TURBO
Continuous change

## ملاحظات :

# مبادئ الآلات الكهربائية

# Electric Machinery Fundamentals

للدكتورة زهرة غانم

اللجنة الأكاديمية لقسم الهندسة الصناعية

2025

TurboIEG.Com

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# Chapter one: Introduction To machinary

all electric machines rotate around an axis, called (shaft)

⟹ Basic of Rotational motion :.

① angular position ($\theta$) → (deg, rad).

the angle at which the object Rotate : or oriented.

② angular velocity ($\omega$) → (rad/s) (speed)

Rate change of angular position wR To time

ccw → ⊕

$$\omega = \frac{d\theta}{dt}.$$

for electrical mechines.

$\omega_m$ : angular velocity (rad/s)

$n_m$ : " " (rev/min)

$f_m$ : " " (rev/sec)





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$n_m = 60 f_m$

$f_m = \frac{\omega_m}{2\pi}$

$n_m = \frac{60}{2\pi} \omega_m$

(3) Angular acceleration ($\alpha$) → (rad/s²)

the rate change of angular velocity.

$\alpha = \frac{d\omega}{dt}$.





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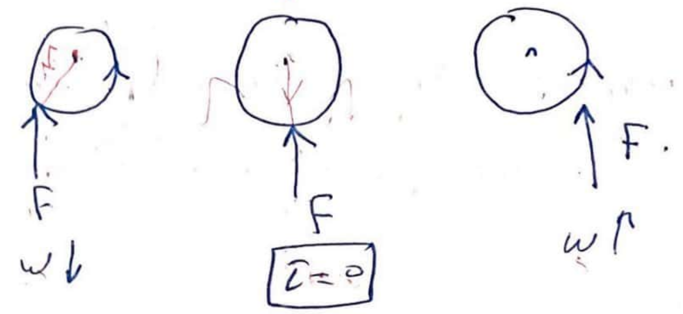
4) Torque ($\tau$) $\longrightarrow$ (N.m)

"Twisting force" the product of the force applied to the object and the smallest distance between the line of action of the force and the object's axis of rotation.

$\tau = F r \sin\theta \longrightarrow$ Newton.meter. (N.m)




5) work (w) $\longrightarrow$ (J)

$w = \int \tau \, d\theta \longrightarrow \boxed{w = \tau\theta}$ Joule.

6) power (P) $\longrightarrow$ (J/s = watt)

$p = \frac{dw}{dt} = \tau \frac{d\theta}{dt} = \tau\omega$.

rate change of work per unit time.





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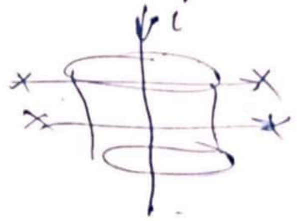
## (1.4) magnetic field :-

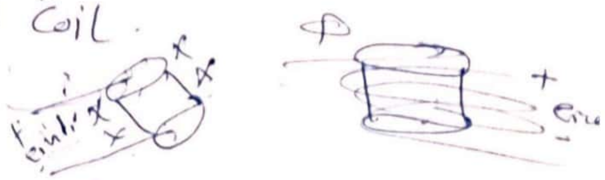
magnetic field is used in machines (like Motors and generators) and in transformers

<u>four Basic</u> principles of describes how magnetic field used in these devices :-

① current - carrying wire produces a magnetic field in the Area around it .




② time changing magnetic field Induces a voltage in a coil of wire if it passes through that coil .




①, ② are the principles of Transformer .

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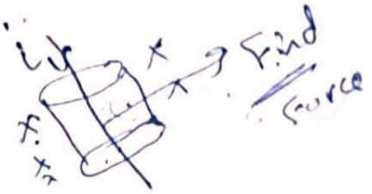
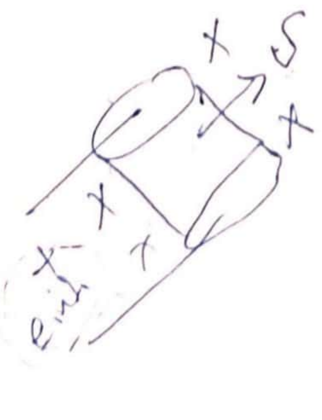
(3) A ~~ac~~ current carrying wire in the presence of amagnetic field has aforce Induced on it (Basic of Motor)




(4) A moving wire in the presence of a amagnetic field has avoltage Induced in it
⇒ (Basic of Generator).







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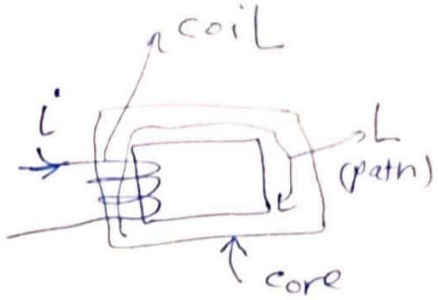
# * Production of a magnetic field

Ampere's law $\int H \cdot dL = I_{net}$.




H: magnetic field Intensity

L: path length of the core.

I: Current.

$$\boxed{H = \frac{Ni}{L}}$$

current
coil of wire cuts the path N times.

H $\longrightarrow$ Amper.Turns/m
(A.Turns/m)

the flux density in the core (B)

$$\boxed{B = \mu H}$$

B: flux density

$\mu$: magnetic permeability (henry/m)

B $\rightarrow$ henry.A.Turns/m2
$\rightarrow$ weber/m² $\Rightarrow$ Tesla (T)

$\mu_0$ for free space $\rightarrow$ $\mu_0 = 4\pi \times 10^{-7}$.

relative permeability $\mu_r = \frac{\mu}{\mu_0}$ $\rightarrow$ for ferromagnetic material

* for steel $\mu_r = 2000 \rightarrow 6000$





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$$B = \mu H = \frac{\mu N i}{L}$$

Total flux in the core $\Phi$

$\boxed{\Phi = BA}$ $\quad \Phi = \frac{\cancel{B}\mu N i A}{L}$

$\boxed{\Phi \longrightarrow \text{weber}}$

To find the total flux in the core $\Rightarrow$ $L_c$, $\mu$, $i$, $A$ > known

~~For to simply~~

convert magnetic circuit To Electrical circuit for accurate calculation of the $\Phi$





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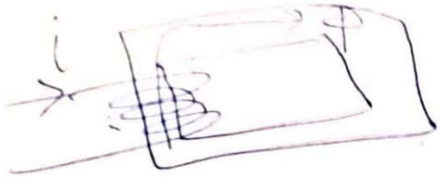
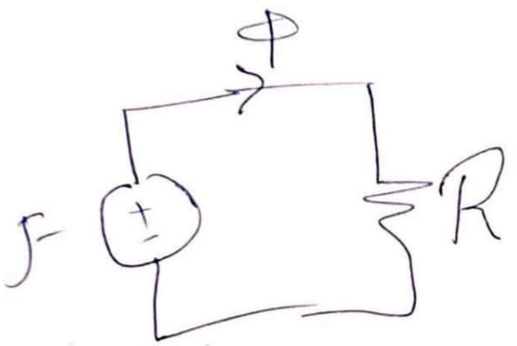



$\Rightarrow$ $Ni$ is the force to get the flux

$\mathcal{F} = Ni$ magnetmotive force (Ampere.Turns)

$\Phi \rightarrow$ like electrical current.

path $\rightarrow$ like $R$
Comp




$$\Phi = BA = \frac{\mu A N i}{L} = \underbrace{\frac{\mu A}{L}}_{\mathcal{R}} \mathcal{F}$$

$$\Rightarrow \mathcal{F} = \Phi \mathcal{R}$$

$$\Rightarrow \mathcal{R} = \frac{L}{\mu A}$$ Reluctance equivalent to electrical Resistance $R$

$\mathcal{F} \rightarrow$ equivalent to $\underline{V}$

$\Phi \rightarrow$ equivalent to $I$.





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$R = \frac{L}{\mu A}$ $\quad$ $R = \frac{F}{\phi} = \frac{\text{Ampere turns}}{\text{weber}}$

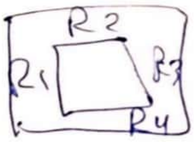
$\boxed{R \longrightarrow \text{Amp. Turns/Wb}}$ unit

$P = \frac{1}{R} \longrightarrow$ permeance.

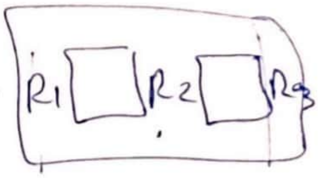
$\Rightarrow$ R like Electrical Resistance.

for series $R_{eq} = R_1 + R_2 + \cdots$

for parallel $\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots$

series $\longleftarrow$


the same flux

parallel. $\longleftarrow$


different flux

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Calculations of the flux in the core are always approximation → Reasons

① R is not accurate → corners

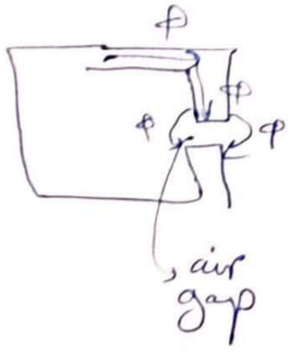
② μ is not constant Φ.

③ Leakage fluxes neglected.

④ effect of the air gap in the core increasing area of flux.

⇒ fringing the air gap.

تهزيب





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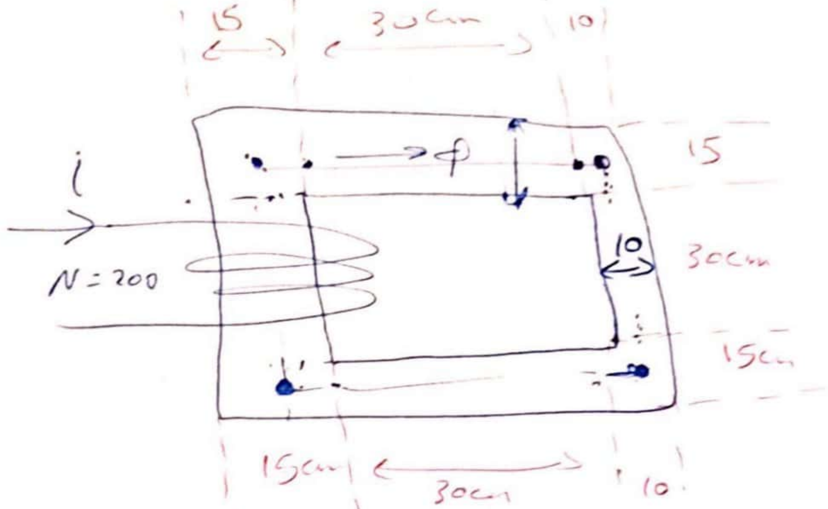
# Ex




depth = $\boxed{10cm}$

$\mu_r = 2500$

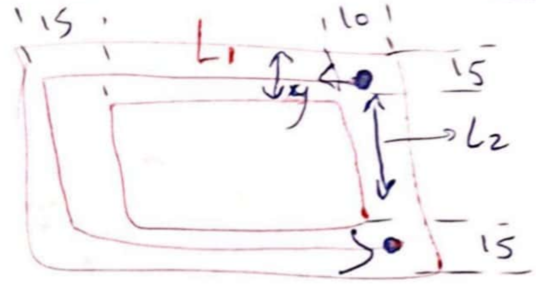
$I = 1A$

find Total flux ??

$\boxed{\mu = \mu_0 \mu_r}$

$\boxed{\text{Area}}$ أهم شئ ملاحظة

$$R_1 = \frac{L_1}{\mu A_1} \rightarrow \mu = \mu_0 \mu_r$$




$$L_1 = 5+30+7.5+7.5+30+7.5+7.5+30+5 = 1.3m$$

$$R_1 = \frac{1.3m}{(4\pi \times 10^{-7})(2500)(0.015)}$$

$L_1 \rightarrow A_1 = 15 \times 10$

$L_2 \rightarrow A_2 = 10 \times 10$

$R_1 = 27600$ A.turns/wb

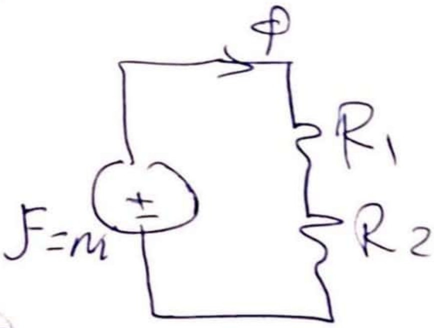
ضروري تحويل
Cm → m

$\boxed{\text{Area} = \text{depth} \times y}$

حسب $L_1$ من center لل center

$$R_2 = \frac{L_2}{\mu A_2} = \frac{7.5+30+7.5}{\mu (0.01)} = \frac{0.45}{(4\pi \times 10^{-7})(2500)(0.01)} = 14300 \text{ A.turns/wb}$$

$R_1$, $R_2$ series




$R_{eq} = R_1 + R_2$

$$\Phi = \frac{F}{R_{eq}} = \frac{Ni}{R_{eq}} = \boxed{0.0048 wb}$$





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ex

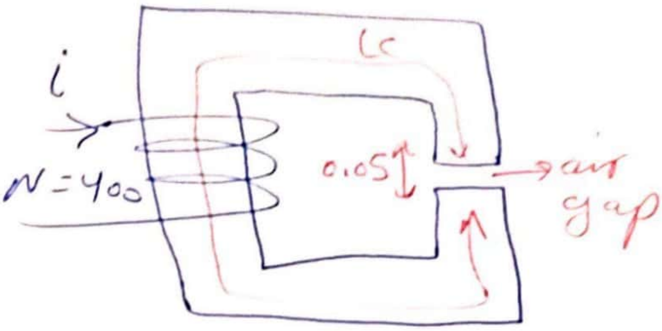
$L_c = 40cm$

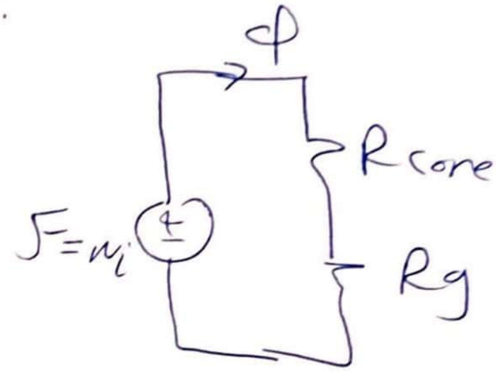
$Area = 12 cm^2 = A_c$

$\mu_r = 4000$

if fringing in the air gap Increasing Area by 5%.

find $i$ to get $0.5T$ in the air gap ??




$$R_{core} = \frac{L_c}{\mu A_c}$$

$$= \frac{(40\times10^{-2})}{(4000)(4\pi\times10^{-7})(12\times10^{-4})}$$

$R_{core} = 66300$ A.turns/Wb

$$R_g = \frac{L_g}{\mu_0 A_g} = \frac{(0.05\times10^{-2})}{(4\pi\times10^{-7})(A_g)}$$

$A_g$ = Area of the air gap

$A_g = A_c + 5\% A_c$

$= 12 + \frac{5}{100}\times12$

$A_g = 12.6 cm^2$

$$R_g = \frac{(0.05\times10^{-2})}{(4\pi\times10^{-7})(12.6\times10^{-4})}$$

$= 316000$ A.turns/Wb

$R_{eq} = R_g + R_{core}$

$\boxed{B = 0.5T}$

$$\phi = BA = \frac{F}{R_{eq}} = \frac{Ni}{R_{eq}}$$

$\Rightarrow \boxed{i = 0.602A}$

# * Behavior of ferromagnetic material.

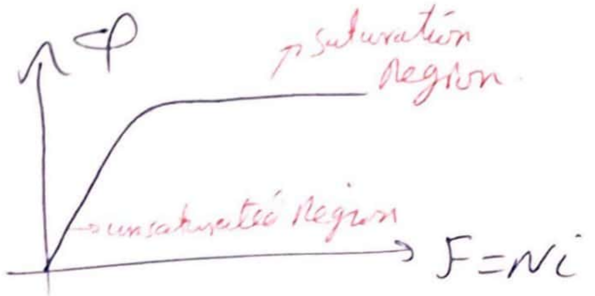
If a DC current is applied to the core.

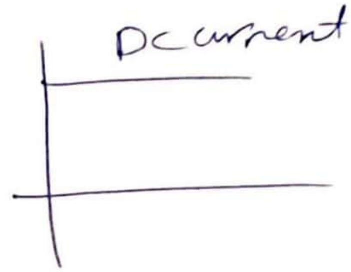
if $i \uparrow \longrightarrow F = Ni \uparrow \longrightarrow \phi \uparrow$

small increase in $I \longrightarrow$ huge Increase of $\phi$

then if $I \uparrow \longrightarrow F \uparrow \longrightarrow \phi \uparrow$ but with small amount.

until reach a certain $I \longrightarrow$ ~~then~~ $\phi$ still constant.




saturation curve OR magnetization curve

$$H = \frac{Ni}{L} \longrightarrow \frac{F}{L} \rightarrow$$

$$\phi = BA \longrightarrow B = \frac{\phi}{A}$$

Slope $= \frac{B}{H} = \mu$


another saturation or magnetization curve.

Note that $\mu$ is not constant with $I$ through core.





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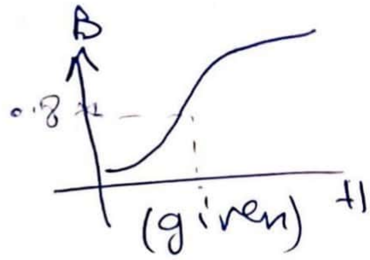
ex Square magnetic core has $L = 55\,cm$

and $A = 150\,cm^2$, 200 turns

$N$




① How much current is required to produce $0.12\,Wb$ ?

$B = \frac{\Phi}{A} = 0.8T \rightarrow$ from fig at $B = 0.8\,T$

$H = 115$ from curve.

$F = Ni = HL \rightarrow H = \frac{Ni}{L}$

$\Rightarrow i = 0.316A$

② The $\mu$.

$\mu = \frac{B}{H} = 0.00696\ H/m$.

$\mu_r = \frac{\mu}{\mu_0} = 5540$.

③ Reluctance

$\mathcal{R} = \frac{F}{\Phi} = 5270\ A.T/Wb = \frac{Ni}{\Phi}$





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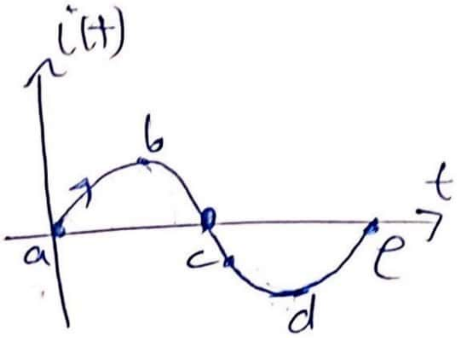
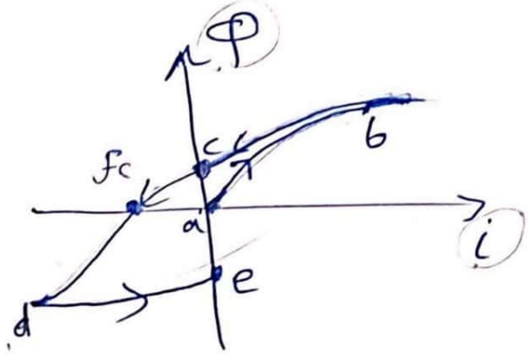
* Energy losses in a ferromagnetic core.

If an Ac current is applied to the core ~~of~~

Assume $\phi = 0$.




1) If $i$ increased from $a \to b$ flux in the core will increased from ab.




2) after (b) the current falls again → the flux also falls but with different path

3) if $I = 0$ at Point (c) the flux in the core is not zero $\Rightarrow \boxed{i = 0 \Rightarrow \phi \neq 0}$

point (c) ⇒ this value called Residual flux $\phi_{res}$

4) If current Increases but with negative value ⇒ $\phi$ increase in opposite direction





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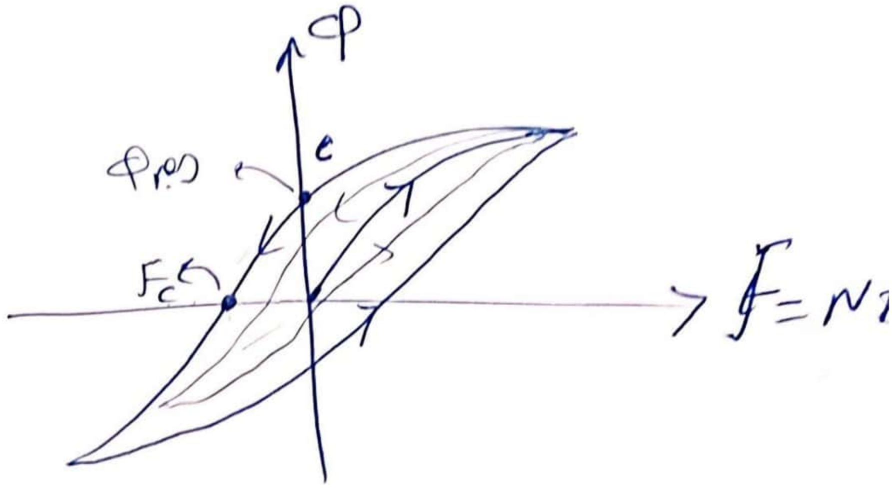
If $I$ at point (d)
$\phi$ at point (d)

Note that the flux takes different paths.

Relation between $\phi$, $I$ $\Rightarrow$ called hysteresis loop.




hysteresis loop

always the flux takes different path. for the same value of the current.

- point $c \longrightarrow \phi_{res}$ : Residual flux
  Residual. $\quad \phi = \phi_{res} \Rightarrow i = 0$, $F = 0$

- $F_c$ : Coercive force : the force need to force the flux to zero. applied to the core in the opposite direction.





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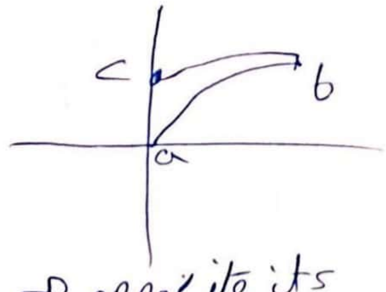
## * Why hysteresis *

(1) within Ferromagnetic materials There's are many Small Regions called domains, each domain acts as asmall permanent magnet oriented Randomly within the material. So total flux = 0

(2) If an external field is applied to ferromagnetic material, Some of the domains will oriented toward the external field (Randomly)

(3) If $i \uparrow$ $\phi \uparrow$ more domains oriented toward the field (external) until ~~Rea~~ all domains oriented toward the external field $\Rightarrow$ Reach saturation (a $\rightarrow$ b)




(4) If ~~the~~ $i \downarrow$ $\rightarrow$ some of domains reoriented toward the flux in opposite direction (as $i \downarrow$ $\phi$ opposite its direction)

(5) If $i = 0 \xRightarrow{\phi \neq 0}$ some domains still oriented toward the flux (point c)

$\Rightarrow \phi_{res}$.





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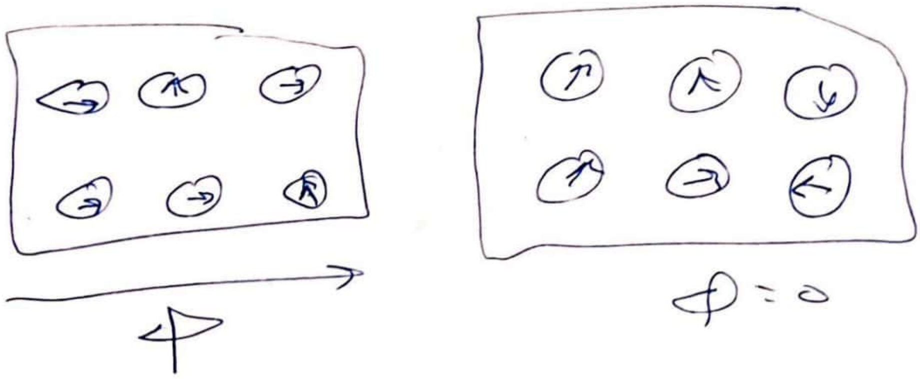


- We need coercive force $F_{cor}$ to reoriented all domains $\Rightarrow$ loss

- hysteresis loss: energy required to accomplish the reorientation of domains during each cycle of the AC current applied to the core.





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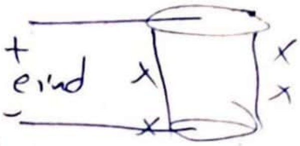
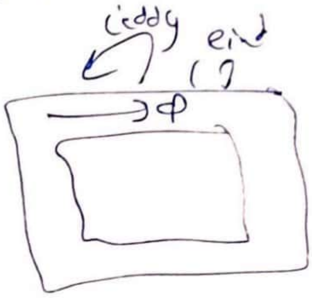
## (1.5) Induced voltage from time changing flux.




$$e_{ind} = -\frac{d\phi}{dt}$$

$$e_{ind} = -N\frac{d\phi}{dt}$$

time changing flux Induces voltage within the core as that within the coil




These voltages cause a swirls of current within the core like eddies $\rightarrow$ eddy currents.

$\Rightarrow$ eddy current flow within the resistine core. $\rightarrow$ so energy dissipated

$\Rightarrow$ heat.

To decrease the effect of eddy currents:

① Core is broken into strips or laminations to get small Area for the current.

② Add Insulating material between strips (air)

③

Core loss $\begin{cases} \rightarrow \text{eddy current loss} \\ \rightarrow \text{hysteresis loss.} \end{cases}$





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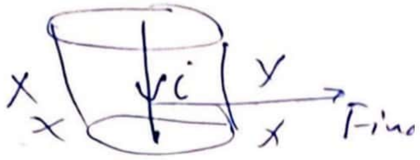
(1.6) current-carrying wire in presence of $\phi$ produce a force in the wire.

$F_{ind} = i\, L \times B$

$F_{ind} = i L B \sin\theta$

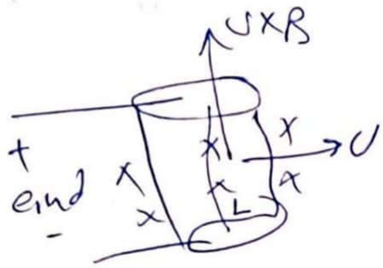



$\Rightarrow$ Motor Action.

(1.7) moving wire in presence of $\phi \Rightarrow e_{ind}$

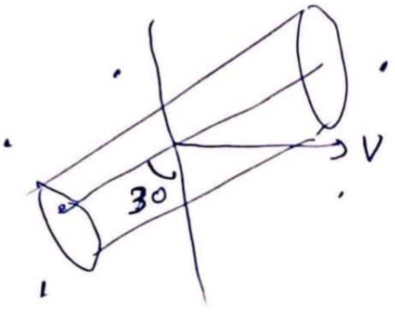
$e_{ind} = V \times B \cdot L$

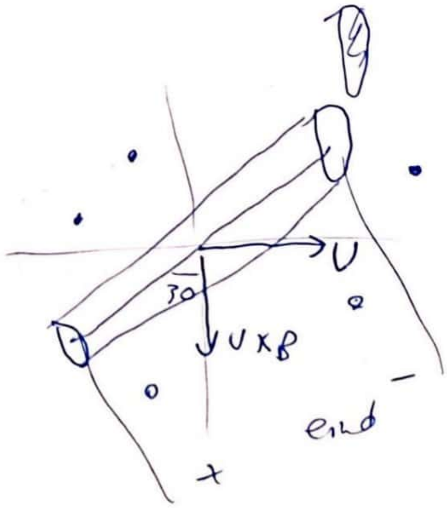
$= VB\sin\theta \; L\cos\phi$




$\Rightarrow$ Generator Action

ex $\quad e_{ind} = VB\sin 90 \; L\cos 30$





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# (2.7) voltage Regulation and effeciency.

Vo changes with load even if vin Constant.

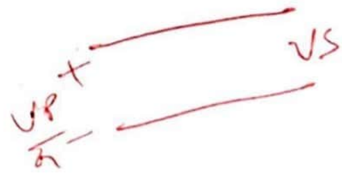
full load voltage Regulation: is a quantity that Compares the output voltage of the transformer at no load with the out put voltage at full load.

$$VR = \frac{V_{snL} - V_{sfL}}{V_{sfL}} \times 100\%.$$

at no load $V_{snL} = V_P/a$

$\boxed{\text{for Ideal}}$ transformer $V_{snL} = V_{sfL}$

$$\boxed{VR = 0}$$




$\boxed{\text{for Real}}$ transformer

$V_{snL} \neq V_{sfL}$

$VR < 0$

$VR > 0$





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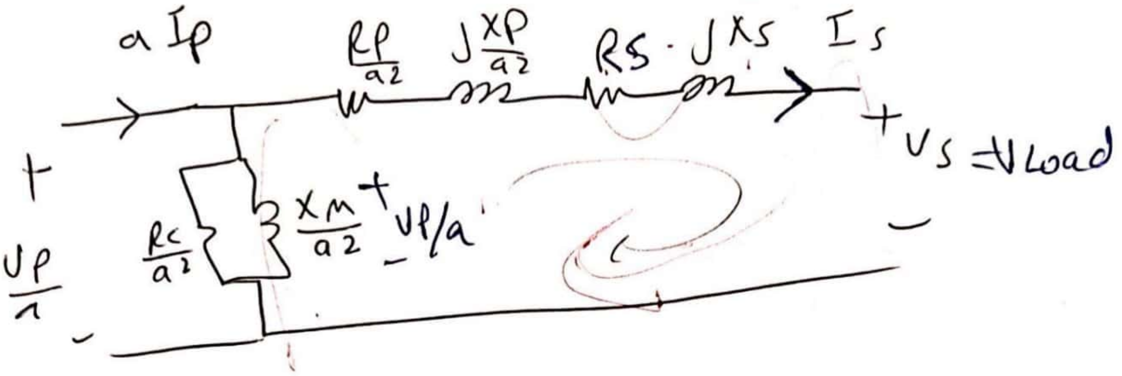
## $\underline{\underline{eq}}$ Circuit Referred To secondary side




by KVL

$$V_{s_{nL}} = \frac{V_P}{a} = I_s(R_{eq_s} + jX_{eq_s}) + V_s$$

$$R_{eq_s} = \frac{R_P}{a^2} + R_s$$

$$X_{eq_s} = \cancel{X}_s + \cancel{j}\frac{X_P}{a^2}$$

$$\boxed{V_s = V_{s\,fL}}$$

$$\boxed{\frac{V_P}{a} = V_{s\,nL}}$$

$V_{snL}$ change with power factor.

① for lagging power factor $\qquad I_s = I_s \angle -\theta$

$$V_{snL} = V_P/a > V_{s\,fL}$$

$$\boxed{V_R > 0}$$

(22)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② for loading power factor $\quad I_s = I_s \angle{+\theta}$

$$V_{snL} < V_{sfL}$$

$$\boxed{VR < 0}$$

③ for unity pf. $\quad I_s = I_s \angle 0$

أكبر

$$V_{snL} > V_{sfL}$$

$$\boxed{VR > 0}$$

---

effeciency : $\eta = \frac{P_o}{P_{in}} \times 100\%$.

$$P_o = V_s I_s \, pf.$$

$$P_{in} = P_o + P_{loss}.$$

$$P_{loss} = P_{cu} + P_{core}.$$

$$P_{cu} = |I_s|^2 R_{eqs}..$$

$$P_{core} = \frac{(VP/a)^2}{R_{cs}} \qquad R_{cs} = \frac{R_c}{a^2}$$





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Ex 15 KVA , 2300/230 V , Power Transformer.
Power Vp Vs

open circuit test (at LVs) $V_{oc} = 230V$ $I_{oc} = 2.1A$ $P_{oc} = 50w$

short circuit test (HVs) $V_{sc} = 47V$ $I_{sc} = 6A$ $P_{sc} = 160w$.

① find equivalent circuit Referred to LVs.
② Calculate VR at 0.8 lag, lead pf and unity pf
③ $\eta$ at 0.8 lagging pf.

from open circuit test

$$Y_{oc} = \frac{I_{oc}}{V_{oc}} \angle -\theta$$

نعوض بالقيم بسؤال $\theta = \cos^{-1} \frac{P_{oc}}{V_{oc} I_{oc}} = 84°$

$$Y_{oc} = 0.00913 \angle -84$$

this test at LVs → secondary

$$R_{cs} = 0.00913 \cos -84 = 1050\Omega$$

$$X_{ms} = 0.00913 \sin -84 = 110\Omega$$

$$a = \frac{V_P}{V_s} = \frac{2300}{230}$$

$$R_c = a^2 R_{cs} = 105k$$

$$X_m = a^2 X_{eq_s} = 11k\Omega$$

$Z_P = a^2 Z_S = 10$





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from short circuit test

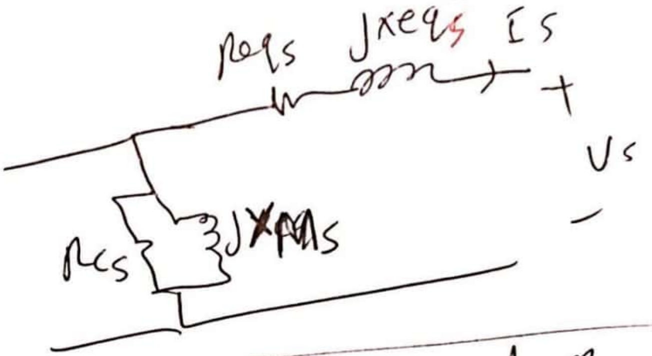
$$Z_{sc} = \frac{V_{sc}}{I_{sc}} \angle \theta \qquad \theta = \cos^{-1} \frac{P_{sc}}{V_{sc}\, I_{sc}}$$

$$Z_{sc} = 7.833 \angle 55.4$$ ← this test at (HVS) primary

$$= \underbrace{4.45}_{R_{eqp}} + j\,\underbrace{6.45}_{X_{eqp}}$$

$R_{eqp} = 4.45 \longrightarrow R_{eqs} = \frac{R_{eqp}}{a^2} = 0.0445\,\Omega$

$X_{eq} = 6.45 \longrightarrow X_{eqs} = \frac{X_{eqp}}{a^2} = 0.0645\,\Omega$




To find VR and $\eta$.

$V_{sFL} = V_s = \underline{230V}$ ← موجودة بالسؤال

$$\underline{I_s} = \frac{S}{V_s} = \frac{15k}{230} = \underline{65.2\,A}$$

① at 0.8 lagg → lag    pf = cos θ.

$$I_s = 65.2 \angle -\cos^{-1} 0.8$$

$$= 65.2 \angle -36.87\,A$$

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$$V_{snL} = \frac{V_P}{a} = I_s(R_{eqs} + jX_{eqs}) + V_{sfL}$$

$$= 65.2\angle{-36.87}\,(0.0445 + j0.0645) + 230$$

$$V_{snL} = \frac{V_P}{a} = 234.85\angle{0.4} > \underbrace{230}_{\text{lagging}} = V_{sfL}$$

$$VR = \frac{V_P/a - V_{sfL}}{V_{sfL}} \times 100$$

$$VR = \frac{234.85 - 230}{230} \times 100\% = 2.1\% > 0$$

---

② at 0.8 leading pf $\boxed{V_{sfL} = 230V}$ ثابت

$$I_s = 65.2\angle{+\cos^{-1} 0.8}$$

$$I_s = 65.2\angle{36.87}$$

$$\frac{V_P}{a} = V_{snL} = I_s(R_{eqs} + jX_{eqs}) + V_{sfL}$$

230

$$\frac{V_P}{a} = 229.85\angle{1.24} < 230 \quad \text{leading}$$

$$\boxed{VR = -0.06\%} < 0$$

---

③ at pf = 1 $\quad I_s = 65.2\angle{0}$

$\boxed{V_{sfL} = 230\,V}$

نعوض بنفس المعادلة $V_{snL} = \frac{V_P}{a} = 232.9\angle{1.04} > V_{sfL}$ 230

$$\boxed{VR = 1.28\%} > 0$$





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③ $\eta$ at 0.8 lagging

$I_s = 65.2 \angle -36.87$ $\boxed{V_s = 230}$

$\frac{V_P}{a} = 234.85$

$P_o = V_s I_s \, pf$

$= (230)(65.2)(0.8)$

$P_o = 12\,kW$

$R_{eqS}$

$P_{cu} = |I_s|^2 R_{eqs} = (65.2)^2 (0.0445) = 189\,W$

$P_{core} = \frac{(V_P/a)^2}{R_{CS}} = \frac{(234.85)^2}{1050} = 52.5\,W.$

$P_{in} = P_o + P_{cu} + P_{core}$

$\eta = \frac{P_o}{P_{in}} \times 100\% = 98.07\%$

$\boxed{\text{Note that}}$ $P_{cu} = 189 \approx \boxed{P_{sc} = 160\,W}$

test no
shortcircuit
test
copper loss

$P_{core} = 52.5\,W \approx \boxed{P_{oc} = 50\,W}$

from
open circuit
test
core loss





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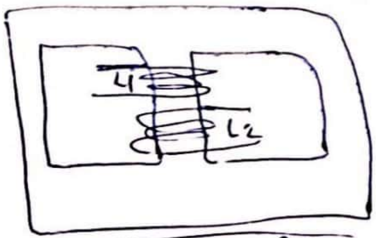
# Chapter Two: Real and Ideal transformer.

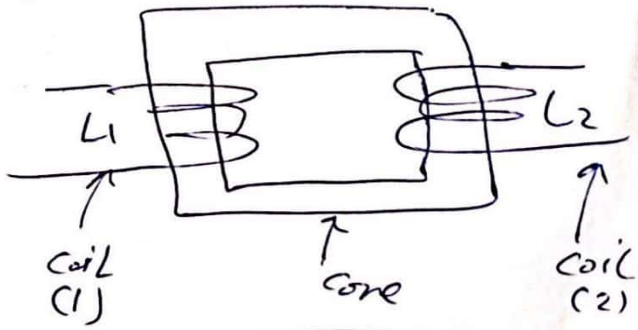
* Transformer is a device that changes ac electric Power at one voltage level to another voltage level, through the Action of magnetic field.

* It consists of two or more coils of wire wrapped around a ferromagnetic material core.

⇒ no electrical connection between coils.




Type (1) Shell form




Type (2) Core form





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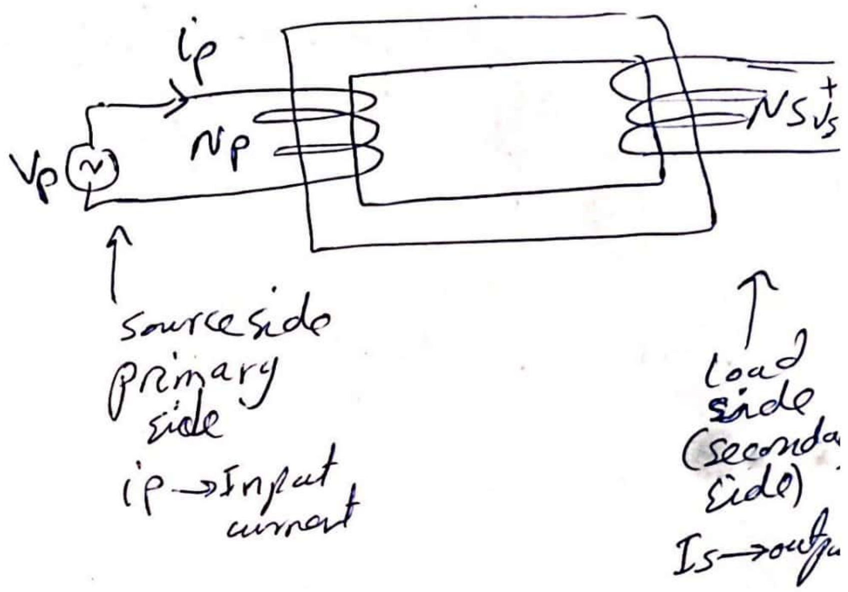
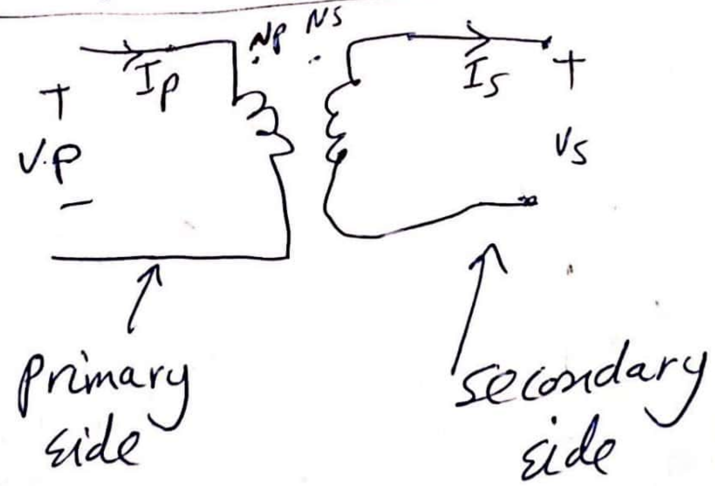
## 2.3 the Ideal transformer:-

is a lossless device with an Input winding and an output winding ($L_1, L_2$).




schematic symbol of Transformer





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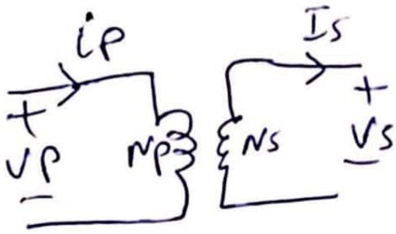
For an Ideal transformer.

→ find Relations between $V_p$, $V_s$ and $I_p$, $I_s$, $Z_p$, $Z_s$ and Power




$$\frac{V_p(t)}{V_s(t)} = \frac{N_p}{N_s} = a$$

$a = \frac{N_p}{N_s}$ → turns Ratio

$$\boxed{V_p = a V_s}$$

If $a > 1 \Rightarrow V_p > V_s$ stepdown

If $a < 1 \Rightarrow V_p < V_s$ step up.

If $a = 1 \Rightarrow V_p = V_s$ → unity.

$$N_p I_p = N_s I_s$$

$$\frac{I_p}{I_s} = \frac{N_s}{N_p} = \frac{1}{a}$$

$$\boxed{I_p = \frac{I_s}{a}}$$





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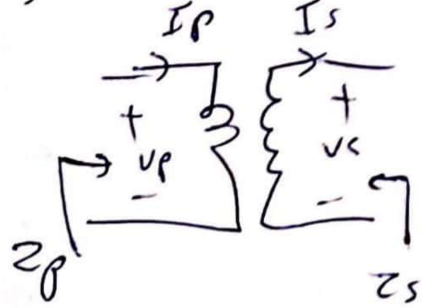
## Input Impedance $Z_p$

$$Z_p = V_p / I_p \qquad Z_s = V_s / I_s$$




$$V_p = aV_s$$
$$I_p = \frac{I_s}{a}$$
نعوض

$$Z_p = (aV_s) / \left(\frac{I_s}{a}\right)$$

$$Z_p = a^2 \frac{V_s}{I_s} = a^2 Z_s$$

$$\boxed{Z_p = a^2 Z_s}$$ reflected Impedance from secondary To primary side

⟹ for the power

$$P_{in} = V_p I_p \cos\theta$$ ⟶ Average OR Real power

$$P_o = V_s I_s \cos\theta$$

$$\boxed{pf = \cos\theta}$$

$$V_p = aV_s$$
$$I_p = \frac{I_s}{a}$$
نعوض

$$\boxed{P_{in} = P_o}$$ for Ideal Transformer

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## for Reactive power Q.

$Q_{in} = V_p I_p \sin\theta \leftarrow \begin{cases} V_p = a V_s \\ I_p = \frac{I_s}{a} \end{cases}$

$Q_o = V_s I_s \sin\theta$

$\boxed{Q_{in} = Q_o}$ Ideal Trans.

for Apparent power S.

$S_{in} = V_p I_p \quad S_o = V_s I_s$

$\boxed{S_{in} = S_o}$ Ideal Transf.

To Analyze any electrical circuit contains transformer $\Rightarrow$ take an equivalent for the Transformer.





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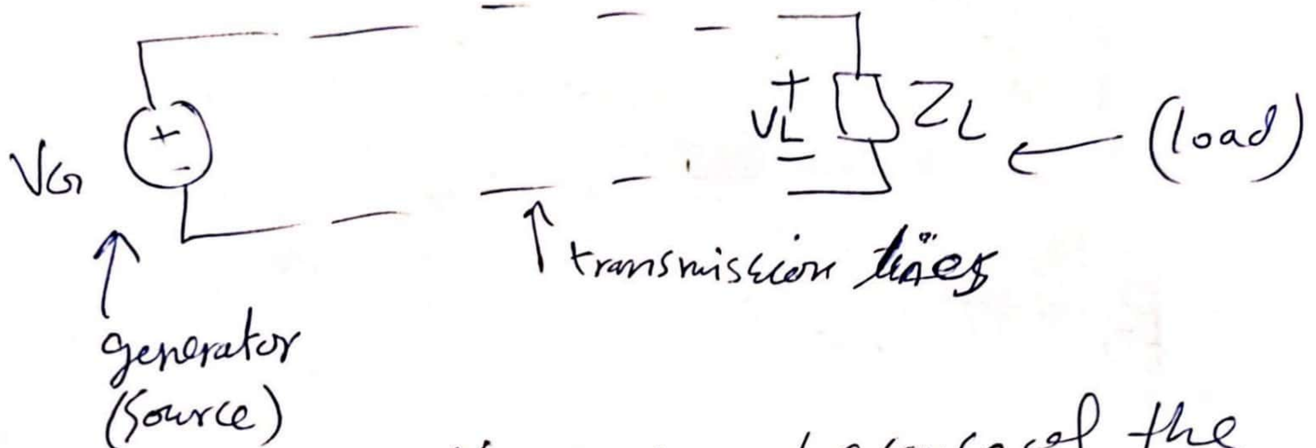
Transformer used to reduce losses through transmission lines




$V_L < V_G$ because of the losses in the lines

To solve this problem → transformer used to Increase $V_G$ ⇒ so losses decreased through lines

as shown in example below

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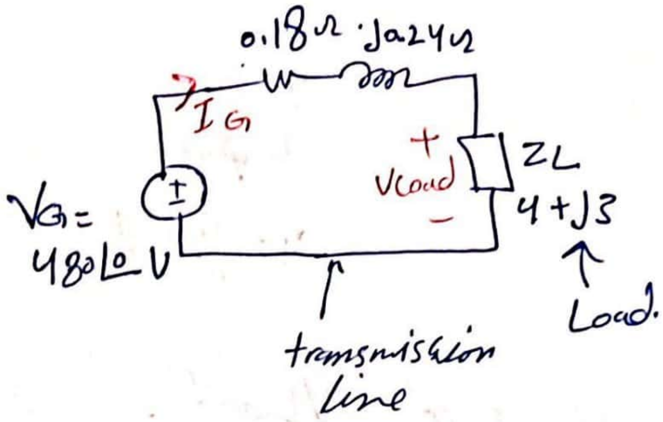
ex

A single power system as shown.




① find $V_{Load}$.

$$I_G = \frac{V_G}{Z_{eq}}$$

$$= \frac{480\angle 0}{0.18 + j0.24 + 4 + j3}$$

$$\boxed{I_G = 90.8\angle -37.8 \text{ A}}$$

$4 + j3 \rightarrow 5\angle 36.9$

$$V_{Load} = I_G Z_{Load}$$
$$= (90.8\angle -37.8)(4 + j3)$$

$$\boxed{V_{Load} = 454\angle -0.9 \text{ V}}$$

② find transmission line losses = power loss.

$$\Rightarrow P_{loss} = |I_G|^2 (R_{line})$$

$$P_{loss} = (90.8)^2 (0.18) = 1484 \text{ W}$$

$P_{loss}$ is high and $V_L$ is low
to decrease losses → use transformer after $V_G$ (step up) and step down Tr after before (load)





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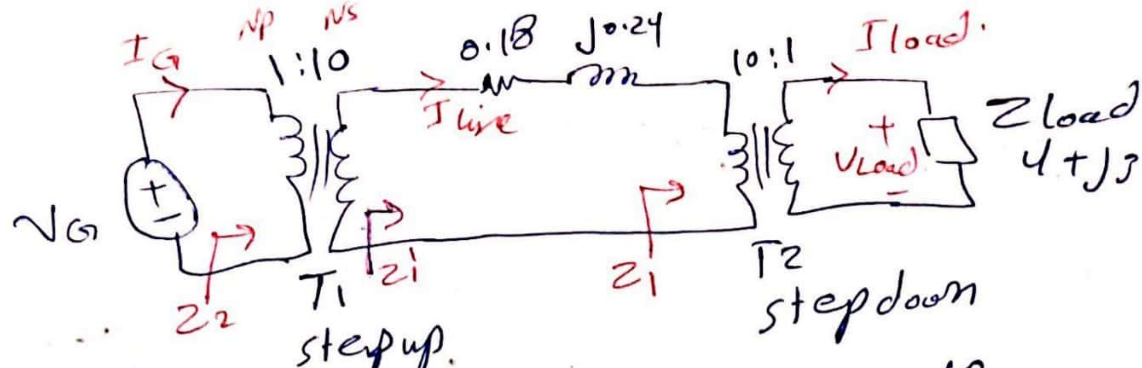



$a_1 = \frac{N_P}{N_S} = \frac{1}{10}$

$a_2 = \frac{10}{1}$.

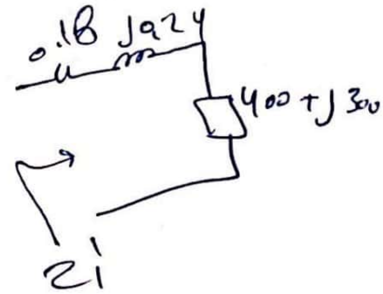
① find VLoad → we must find equivalent Impedance $(Z_P = a^2 Z_S)$

$Z_1 = a_2^2 Z_{load}$

$Z_1 = 400 + j300$.

$Z_1' = 0.18 + j0.24 + 400 + j300$

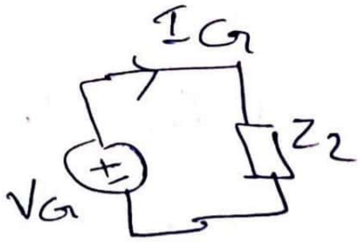
$$\boxed{Z_1' = 400.18 + j300.24}$$




Now $Z_2 = a_1^2 Z_1'$.

$Z_2 = \left(\frac{1}{10}\right)^2 (400.18 + j300.24)$

$$\boxed{Z_2 = 4.0018 + j3.0024}$$




Now $I_G = \frac{V_G}{Z_2}$

$I_G = \frac{480\angle 0}{4.0018 + j3.0024}$

$$\boxed{I_G = 95.94 \angle -36.88}$$





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Now To find I line

$$\boxed{I_p = \frac{I_s}{a}}$$

$$I_{line} = \frac{I_G}{\cancel{a_1}} a_1$$

$$I_{line} = 9.594\angle{-36.88}$$

To find I load.

$$I_{load} = a_2 I_{line}$$

$$I_{load} = 95.94\angle{-36.88}.$$

$$V_{Load} = I_{load} Z_{Load}.$$

$$= (95.94)\angle{-36.88}(4+j3)$$

$$\boxed{V_{load} = 479.7\angle{-0.01}\ V}$$

(2) Ploss → losses in transmission line

$$P_{loss} = |I_{line}|^2 R_{line}$$

$$P_{loss} = (9.594)^2(0.18) = 16.7w$$

---

* Note that loss is reduced with transformer

with Trans → Ploss = 16.7w

without Trans → Ploss = 1484w





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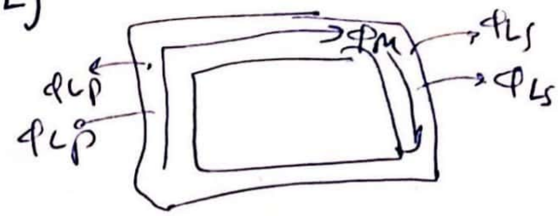
② Leakage fluxes losses:-

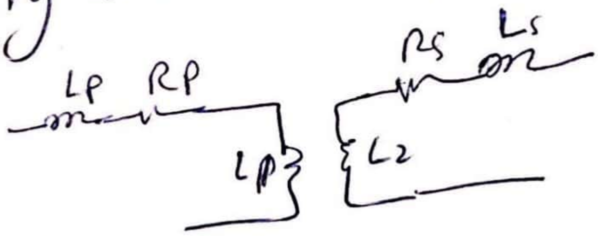
- <u>Leakage fluxes</u>: fluxes leave core to the air ($\phi_L$)

$\phi_{LP}$ , $\phi_{LS}$




- $\phi_M$ : Mutual flux that links primary and secondary coils ($\phi_M$)
(flux remains in the core)

these fluxes produce a self Inductance in the primary and secondary coils. ($L_P$, $L_S$)




$L_P$: primary self Inductance.
$L_S$: ~~prim~~ secondary self Inductance.

$$Z_P = jwL_P = jX_P$$
$$Z_S = jwL_S = jX_S$$
→ Impedance.

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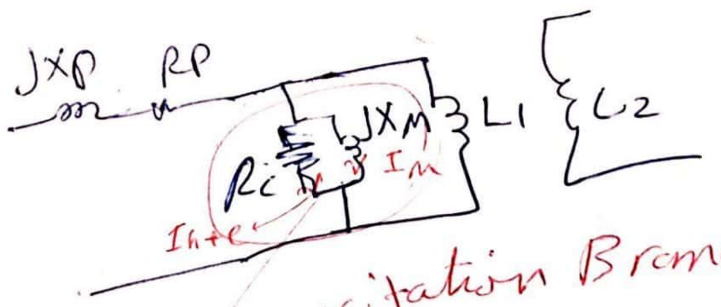
③ eddy current losses: resistive heating losses in the core of the Transformer.

~~④ eddy cu~~

④ Hysteresis loss: rearrangement of the magnetic domains in the core.

~~edd~~ Core loss $\begin{cases} \text{eddy loss.} \\ \text{hysteresis loss.} \end{cases}$

Core loss can modeled by an excitation Branch which is parallel with the primary core.




excitation Branch.

Rc — ~~loss~~ heat loss of the core.

Xm: magnetization Reactance.





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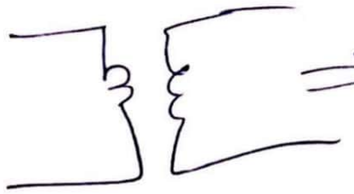
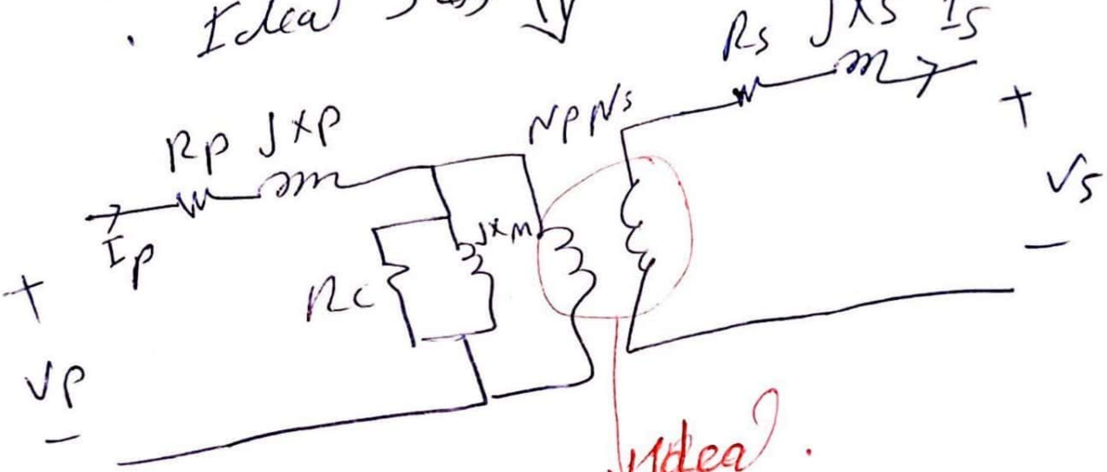
So the equivalent Impedance of the Real Transformer.

Real ⟹ Ideal Transformer.

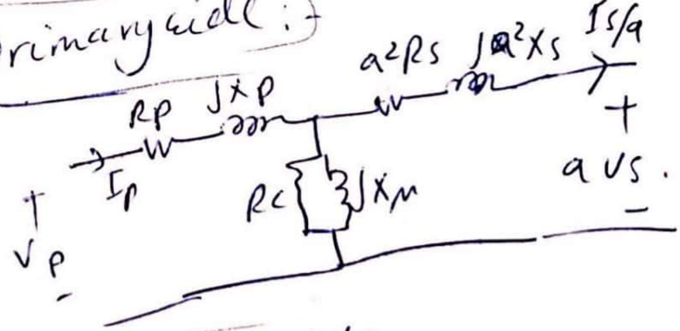


⟹ Real.

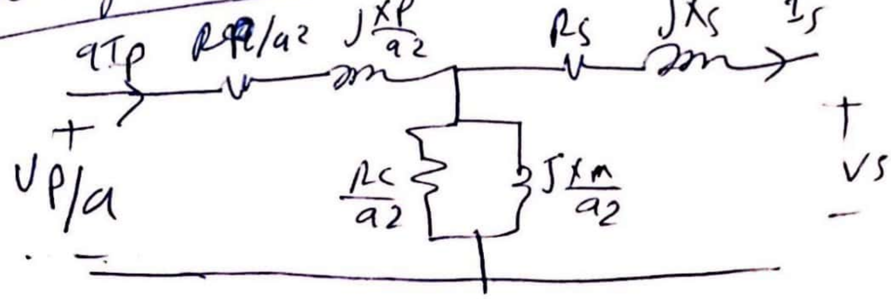
Ideal Jalls ⇓



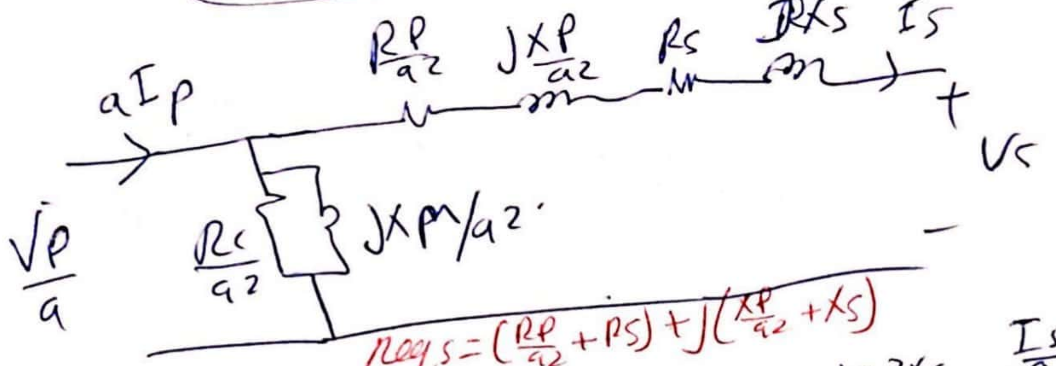

* equivalent referred to primary side :-




* equivalent referred to secondary side

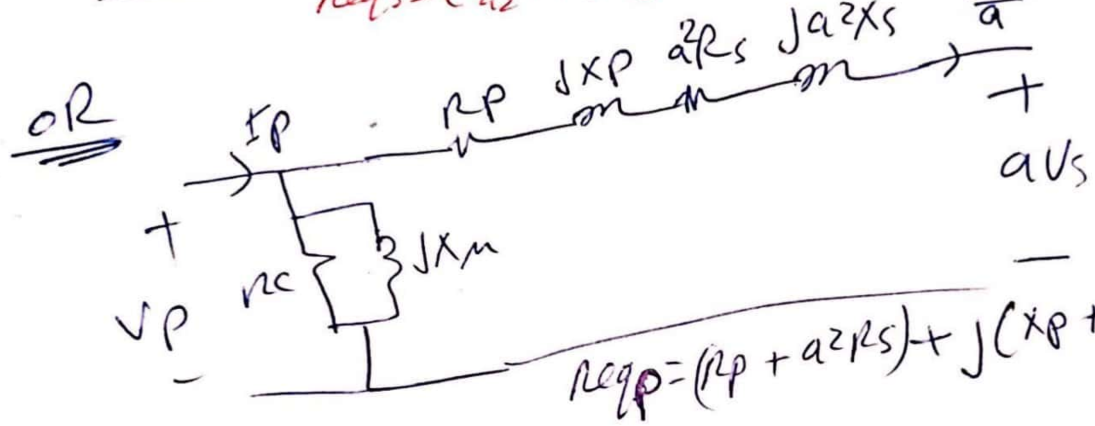


# Approximate equivalent circuit



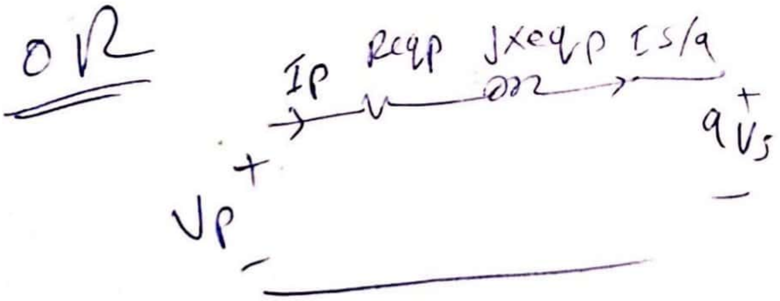

$$R_{eq,s} = \left(\frac{R_P}{a^2} + R_S\right) + j\left(\frac{X_P}{a^2} + X_S\right)$$

OR




$$R_{eq,p} = (R_P + a^2 R_S) + j(X_P + a^2 X_S)$$

OR





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To find the components of Real Transformer we have three Tests:-

(1) open circuit test  (2) Short circuit test

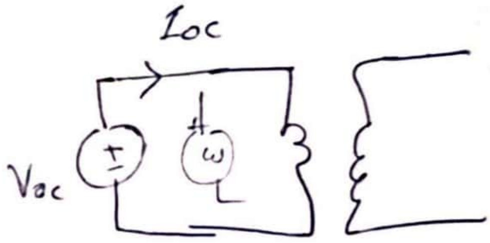
(3) DC Test.

(1) open circuit Test.

Test apply to the low voltage side (LVS)

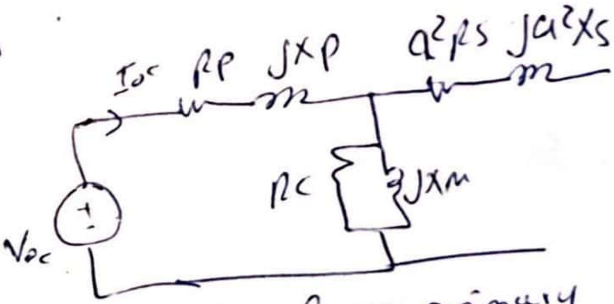
$\Rightarrow$ High voltage side still open (HVS)

* If we apply Test on primary side




find Voc, Ioc, Poc.

$\Rightarrow$ (practical value)




(Ref. To primary side)

$Z_{in} = R_p + jX_p + R_c \| jX_M$

$R_p \ll R_c$

$X_p \ll X_M$

so $Z_{in} \approx R_c \| jX_M$

use $Y_{oc} = \frac{1}{Z_{in}} = \frac{1}{R_c} - \frac{j}{X_M}$





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$$Y_{oc} = \frac{1}{R_c} - \frac{J}{X_M} \qquad Y = \frac{1}{Z} = \frac{I}{V}$$

$$Y_{oc} = \frac{I_{oc}}{V_{oc}} \angle -\theta$$

$$P_{oc} = V_{oc} I_{oc} \cos\theta$$

$$\Rightarrow \theta = \cos^{-1} \frac{P_{oc}}{V_{oc} I_{oc}}$$

$$Y_{oc} = \frac{I_{oc}}{V_{oc}} \angle -\theta = \frac{1}{R_c} - \frac{J}{X_M}$$

$$\left.\begin{aligned} \frac{1}{R_c} &= \frac{I_{oc}}{V_{oc}} \cos -\theta \longrightarrow R_c \\ \frac{1}{X_M} &= \frac{I_{oc}}{V_{oc}} \sin -\theta \longrightarrow X_M \end{aligned}\right\}$$

---

by using open circuit Test we find $R_c$ $X_M$

and so we can find

Ploss in the core.

$$\boxed{P_{oc} \cong P_{core\,loss}}$$





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## ② Short circuit Test :-

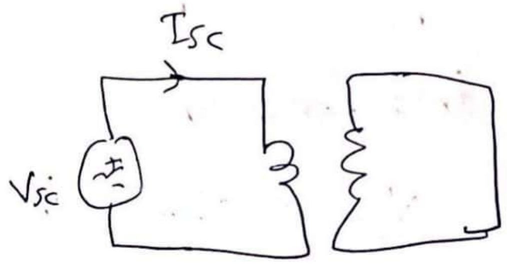
Apply to the High voltage side (HVS)

→ (LVS) still ~~open~~ . short .

If the test Apply to the primary

. take $V_{sc}$ / $I_{sc}$

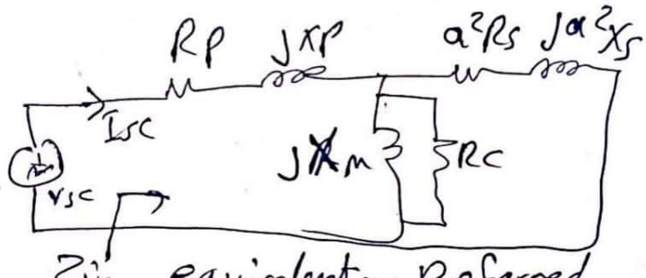
$P_{sc}$ .




$Z_{in} = R_p + jX_p + R_c \| jX_m \| Z_s$

$Z_s = a^2R_s + ja^2X_s$

$Z_s << R_c$




equivalent – Referred to primary

$$\Rightarrow Z_{in} = R_p + jX_p + a^2R_s + ja^2X_s$$

$$Z_{in} = \underbrace{(R_p + a^2R_s)}_{R_{eqp}} + j\underbrace{(X_p + a^2X_s)}_{X_{eqp}}$$

$$Z_{in} = R_{eqp} + jX_{eq_p} = \frac{V_{sc}}{I_{sc}} \angle \theta$$

$$\theta = \cos^{-1} \frac{P_{sc}}{V_{sc} I_{sc}}$$

$$R_{eqp} = \frac{V_{sc}}{I_{sc}} \cos\theta$$

$$X_{eqp} = \frac{V_{sc}}{I_{sc}} \sin\theta$$

from this test we find copper loss





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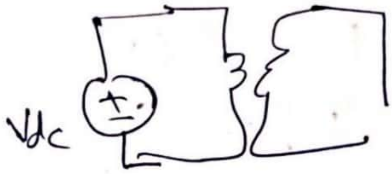
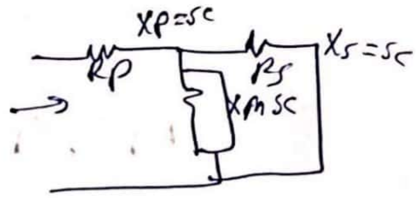
# ③ DC Test

* Apply DC Voltage to Any side of the transformer.

$X \longrightarrow$ short Circuit




$Z_{in} = \boxed{R_p = \frac{V_{DC}}{I_{DC}}}$




- If test on primary.
- If test on secondary $R_s = \frac{V_{DC}}{I_{DC}}$ on secondary.





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## Example :-

20 kVA , 8000 / 240 V , 60 Hz . transformer .
($V_P$ , $V_S$)

the following Test taken .

$a = \frac{V_P}{V_S} = \frac{8000}{240}$

* open-Circuit test (on primary) $V_{oc} = 8000V$ $I_{oc} = 0.214A$ $P_{oc} = 400W$

* Short-Circuit test (on primary) $V_{sc} = 489V$ $I_{sc} = 2.5A$ $P_{sc} = 240W$

from open circuit $\Rightarrow$

$Y_{oc} = \frac{I_{oc}}{V_{oc}} \angle -\theta \Rightarrow \theta = \cos^{-1}\frac{P_{oc}}{V_{oc} I_{oc}} = +76.5$

$Y_{oc} = \frac{0.214}{8000} \angle -76.5 = \underbrace{0.0000063}_{\frac{1}{R_c}} - j\underbrace{0.0000261}_{\frac{1}{X_m}}$

$Y_{oc} = \boxed{R_c = 159\,k\Omega \quad X_m = 38.4\,k\Omega}$ on primary .

from short Circuit test

$Z_{sc} = \frac{V_{sc}}{I_{sc}} \angle \theta$ $\theta = \cos^{-1}\frac{P_{sc}}{V_{sc} I_{sc}} = 78.7$

$Z_{sc} = 195.6 \angle 78.7 = \underbrace{38.4}_{R_{eq_p}} + j\underbrace{192\Omega}_{X_{eq_p}}$ . $\rightarrow$ test on primary

$R_{eqp} = R_p + a^2 R_s$

$X_{eqp} = X_p + a^2 X_s$





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If test on secondary side (Short circuit test)

$$\boxed{\begin{aligned} R_{eq_s} &= R_s + \frac{R_p}{a^2} \\ X_{eq} &= X_s + \frac{X_p}{a^2} \end{aligned}}$$





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## (2.4) Real Transformer :-

with losses.

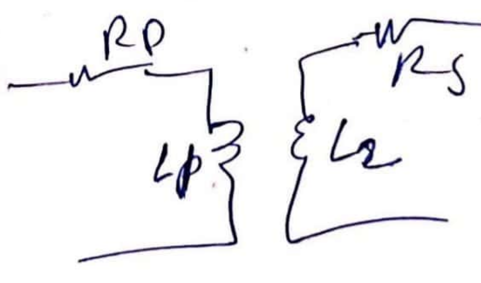

* losses in transformer :-

(1) Copper losses ($I^2R$) : are the Resistive heating losses in the primary and secondary windings of the Transformer.

$\Longrightarrow R_p \rightarrow R_s \rightarrow$ winding ($L_s$, $L_p$)

Model → Resistance $R_p$ with primary core.

→ Resistance $R_s$ in series with secondary coil.





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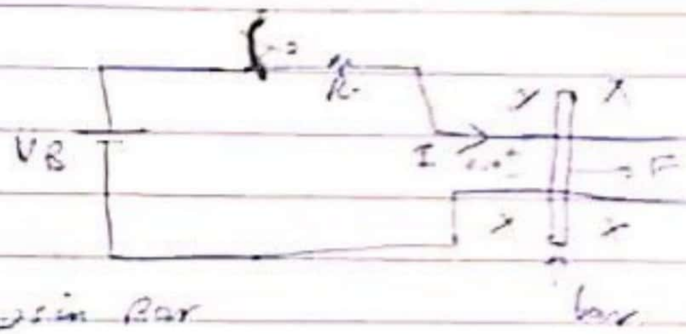
(1.8) Linear DC machines.

to understand DC machines.




① close S → current flows in Bar

$$I = \frac{V_B - e_{ind}}{R}$$

Initial $e_{ind} = 0$ $I = \frac{V_B}{R}$

② current carrying wire in presence of a field → force
~~Bind = VBL~~ Force $F = iLB$ right

Bar accelerate to right, $v\uparrow$, $e_{ind}\uparrow$
$e_{ind} = vBL$ upward.

$I = \frac{V_B - e_{ind}}{R}$ ↓ reduce
as $e_{ind}\uparrow \rightarrow I\downarrow$

$I\downarrow$, $F\downarrow \xrightarrow{F=0}$ ~~ind~~ ~~eind~~
until $v$ steady state $\boxed{e_{ind} = V_B}$
$e_{ind} = V_B = V_{ss}BL$

$I = 0$. $I = 0$ constant no load speed $V_{ss}$

⟹ principle of Motor at no load.

① $i = \frac{V_B}{R}$ ② $F_{ind} = iLB$ ③ $v\uparrow$ ④ $e_{ind} = vBL$ ↑
⑤ $I\downarrow$ $F_{ind}\downarrow \rightarrow F_{ind} = 0$ $e_{ind} = V_B$





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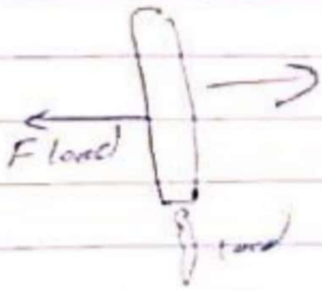
If an external load is added.

$F_{app}$ Fload is opposite to the direction of motion

① $F_{net} = F_{load} - F_{ind}$

slow the bar $v \downarrow$




② $e_{ind} = vBL \downarrow < V_B$.

③ $I = \frac{V_B - e_{ind}}{R} \uparrow$

④ $F_{ind} = iLB \uparrow$ until $F_{ind} = F_{load}$

steady state velocity at lower

$v_s < v_{ss}$

electrical power $e_{ind} i$ convert to mechanical power $F_{ind} v$

in Real machines $\boxed{\tau \omega}$

① $F_{ind} = 0$ Fload applying ② $v \downarrow$ ③ $e_{ind} \downarrow$ ④ $I \uparrow$

$F_{ind} \uparrow \rightarrow F_{ind} = F_{load}$.

Motor



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* as a generator:- Fapplied.

① Fapplied is applied to the direction of motion

② $v\uparrow$

③ $e_{ind}\uparrow > V_B$ (I reverse direct) I change direction

$I = \frac{e_{ind} - V_B}{R}$ (charge Battery)

④ $F_{ind}\uparrow$ to left $\longrightarrow$ $F_{ind} = F_{app}$

mechanical power $F_{ind}\,v$ $\longrightarrow$ convert to $e_{ind}\,i$

ex (1:10)

Generator

③



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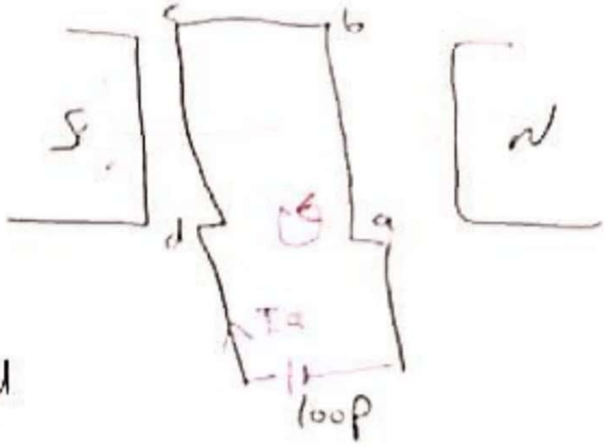
# DC Machines




$e_{ind} = VBL\sin\theta$

F → $\tau = iL\sin\theta\, B\cos\theta$

$e_{ind}$ from ab, cd

$e_{ind} = 2VBL$

for Rotational motion

$\omega = v$

$B = \frac{\varphi}{A}$

$e_{ind} = 2\cancel{V}BL$

$e_{ind} = 2\omega \frac{\varphi}{A} L$ k const

$\boxed{E_a = k\varphi\omega}$ OR $\boxed{E = k\varphi n}$

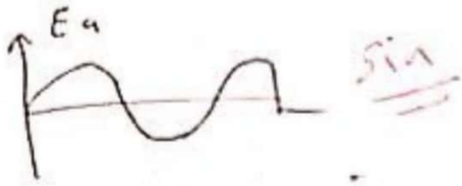
$\tau = 2iLB$  $B = \frac{\varphi}{A}$

$\boxed{\tau = k\varphi I}$

the most Important equations.

$E_a \rightarrow$ Ac signal

must converted to DC





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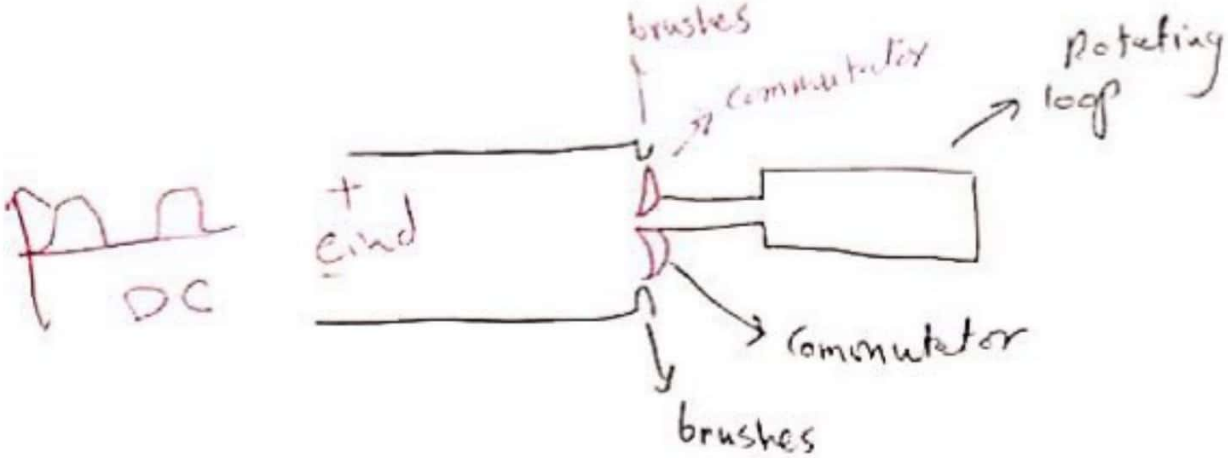
To convert output AC to DC

⟹ Commutation process

Commutation process : is the process of switching the loop connections on the rotor of a DC machine just as the voltage in the loop switches polarity, in order to maintain an essentially constant dc output voltage.

Rotating segments are attached to Rotating loop are called Commutator segments (copper bars).

stationary pieces that ride on top of the moving segments are called brushes (graphite)







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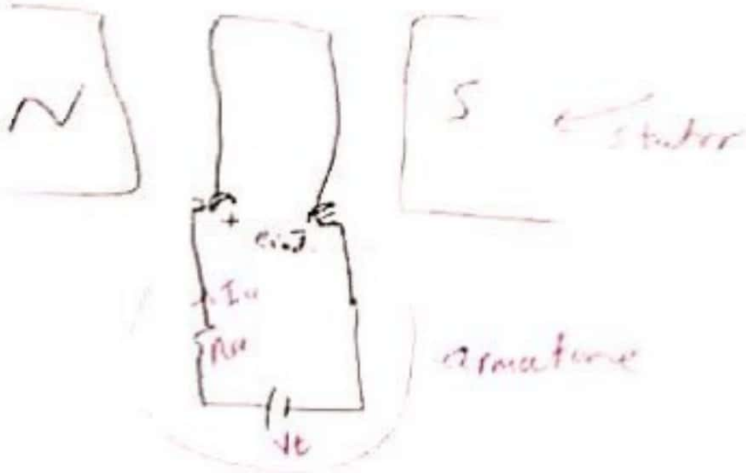


Stator : consist of field winding to produce magnetic field (field winding)
(stationary part) → جزء ثابت

Rotor : Rotating part → جزء دوار
consist of armature winding
(loop)

if ~~Ia~~ $V_t > e_{ind}$ → Motor

if $e_{ind} > V_t$ → Generator.

loop Rotating around fixed shaft.




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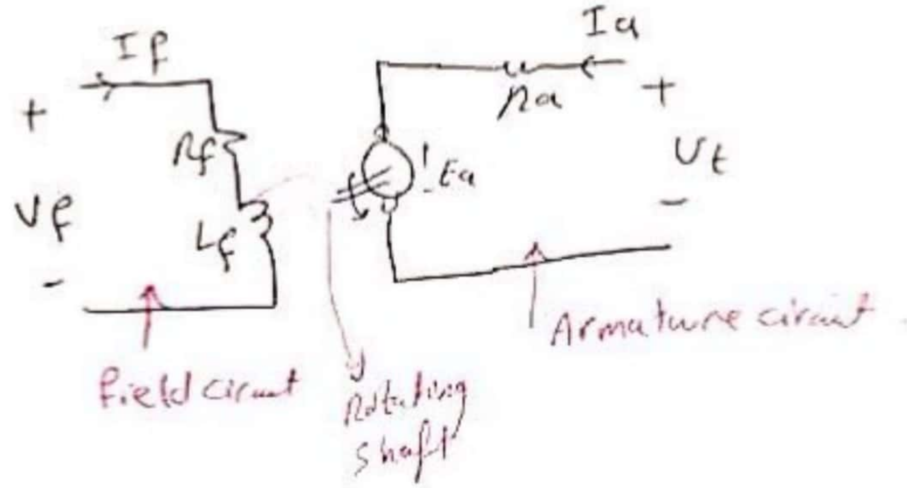
# Chapter (8) Dc Motors.

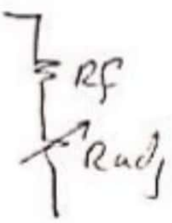
equivalent Circuit for Dc Motors.




Stator : Consist of field ~~wing~~ winding Lf (coiLs)

— Rf Internal Resistance of Lf

Radj Insert in series with Rf for speed control.




- Vf to give If → If pass through Lf ⇒ giving a magnetic field

This field effected ~~rotary shaft~~ Rotor with an existing of Ia the shaft (Rotor) Rotate around the fixed shaft.





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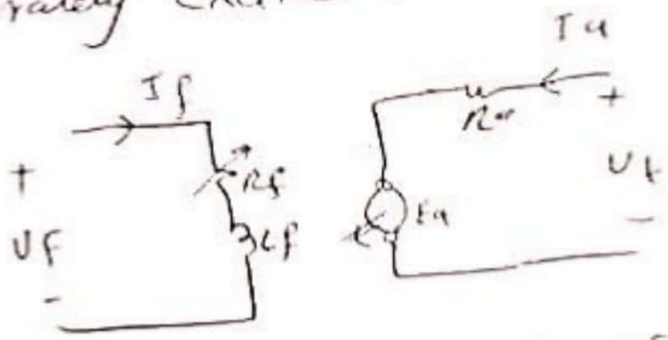
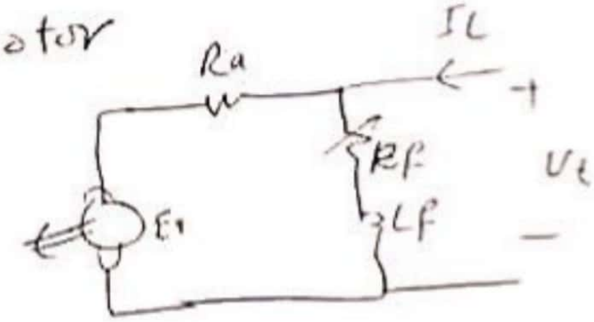
## Types of Motor :-

① separately excited Motor



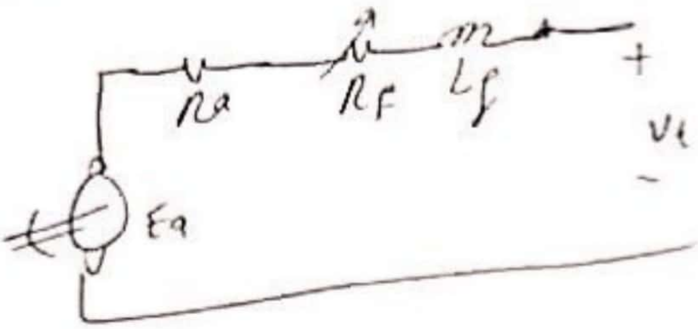

exa use two sources $V_f$, $V_t$.

② Shunt Motor




use one source ($V_t$), field shunt armature.

③ series Motor




field series with Armature.





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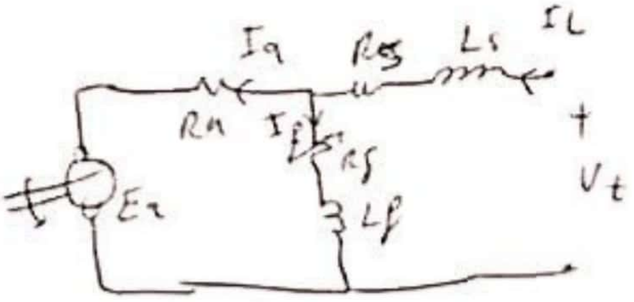
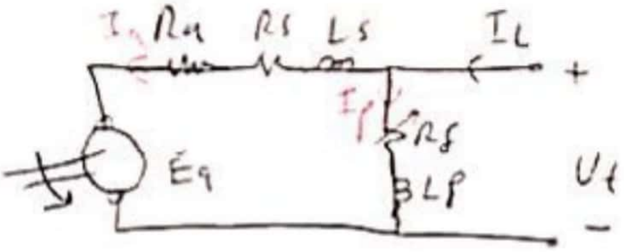
(4) Compounded Motors

series + shunt field




Short-shunt




long-Shunt





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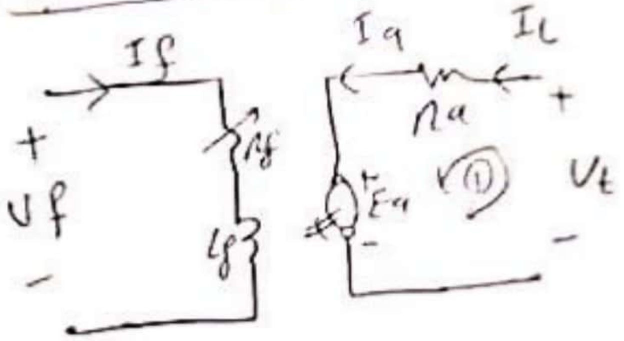
## * Separately excited and Shunt Motor




$I_L = I_a$

loop 1

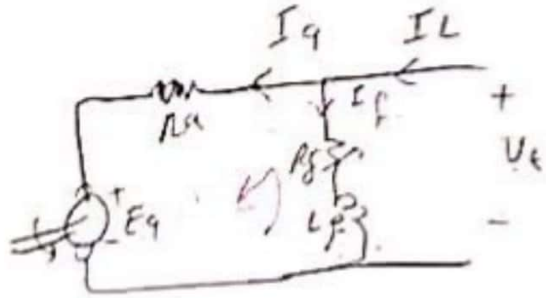
$$\boxed{V_t = I_a R_a + E_a}$$

$$\boxed{I_f = \frac{V_f}{R_f}}$$

$L_f \rightarrow$ short circuit DC source

$$\boxed{V_t = E_a + I_a R_a} \quad (1)$$

**(for shunt Motor)**




$I_L = I_a + I_f$

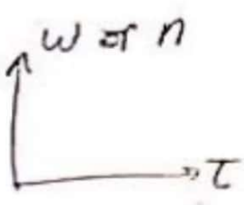
$I_f = \frac{V_t}{R_f}$

$$\boxed{V_t = E_a + I_a R_a} \quad (2)$$

equation (1) $\approx$ (2)

So terminal characteristic of shunt Motor is the same as separately excited Motor (SEM)

terminal characteristic for motors between speed and load ($\tau$)




To find $(\omega, \tau) \rightarrow$





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$$\boxed{V_t = E_a + I_a R_a} \quad *$$

$$E_a = k\phi n \quad \text{OR} \quad k\phi\omega \qquad (1)$$

$$\tau = k\phi I_a \qquad (2)$$

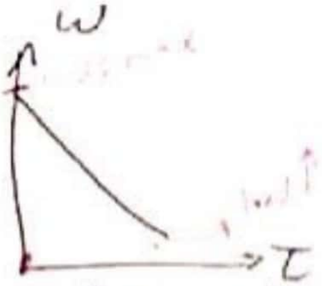
$$\boxed{n = \frac{60}{2\pi}\omega}$$

$$V_t = k\phi\omega + \frac{\tau}{k\phi} R_a$$

$$\boxed{\omega = \frac{V_t}{k\phi} - \frac{R_a}{(k\phi)^2}\tau}$$

at $\tau = 0$ $\boxed{\omega = \frac{V_t}{k\phi}}$

max speed




for shunt and S.E.M

at $\boxed{\tau = 0} \longrightarrow$ no load condition

(1) $I_a = 0$

(2) $\tau = 0$

(3) $\omega = \omega_{ss}$ max speed.

(4) $V_t = E_a$





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all DC machines have an armature Reaction problem.

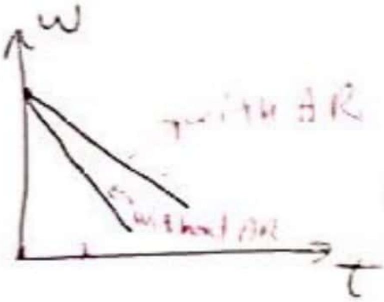
Armature Reaction (AR): with load, $I_a \uparrow$, $I_a$ will produce a magnetic field of its own

this field will distort the orginal magnetic field from field circuit

so total flux will decrease → weakening of the flux $\phi \downarrow$

$$\phi = \phi_F - \phi_a \downarrow$$

if $\phi \downarrow \longrightarrow \omega \uparrow$ speed of motor will Increase




AR: the distortion of the flux in DC machines ~~due to~~ when the load is added to Increase

⇒ To solve the problem AR → compensating winding used (CW)





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using Compensating winding (CW) to decrease the Armature Reaction (AR) problem.

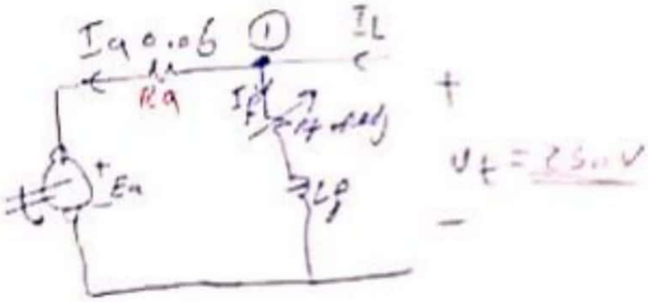
---

ex 50hp, 250V, 1200 r/min dc shunt Motor with compensating winding. $R_a = 0.06\,\Omega$, $R_{adj} + R_f = 50\,\Omega$, noload speed 1200 r/min

$N_F = 1200$ Turns

* find the speed of the Motor If Input current is 100, 200, 300 A
* Find Torque

① speed at Input current




$I_L = 100A$

$$I_f = \frac{V_t}{R_f + R_{adj}} = \frac{250}{50} = 5A$$

$I_a = I_L - I_f \longrightarrow$ Node ①

$= 100 - 5 = 95A$

$V_t = E_a + I_a R_a$

$E_a = V_t - I_a R_a = 244.3V$

$\boxed{E_a = 244.3 = K\Phi n}$ ① $\Rightarrow$ n speed $K\Phi$ ??

to find $K\Phi$ choose a Ref values

from example noload speed = 1200 r/min

at noload

$E_a = V_t = 250\,V$

$I_a = 0$

$I = 0$

$\boxed{E_{a_0} = 250 = K\Phi\, 1200}$ ②





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$$\frac{①}{②} \quad \frac{E_a}{E_{a0}} = \frac{K\phi n}{K\phi\, 1200}$$

$$\frac{244.3}{250} = \frac{n}{1200} \longrightarrow n = 1173 \text{ r/min}$$

To find torque at $I_L = 100A$.

$P_{conv} = E_a I_a = \tau_{ind}\, \omega$.

$$\tau_{ind} = \frac{E_a I_a}{\omega} = \frac{244.3 \times 95}{\frac{2\pi}{60}(1173)} = 190 \text{ N.m}$$

$$\omega = \frac{2\pi}{60} n$$

---

② find speed, $\tau$ at $I_L = 200A$

$I_a = I_L - I_f \qquad I_f = \frac{V_t}{R_f + R_{adj}} = 5A$

نفس الحل السابق

$\boxed{I_a = 195A}$

$E_a = V_t - I_a R_a \longrightarrow \boxed{E_a = 238.3V = K\phi n}$ ①

no load $\longleftarrow \boxed{E_{a0} = 250 = K\phi\, 1200}$ ②

$E_{a0} = V_t = 250$

$$\frac{①}{②} = \frac{238.3}{250} = \frac{\cancel{K\phi} n}{\cancel{K\phi}\, 1200} \longrightarrow n = 1144 \text{ r/min} \downarrow$$

$$\tau = \frac{E_a I_a}{\omega} \longrightarrow \tau_{ind} = \frac{238.3 \times 195}{\frac{2\pi}{60}(1144)} = 388 \text{ Nm} \uparrow$$

---

③ speed, $\tau$ at $I_L = 300A$ نفس الحل

$I_a = I_L - I_f = 295A \longrightarrow E_a = V_t - I_a R_a = 232.3V = K\phi n$

$$\frac{232.3}{250} = \frac{K\phi n}{K\phi 1200} \rightarrow n = 1115 \text{ r/min} \downarrow$$

$$\tau = \frac{E_a I_a}{\omega} = 587 \text{ N.m} \uparrow$$

if load $\uparrow$ $I_L \uparrow$ $n \downarrow$

$\tau \uparrow$





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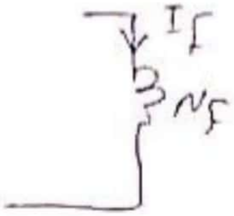
with AR : Armature Reaction effect.

$$F_{net} = F_F - F_{AR}$$

$$N_F I_F^* = N_F I_F - F_{AR}$$




$$\boxed{I_f^* = I_f - \frac{F_{AR}}{N_F}}$$

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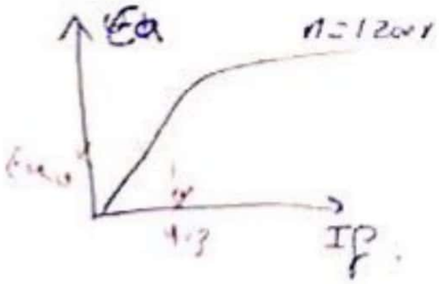
ex 50hp, 250V, 1200 r/min dc Shunt Motor
without compensating winding $R_a = 0.06\,\Omega$.
$R_f + R_{adj} = 50\,\Omega$, no load speed 1200 r/min, $N_F = 1200$ t/p
F of Armature Reaction $F_{AR} = 840$ A turns
If load current 200A → magnetization curve given

* find speed if $I_L = 200A$.




$$I_f = \frac{V_t}{R_f + R_{adj}} = \frac{250}{50} = 5A$$

$$I_a = I_L - I_f = 195A.$$

$$E_a = V_t - I_a R_a$$

$$\boxed{E_a = 238.3V = k\phi n} \quad (1)$$

$$I_f^* = I_f - \frac{F_{AR}}{N_F} = 5 - \frac{840}{1200} = 4.3A.$$

from curve of $I_f^* = 4.3 \rightarrow E_{ao} = 233V$ $n_o = 1200$ r/min

$$E_{ao} = 233 = k\phi n_o \rightarrow \boxed{233 = k\phi 1200} \quad (2)$$

$$\frac{(1)}{(2)} = \frac{238.3}{233} = \frac{k\phi n}{k\phi 1200} \rightarrow n = 1227 \text{ r/min} \uparrow$$

<u>n↑ with AR</u>





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# Speed control of shunt DC Motor:-

① Change $R_F$.

If $R_f \uparrow \rightarrow I_f = \frac{V_t}{R_f \uparrow} \downarrow \rightarrow$ if $I_f \downarrow$

$\phi \downarrow \rightarrow E_a = k\phi\omega \downarrow \rightarrow I_a = \frac{V_t - E_a \downarrow}{R_a} \uparrow$

If $I_a \uparrow \rightarrow \tau_{ind} = k\phi I_a \uparrow$, if $\tau_{ind} \uparrow$

$\omega \uparrow$

(if $R_f \uparrow \rightarrow \omega \uparrow$)

② Change UA (terminal voltage)

If $V_t \uparrow \rightarrow I_a = \frac{V_t \uparrow - E_a}{R_a} \uparrow \rightarrow$

if $I_a \uparrow \rightarrow \tau_{ind} = k\phi I_a \uparrow \uparrow \rightarrow$ if $\tau_{ind} \uparrow$ $\omega$

(if $V_t \uparrow \rightarrow \omega \uparrow$)

③ Insert $R_{adj}$ in series with $R_a$

If $R_a \uparrow \rightarrow I_a = \frac{V_t - E_a}{R_a \uparrow} \downarrow \rightarrow \tau_{ind} \downarrow \rightarrow \omega \downarrow$

⇒ this method is bad because of power waste.





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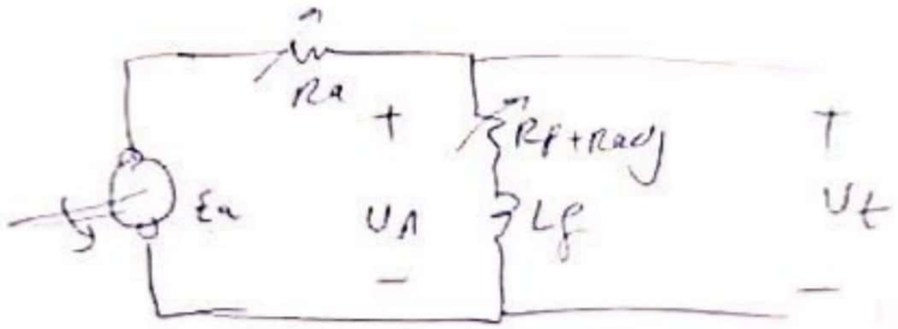
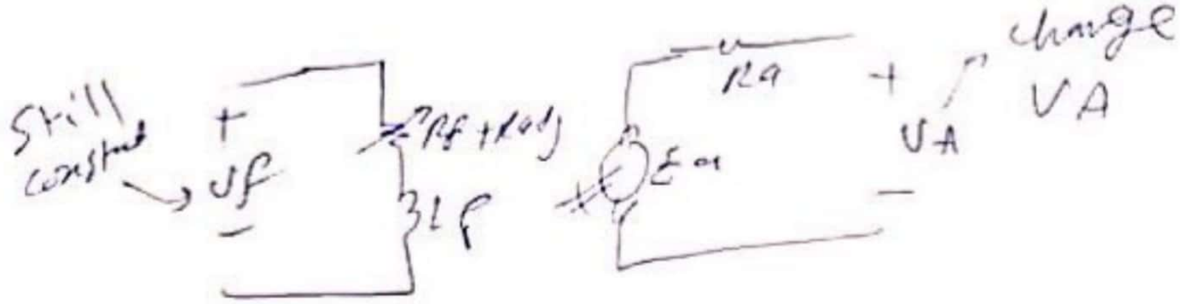



① change Rf + Radj
② change Ra
③ change VA

To change VA and Vt still constant
use shunt motor as separately
excited motor





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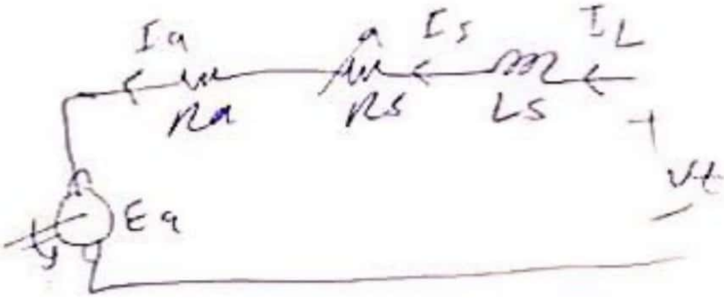
* series motor:




$I_L = I_a = I_s$

$$\boxed{V_t = E_a + I_a(R_a+R_s)}$$

If load change $I_L = I_a = I_s$ change

$\Rightarrow$ so $\phi$ change

$\phi \propto I_a \rightarrow \boxed{\phi = c I_a}$

$E_a = k\phi\omega \rightarrow \quad \tau = k\phi I_a$

$\phi = c I_a$

$V_t = E_a + I_a(R_a + R_s)$

$V_t = k\phi\omega + \frac{\tau}{k\phi}(R_a+R_s)$

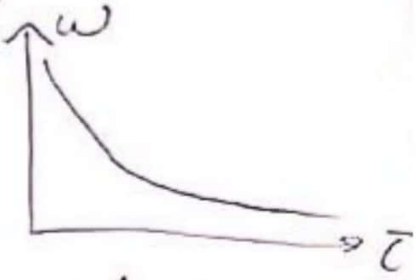
$$\boxed{\omega = \frac{V_t}{\sqrt{kc\,\tau_{ind}}} - \frac{R_a+R_s}{kc}}$$

$\omega \propto \tau_{ind}$

at $\tau = 0 \rightarrow$ noload

$\boxed{\omega = \infty}$

motor run away at no load




speed - Torque

never unload series motor

series motor has higher starting Torque than shunt motor.





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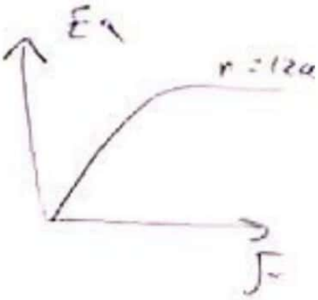
**Ex** 250V, series motor, with compensating winding

$R_a + R_s = 0.08\Omega$, $N_s = 25$ turns.




~~$E_a = V_t - I_a$~~

find speed and Torque if $I_a = 50A$

$$E_a = V_t - I_a(R_a + R_s)$$

$$E_a = 250 - (50)(0.08) = 246V$$

$$\boxed{E_a = 246 = K\phi n} \quad (1)$$

$$F = N_s I_s = N_s I_a = 1250 \text{ A}\cdot\text{turns}$$

from curve at $F = 1250 \rightarrow E_{a0} = 80V$

$$\boxed{80 = K\phi(1200)} \quad (2)$$

$$\frac{(1)}{(2)} = \frac{246}{80} = \frac{K\phi n}{K\phi\, 1200} \rightarrow n = 3690 \text{ r/min}$$

$$\tau_{ind} = \frac{E_a I_a}{\omega} = \frac{246 \times 50}{\frac{2\pi}{60} \times 3690} = \underline{31.8 \text{ Nm}}$$





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Speed control of series Motor:-

① change $R_a + R_s$

if $(R_a+R_s)\uparrow \longrightarrow I_a = \frac{V_t - E_a}{R_a+R_s \uparrow} \downarrow$

If $I_a \downarrow \longrightarrow T_{ind} = k\phi I_a \downarrow$

$\Rightarrow \omega \downarrow$ (waste power)

② change $V_t$

if $V_t \uparrow \longrightarrow I_a = \frac{V_t\uparrow - E_a}{R_a+R_s} \uparrow$

if $I_a \uparrow \longrightarrow T_{ind} \uparrow \longrightarrow \omega \uparrow$.





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9.10 DC Motors effeciency.

* losses

1. Copper loss. $(I^2 R_P)(I^2 R_f)$
2. Brush drop loss.
3. Mechanical loss
4. Core loss
5. Stray losses.

To find $R_P$

1. Block Rotor so that it can't move
2. Apply DC small voltage to Armature, change voltage until $I_a = I_a$ rated.

Then $R_A = \frac{V_A}{R_A}$

To find $R_f$

1. supply $I_f = I_f$ rated.

$\Rightarrow R_f = \frac{V_f}{I_f}$.

Then $P_{copper} = I_a^2 R_a + I_f^2 R_f \Rightarrow$ Copper loss





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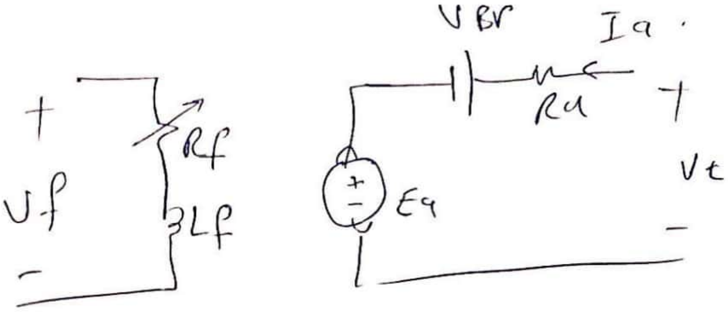


(1) brushes loss.

$P_{brush} = I_a V_{br}$.

(3) Rational loss at full load = Rational loss at no load.

$\Rightarrow$ To find $P_{rational} \rightarrow$ no load Test.

at no load $I_a \approx$ zero

$$\boxed{P_{rational} = P_{core} + P_{mech}}$$

OR $P_{rational} = \cancel{E_a}\ V_t I_a$ at no load test.

(4) stray loss = 1% Pin.

Pin : Input power.

$$\boxed{P_{in} = V_t I_L}$$ at full load.

effeciency $\Leftarrow$ $\eta = \frac{P_o}{P_{in}} \times 100\% = \frac{P_{in} - P_{copper} - P_{rot} - P_{stray}}{P_{in}} \times 100\%$

(2)


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ex 50hp, 250 V, 1200 r/min DC Shunt Motor.
has a rated $I_a = 170A$, a rated field current $I_f = 5A$.
- at Rotor blocked Test: $V_A = 10.2V$ & $I_a = 170A$.
- $V_f = 250V \Rightarrow I_f = 5A$.
- $V_{Br} = 2V$.
- At noload $V_t = 240V \longrightarrow I_a = 13.2A$.
$I_f = 4.8A$, $n = 1150 r/min$.

$\boxed{\text{* Calculate effeciency}}$

$R_A \rightarrow$ from blocked Rotor Test.

$$R_A = \frac{V_A}{I_a} = \frac{10.2}{170} = 0.06 A$$

$$R_f = \frac{250}{5} = \frac{V_f}{I_f} = 50 \Omega.$$

$$P_A = I_a^2 R_a = (170)^2 (0.06) = \underline{1734 W}.$$

$$P_f = (I_f)^2 R_f = (5)^2 (50) = \underline{1250 W}.$$

$$P_{brush} = V_{Br} I_a = (2)(170) = \underline{340 W}$$

$P_{rot} = V_t I_a$ at no load Test.

$$P_{rot} = (240)(13.2) = 3168 W$$





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$P_{in} = V_T I_L$
$= (250)(175) = 43\,750W$.

$P_o = P_{in} - P_{loss}$

$P_{loss} = P_{Brus} + P_A + P_f + P_{rot}$

$P_o = 36820W$

$\eta = \frac{P_o}{P_{in}} \times 100\%$.

$\therefore \eta = \frac{36820}{43750} \times 100\% = 84.2\%$





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