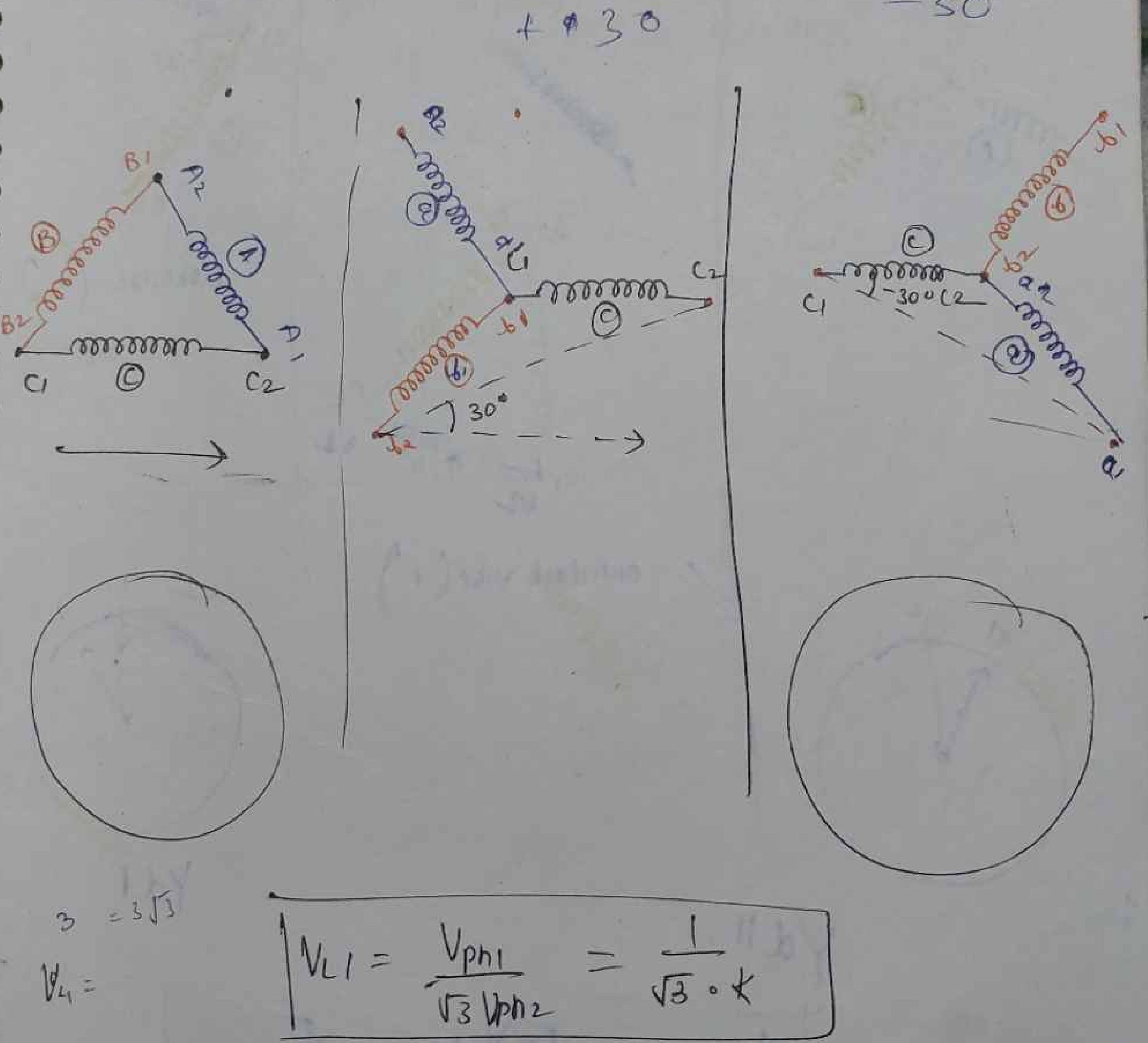
ab c a b a



Dy 6

Delta star connection :-

$\Delta - Y$ connection generally preffered for step-up transformer



3 = 3√3

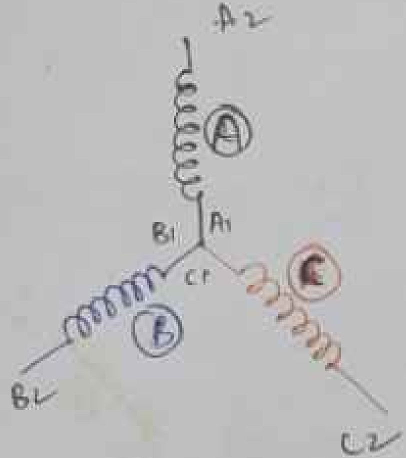
$V_{L1} =$

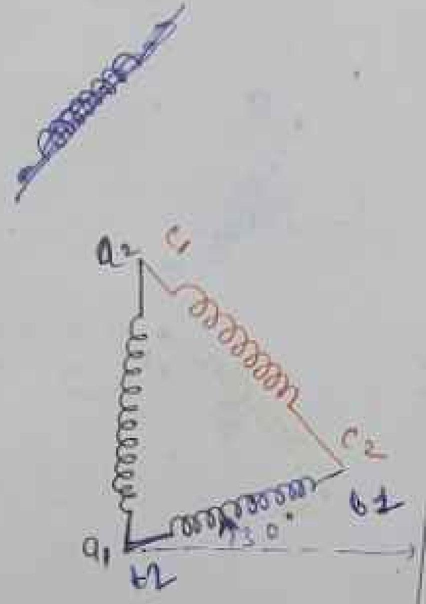
$$\boxed{V_{L1} = \frac{V_{ph1}}{\sqrt{3} V_{ph2}} = \frac{1}{\sqrt{3} \cdot K}}$$

$$\boxed{\frac{I_{L2}}{I_{L1}} = \frac{I_{ph_2}}{\sqrt{3} I_{ph1}} = \frac{1}{\sqrt{3} \cdot K}}$$

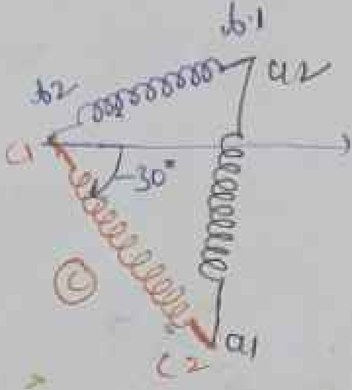
$\sqrt{3} V_{L1} =$

Star to delta :

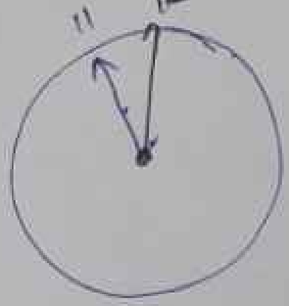




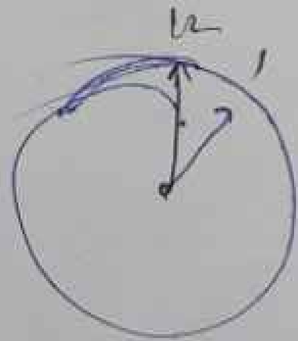
anticlock wise (+)



clockwise (−)



Yd11



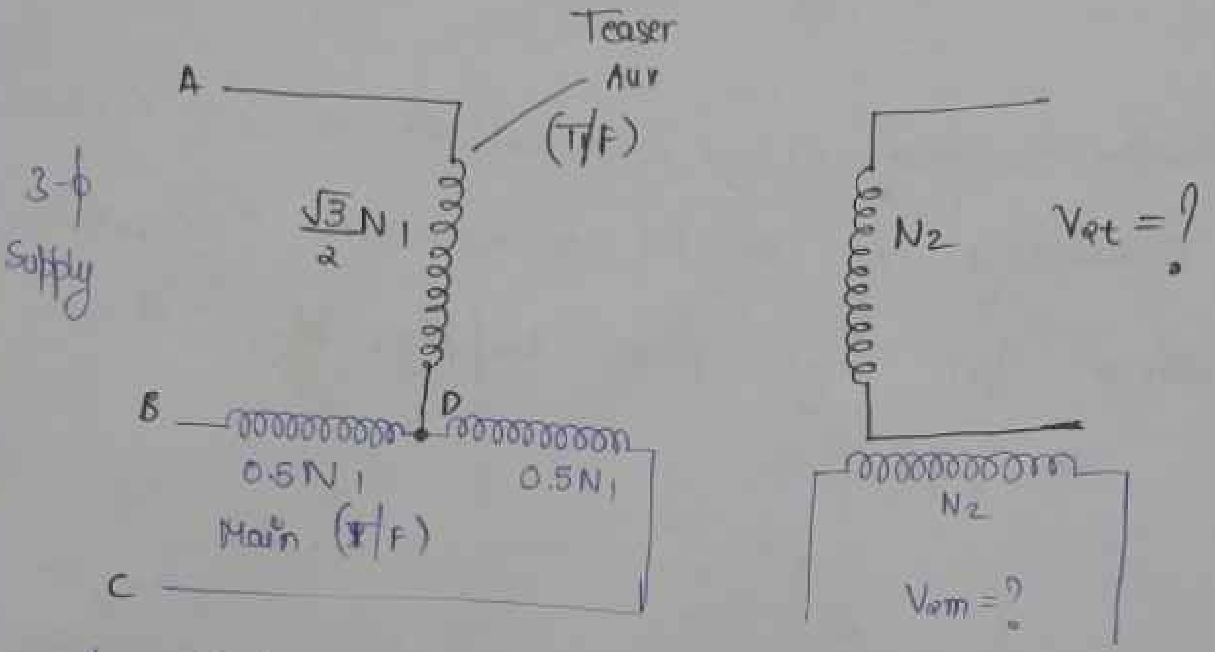
Yd1

$$\boxed{\begin{aligned} \frac{V_{L1}}{V_{L2}} &= \frac{\sqrt{3}\,V_{ph1}}{V_{ph2}} = \frac{\sqrt{3}}{K} \\ \frac{I_{L2}}{I_{L1}} &= \frac{\sqrt{3}\,I_{ph2}}{I_{ph1}} = \frac{\sqrt{3}}{K} \end{aligned}}$$

Note :-

① Distribution transformer always connected in det Δ – Y due to availability of neutral on secondary side which is required for single phase supply. But, it is a step down transformer.

Scott connection | T-T connection | 2φ- 3φ conversion | 3-φ to 2-φ conversion



Let 3-φ supply

$\overline{V_{BC}} = V_m \angle 0^\circ$

$\overline{V_{CA}} = V_m \angle -120^\circ$

$\overline{V_{AB}} = \angle -240$

Primary voltage of main T/F :-

$\overline{V_{1m}} = \overline{V_{BC}} = V_m \angle 0^\circ$

$\frac{\overline{V_{1m}}}{\overline{V_{2m}}} = \frac{N_1}{N_2} \Rightarrow \overline{V_{2m}} = \frac{N_2}{N_1}\overline{V_{1m}}$

$$\boxed{\overline{V_{2m}} = \left(\frac{N_2}{N_1}\right) V_m \angle 0^\circ}$$

Primary voltage of teaser T/F :-

$$\overline{V_{1t}} = \overline{V_{AD}}$$

Here $\overline{V_{AD}} = \overline{V_{AB}} + \overline{V_{BD}}$

$$\overline{V_{AD}} = V_m \angle -240 + \overline{V_{BD}}$$

Here

$$\overline{V_{BC}} = \overline{V_{BD}} + \overline{V_{DC}}$$

$$\overline{V_{BD}} = \overline{V_{DC}} = \frac{\overline{V_{BC}}}{2}$$

$$\overline{V_{BD}} = \overline{V_{DC}} = \frac{V_m}{2} \angle 0^\circ$$

$$\overline{V_{AD}} = V_m \angle -240 + \frac{V_m}{2} \angle 0^\circ$$

$$\overline{V_{AD}} = \frac{\sqrt{3}}{2} V_m \angle 90^\circ$$

$$\frac{V_{1t}}{V_{2t}} = \left(\frac{\frac{\sqrt{3}}{2} N_1}{N_2} \right)$$

$$\therefore \boxed{V_{2t} = \frac{N_2}{\frac{\sqrt{3}}{2} N_1} \times V_{1t}}$$

$$V_{2t} = \frac{N_2}{\frac{\sqrt{3}}{2} N_1} \times \frac{\sqrt{3}}{2} V_m \angle 90^\circ$$

$$\boxed{V_{2t} = \frac{N_2}{N_1} V_m \angle 90^\circ}$$

WM 85991$\neq$

AD में tapping 57.7% of full winding for neutral

$$V_{AN} = \frac{V_L}{\sqrt{3}} = .577 V_L$$

$$V_{AD} = \frac{\sqrt{3}}{2} V_L = .866 V_L$$

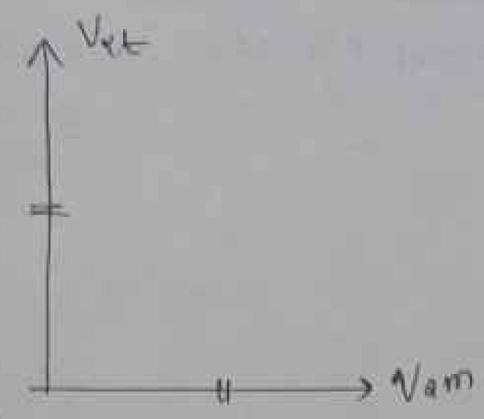
5 ∠ j√3

70.89

5∠

$\frac{V 8.2}{4}$ ∠19.1

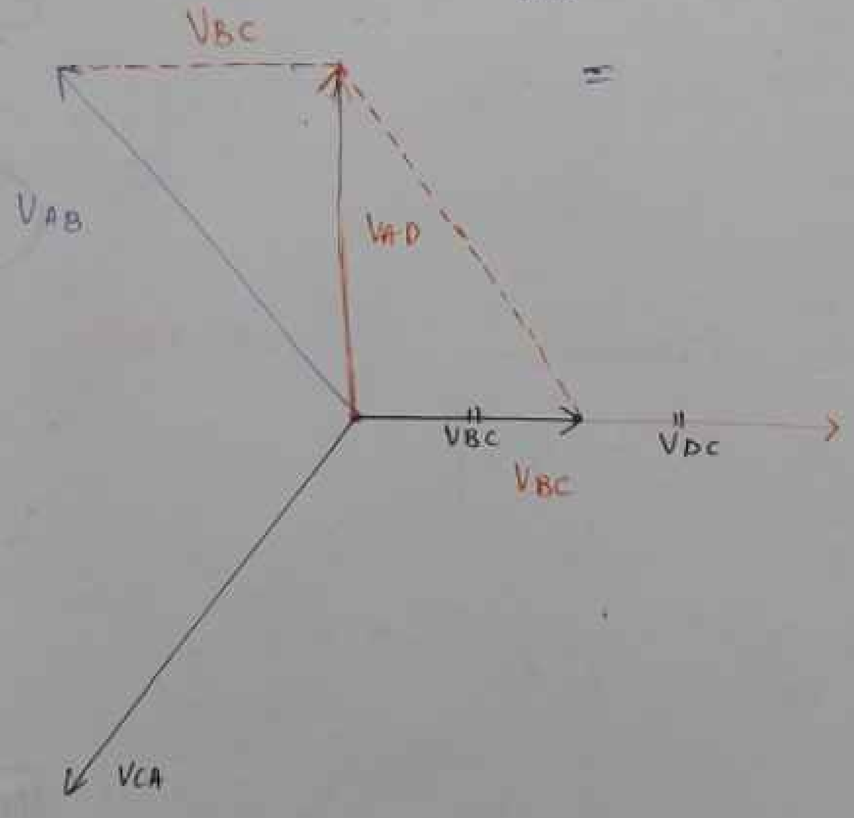
$1.3 V_L \angle 19.1$



V_{xt} leads V_{xm} by angle (90°)

$V_{AD} = V_{AB} + V_{BD}$

=



Result :-

Scott connection is used for 3-ϕ to 2-ϕ consversion or 2-ϕ to 3-ϕ consversion.

Application :- To run furnaces

(a) To run 2-ϕ motor.

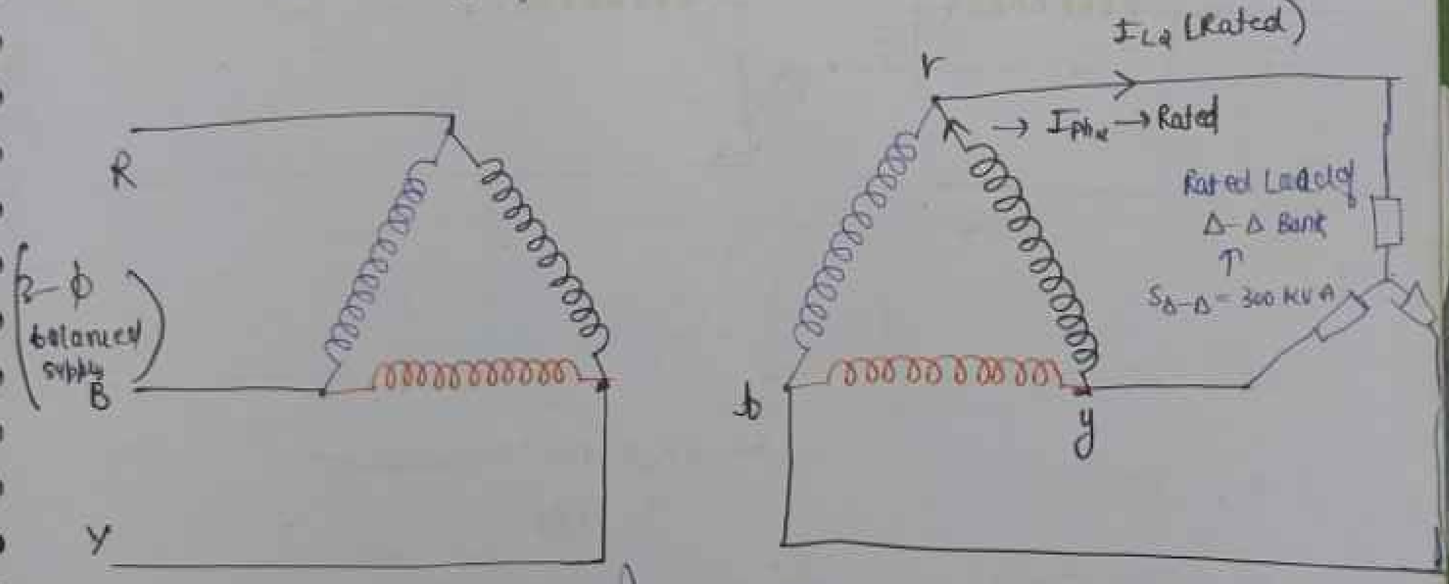
(b)

(6) Open delta connection :- (V - V connection)

Case-1 :- Δ - Δ connected 3-φ transformer bank at rated load ($S_{\Delta-\Delta}$).

When we apply a balanced 3-φ to the primaries of Δ-Δ bank then we obtained balanced 3-φ on secondary side. So, we can transfer 3-φ power by Δ - Δ bank

suppose rating of each 1-φ T/F = 100KVA



Let

$$\overline{V_{RY}} = V_m \angle 0^\circ$$

$$\overline{V_{YB}} = V_m \angle -120^\circ$$

$$\overline{V_{BR}} = V_m \angle -240$$

Balanced 3-φ

$$\overline{V_{ry}} = V_{m_2} \angle 0^\circ$$

$$\overline{V_{yb}} = V_{m_2} \angle -120^\circ$$

$$\overline{V_{br}} = V_{m_2} \angle -240^\circ$$

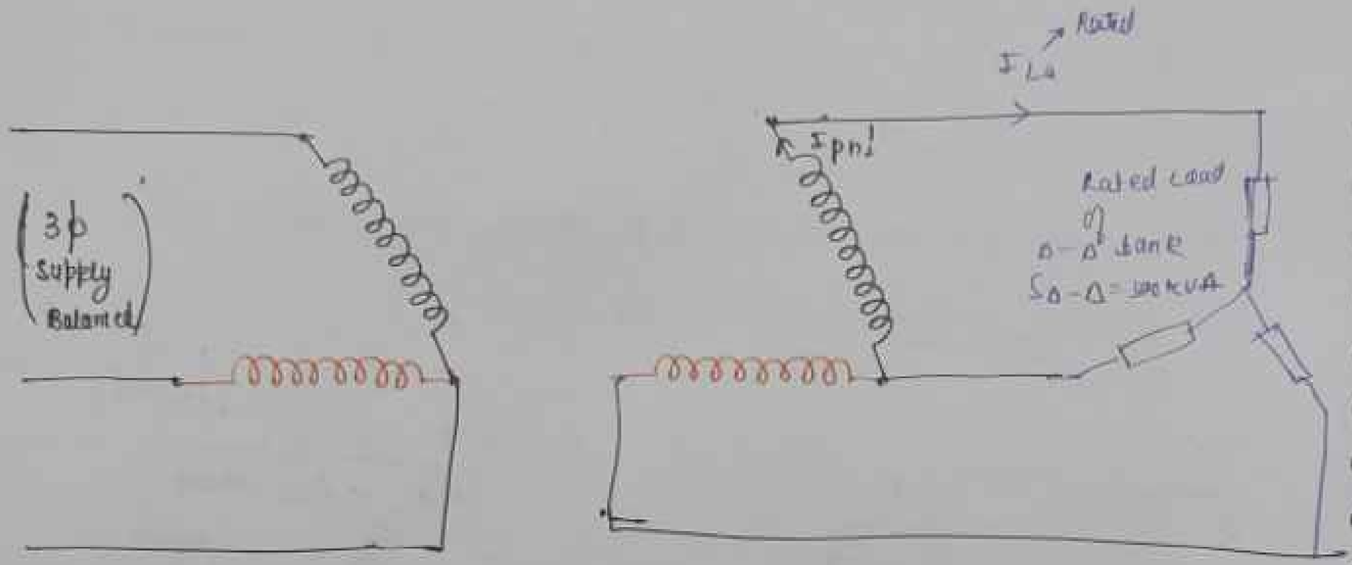
By KVL

$$\boxed{\overline{V_{ry}} + \overline{V_{yb}} + \overline{V_{br}} = 0}$$

$$\boxed{I_{L_2} = \sqrt{3}\, I_{ph_2}}$$ (Rated

Rated

Case 2 If one of the transformer of Δ-Δ bank gets damage and loading remains $S_{\Delta-\Delta}$



Let

$\overline{V_{RY}} = V_m \angle 0°$

$\overline{V_{YB}} = V_m \angle -120°$

$\overline{V_{BR}} = V_m \angle -240$

Balanced 3φ

$\overline{V_{ry}} = V_{m_2} \angle 0°$ (remain same)

$\overline{V_{yb}} = V_{m_2} \angle -120°$ (remain same)

$\overline{V_{br}} = ?$ (damaged one)

By KVL

$\overline{V_{ry}} + \overline{V_{yb}} + \overline{V_{br}} = 0$

$\Rightarrow \overline{V_{br}} = -(\overline{V_{ry}} + \overline{V_{yb}})$

$= -(V_{m_2} \angle 0° + V_{m_2} \angle -120°)$

$\boxed{V_{br} = V_{m_2} \angle -240°}$

∴ V_{br} also remains same $= V_{br}$

$$I_{ph_2}' = I_{L_2}$$

$$I_{ph_2}' = \sqrt{3}\, I_{ph_{2\,rated}}$$

% Rise in loading on each T/F $= \dfrac{I_{ph_2}' - I_{ph_2}}{I_{ph_2}} \times 100$

$$= \frac{\sqrt{3} I_{ph_2} - I_{ph_2}}{I_{ph_2}} \times 100$$

$$= \frac{I_{ph_2}}{I_{ph}} \frac{(1.732 - 1)}{} \times 100$$

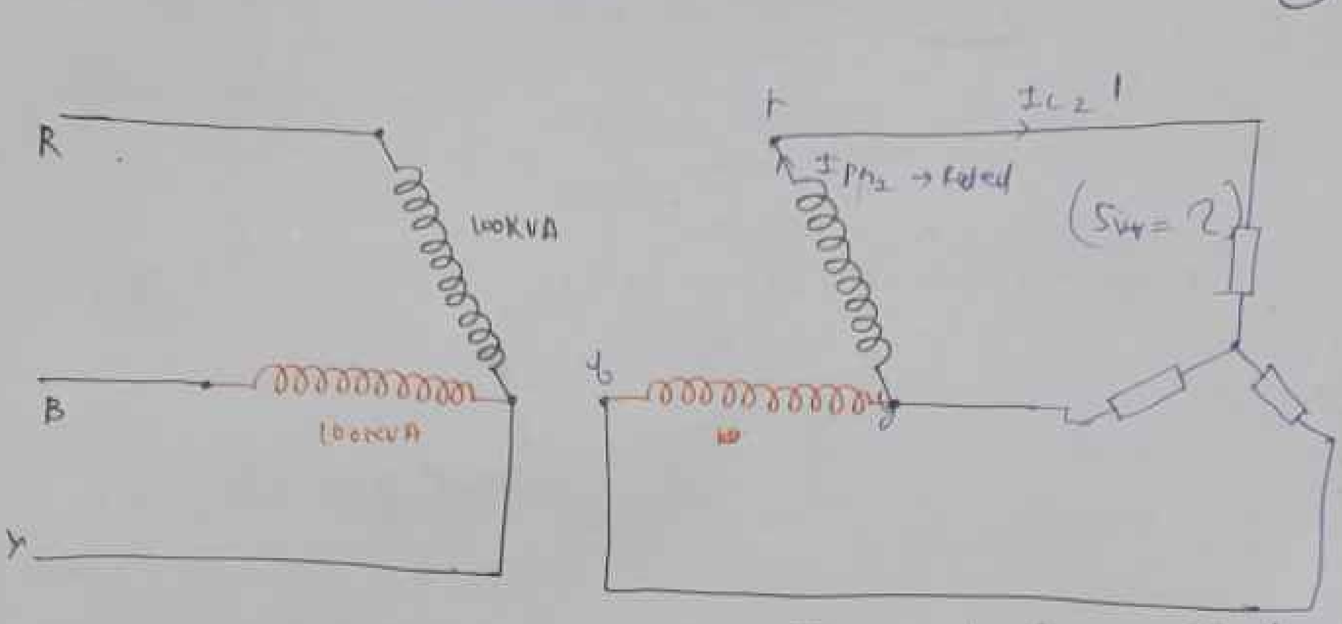
$$= .732 \times 100$$

$$\boxed{\text{\% Rise in loading on each T/F} = 73.2\,\%}$$

So, in case of open delta connection balancing remains the same but both the tranformers gets over loaded

Case → 3 :- Rated loading of open delta connection, so, no one T/F is of over loaded.

If one T/F of Δ-Δ bank gets damaged then loading (SV-V). so, no one T/F is overloaded.



$I_{Ph_2} = I_{L2}' = \frac{I_{L2}}{\sqrt{3}} \rightarrow$ (Rated)

$$\boxed{I_{L2}' = \frac{I_{L2}}{\sqrt{3}}}$$

$$S_{\Delta-\Delta} \propto I_{L_2}$$

$$S_{V-V} \propto I_{L2}'$$

$$\therefore \boxed{S_{V-V} = \frac{1}{\sqrt{3}} S_{\Delta-\Delta}} \quad \#$$

$$\boxed{S_{V-V} = \frac{1}{\sqrt{3}} \times 300 = 173.2 \text{ KVA}}$$

$$\boxed{S_{V-V} = 57.7\% \text{ of } S_{\Delta-\Delta}}$$

or

ratting of S_{V-V} 86.6% of ratting of left 2T/F

⇒ In open delta connection if no-one T/F is overloaded then loading is reduced to 57.7% of $S_{\Delta-\Delta}$ or 40 reduced by 42.3% of $S_{\Delta-\Delta}$ or 86.6% of total KVA of both the

⇒ ~~trans~~ transformer or reduced by 13.4% of total KVA of both the transformer.

Parallel operation of Transformer :-

~~In~~ It is an arrangement in which two or more T/F primaries are connected with same supply and secondaries are connected to carry the same load.

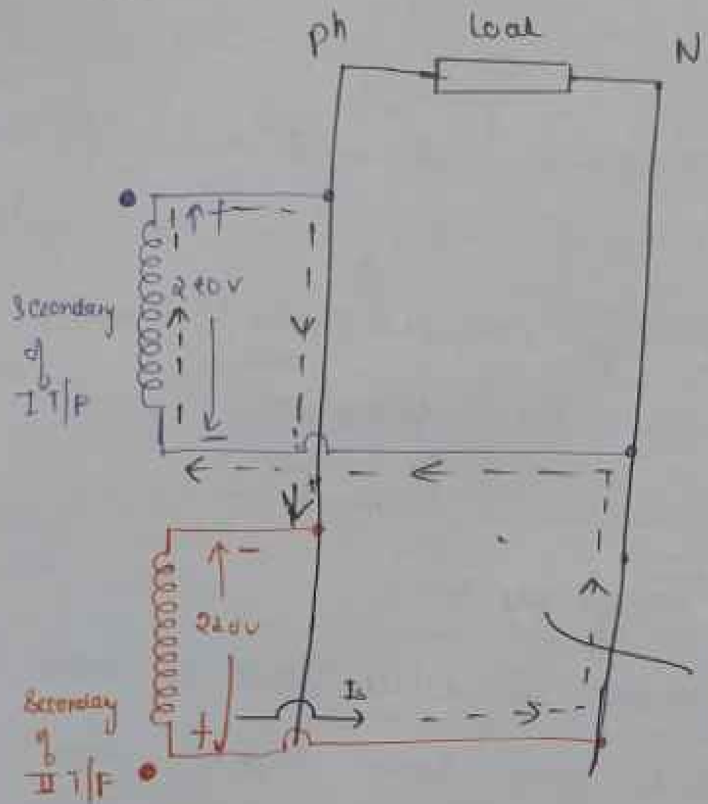
Necessary condition for parallel operation :-

(necessary)

1. Polarity must be properly checked it means polarity of all the transformer connected in parallel must be same other wise a dead short circuit will occur and transformer gets damaged.

Application :-

1. rialability increases
2. eff addition ~~uw~~ $\frac{w}{4}$
3. It reduces cost.



$$I_{SC} = \frac{220+220}{Z_{eA} + Z_{eB}}$$

(Dead short circuit occurs)

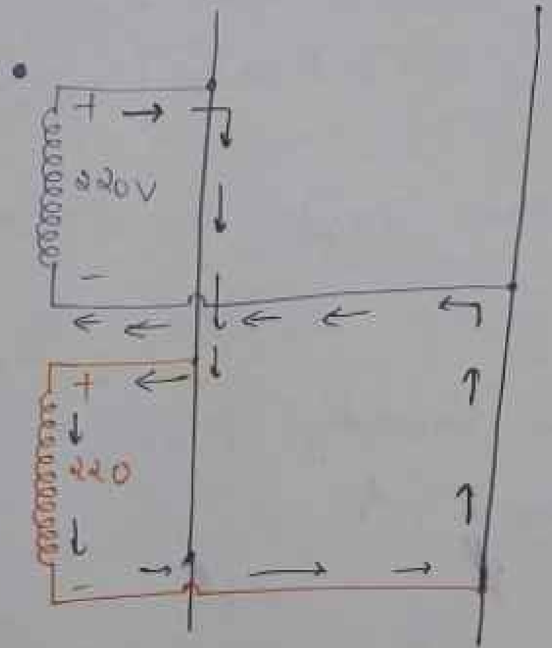
(2) In case of 3-ϕ transformer all the transformers belongs to same phasor group (same relative phase displacement) and must have same phase sequence other wise a circulating current will flow

1. Dd 6, Yy 0 X (if 0) are of same phasor group
2. Yd 1, Δy 1 same phasor group
3. Yd 11, Dy 1 X (diff phasor group)

(necessary)

(3) Con

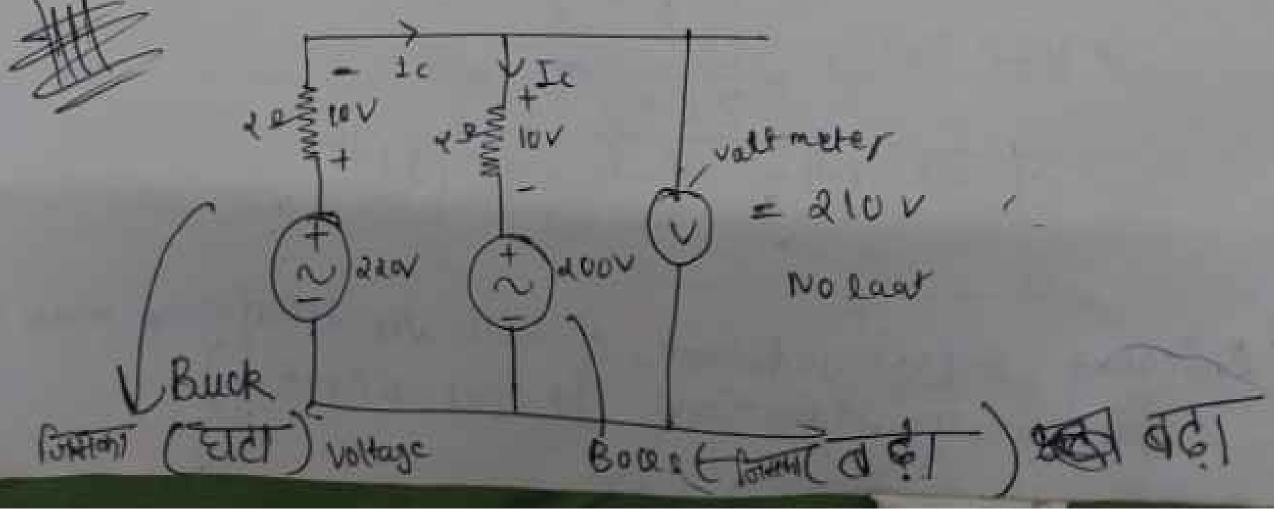
voltage ratio of all the transformer connected in parallel must be same otherwise a circulating current will flow which causes unnecessary copper loss and net available KVA at output reduces.



$$I_c = \frac{220 - 200}{Z_{eA} + Z_{eB}}$$

$$\boxed{I_c = \frac{20}{Z_{eA} + Z_{eB}}}$$

<u>Example :-</u> by equivalent ckt



$$I_C = \frac{220 - 200}{4} = \frac{20}{4} = 5$$

$$\boxed{\text{Unnecessary copper loss} = I_C^2 (Z \text{ of both})}$$

$$= (5)^2 [2 + 2]$$

$$\boxed{\text{Loss} = 100 \text{ W}}$$

(v) In order to share load according to their individual KVA ratting the magnitude of impedance (Ω impedance) must be inversely proportional to their individual KVA ratting.

OR

Their per unit (Pu) impedance with respect to their individual KVA ratting must be same.

$$\text{KVA Rating} = VI$$

$$\text{KVA Rating} = V \cdot \frac{V}{Z}$$

$$\text{KVA Ratting} = \frac{V^2}{Z(\Omega)}$$

$$\boxed{\text{KVA Ratting} \propto \frac{1}{Z(\Omega)}}$$ ###

(Equivalent leakage impedance of both the transformer must be inversely proportional to their VA ratting)

T_A : 200 KVA, 200/100 V, $Z_A = 10\,\Omega$

T_B : 100 KVA, 200/100 V, $Z_B = 20\,\Omega$

or

$$Z_{pu} = \frac{Z_{actual}}{Z_{Base}}$$

$$= \frac{V_b^2}{(VA)_b}$$

$$Z_{pu} = \frac{Z(\cdot)(VA)_b}{V_b^2}$$

$$= \frac{10 \times 200 \times K}{(200)^2}$$

$$= \frac{10 \times 1000}{200}$$

$$= 50\,pu$$

$$(Z_B)_{pu} = \frac{20 \times 100K}{(200)^2}$$

$$= \frac{20 \times 100 \times 1000}{200 \times 200}$$

$$= 50\,PU$$

same Δ

(5) All the transformer connected in parallel must have same $\frac{X}{r}$ ratio other wise they will not share killowatt according to their KVA ratting.

$$\cos\theta_A = \frac{R_{eA}}{\sqrt{R_{eA}^2 + X_{eA}^2}} \qquad \cos\theta_B = \frac{R_{eB}}{\sqrt{R_{eB}^2 + X_{eB}^2}}$$

$$\cos\theta_A = \frac{1}{\sqrt{1+\left(\frac{X_{eA}}{R_{eA}}\right)^2}}$$

$$(KW)_A = V I_A \cos\theta_A \qquad (KW)_B = V I_B \cos\theta_B$$

$$(KW) \propto I$$

$$\boxed{\frac{X_{eA}}{R_{eA}} = \frac{X_{eB}}{R_{eB}}}$$

Result :-

1. Condition 1 is known as most essential condition
2. condition 1 and 2 are known as absolute essential condition
3. Condition 1, 2, 3, 4, 5 all are known as essential condition.

In-rush current :-

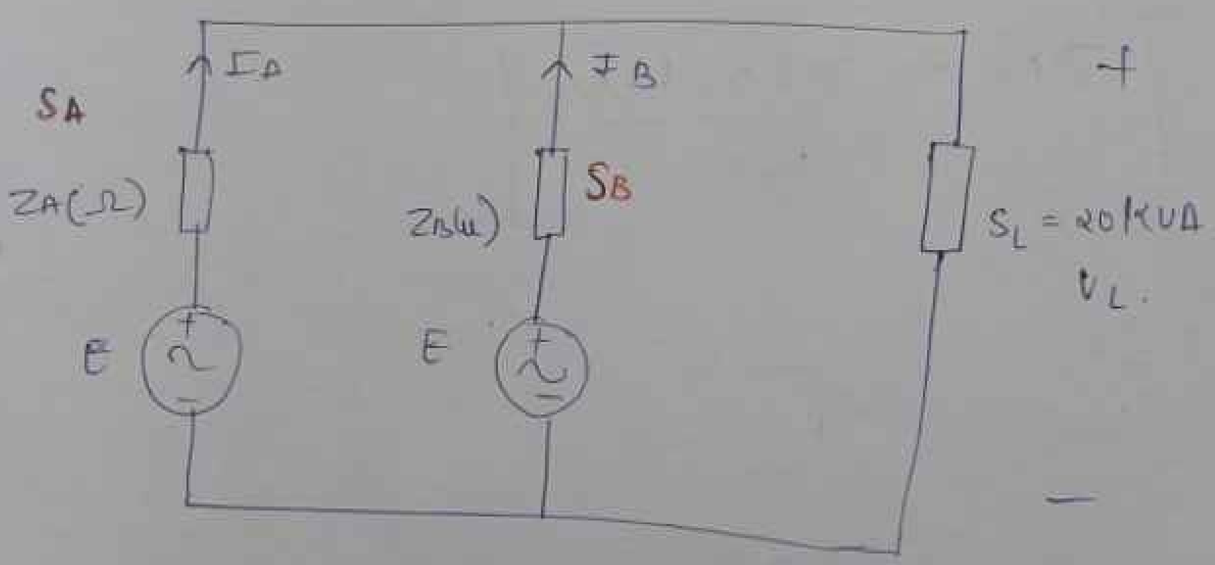
At starting of transformer no load current is very high similiar to I-M motor. So, the reduce this current transformer is ON at peak voltage. If it is on at ~~ze~~ V zero voltage current will be at its peak.

If two transformer $T_A = 15$ KVA, 0.15 PU and T_B : 5 KVA, 0.18 PU share a common load of 20 KVA then find the individual KVA shared by all the transformer.

$T_A = 15$ KVA, 0.15 PU

$T_B = 5$ KVA, 0.15 PV

$S_L = 20$ KVA



$$S_A = E I_A$$

$$I_A = I_L\left(\frac{Z_B}{Z_A + Z_B}\right) \longrightarrow S_A = E \cdot I_L\left(\frac{Z_B}{Z_A + Z_B}\right)$$

$$\therefore \boxed{S_A = S_L\left(\frac{Z_B}{Z_A + Z_B}\right)}$$

$$S_B = E I_B$$

$$I_B = I_L \left(\frac{Z_A}{Z_A + Z_B} \right)$$

$$\boxed{S_B = E I_L \left(\frac{Z_A}{Z_A + Z_B} \right)}$$

$$\boxed{S_B = S_L \left(\frac{Z_A}{Z_A + Z_B} \right)}$$

$$\boxed{Z_{PU} = \frac{Z(\Omega)\,(V_A)_b}{V_b^2}}$$

$$Z_A = \frac{Z_{PU} \times V_b^2}{(V_A)_b}$$

$$= \frac{.15 \times x^2}{15 \times 1000}$$

$$\boxed{Z_A = 10^{-5} x^2}$$

$$\boxed{Z_B = \frac{Z_{PU} \times V_b^2}{(V_A)_b} = \frac{.15 \times x^2}{5 \times 1000} = 3 \times 10^{-5} \times x^2}$$

$$\therefore \boxed{S_A = 20k \left[\frac{3 \times 10^{-5} \times x^2}{3 \times 10^{-5} x^2 + 10^{-5} x^2} \right] = 15KVA}$$

$$\boxed{S_B = 20K\left[\frac{10^{-5}x^2}{10^{-5}x^2+3\times10^{-5}x^2}\right] = 5KVA}$$

No over loading and no under loading occurs.

Rated loaded

Z_A = $\frac{\cdot}{}$

Z_B = $\frac{\cdot L}{5}$

$\therefore$ S_A

$$\frac{\frac{2}{3}\times\cancel{10^{-5}}\times x^2}{\left(\frac{2}{3}+3\right)\times\cancel{10^{-5}}\times x^2}$$

$$\frac{2}{11}\times 20K$$

$$\boxed{S = \frac{}{11}}$$

$$\boxed{= \frac{40}{11} KVA}$$

$$\boxed{S_A = 16.3636 KVA}$$

$$\boxed{S_B = 3.63 KVA}$$

D.C machine :-

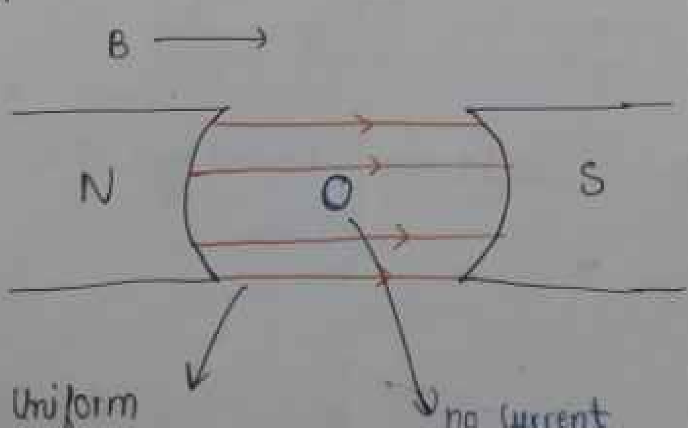
① D.C motors are used when load demand high starting torque, wide range of speed control, quick reversal, high accelerating and deaccelerating torque

Working Principle of D.C machine :-

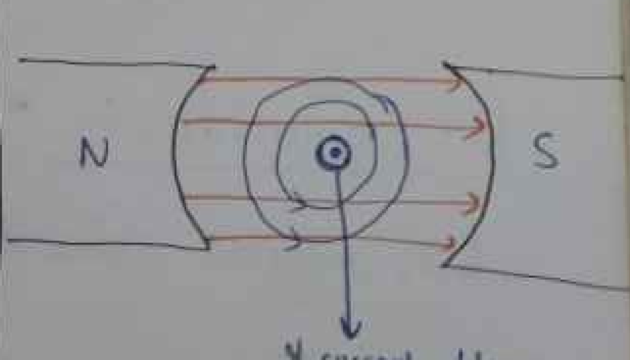
① D.C Motor :-

→ When a current carrying conductor placed in a magnetic field it experiences a force known as as Lorentz force whose direction is given by ~~flm~~ Flemings left hand rule which is also known as ~~k~~ motor rule.

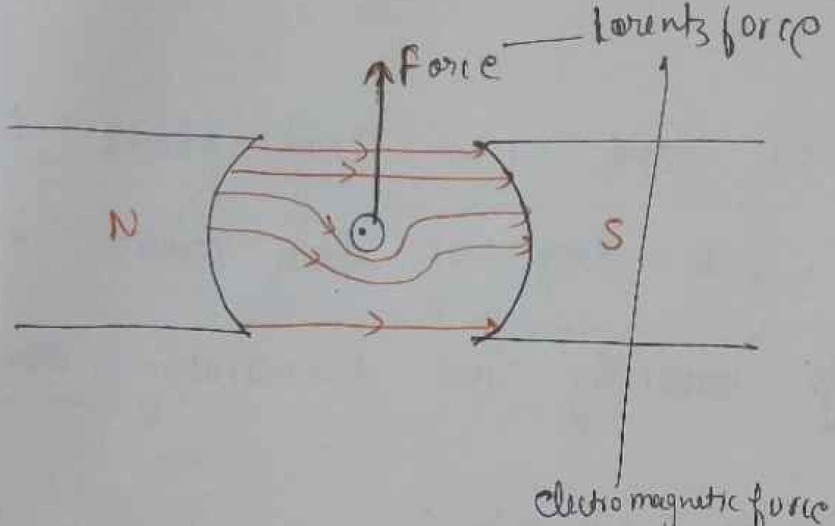
①



②



By they do not cut each other so, flux distort ф



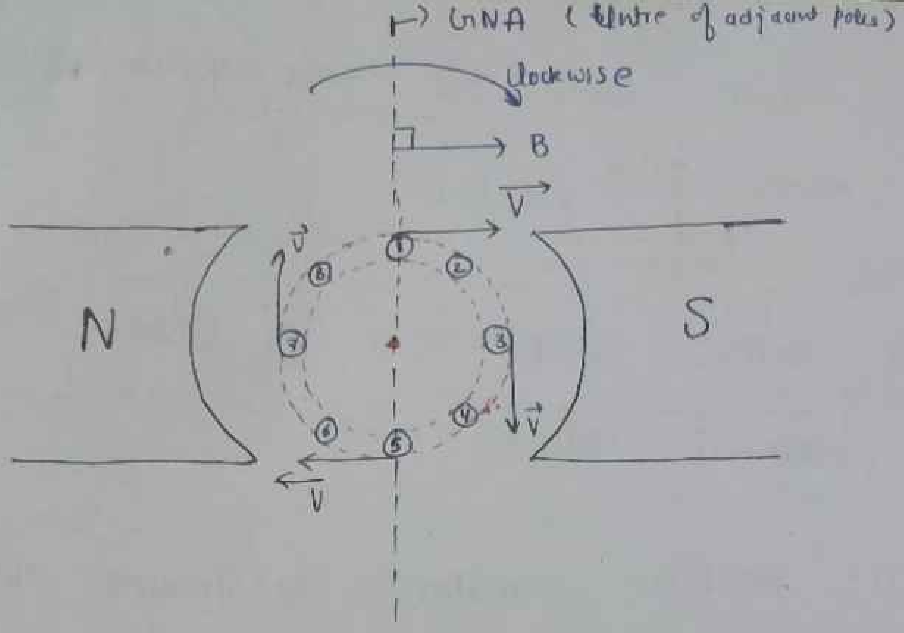
$$\boxed{\vec{F} = I\,(\vec{l} \times \vec{B})}$$

B = magnetic feild density (Tesla)
I = Active length of conductor
L = current in conductor

$$\boxed{F = BIl\sin\theta}$$

angle b/w $\vec{B}$ and $\vec{l}$

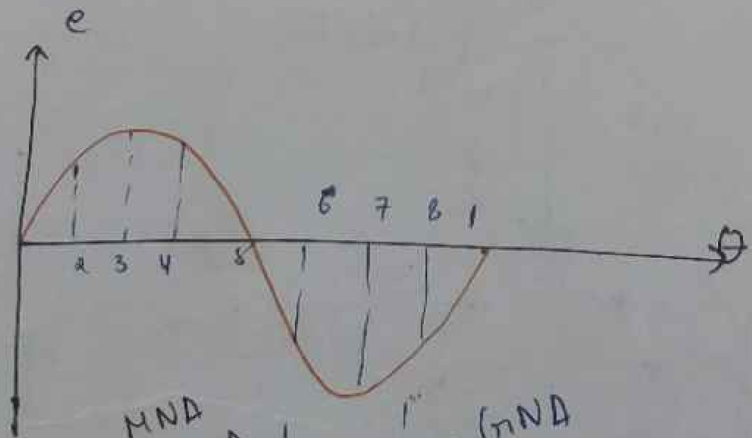
D.C generator :- "It works on Farraday's law of electro magnetic induction".

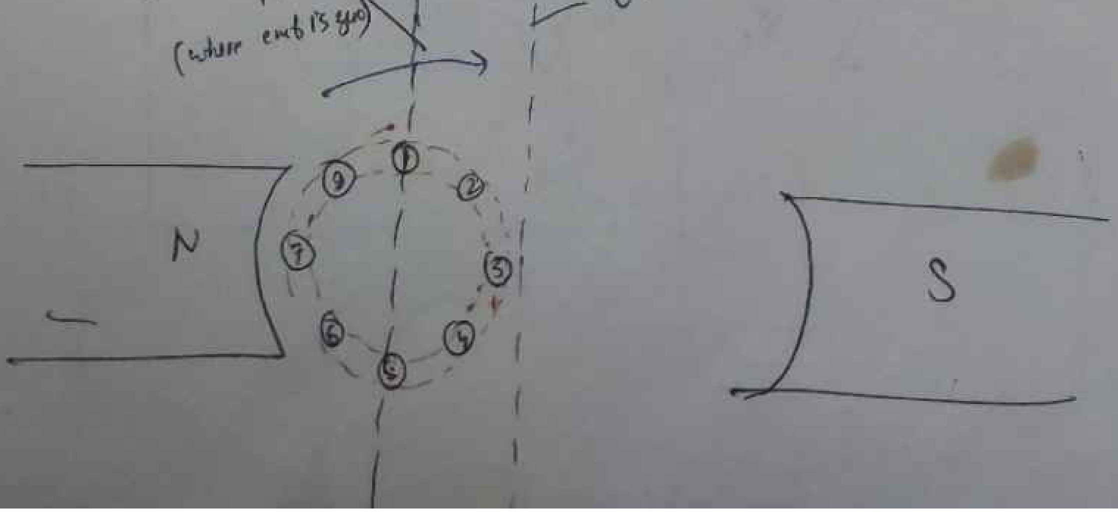


$\vec{V}$ = always tangent to direction of rotation

$e = l(\vec{V} \times \vec{B})$ $\quad$ v = velocity.

$\boxed{e = Blv \sin\theta}$ — angle $\vec{V}$ and $\vec{B}$



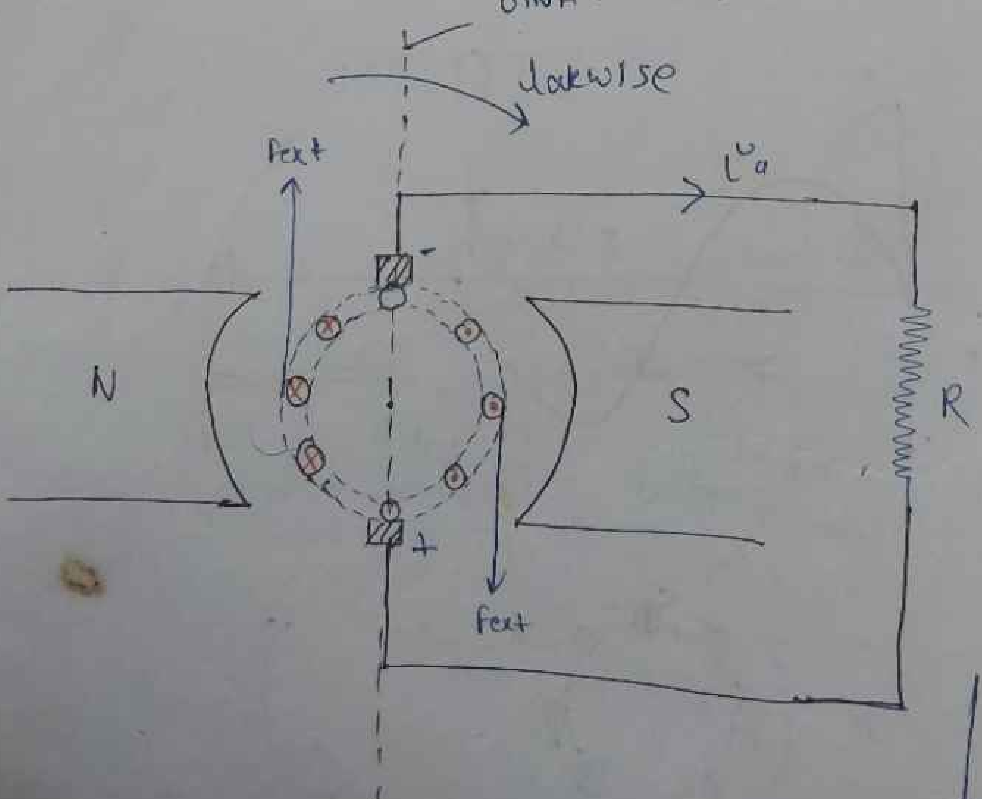


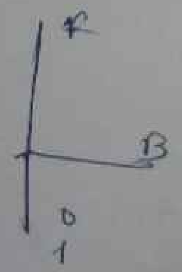
φ ⇒ The axis which bisect the pole pitch is known as geometric neutral axis (GNA)

⇒ The axis which is perpendicular to field lines is known as magnetic neutral axis.

⇒ In the D.C machine armature the induced emf is alternating.

⇒ The direction of current is given by ~~the~~ Flemings right hand rule which is also known as generator rule.

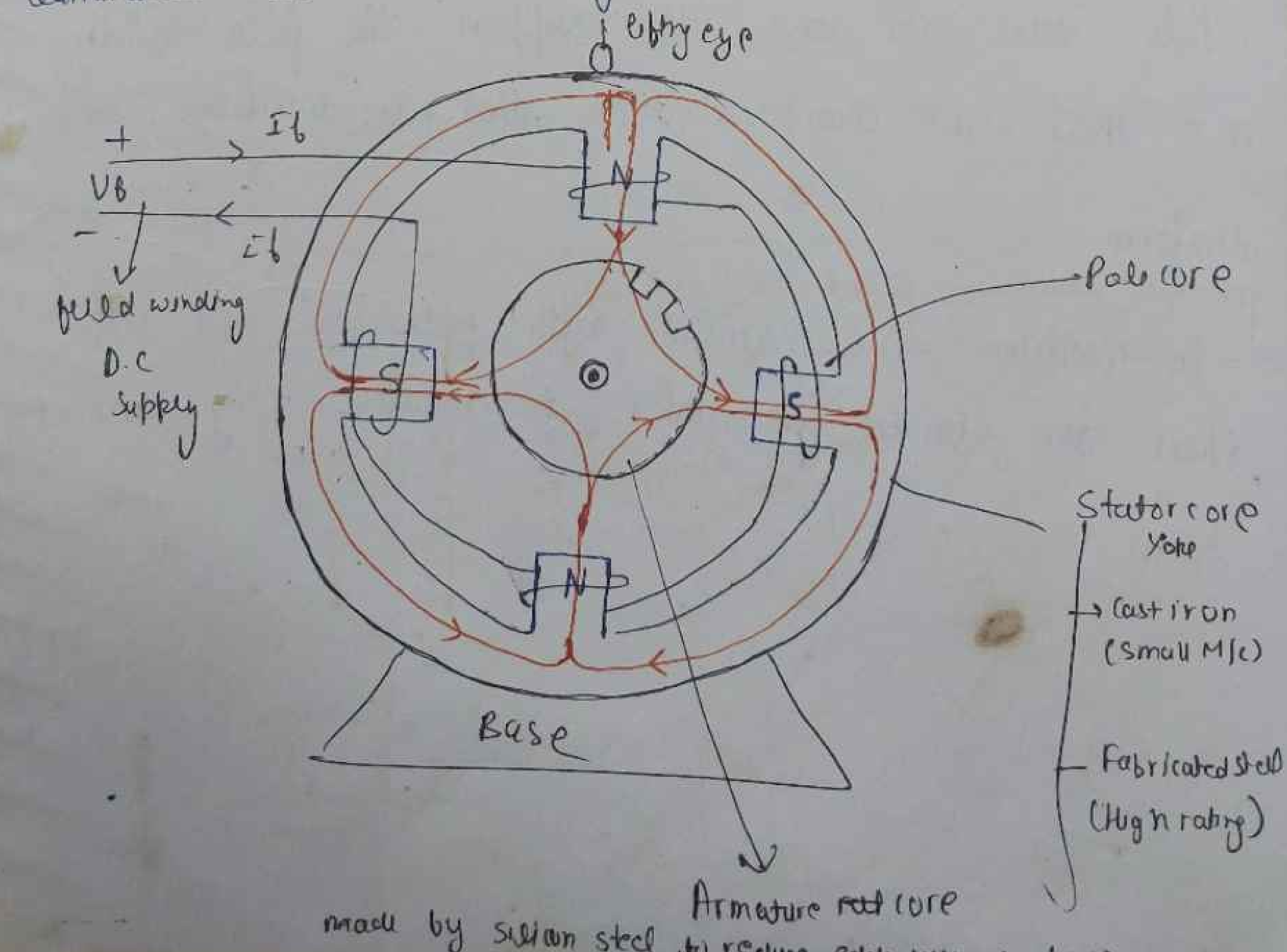




Construction of D.C machine :-

① **Stator / Yoke :-** The function of yoke in case of D.C machine is to carry the flux and also provide mechanical support to the whole machine.

⇒ Generally stator core is not laminated but in case of D.C motor is to be operated threw a power electronic converter for speed control. It is laminated to reduce eddy current losses



made by silicon steel to reduce eddy current loss

ϕ = flux per pole

⇒ Yoke handle flux $\phi/2$ or in each 1/4 part.

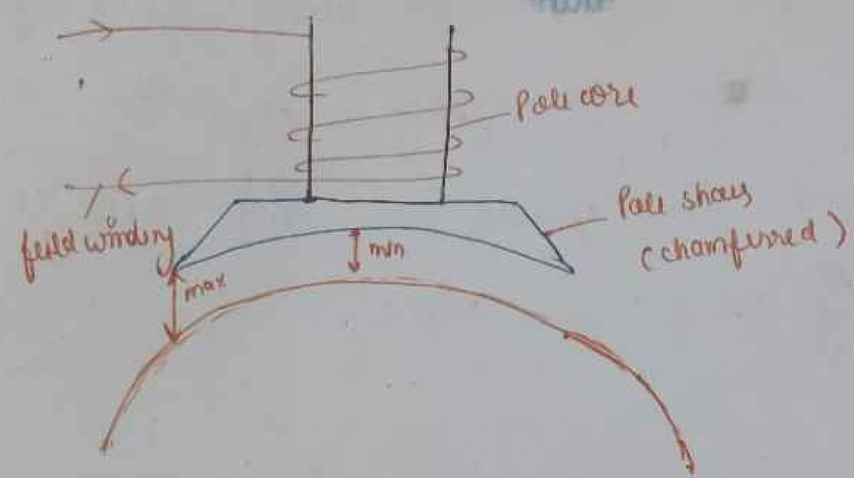
⇒ Armature handle flux ϕ_2.

$$\boxed{\text{speed}\uparrow (N) \propto \frac{1}{\text{flux}\downarrow}}$$

Pole core :-

→ Pole shoes are used to support the feild winding and these are chamferred. so, that flux distribution becomes uniform.

⇒ In modern D.C machine both pole core and pole shoes are ~~lamino~~ laminated to reduce eddy current losses.

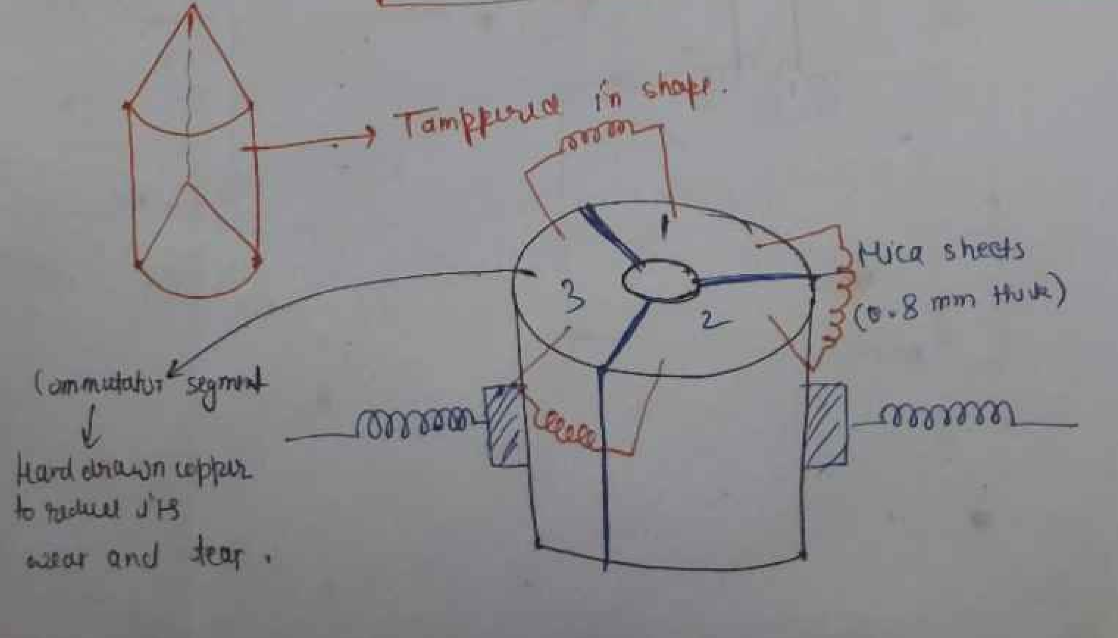


Commutator :-

It is a mechanical convertor, ~~used~~ it is used to convert AC ⟶ DC (Rectifier) in case of D.C generator. and used to convert DC ⟶ AC (invertor) in case of motor.

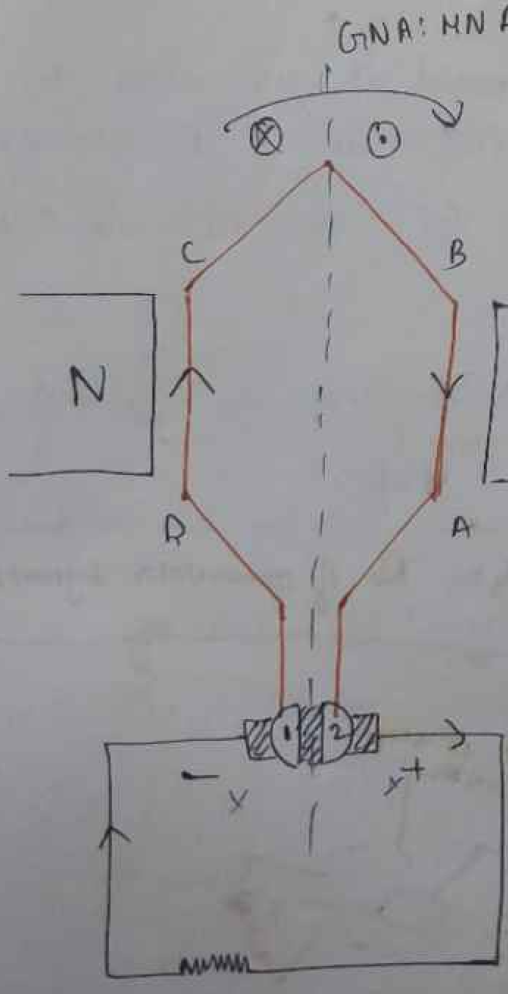
Commutator segments are tampered in shape so, that their assembly gives a circular shape.

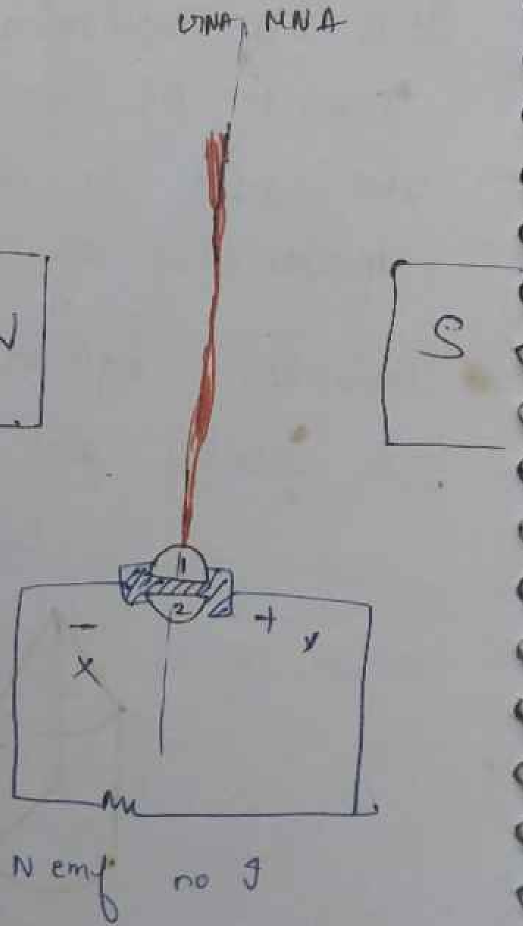
$\boxed{\text{No of coils} = \text{No of commutator segments}}$

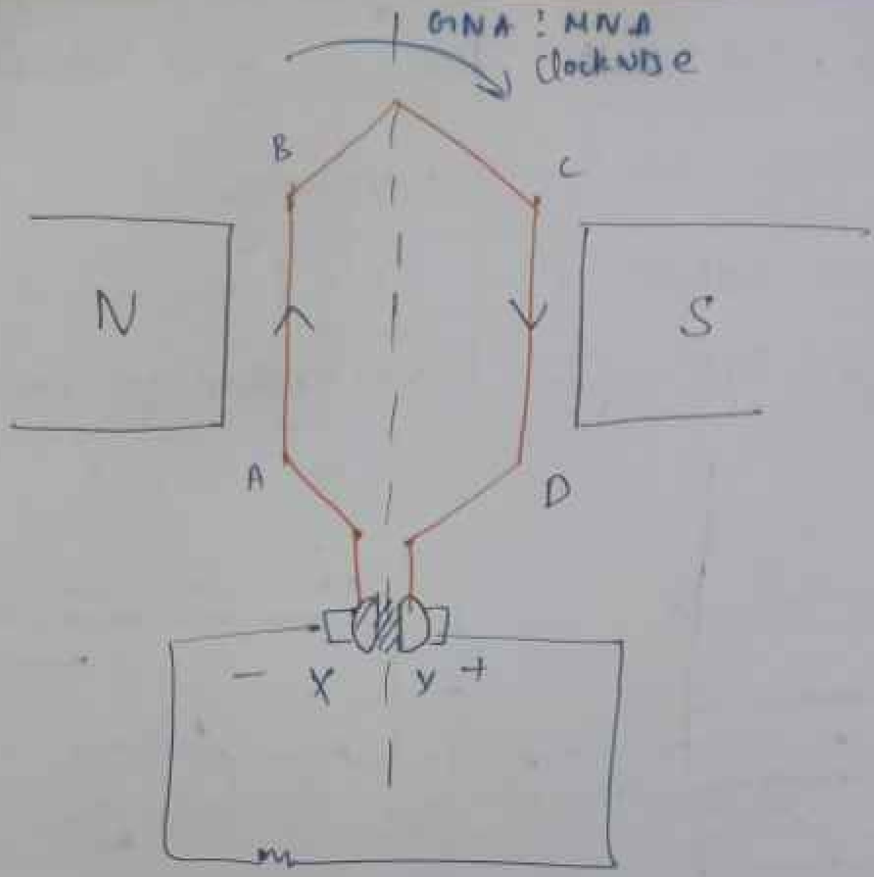


⇒ Brushes are stationary sliding contacts on commutator in order to supply or collect the current physically brush are placed on direct axis (N – S) axis but magnetically it is on MNA.

⇒ Commutator makes armature flux stationary and unidirectional electro magnetic torque.

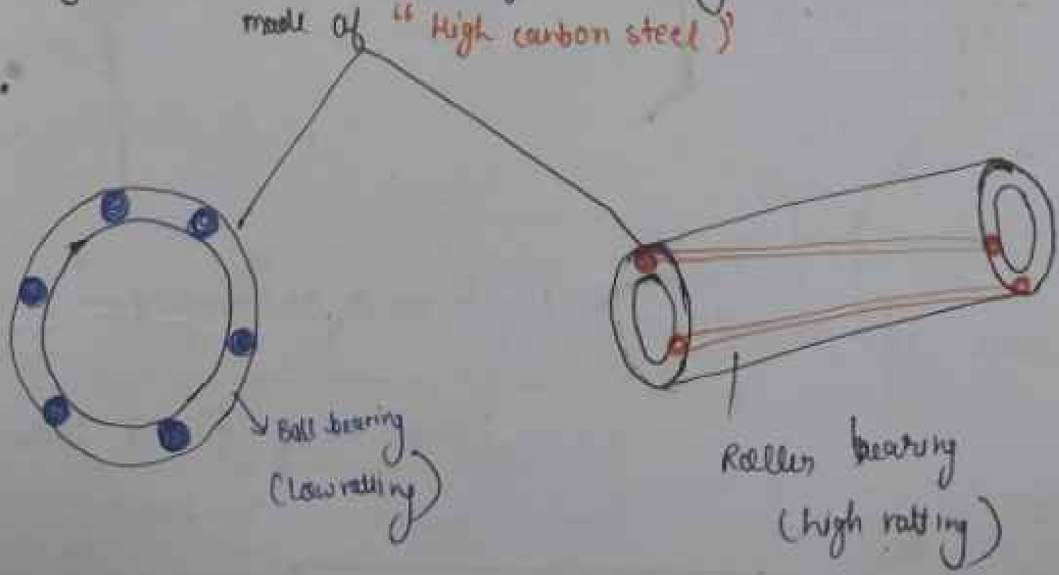






emf induced

④ Bearings :- Function of bearing is to reduce friction.



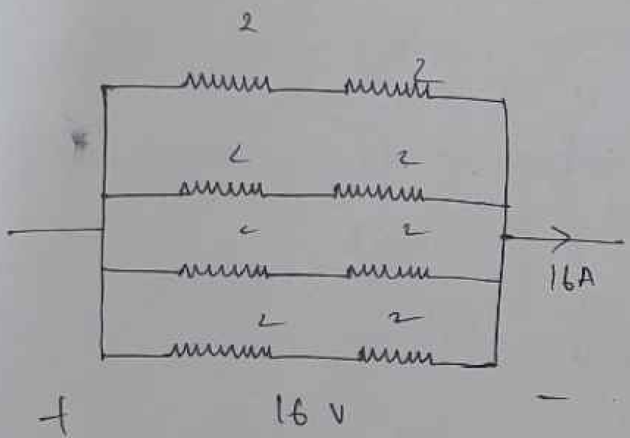
An Armature winding

~~Wave winding~~

Lap winding :-

Total no of parallel paths (A) = P

Preferred ~~for~~ for high current



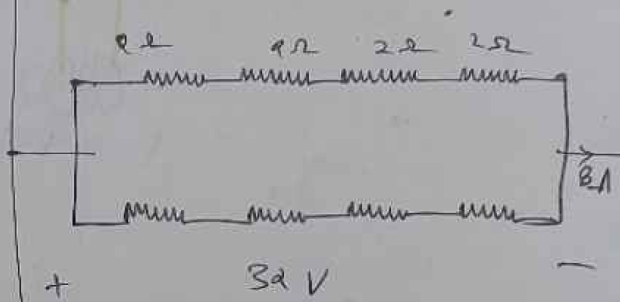
$R_a = 1\Omega$

$$\boxed{\begin{aligned} R_a &= \frac{2 \times 8}{(4)^2} \\ &= 1\Omega \end{aligned}}$$

Wave winding :-

A = 2

② Preffered for high voltage



$R_a = 4\Omega$

$$\boxed{\begin{aligned} R_a &= \frac{2 \times 8}{(2)^2} \\ R_a &= 4\Omega \end{aligned}}$$

$$\boxed{\text{Resistance of armature} = \frac{\text{Resistance of one conductor} \times \text{total no of cond r}}{(\text{total no of parallel paths})}}$$

$$\boxed{R_a = \frac{R_a \cdot Z}{A^2}}$$

165 (33)

$R_a = .05$, $A = 6$

$$\boxed{R_a = \frac{R.Z}{A^2}}$$

$R.Z = R_a \times A^2$

$R.Z = 36 \times .05$

$A = 2$,

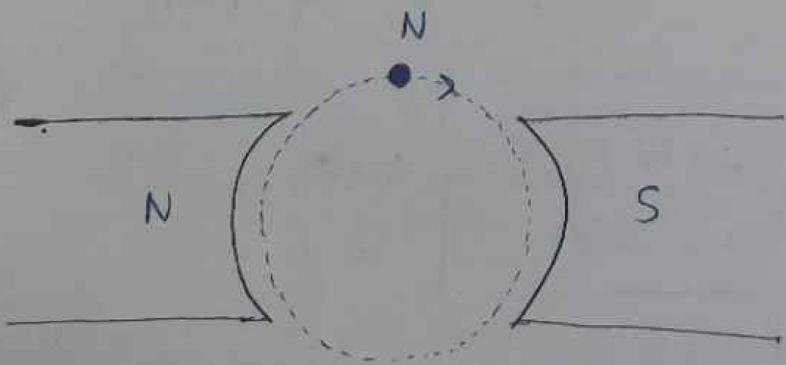
$R_a = \frac{36 \times .08}{4}$

$= \frac{\cancel{36}^{9} \times .08}{\cancel{4}}$

$$\boxed{R_a = .45}$$

Avg value of induced emf per conductor (E_Z)

$$\boxed{E_Z = \frac{\text{Flux cut by conductor in one rotation}}{\text{Time taken to complete one rotation}}}$$



N = speed of armature (RPM)

Z = total no of conductor

P = total no of poles

A = total no of parallel path

Rotation per minute = N

Rotation per sec = $\frac{N}{60}$

Time taken to complete one rotation = $\frac{60}{N}$ sec

Flux cut by conductor in 1 rotation = $P\phi$

$$\therefore \quad E_z = \frac{P\phi}{60/N}$$

$$\boxed{E_z = \frac{NP\phi}{60}}$$ by one conductor

So, total emf induced due to Z conductor

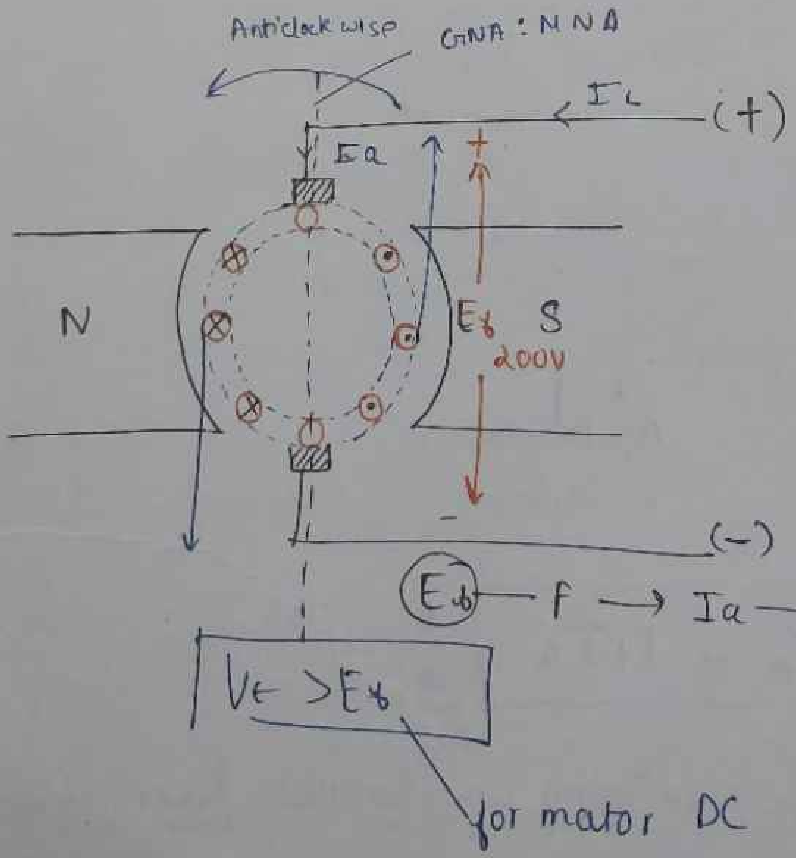
$$E_z' = \frac{NP\phi Z}{60}$$

So, avg emf induced per parallel path

$$\boxed{E_g = \frac{NP\phi Z}{60A}}$$ volt.

Back emf or counter emf :-

Without any opposition no energy conversion ~~on~~ in a D.C motor as the armature rotate, armature conductors cuts the magnetic feild and induc-es an emf. Since, induced emf opposes the supply voltage. So, it is called as back emf or counter emf.



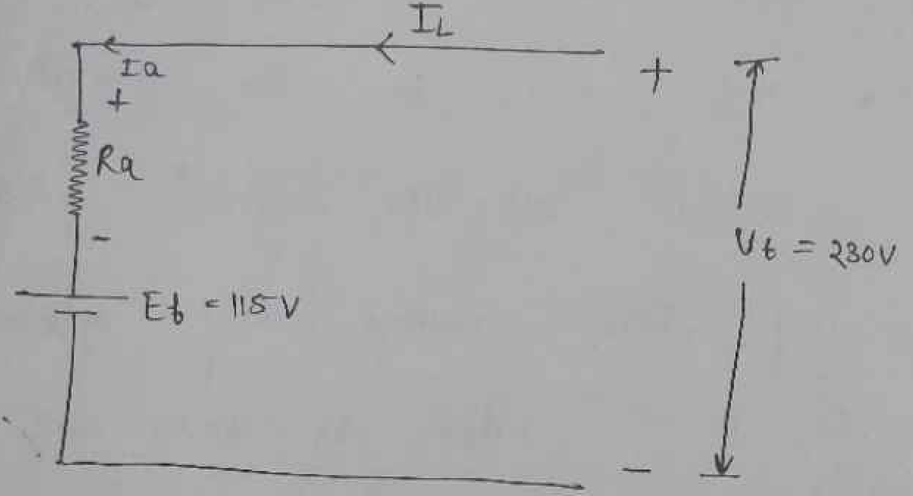
$E_b \rightarrow F \rightarrow I_a \rightarrow V_t$

$\boxed{V_t > E_b}$

for motor DC

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

Mechanical power developed in rotor :-



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

$$\boxed{\underbrace{V_t I_a}_{\text{input electrical power } (P_i)} = \underbrace{I_a^2 R_a}_{\text{Armature Cu losses}} + \underbrace{I_a E_b}_{P_m}}$$

$$\boxed{P_m = E_b I_a}$$ ##

Condition of maximum mechanical power developed :-

$$P_m = V_t I_a - I_a^2 R_a$$

$$\frac{dP_m}{dI_a} = V_t - 2 I_a R_a$$

$$\frac{dP_m}{dI_a} = 0, \quad \boxed{I_a R_a = \frac{V_t}{2}}$$

$$E_b = V_t - I_a R_a$$

$$E_b = V_t - \frac{V_t}{2}$$

$$\# \quad \boxed{E_b = \frac{V_t}{2}} \quad \#$$

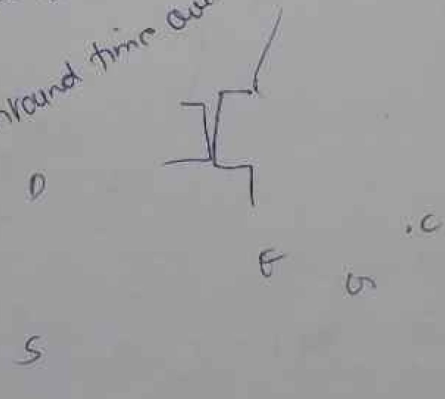
$$\boxed{P_{max} = \frac{V_t I_a}{2}}$$

(η) at Max power output :- (η)

$$\eta = \frac{P_{sh}}{P_{in}} = \frac{P_m}{P_{in}}$$

Insulated gate Bipolar transistor

Ground time overshoot



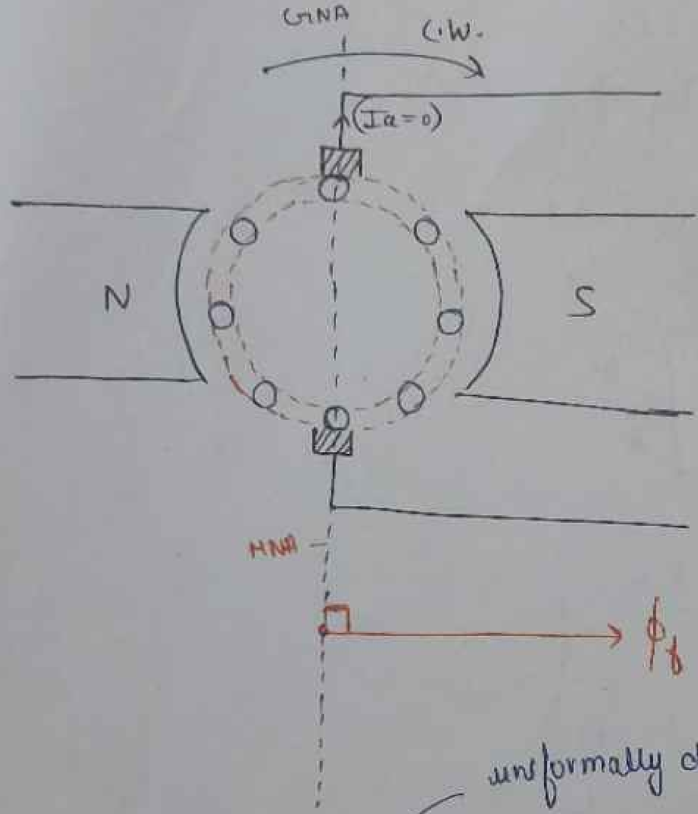
$$= \frac{\frac{\cancel{V_t I_a}}{2}}{\cancel{V_t I_a}} \times 100$$

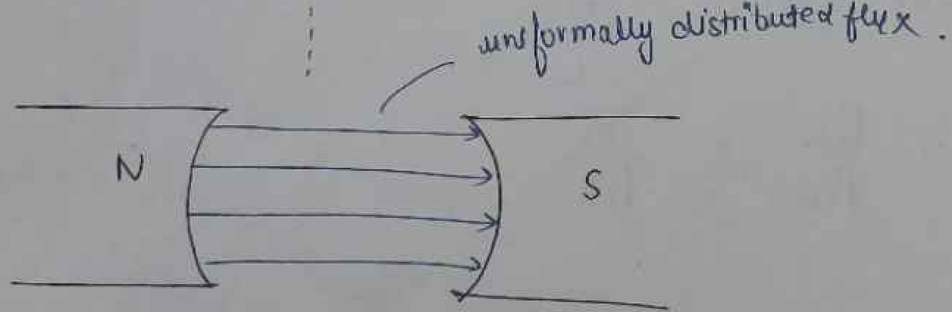
$$\boxed{\eta = 50\%}$$

$$\boxed{\eta = \frac{E_b I_a}{V_t I_a} \times 100 = \frac{E_b}{V_t} \times 100}$$

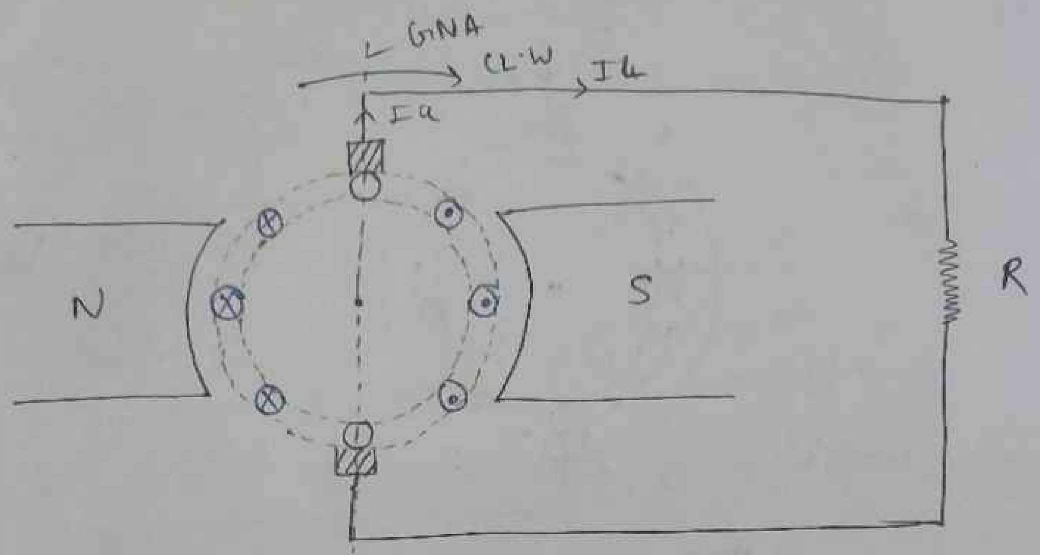
Armature reaction :-

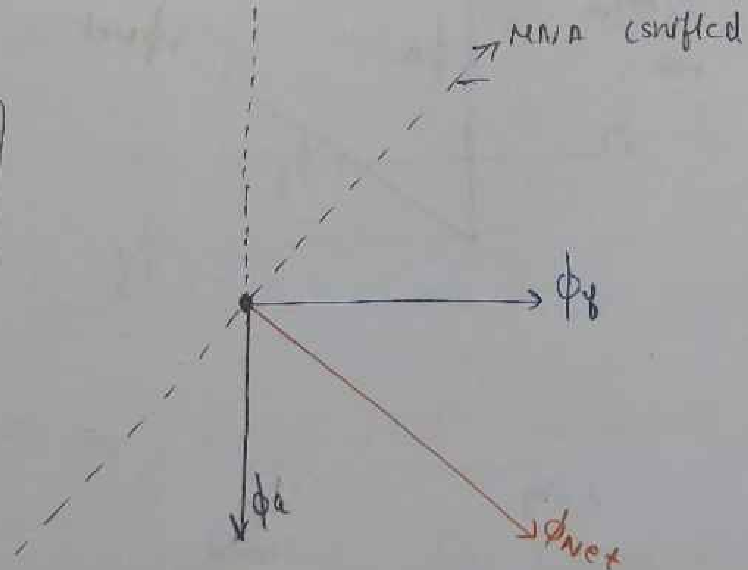
Generator at no-load :-



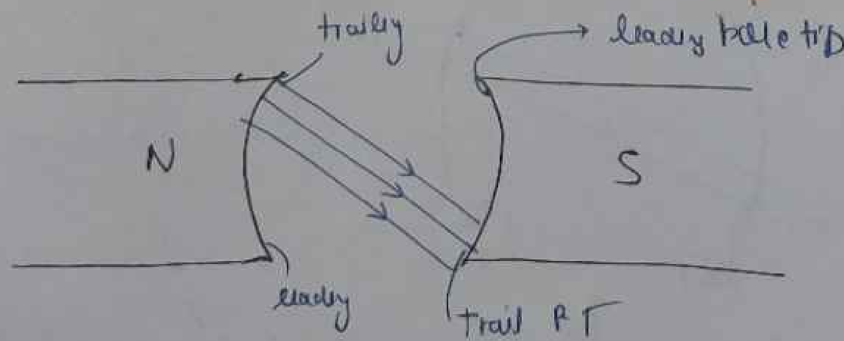


Generator at load :-





Determine ϕ_a by considering a turn



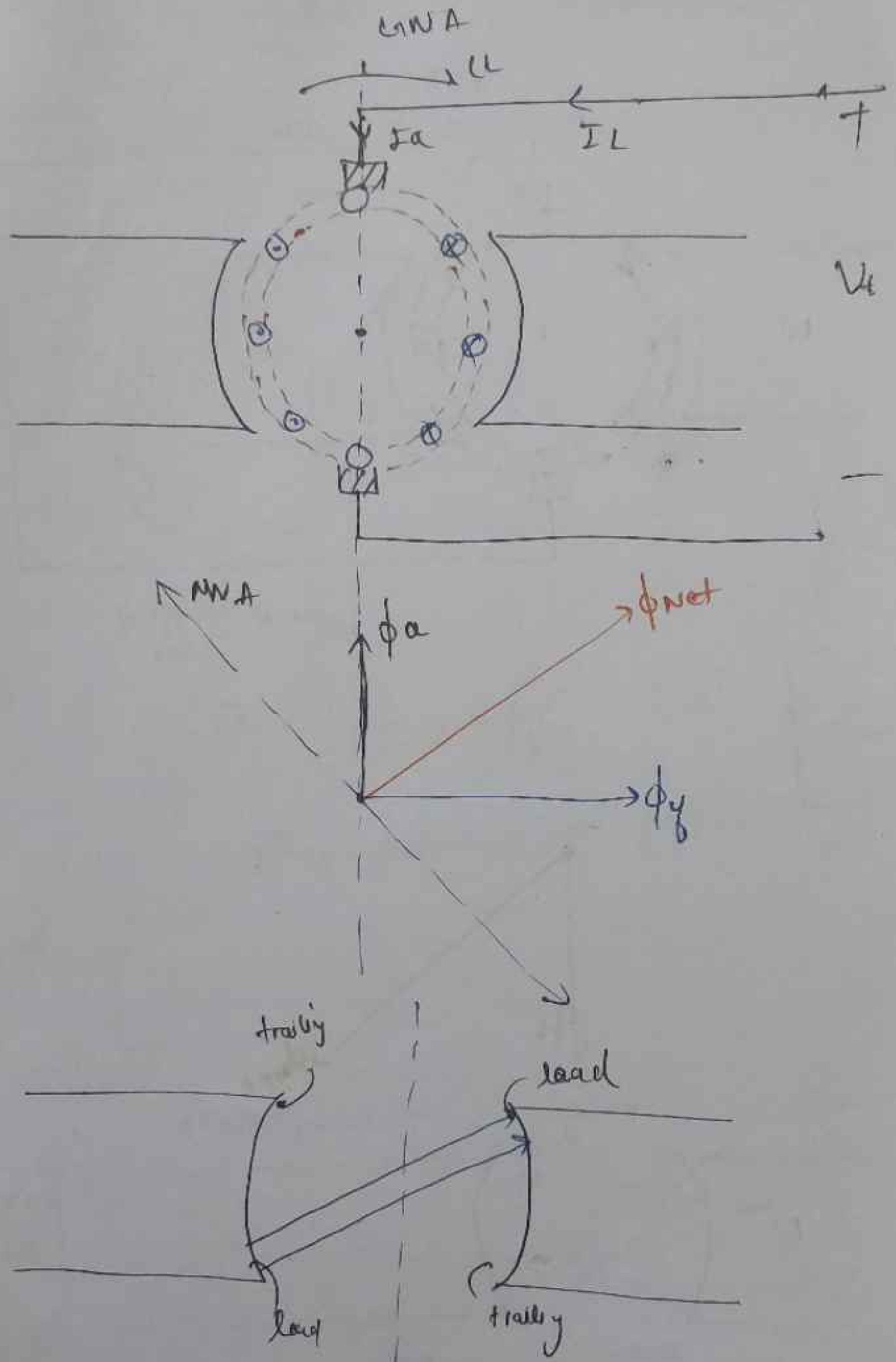
Rotation से ~~test~~ leading

\#

⇒ In case of D.C generator due to armature reaction MNA shift in the direction of generator rotation. so, to improve commutation brushes need to be forward shift (करते है).

⇒ Due to armature reaction in case of D.C generator net flux decreases on leading pole tip and ~~decreases~~ increases in trailing pole tip.

Motor



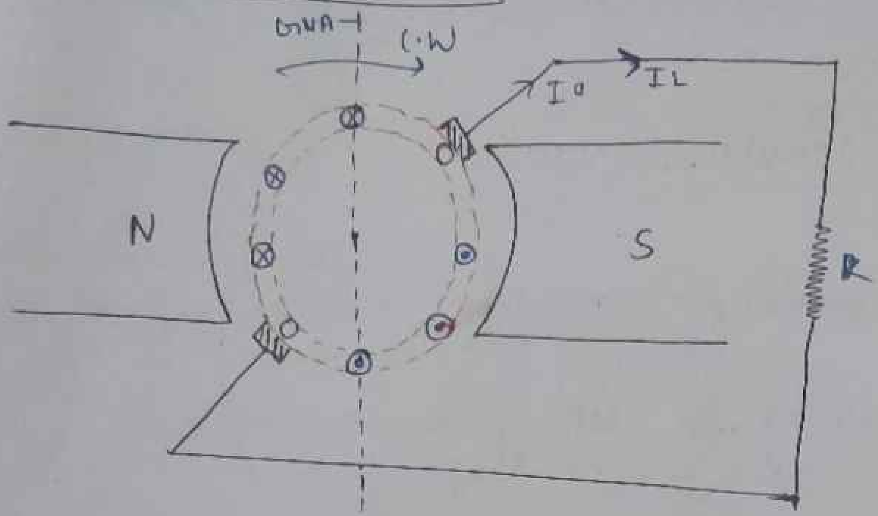
⇒ In case of D.C motor due to armature reaction MNA shift ~~or~~ in opposite direction of motor rotation so, to improve commutation brushes need to be backward shift and net flux decreases on trailing pole tip and increases on leading pole tip.

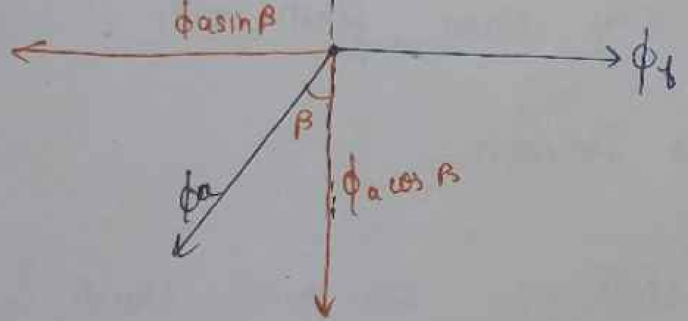
Effect of armature reaction :-

1. In D.C machine armature reaction effect is entirely cross magnetising. So, net flux gets distort.
2. Due to shifting of MNA their is a short circuit current which may cause flash over.
3. Net iron losses increases.

Effect of brush shifting :- Due to brush shifting armature flux having two component demagnetising and cross magnetising. So, due to brush shifting extra demagnetising effect occurs.

Generator at load :-

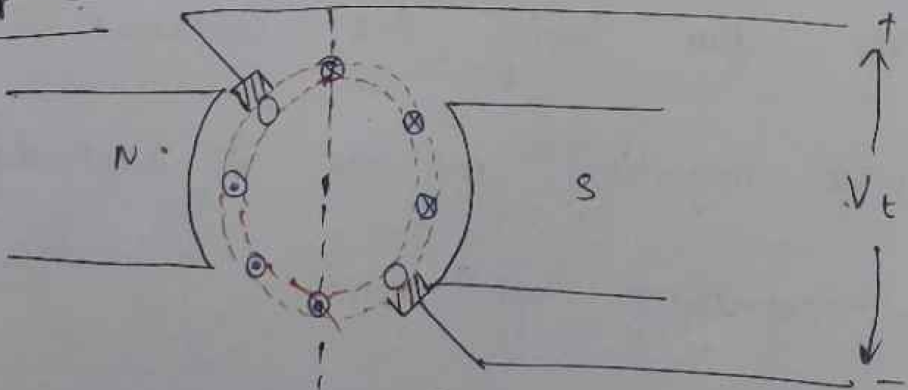


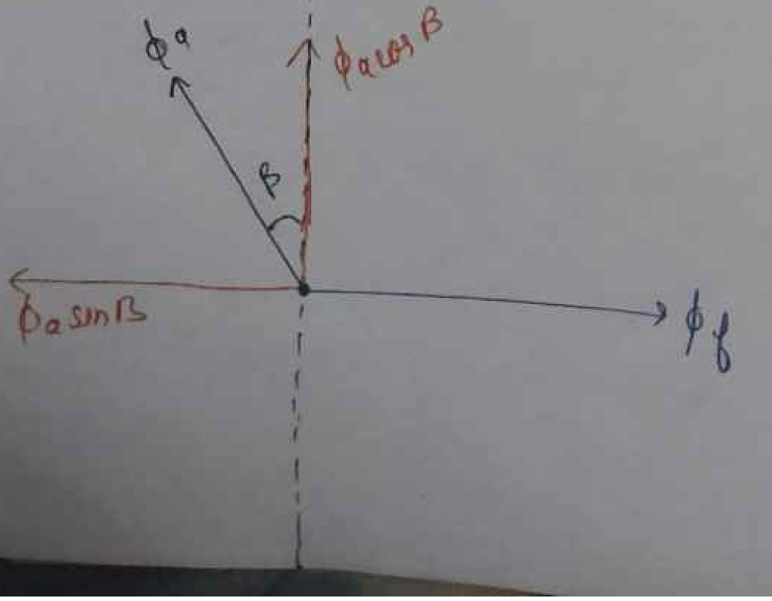


$\phi_d = \phi_a \sin\beta$

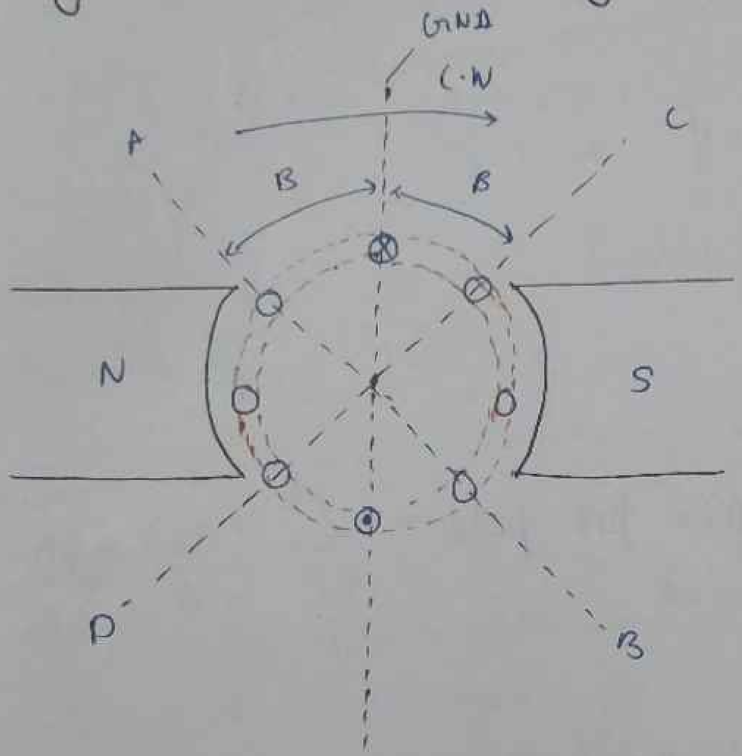
$\phi_c = \phi_a \cos\beta$

Motor :-





Demagnetising and cross magnetising amperes turns :-



~~Degn~~ Demagnetising conductor spread on 4β out of $360°$.

'X' magnetising conductor spread on $(360° - 4\beta)$ out of $360°$

I_c = conductor current.

$$\boxed{I_c = \frac{I_a}{A}}$$

conductors per pole = $\frac{Z}{P}$

Turns per pole = $\frac{Z}{2P}$

ATs per pole = $\frac{Z}{2P} \times \frac{I_a}{A}$ (or for $180°$ electrical)

For $180°$ = $\frac{Z}{2P} \times \frac{I_a}{A}$

$$1^\circ = \frac{Z}{2P} \times \frac{I_a}{A(180^\circ)}$$ in 180° electrical

$$2B = \frac{Z}{2P} \times \frac{I_a(2B)}{A(180^\circ)}$$ 2B conns

for 4B in 360° electrical $= \frac{Z}{2P} \frac{4B}{360^\circ}$

$$\boxed{\text{Demagnetising ATs per pole} = \frac{Z}{2P} \times \frac{I_a}{A} \times \frac{4\beta}{360^\circ}}$$

$$\boxed{\text{'X' } \cancel{\text{mg}} \text{ magnetising ATs per pole} = \frac{Z}{2P} \frac{I_a}{A} \frac{(360^\circ - 4B)}{360^\circ}}$$

β = Brushes shifted by β angle (electrical)

Methods to reduce armature reaction :-

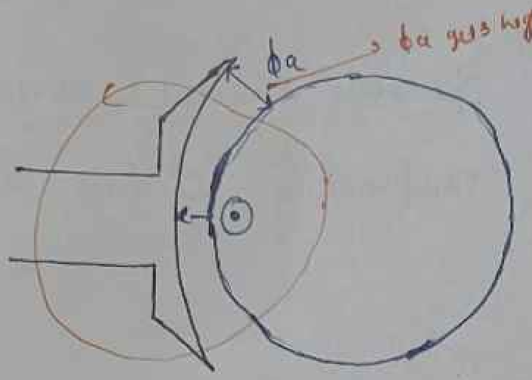
$$\boxed{\downarrow \phi_a = \frac{T_s I_a}{S \uparrow}}$$ T_s = Turns.

Armature reaction can be decreased by increasing reluctance of ϕ_a

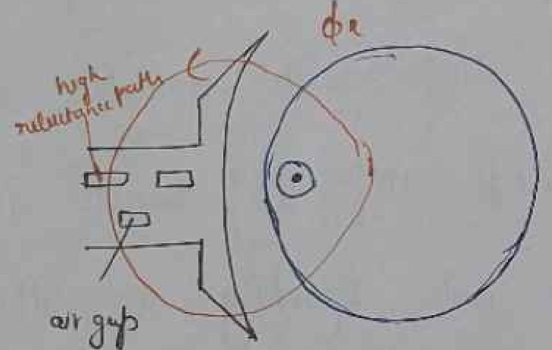
(1) By using chamferred pole shoes with high

reluctance pole tip.

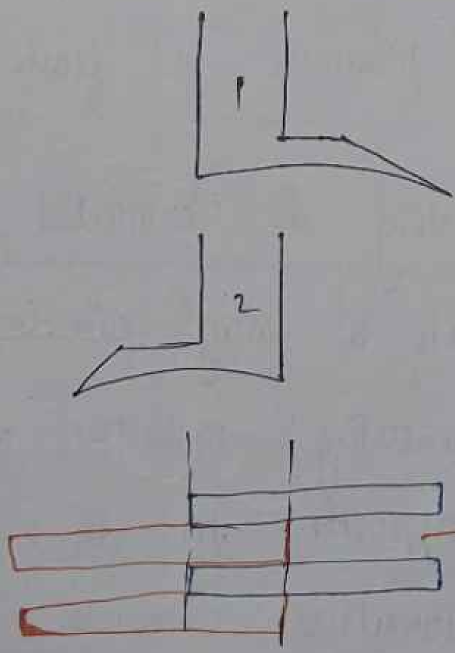
(1)



(2)



(3)



These two techniques also reduces main flux. so, used for small ratting machines.

Compensating coil:-

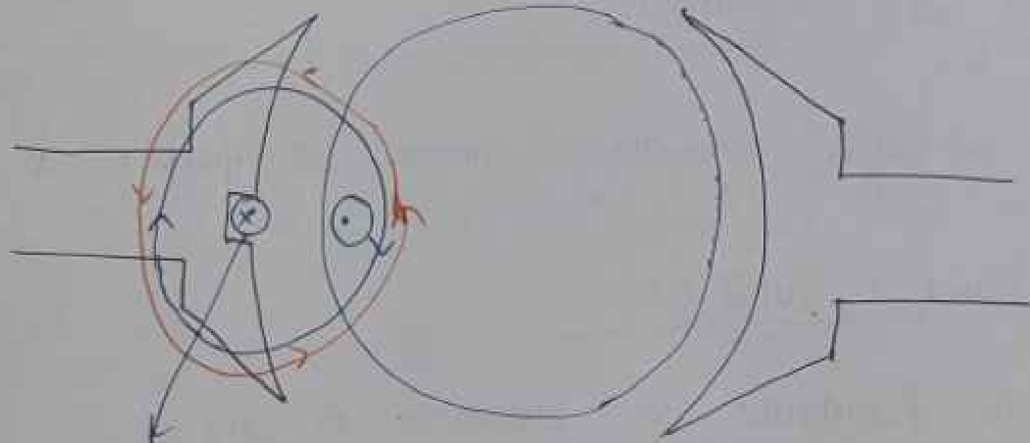
⇒ In large ratting machine operating under varying load condition at high speed compensating windings are essential.

⇒ As load varies armature current also vary. So, flux also varry and it link with armature conductor and induces statically induced emf it results in unbalance circulating curret and sparking at the brushes. But due to high speed this spark will spread on commutator surface and produces a flash over.

⇒ The compensating winding is connected in series with armature in such a way direction of current threw compensating conductor in any pole phase will be opposite to direction of current threw adjacent armature conductor.

⇒ Compensating winding is provided in pole shoes cutting it into teeth.

⇒ The compensating winding flux will neutralize armature flux under pole. So, that armature reaction effect is removed & it both MNA and GNA becomes coin sides.



compensation coil.

$$\boxed{\phi_{net} = \phi_f + \phi_a + \phi_c}$$

$\therefore$ $\boxed{\underset{must}{\phi_c} = -\phi_a}$

Commutation :-

→ The reversal of current in a coil when its commutator segments passes by brush is known as commutation.

⇒ The time taken for a brush to span from 1 segment to another segment is known as commutation time T_c.

⇒ If current in the coil under going commutation reverses completely with in commutating time then commutation is successful and it is called as linear or ideal commutation.

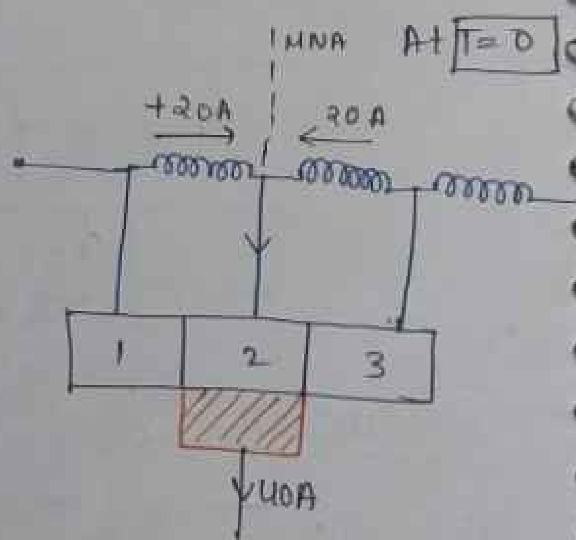
⇒ Successful commutation means no sparking at the brushes.

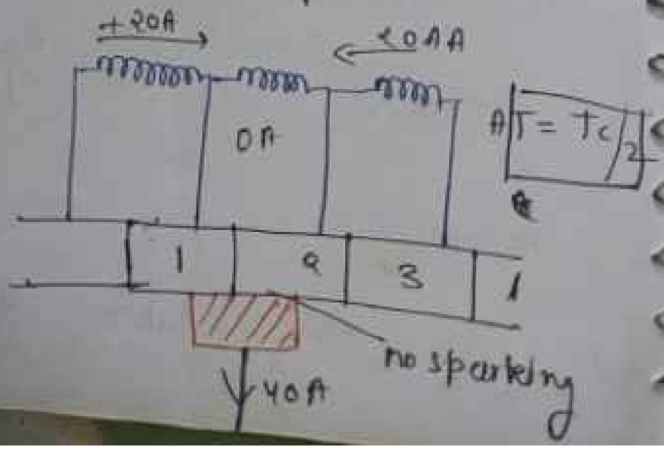
Case-1 Ideal case :-

The inductance of armature is zero.

$$\boxed{L_a = \frac{N^2}{S}}$$

but $\boxed{L_a \approx 0}$





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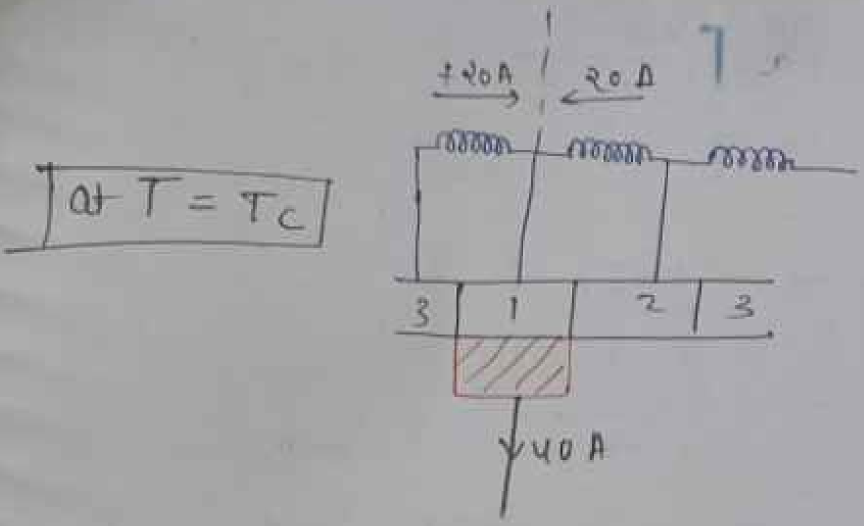


Case - 2 :- Practically if current in the coil under going commutation ~~is no~~ does not reverses with in commutating time, then it is known as non-linear or delay commutation and a spark is produce at trailing edge of ~~..~~ brush.

The change in current is opposed by reactance ~~voltage~~ voltage. Therefore any unchanged current will jump into air and produces a spark.

The ~~ind~~ inductance of ~~armat~~ armature is Non ≠ 0 ~~zero~~

$$L_a = \frac{T_s^2}{S}$$

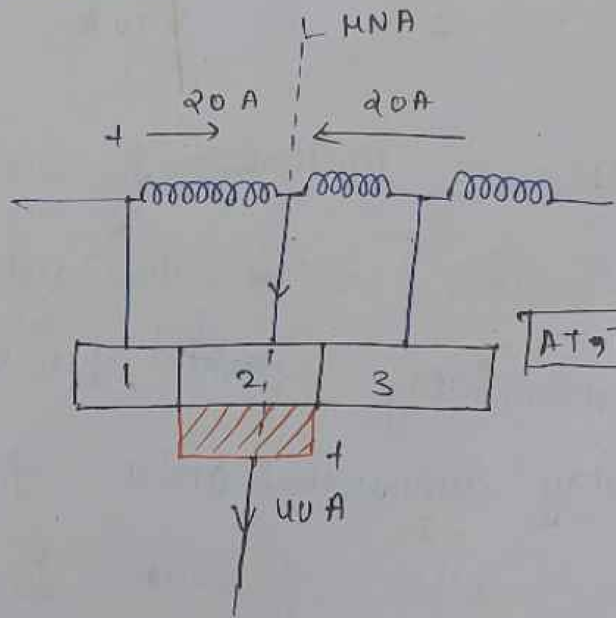
$$e = -L_a \frac{dI_c}{dt}$$

reactance voltage

$$e = -L_a\left[\frac{-I_c - I_c}{T_c}\right]$$

$$\boxed{\downarrow e = \frac{2 L_a I_c}{T_c \uparrow}}$$

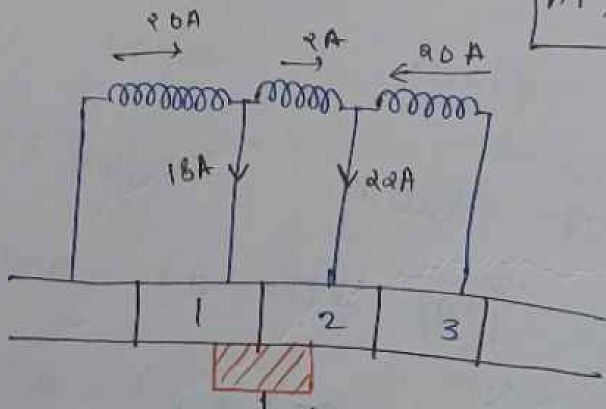
1-



$\boxed{At,\ T = 0}$

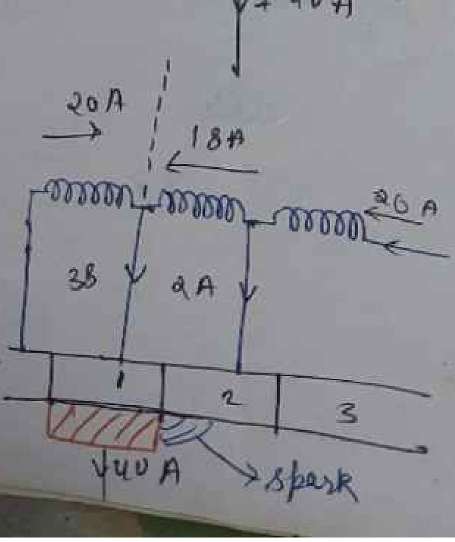
2-

$\boxed{At,\ T = \frac{T_c}{2}}$

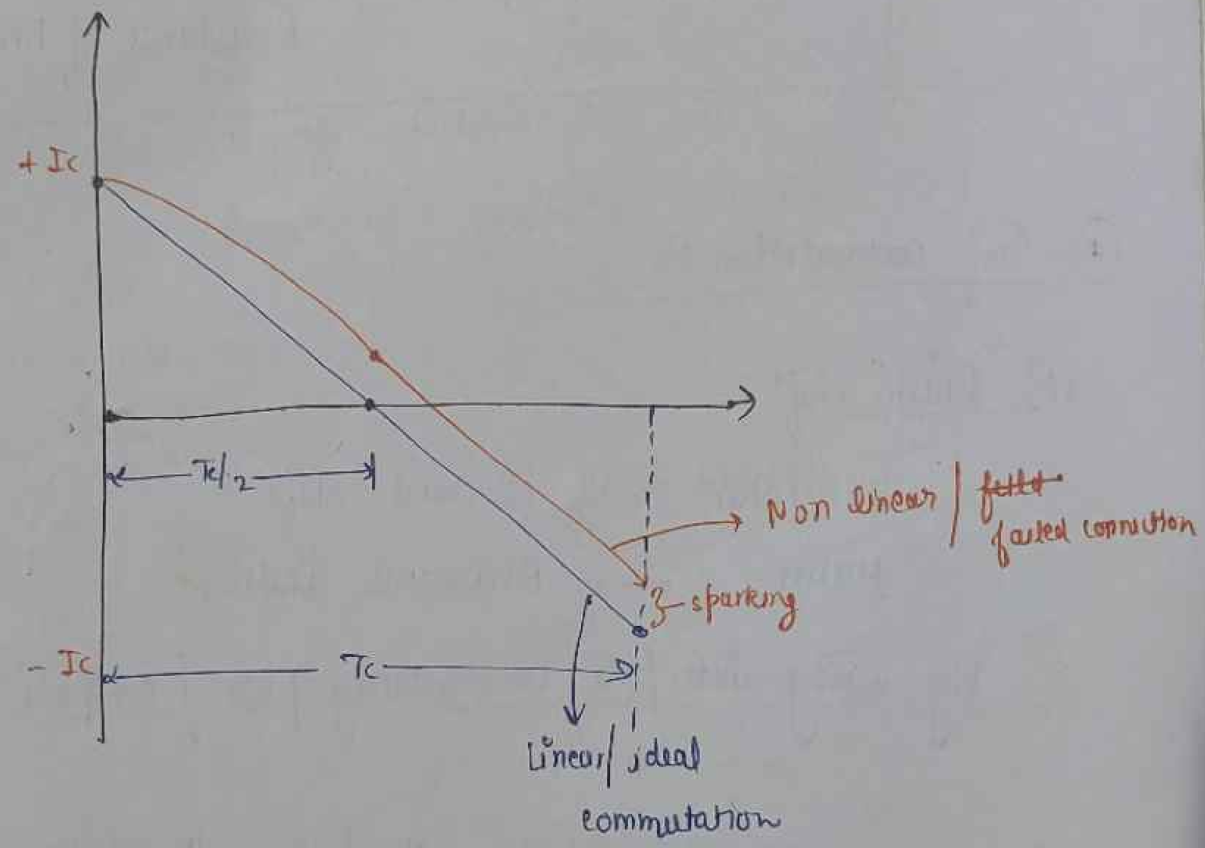


3-

$\boxed{At,\ T = T_c}$



Brush width = (2 to 3) commutator seg.



Methods to improve commutation :-

① Resistance commutation :- High resistance carbon brushes are used to improve commutation. It does not eliminate the spark but reduces its intensity and improve commutation.

⇒

⇒ Since it is a soft material. So, offer self lubricating property but disadvantage due to high brush contact drop.

$$\boxed{\downarrow \text{Intensity of spark} \propto \frac{1}{\text{Resistance of Brush} \uparrow}}$$

② Emf commutation :-

Ⓐ Brush shift :-

Generator → forward shift

Motor ⟶ Backward shift.

Ⓑ By using interpole / commutating pole / compole :-

→ Interpoles are small pole compare to main pole. located in inter polar region. Interpole windings are also connected in series with armature winding.

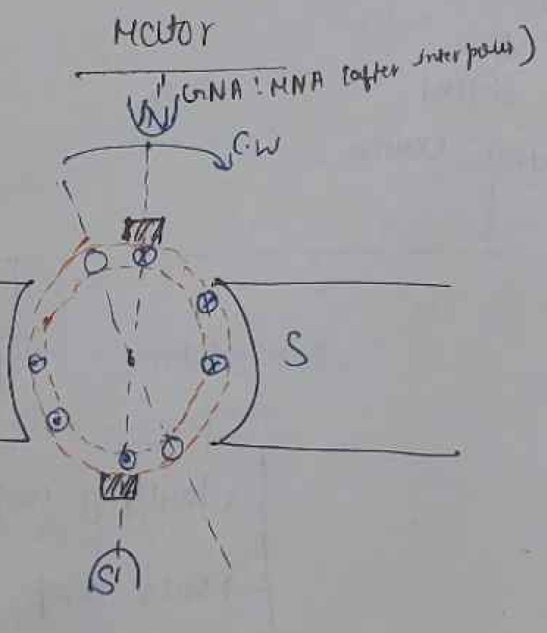
→ Interpoles are champhered or tampered in shape with more air gap. So, that they does not saturate easily

$$\boxed{\phi = \frac{NI}{S}}$$

for const flux if $S\uparrow$ ∴ more I can be applied

⇒ Inter poles are used to nutralized reactance voltage in the coil undergoing commutation by providing commutating flux or counter flux.

⇒ Polarity of Interpole should be equal to polarity of pole ~~ad~~ ahead of generator rotation and behind of motor rotation.



Interpole polarity is decided by पीछे का पोल in direction of rotation of motor

Interpole polarity is decided by आगे का पोल in direction of rotation of motor

S 6

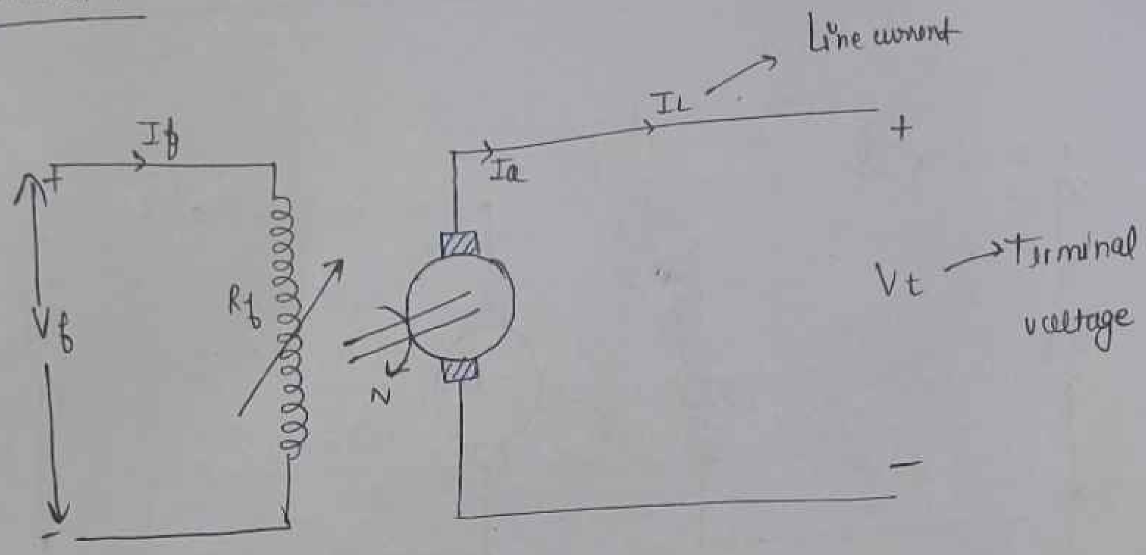
Types of D.C Machines

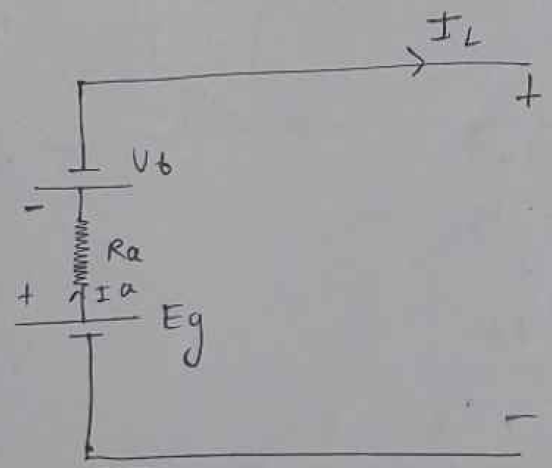
- Seperately excited D.C M/C
- Self excited D.C M/C
  - Compound M/C
    - ~~Short~~ & Long shunt compound wound
      - Differential comp
      - Cummulative comp
        - level/Flat comp
        - over comp
        - under comp
    - short shunt compound wound
      - Differential comp
      - Cummulative comp
        - level/flat Comp
        - Over Comp
        - Under Comp
  - D.C shunt M/C
  - ~~Com~~ D.C Series M/C

(1) Seperately excited D.C machines :-

Both armature and field windings ~~as~~ are electrically isolated

Generator :-





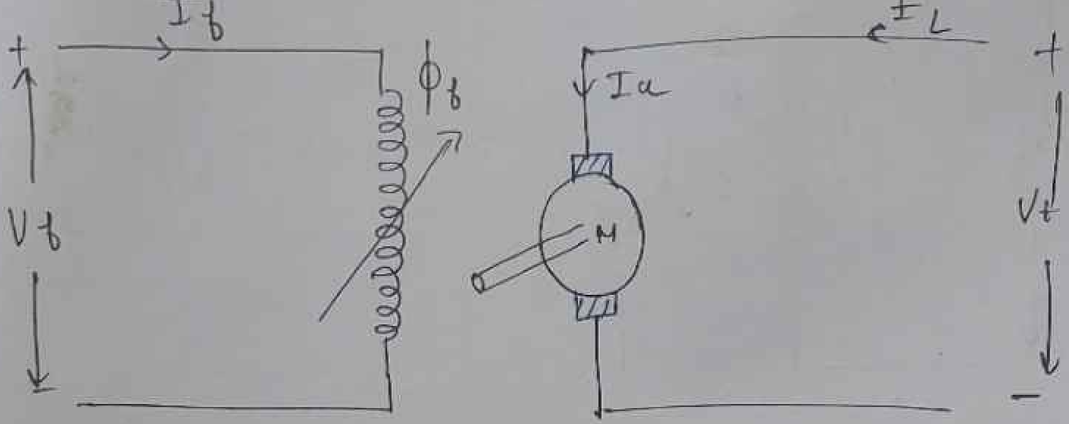
V_b = Brush contact drop

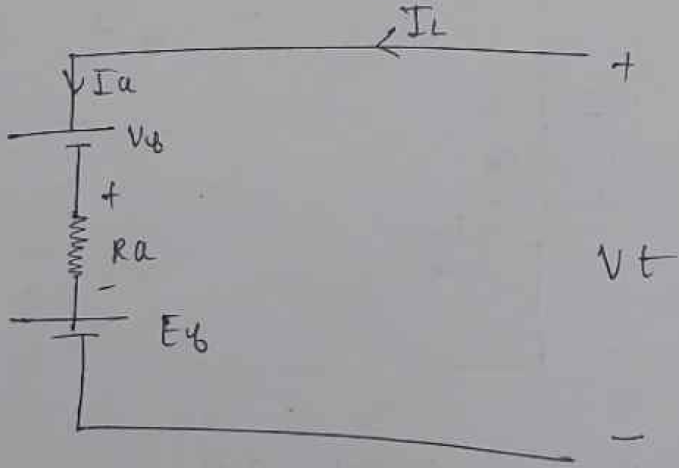
V_b = 1V - 2V Per brush

$$\boxed{E_g = I_a R_a + V_b + V_t}$$

$$\boxed{E_g > V_t}$$

Motor :-





~~$V_t > E_g$~~

$$\boxed{V_t > E_b}$$

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

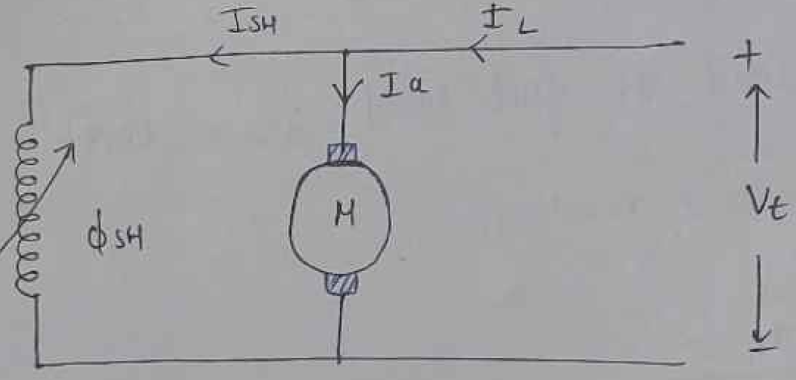
Self excited :-

Both armature and field winding are electrically connected.

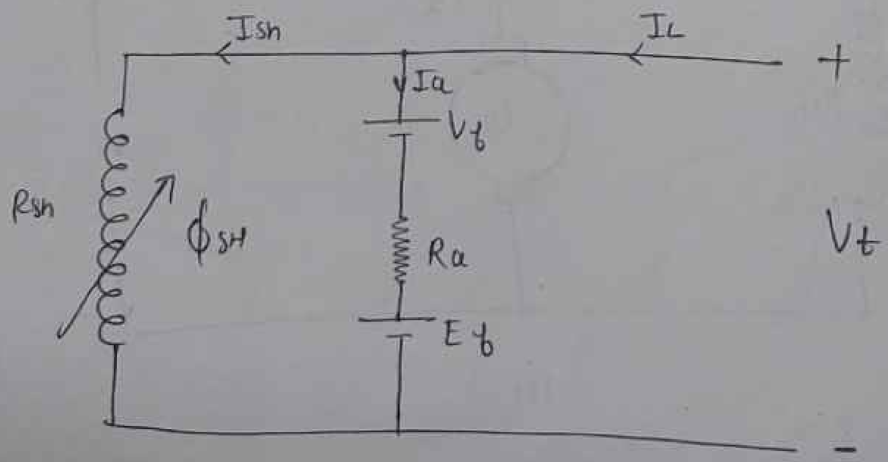
(1) D.C shunt Machine :-

Feild winding is in parallel with armature :-

Motor :-



($\uparrow R_{sh}$)
↓
($T_s \uparrow$, thinwire)
Turns



$$\boxed{I_L = I_{SH} + I_a}$$

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

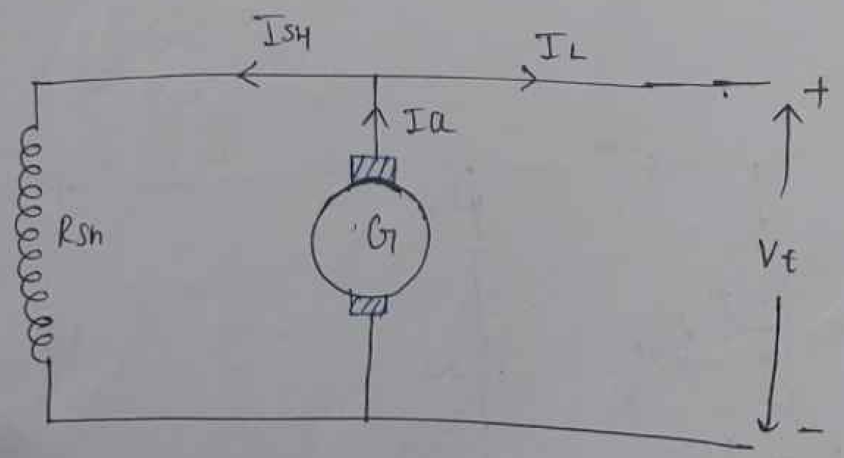
$$V_t = I_{SH} R_{SH}$$

$$\boxed{I_{SH} = \frac{V_t}{R_{SH}}}$$

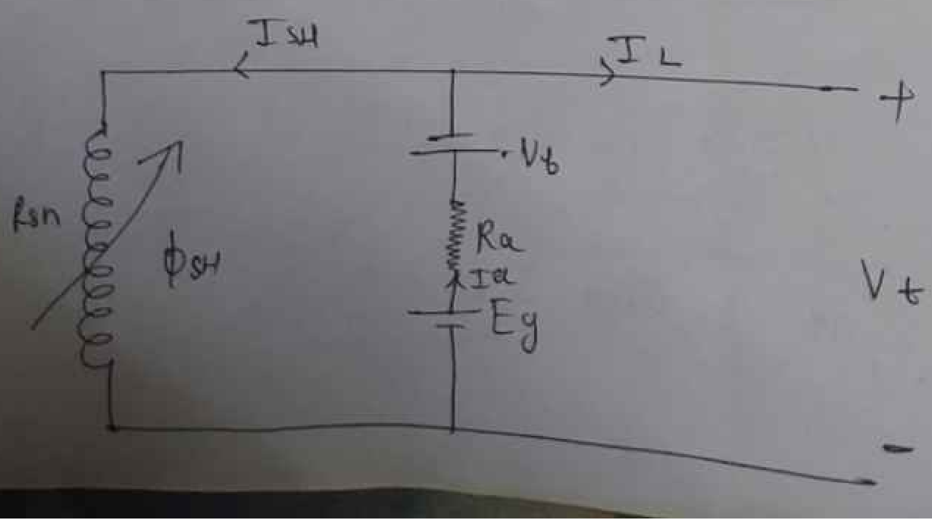
$$\boxed{\phi_{sh} \propto I_{SH} = \frac{V_t}{R_{SH}}}$$

from no load to full load ϕ_{SH} = const without armature reaction

<u>Generator :-</u>



|||



$$\boxed{V_t = I_{SH} R_{SH}}$$

$$\boxed{E_g = I_a R_a + V_t + V_t}$$

$$\boxed{I_a = I_{SH} + I_L}$$

D.C Machine :-

(1) **Front pitch :-** Distance b/w last conductor of I coil and I conductor of second coil.

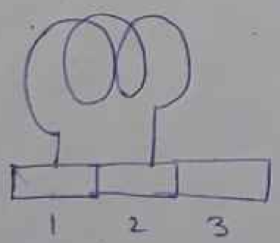
(2) **Back-pitch :-** Distance b/w first and last conductor of same coil

(3) **Average pitch :-**

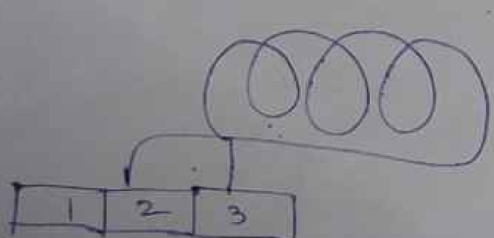
$$\frac{Y_F + Y_B}{2}$$

(4) **Resultant pitch :-** Distance b/w conductors of two consecutive coils

(5) **Progressive winding :-** If coil goes forward called Progressive i.e last conductor connected to next commutator segment.

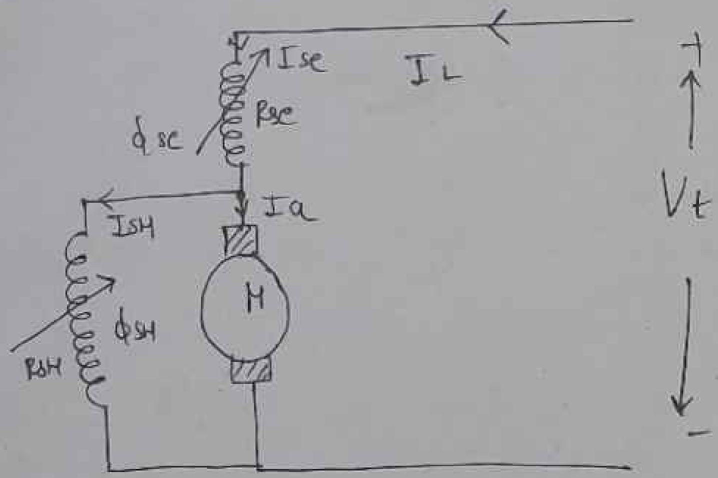


(6) **Retrogressive winding :-** If coil goes backward is called retrogressive winding. i.e last conductor connected to previous segment.



D.C compound :-

short shunt compound wound :-



$$\boxed{V_t = I_{se}R_{se} + V_b + I_aR_a + E_b}$$

$$\boxed{I_{sh} R_{SH} = V_b + I_aR_a + E_b}$$

$$\boxed{I_L = I_{se} = I_{SH} + I_a}$$

Cummulative :-

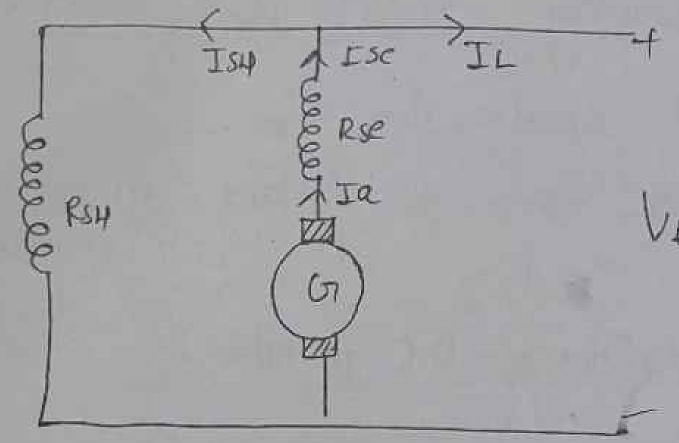
$$\boxed{\phi_{Net} = \phi_{SH} + \phi_{se}}$$

differentially :-

$$\boxed{\phi_{net} = \phi_{SH} - \phi_{se}}$$

$$\boxed{\phi_{SH} > \phi_{se}}$$

Long shunt compound wound :-



$$\boxed{E_g = I_aR_a + V_b + I_{se}R_{se} + V_t}$$

$$\boxed{V_t = I_{SH} \cdot R_{SH}}$$

$$\boxed{I_a = I_{se} = I_{SH} + I_L}$$

Rarely used D.C machine

Result :-

① During short circuit of differentially compound D.C generator $V_t = 0$, $\phi_{se}\uparrow$, $\downarrow\phi_{net} = \phi_{sh} - \phi_{se}\uparrow$, $E_g\downarrow$, $I_{se}\downarrow$. So, does not damage during S.C. So, these are used in arc welding.

② When starting a differentially connected compound motor it is desireable to short circuit the series field winding to avoid the motor from starting in reverse direction.

Procedure :- at starting $N=0$, $I_{se}\uparrow$, $\phi_{se}\uparrow$,

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

$\phi_{net} < 0$, so, start, in -ive direction (reverse)

Operating characteristics of D.C generator :-

$$\boxed{N, E_g, I_f, V_t, I_L}$$

① Open circuit characteristics / saturation curve / magnetisation curve

E_g v/s I_f , $N =$ const, at $=$ No load.

② External characteristics

V_t v/s I_L , $N =$ const, $I_f =$ constant.

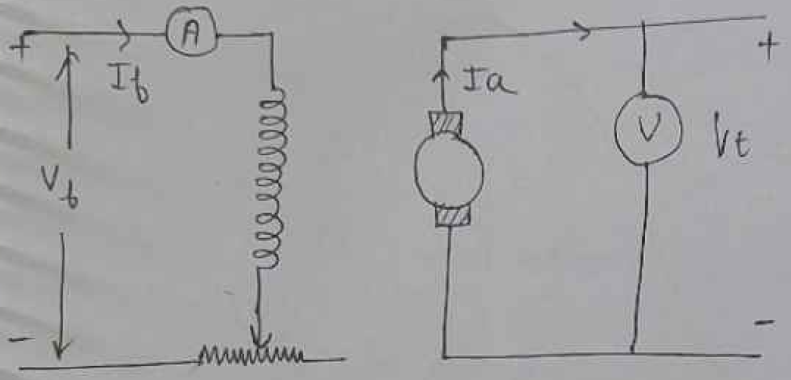
③ Armature / regulation curve :-

I_a v/s I_f , $N =$ constant, $V_t =$ constant.

④ Load curve :-

V_t v/s I_f $N =$ constant
$I_a =$ constant

Seperately excited D.C generator :-



Concept
① **A.C machine** : BH curve area ↓ $\{\phi_{residual} \downarrow\downarrow\downarrow \approx 0\}$, saturation neglected
② **D.C Machine** B-H curve area ↑ $\phi_{resi} \uparrow\uparrow\uparrow$, saturation included

at no load $I_a = I_L = 0$

$$E_g = V_t + I_a R_a + V_b$$

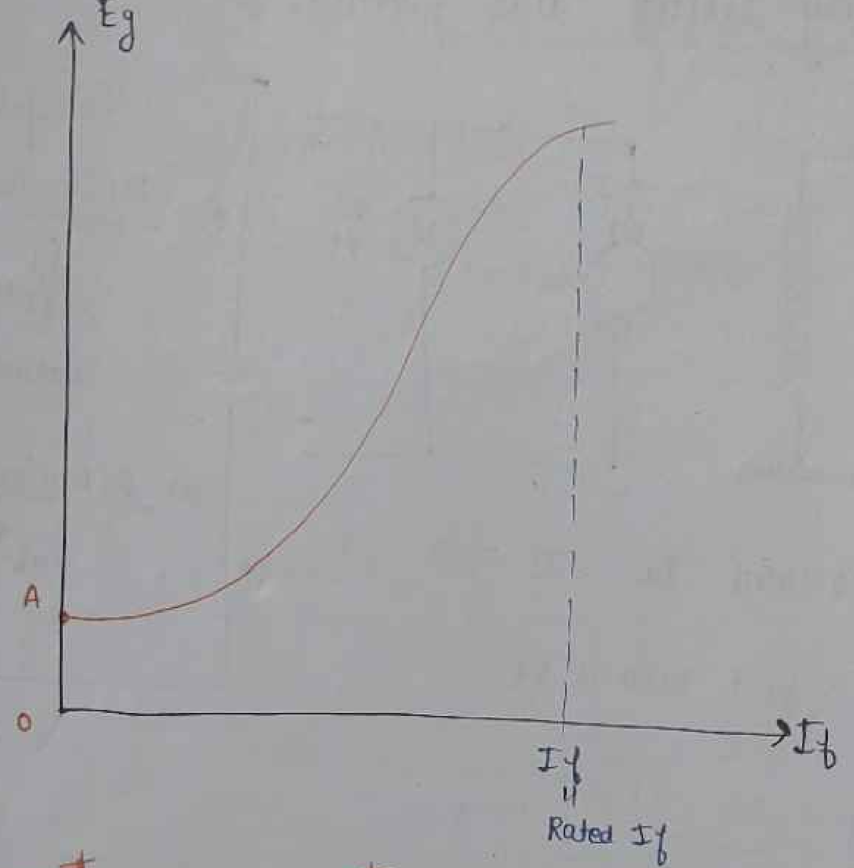
$$\boxed{E_g = V_t = (V)}$$ voltmeter reading

$$E_g = \frac{NP\phi Z}{60 A}$$

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

$\phi \propto I_f$
→ without saturation: air gap line to inplead core (linearnar)
→ with saturation B-H curve (Non linear .

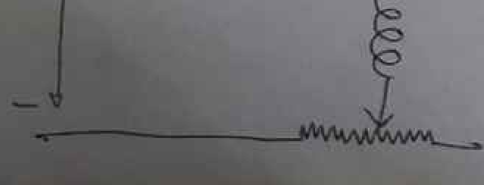
$$\boxed{E_g \propto I_f} \longrightarrow \text{BH curve}$$

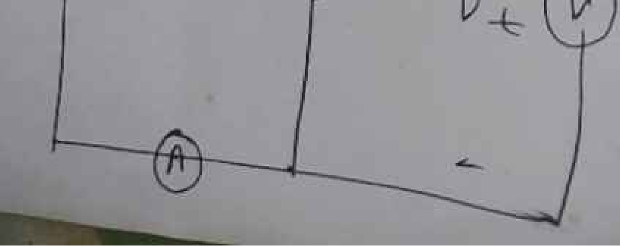


OA = Induced emf due to residual flux

2V — 4V or minimum.

Ⓑ <u>Load characteristics :-</u>



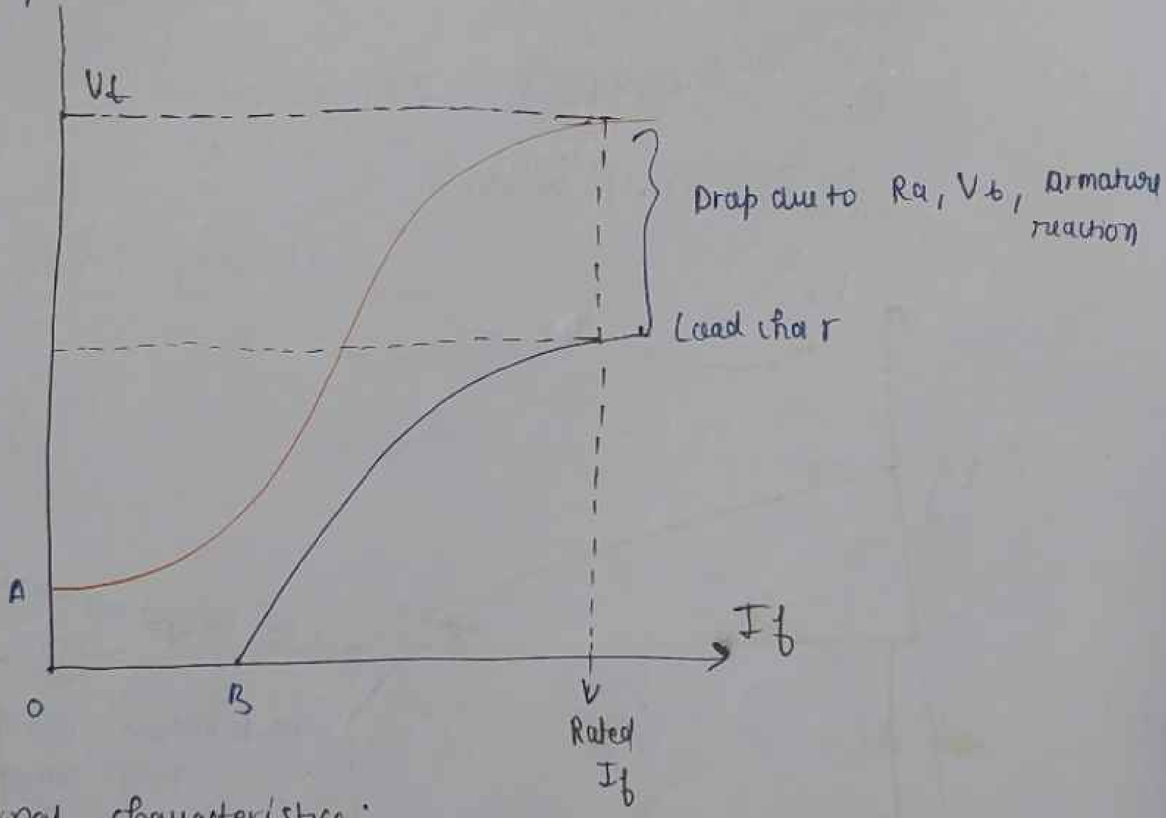


$\boxed{V_t \text{ v/s } I_f}$, $N =$ constant

$I_a =$ constant (Rated)

$E_g = V_t + I_a R_a + V_b$

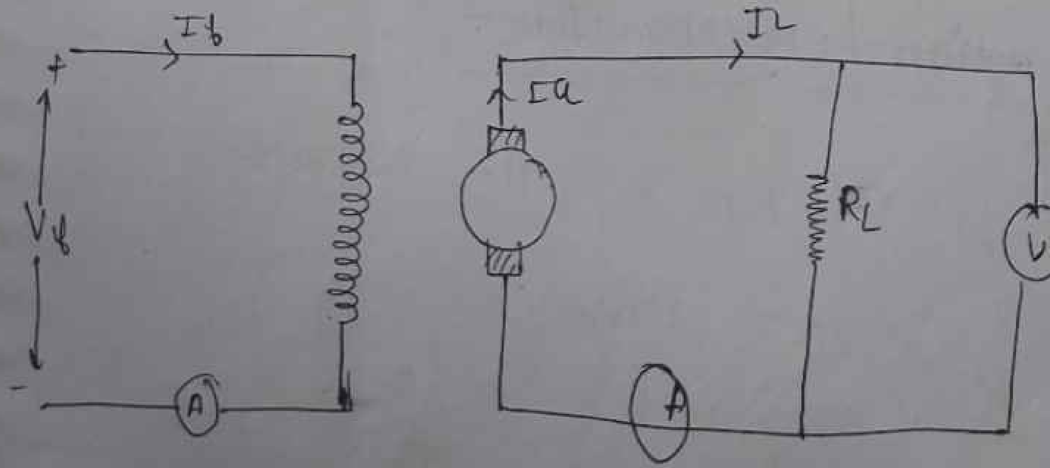
$$\boxed{V_t = V = E_g - (I_a R_a + V_b)}$$



Ⓒ External characteristics :-

V_t v/s I_L, $N =$ Const

$I_f =$ const



$$\boxed{V_t = E_g - (I_L R_a + V_b + \text{Armature reaction})}$$

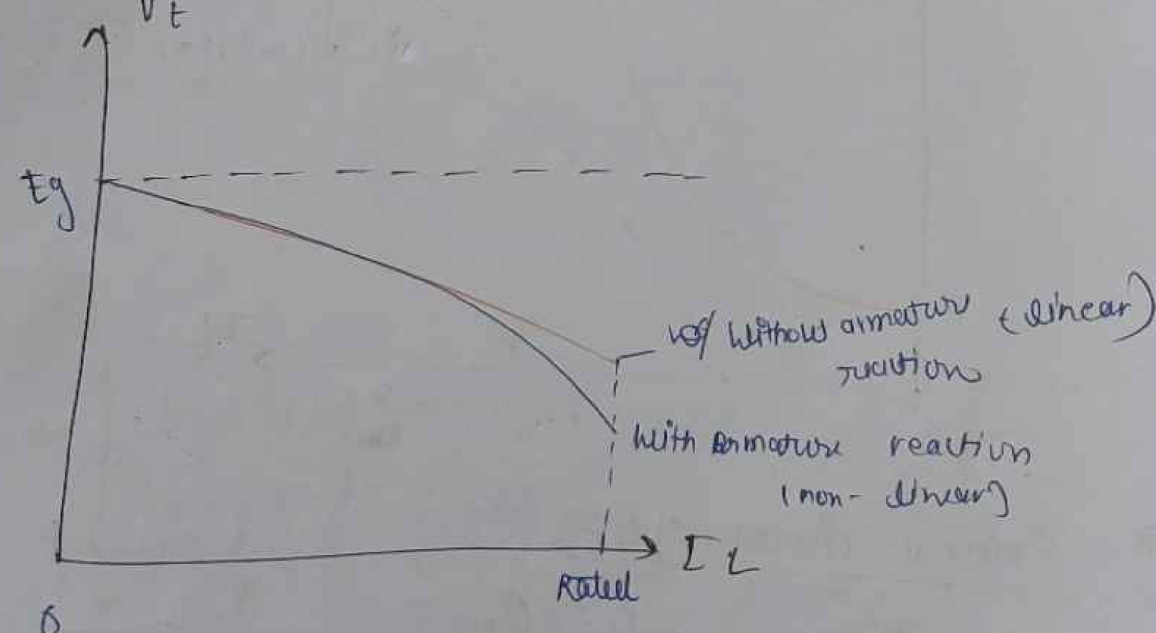
$$V_t = E_g - I_L(R_a + R_b)$$

$$\downarrow \quad \downarrow \quad \downarrow$$

$$y \quad c \; + \; x\underline{m}$$

$$\therefore m = -(R_a + R_b)$$

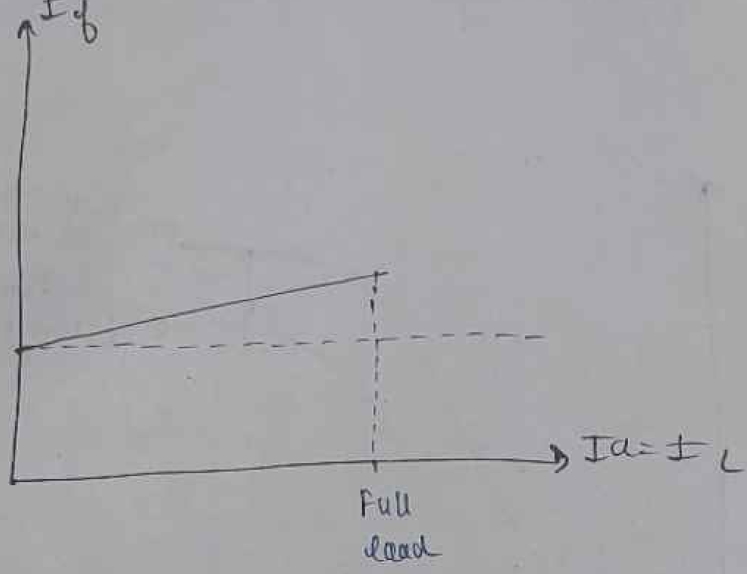
$$\therefore m \approx 0.1 \text{ (very less)}$$



(d) Armature ~~reaction~~ / regulation chars :-

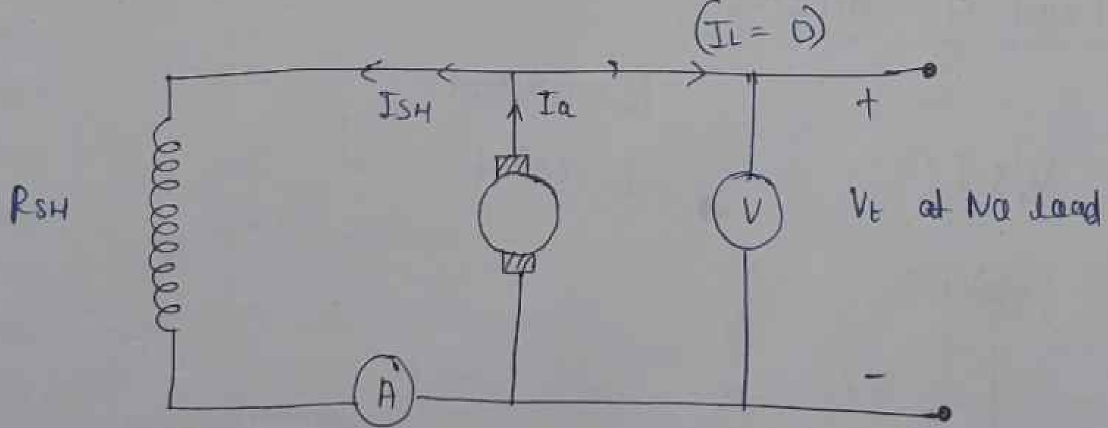
I_a V/s I_f , N = constant

V_t = const



(B) D.C shunt generature :-

E_g v/s I_f N = constant
at No load



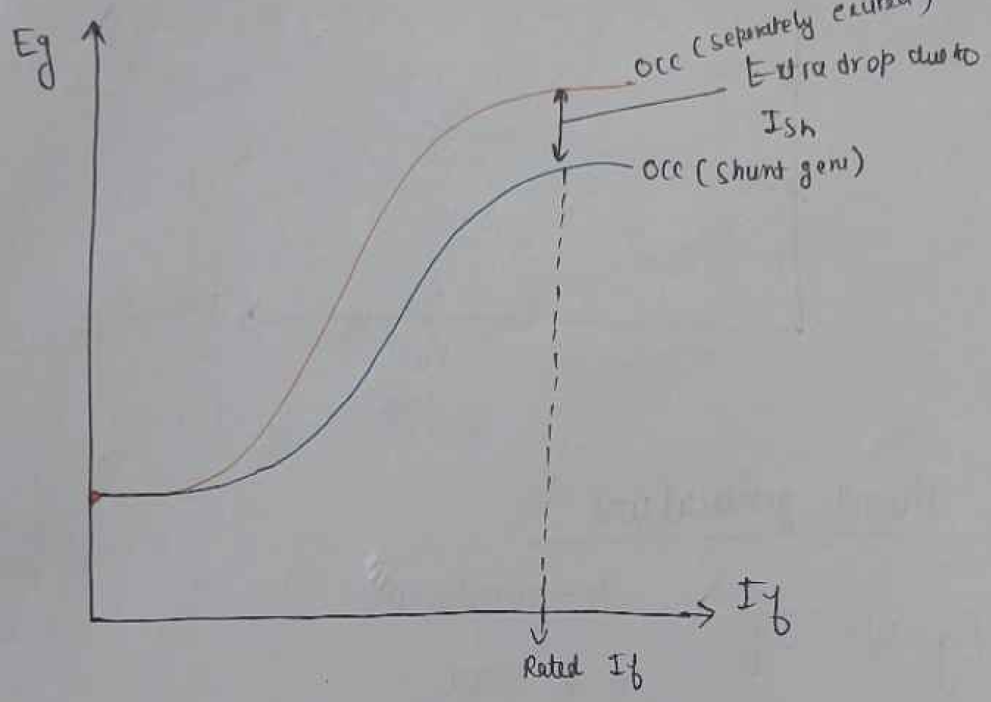
$$E_g = (I_a R_a + V_b + AR) + V_t$$

here $I_a = I_{SH}$ ↓↓↓↓ (very less)

$$V_t = E_g - (I_a(R_a + R_b) + A.R)$$

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

$\boxed{I_a = I_{SH}}$

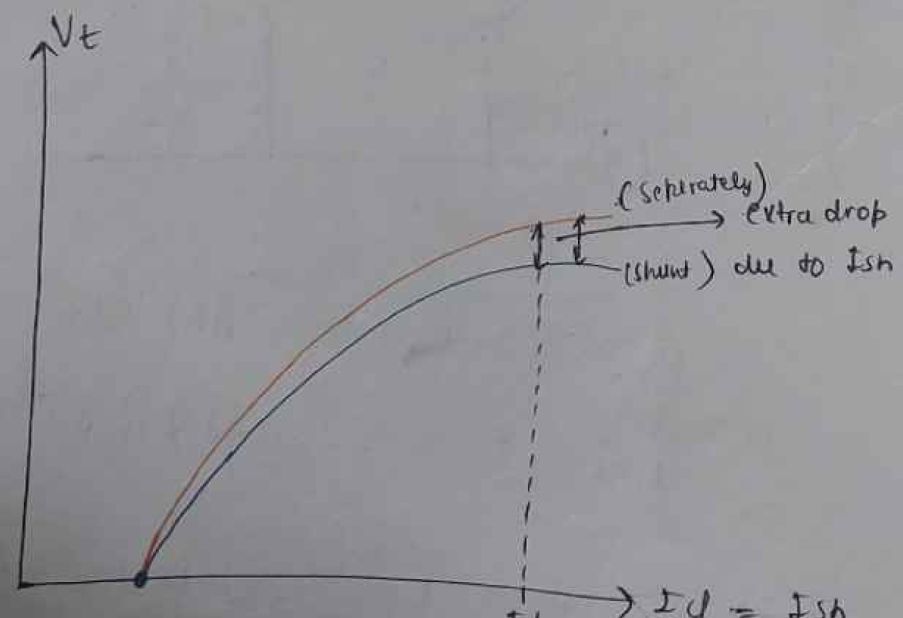


(B) Load characteristics :-

V_t v/s I_f

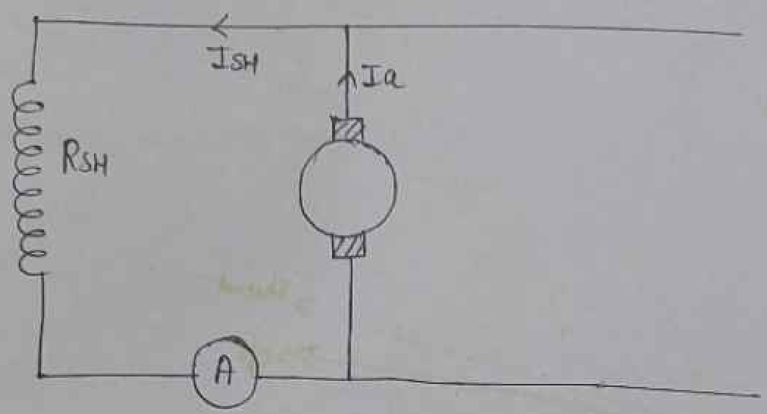
N = constant

I_L = const



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

(i) External characteristics :-

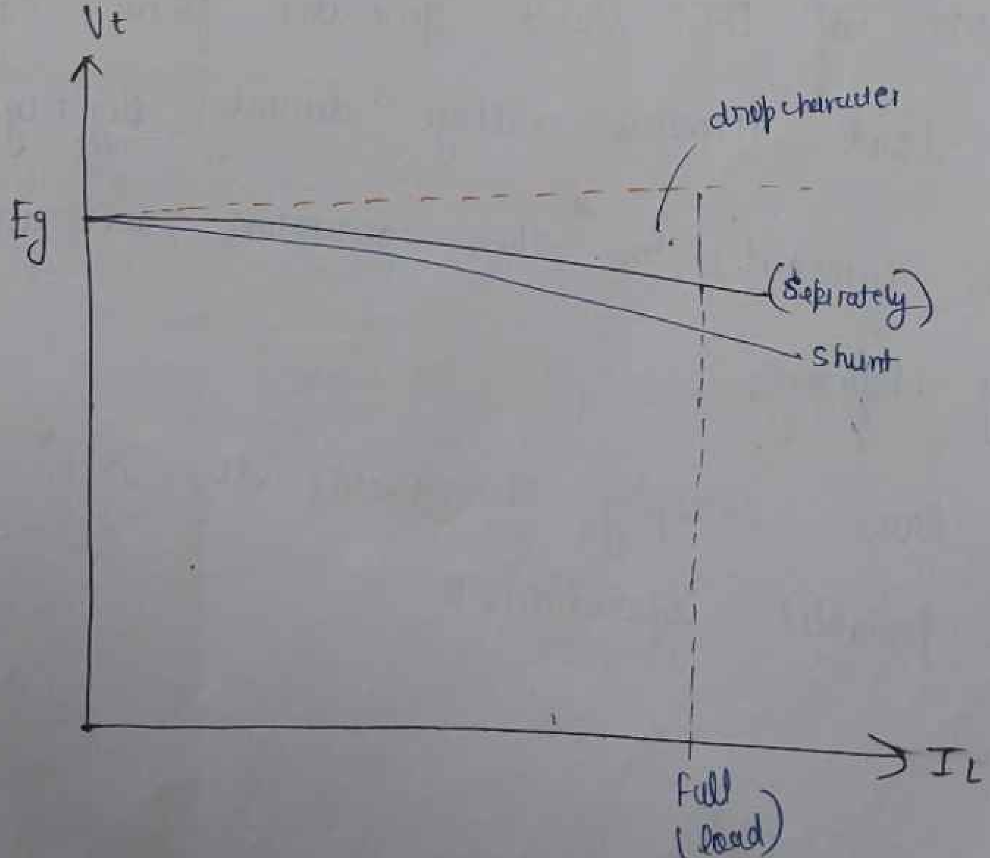


Seperately

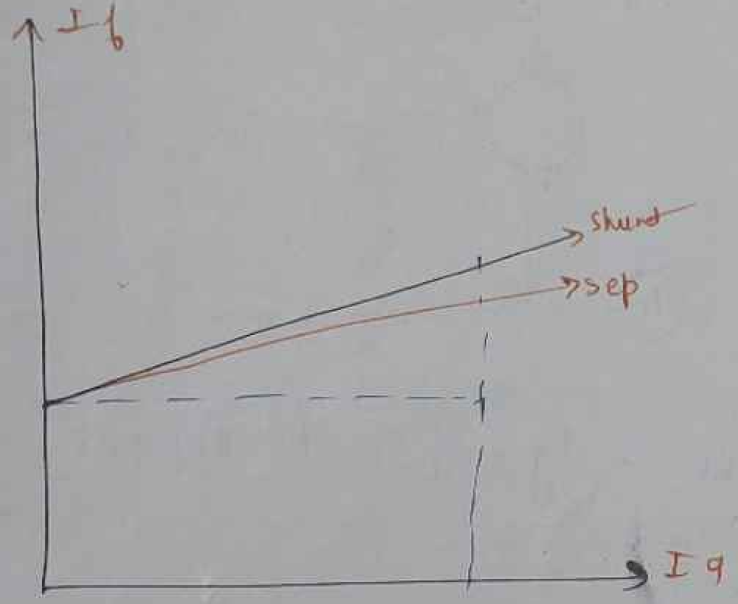
$$\boxed{V_t = E_g - [I_L(R_a + R_b) + AR]}$$

shunt :-

$$\boxed{V_t = E_g - [(I_L + I_{sh})(R_a + R_b) + AR]}$$

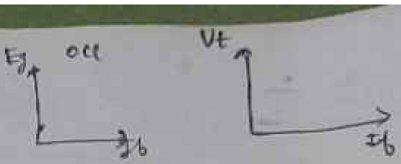


Armature / regulation curve :-



⇒ In case of D.C shunt generator from noload to full load terminal voltage decreases slightly (almost remains constant). So, these generators are used for battery charging.

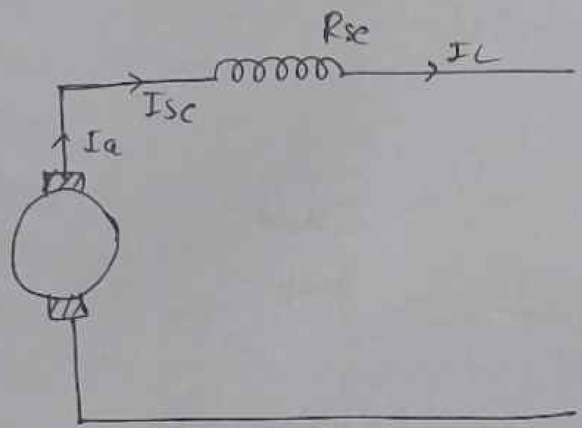
⇒ It have drooping characterstics. So, it is suitable for parallel operation.



D.C series generator :-

$V_t = E_g - (V_b + I_a R_a)$
$N = \text{const}$
$I_a = \text{const}$

OCC :-



E_g v/s I_f $\left(\begin{array}{l} N = \text{const} \\ \text{at no load} \end{array} \right)$

$I_L = 0 = I_a = I_{se} = I_f\ 0$

Not possible.

Load characteristics :-

$V_t = E_g - I_a(R_b + R_a)$

$N_s = \text{const}$

$\therefore I_a = I_f = \text{const}$

changing I_f and const I_a

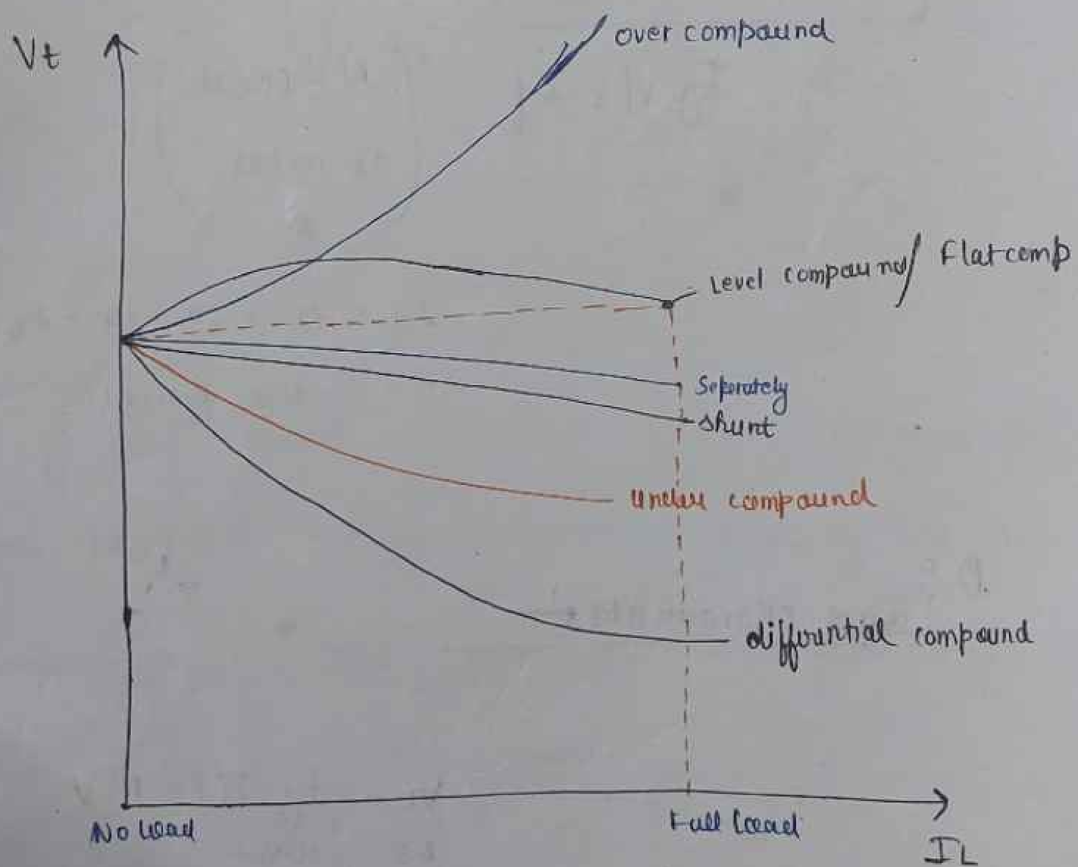
$\therefore$ Not possible

Result :-

⇒ In case of D.C series generator it is not possible to draw all the characteristics.

⇒ External characteristics :-

compound generator :-



Operating characteristics of D.C motor :-

$$E_b = \frac{NP\phi Z}{60A}$$

$$\boxed{P_m = E_b I_a}$$

$$T_a = \frac{P_m}{\omega} = \frac{E_b I_a}{\omega}$$

$$T_a = \frac{K\phi\omega \cdot I_a}{\omega}$$

$$\boxed{T_a = K_a \phi I_a}$$

$$\because E_b = \underbrace{\left(\frac{2\pi N}{60}\right)}_{\omega}\underbrace{\left(\frac{PZ}{2\pi A}\right)}_{K_a}$$

$$\boxed{E_b = K_a \phi \omega}$$

$K_a = \frac{PZ}{2\pi A}$ = armature current

char drawn b/w

$\boxed{\omega, T_a, I_a}$ $\underbrace{V_t}_{\text{const}}$

① Speed - Torque ($\omega - T_a$) char

$\boxed{\omega \text{ V/s } I_a}$, $\boxed{V_t = \text{const}}$

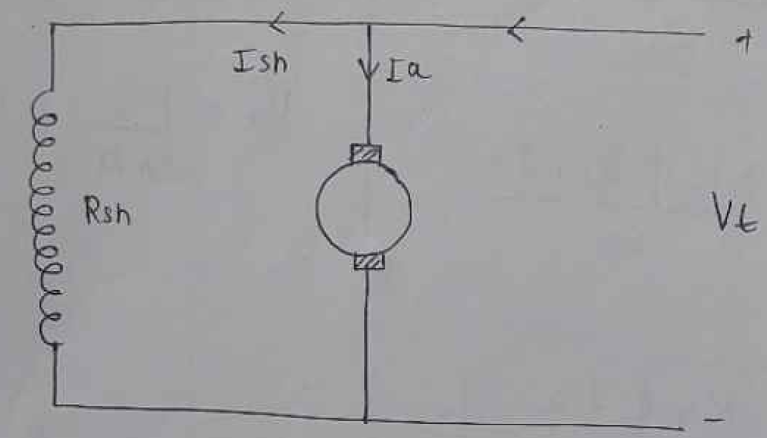
② Torque- Armature current ($T_a - I_a$) char

$\boxed{T_a \text{ V/s } I_a}$, V_t = const

③ Speed and armature current charact ($\omega - I_a$)

$\boxed{\omega \text{ V/s } I_a}$, $\boxed{V_t = \text{const}}$

D.C shunt motor :- preferred slightly more, then almost constant then constant



$$V_t = E_b + I_a R_a$$

$$E_b = V_t - I_a R_a$$

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

$$E_b = K_a \phi \omega$$

$$T_a = K \phi I_a$$

① Speed torque char :-

$$\boxed{E_b = V_t - I_a R_a}$$

$$K_a \phi \omega = V_t - I_a R_a$$

$$\omega = \frac{V_t}{K_a \phi} - \frac{R_a}{K_a \phi} I_a$$

$$I_a = \frac{T_a}{K_a \phi}$$

$$\boxed{\omega = \frac{V_t}{K_a \phi} - \frac{R_a T_a}{(K_a \phi)^2}}$$

Case I :- If AR armature reaction is neglected

$$\boxed{\phi \propto I_{SH} = \frac{V_t}{R_{SH}}}$$

$\therefore$ from noload to full load ϕ remains constant.

$$\boxed{\omega = \frac{V_t}{K_a \phi} - \frac{R_a}{(K_a \phi)^2} T_a}$$

$$y = c + m x \text{ (line)}$$

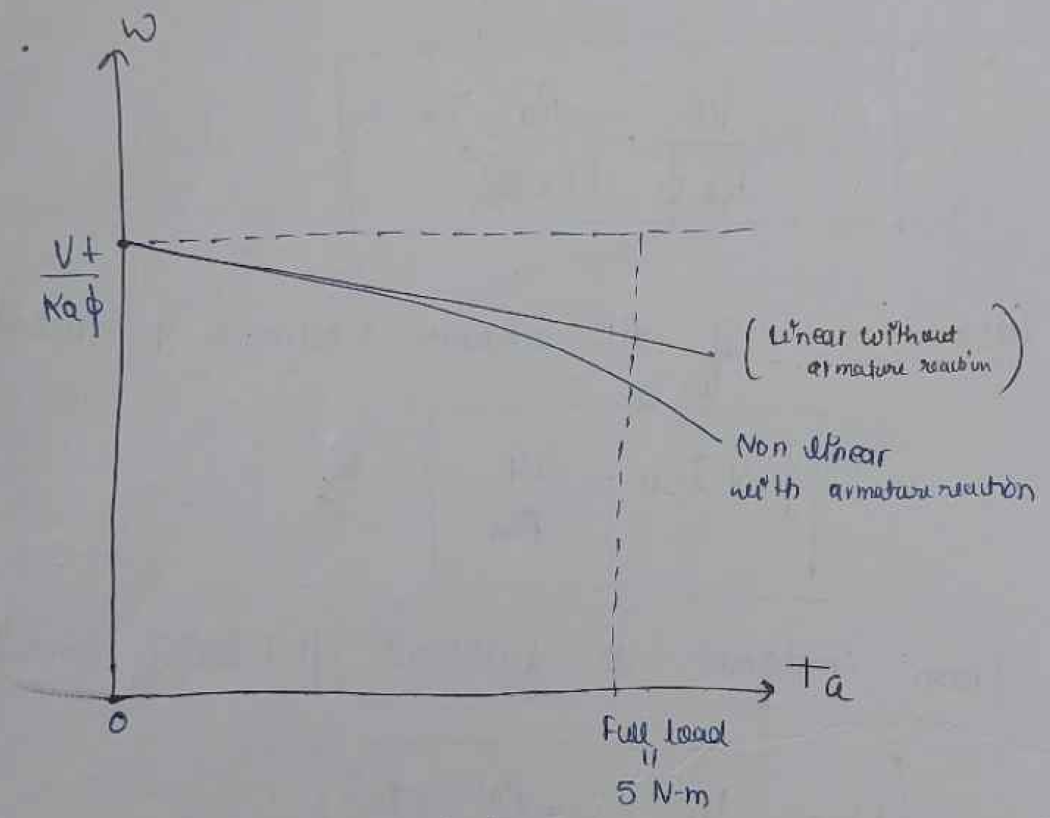
$$\text{slope} = \frac{-R_a}{(K_a \phi)^2}$$

$\boxed{\text{slope} = .01}$ means speed slightly decreases

Case - II If armature reaction considered.

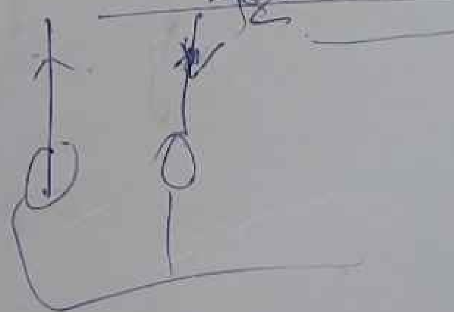
As load ↑ , ϕ ↓ .

$$\omega = \frac{\uparrow V_t}{K_a \phi \downarrow} - \uparrow \frac{R_a}{(K_a \phi \downarrow)^2 \downarrow} T_a$$



② Speed - armature current :-

$$\boxed{E_b = V_t - I_a R_a}$$



$$K_a \phi \omega = V_t - I_a R_a$$

$$\boxed{\omega = \frac{V_t}{K_a \phi} - \frac{R_a I_a}{K_a \phi}}$$

Case → I   if ~~A.R~~ neg armature reaction neglected.

$$\boxed{\phi \propto I_{sh} = \frac{V_t}{R_{sh}}}$$

from no load to full load ϕ remains constant.

$$\boxed{\omega = \frac{V_t}{K_a \phi} - \frac{R_a}{(K_a \phi)} I_a} = \frac{1}{K_a \phi}(V_t - I_a R_a)$$

$$y = c \quad m \quad x \rightarrow \text{line)}$$

$$\boxed{\text{slope} = -\text{ive} = \frac{-R_a}{K_a \phi}}$$

$$\boxed{\text{slope} = -0.1}$$ (speed ~~increases~~ decreases very less or slightly)

Case - II if Armature reaction included.

As load ↑ ϕ ↓

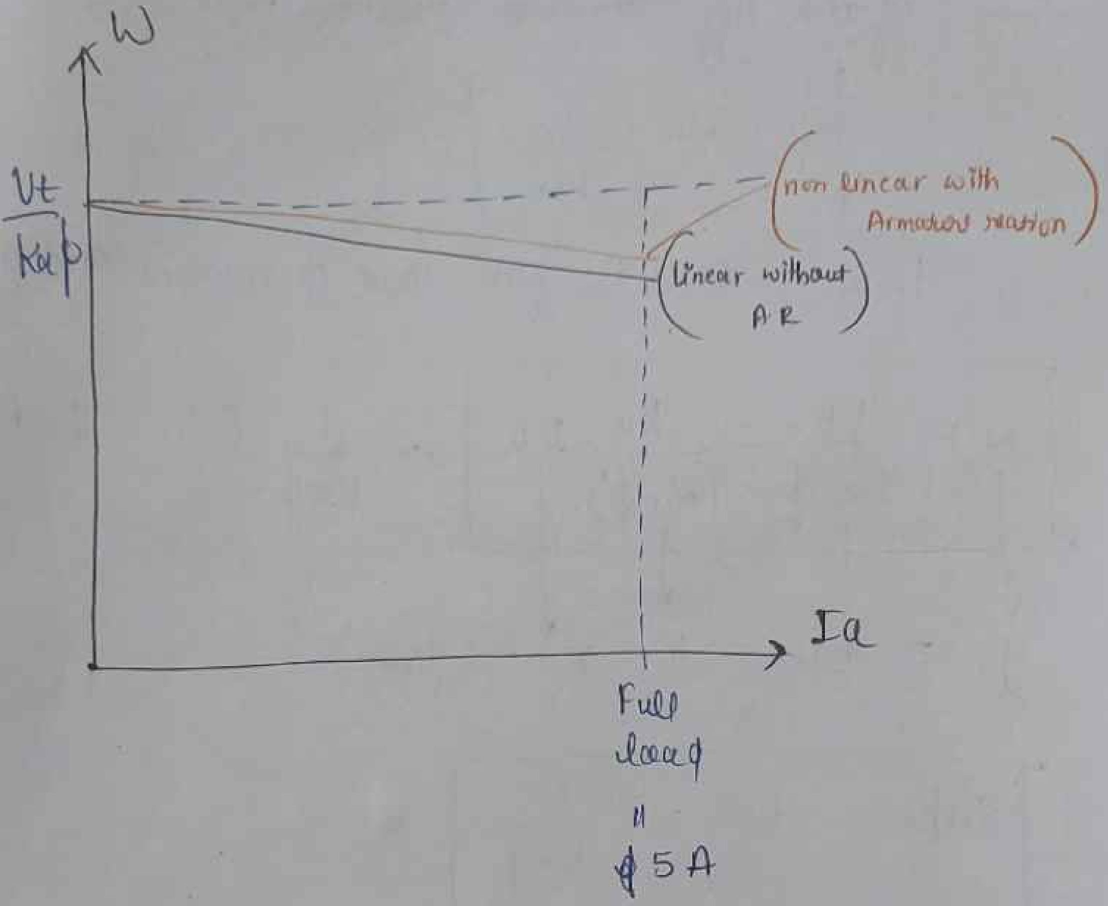
$$\omega = \frac{V_t}{K_a \phi} - \frac{R_a}{K_a \phi} I_a$$

$$\omega = \frac{1}{K_a \phi} \underbrace{(V_t - I_a R_a)}_{\text{Constant}}$$

due to armature reaction if ϕ ↓ the ω ↑.

$\therefore$ $\boxed{\omega \uparrow \propto \frac{1}{\phi}}$ with armature reaction

ω increases



③ <u>Torque - armature current characteristics :-</u>

$$\boxed{T_a = K\phi I_a}$$

Case→I without armature reaction

$\phi = \text{const}$

$$T_a = (K_a\phi)\, I_a$$

$$\downarrow \quad \downarrow \quad \downarrow$$

$$y = m \quad x$$

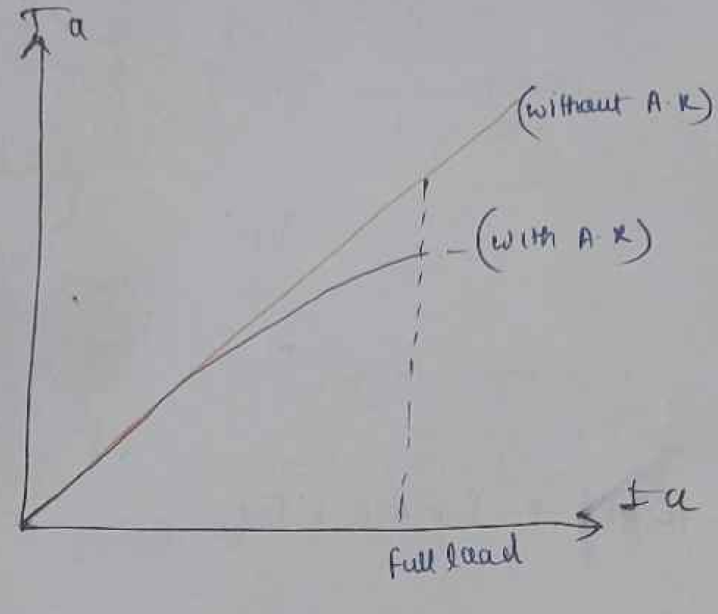
$$\boxed{m = K_a\phi}$$

Case II with armature reaction.

$$\boxed{T_a = K_a(\phi)(I_a)}$$

∴ for same Ia at full load of ϕ↓

so Ta also ~~dec~~ decreases

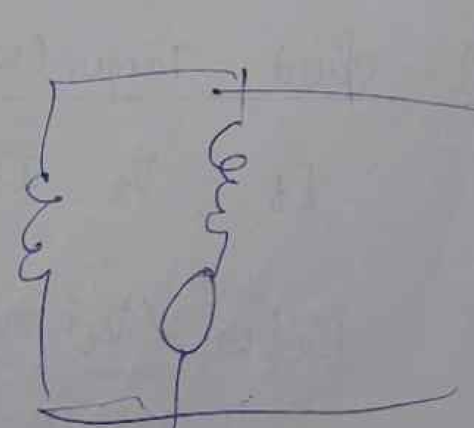


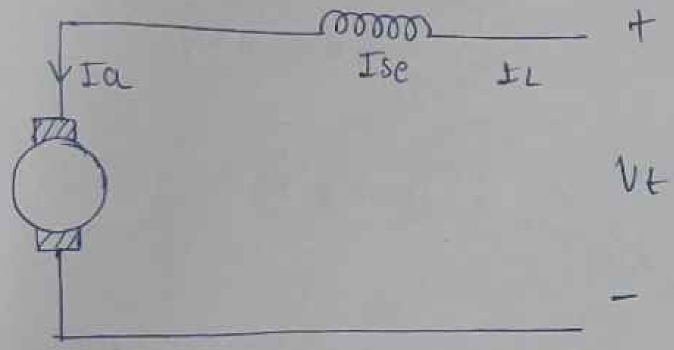
Result :

⇒ # In case of D.C shunt motor from no load to full load speed decrease slightly (almost remains constant). So, these motors are used in lathe machine.

⇒ # In case of D.C shunt motor without armature reaction all the characterstics are linear but due to armature reaction becomes non linear.

(2) D.C series motor :





$$V_t = I_a R_a + I_{se} R_{se} + E_b$$

$$E_b = V_t - I_a \underbrace{(R_a + R_{se})}_{\downarrow}$$

$$E_b = V_t - I_a R_a'$$

$$\boxed{T_a = K \phi I_a}$$

<u>Case → I</u> Without Armature reaction

$$\phi \propto I_{se} = I_a \quad (\text{Linear})$$

$$\boxed{\phi = X I_a}$$

① <u>Speed - Torque (ω - T_a)</u>

$$E_b = V_t - I_a R_a'$$

$$K_a \phi \omega = V_t - I_a R_a'$$

$$\omega = \frac{V_t}{K_a \phi} - \frac{R_a'}{K_a \phi} I_a$$

$$\omega = \frac{V_t}{K_a\phi} - \frac{R_a'}{(K_a\phi)^2} T_a$$

Case - I

$$\phi = \lambda I_a$$

$$T_a = K\phi I_a$$

$$T_a = K_a\phi I_a$$

$$T_a = K_a\phi \frac{\phi}{\lambda}$$

$$\phi = \sqrt{\frac{T_a\lambda}{K_a}}$$

$$\omega = \frac{V_t}{K_a\sqrt{\frac{T_a\lambda}{K_a}}} - \left(\frac{R_a'}{K_a^2 \cdot \frac{T_a\lambda}{K_a}}\right) T_a$$

$$\omega = \frac{V_t}{\sqrt{K_a\lambda}\cdot\sqrt{T_a}} - \frac{R_a'}{K_a\lambda}$$

~~Taccelerat~~

$$\boxed{\omega = \frac{V_t}{\sqrt{K_a\lambda}} \cdot \frac{1}{\sqrt{T_a}} - \frac{R_a'}{K_a\lambda}}$$

$R_a' = R_a + R_{se} = low \approx 0$

$$\omega \approx \frac{V_t}{\sqrt{K_a \lambda}} \cdot \frac{1}{\sqrt{T_a}}$$

$$\omega \propto \frac{1}{\sqrt{T_a}}$$

$$\boxed{T_a \propto \frac{1}{\omega^2}}$$

at starting $\omega = 0$

$\therefore$ $T \longrightarrow \infty$ from above eqn

$\therefore$ D.C series motor is not started at no load .

$T = K \phi I_a$

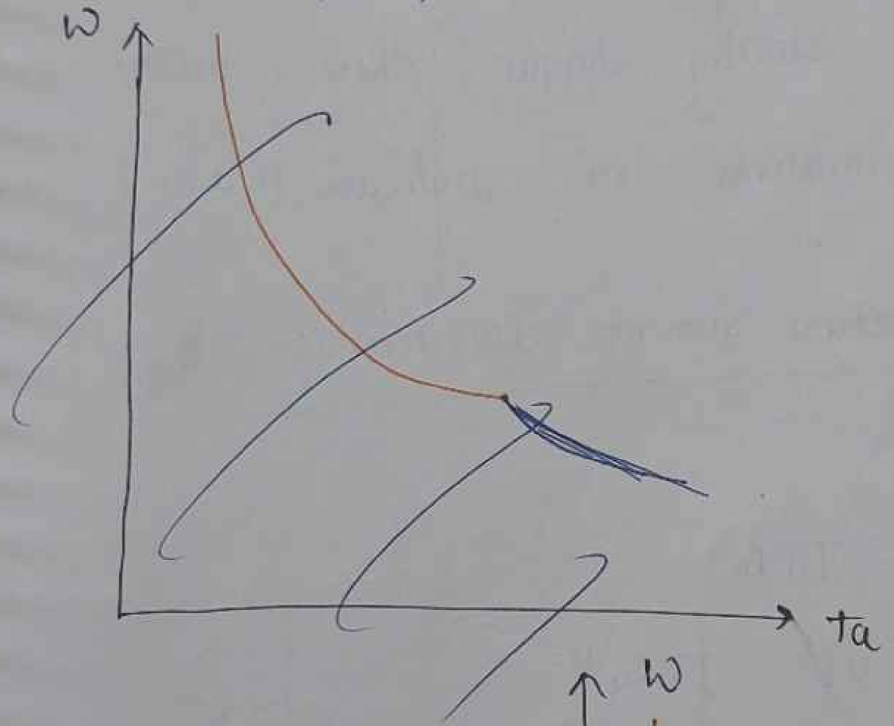
Case - II with saturation :-

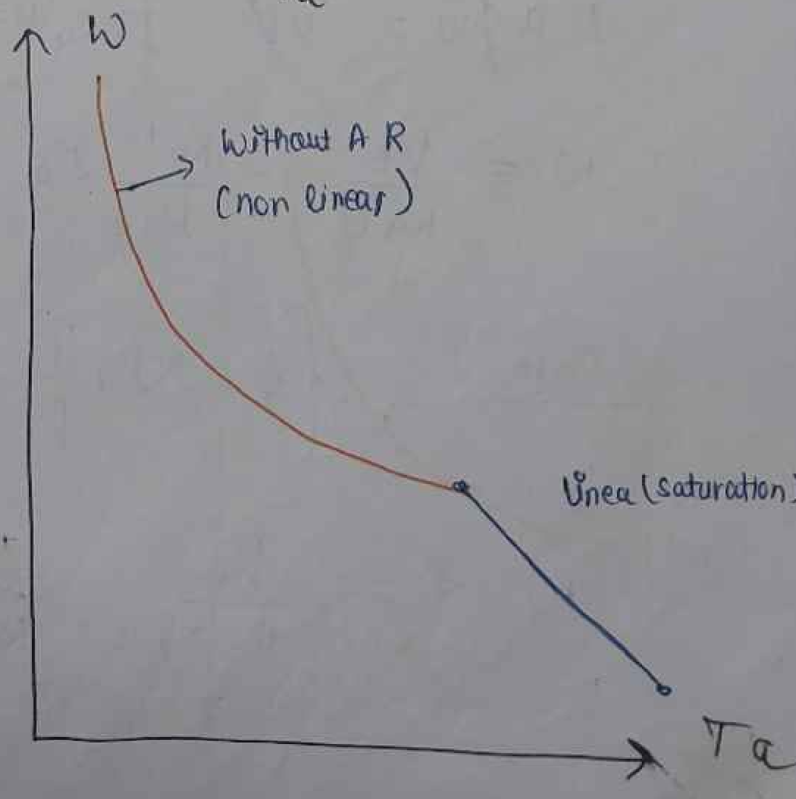
ϕ = constant

$$\omega = \frac{V_t}{K_a\phi} - \frac{R_a'}{(K_a\phi)^2} T_a$$

$$y \quad c + m \cdot x$$

Linear





Result :-

⇒ If a D.C series motor is started at noload then it will accelerate with dangerously a high starting torque and at no load motor may gets damaged.

⇒ Due to high starting torque these motors are used in locomotives or train or traction.

Speed and armature current characteristics :-

$$E_b = V_t - I_a R_a'$$

$$K_a \phi \omega = V_t - I_a R_a'$$

$$\omega = \frac{V_t}{K_a \phi} - \frac{R_a'}{K_a \phi} I_a$$

Case - I $\{\phi = \lambda I_a\}$

$$\therefore \omega = \frac{V_t}{K_a \lambda I_a} - \frac{R_a' \cancel{I_a}}{K_a \lambda \cancel{I_a}}$$

$$\boxed{\omega = \frac{V_t}{K_a \lambda I_a} - \frac{R_a'}{K_a \lambda}}$$

If, $R_a' = 0$

$$\omega = \frac{V_t}{K_a \lambda I_a}$$

$$\boxed{\omega \propto \frac{1}{I_a}}$$

$$\boxed{I_a \propto \frac{1}{\omega}}$$

at starting

$\omega = 0$

$I_{se} \longrightarrow \infty$

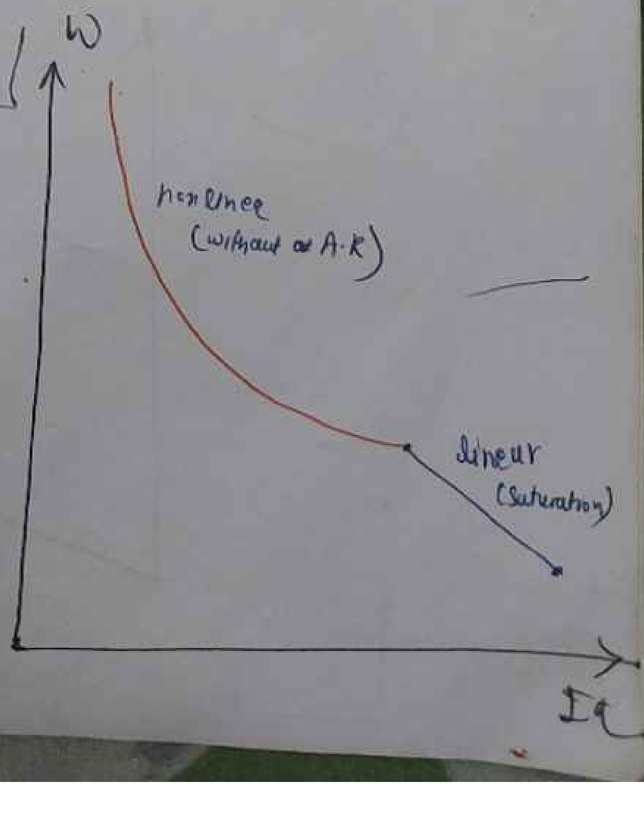
<u>Case → II :</u>

$\phi = \text{const}$

$$\omega = \frac{V_t}{K_a \phi} - \frac{R_a'}{K_a \phi} I_a'$$

$$\boxed{y = c + m \cdot x}$$

linear



Torque armature current characterstics :-

$$\boxed{T_a = k\phi I_a}$$

Case → I Without armature reaction.

$$\boxed{\phi = \lambda I_a}$$

$$T_a = (K_a \lambda) I_a^2$$

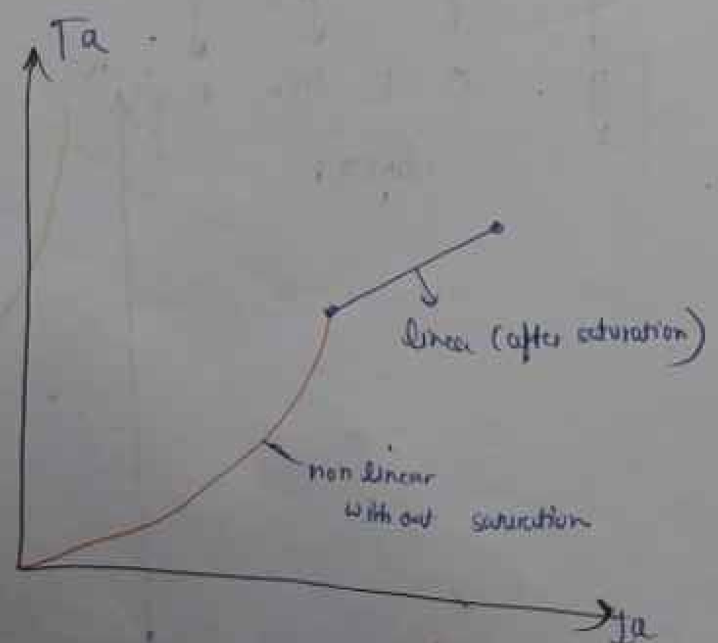
$y \propto x^2 \longrightarrow$ (Parabola)

Case II :- Saturation

ϕ = constant

$T_a = K_a \phi I_a$

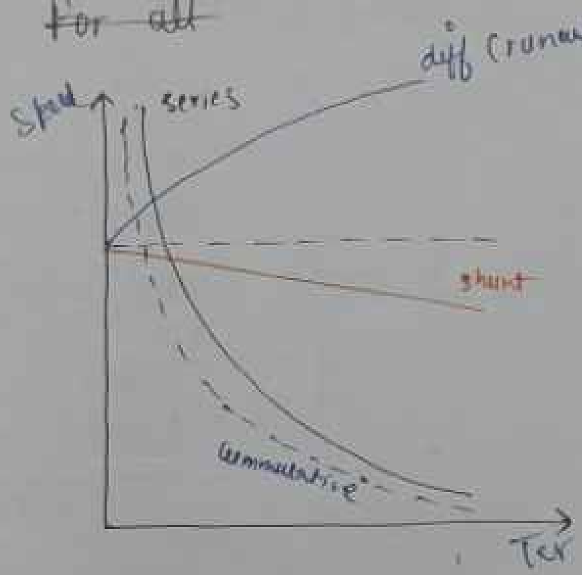
$y = mx$ (linear

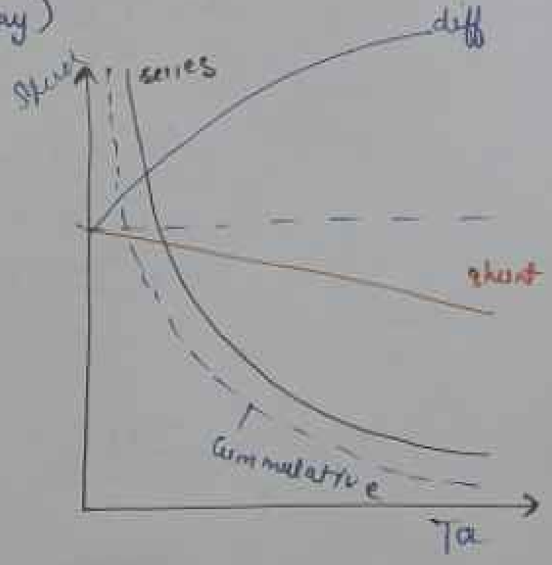


Result :-

(1) In case of D.C series motor all the characteri-stics are non-linear but due to saturation becomes linear

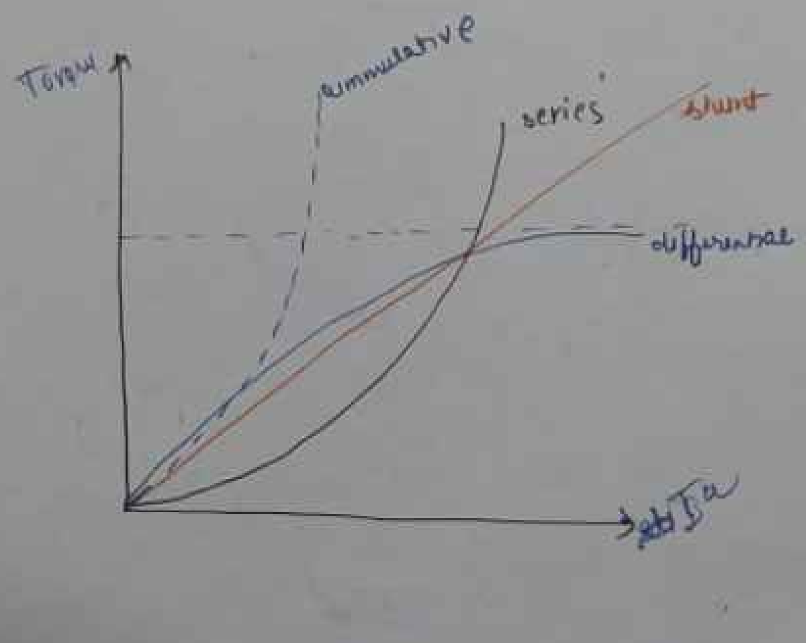
(2) ~~For all~~





$T = K\phi I_a$

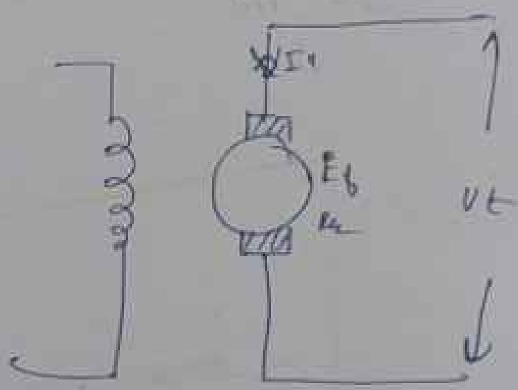
$E_b = K\phi\omega.$



Q A ~~240~~ 240V, 50A, 1500 RPM seperately excited D.C motor having armature resistance of .2 Ω find its starting current.

$$E_B = \frac{NP\phi Z}{60A} =$$ at starting $N = 0$

$$E_B = 0$$



$$V_t = E_B + I_a R_a$$

$$V_t = I_a R_a$$

$$I_a = \frac{2400}{2}$$

$$I_a = 1200$$

$$I_{FL} x = I_a$$

$$x = \frac{I_a}{I_{FL}}$$

$$= \frac{120\cancel{0}}{5\cancel{0}}$$

$$\boxed{x = 24}$$

$$\boxed{I_{st} = 24 I_{FL}}$$

(05.11.30)

Starters are used to limit high starting current, starter is a resistor connected in series with armature

Types of starter :-

(1) Shunt motor starter :-

(1) 3 point starter
(2) 4-point starter.

(2) Series motor starter :-

(1) 2-point starter

(1) 3- point starter :-

Construction :- Starter is a variable resistance integrated into number of sections. The contact point of these sections is known as studds. These are of OFF, 1, 2, 3, 4, 5(RUN).

⇒ There are three main points line terminal L which is connected to positive or negative terminal of supply, feild terminal F which is connected to feild winding and armature terminal A which is connected to armature.

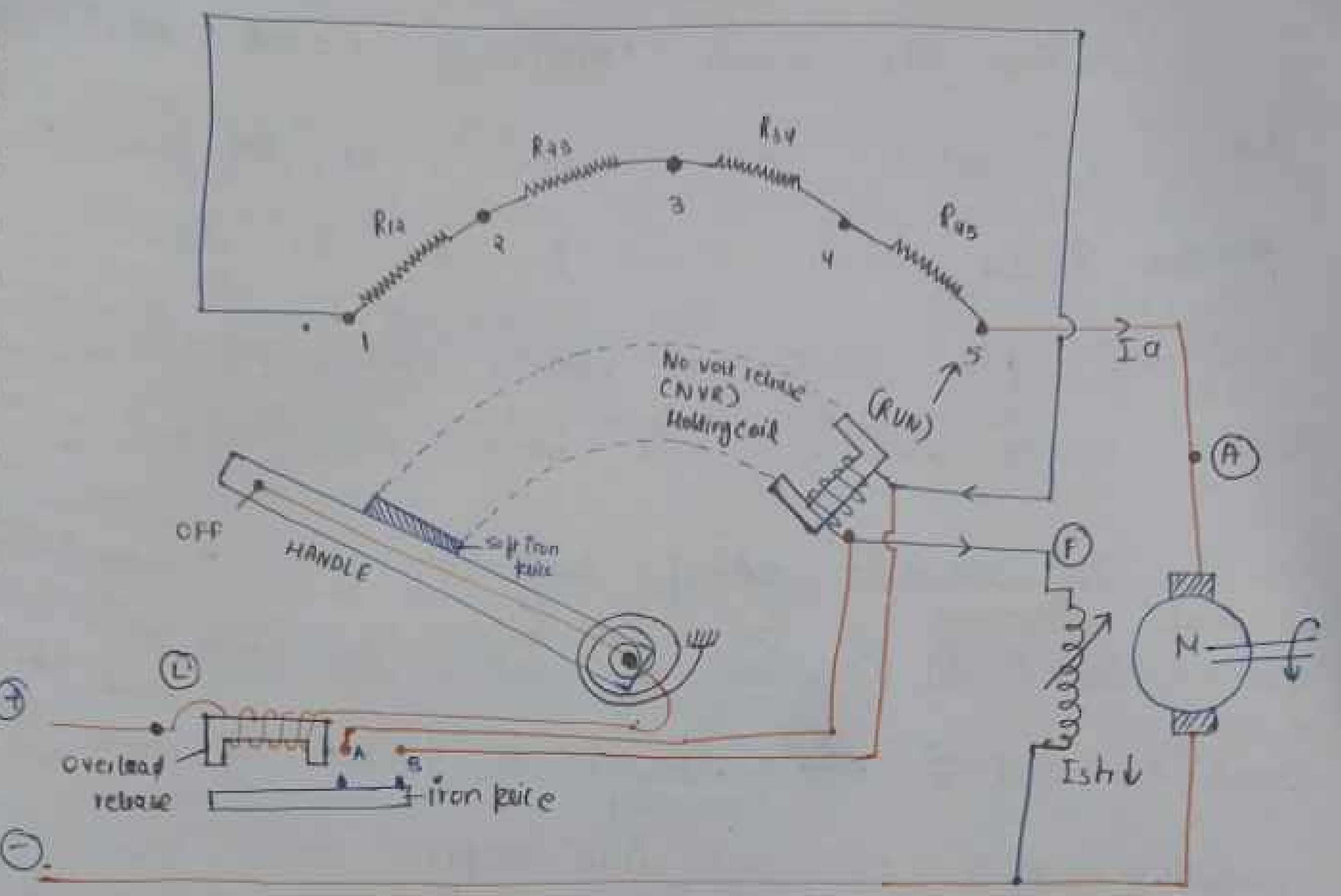
Spring – phospher bronze (non magnetic material)

⇒ The line terminal L is connected to an electromagnet which is known as over load relay release (OLR). The other end of (OLR) is connected to lower conducting end of handle where a spiral spring also attached and handle also contain a soft iron peice.

⇒ This handle is free to rotate from studd OFF to RUN against the force of spring.

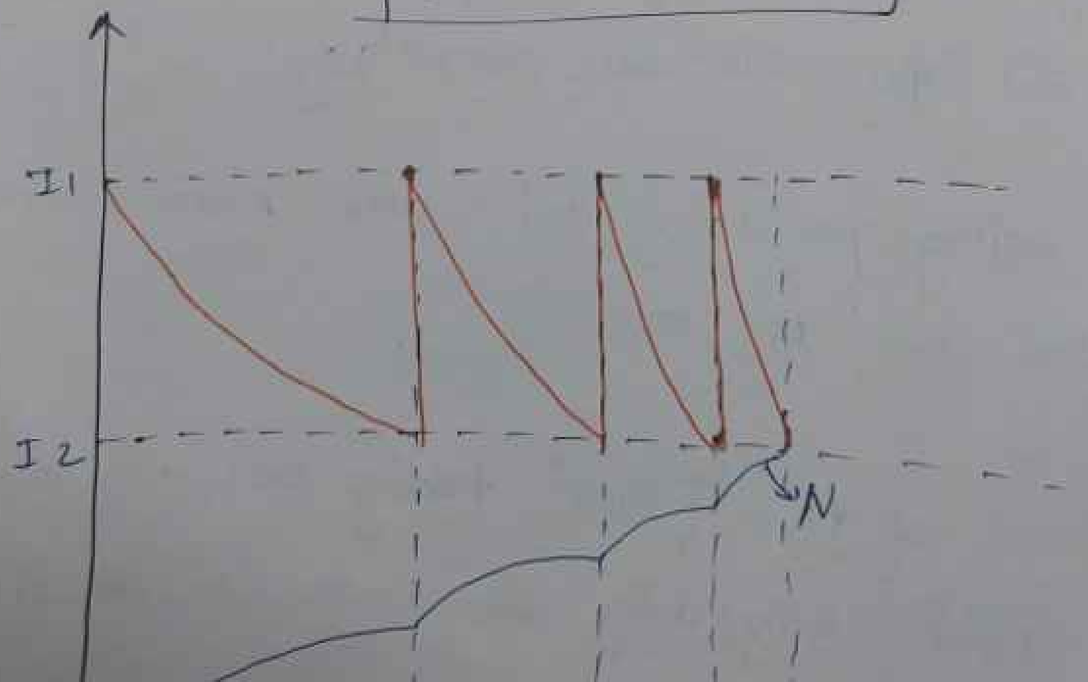
⇒ A parallel path is derived from studd 1 and given to another electromagnet known as no volt release. which is further connected to F terminal.

⇒



Working :-

$$\boxed{t_{12} > t_{23} > t_{34} > t_{45}}$$



⇒ For starting the motor handle is moved to come in contact with studd-(1) as the ~~studd (1)~~ ~~touches~~ handle touches studd (1) all the starting resistance gets connect in series with armature. So, starting current reduces and motor start rotation.

⇒ After the armature pickup sufficient speed handle is moved to studd (2) their by cutting out resistance b/w studd one and (2) ~~mov o moment~~ movement of handle is continued smoothly untill the soft iron keeper touches the holding coil.

⇒ During waiting period of each studd the armature current falls and speed increases exponentially.

⇒ The waiting period of each studd reduces progressively from(1)-(2) and so on.

⇒ In case of power failure holding coil gets demagnetise and spiral spring bring the handle to its OFF position.

⇒ In case the armature current exceeds a preset value due to overload then overload release becomes more strong and attract the soft iron piece. So, that terminal A and B OFF of holding coil gets short circuit and holding coil get demagnetise and handle move to OFF position.

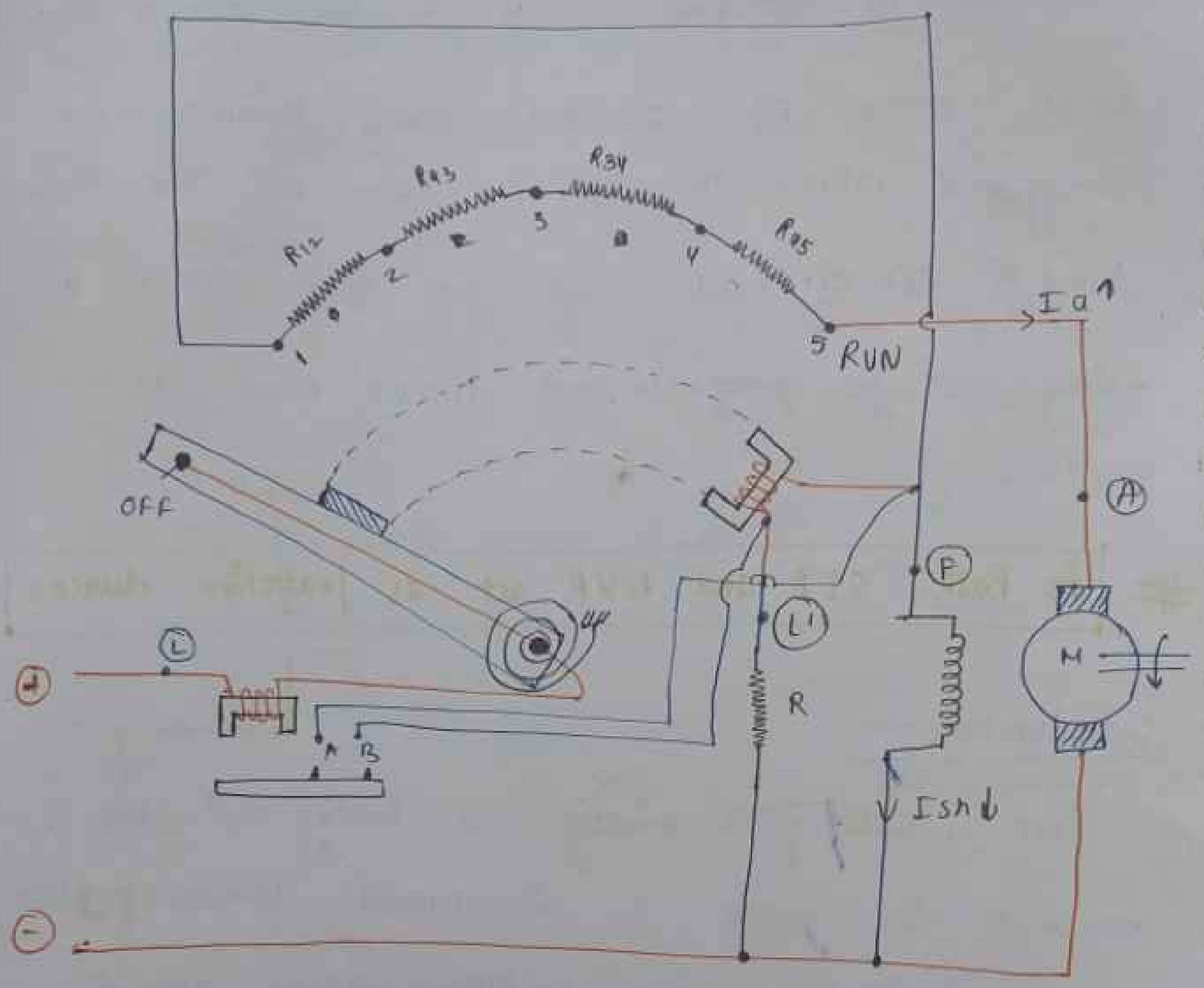
For Both OLR and NVR act as protective devices

Disadvantage :-

① Since, both field winding and holding coil are connected in series. So, it cannot be used where speed controlled by flux weakening method. Otherwise holding coil releases handle and motor gets turn OFF.

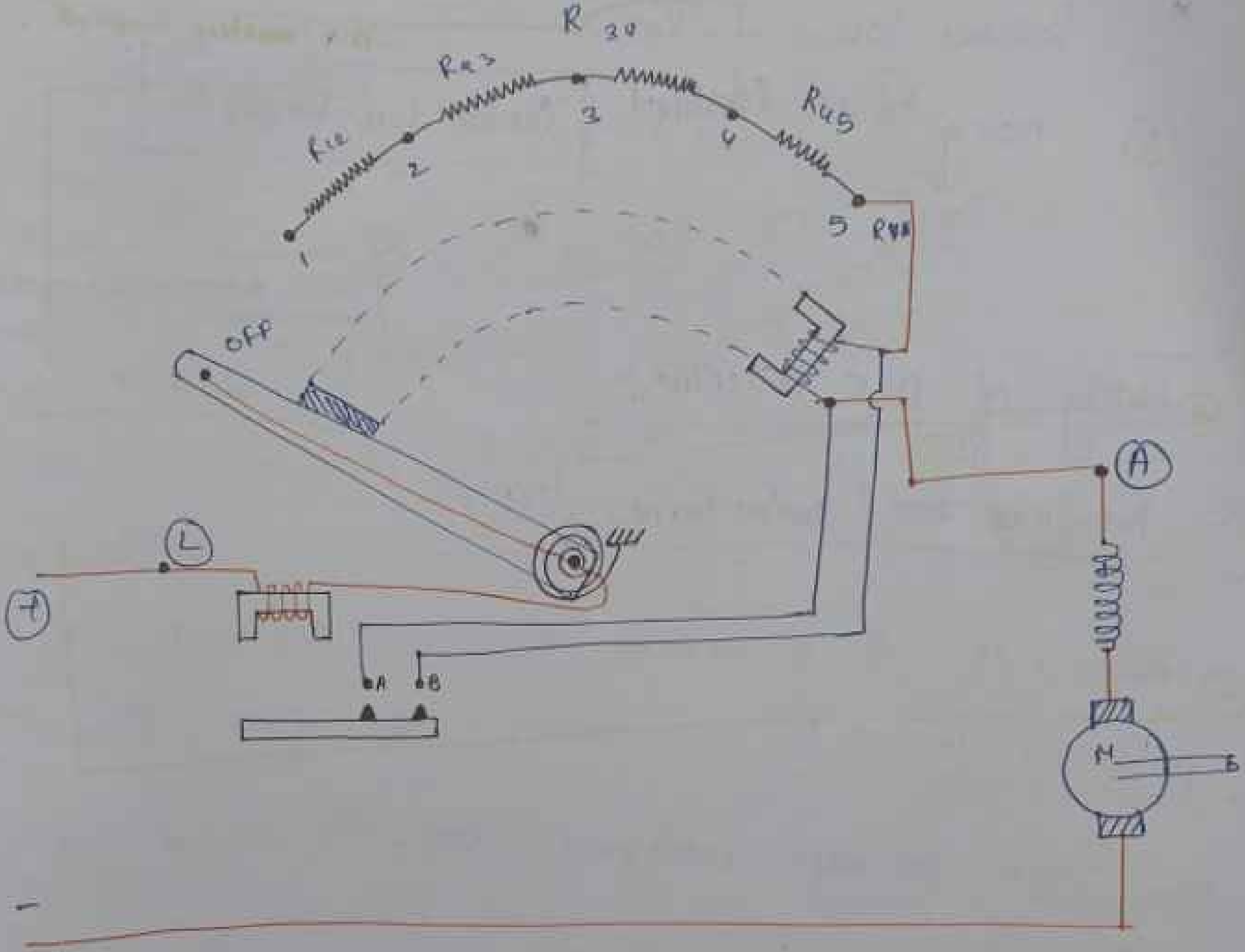
4 point starter :-

This starter have points and both field winding and holding coil are connected in parallel. So, it can ~~not~~ be use where speed controlled by flux weakening method.


R12
R23
R34
R45
1
2
3
4
5
RUN
Ia
OFF
A
F
L'
L
M
R
A
B
Ish

D.C series motor starter

① 2- point starter :-



Losses :-

① Rotation Loss (Wo) :- Mechanical Loss + Armature core loss

② Cu Loss → Armature Cu Loss ($I_a^2 R_a$)
→ Feild winding Cu loss ($I_f^2 R_f$)

NOTE :-

① $\boxed{\text{Constant Loss} = \underbrace{\text{Armature core loss} + \text{Mech loss}}_{\text{for T/F const}} + I_f^2 R_f}$ (for I-M constant)

② Variable Loss = $I_a^2 R_a$

③ max η cond^n Constant $\boxed{\text{Constant loss} = \text{Variable Loss}}$ D.C machine constant.

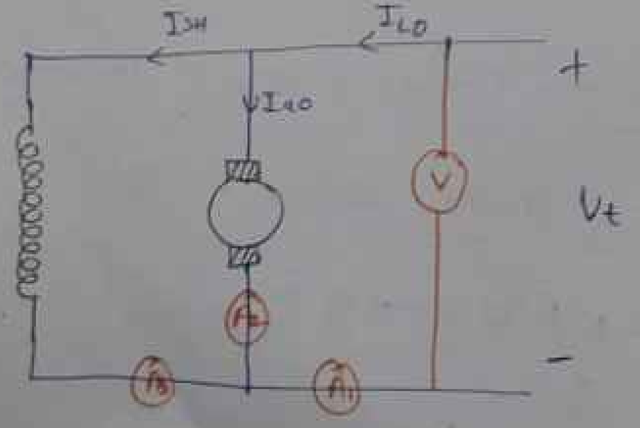
~~A-V~~ < low resistance ~~for~~ a current value = A - ①

High resist = V - A

Testing of D.C machine :-

① No load test / swinburnes test :

Since, it is a no load test. So, it cannot be performed for D C series motor. And from this test we can ~~no~~ calculate rotational loss.



$$\boxed{P_i = P_o + \text{Loss}}$$

at ~~starting~~ no load $P_i = 0 + \text{loss}$ — Arma cu loss, Field cu loss, Armature core loss, mech loss

$$V_t I_{L0} = I_{a0}^2 R_a + V_t I_{sh} + W_0$$

$$\boxed{W_0 = V_t I_{L0} - I_{a0}^2 R_a - V_t I_{sH}}$$

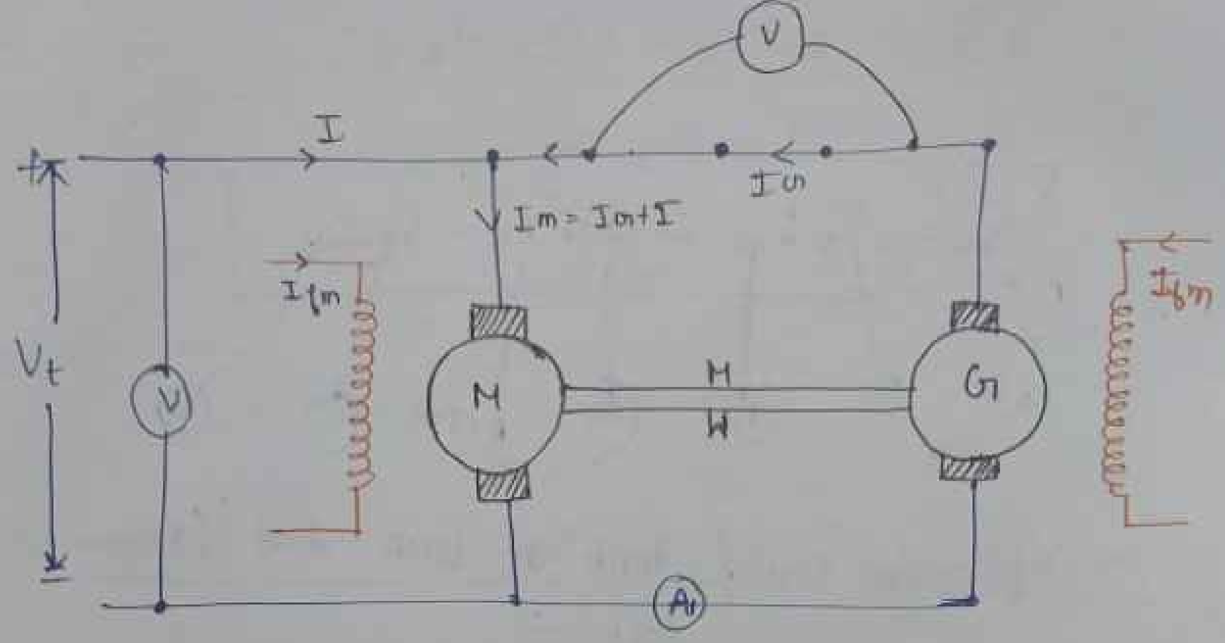
Cal V1 A1 AL D.C test A3

Hopkinson test / back to back test / Regenerative test :-

⇒ In this method 2 identical D.C machines are coupled mechanically as well as electrically and tested simaltaneou-sly one of the machine run as motor and another as generator.

⇒ This method can be used for large ratting machine because the input power is only losses of both the machines.

⇒ This method can be applied for both shunt ~~ca~~ and series motor.



P_i = Losses of Both the m/ machines

$$V_t I = W_0 + I_m^2 R_a + W_0 + I_G^2 R_a$$

$$\boxed{W_0 = \frac{V_t I - (I_m^2 + I_G^2) R_a}{2}}$$

Power input to motor $= V_t I_m$

Let efficiency of motor is -

$$\boxed{\eta_m = \frac{\text{motor O/P}}{\text{motor I/P}}}$$

motor O/P = $\eta_m \cdot$ motor I/P

$$\boxed{\text{motor O/P} = \eta \cdot V_t \cdot I_m} \quad (1)$$

Power O/P generator $= V_t I_G$

let efficiency of Generator:-

$$\boxed{\eta_G = \frac{\text{Generator O/P}}{\text{Generator I/P}}}$$

$$\boxed{\text{Generator I/P} = \frac{\text{Generator O/P}}{\eta_G} = \frac{V_t I_G}{\eta_G}} \quad \text{—— (2)}$$

Gen

(1) = (2)

$$\eta_m \cdot V_t I_m = \frac{V_t I_G}{\eta_G}$$

$$\eta_G \cdot \eta_m = \frac{I_G}{I_m}$$

$$\boxed{\eta_G = \eta_B = \eta}$$ identical machines

$$\boxed{\eta = \sqrt{\frac{I_G}{I_m}}}$$

$$\boxed{I_G < I_m}$$

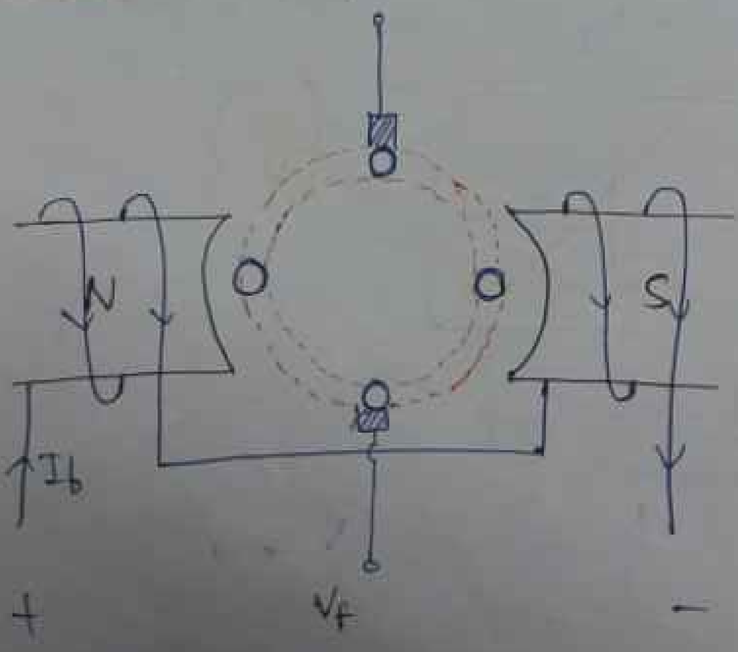
$$\eta < 1$$

Retardation test :-

This test is conducted to calculate rotational losses and also to seperate ~~the~~ armature core and mechanical losses by conducting this test in two ways :-

Way - 1 :- Run the motor slightly more than rated speed and ~~#~~ disconnect only armature and field winding remains connected to the supply. In this case all the stored kinetic energy waste in rotational loss.

$$\boxed{\text{Rotational loss} = \text{Armature core loss} + \text{mechanical loss}}$$



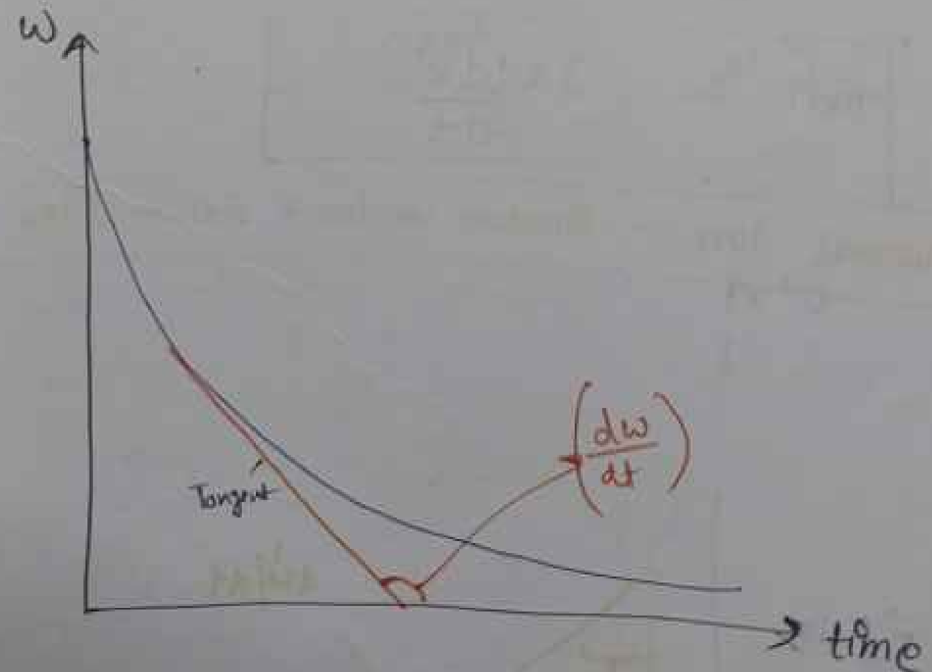
$$\boxed{\frac{d}{dt}(\text{stored } K.E) = \text{Mech loss} + \text{Armature core loss}}$$

$$\boxed{KE = \frac{1}{2} J \omega^2}$$

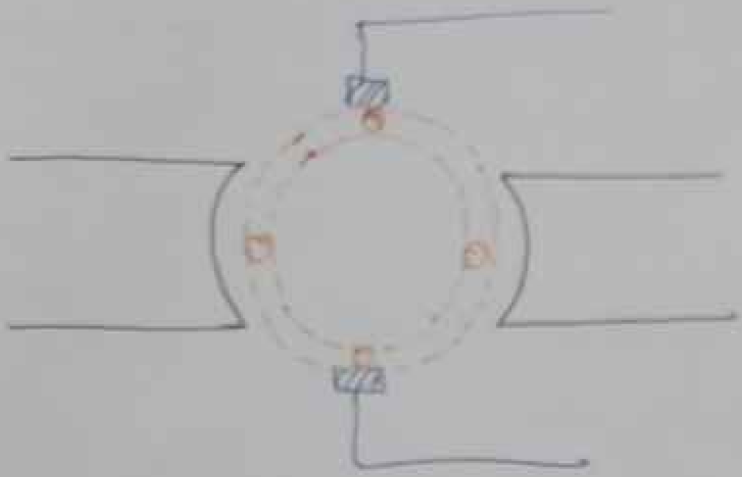
J = moment of inertia ($kg \cdot m^2$)
ω = speed of the motor

$$W_0 = \frac{d}{dt}\left(\frac{1}{2} J \omega^2\right)$$

$$\boxed{W_0 = J\omega \frac{d\omega}{dt}}$$



Way → 2 :- Repeat the same process but field winding is also disconnected from the supply. In this case stored kinetic energy waste into mechanical class .



$$\frac{d(KE)}{dt} = \text{Mechanical loss} + 0$$

$$\cancel{KE = \frac{1}{2} J (\omega')^2}$$

$$\boxed{KE = \frac{1}{2} J (\omega')^2}$$

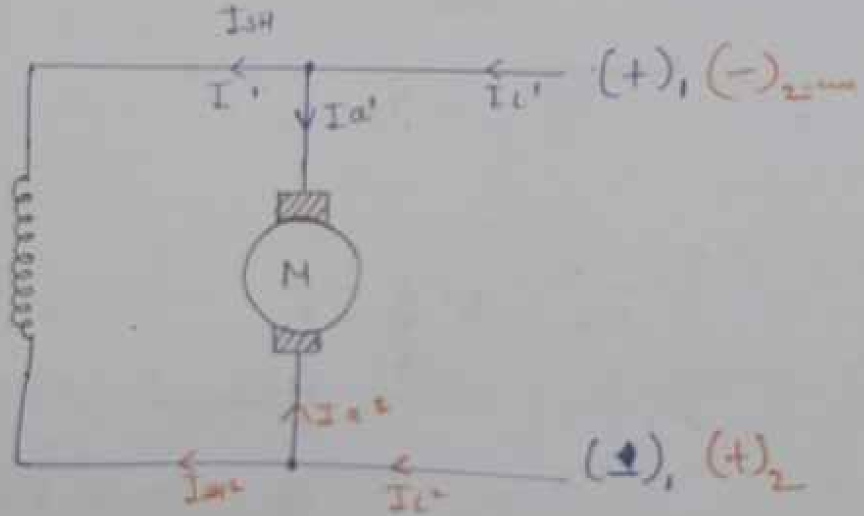
$$\boxed{\text{mech loss} = J \omega' \frac{d\omega'}{dt}}$$

$$\boxed{\frac{d\omega}{dt} > \frac{d\omega'}{dt}}$$

Retardation in way-1 > Retardation in way-2

max loss occurs

<u>Concept :- 1</u> If supply terminals of a D.C shunt motor are interchanged then it will continue to run in the same direction.



$$\boxed{T_a^1 = K \phi I_a}$$

(+) (+) (+)

$$\boxed{T_a^2 = K \phi I_a^2}$$

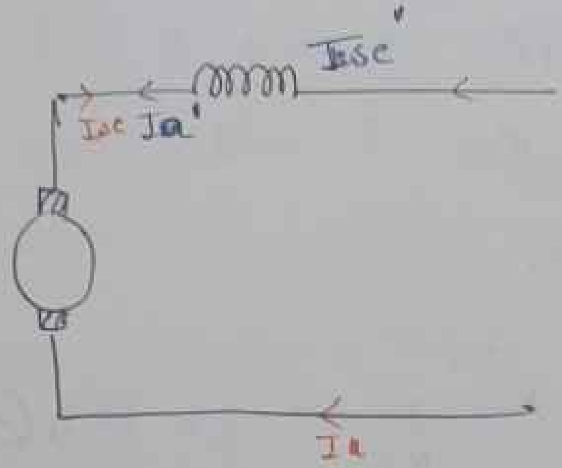
(+) (−) (−)

$T = \phi k I_a$

$T = K \phi I_a$

$T = K \phi I_a$

Concept - 2 :- If supply terminal of D.C series motor are interchange. Then it will



$$\boxed{T_a' = K \phi I_a'}$$

(+) (+) (+)

$T = K \phi I_a$

$$\boxed{T_a^2 = K \phi I_a^2}$$

(+) (−) (−)

$T = K \phi^2 I^2$

Universal motor or single phase A.C series motor :-

When a single phase A.C supply is given to a D.C series motor it runs normally but with large noise and sparking at the brushes. So, yoke and pole shoes are laminated to reduce eddy current losses, number of series field winding turns are also reduced to reduce field winding reactance, high resistance brushes are used with increased brush area.

⇒ The machine is generally operated at lower flux density. So, runs at very high speed. (7000 rpm to 10,000 rpm). It is popular in kitchen application such as mixer, juicer and hand tool application such as drilling machine, vacuum cleaner, hair dryer, grinder.

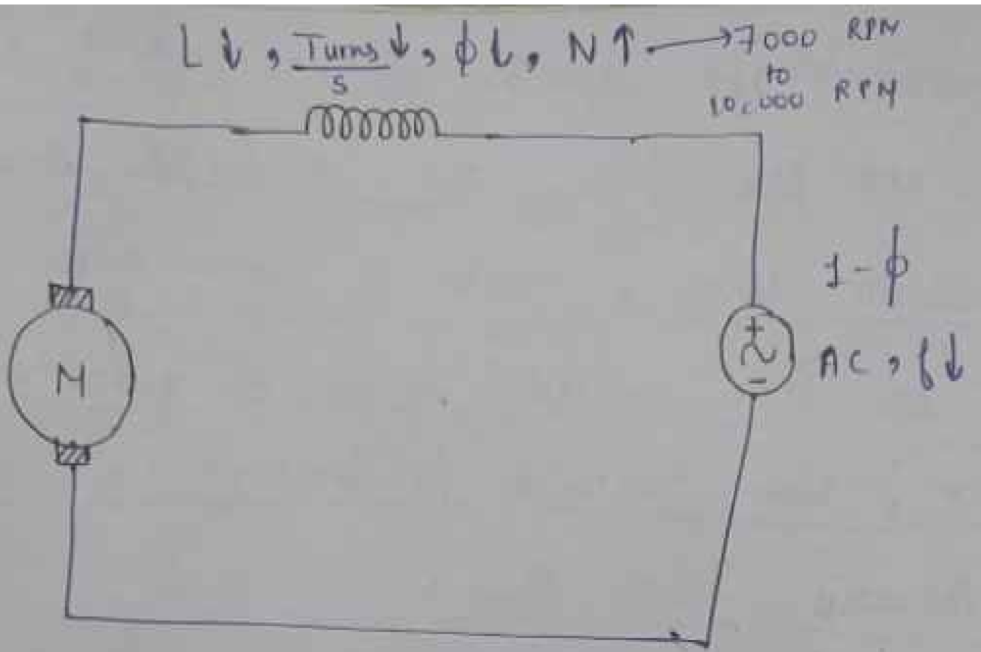
⇒ Low frequency operation of D.C series motor used in European railway to improve commutation, power factor and efficiency.

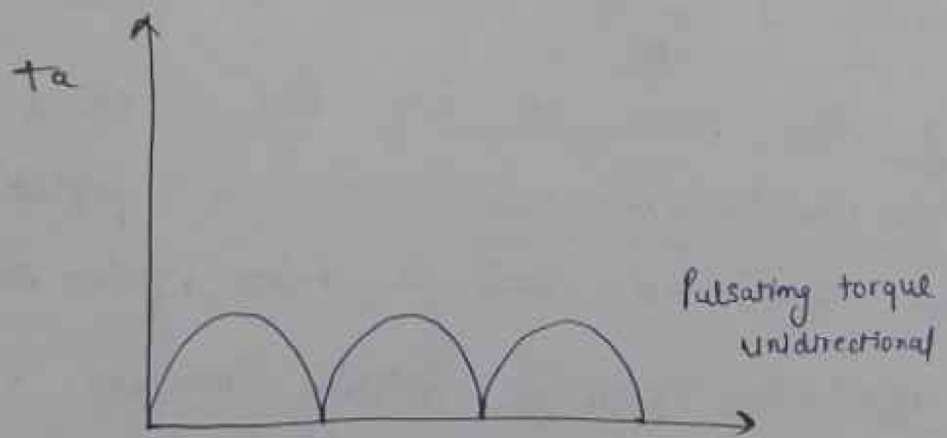
⇒ Work on both AC and D.C.

$E_b = V_t$ $\quad V_t = E_b + I_a R_a$ $\quad E_b = K \phi \omega$

$V_t - I_a R_a = E_b$

$$\boxed{\frac{V_t - E_b}{I_a} = R_a}$$





① Breaking :-

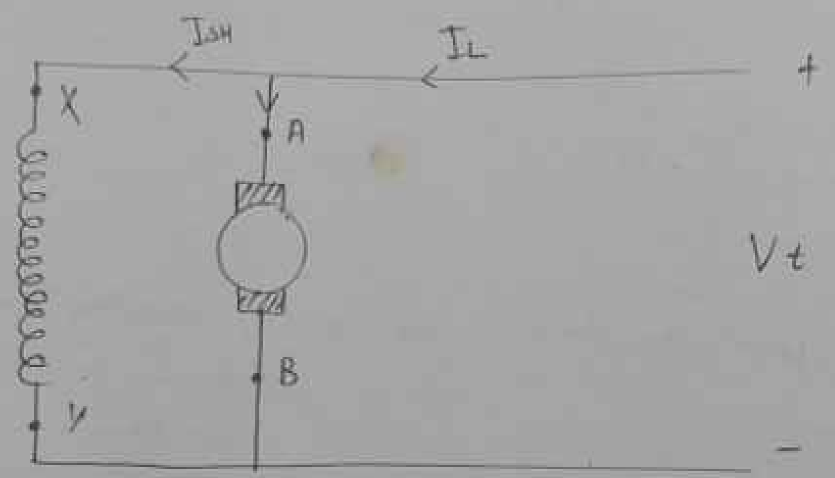
Plugging / counter current breaking :-

For breaking purpose the torque is to be negative.

So, the torque can be reversed by reversing field winding terminals or by reversing the armature winding terminals but the inductance of armature is low compare to field. So, armature terminals are to be reversed.

⇒ During plugging stored kinetic energy dessipate into heat.

Matering mode :-



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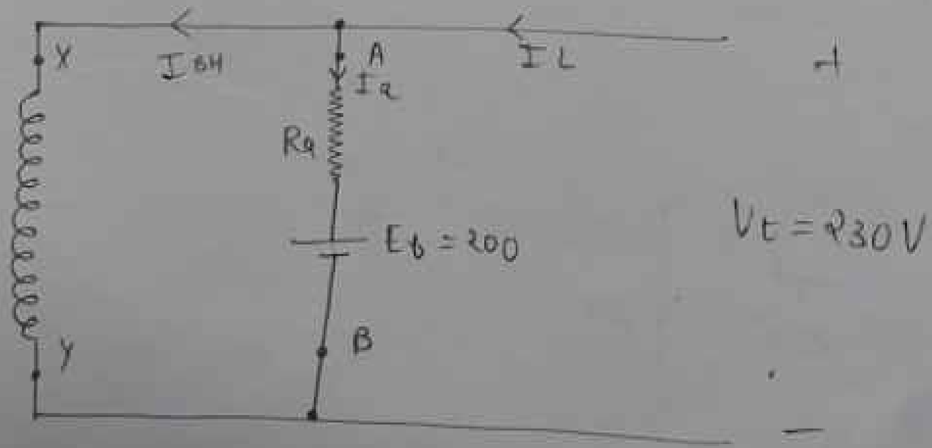
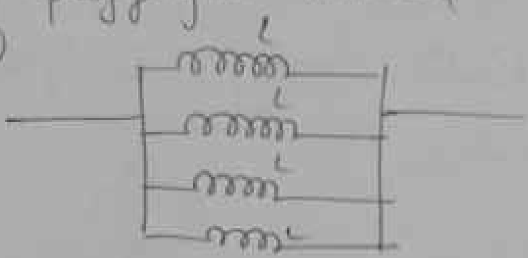


$$\boxed{I_a = \frac{V_t - E_b}{R_a}}$$

If plugging in armature



parallel path

$L_{eq} = L/4$

In a field.

$A = 1$

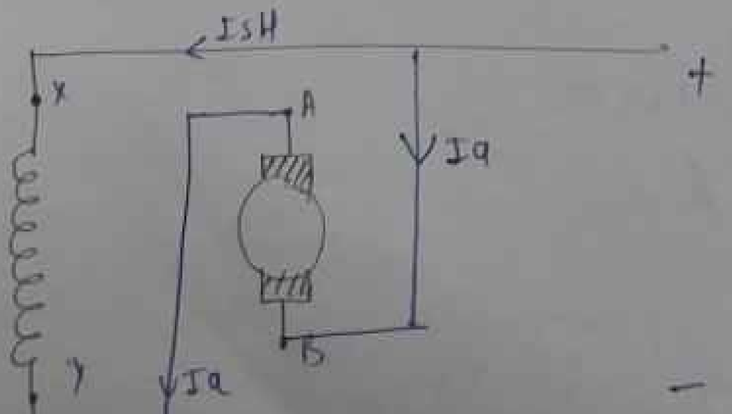
$\boxed{P.P}$

$L_{eq} = L$

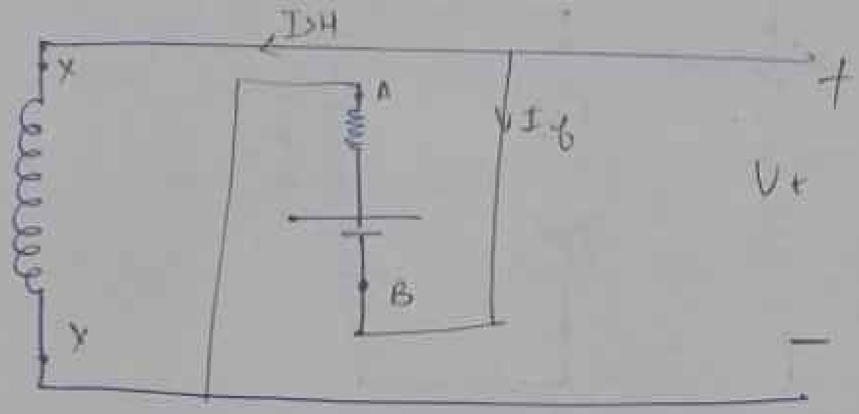
$\therefore \boxed{L_{field} > L_a}$

more oppose to reverse current. So, retarding time increases and it takes more time.

Breaking mode :-



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



$$\boxed{I_b\uparrow = \frac{V_t + E_b}{R_a} = \frac{230+200}{R_a}}$$

voltage added so, $I_b \uparrow$

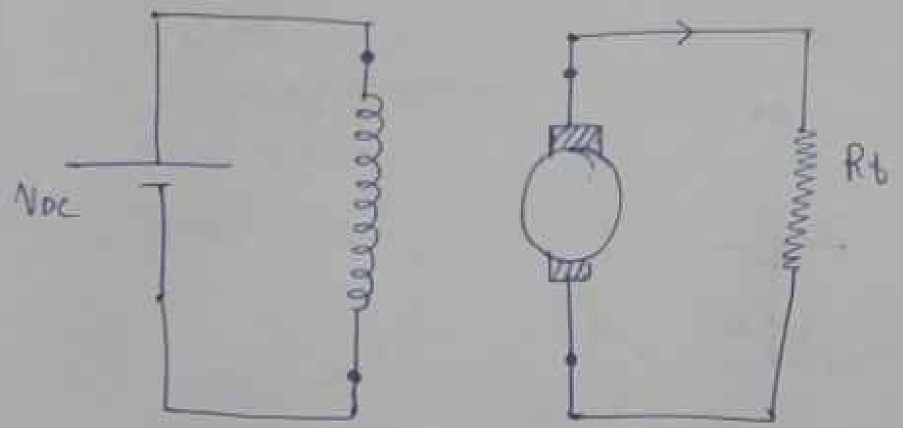
In motor is $\boxed{I_a \propto V_t - E_B}$

$$\boxed{\uparrow T_a = K_a \phi I_b \uparrow}$$

so, retardation or plugging takes place fastly.

Dynamic method :-

For dynamic breaking armature is disconnected from the supply and external resistor R_b is connected. so, it act as seprated excited D.C generator and its stored kinetic energy waste in losses.



Regenerative breaking :-

In case of motor speed become more than its noload speed than it will work as D.C generator. So, a reverse torque experience by rotor. And its speed control automatically.

Condition for D.C shunt generator voltage build up :-

① Pole should contain residual flux which is obtained by field flashing (charging).

② Speed should be more than critical speed i.e

$$\boxed{N > N_c} \Rightarrow \boxed{E_g > V_{Drop}}$$

(3) Combined resistance of feild and armature should be less than ~~critici~~ critical resistance.

(4) * Feild and armature winding should be properly connected in such a way their initial mmf should add residual flux. Otherwise voltage build up is zero.

(5) Best condition for D.C shunt generator voltage build up initially noload is connected.

D.C series generator voltage build up conditions :-

following conditions are necessary :-

(1) Same

(2) Same

(3) Combined resistance of armature, series feild, load must be less than critical value. $\boxed{R_a + R_{se} + R_L < R_c}$

(4) same as previous

(5) Best condition for voltage build up in D.C series generator initially same load is connected.

① A D.C shunt generator build up voltage normally if its field winding is reversed then.

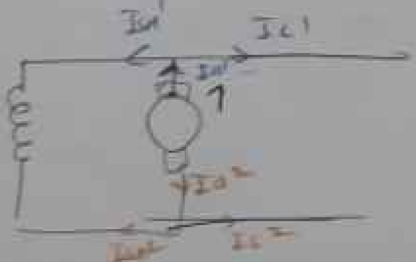
① Voltage, buildup normally.

② voltage build up normally in opposite direction.

③ No voltage build up but v/g ~~ar~~ across armature is 8 V.

④ Zero

Q If only direction of rotation is reversed.

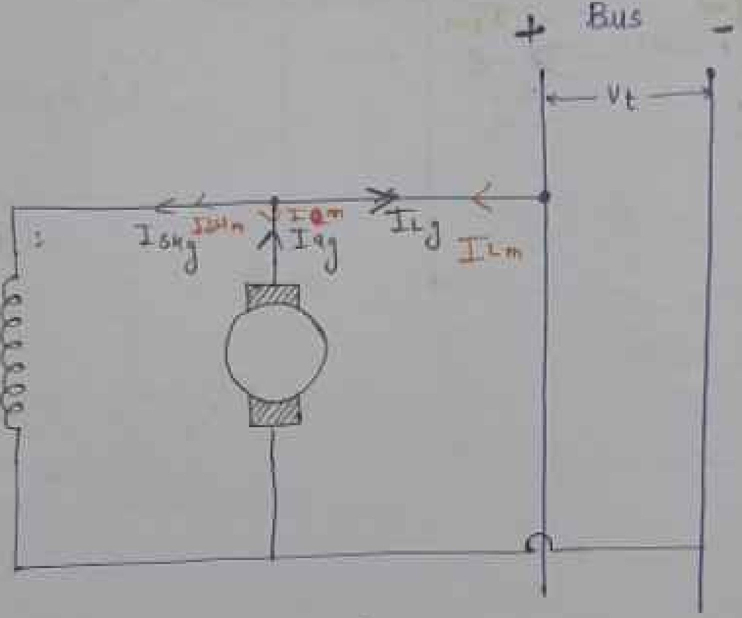


V. Build = Zero

Q If both direction of rotation and field winding terminals are reversed. both Residual and new current ~~an~~ flux oppo

ⓐ Voltage build up ~~a~~ normally

(1) A D.C shunt generator supply power to a bus bar and if its mechanical input fail then. It will work as a D.C shunt motor running in the same direction.



$T = K\phi I_a$

$T = \cancel{K\phi I_a}$

$T \propto \phi I_a$

$T = -\phi$

Generator ($E_g > V_t$)

as E_b becomes greater than V_t Motor ($E_b > V_t$)

Generator

$$\boxed{(T_a)_g = K\phi I_a}$$

$\oplus$ $\oplus$ $\oplus$

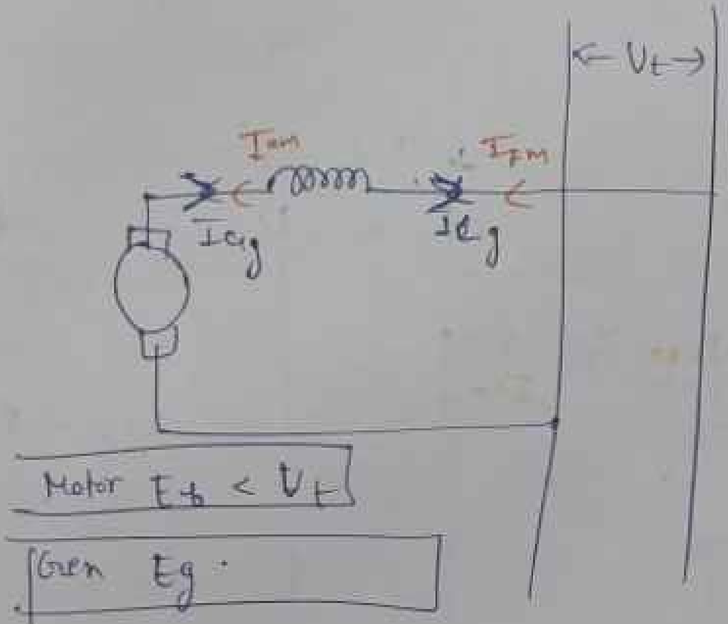
Motor

$(T_a)_m = \ominus K_a \phi I_a$

$\oplus$ $\oplus$ $\ominus$

Same direction

Q If a D.C series generator supply power to a bus bar then if its prime mover fail. It will work as



$(T_a)_g = K \phi I_a$

$= K \phi I_a$

$\ominus \quad \ominus$

$\boxed{(T_a)_m = \ominus K \phi I_a}$

$\ominus \quad \ominus$

= If its prime mover fails it will works as D.C series motor running in opposite direction.

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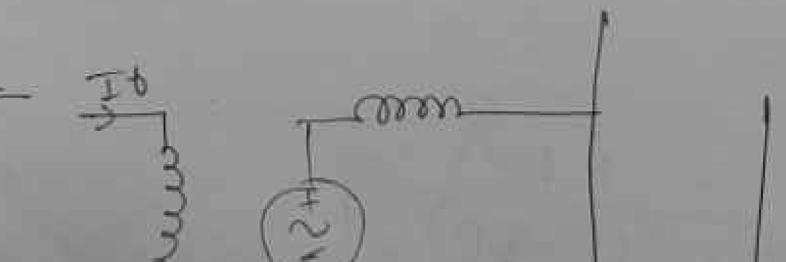
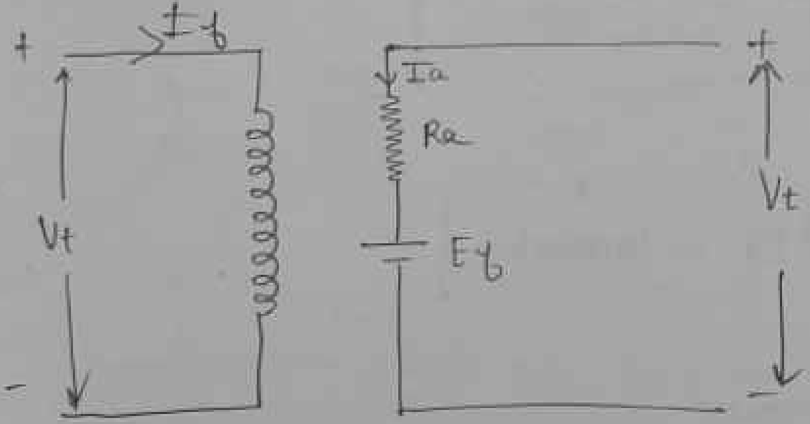


If E_f becomes less than V_t then ~~motor~~ generator becomes motor and E_f becomes E_b

If field winding of D.C motor directly dis connect from supply
its speed ∞ increases



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

$$E_b = V_t - I_a R_a$$

$$\boxed{K\phi\omega = V_t - I_a R_a}$$

By variation in armature terminal voltage

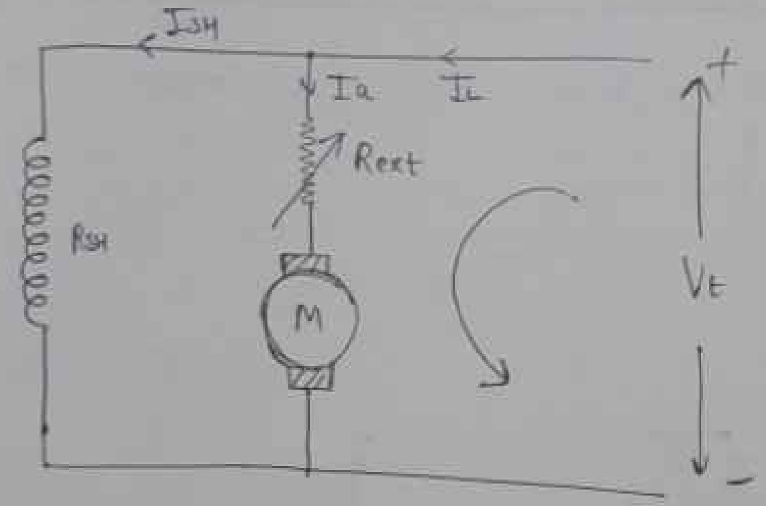
$$\boxed{\omega = \frac{1}{K_a\phi}(V_t - I_a R_a)}$$

By variation in armature resistance

flux weakening method

① By variation in armature resistance :-

$I_r = sE_2$



$$\boxed{T_a = K\phi I_a = \text{constant}}$$

$$\boxed{I_a = \text{const}}$$

By KVL

$$V_t = I_a(R_{ext} + R_a) + E_b$$

$$E_b = V_t - I_a(R_{ext} + R_a)$$

$$\boxed{\downarrow \omega = \frac{1}{K_a\phi}\left[V_t - I_a(R_{ext} + R_a)\right]}$$

below rated

$$P_m = E_b I_a = K_a \phi \omega I_a$$

$$\boxed{\downarrow P_m \propto \omega \downarrow}$$

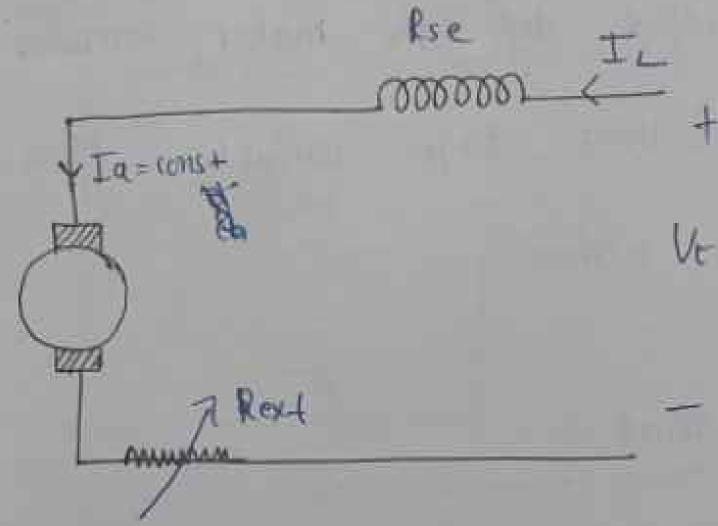
power o/p decreases

$P_i = V_t I_L$

$$\boxed{P_i = V_t (I_a + I_{sh})}$$

$P_i \rightarrow$ constant

D.C series motor :-



$$V_t = I_a(R_a + R_{ext} + R_{se}) + E_b$$

$$E_b = V_t - I_a(R_a + R_{ext} + R_{se})$$

$$\boxed{\omega = \frac{1}{K_a \phi}\left[V_t - I_a(R_a + R_{ext} + R_{se})\right]}$$

Result same as ~~g~~ previous.

Result → 4 :-

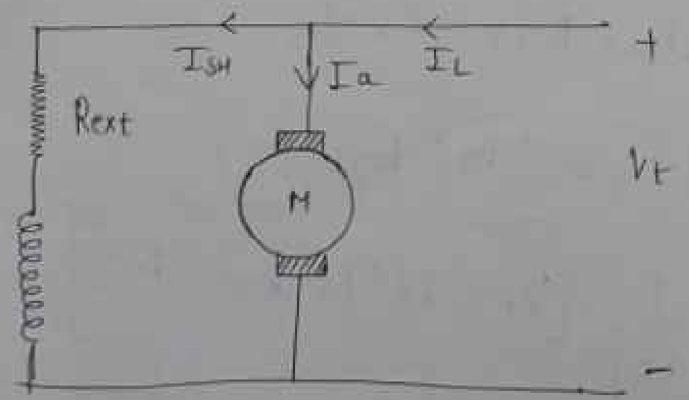
① Since armature current remains constant. So, power delivered from supply mains to the motor remains constant.

② The power output decreases in proportional to speed

③ Since, torque developed by the motor remains constant. So, it is known as constant torque variable power drive.

④ It is less efficient method.

Flux weakening method :-



$$I_{sh} = \frac{V_t}{(R_{sh} + R_{ext})}$$

$$\boxed{\downarrow \phi_{sh} \propto I_{sh} \propto \frac{1}{(R_{sh} + R_{ext})\uparrow}}$$

Induction motor speed control all method = Torque always const

$$V_t = I_a R_a + E_b$$

$$\omega = \frac{1}{K_a \phi}(V_t - I_a R_a)$$

$R_a \approx 0$ (negligible resistance)

$$\cancel{\omega = \frac{V_t}{K_a\phi}} \quad \boxed{\omega = \frac{V_t}{K_a \phi}} \Rightarrow \boxed{\omega\uparrow \propto \frac{1}{\phi\downarrow}}$$

abourrated .

$$P_m = T_a \times \omega$$

$$\boxed{\omega = \frac{P_m}{T_a}}$$

if wct changes then for const P_{out} T_a changes

$$\boxed{\downarrow T_a \propto \frac{1}{\omega\uparrow}}$$

$$\boxed{P_m = E_a I_a = \text{constant}}$$

$$\boxed{\uparrow I_a \propto \frac{1}{E_b\downarrow}}$$

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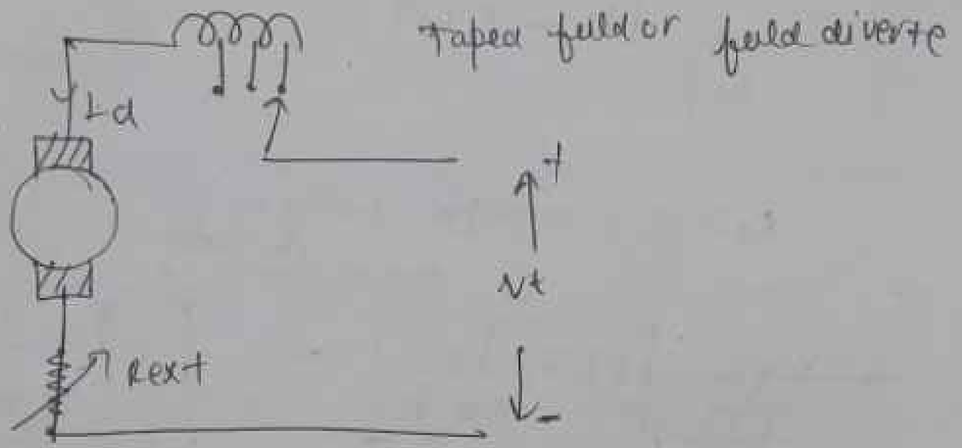
~~165~~553

D.C series motor :-



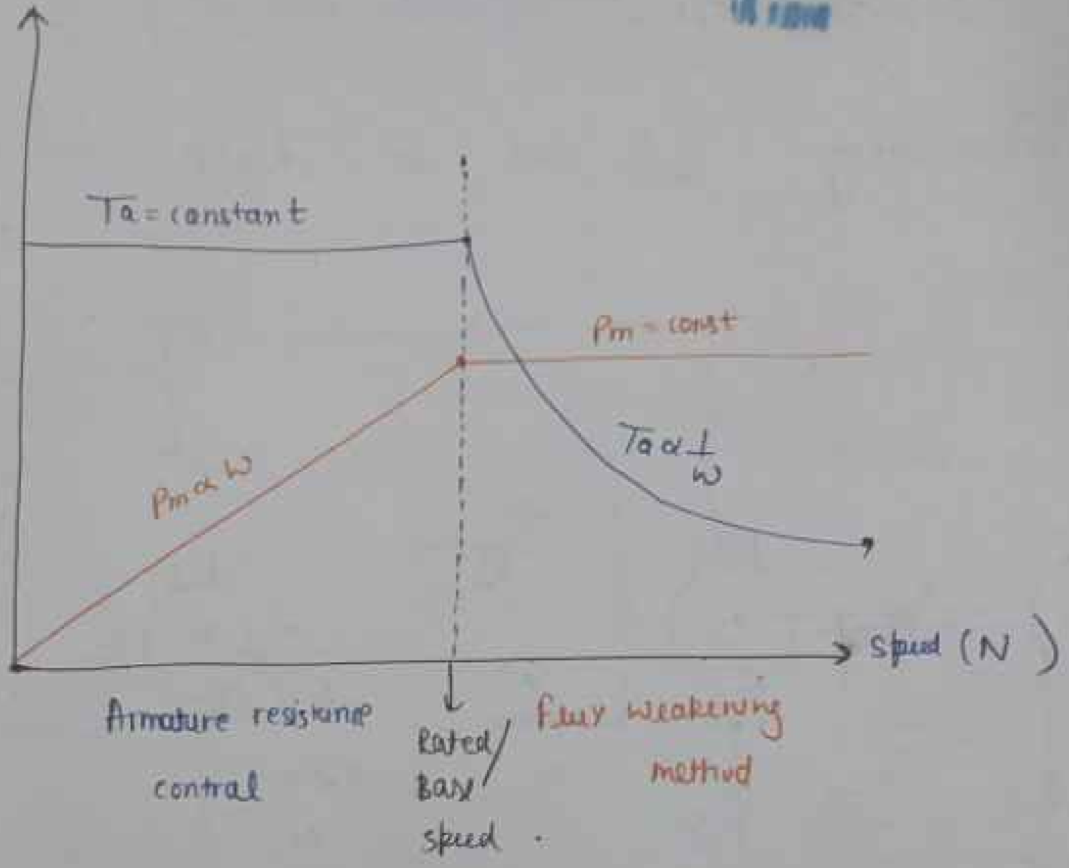
Results :- In this method mechanical power developed by motor remains constant but torque developed by armature decreases in inversely proportional to speed.

⇒ Armature current increases as speed increases.

⇒ Speed obtained are above rated.

⇒ Top speeds are obtained at very high armature current. So, armature gets overheated.

In these methods P_m or T_e constant



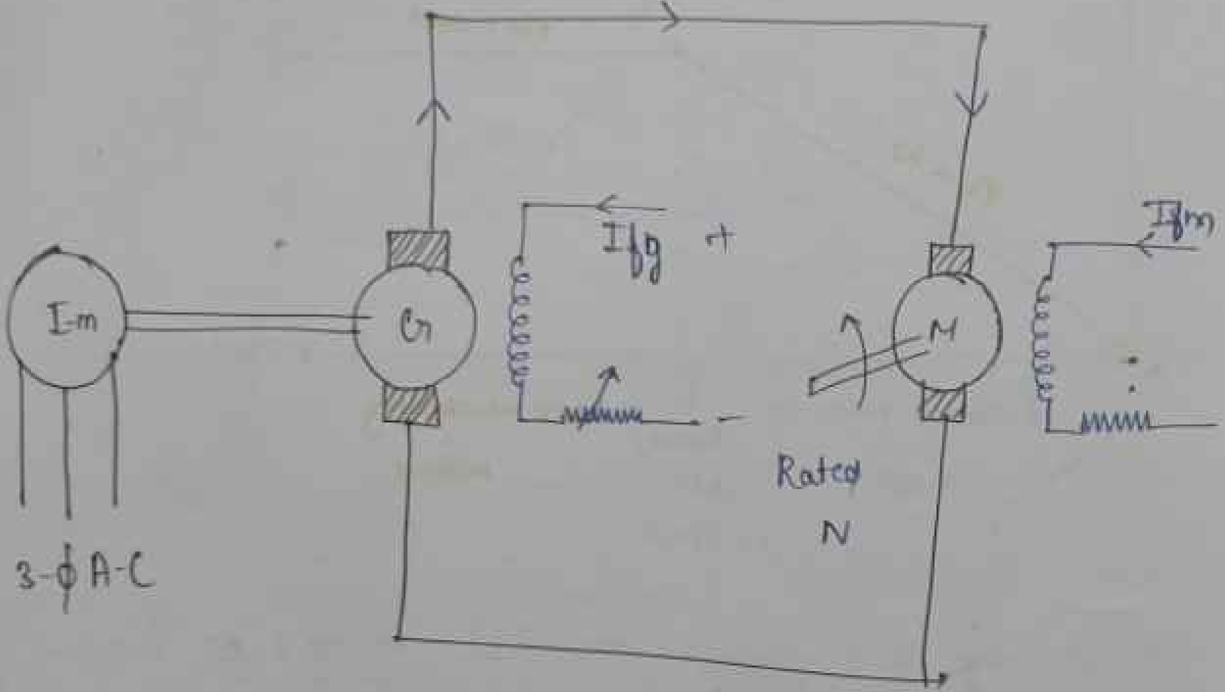
Speed control by variation in armature terminal voltage or Ward-Leonard method of speed control :-

=> Speed below rated speed are obtained by decreasing the feild flux of a D.C generator and above base speed are obtained speed are obtained by decreasing the field flux of D.C motor.

→ This system of speed control is best suited for unlimited range of speed control in both the direction. So it is used in industries such as rolling ~~mell~~ meal

• paper machiner.

→ Disadvantage is due to higher initial cost.



$$Vt = Eb + (I_a R_a)$$

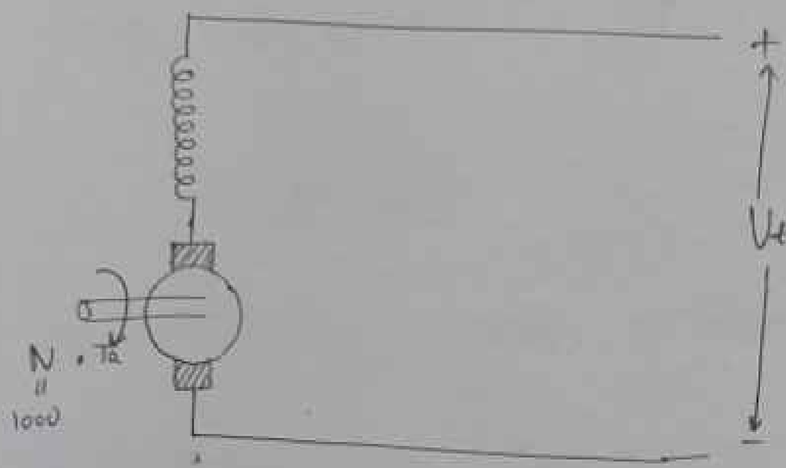
$$I_a R_a \approx 0$$

$$Vt = Eb$$

$$Vt = K\phi\omega$$

$$\boxed{\downarrow Vt \propto \omega \downarrow}$$

Speed control of traction motor :-



$V_t = E_b + I_a R_a$

$V_t \propto E_b$

$V_t = K_a \phi \omega$

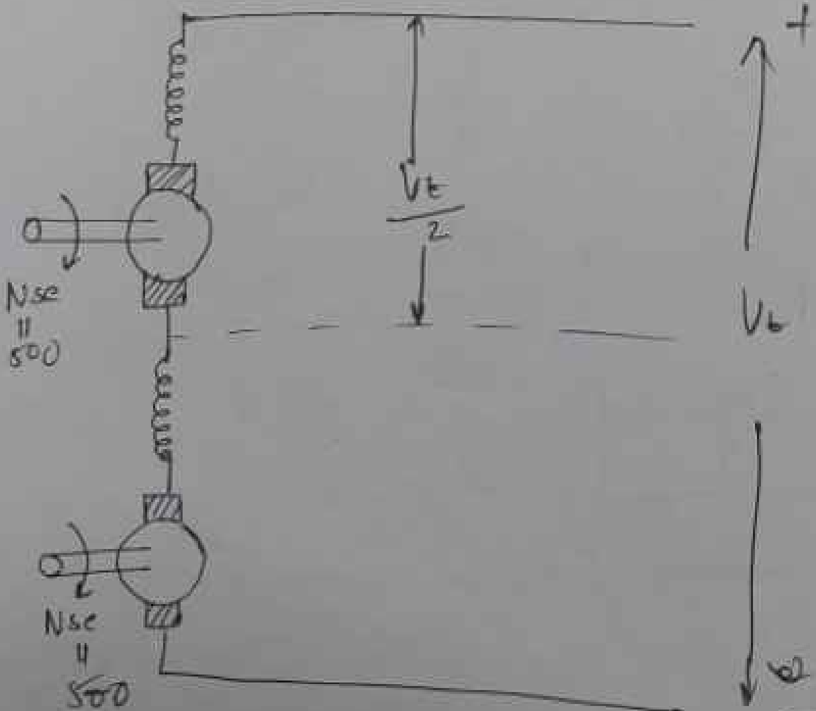
$\omega \propto \frac{V_t}{\phi}$

$$\boxed{N \propto \frac{V_t}{I_a}} \quad - (1)$$

Connected in series :- (identical)

$T_a = K \phi I_a$

$$\boxed{T_a \propto I_a^2} \quad - (2)$$



$~~Nse~~$ $N_{se} \propto \frac{V_t/2}{I_a}$

$N_{se} \propto \frac{V_t}{2 I_a}$

from (1)

$$\boxed{N_{se} = \frac{N}{2}}$$

from (2)

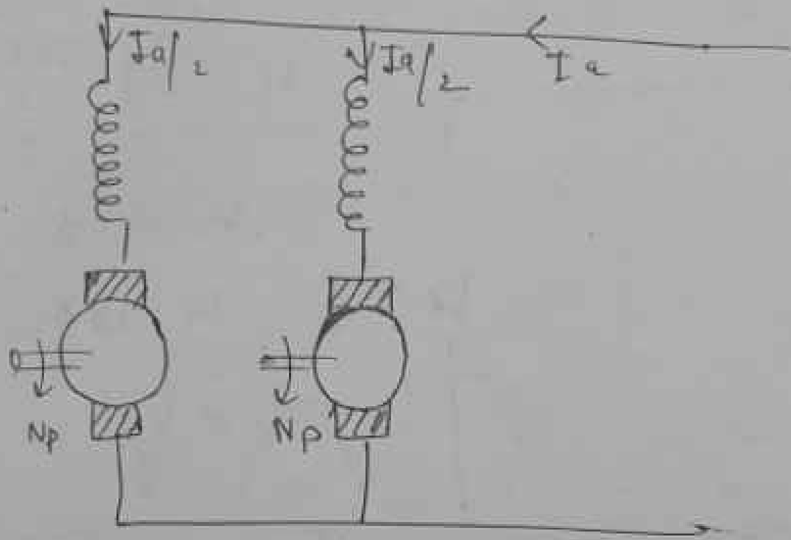
$(T_a)_{se} \propto I_a^2$

$$\boxed{(T_a)_{se} = T_a = \text{const}}$$

$\frac{V_t}{2}$ $E_b = K\phi\omega = V_t - I_a R_a$

$\omega \propto V_t$

Connected in parallel



$$N_p \propto \frac{V_t}{\frac{I_a}{2}}$$

$$N_p \propto \frac{2V_t}{I_a}$$

from ①

$$\boxed{N_p = 2N}$$

$$(T_a) \propto (I_a/2)^2$$

$$(T_a)_p \propto \frac{I_a^2}{4}$$

$$\boxed{(T_a)_p = \frac{T_a}{4}}$$

Result = $N_p = 4N_{se}$

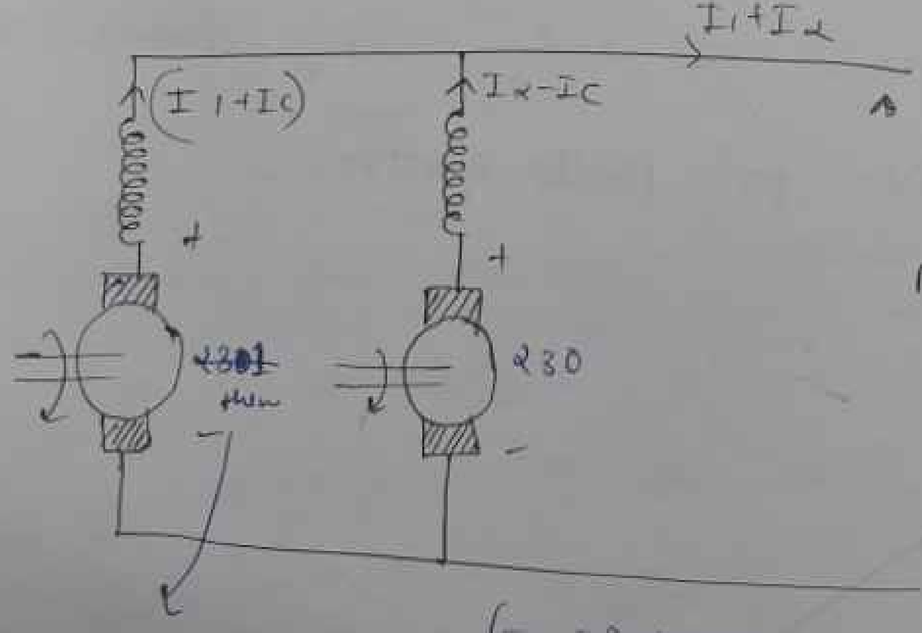
& $T_p = \frac{T_{se}}{4}$

Parallel operation of D.C generator :-

For parallel operation of D.C generator terminal voltage and polarity should be same

D.C series generator :-

For satisfactory parallel operation of D.C series generator it is necessary to connect the armature ~~ther~~ threw a heavy copper bar known as equalizing bar.



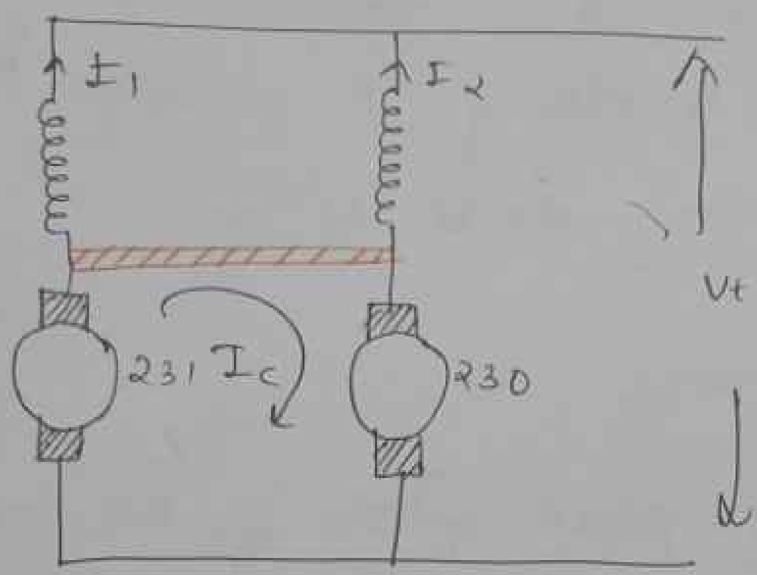
Noload.

Without equilising bar

(I_1+I_2) increases and $(I_2 \cdot I_C)$ decreases.

$\therefore E_{g1} = 235V$ and $E_{g2} = 225$

and this carry one and a stage comes ~~motor~~ generator become (+)

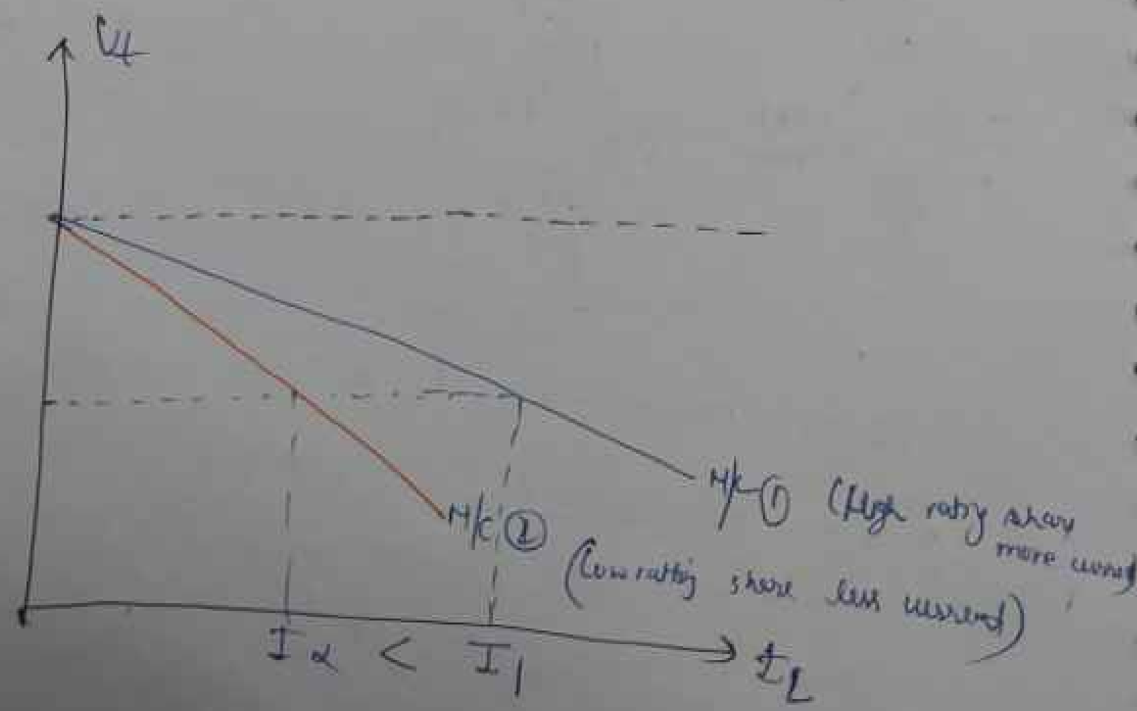


with ~~equal~~ equalizer bar

then Ic gets the shortest path.

Shunt generators in parallel:

D.C shunt generators are having drooping characteristics. So these are popular for parallel operation.



Special machine :-

Repulsion type motor :- In A.C series motor rotor and stator windings are conductively coupled but incase of repulsion motor both stator and to rotor windings are inductively coupled means it works on transformer action. According to construction and working principle repulsion type motors are of two types.

① **Repulsion motor :-**

- **Principle :-** Start and run on repulsion principle

② **Repulsion start Induction run motor :-**

Principle :- It start on repulsion principle but at a particular speed it runs as single phase induction motor.

Construction :- Stator having non salient poles and a single phase distributed winding similar to single phase induction motor.

⇒ Stator windings are connected to 1-ϕ A.C supply

⇒ The rotor or armature is similar to D.C motor having commutator and brushes

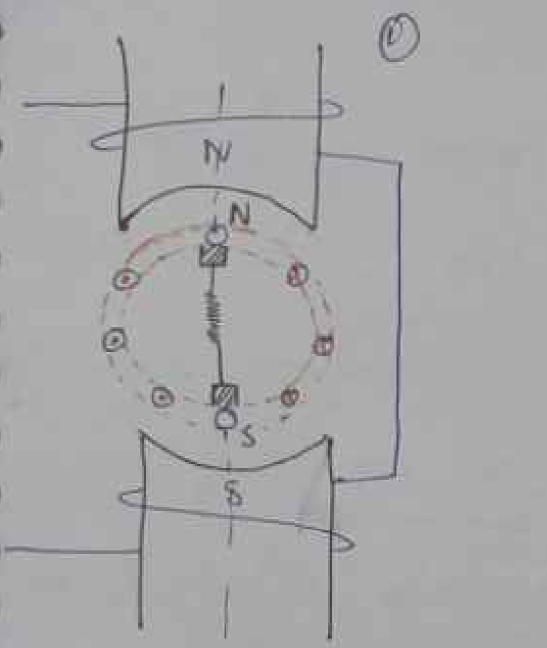
⇒ The brushes are short circuited by a low resistance

⇒ Repulsion motor runs below synchronous speed

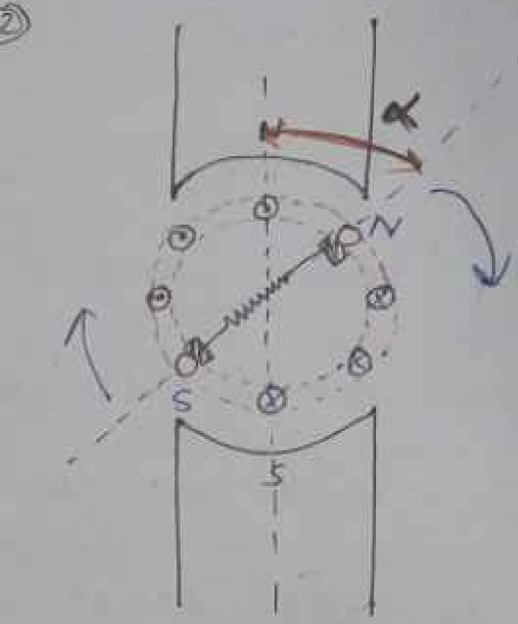
it ~~dofe~~ develop the torque in the direction which the brushes are shifted used to when high starting torque and adjustable speed required. So, used in oil winder.

⇒ The commutation is best when the ~~ro~~ rotor runs near to Ns. By shifting the brushes speed, torque, direction of rotation ~~of~~ can be controlled

⇒ Since it runs below synchronous speed. So, commutation problem. So, demand more maintenance, runs with vibration and noise

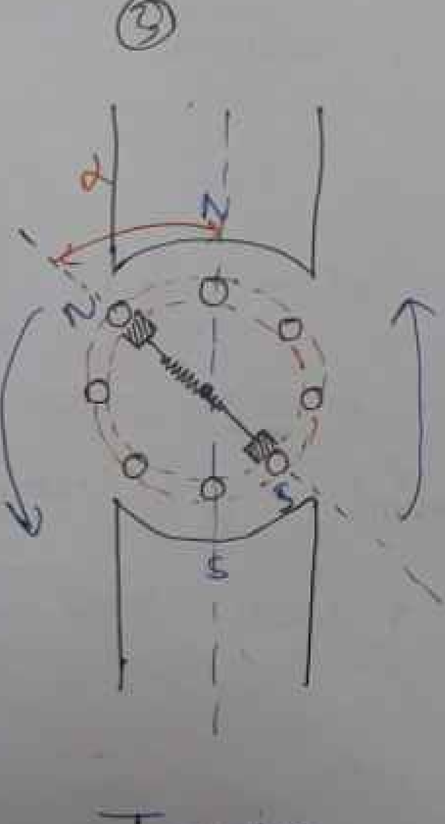


$\boxed{T = 0}$ $\because$ $\boxed{\alpha = 0}$



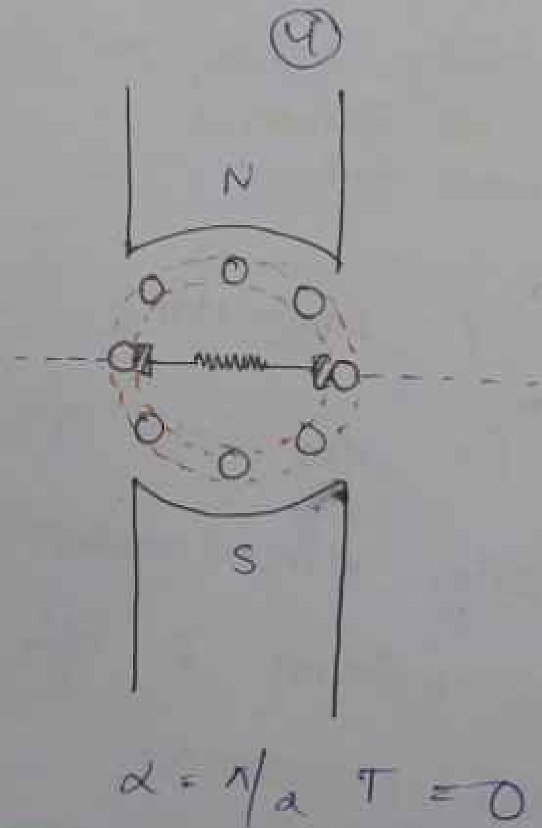
$T \neq 0$ (+ive)

$0^\circ < \alpha < 90^\circ$



$T = -\text{ive}$

$-90^\circ < \alpha < 0^\circ$



$\alpha = \pi/2$ $T = 0$

$$\boxed{\begin{array}{c} T \propto \sin\alpha\cos\alpha \\ \text{or} \\ T \propto \sin 2\alpha \end{array}}$$

$\boxed{T_{max} \text{ at } \alpha = 45^\circ}$

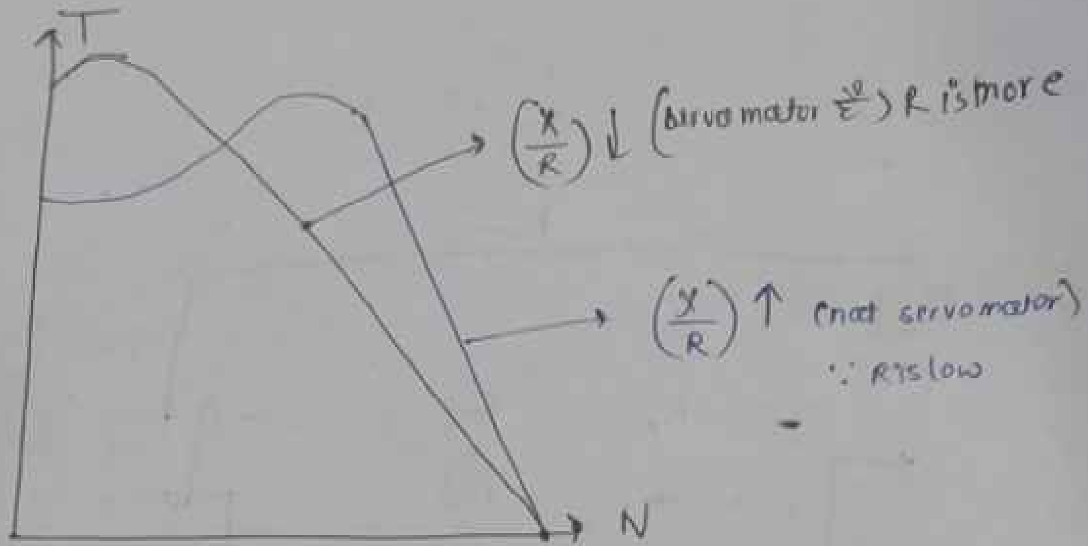
Servo motor :-

→ These motors are used in control system and these motors respond to the error signal abruptly known as servo motor these motors are designed with high torque to inertia ratio. So, rotor of servo motor designed with long axial to length and smaller diameter to reduce rotor inertia.

⇒ Used in radar, process controller, tracking and guiding system robotics, computers, automatic manufacturing.

⇒ A.c servomotor :-

A.c servo motor is a two phase induction motor having thinner conductor bar in squirrel cagged rotor. so, resistance is high which gives a linear torque slip characteristics.

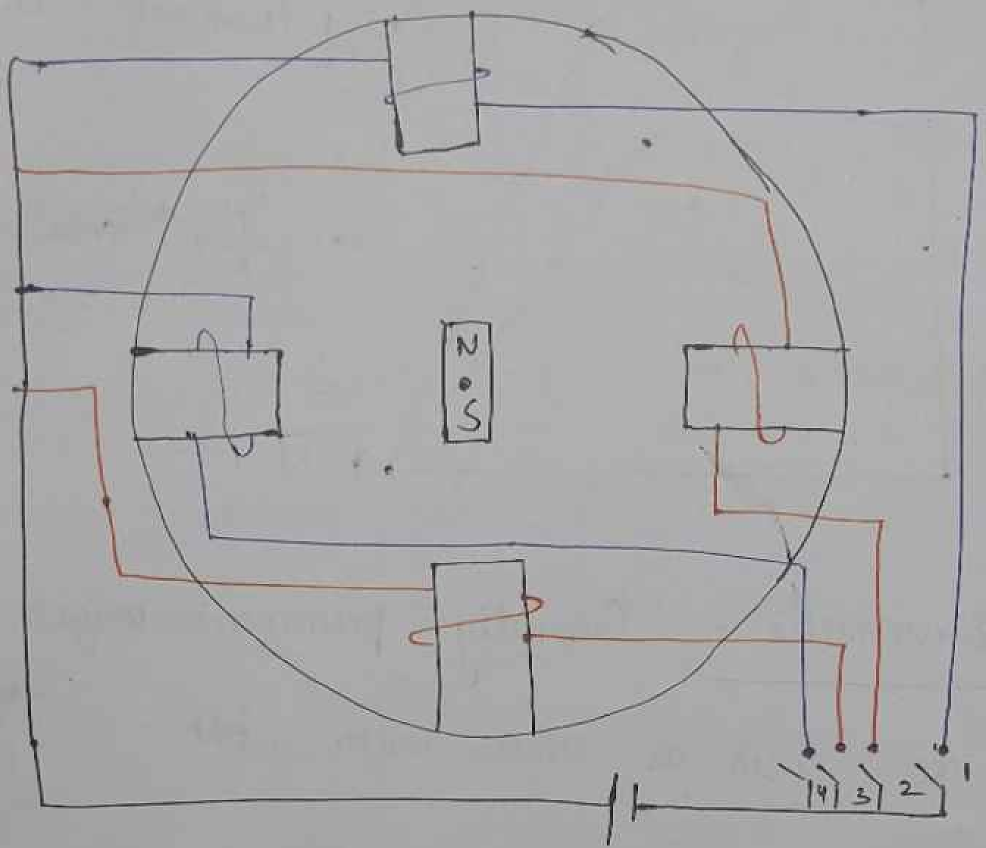


② D.C Servomotor :- Generally permanent magnet D.C motors are used as servo motor. ~~For~~

⇒ For fast response armature control methods are used.

Stepper motor :- Stepper motor does not rotate continuously but rotate in discrete (steps) manner.

⇒ The rotor of a stepper motor is a permanent magnet



α = The angle by which rotor rotates for 1 pulse
↓ step angle.

$$\boxed{\alpha = \left(\frac{T_s - T_r}{T_s \cdot T_r}\right) \times 360^\circ}$$

T_s = No of stator teeth | Pole

T_r = No of Rotor teeth.

$$m = \frac{T_s}{T_s - T_r} = \text{No of phases}$$

$$\boxed{\alpha = \frac{360^\circ}{m \cdot T_r}}$$

→ The rotor na winding, no commutator and no brushes.

→ These f are more popular in computer industry because they can be easily controlled by computers, micro ~~tot~~ processors and programable controllers. (compactibility with digital system)

⇒ α is from $.72^\circ$ ~~to~~ to 90° but most common it is $1.8^\circ, 2.5^\circ, 7.5^\circ, 15^\circ$.

⇒ Higher the resolution higher the accuracy of positioning of an object by the motor.

Resolution = No of steps per revolution

$$\boxed{R = \frac{360^\circ}{\alpha}}$$

motor shaft speed (n) = Rotation per second.

$$\boxed{n = \frac{\alpha f}{360^\circ}}$$

f = stepping frequency (pulse per second)
(Pulse rate)

$$\boxed{\text{Step angle } (\alpha) \propto \frac{1}{\text{No of steps}}}$$

$$\boxed{\text{Resolution} \propto \text{No of steps}}$$

$$\boxed{\text{Accuracy} \propto \text{Resolution}}$$

∴ {more no of steps = more resolution = more accuracy}

Q A stepper motor has a step angle of 2.5°. Find its resolution.

$R = \frac{360}{2.5} = 144$

$$\boxed{R = 144 \text{ steps per rev}}$$ Ans

Q In above question find no of step require for the shaft to make 25 revolution.

∵ 1 revolution = 144 steps

~~∴ 25 steps = 144 × 25~~

25 steps = 144 × 25 = 3600

= 3600 Steps Ans

Q In above question find shaft speed of ~~at~~ the stepping frequency is 3600 PPS.

$$n = \frac{\alpha f}{360}$$

$$= \frac{2.5 \times \cancel{3600}^{10}}{\cancel{360}}$$

$$\boxed{n = 25 \text{ RPS}}$$

Q A single stack 3-ϕ ~~VR~~ variable reluctance has a step angle of 15° find no of its stator and rotor poles $T_s, T_r = ?$

$$m = \frac{T_s}{T_s - T_r}$$

$$\alpha = \frac{(T_s - T_r)\, 360°}{T_s \cdot T_r}$$

$$\alpha = \frac{1}{T_r \cdot m} \cdot 360°$$

$$T_r\, 15' = \frac{\cancel{360}^{120}}{\cancel{3}}$$

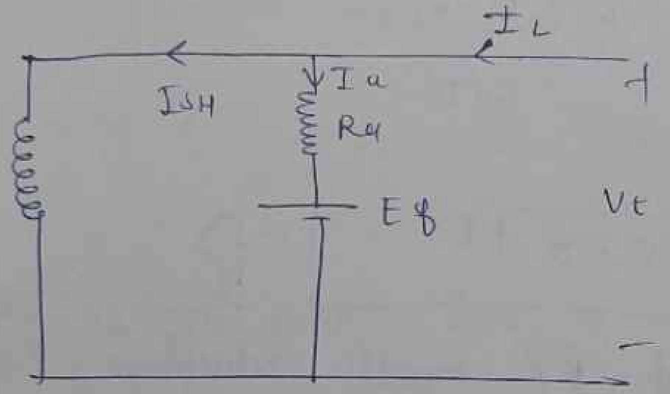
$$\boxed{T_r = \frac{120}{15} = 8.}$$

$$3 = \frac{Ts}{Ts-8}$$

$$3Ts - 24 = Ts$$

$$\boxed{Ts = 12}$$

(a)



$$V_t = E_g + \underbrace{I_a R_a}_{\approx 0}$$

$$V_t \approx E_g$$

$$V_t \approx K_a \phi \omega$$

$$V_t \propto \phi \cdot \omega$$

$$\boxed{\omega \propto \frac{V_t}{\phi}} \quad (1)$$

$$\phi \propto I_{sh} = \frac{V_t}{R_{SH}}$$

$$\phi \propto V_t$$

$\omega = \text{constant}$

$T_a = K_a \phi I_a = T_L$ (for operation)

$T_L \propto \omega^2$

$K_a \phi I_a \propto \omega^2$

$I_a \propto \frac{1}{\phi} \propto \frac{1}{V_t}$

$\downarrow$ 2 times

$\downarrow$ आधा

3

7