07/01/2020

1 unit of Electrical Energy = 1 Kwh

D.C. Generator

Assignment

(1) Write Down with detail explanation and diagram Faraday's law of electromagnetic induction.

(2) Lenz Law

B - Magnetic induction / Magnetic field vector / Magnetic flux Density.

ϕ_B = Magnetic flux

A = Area vector

$\phi_B = \vec{B} \cdot \vec{A}$

Flux change → Generate fluctuation in Galvanometer

2nd $\left[e = \left| \frac{d\phi_B}{dt} \right| \right]$ - Amount of emf induced

3rd Law : Magnitude

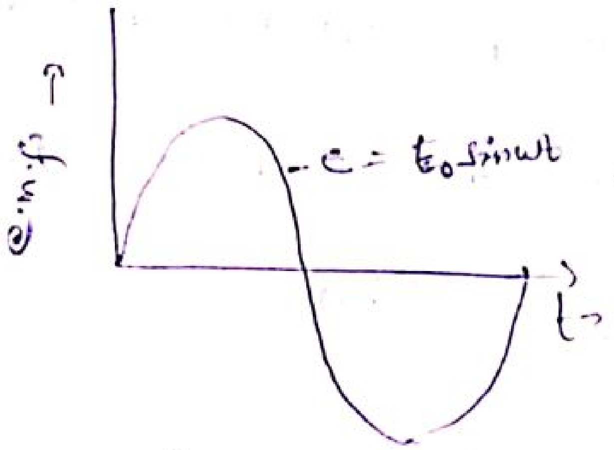
$$e = -\frac{d N \phi_B}{dt}$$

$$= -N \frac{d(BA \cos \omega t)}{dt}$$

$$= -NBA(-\omega)\sin \omega t$$

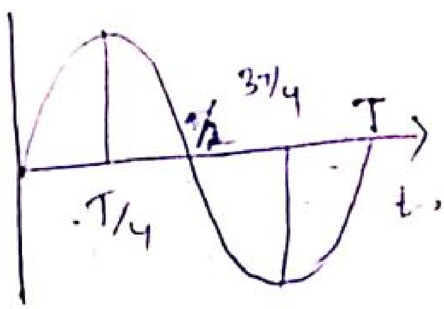
$$e = NBA\omega \sin \omega t$$

$$\boxed{e = E_0 \sin \omega t}$$



e = Instantaneous value of induced emf.

E_0 : Peak or maximum value of induced emf.



$$e = E_0 \sin\left(\frac{2\pi}{T} \times t\right)$$

$$e = E_0 \sin\left(\frac{2\pi}{T} \times 0\right) = 0$$

$$e = E_0 \sin\left(\frac{2\pi}{T} \times \frac{T}{4}\right) = E_0 \sin \pi/2 = E_0$$

Scanned with CamScanner

$t = T/2 \rightarrow e = 0$

$t = \frac{3T}{4} \quad e = -E_0$

$t = T \quad e = 0$

$e = E_0 \sin\theta$

$\theta = 0 \qquad e = E_0 \sin 0 = 0$

$\theta = \pi/2 \qquad e = E_0 \sin \pi/2 = E_0$

$\theta = 3\pi/2 \qquad e = E_0 \sin 3\pi/2 = -E_0$

$\theta = 2\pi \qquad e = E_0 \sin 2\pi = 0$

Q Induced Emf follows which Fleming's rule?

Q Different parts of generator?

10.01.2020

Essential component of Generator

→ A magnetic field

→ Conductor or group of conductors

→ Motion of the conductor w.r.t magnetic field..

Scanned with CamScanner

Construction

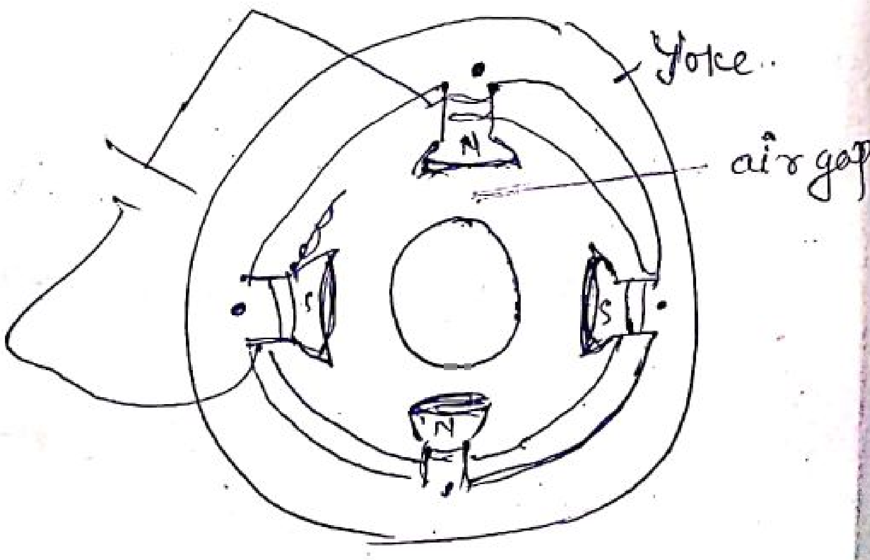
This D.C Generator and D.C Motor have the same general construction.

i) Field System
ii) Armature core
iii) Armature winding
iv) Commutator
v) Brushes.

i) Field System

- The function of the field system is to produce uniform magnetic field with which the armature rotates.

- It consist of a no. of salient poles (even number) bolted to the inside of the circumference is called yoke.



- The yoke is generally made up of solid Cast steel whereas the pole pieces are Composed up stacked lamination.
- The field coils are mounted on the poles such that the adjacent poles are opposite polarity after ~~too~~ excitation
- The field coils are mounted and carry DC exciting current
- The field coils are ~~such~~ connected in such a way that the adjacent poles have opposite polarity.
- The mmf developed by the field coils produce magnetic flux that passes through the pole pieces.
- The practical DC machine having air gap ranging from 0.5mm to 1.5mm

ii) Armature core

- The armature core is keyed to the machine shaft and rotate between the field poles.
- It consist of slotted soft iron lamination.

that are stacked to form a cylindrical pole.

- The laminations are individually coated ~~with~~ to a thin insulating film so that they donot come electrical contact with each other.

- The laminations are slotted to keep the coil and provide safety to the armature winding.

x. Armature core permits rotation for mechanical generator action since

- It provides mechanical support to the armature winding.
- since it houses the conductor emf is induced within the armature winding.
- It provides low reluctance path for the magnetic flux.

iii) Armature Winding

- The slot of the armature core hold / houses insulated conductors that are connected in a suitable manner this is known as armature winding.

Scanned with CamScanner

- In armature winding working emf is produced.
- The armature conductors are connected in series and parallel manner
- The conductors are connected in series to produce more voltage
- The conductors are connected in parallel to produce more current.
- The conductors are connected in a series parallel symmetrical manner to from a closed loop.

iv) <u>Commutator</u>

- A commutator is a mechanical rectifier. It converts AC voltage generated in armature winding into direct voltage across the brush.
- The commutator is made up of copper segment
- Two half of the commutator is insulated from each by a thin mica sheets.
- It is mounted on the shaft of the machine
- The armature conductors are soldered to the commutator segment in a suitable manner to give rise armature winding.

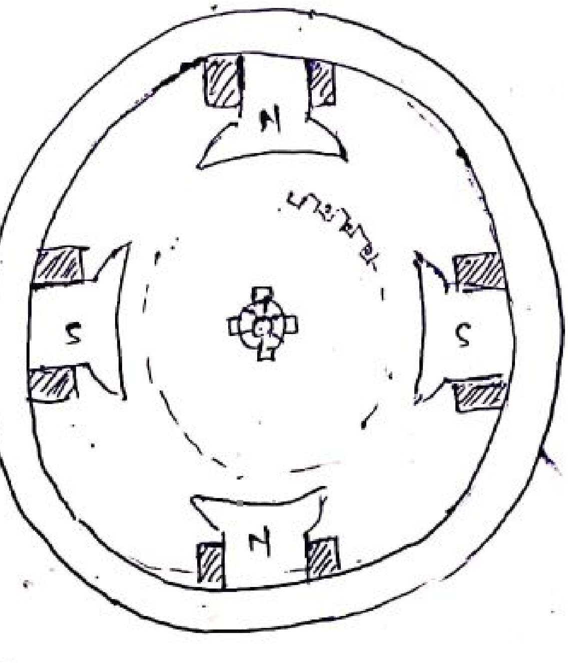
a) Lap winding

b) Wave winding

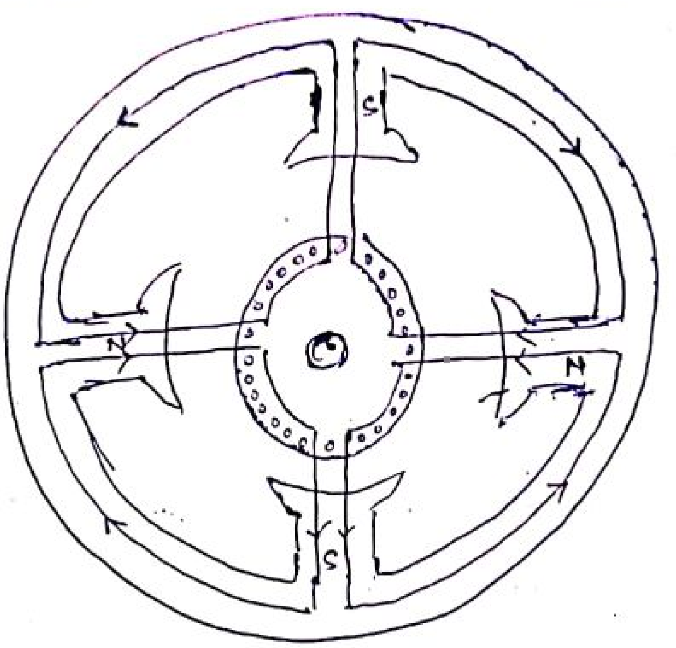
V) Brushes

Used to ensure electrical connection between the rotating commutator and external stationary load.

- The brushes are made up of carbon and rest on the commutator.
- The brush pressure is adjusted by means of a adjustable spring.
- Multipole machines have as many ~~as~~ brush as no. of poles

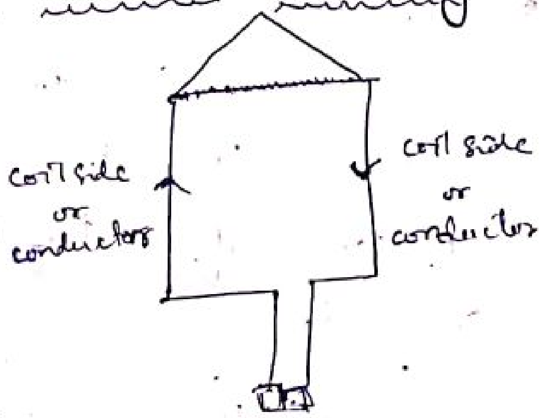


Scanned with CamScanner



General features of DC Armature Winding

1 coil = 2 conductor.



- A DC machine (generator or motor) generally employs winding distributed in slots over the circumference of the armature core.

- Each conductor lies perpendicular to the magnetic flux so voltage induced on each conductor is given by $\boxed{e = Blv}$ volts.

$$e = \frac{d\Phi_B}{dt} = \frac{d}{dt} BA$$

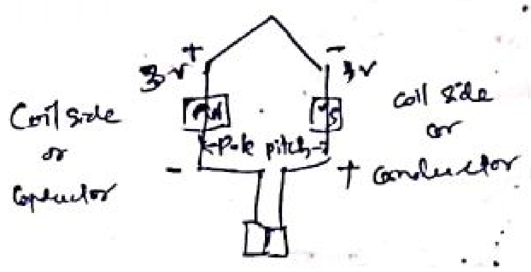
$$= B \frac{d}{dt} l \times b$$

$$= B \cdot l \frac{ds}{dt}$$

$$e = Blv.$$

- B = magnetic flux density
- l = length of the conductor
- v = velocity of the conductor

Scanned with CamScanner



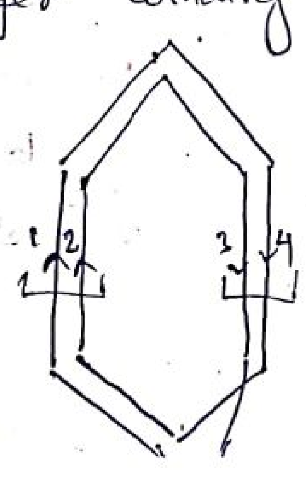
- If coil sides are pole pitch apart the voltage induced in that coil is the algebraic sum of voltage induced in each coil side or conductor. (phase difference $\phi = 0$)

- When the coil sides of a coil are less than pole pitch apart then the voltage induced in the coil is the phasors of the voltage induced in each conductors.

  ϕ is the phase difference between voltage induced in two coil sides

$$V = \sqrt{3^2 + 3^2 + 2 \times 3 \times 3 \times \cos\phi}$$

- Most of the DC armature winding are double layer winding



Scanned with CamScanner

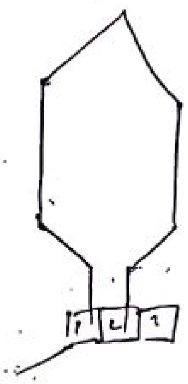
- one coil side of a coil lies on ~~the og~~ top of a slot then another coil side of same coil will have bottom of another slot.

- The coil sides are connected through a commutator segment in such a manner to from series parallel system

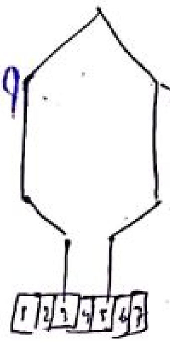
- The DC armature winding is a closed circuit.

<u>Terminology</u>

<u>Commutator</u> <u>Pitch</u> :- (Y_c)

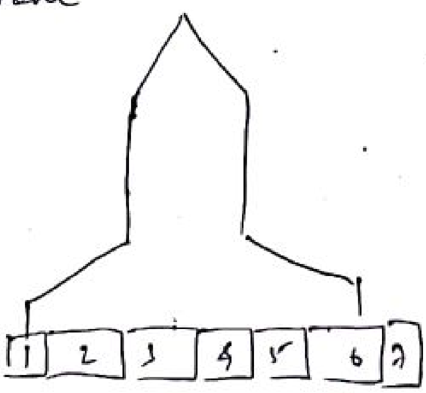


$Y_c = 2-1 = 1$



$Y_c = 5-3 = 2$

Commutator segment



$Y_c = 6-1 = 5$

- The no. of commutator segment span by a coil is called commutator pitch.
- It is denoted by Y_c.

Pole pitch (Y_p):

Slots = 36

poles = 4

$\text{slots}/\text{pole} = 36/4 = 9\ Y_p$

No. of slots per pole is called pole pitch.

OR

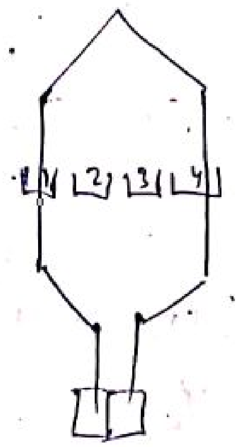
- It is the distance measured in terms of no. of armature slots between 2 consecutive poles
- Denoted by Y_p.

Coil span or coil pitch (Y_s):

It is the distance measured ~~between~~ in terms of no. of armature slots between 2 coil sides of a coil is called coilspan or coil pitch.

It is Denoted By (Y_s).

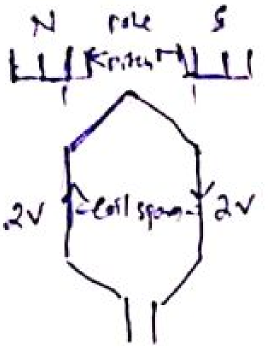
$Y_s = 4 - 1 = 3$ slots



Scanned with CamScanner

Full pitched coil

21/01/20

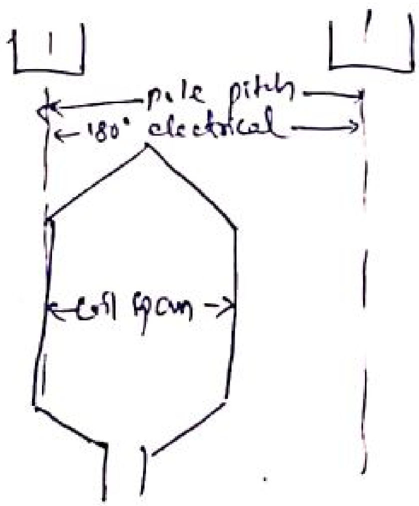


$$V_R = \sqrt{2^2 + 2^2 + 2 \times 2 \times 2 \cos 0^\circ}$$
$$= \sqrt{4 + 4 + 2 \times 4}$$
$$= \sqrt{16}$$
$$= 4$$

$Y_s = Y_p$

- A coil is called <u>full pitched coil</u> if coil span is equal to pole pitch.
- The phase difference between the voltage induced 2 coil sides of a full pitched coil is zero.
- The total voltage induced in a full pitched coil is the algebraic sum of the voltage induced in each coil side.

Fractional pitched coil



Scanned with CamScanner

- If coil span ~~of~~ ~~tet~~ a coil is less than pole pitch it is called fractional pitch coil.
- The phase difference between the voltage induced two coil sides of a fractional pitched coil is not zero.

Full pitched coil is seldom used because it require more copper.

Fractional pitched coil is frequently used because it requires less copper.

Armature winding

Different armature coils in an DC armature winding must be connected in series with end connection with each other to produce a generated voltage.

Windings are of two types

1) Simplex lap winding
ii) Simplex wave winding

Scanned with CamScanner

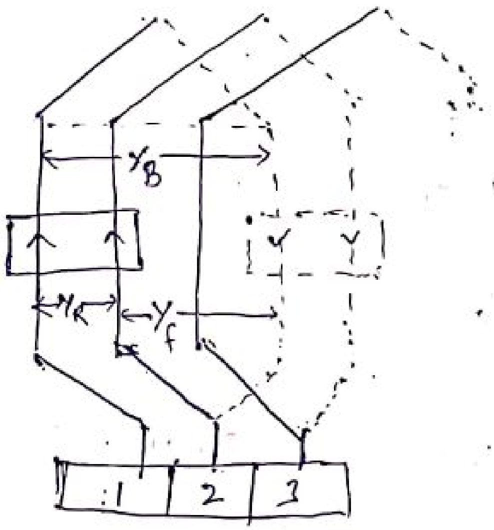
1) Simplex lap winding

In simplex lap winding $Y_C = 1$ and

$Y_S \simeq Y_P$

In lap winding ends of any coil connected to adjacent commutator segment.

If we proceed in this way the ends of the last coil will connected to ends of the first coil so that a close circuit winding will produce.

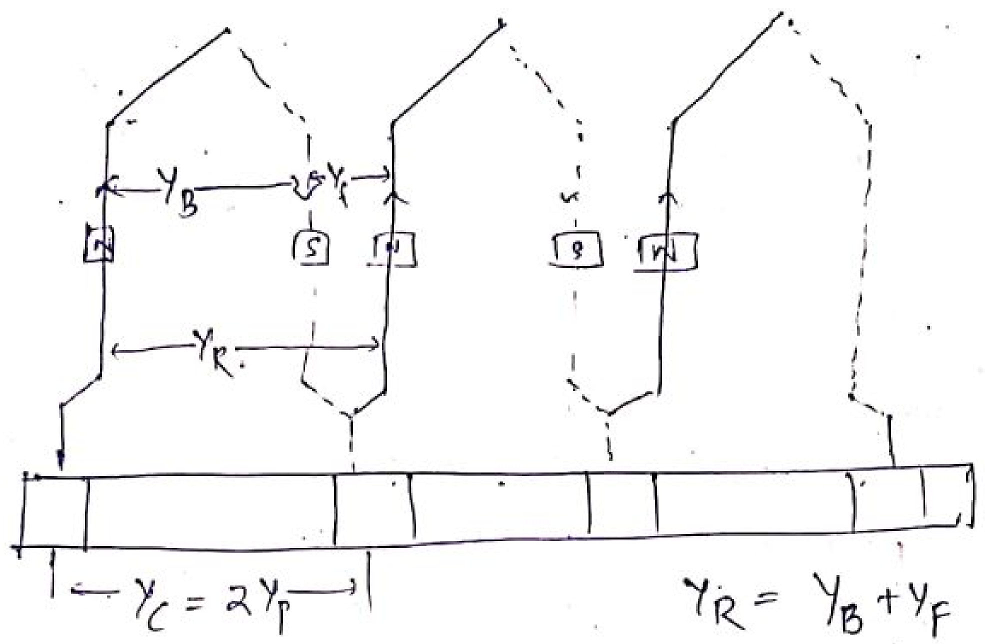


$Y_R = Y_B \sim Y_F$

The name lap winding is due to the overlapping of the succeeding coil to the preceding one

Scanned with CamScanner

ii) Simplex Wave winding



In Simplex wave winding Y_c is approximately equal to 2 pole pitches

i.e $Y_c \simeq 2Y_p$

$Y_s \simeq Y_p$

After passing armature winding the end of the end last coil falls just before or after the ends of the first coil.

Continuing in this way the winding will produce a single conductor

It is called wave winding because it looks wavy in nature.

Back pitch (Y_B)

It is the distance ~~between 2~~ measured in terms of armature ~~slots~~ or conductors between 2 coil sides of a coil connected back.

Front Pitch (Y_f)

It is the distance measured in terms of no. of ~~armature slots~~ armature ~~or~~ conductors between 2 coil sides of a coil connected front to in a commutator segment.

Resultant Pitch (Y_R).

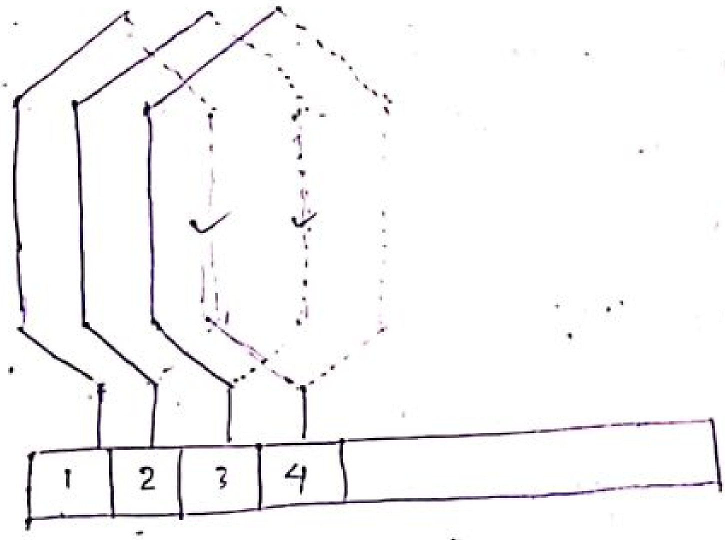
It is the distance measured in terms of no. of armature ~~slots or~~ conductors between beginning of the first coil to the beginning of the next coil.

Progressive winding

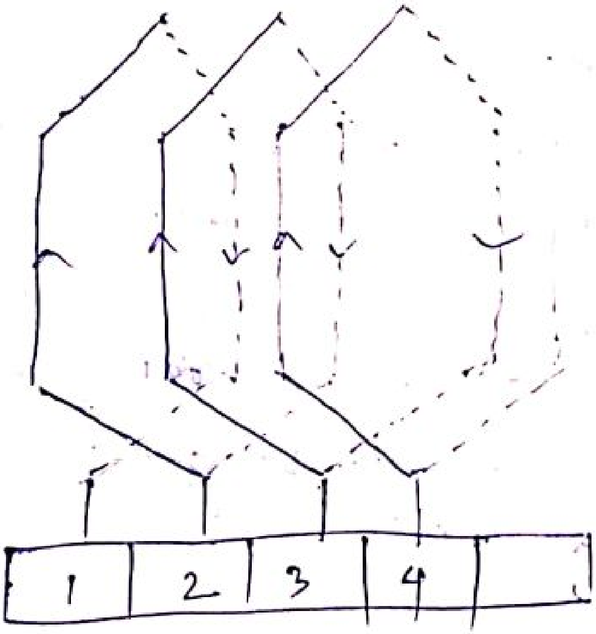
The winding is called progressive winding if one traces through the winding the connection to the commutator segment around the machine will progress in the same direction as it being traces through individual coil.

Retrogressive winding

The winding is called Retrogressive winding if one traces through the winding the connection to the commutator segment around the machine will progress in the opposite direction as it being traced through individual coil.



Progressive: $Y_c = +1$



Retrogressive: $Y_c = -1$

Scanned with CamScanner

Rules for drawing DC armature winding

1) $(Y_F) \simeq Y_B \simeq Y_P$

front pitch = Back pitch = pole pitch

Front pitch(Y_F) is equal to Back pitch (Y_B) is nearly equal to pole pitch (Y_P)

2) Front pitch and Back pitch are odd.

Y_F & Y_B are odd.

3) No. of commutator segments is equal to no. of slots = No. of Armature coils.

Relation between different pitches of ~~different~~ (armature) lap winding.

$$Y_F \simeq Y_B$$

$Y_F = 11$, $Y_B = 13, 9$

$$Y_B = Y_F \pm 2$$

$$\left.\begin{array}{l} Y_B = Y_F + 2 \\ Y_C = +1 \end{array}\right\} \text{For progressive winding } (Y_B > Y_F)$$

$$\left.\begin{array}{l} Y_B = Y_F - 2 \\ Y_C = -1 \end{array}\right\} \text{for retrogressive } (Y_B < Y_F)$$

Retrogressive winding is seldom used because it requires more copper

$$Y_p = \frac{Z}{P}$$

Z = No. of conductors

P = No. of poles

$$\boxed{\begin{aligned} Y_B &= \frac{Z}{P} + 2 \quad \} \text{ For progressive winding} \\ Y_B &= \frac{Z}{P} - 2 \quad \} \text{ For Retrogressive winding} \end{aligned}}$$

$$Y_F \text{ — } Y_P \text{ — } Y_B$$

$$\left.\begin{aligned} Y_B &= \frac{Z}{P} + 1 \\ Y_F &= \frac{Z}{P} - 1 \end{aligned}\right\} \text{ For Progressive winding}$$

$$Y_B - Y_F = \frac{Z}{P} + 1 - \frac{Z}{P} + 1$$

$$Y_B - Y_F = 2$$

$$Y_B = Y_F + 2$$

Scanned with CamScanner

$$\left.\begin{aligned} Y_B &= \frac{Z}{P} - 1 \\ Y_F &= \frac{Z}{P} + 1 \end{aligned}\right\}$$ For retrogressive winding

Q In a dc generator the armature having 10 slots. Calculate the pole pitch for i) 2 pole
ii) 4 pole.

i) 2 pole

Y_p = No. of slots per pole $= \frac{10}{2} = 5$ slots

ii) 4 pole

$\frac{10}{4} = 2.5 \simeq 2$ slots / pole.

Q A 4 pole simplex lap winding Armature contain 16 slots and 2 coil sides per slots. Calculate the Y_F, Y_B and Y_C Y_p for i) progressive winding ii) retrogressive winding

No. of slots = 16

No. of ~~coil~~ conductor $= 16 \times 2 = 32$

No. of pole = 4

$Y_p = \frac{32}{4} = 8$ nos.

For progressive winding.

$Y_c = +1$

$Y_P = 8$

$Y_B = \frac{Z}{P} + 1$

$Y_B = 8+1 = 9$ conductors.

$Y_F = \frac{Z}{P} - 1$

$Y_F = 8-1 = 7$ conductors.

For retrogressive winding

$Y_k = -1$

$Y_P = 8$

$Y_B = \frac{Z}{P} - 1 = 7$ conductors

$Y_F = \frac{Z}{P} + 1 = 9$ conductors

$Y_B < Y_F$

Q Design a 4 pole Simplex lap winding suitable for an armature containing 20 slots. Assume 2 conductors per slots. of single turn coil. (progressive lap winding)

Pole = 4

No. of slots = 20

$Z = 40$

$\therefore Y_p = \frac{Z}{P} = \frac{40}{4} = 10$ Nos.

$Y_B > Y_F$

$Y_c = +1$

$Y_B = \frac{Z}{P} + 1 = 10+1 = 11$

$Y_F = \frac{Z}{P} - 1 = 10 - 1 = 9$

Back Connection	Front connection
1 to (1+11) = 12	12 to (12−9) = 3
3 to (3+11) = 14	14 to (14−9) = 5
5 to (5+11) = 16	16 to (16−9) = 7
7 to (7+11) = 18	18 to (18−9) = 9
9 to (9+11) = 20	20 to (20−9) = 11
11 to (11+11) = 22	22 to (22−9) = 13
13 to (13+11) = 24	24 to (24−9) = 15
15 to (15+11) = 26	26 to (26−9) = 17
17 to (17+11) = 28	28 to (28−9) = 19
19 to (19+11) = 30	30 to (30−9) = 21

The position of the brush that can be defined by using current direction through the coil to that commutator segment.

Positive Brush

A brush is called positive brush if current will be collected from the coil and sends to the external load through the brush.

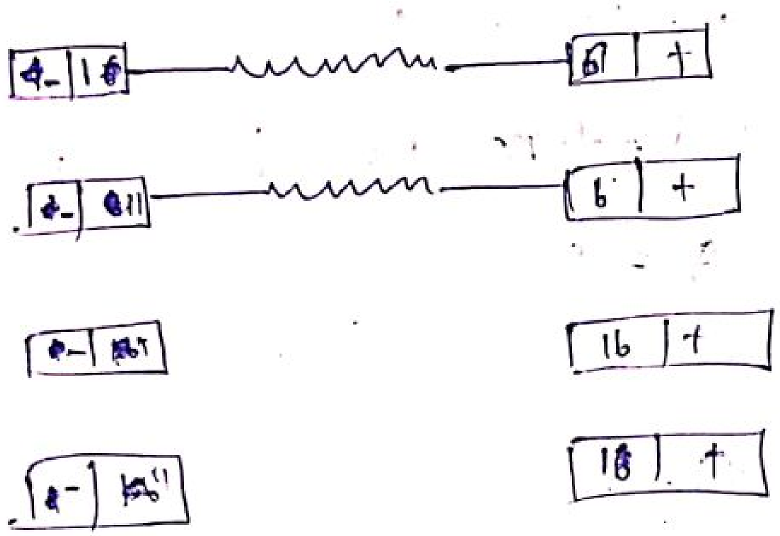
Negative Brush

A brush is called negative brush if current passes through that brush from external load to the coil.

From the winding diagram by knowing the direction of the current in the coil by using Flemings Right Hand Rule, we can fix the brush to the commutator segment.

From the above fe winding diagram it is clear 4 brushes are required 2 positive and 2 negative.

It is clear that no. of brushes required for lap winding is equal to no. of poles.



[- | 1] 1 - 12 - 3 - 14 - 5 - 16 - 7 - 18 - 9 - 20 → [6 | +]

[- | 11] 30 - 19 - 28 - 17 - 26 - 15 - 24 - 13 - 22 - 11 - [6 | +]

[- | 1] - 10 - 39 - 8 - 37 - 6 - 35 - 4 - 33 - 2 - 31 → [16 | +]

[- | 11] - 21 - 32 - 23 - 34 - 25 - 36 - 27 - 38 - 29 - 40 [16 | +]

Scanned with CamScanner

From this figure we found that there are 4 parallel path and each parallel path having 10 conductors.

In simplex lap winding no. of parallel path is equal to Number of poles.

No. of parallel path (A) = No. of poles (P)

$$A = P$$

$$I_a = 4 I_p$$

$$\boxed{I_a = A I_p}$$

I_a = Armature current

$(I_a) = A I_p$

A = no. of parallel path

I_p = current in each parallel path.

☆ The emf induced in each conductor is same.

Scanned with CamScanner

Generated emf of Armature (E_g)

= Generated E.m.f of each parallel path.

= Generated emf of each conductor X no. of conductor in that parallel path.

$A = P$

$I_a = A I_p$

$E_g = e \times \left(\frac{Z}{A}\right)$

e = generated emf in each conductor

$\frac{Z}{A}$ = No. of conductor in each parallel path.

Armature Resistance (R_a)

L = length of conductor

a = Area of cross-section of conductor

ρ = specific resistance

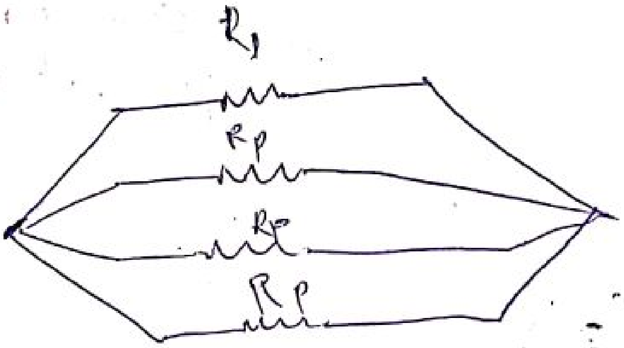
Resistance of a conductor = $\frac{\rho L}{a}$

Resistance of a parallel path = Resistance of a conductor X No. of conductor in each parallel path.

Scanned with CamScanner

Resistance of a parallel path $(R_p) = R \times \left(\frac{Z}{A}\right)$

$$R_p = R \times \left(\frac{Z}{A}\right)$$



$$R = \frac{R_p}{y}$$

Armature resistance = Equivalent resistance of all parallel path.

$$R_a = \frac{R_p}{A}$$

$$R_a = \frac{1}{A}\left(\frac{RZ}{A}\right) = \frac{RZ}{A^2}$$

$$\boxed{R_a = \frac{\rho L Z}{a A^2}}$$

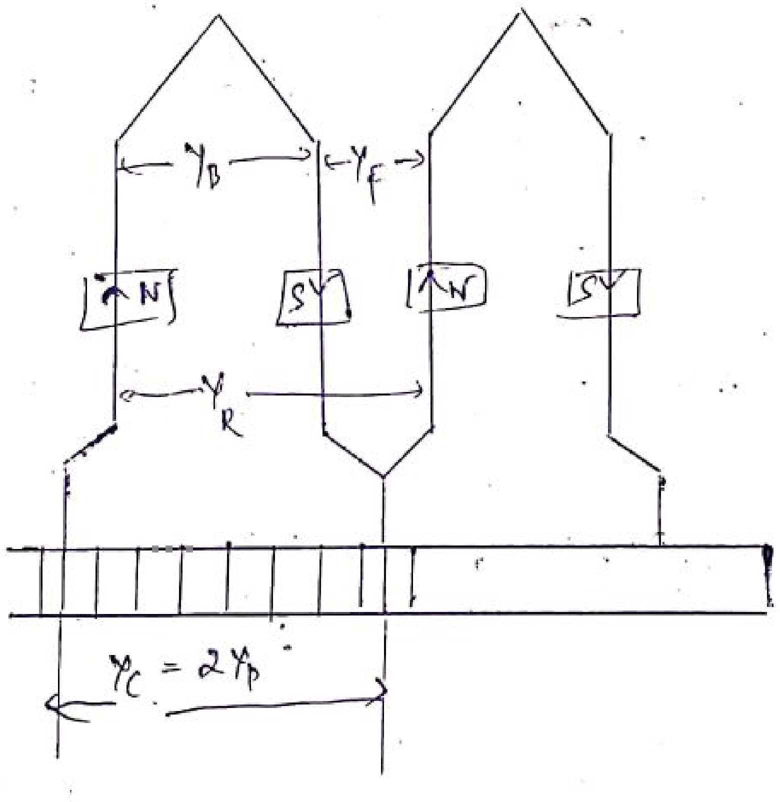
Scanned with CamScanner

Simplex Wave Winding

$Y_C \simeq 2Y_P$ $\qquad 20 \simeq 2 \times 10$

Y_P = No. of slots / pole

Y_C = No. of commutator segment spanned by a coil.



$Y_R = Y_B + Y_F$

$$\text{Avg. Pitch} = Y_A = \frac{Y_B + Y_F}{2} \simeq Y_P$$

Scanned with CamScanner

Progressive wave winding

After passing once around the armature the winding connects to a commutator segment right of the starting point is called progressive wave winding.

Retrogressive wave winding

After passing once around the armature the winding connect to a commutator segment left of the starting point is called retrogressive wave winding.

Various pitches of wave winding

Back pitch (Y_B) = It is the distance between 2 coil sides of a coil in terms of no. of conductors connected back.

It is odd.

Front pitch (Y_F) = It is the distance between 2 coil sides of a coil in terms of no. of connected to a commutator segment.

It is odd.

Scanned with CamScanner

Resultant Pitch (Y_R) It is the distance between beginning of 1st coil side to beginning of the next coil side of another coil in terms of no. of armature conductors is called resultant pitch.

Avg. Pitch

$$Y_A = \frac{Y_B + Y_F}{2}$$

Y_A must be a whole number.

Condition for wave winding

→ Y_F and Y_B are odd.

→ $Y_B \simeq Y_F \simeq Y_P$

→ $Y_A = \frac{Y_B + Y_F}{2} \simeq Y_P$

→ Y_A must be a whole number

$Y_P P$ = Total number of slots

$Y_A \simeq Y_p$

$Y_p P$ = Total number of slots = No. of conduct

$$\boxed{Y_A P = Z \pm 2}$$

$$Y_A = \frac{Z \pm 2}{P}$$

No. of Commutator segment (N_c) = No. of slots = No. of coils

= $\frac{1}{2}$ No. of coil sides

$$Y_C = 2Y_P$$
$$= 2 \cdot \frac{\text{No. of slots}}{\text{pole}}$$

$$Y_C = 2 \cdot \left(\frac{N_c \pm 1}{P} \right)$$

$$Y_C = \frac{2N_c \pm 2}{P}$$

No. of commutator segment (N_c)

= No. of slots.

$2N_c = Z$

$$Y_A = Y_C \simeq Y_p$$

Y_C measured in terms of commutator segment

31/01/2020

$$\boxed{Y_A = \frac{Z \pm 2}{P}}$$

$$\boxed{Y_C = \frac{N_C \pm 1}{P/2}} \qquad \boxed{Z = P Y_A \pm 2}$$

Q A 4pole armature have 30 conductors. The armature is to be simplex wave wound. Determine for a retrogressive winding Y_B, Y_F, Y_C

Ans
$P = 4$
$Z = 30$

$$Y_A = \frac{Z-2}{P} = \frac{30-2}{4} = \frac{28}{4} = 7 \text{ conductors}$$

$$Y_A = \frac{Y_B + Y_F}{2}$$

Let $Y_B = 7$ conductors

$Y_F = 7$ conductors

$Y_C = 7$ segments

Q For a 4 pole simplex wave winding armature has 21 slots and 21 segments. Determine the Y_c.

Ans Y_c = $P = 4$, No of slots = 21
No. of conductors = 42

$N_c = 21$

$$Y_c = \frac{N_c \pm 1}{P/2} = \frac{21 \pm 1}{4/2}$$

$$= \frac{22}{2} \quad \Big| \quad \frac{20}{2}$$

$$= 11 \quad \Big| \quad 10$$

For progressive | For retrogressive

Q Design a 4 pole wave winding for an armature with 21 slots. Assume single turn coil and 2 conductors per slots.

Ans $P = 4$, No. of slots $= 21 = N_c$

$Z = 21 \times 2 = 42$

For progressive winding

$$Y_A = \frac{Z+2}{P} = \frac{42+2}{4} = \frac{44}{4} = 11$$

$Y_A \simeq Y_B \simeq Y_F$ = 11 conductors.

Y_C = 11 segments

Back connection

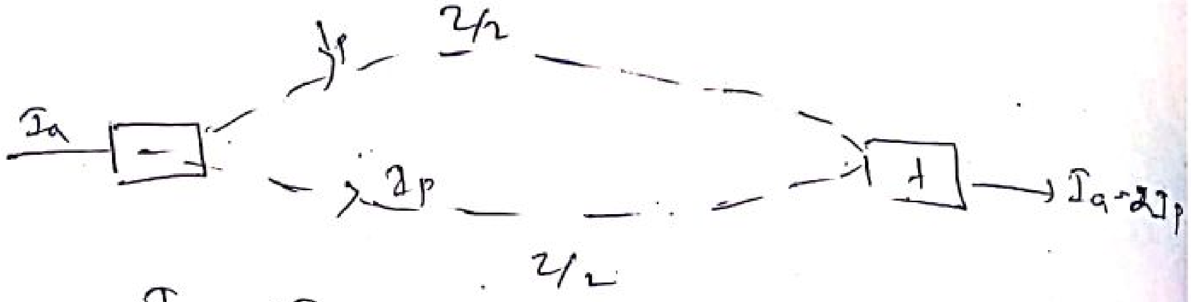
1 to (1+11) = 12
23 to (23+11) = 34
3 to (3+11) = 14
25 to (25+11) = 36
5 to (5+11) = 16
27 to (27+11) = 38
7 to (7+11) = 18
29 to (29+11) = 40
9 to (9+11) = 20
31 to (31+11) = 42
11 to (11+11) = 22
33 to (33+11) = 44 (2)
13 to (13+11) = 24
35 to (35+11) = 46 (4)
15 to (15+11) = 26
37 to (37+11) = 48 (6)
17 to (17+11) = 28
39 to (39+11) = 50 (8 No)

Front connection

12 to (12+11) = 23
34 to (34+11) = 45 (3 No)
14 to (14+11) = 25
36 to (36+11) = 47 (5 No)
16 to (16+11) = 27
38 to (38+11) = 49 (7 No)
18 to (18+11) = 29
40 to (40+11) = 51 (9 No)
20 to (20+11) = 31
42 to (42+11) = 53 (11 No)
22 to (22+11) = 33
44 to (44+11) = 55 (13 No)
24 to (24+11) = 35
46 to (46+11) = 57 (15 No)
26 to (26+11) = 37
6 to (6+11) = 17
28 to (28+11) = 39
8 to (8+11) = 19

Scanned with CamScanner

Simplex Wave winding is always having 2 parallel path irrespective of No. of poles.



$I_a = 2I_p$, I_p = current in each parallel path

Generated emf (E_g) = Emf generated in each parallel path

= Avg of emf a conductor (e)

$\times$ No. of conductors in each parallel path ($Z/2$)

$$\boxed{E_g = e \times Z/2}$$

Resistance:

$$R_a = \frac{R_p}{2}$$

R_p = Resistance of each conductor $\times$ No. of conductors/parallel path.

Scanned with CamScanner

R = Resistance of each conductor

$$R = \rho \frac{L}{A}$$

$$R_p = \rho \frac{L}{a} \times \frac{Z}{2}$$

$$R_a = \frac{R_p}{2}$$

$$\boxed{R_a = \rho \frac{L}{a} \cdot \frac{Z}{4}}$$

Scanned with CamScanner

EMF Equation of D.C. Generator

$$E_g = e \times \frac{Z}{A}$$

A = P for Lap winding
A = 2 for wave "

P = No. of poles

ϕ_B = Magnetic flux per pole

N = r.p.m (revolution per minute)

Z = No. of conductors

A = No. of parallel paths

Consider an armature winding and a field system having above specification

Generated Emf (E_g) = Avg. emf of each conductor × No. of conductor in each parallel path (Z/A)

Flux change through a conductor when it moves once.

$$d\phi_B = P\phi_B - 0 = P\phi_B.$$

Scanned with CamScanner

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

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

$$e = \frac{d\phi_B}{dt} = \frac{P\phi_B}{\frac{60}{N}} = \frac{P\phi_B N}{60}$$

$$\boxed{e = \frac{P\phi_B N}{60}}$$

$$E_g = e \times \frac{Z}{A}$$

$$\boxed{E_g = \frac{P\phi_B N}{60}\left(\frac{Z}{A}\right)}$$ Volts.

For simplex lap wind $A = P$

$$= \frac{\cancel{P}\phi_B N}{60}\left(\frac{Z}{\cancel{P}}\right)$$

$$\boxed{E_g = \frac{\phi_B N Z}{60}}$$

Scanned with CamScanner

For simplex wave winding

$$\boxed{E_g = \frac{P\phi_B N Z}{120}}$$

07/02/2020

Calculate the emf generated by a 4 pole wave wound generator having 65 slots with 12 conductors per slot when driven at 1200 rpm. The flux per pole is $\phi_B = 0.02 wb$

Ans.

$$E_g = \frac{\overset{2}{\cancel{4}} \times 0.02 \times \overset{20}{\cancel{1200}} \times 780}{\cancel{60} \times \cancel{2}}$$

$\phi_B = 0.02 \, wb/m^2$

$P = 4$

$N = 1200$

Slots $= 65$

12 conductors / slot

$Z = 65 \times 12 = 780$

$A = 2$

$E_g = 624 V$

Armature Resistance (R_a)

The resistance offered by armature is called armature resistance. (R_a)

i) Armature winding Resistance
ii) Brush contact Resistance

Types of DC Generator

In field system we are using electromagnet rather than permanent magnet.

Depending upon the magnetic field system the DC generators are divided into 2 types

a) Separately excited
b) self excited

DC Generator

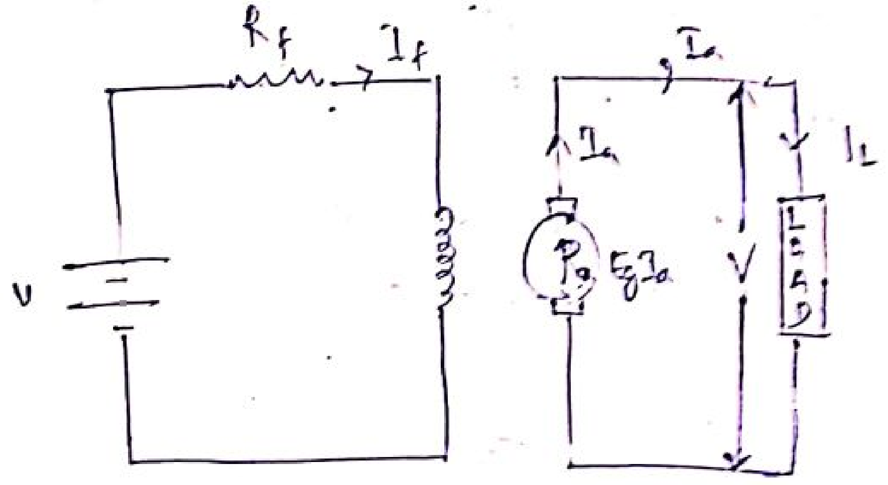
Separately excited | Self excited

a) Separately excited DC Generator

In a dc generator if the field magnet winding is provided or is supplied from an independent external source is called Separately excited DC Generator.

→ It is rarely used.

Scanned with CamScanner



Armature current = $I_a = I_L$

Terminal voltage = $V = E_g - I_a R_a$

Power Generated = $E_g I_a$

Power delivered to load $= E_g I_a - I_a^2 R_a$

$$= (E_g - I_a R_a) I_a$$

$$= V I_a$$

$$= V I_L$$

Q. A separately excited dc generator when running at 1200 rpm supplies 200 A at 125V to a ckt of constant resistance. What will be the generated voltage when the ~~speed~~ field is dropped to 1000 rpm and field current is reduced 80%. Armature resistance 0.04 Ω

~~Sepa~~ b) Self excited dc generator

Self excited

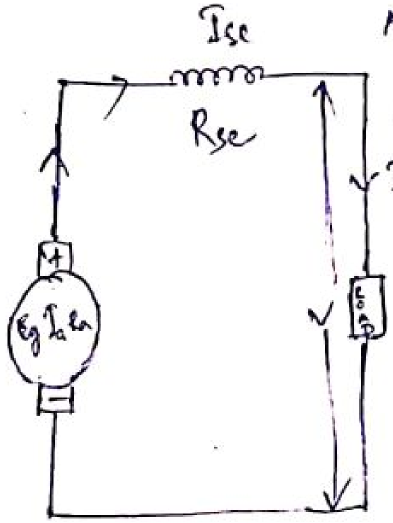
- Series field
- Shunt field
- compound field
  - Short shunt
  - Long shunt

i) ~~series field~~

A dc generator whose field magnet winding is supplied current from the output of the generator itself, is called self excited dc generator.

i) Series field DC generator / series Generator

In a series wound dc generator the ~~Series~~ field winding is connected in series with the armature winding



Armature current

$I_a = I_{se} = I_L$

Generated voltage = E_g

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

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

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

Scanned with CamScanner

Power Generated $= E_g I_a$

Power delivered to load $= V I_L = V I_a$

Power delivered to load $= E_g I_a - I_a^2 R_a - I_{se}^2 R_{se}$

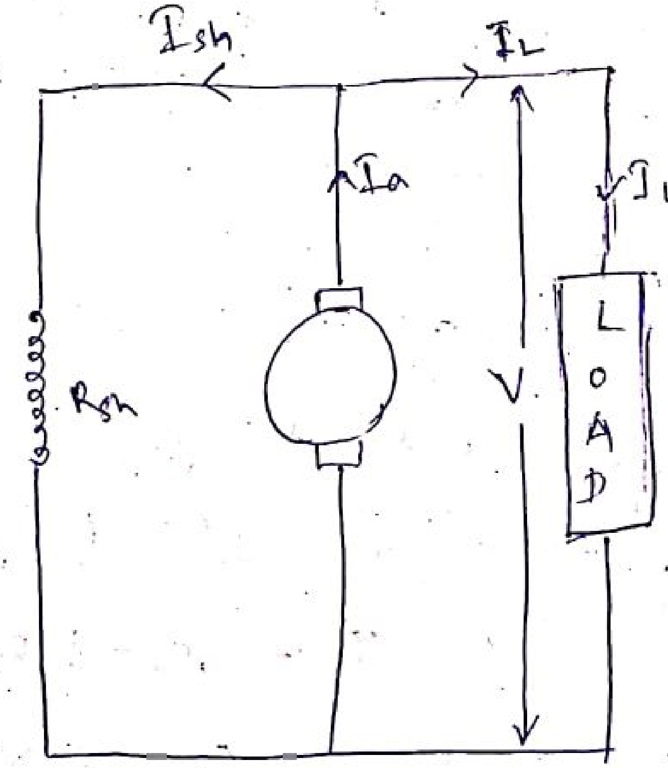
$$= (E_g - I_a R_a - I_a R_{se}) I_a$$

$$= [E_g - I_a (R_a + R_{se})] I_a$$

$$= V I_a$$

Shunt-field DC generator / shunt DC generator

In a DC generator whose field magnetic winding is in parallel with the armature winding is called shunt DC generator.



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

Terminal voltage(V) = Voltage across the load

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

$$I_L = I_a - I_{sh} \Rightarrow I_L = I_a - \frac{V}{R_{sh}}$$

Generated voltage = E_g

Terminal voltage (V) = $E_g - I_a R_a$

power Generated = $E_g I_a$

power delivered to load = $V I_L$

$= (E_g - I_a R_a) I_L$

Compound Generator

In compound generator there are 2 sets of field winding

i) Series field winding

ii) shunt field winding

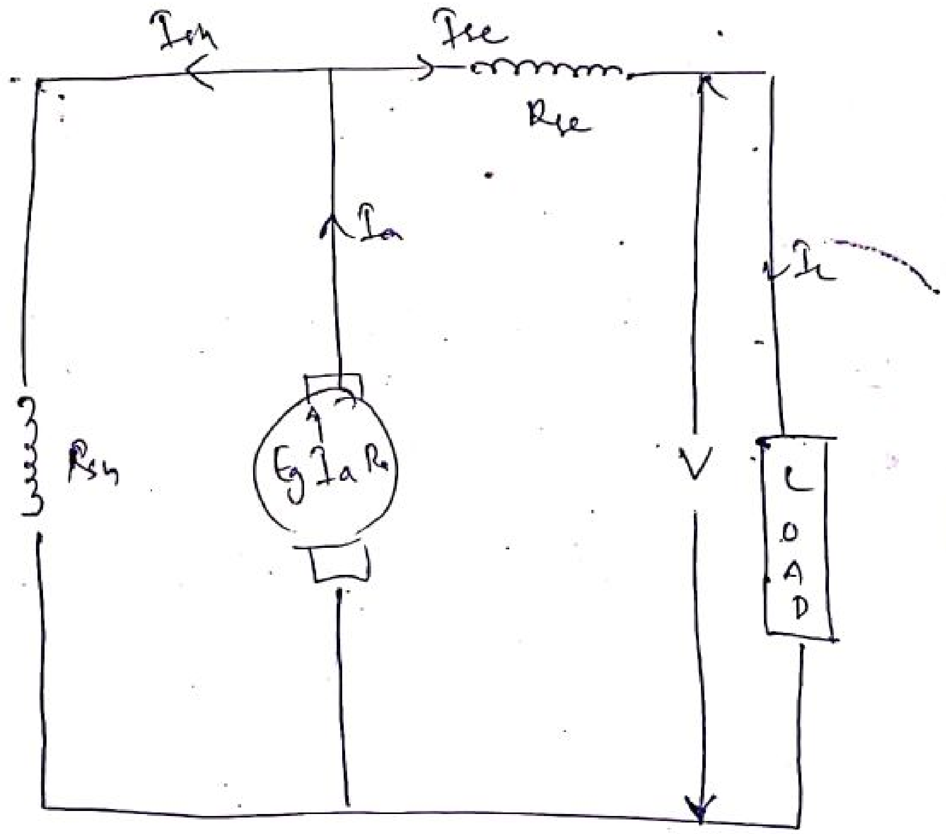
Again compound field dc generator is again divided into 2 types

1) short shunt

2) Long shunt

1) Short shunt compound generator

In Short shunt ~~generator~~ generator the shunt field winding is only parallel to armature winding.



$I_a = I_{sh} + I_L$

$I_L = I_{se}$

Generated voltage $= E_g$

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

$I_L = I_a - I_{sh}$

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

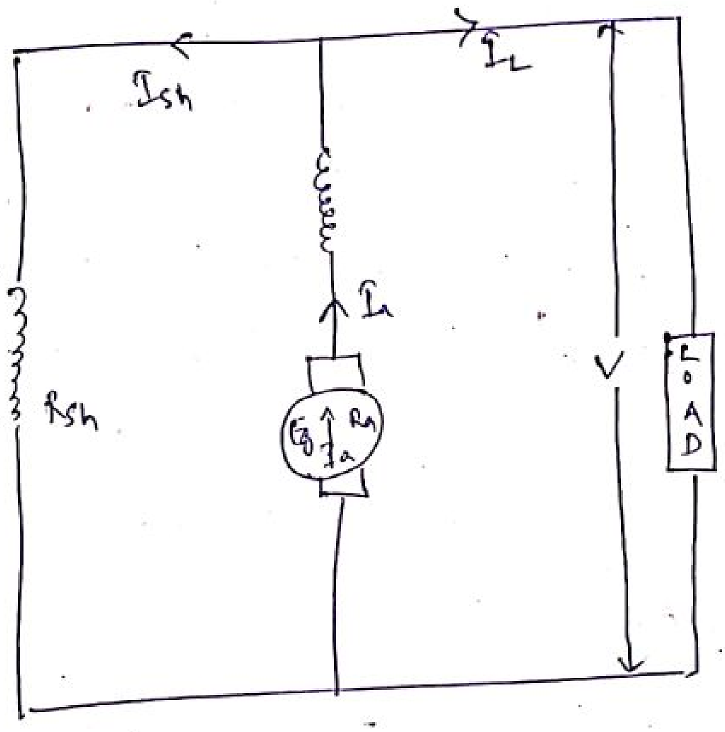
Power generated $= E_g I_a$

Power delivered to load $= V I_L$

Long shunt compound generator

Inf long the shunt field winding is in parallel to both armature winding and series field winding long shunt.

$$I_a = I_{se}$$



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

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

Generated emf = E_g

Terminal voltage(V) = $E_g - I_aR_a - I_{se}R_{se}$

$= E_g - I_aR_a - I_aR_{se}$

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

Power generated = E_gI_a

Power delivered to load = VI_L

Scanned with CamScanner

Brush contact drop

It is the voltage drop over the brush contact resistance when current flows

★ A 4 pole shunt generator with wave wound armature have 41 slots and each conductor having 12 slots. The armature resistance is 0.05 Ω. shunt resistance = 200Ω. ϕ_B = 25 mwb. Load resistance R_L = 10Ω. Calculate the voltage across load when the machine is running at 1000 rpm?

Ans $P = 4$, $A = 2$

Slots = 41

Conductor = 12

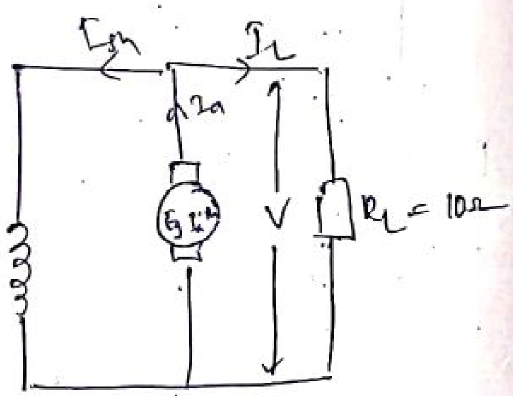
$R_a = 0.05\,\Omega$

$R_{sh} = 200\,\Omega$

$\phi_B = 25\text{ mwb} = 25\times10^{-3}\text{ wb}$

$R_L = 10\,\Omega$

$N = 1000\text{ rpm}$



$V = E_g - I_a R_a$

$Z = 41\times12 = 492$

$R_a = 0.05\,\Omega$

Scanned with CamScanner

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

$$= \frac{4 \times 25 \times 10^{-3} \times 1000}{60} \times \left(\frac{492}{2}\right)$$

$$= 410V$$

$$I_L = \frac{V}{R_L}, \quad I_{sh} = \frac{V}{R_{sh}}$$

$$I_L + I_{sh} = V\left(\frac{1}{R_L} + \frac{1}{R_{sh}}\right) = I_a$$

$$V = E_g - I_a R_a$$

$$= E_g - V\left(\frac{1}{R_L} + \frac{1}{R_{sh}}\right) R_a$$

$$V = 410 - V\left(\frac{1}{10} + \frac{1}{200}\right) 0.05$$

$$= 410 - V(0.1 + 0.005) \times 0.05$$

$$V = 410 - V\cancel{(0.10025)} \cdot \cancel{0.}\ 5.25 \times 10^{-3}$$

$$V(1 + 0.00525) = 410$$

$$V = \frac{410}{1.00525} = \cancel{372.64}\ 407.85V$$

Scanned with CamScanner

Q A long shunt compound generator has a full load output of 100 kWatt at 250 V. The armature $R_a = 0.05\,\Omega$

$R_{se} = 0.03\,\Omega$

$R_{sh} = 55\,\Omega$

Find the armature current I_a and generated emf E_g.

Ans

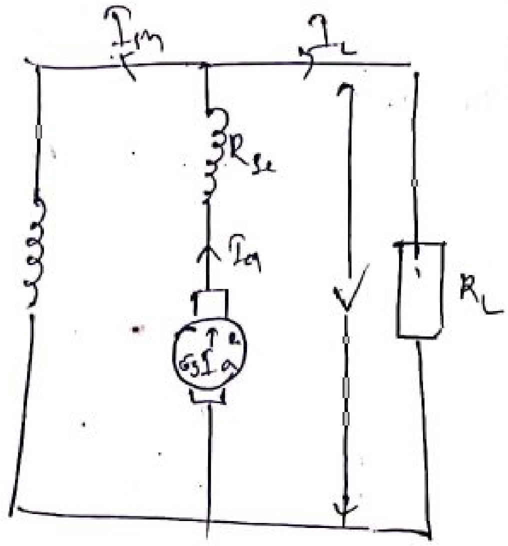
$E_g =$

$P = 100\,kW$

$V = 250\,V$

$I_L = \frac{P}{V} = \frac{100 \times 10^3}{250}$

$= 400\,A$



$I_{sh} = \frac{V}{R_{sh}} = \frac{250}{55} = 4.54\,A$

$I_a = I_L + I_{sh}$

$= 400 + 4.54\,A$

$= 404.54\,A$

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

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

$= V + (R_a + R_{se}) I_a$

$= 250 + (0.05 + 0.03) \times 404.5 = 282.36$

Scanned with CamScanner

Losses in DC Generator

There are 3 types of losses in a DC generator

1) Iron loss or core loss
2) Copper loss
3) Mechanical loss (Friction + windage) (Const loss)

Iron Loss (Const)

- Hysteresis loss
- Eddy current loss.

Copper Loss

- Armature cu loss — $I_a^2 R_a$
- Shunt field cu loss (Constant) — $I_{sh}^2 R_{sh}$
- Series field cu loss — $I_{se}^2 R_{se}$

Mechanical loss

- Friction
- windage

1) <u>Iron Loss</u> / core loss.

This losses occur in a armature of a dc machine are due to rotation of armature in the magnetic field of the poles

a) Hysteresis loss
b) Eddy current loss.

Scanned with CamScanner

a) Hysteresis loss

It occurs in armature of a DC machine since any part of armature is subjected to magnetic field reverses as it pass successive poles. Due to this some amount of power has to be spend which is called hysteresis loss.

It is given by Steinmetz formula.

$$\boxed{\text{Hysteresis loss}: P_h = \eta B_{max}^{1.6} f V \text{ watt}}$$

η : Steinmetz hysteresis coefficient

B_{max} : Maximum flux density in armature

f : frequency of magnetic reversal

V : volume of armature

b) Eddy current loss

Voltage induced in armature conductor present in armature slots so a current is flowing which is called armature current. The armature core is also subjected to changing magnetic field

According to Faraday's law emf is also induced in the armature core. If the armature core is solid one it will provide a conducting path to flow induced current produced by induced emf in the armature core. This is a unwanted current which produce excess heat of the armature and causes power loss. This is called eddy current loss. ~~Due~~ To reduce this eddy current loss iron core is thin laminated and insulated from each other.

$$\boxed{\text{Eddy current loss} = P_e = K_e B_{max}^2 f^2 t^2 v \text{ watt}}$$

K_e = Constant depending upon electrical resistance of core.

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

f = frequency of magnetic field reversed in Hz

t = thickness of lamination in m

v = volume of core in m^3.

ii) Copper loss

This loss due to armature current different winding of the machine.

Armature Copper loss = $I_a^2 R_a$

Series field copper loss = $I_{se}^2 R_{se}$

Shunt field copper loss = $I_{sh}^2 R_{sh}$

The ~~armature and~~ shunt field cu loss is constant loss

iii) Mechanical loss

This losses are due to friction and windage.

Friction loss

Bearing friction, Brush friction

Windage loss

Air friction of rotating armature

This losses are constant for constant speed DC machine.

Scanned with CamScanner

Constant losses

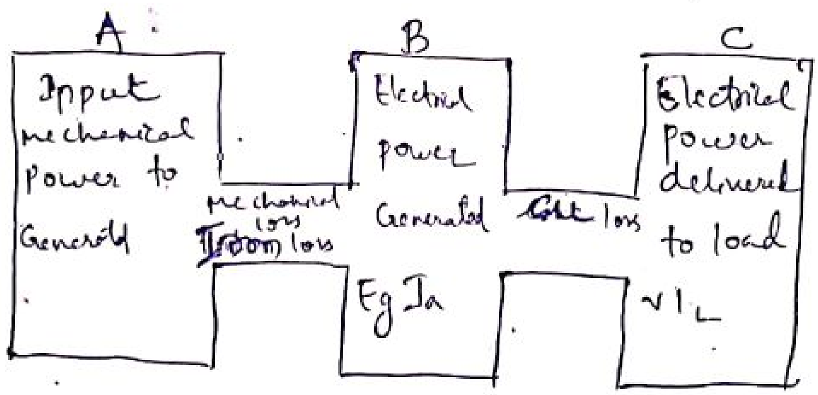
The losses ~~remains constant~~ doesnot change with change of load current is called constant loss.

a) Iron loss or coreloss
b) Mechanical loss
c) Shunt field cu. loss

Variable loss

The loss changes with change of load current is called variable loss.

a) Armature cu. loss $(I_a^2 R_a)$
b) series field cu loss. $(I_{se}^2 R_{se})$



Mechanical Efficiency (η_m)

$$\eta_m = \frac{B}{A} = \frac{E_g I_a}{\text{Input mechanical power}}$$

Electrical Efficiency (η_e)

$$\eta_e = \frac{C}{B} = \frac{VI_L}{E_g I_a}$$

Scanned with CamScanner

Commercial overall Efficiency (η)

$$\eta = \eta_m \times \eta_e = \frac{\cancel{B}}{A} \times \frac{C}{\cancel{B}} = \frac{C}{A}$$

$$\eta = \frac{VI_L}{\text{Input mechanical power}}$$

Condition for Maximum Efficiency

Consider a shunt generator

Generator output $= VI_L$

Generator input = Generator output + losses

$= VI_L +$ const. losses + variable

$= VI_L + W_c + I_a^2 R_a$

$I_a = I_L + I_{sh}$ But I_{sh} is negligible

$$I_a \simeq I_L$$

Generator output $= VI_L$

Generator ~~output~~ Input $= VI_L + W_c + I_L^2 R_a$

$$\eta = \frac{\text{Generator output}}{\text{Generator input}} = \frac{VI_L}{VI_L + W_c + I_L^2 R_a}$$

$$= \frac{VI_L / VI_L}{\dfrac{VI_L + W_c + I_L^2 R_a}{VI_L}}$$

Scanned with CamScanner

$$= \frac{1}{1 + \frac{W_c}{VI_L} + \frac{I_L^2 R_a}{V\cancel{I_L}}}$$

$$= \frac{1}{1 + \frac{W_c}{VI_L} + \frac{I_L R_a}{V}}$$

For $\eta = \eta_{max}$

Denominator should minimum.

$$\left(1 + \frac{I_L R_a}{V} + \frac{W_c}{VI_L}\right) - min$$

$$\frac{d}{dI_L}\left(1 + \frac{I_L R_a}{V} + \frac{W_c}{VI_L}\right) = 0$$

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

$$\frac{R_a}{\cancel{V}} = \frac{W_c}{\cancel{V}I_L^2}$$

$$\boxed{I_L^2 R_a = W_c} \qquad I_L \simeq I_a$$

Variable loss = Constant

$$\boxed{I_L = \sqrt{\frac{W_c}{R_a}}}$$

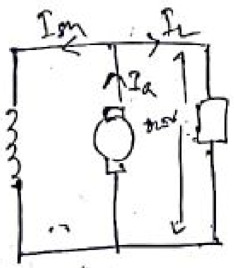
For efficiency to be maximum the variable ~~flux~~ loss must be equal to constant loss.

Q. A 4 pole long shunt lap wound generator supplies 25 kW at a terminal voltage of 500 V. $R_a = 0.03\,\Omega$.

Q. A shunt generator have full load current of 196 A at 220 V. $R_{sh} = 55\,\Omega$. Full load efficiency 88%. Find R_a 4 I_L corresponding to max^m efficiency. stray ~~of~~ (Iron loss) = 720 watt

Iron loss = 720 watt $\quad R_{sh} = 55\,\Omega \quad \eta_{fl} = 88\%$.

Ans $I_L = 196 \qquad V = 220\,V$



$$I_{sh} = \frac{V}{R_{sh}} = \frac{220}{55} = 4\,A$$

$$I_a = I_L + I_{sh} = 196 + 4 = 200\,A$$

$$\eta = \frac{o/p}{i/p} = \frac{25\times10^3 \text{ watt}}{o/p + \text{Const. loss} + \text{variable loss}}$$

$$0.88 = \frac{\cancel{25\times10^3}\ o/p}{\cancel{25\times10^3}\ o/p + 720 + I_{sh}^2 R_{sh} + I_a^2 R_a}$$

$$0.88 = \frac{\cancel{25\times10^3}\ o/p}{o/p\ \cancel{25\times10^3} + 720 + (4)^2\times55 + (200)^2 \cdot R_a}$$

$$o/p = VI_L = 220\times196 = 4312$$

$$0.88\,(4312 + 720 + 1800 + 40000 R_a) = 4312$$

$$(0.88)\times(5912) + 0.88\times40000 R_a = 4312$$

$$5202 + 35200 R_a = 4312$$

$$R_a = \frac{4312 - 5202}{35200} = -\frac{890}{35200} = -0.025\,\Omega$$

Armature Reaction

Q. $P = 4$

$P_{out} = 25\ kw$

$V = 500V$

$A = P = 4$

$R_a = 0.03\Omega$

$N = 1200\ rpm$

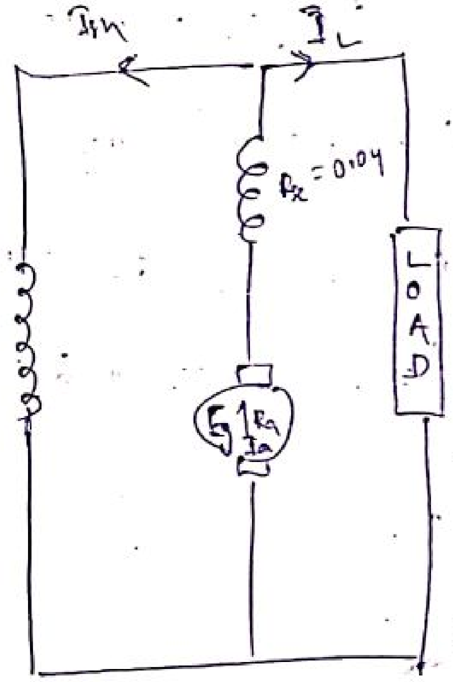
$R_{se} = 0.04\Omega$

$R_{sh} = 200\Omega$

$V_b = 1V$

$\phi_B = 0.02\ wb$

$E_g = ?$ $Z = 2.$



Q. $I_{FL} = 196A$

$V = 220V$

Stray losses = 720W

$R_{sh} = 55\Omega$

$\eta_{FL} = 88\%$

$R_a = ?$

Scanned with CamScanner

$I_{sh} = \frac{V}{R_{sh}} = \frac{220}{55} = 4A$

$I_a = I_{FL} + I_{sh} = 196 + 4 = 200A$

$(P_{out})_{FL} = VI_{FL} = 220V \times 196 = 43120$ watt.

$P_{in} = (P_{out})_{FL}$ + const. losses + variable losses

$= (P_{out})_{FL}$ + (stray + shunt field cu. loss)

+ Armature cu. loss.

$P_{in} = 43120 + (720 + I_{sh}^2 R_{sh}) + I_a^2 R_a$

$= 43120 + 720 + 16 \times 55 + (200)^2 R_a$.

$$\eta_{FL} = \frac{(P_{o/p})_{FL}}{P_{i/p}}$$

$$P_{i/p} = \frac{(P_{o/p})_{FL}}{\eta_{FL}}$$

$$= \frac{43120}{0.88} = 49000$$

$43120 + (720 + 880) + 40000 R_a = 49000$

$$1600 + 40000 R_a = 47000 - 43120$$

$$40000 R_a = 5880 - 1600$$

$$R_a = \frac{4280}{40000} = 0.107 \Omega$$

$R_a = 0.107 \Omega$

$$I_L = \sqrt{\frac{W_c}{R_a}} = \sqrt{\frac{1600}{0.107}} = 122.28 A$$

Shunt-field coil resistance (R_{sh}) is 55Ω. If the full load efficiency is 88%. find the armature resistance (R_a) and also find the load current corresponding to maximum efficiency.

Scanned with CamScanner

ARMATURE REACTION

In DC generator the magnetic field is produced by the field winding is called main field flux.

In armature winding when armature current flows Due to this armature current a magnetic field is produced is called armature field. The flux produced by Main field is called main field flux

→ The flux produced by armature field is called armature flux.

→ The ~~reaction~~ effect of armature flux to the main field flux is called armature reaction.

The armature reaction does 2 operation

a) Cross Magnetisation (Distort the main field flux)

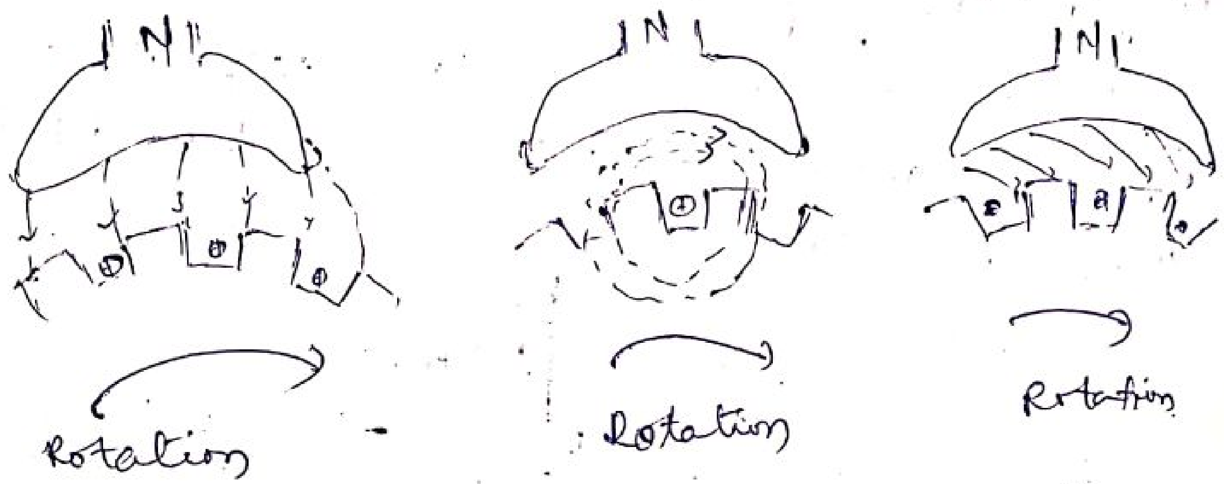
b) De-magnetisation (weakens the main field flux)

a) Cross Magnetisation

In cross magnetisation the armature field flux is perpendicular to main field flux. so the main field flux distorted. Due to this cross magnetisation sparking occurs.

b) Demagnetisation

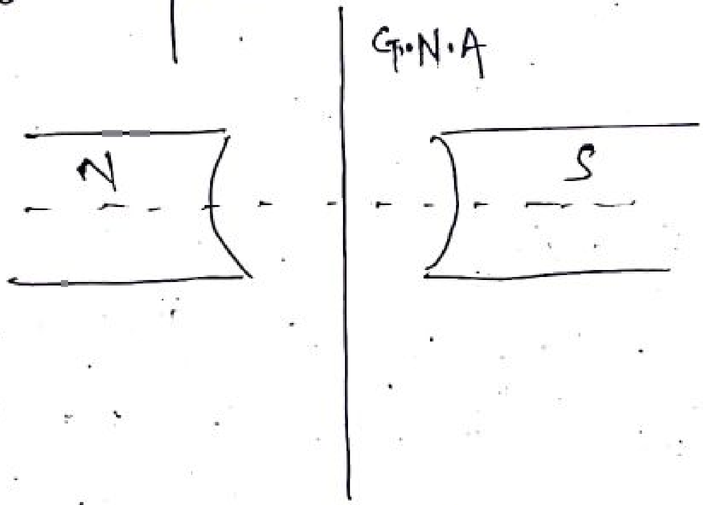
In Demagnetisation the armature field flux is directly opposite to the main field flux. as a result the generated emf decreases.



14/02/2020

1. GNA (Geometric Neutral Axis)

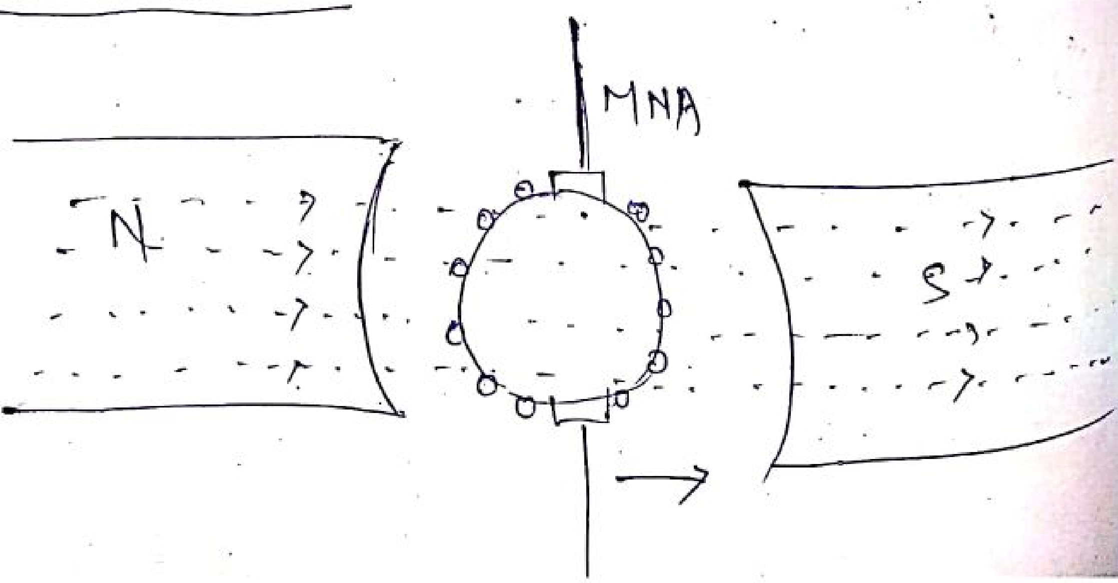
It is the axis that bisect the angle produced by the line passing through the adjacent poles.



For a two pole machine

2. M.N.A (Magnetic Neutral Axis)

It is a line which is perpendicular to the mean direction of flux inside the armature



The armature conductor in the direction of MNA produce no induced emf.
So no current will flow through this conductor.

- For sparkless commutation the brushes must be lie in the direction of MNA.

- When there is no armature current the MNA coincide with G.N.A.

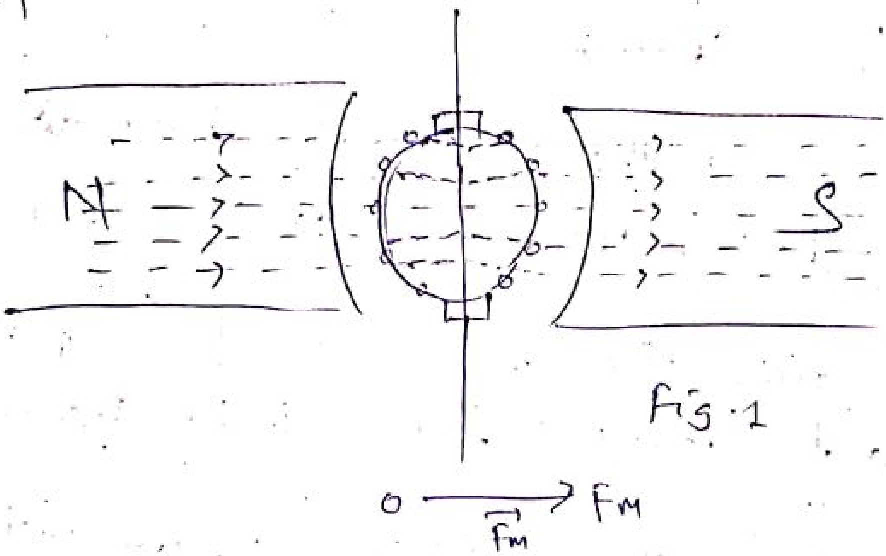


Fig. 1

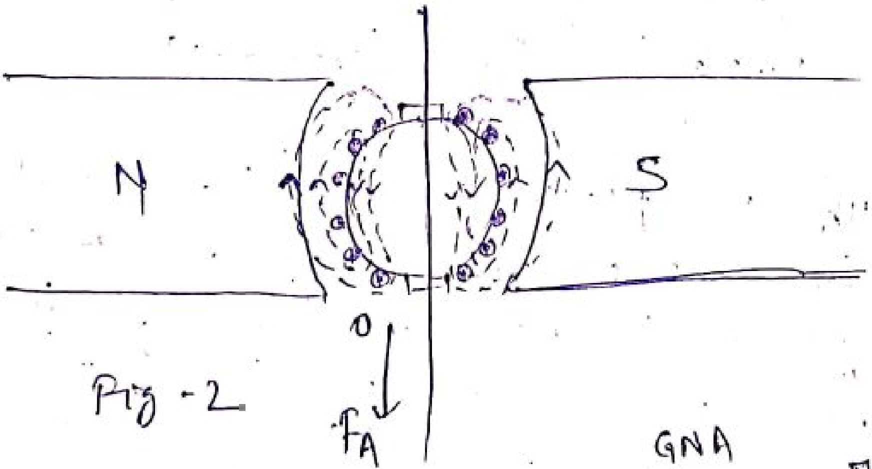


Fig. 2

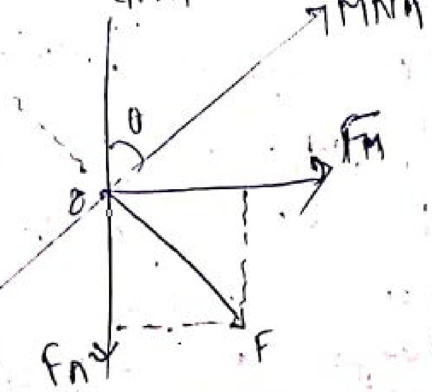


Fig. 4

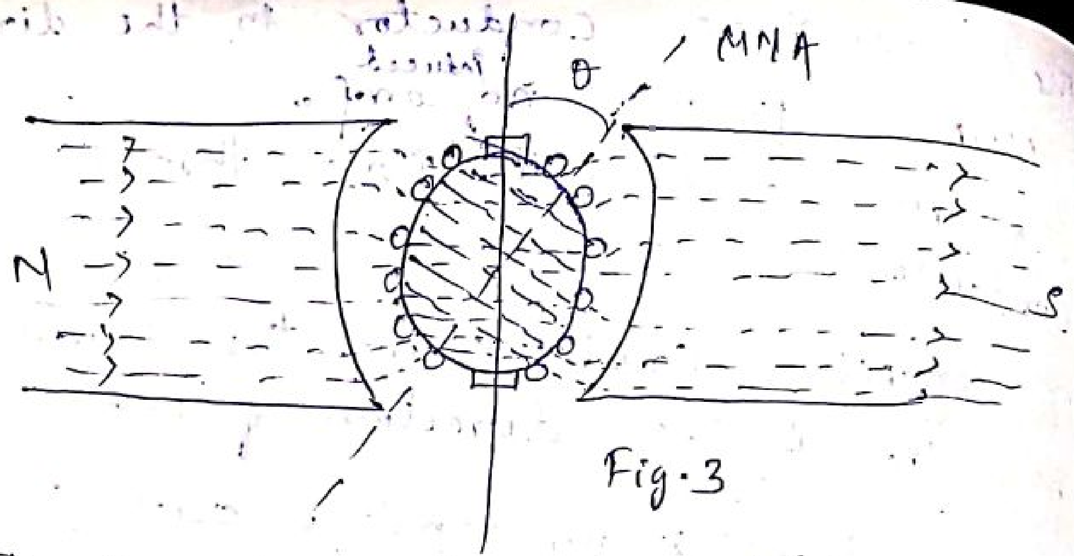


Fig.3

In fig.1 gives the direction of magnetic field flux direction.

Fig.2 gives the armature flux direction inside the armature No field flux.

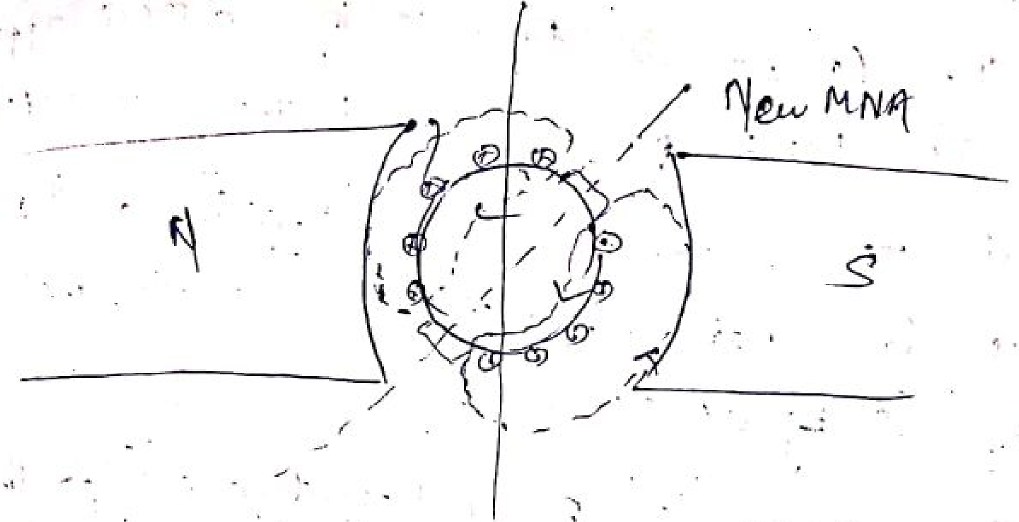
Fig-3 gives the resultant flux of both fieldflux and armature flux inside the armature

Fig-4 gives phasor diagram of resultant flux inside the armature.

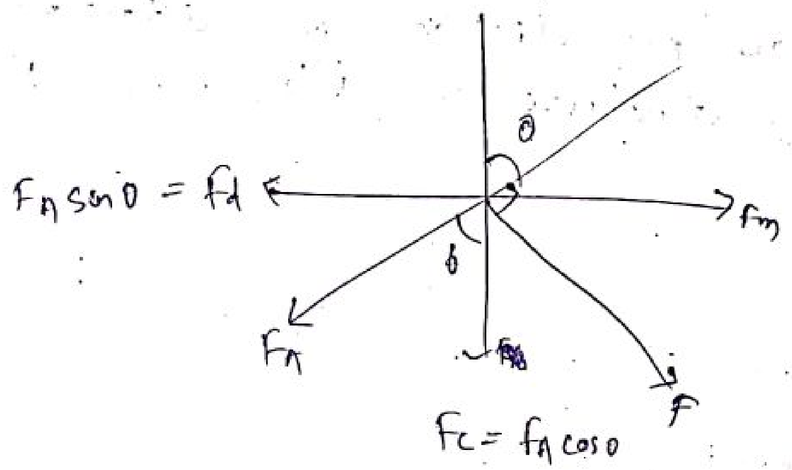
As MNA is perpendicular to mean flux direction inside the armature so MNA shift to angle θ in the direction of rotation of armature i.e towards right.

The brush position also shift in the direction of MNA.

In the angle θ the conductors reverses their current direction ~~as~~ brush position changes to new MNA.



The new F_A is in the dirn of new MNA.



$$\vec{F_A'} = \vec{F_c'} + \vec{F_d}$$

$$F_c = F_A \cos\theta$$

$$F_d = F_A \sin\theta$$

~~In order to achieve~~ Due to brush shift the MMF_A of the armature is also rotated through the same angle θ it is because some of the conductor which where earlier under N pole now come under S pole and vice versa.

The F_A can be resolved into 2 components F_c and F_d.

The component F_d is in direct opposite to the MMF ~~of~~ OF$_A$ due to the Main pole.

→ It has a demagnetising effect on the flux due to main poles. It weakens the main flux. ~~The~~ So E_g decreases.

→ The component F_c is at right angle to the MMF OF$_A$ due to main pole. It distort the main flux for this reason it is called Cross magnetisation or distorting component of armature reaction.

18.02.2020

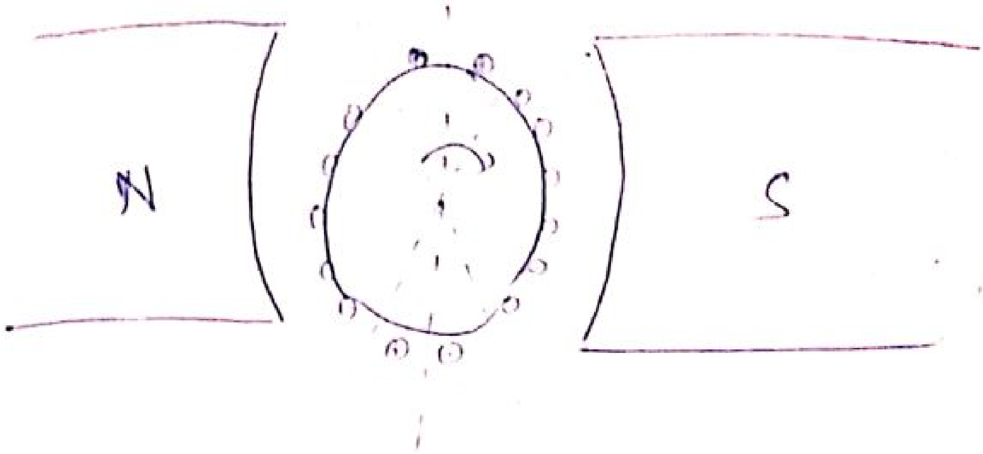
$$MMF = Ni$$

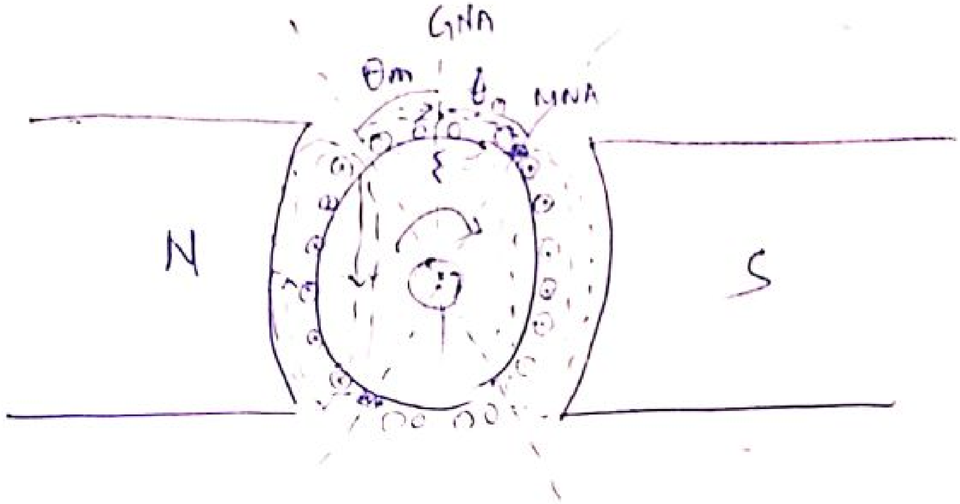
I = current through each conductor

$$I = \frac{I_a}{A}$$

$$I = I_a/2 \quad \text{For wave winding}$$

$$I = \frac{I_a}{P} \quad \text{For lap winding}$$





Demagnetising and cross magnetising ampere turn

$$\boxed{\theta_m = \theta_e \times P/2}$$

~~360~~

Demagnetising Ampere Turn

~~4θm~~ The conductor present in 4θm angle produces demagnetization

$360 = Z$

$1 = \frac{Z}{360} = \frac{Z}{2\pi}$ → $4\theta_m = \left(\frac{Z}{2\pi} \times 4\theta_m\right)$ No of conductors.

Scanned with CamScanner

No. of turns producing demagnetising

$$= \frac{1}{2}\left(\frac{4\theta_m}{2\pi}\right)Z$$

→ Ampere turn producing demagnetising.

$$= \frac{1}{\cancel{2}}\left(\frac{4\theta_m \times Z}{\cancel{2}\pi}\right)I$$

$$\Rightarrow \boxed{A.T_d = \frac{\theta_m}{\pi} ZI}$$

$$\boxed{AT_d = \frac{2\theta_m}{360} ZI}$$

$$AT_d/\text{pole} = \frac{1}{2}\,\frac{2\theta_m}{360} ZI$$

$$\boxed{\frac{AT_d}{\text{pole}} = \frac{\theta_m}{360} \cdot Z \cdot I}$$

Cross magnetisation A.T. (AT_c)

Total armature conductor $= Z$.

Total turn $= Z/2$

Current through each conductor $= I$

Total A T $= \frac{Z}{2} I$.

Total A.T/pole $= \frac{Z}{2P} I$

Scanned with CamScanner

$$AT_c/\text{pole} = AT_T/\text{pole} - AT_d/\text{pole}$$

$$= \frac{ZI}{2P} - \frac{\theta_m}{360} ZI$$

$$\boxed{AT_c/\text{pole} = ZI\left(\frac{1}{2P} - \frac{\theta_m}{360}\right)}$$

Q. A 4 pole generator has a wave wound generator with 722 conductors and it delivers 100A ~~at~~ (on) full load. If the brush lead is 8° calculate armature demagnetisation and cross magnetisation ampere turn perpole.

Ans

$A = 2$ $\theta_m = 8°$

$P = 4$

$Z = 722$

$I_a = 100A$

$$I = \frac{I_a}{2} = \frac{100}{2} = 50A$$

$$AT_d = \frac{8}{360} \times 722 \times 50$$

$= 802.22 \simeq 802\ AT$

$$AT_T/\text{pole} = \frac{ZI}{2P} = \frac{722 \times 50}{2 \times 4} = 4512\ AT$$

$$AT_c/\text{pole} = AT_T/\text{pole} - AT_d/\text{pole}$$

$= 4512 - 802 = 3710\ AT$

Scanned with CamScanner

Q An 8 pole DC generator have 480 armature and wave winding. $I_a = 200A$. find the armature reaction both demagnetization and cross magnetization ampere turns per pole if brushes are shifted by 6° mechanical from GNA.

Ans $P = 8$, $A = 2$

$Z = 480$

$I_a = 200A = I$

$\theta_m = 6°$

$$I = \frac{I_a}{A} = \frac{200}{2} = 100$$

$$AT_d = \frac{\theta_m}{360} ZI$$

$$= \frac{6}{360} \times 480 \times 100$$

$$= 800\ AT$$

$$AT_c = ZI\left(\frac{1}{2P} - \frac{\theta_m}{360}\right)$$

$$= 480 \times 100 \left(\frac{1}{2\times 8} - \frac{6}{360}\right)$$

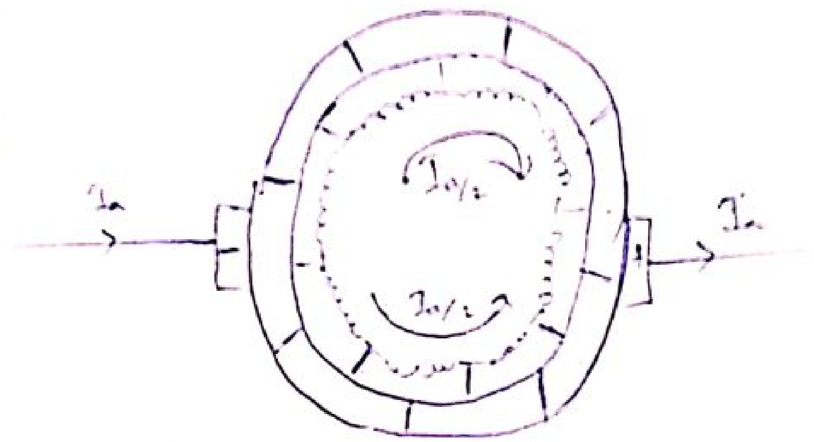
$$= 2200\ AT$$

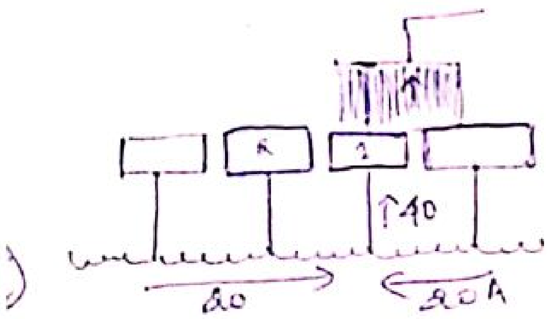
$$AT_T = \frac{ZI}{2} = \frac{480 \times 100}{2} = 24000\ AT$$

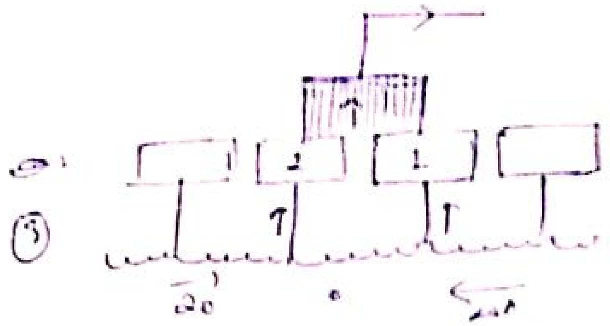
$$AT_T/\text{pole} = \frac{24000}{8} = 3000\ AT$$

Scanned with CamScanner

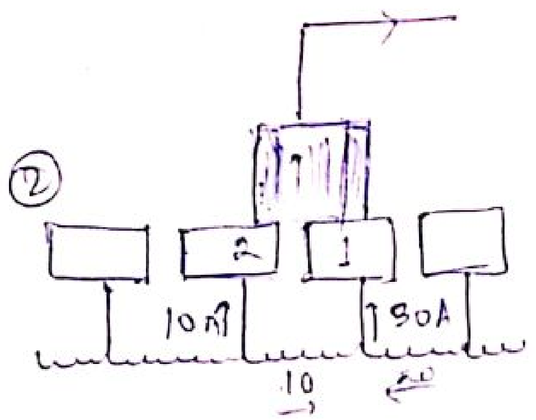
Commutation

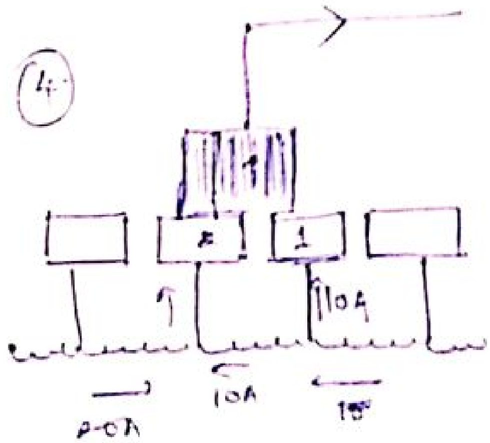


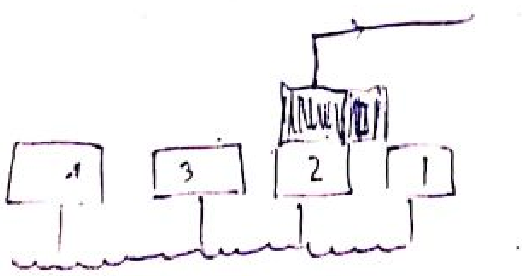




The reversal of current through a coil when it passes through a brush is called commutation







Scanned with CamScanner

* The resistance is inversely proportional to the contact area between the commutator segment and the brush.

Fig. 1

The resistance of commutator segment 1 is zero. So 20A current flow through the coil A from left to right. The coil A is in left side of brush

In fig 2 the resistance of commutator segment 2 decreases and resistance of commutator segment 1 increases so the current through the coil is 10A through left to right. The brush touches 3/4th part of commutator segment 1 and brush touches 1/4th of the commutator - 2nd.

In Fig. 3

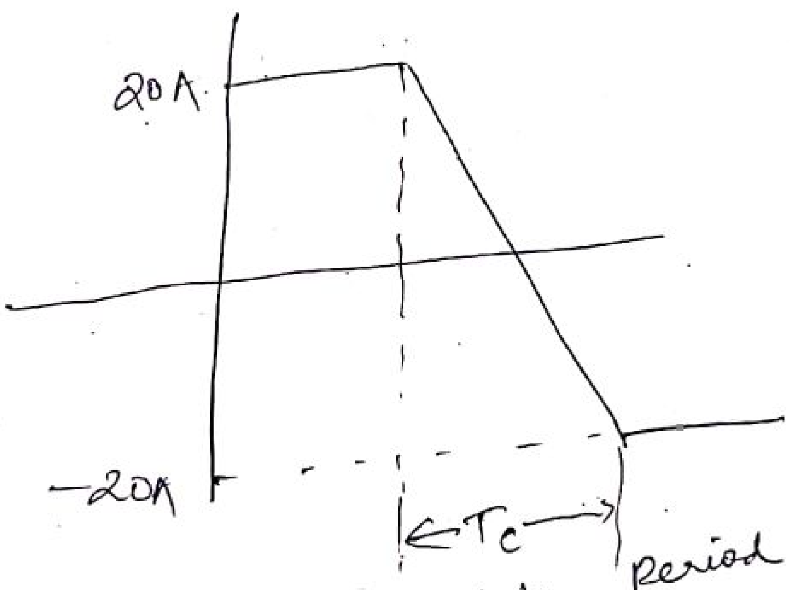
Now the brush touches half of the commutator segment 1 and 2. Now the current through the coil A is zero.

Fig. 4

The brush touches $\frac{3}{4}$th part of commutator segment (2) and $\frac{1}{4}$th part of commutator segment (1). Now the current through coil A is 10A from right to left.

Fig 5

The brush in fig (5) the brush touches completely the commutator segment (2) so the commutator segment (2) ~~completely~~. become short circuited. All the 40A current will pass through the commutator segment (2). As a result the current through the coil A is 20A right to left



T_C = commutation period.

Commutation Period

It is the time taken by a coil to reverse current through it when it passes through the brush.

~~Q Methods of improving commutation~~

Q Drawbacks of Commutation

Q Ideal commutation.

Q Methods of improving commutation.

a) Resistance Method

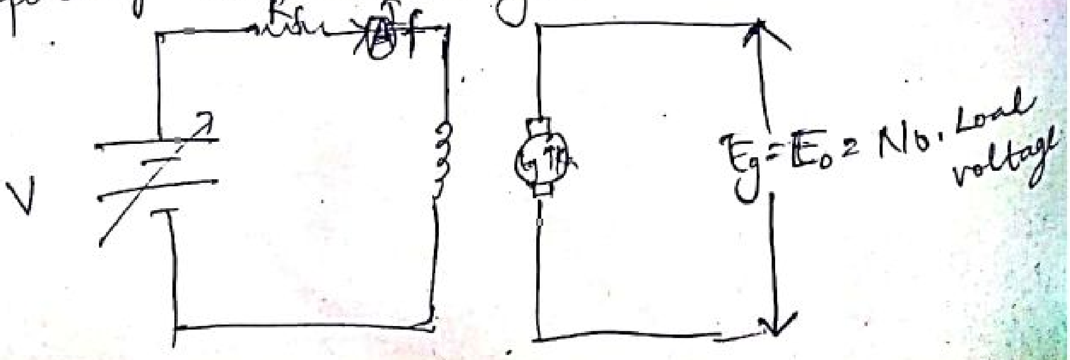
b) EMF commutation method.

Characteristics of DC Generator

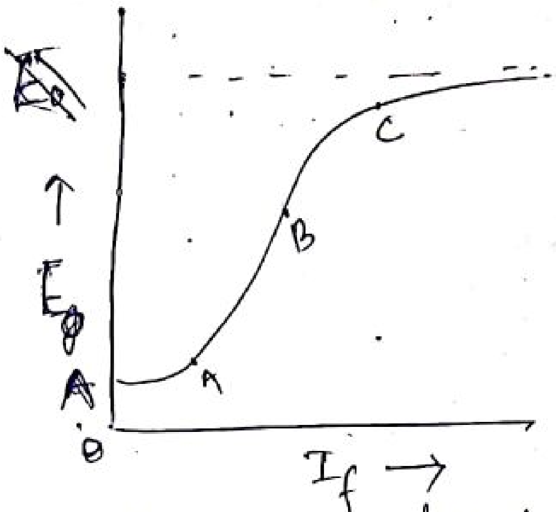
1) O.C.C (open ckt characteristics) $E_0 \sim I_F$
2) Internal Characteristics ($E \sim I_a$)
3) External Characteristics ($V \sim I_L$)

1) Open ckt Characteristics

Separately excited DC generator



It is a graph between generated voltage at no load (E_0) ~~I_F~~ vs field current (I_f).



The OCC is called magnetic characteristics or no. load saturation curve i) when the field current is zero. there is some generated ~~emf~~ OA due to residual magnetism in the field poles.

ii) upto point B the curve is linear because the reluctance of the iron core is negligible as compare to air gap reluctance.

iii) After point B upto point C the graph is non-linear because the core reluctance comes into picture.

iv) After point C the emf generated is constant irrespective of field current.

Scanned with CamScanner

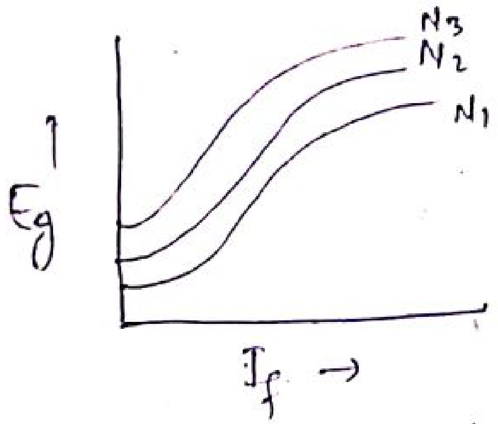
Scanned with CamScanner

2) Internal Characteristics

It is a graph or curve between the generated voltage (E) vs the armature current (I_a). $\boxed{E < E_0}$

$E_0 = E +$ voltage drop due to Armature Reactn

25/02/2020



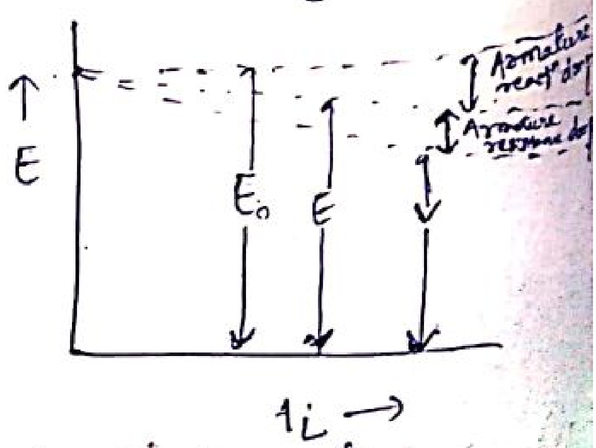
$N_3 > N_2 > N_1$

Internal & External characteristics

The external characteristics and internal characteristics of a separately excited dc generator

$\boxed{\text{Load current = Armature current}}$

can be drawn on a same graph because $I_A = I_L$



O.C. voltage is independent of load current.

Scanned with CamScanner

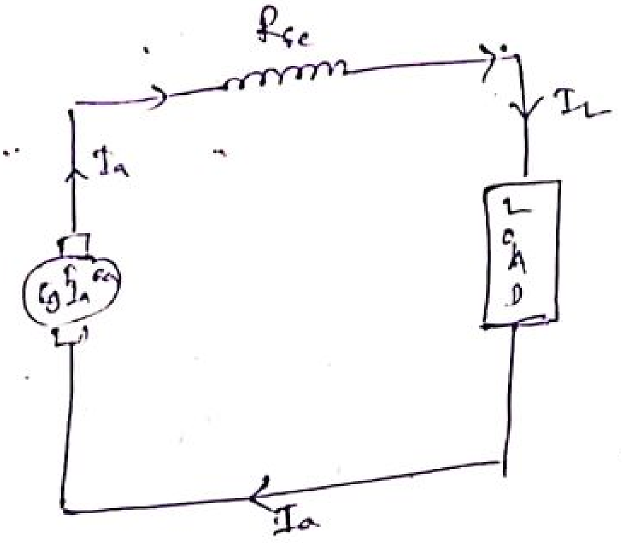
As the load current increases the terminal voltage falls due to 2 reason

i) The armature reaction ~~w~~ weaken ~~against~~ the main flux due to demagnetisation. The voltage obtained is E which is less than E_0 :(no loadvoltage

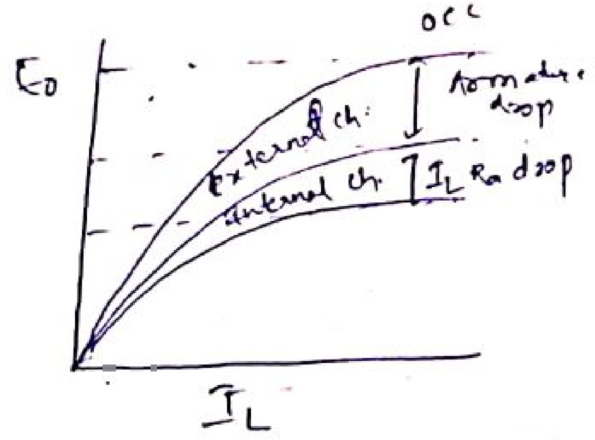
ii) The voltage drop due to armature resistance. $(I_L R_a)$

$$\boxed{V = E - I_L R_a}$$

Characteristics of Series Generator

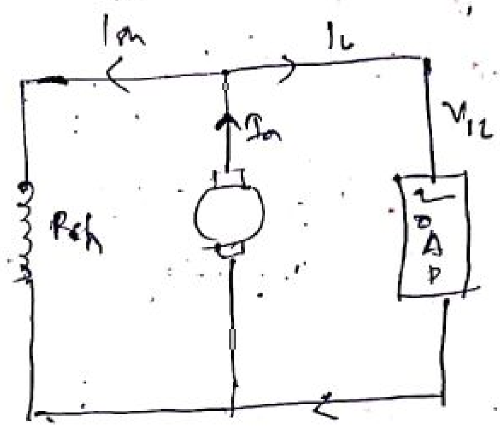


$I_a = I_{se} = I_L$



Scanned with CamScanner

Characteristics of shunt generator



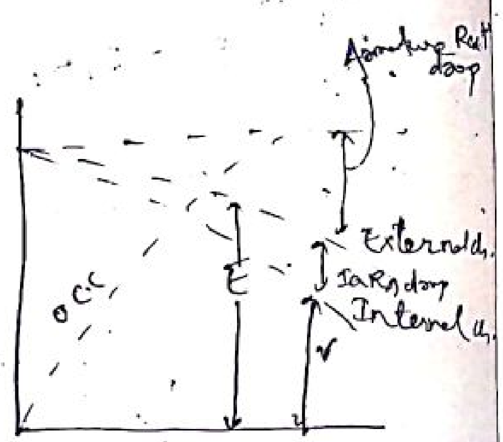
$$N_{se} I_{se} = N_{sh} I_{sh}$$

$$I_{se} >> I_{sh}$$

$$\boxed{N_{se} << N_{sh}}$$

$$I_a \simeq I_L$$

as I_{sh} is small $I_a >> I_{sh}$.



Assignment

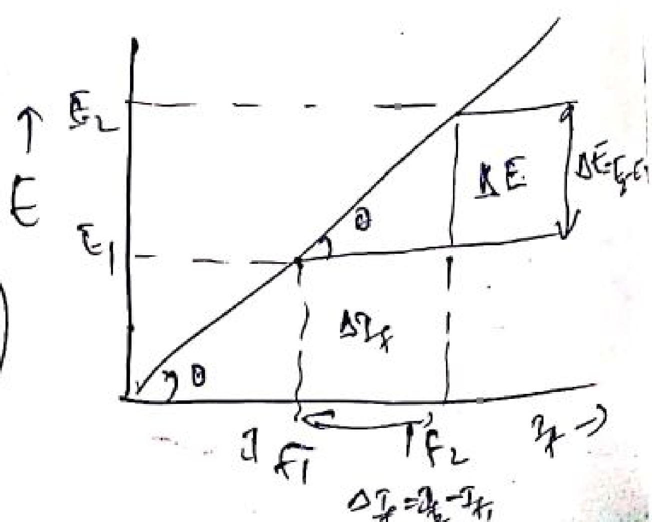
Q. Characteristics of Compound Generator.

Voltage Build up in a ~~series~~ self excited generator

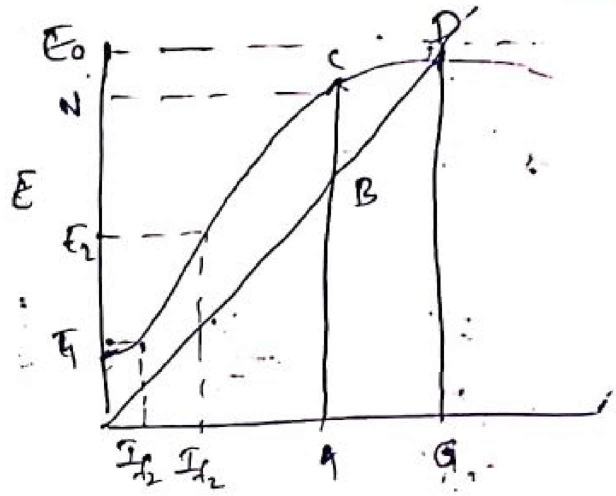
Shunt Generator.

$$\tan\theta = \frac{\Delta E}{\Delta I_f} = R_f$$

(shunt field resistance)



Scanned with CamScanner



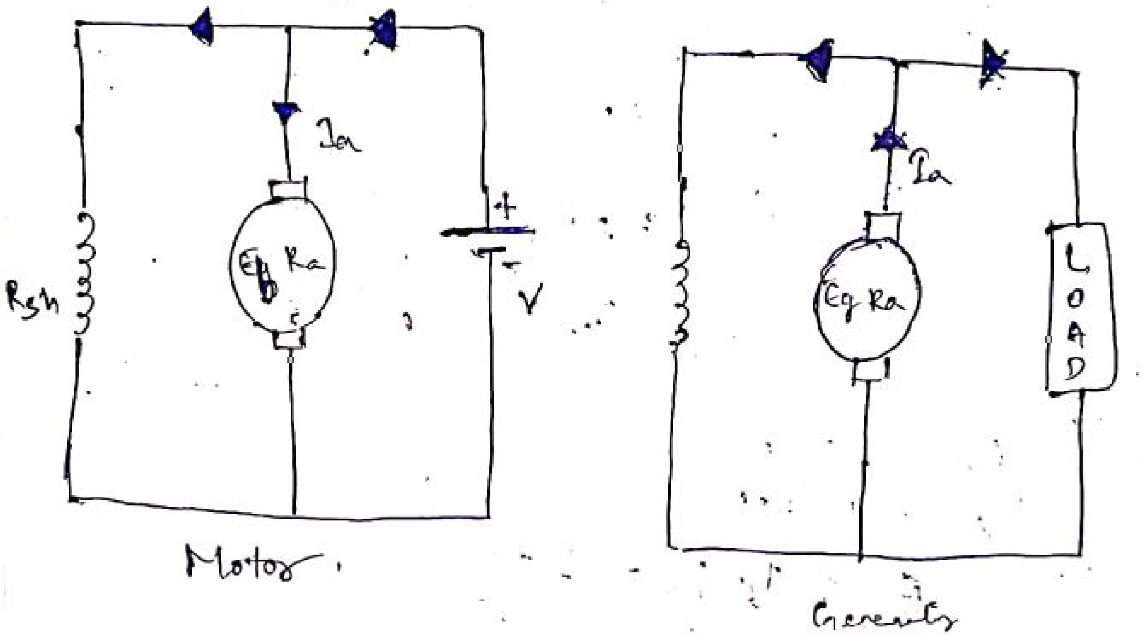
$AC = ON = E$

$AC = AB + BC$

$$E = I_f R_{sh} + L \frac{dI_f}{dt}$$

Scanned with CamScanner

D.C. Motor



Basic Principle of Motor

When a current carrying conductor is placed inside a magnetic field the conductor will experience a force or force exerted upon conductor.

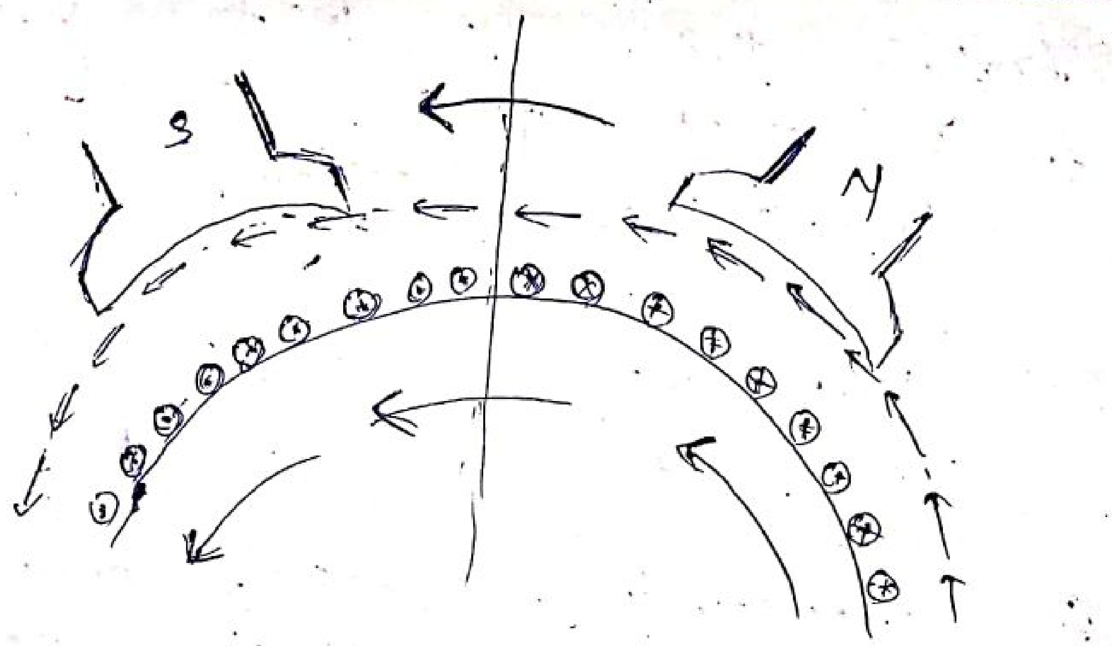
$$F = Bil$$

F = Force upon a conductor

B = magnetic flux density
or
Magnetic Induction
or
Magnetic field vector.

i = Current in the conductor

l = Length of the conductor.



A part of motor i.e. both field system and armature system shown in figure. The armature conductor under south pole carries a current upward shown in dotted line

The conductor under north pole carries current in downward direction shown as a cross symbol.

According to the motor principle when a current carrying conductor placed inside a magnetic field a force is exerted upon it.

The direction of force is given by Flemmings left hand thumb rule.

Applying this rule we found that a force is exerted upon each conductor in anticlockwise direction.

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

As conductor is a part of armature and armature is in cylindrical shape a torque will exerted upon the conductor The torque will act upon the whole conductor. i.e upon the whole armature as a result the armature will rotate about an axis passing through its centre is called shaft.

Back emf (E_b)

A Gross Torque will act upon the armature so the armature will rotate.

According to faraday's law of electromagnetic induction when flux changes through a conductor an emf will produce upon the conductor.

A net induced emf will produce upon the armature, (Eg) is called Eg.

According to Lenz law the emf generated is due to the supply voltage (V) and it will oppose it.

As the generated emf oppose the supply voltage this is called back emf.

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

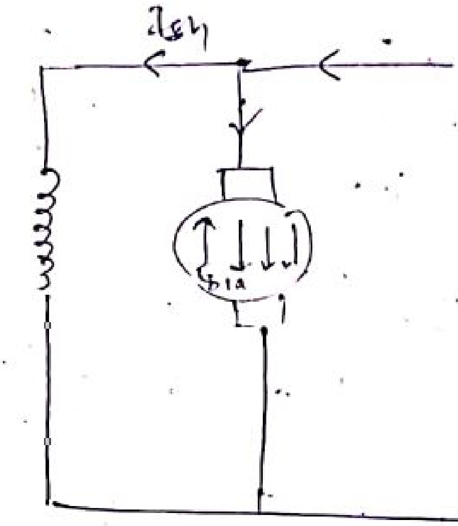
$$\boxed{\tau \propto \phi I_a}$$

$\therefore \phi \uparrow \propto E_b \uparrow$

Significance of back emf

- The back emf will playing a major role to maintain a constant speed of a motor.
- The back emf will act as a speed governor.
- When speed of a motor increases the back emf increases as a result the armature current decreases and torque of the motor decreases so the motor comes to its normal speed.
- If the speed of the motor decreases the back emf decreases the armature current increases so the torque increases, so the motor comes to its normal speed.

Voltage Eqⁿ of A DC motor



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

$$V - E_b = I_a R_a$$

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

voltage Eqⁿ

V = Supply DC voltage to armature

E_b = Back emf

I_a = Armature current

R_a = Armature Resistance.

8

Power Equation

Multiply I_a on both sides of voltage Eqⁿ

$$V = E_b + I_a R_a$$

$$\boxed{V I_a = E_b I_a + I_a^2 R_a}$$

$V I_a$ = Electric power supply to motor

$E_b I_a$ = mechanical power developed due to armature / output power

$I_a^2 R_a$ = power loss (copper loss)

Scanned with CamScanner

The output power $E_b I_a$ can be converted into mechanical power.

* Condition for max^m power

$$V I_a = E_b I_a + I_a^2 R_a$$

$$P_m = E_b I_a = V I_a - I_a^2 R_a$$

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

P_m depends upon armature current I_a as V and R_a are constant.

For $(P_m)_{max} = \frac{dP_m}{dI_a} = 0$

$$\frac{d}{dI_a}\left(V I_a - I_a^2 R_a\right) = 0$$

$$\Rightarrow \frac{d V I_a}{dI_a} - R_a \frac{d}{dI_a} I_a^2 = 0$$

$$\Rightarrow V - 2 I_a R_a = 0$$

~~$2 I_a R_a = V - E_b \Rightarrow$~~

$$V = 2 I_a R_a$$

$$I_a R_a = \frac{V}{2}$$

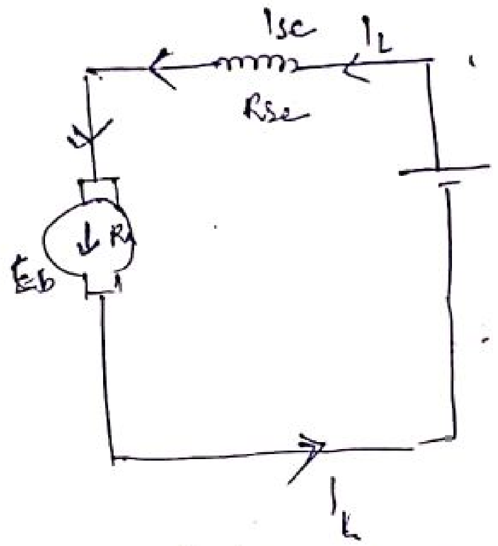
$V = E_b + I_a R_a$

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

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

Scanned with CamScanner

Series Motor



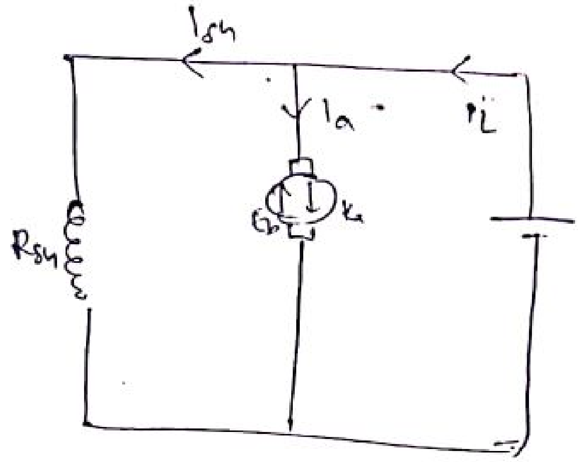
Field winding is series with Armature

$I_{se} = I_a$

$N \, I_a$

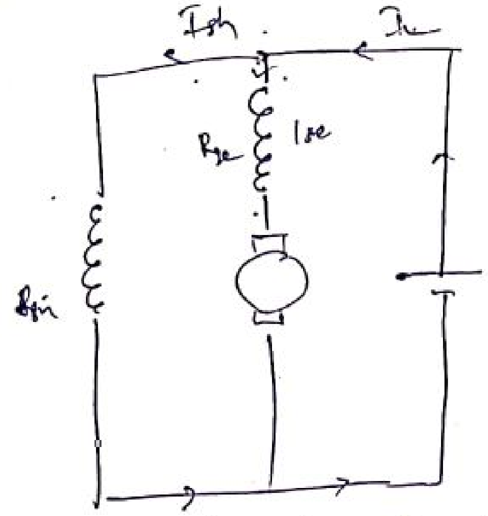
N is minimum

Shunt Motor

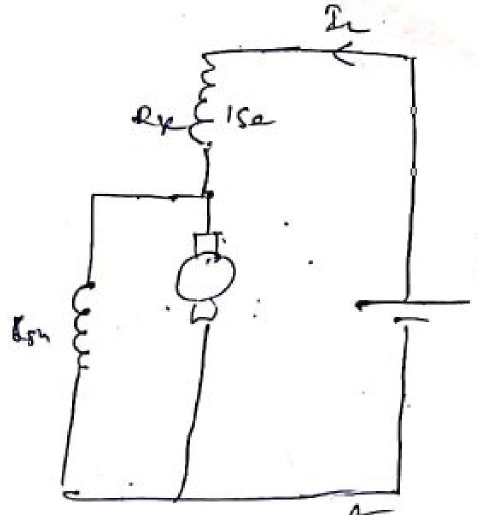


N (tour) is maximum.

Scanned with CamScanner



Long shunt



Short shunt

Q. A 220V shunt motor takes a total current of 20A. The shunt field resistance is 250Ω, while R_a is 0.3Ω. Calculate the Back emf.

Ans

$V = 220V$

$I_L = 20A$

$R_{sh} = 250\Omega$

$R_a = 0.3\Omega$

$V = E_b + I_a R_a$

$I_L = I_a + I_{sh}$

$I_L - I_{sh} = I_a$

$20 - \frac{V}{R_{sh}} = I_a \Rightarrow 20 - \frac{220}{250} = I_a$

$20 - 0.88 = 19.12$

Scanned with CamScanner

$$E_b = V - I_a R_a$$
$$= V - (19.12 \times 0.3)$$
$$= 220 - (19.12 \times 0.3)$$
$$= 214.26$$

Q A 4 pole dc motor is connected to a 500V dc supply and taking an armature current of 80A. Armature resistance is 0.4Ω. The armature is wave wound with 522 conductors. and useful flux per pole is 0.025 wb. determine the Speed of the motor.

$P = 4$

$A = 2$

$Z = 522$

$\phi_B = 0.025$ wb

$R_a = 0.4\,\Omega$

$I_a = 80$ A

$V = 500$ V

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

$$E_b = V - I_a R_a$$
$$= 500 - 80 \times 0.4 = 468V.$$

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

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

$$N = \frac{468 \times 60}{4 \times 0.025} \times \frac{2}{522} = 1075 \text{ r.p.m}$$

TORQUE EQ^N OF A DC MOTOR

Torque is a turning force and it is given by $\vec{\tau} = \vec{F} \times \vec{r}$

When supply voltage(V) is given to a armature a current will flow through the armature conductor. A force is experienced by the conductor and this is given by

$$F = Bil$$

B = magnetic flux density
i = current through the conductor $= \frac{I_a}{A}$
l = length of the conductor.

As armature is cylindrical in shape and shaft ~~is passing~~ through which the armture is rotating passes through the Center. a torque is acted upon the armature conductor.

Scanned with CamScanner

Torque due to a conductor = $\vec{F} \times \vec{r} = Fr$

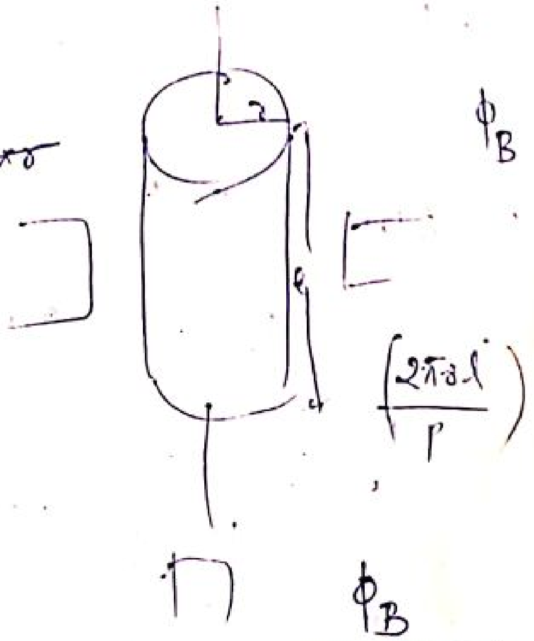
Torque due to whole armature conductors = ZFr

Armature Torque or Gross Torque (T_a) = ZFr

$$T_a = ZFr$$

$$= Z\,Bil\,r$$

$$= Z \frac{\phi_B}{\frac{2\pi \cancel{r} l}{P}} \times \frac{I_a}{A} \times \cancel{l} \times r$$



$$\boxed{T_a = \frac{Z P \phi_B I_a}{2\pi A}}$$

$$\frac{\phi_B}{\frac{2\pi r l}{P}}$$

ϕ_B = flux per pole

$2\pi r l$ = Total Surface area

surface area per pole $= \frac{2\pi r l}{P}$

flux density (B) $= \frac{\phi_B}{\frac{2\pi r l}{P}}$

$$T_a = \frac{1}{2\pi} \frac{P \phi_B I_a Z}{A}$$

$$\boxed{T_a = 0.159\,\frac{P\phi_B I_a Z}{A}}$$

$T_a \propto \phi_B I_a$

As P, Z, A ~~~~ are constant.

for shunt motor

ϕ_B is constant. So T_a is only proportional to I_a

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

For series motor

$\phi_B \propto I_a \Rightarrow T_a \propto \phi_B I_a \Rightarrow T_a \propto I_a I_a$

$$\Rightarrow \boxed{T_a \propto I_a^2}$$

$$\therefore T_a = 0.159\,\frac{P\phi_B I_a Z}{A} \quad \text{---} (1)$$

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

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

$$\Rightarrow \frac{P\phi_B Z}{A} = \frac{E_b \times 60}{N} \quad \text{---} (2)$$

Scanned with CamScanner

putting the value of $\frac{P\phi_B Z}{A}$ in Eq^n (1)

$$T_a = 0.159 \left(\frac{P\phi_B Z}{A}\right) I_a$$

$$T_a = 0.159 \times \frac{E_b \times 60}{N} I_a$$

$$T_a = 0.159 \times 60 \frac{E_b I_a}{N}$$

$$\boxed{T_a = 9.55 \frac{E_b I_a}{N}}$$

$$\boxed{T_a = 9.55 \frac{P_m}{N}}$$

<u>Shaft Torque</u> (T_{sh}).

Torque produced by shaft is called shaft torque. The shaft torque does the useful work.

$$T_a - T_{sh} = \text{Loss in torque}$$

$$T_a - T_{sh} = 9.55 \times \frac{\text{Iron \& Friction loss}}{N}$$

$$\text{output power} = T_{sh} \times \frac{2\pi N}{60}$$

$$\frac{P = F \cdot s}{t} = F\left(\frac{s}{t}\right)$$

$$P = F \cdot V$$

$$\downarrow$$

$$\boxed{P = T \cdot \omega}$$

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

$$P = T \cdot \omega$$

$$= T \cdot \frac{2\pi N}{60}$$

$$\text{output power} = T_{sh} \times \frac{2\pi N}{60}$$

$$T_{sh} = \left(\frac{60}{2\pi}\right) \frac{\text{output power}}{N}$$

$$\boxed{T_{sh} = 9.55 \times \frac{\text{Power Output}}{N}}$$

Brake Horse Power (B.H.P)

$$1\,hp = 746\,watt$$

$$W.D/\text{revolution} = F \cdot (2\pi r) = 2\pi (F \times r)$$

$$= 2\pi T$$

$$W.D/\text{min} = 2\pi T N$$

Scanned with CamScanner

$$W.D/sec. = \frac{2\pi T N}{60} : Js^{-1} \text{ or watt}$$

$$\boxed{B.hp. = \frac{2\pi N T}{60 \times 746}}$$

Q Calculate Ta of a 4 pole motor having 774 conductors. 2 paths in parallel 24 mWb flux per pole. When the total armature current is 50A.

Ans
$P = 4$ $\quad I_a = 50$
$A = 2$ $\quad \phi_B = 24\,mWb$
$Z = 774$

$$T_a = 0.159\, Z (\phi_B I_a) \frac{P}{A}$$

$$= 0.159 \times 774 (24 \times 10^{-3} \times 50) \frac{4}{2}$$

$$= 295.35\ Nm$$

Q Iron and friction loss in a motor is 1600 watt. The motor is running at 800 rpm. Calculate the difference between gross torque and shaft torque.

$$T_a - T_{sh} = 9.55 \times \frac{1600}{800} = 19.1 \text{ Nm}$$

Q: A 250 v 4 pole wave wound series motor has 782 conductors on its armature. Ra and Rse is 0.75 Ω. The motor takes a current of 40A. Find its speed and gross torque developed if flux per pole is 25 mWb.

Ans: $T_a = ?$ $N = ?$

$\phi_B = 25 \times 10^{-3}$ wb. $Z = 782$, $I_a = 40A$

$N = 250$, $P = 4$, $A = 2$, $R_a + R_{se} = 0.75 \Omega$

$$T_a = 0.159 \times Z (\phi_B \times I_a) \frac{P}{A}$$

$$= 248.676 \simeq 249 \text{ Nm}.$$

*

$$E_b = V - I_a R_a$$

$$= 250 - 40 \times 0.75$$

$$= 220 v$$

$$T_a = 9.55 \times \frac{E_b I_a}{N} \Rightarrow 249 = \frac{9.55 \times 220 \times 40}{N}$$

$$\Rightarrow N = \frac{9.55 \times 220 \times 40}{249} = 337.5 \simeq 338 \text{ rpm}.$$

Speed of DC motor

we know from emf eqn

$$E_b = V - I_a R_a$$

$$\frac{P \phi_B N}{60}\left(\frac{Z}{A}\right) = V - I_a R_a$$

$$\therefore N = \left(\frac{V - I_a R_a}{\phi_B}\right)\left(\frac{60 \times A}{PZ}\right)$$

Here P, Z, A are constant for a particular motor.

$$N = K\left(\frac{V - I_a R_a}{\phi_B}\right)$$

$$\boxed{N = K \frac{E_b}{\phi_B}}$$

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

Scanned with CamScanner

for shunt motor: ϕ_B = constant

$N \propto E_b$

$N_1 \propto E_{b1}$ $N_2 \propto E_{b2}$

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

for series motor

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

$\phi_B \propto I_a$, $\phi_{B1} \propto I_{a1}$; $\phi_{B2} \propto I_{a2}$

$$N_1 \propto \frac{E_{b1}}{\phi_{B1}} , \quad N_2 \propto \frac{E_{b2}}{\phi_{B2}}$$

$$\frac{N_2}{N_1} = \frac{E_{b2}}{E_{b1}} \times \frac{\phi_{B1}}{\phi_{B2}}$$

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

Scanned with CamScanner

Torque and Speed of a DC motor

$$N = K\frac{E_b}{\phi_B}$$

$$E_b = \frac{P\phi_B NZ}{60A}$$

$$E_b = V - I_a R_a$$

$$T_a \propto \phi_B I_a$$

06/03/2020

Q A 400V shunt motor is running at 600 rpm, Armature current 50A, Armature resistance 0.28 Ω. Find out the armature current if flux is reduced by 5%.

Ans. $V = 400V$, $N = 600 rpm$, $I_a = 50A$, $R_a = 0.28\Omega$

$\phi_{B_1} = 100\%$. $\phi_{B_2} = 95\%$.

$$E_b = V - I_a R_a = 400 - 50 \times 0.28$$
$$= 386$$

$$100\% = E_b$$

$$1\% = \frac{E_b}{100}$$

$$95\% = \frac{E_b}{100} \times 95 = \frac{95}{100} \times E_b = 0.95 \times 386$$

$$E_b' = 366.7 \simeq 367.$$

Scanned with CamScanner

$$I_a' = \frac{V - E_b'}{R_a} = \frac{400 - 368}{0.28} = 114 A$$

When torque increases the speed of the motor increases and vice-versa.

If flux decreases the motor speed increases and motor torque decreases. But this not happen.

When the flux decreases slightly the armature current increases high as a result inspite of weak field the torque is momentarily increased. ~~and will ex~~ to a ~~The surplus to~~ high value and will exceed considerable the value of the load.

The surplus torque available causes the motor to accelerate and back emf to rise.

Q A 220 V shunt motor take 6A on No load and runs at 750 r.p.m. Shunt field resistance is 110Ω. Armature resistance is 0.25Ω. Calculate the speed when loaded taking a current of 52A. assume that the armature reaction weakens the flux by 4%.

Scanned with CamScanner

Scanned with CamScanner

Ans $V = 220V$. $I_{N_L} = 6A$ $R_a = 0.25\Omega$, $R_{sh} = 110\Omega$

$I_L = 52A$, $N_1 = 750$

$\phi_{B_1} = 100\%$ $\phi_{B_2} = 96\%$

$E_b = V - I_a R_a$

$= 220 - 6 \times 0.25$

$= 218.5 \approx 219$

$E_{b_2} = 0.96 \times 219 = 210$

$\cancel{E_b' = 0.96 \times 219 = 209.76}$

$\cancel{\div 210}$

$E_b' = V - I_a R_a = 220 - 52 \times 0.25 = 207$

$$\frac{N_2}{N_1} = \frac{E_b'}{E_b}$$

$$N_2 = \frac{E_b' \times N_1}{E_b}$$

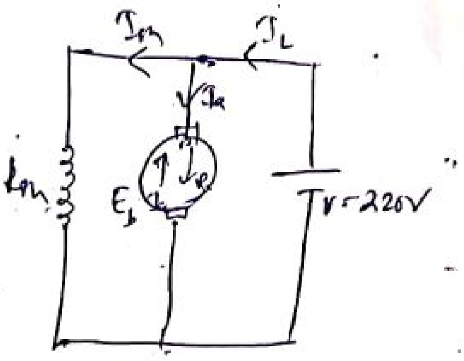
$$= \frac{\cancel{209}\,210}{\cancel{209}\,219} \times 750$$

$= \cancel{719} = 719$

$= \cancel{709}$

$I_{sh} = \frac{V}{R_{sh}} = \frac{220}{110} = 2A$

$I_{a_1} = I_L - I_{sh} = 52 - 2 = 50A$



$$\boxed{\begin{aligned} E_{b_1} &= V - I_{a_1}R_a = 220 - 50\times0.25 = 208V \\ E_{b_2} &= 0.96E_{b_1} = 0.96\times208 \\ &= 200V \end{aligned}}$$

$\cancel{N_1 = KE}$

$$\frac{N_2}{N_1} = \frac{E_{b_2}}{E_{b_1}}$$

$$N_2 = \frac{E_{b_2}\times N_1}{E_{b_1}}$$

$$= \frac{200}{208} \times 750$$

$$= 721.15$$

Q 4 pole 200V DC shunt motor has 360 conductors wave wounded. The full load armature current is 30A. flux per pole is 0.03 wb. $R_A = 0.2\Omega$. Brush contact drop 1V. Determine the full load speed of the motor.

Ans

$V = 200V \quad P = 4$

$Z = 360$

$A = 2$

$I_a = 30A.$

$\phi_B = 0.03$

$R_a = 0.2\Omega$

$V_{Brush\ drop} = 1V$

$E_b = \cancel{4 \times 0.03 \times} \quad \frac{P \phi_B N Z}{60 A}.$

$E_b = V - I_a R_a - 2V$

$= 200 - 30 \times 0.2 = 194 - 2 = 192$

$N = \frac{E_b \times 60 \times A}{P \phi_B Z} = \frac{194 \times 60 \times 2}{4 \times 0.03 \times 360} = 533 \text{ rpm}$

Q. 4 pole 460V shunt motor wave connected armature 880 conductors. $\phi_B = 0.02$ wb/pole $R_a = 0.7\,\Omega$ $I_a = 40A$. calculate speed and torque.

Ans. $P = 4$, $V = 460$ $\phi_B = 0.02$ wb

$Z = 880$, $A = 2$, $I_a = 40$. $R_a = 0.7\,\Omega$

$$E_b = V - I_a R_a$$
$$= 460 - 40 \times 0.7 = 432$$

$$N = \frac{E_b \times 60 \times A}{P \phi_B Z} = \frac{432 \times 60 \times 2}{4 \times 0.02 \times 880} = 736\ \text{rpm}$$

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

$$T_a = \frac{9.55 \times 432 \times 40}{736} = 224\ \text{Nm}$$

$$T_a = \frac{0.159 \times P \phi I_a Z}{A} = \frac{0.159 \times 4 \times 0.02 \times 40 \times 880}{2}$$

$$= 223.87 \simeq 224$$

Scanned with CamScanner

Losses in a DC Motor

There are 3 losses in a D.C motor

i) Copper Loss
ii) IRON Loss
iii) Mechanical Loss

i) Copper loss

Apart from armature copper loss and field copper loss brush contact loss losses also occurs interpoles and compensatory winding. This windings carry armature current.

ii) IRON Loss

Since DC machine both motor and generator are generally operated at constant flux. The iron loss is constant

iii) Mechanical Loss

It is due to friction and windage loss. Since DC machines are operated at constant speed the mechanical loss is treated to be constant.

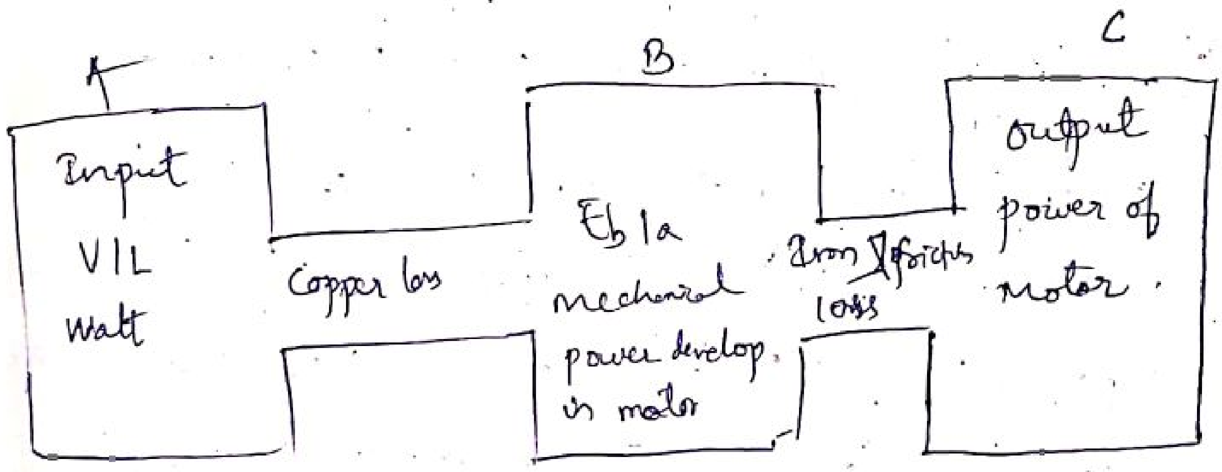
Efficiency

$$\eta = \frac{output}{Input} \times 100$$

$$\eta = \frac{Output}{output + losses} \times 100$$

power stages

Input



Electrical Efficiency $= \eta_e = \frac{B}{A}$

Mechanical efficiency $= \eta_m = \frac{C}{B}$

Overall Efficiency $= \eta_e \times \eta_m = \frac{\cancel{B}}{A} \times \frac{C}{\cancel{B}} = \frac{C}{A}$

Scanned with CamScanner

Characteristics

There are 3 characteristics of DC motor

1) **Torque and Armature current characteristics ($T_a \sim I_a$)**

It is the graph between armature torque (T_a) and armature current (I_a). This is also called electrical characteristics.

2) **Speed - Armature current characteristics ($N \sim I_a$)**

This is the graph between speed of the motor vs armature current. It is a important characteristics. This characteristics helpful to select a motor for a particular operation

3) **Speed and Torque characteristics ($N \sim T_a$)**

This is the graph between speed of a motor Vs armature torque. This is called mechanical characteristics of a motor.

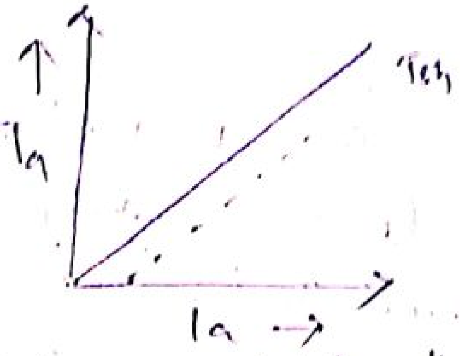
Scanned with CamScanner

Characteristics of a Shunt Motor

($T_a \sim I_a$)

1) $T_a \propto \phi_B I_a$ ϕ_B = constant

$\therefore T_a \propto I_a$



When supply voltage is constant the flux is practically constant. Torque is directly proportional to armature current. The graph obtained torque(Ta) vs Ia is a straight line passing through origin.

Tsh is slightly less than Ta, so the graph is shown in dotted line. So from this graph it is found that large current is required to start a heavy load. So the shunt motor shouldn't start with a heavy load.

2) $N \sim I_a$

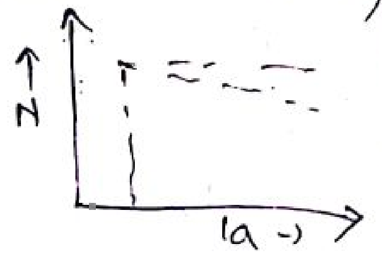
~~It is a graph belo~~

$N \propto \dfrac{E_b}{\phi_B}$

The flux (ϕ_B) and back emf (E_b) is practically const. for a shunt motor under normal condition

Scanned with CamScanner

the speed of the shunt motor remains constant as Ia current (armature current) varies.



3) $N \sim T_a$

- The speed of the shunt motor is ~~practically~~ slightly changes from No load to full load. so the shunt motor is called constant speed motor.

- T_{st} starting torque of shunt motor is small.

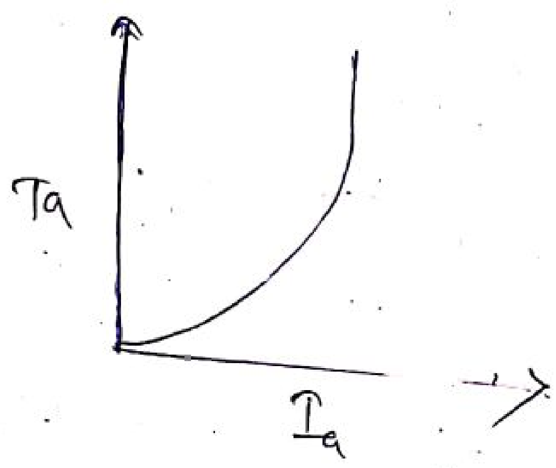
Characteristics of a series Motor

1) Torque & Armature current ($T_a \sim I_a$)

$$T_a \propto \phi_B I_a$$

$$\phi_B \propto I_a$$

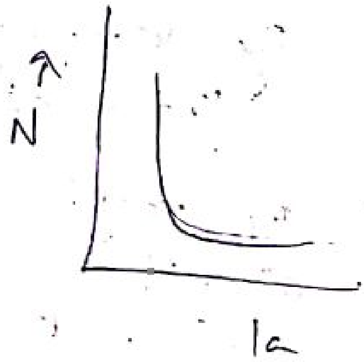
$$T_a \propto I_a^2 \quad (\text{parabolic eq}^n)$$



A upto Magnetic saturation ϕ_B is proportional to I_a. Beyond magnetic saturation ϕ_B is constant. (independent of armature current)

2) $N \sim I_a$

$$N = K \frac{E_b}{\phi_B} = K\left(\frac{V - I_a R_a}{\phi_B}\right)$$



$$N \propto \frac{1}{\phi_B} \qquad \phi_B \propto I_a$$

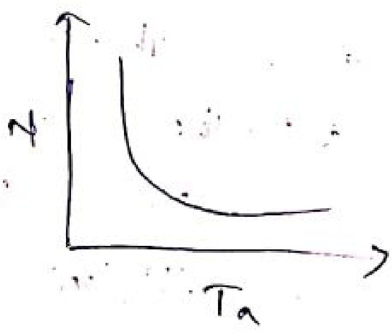
$$N \propto \frac{1}{I_a}$$

Armature drop is negligible. So E_b is taken as constant.

3) Speed ~ Torque $(N \sim T_a)$

$$T_a \propto I_a$$

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



Assignment

Characteristics of DC compound motor

Speed control of DC motor

13/03/2020

$$N = \frac{K(V - I_a R_a)}{\phi_B} = \frac{K E_b}{\phi_B}$$

Speed of DC motor can be controlled:

i) By varying the field flux (ϕ_B)
Known as flux control method

ii) By varying the resistance in armature circuit.
This is known as armature control method

iii) By varying the applied voltage 'V'
This is known as voltage control method

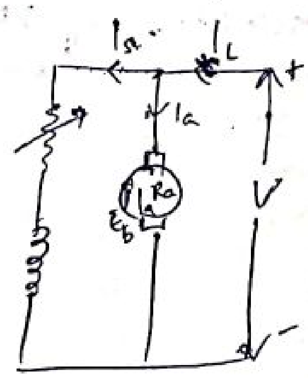
Speed control of DC shunt motor

The speed of DC shunt motor by above three methods.

But the flux control method is frequently used because it is inexpensive and simple.

Flux control method

In this method shunt field flux is controlled by inserting a variable resistor (Rheostat).



If the resistance increases the shunt field current decreases so the field flux decreases and the speed increases.

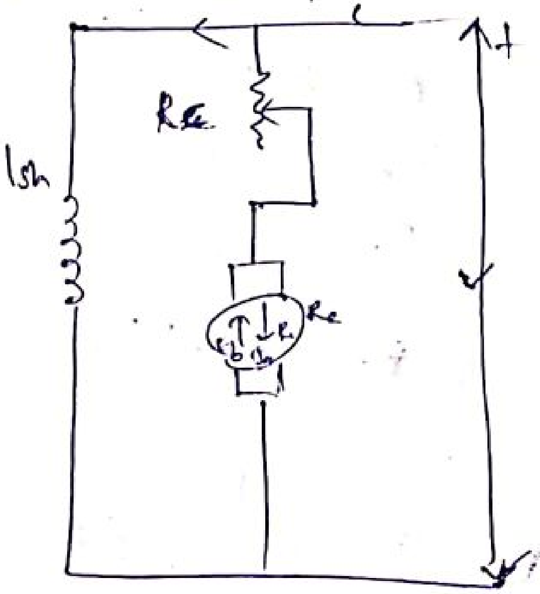
In this method we can increase the speed of the motor from its normal speed.

~~Armature control~~

The field of the shunt motor shouldn't be operated in open field because the speed will be extremely high..

Armature control Method

This method is used to control the speed of DC shunt motor by varying the voltage available across the armature.



$$N = K \frac{V - I_a R}{\phi_B}$$

where $R = R_a + R_c$

A variable resistance R_c is connected in series with the armature. R_c is called control resistance

If $R_c = 0$ then the motor will run at normal speed.

If R_c increases, the voltage drop ($I_a R$) increases the back emf (E_b) decreases. So the speed decreases.

The speed of the motor decreases from its normal speed.

Voltage control method

Q A 220 volt Shunt motor ~~taking~~ taking current 30A. Armature and Shunt field resistances are 0.2 Ω and 100 Ω respectively. Iron and friction loss are 500 watt. Write the efficiency of the motor.

Ans.
$V = 220$

$I_L = 30A$

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

$R_a = 0.2\,\Omega$

~~$I_a = I_{sh} = 500$ watt~~

$$I_{sh} = \frac{V}{R_{sh}} = \frac{220}{100} = 2.2A$$

~~$$I_a = \frac{V}{R_a} = \frac{220}{0.2}$$~~

$$I_a = I_L - I_{sh} = \cancel{28.8A}\ 27.8.$$

$$P_{in} = VI_L = 220 \times 30 = \cancel{6600\ \text{watt}}\ 6600 \quad \cancel{5984}$$

$$P_{out} = P_{in} - \text{losses}$$

loss = Total Cu. Losses + Iron loss + fricti.

50 Watt

Armat Cu loss = $I_a^2 R_a$

Shunt field Cu. loss = $I_{sh}^2 R_{sh}$.

$$\eta = \frac{P_{out}}{P_{in}} \times 100$$

~~Pout = 6600 − (500 + $I_{sh}^2 R_{sh}$) + $I_a^2 R_a$~~

~~Pout = 6600 − (500 + 4.84 × 100) + 1030.84 × 0.2~~

~~= 5400~~

Pout = ~~5484~~ 6600 − (500 + 4.84 × 100) + (772.84 × 0.2)

= ~~5484~~ = ~~5154.56~~

= ~~6600~~ = 5461.44.

$$\eta = \frac{5461.44}{6600} \times 100$$

= 82.7%

Scanned with CamScanner

Voltage control Method

In this method voltage source supplying the field current is different from the voltage source supplying the armature current.

This can be achieved by following 2 methods

i) multiple voltage control method
ii) Ward Leonard method

speed control of series motor

Speed of DC series motor can be controlled

a) Flux control method
b) Armature control method

SPEED CONTROL OF D.C. SERIES MOTOR

The speed of Series motor can be controlled by two method.

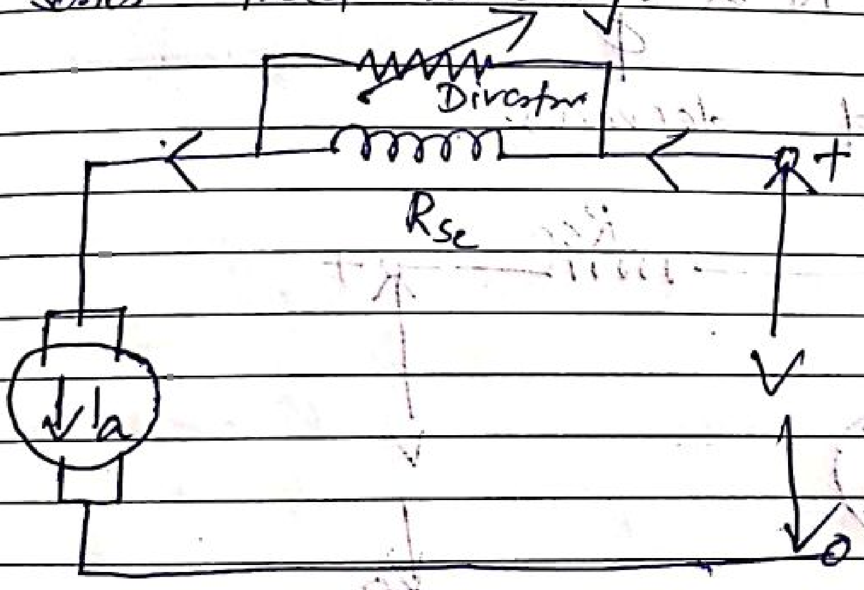
(a) Flux control Method.

(b) Armature resistance control method.

(a) Flux Control Method.

(i) Field diverters:-

In this method a variable resistance (called field diverter) is connected in parallel with series field winding.



The diverter shunt some part of line current from the series field winding.

I_{se} decreases and hence ϕ

So speed N increases. $\left(N \propto \frac{1}{\phi}\right)$

Lowest speed when current through diverter zero.

This is the normal speed.

In this method speed more than normal speed obtained.

Scanned with CamScanner

~~In this~~ (ii) Armature diverter.

To get speed Lower than normal sp a variable resistance (called armature diver is connected parallel with the armature.

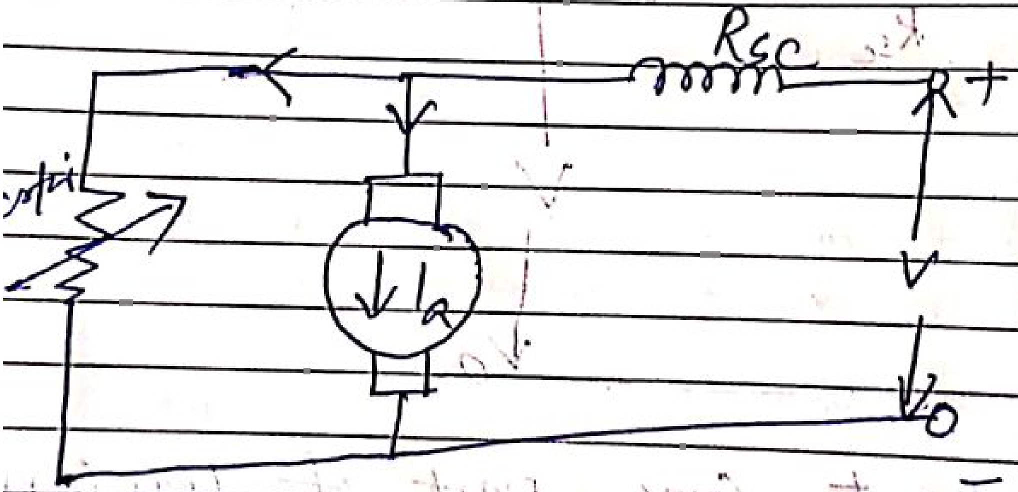
The diverter shunts some of the line curre so armature current decreases. (I_a)

$T \propto \phi I_a$.

I_a decrease means ϕ increase.

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

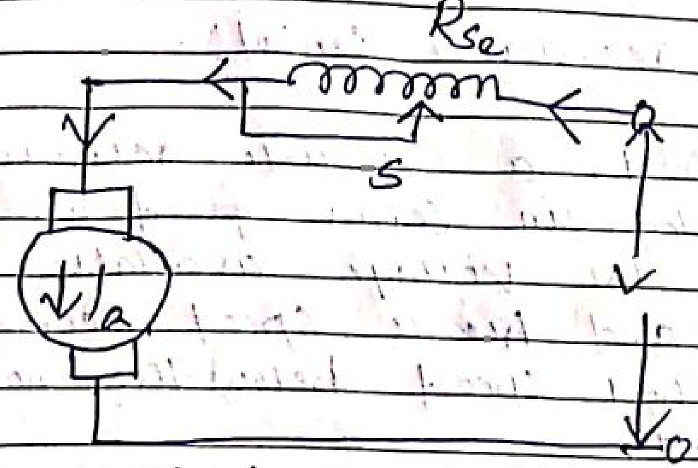
Speed decrease.



(iii) Tapped field control

In this method the flux is reduced, so speed increase by decreasi the number of turns of series field windi The switch S can short cut any part of the field winding, thus decreasing the f increasing the speed.

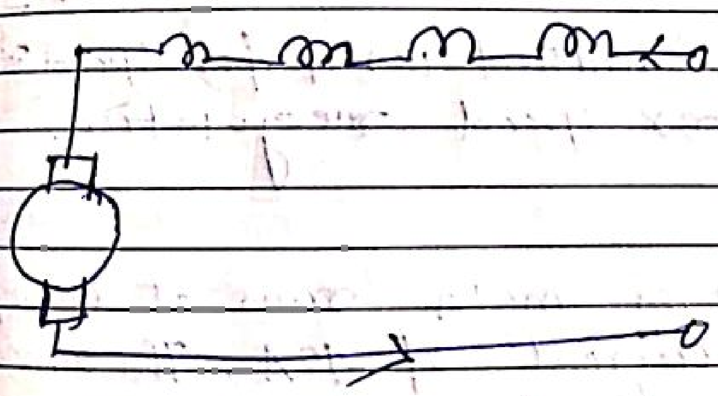
Scanned with CamScanner

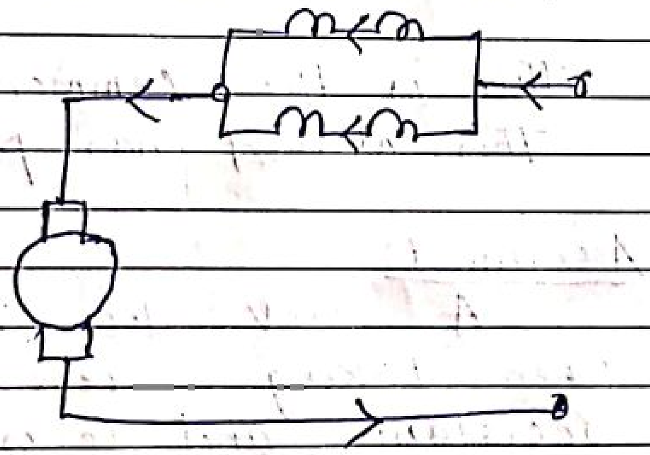


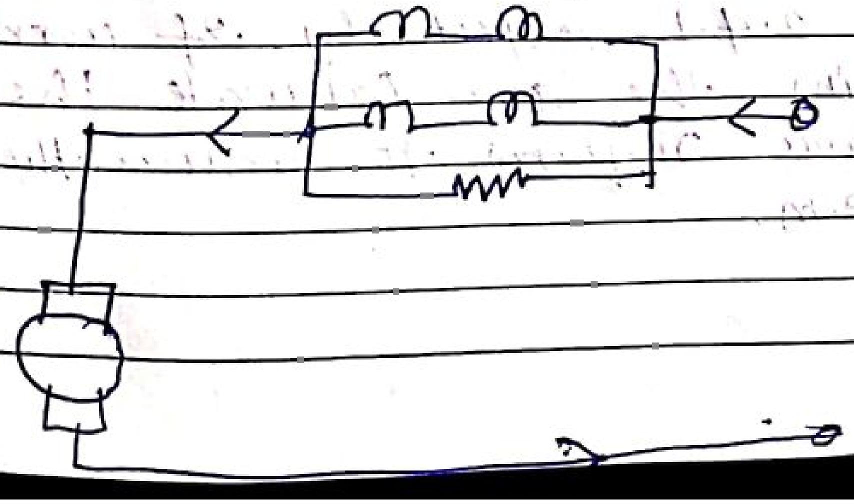
In this method speed higher than normal speed are obtained.

(iv) Parallelising field coils:

This method generally used in case of fan motor. By regrouping the field coils, several fixed speed can be obtained.

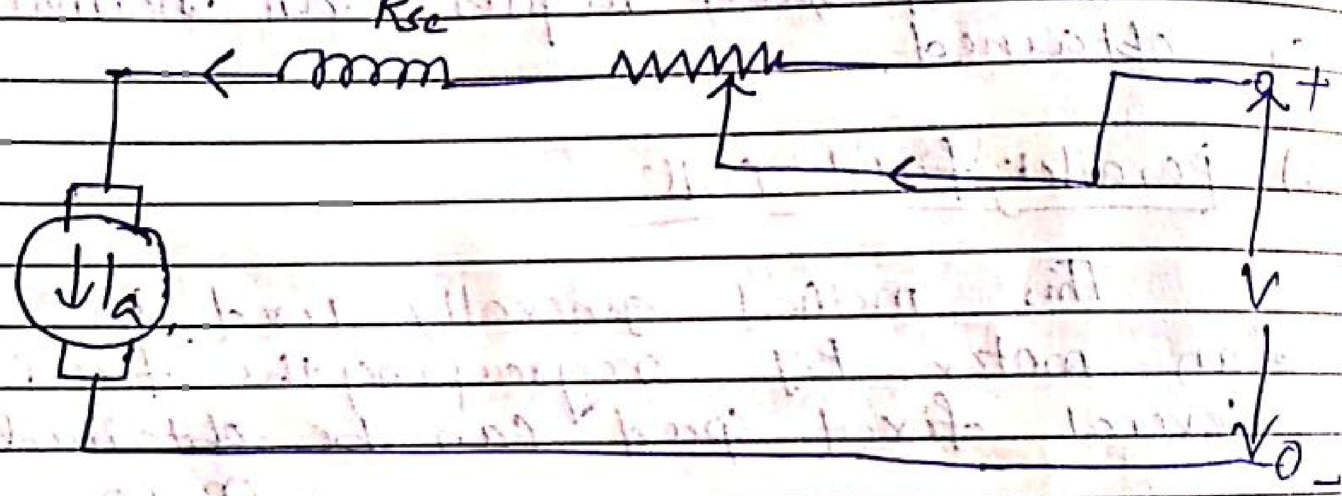






(b) Armature - resistance Control:-

In this method, a variable resistance is directly connected in series ~~field~~ with the sup[ply].
This reduces the voltage available across the armature and hence speed decreases.
In this method speed below the normal spe[ed] can be obtained.



This is the common method used for speed reg[ulation].
This method has poor speed regulation.

Assignment:
A 220V d.c. Series motor runs at 900 r.p.m when taking a line current of 40A. The armature resistance and series field resistance are 0.6 Ω and 0.4 Ω respectively. If current taken remains the same. Calculate the series resistance required to reduce the speed to 600 r.p.m.

Scanned with CamScanner

~~Series~~ SERIES — PARALLEL CONTROL

In series-parallel method of speed control is widely used in traction system, two (or more similar d.c. series motors are mechanically coupled to the same load.

When in parallel : speed $\propto \frac{E_b}{\phi} \propto \frac{E_b}{1/2} \propto \frac{2V}{1}$

When in series speed $\propto \frac{E_b}{\phi} \propto \frac{E_b}{1} \propto \frac{V/2}{1}$

fig.

Scanned with CamScanner

system which is widely used in traction system, two (or more) similar d.c. series motors are mechanical
coupled to the same load.

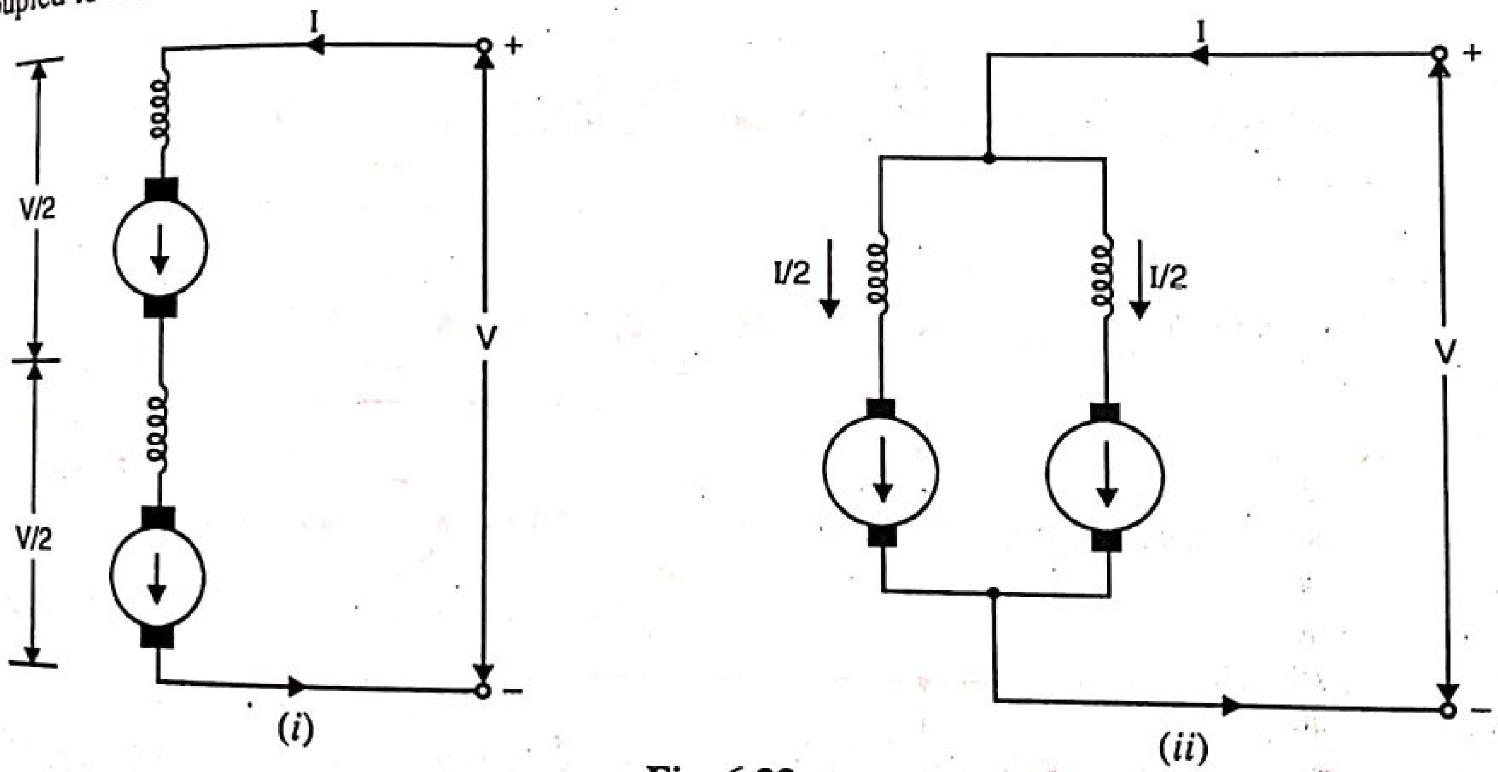


Fig. 6.23

When the motors are connected in series [See Fig. 6.23 (i)] each motor ...

Scanned with CamScanner

ELECTRICAL BRAKING:-

Sometimes it is desirable to stop a d.c. motor quickly.

The motor and its load may be brought to rest by using either.

(a) Mechanical (friction) braking.
(b) Electric braking.

Mechanical braking:-

In mechanical braking, the motor is stop due to friction between the moving parts of the motor and the brake shoe.

K.E dissipated as heat.

Disadvantage:

(i) Non smooth stop.
(ii) Great stopping time.

Sunday

Scanned with CamScanner

(b) Electrical Braking:

The K.E of moving parts (i.e. motor) is co... into electrical energy which is dissipated in a resistance as heat or alternatively, it is ret... to supply source (Regenerative braking).

(i) Rheostatic or Dynamic braking.
(ii) plugging.
(iii) Regenerative braking.

) Rheostatic or Dynamic braking.

In this method, the armature of the runn... motor is disconnected from the supply and is conne... across a variable resistance R.
The field winding left connected to sup...
The armature while slowing down, rotates in strong magnetic field and operate as gen... and sending large current to Resist...
The energy possessed by rotating arma... dissipate quickly as heat through res...
The motor brought to stand still.

EFFICIENCY OF D.C. MOTOR

Brake Test:

In this method, a brake is applied to a water cooled pulley mounted on the motor shaft.

One end of the rope is fixed to the floor via a spring balance S and a known mass is suspended at the other end.

Spring balance reading = S kg-wt.

Suspended mass has a weight = W kg-wt.

Net pull on the rope = (W−S) kg wt
= (W−S) × 9.81 newton

r = radius of the pulley in metres.

Shaft Torque = T_{sh} = (W−S) × 9.81 × r N-m

N = Speed of the pulley in N-r.p.m.

$$\text{output} = \frac{2\pi N}{60} T_{sh}$$

$$= \frac{2\pi N (W-S) \times 9.81 \times r}{60} \text{ watt}$$

V = supply voltage in volts

I = current taken by motor in amp.

Input = VI watts.

Scanned with CamScanner

$$\text{Efficiency} = \frac{2\pi N(W-S) \times r \times 9.81}{60 \times VI}$$

Assign

(1) In a brake Test on a d.c. motor, the effective Load on the brake drum was 23 kg-wt. the diameter of the drum 45 cm and the speed 960 rpm. The input to the motor was 28A at 230V. Calculate (i) the efficiency

(ii) the brake horse power of the motor

(2) A 120 V, 0.75 h.p. motor is tested at 2400 r.p.m. using the prony brake test. The input current is 7A and deflection force on the spring is 4.57 N. The effective length of the torque arm is 50 cm. and its dead weight is 0.03N. Determine the torque and efficiency of the motor.

Ans

Net force on the spring, $F = 4.57 - 0.03 = 4.54\,N$

Shaft torque of motor, $T_{sh} = F \times 0.5 = 4.54 \times 0.5$

$= 2.27\,Nm$

output power, $P_{out} = \frac{2\pi N}{60} \times T_{sh}$.

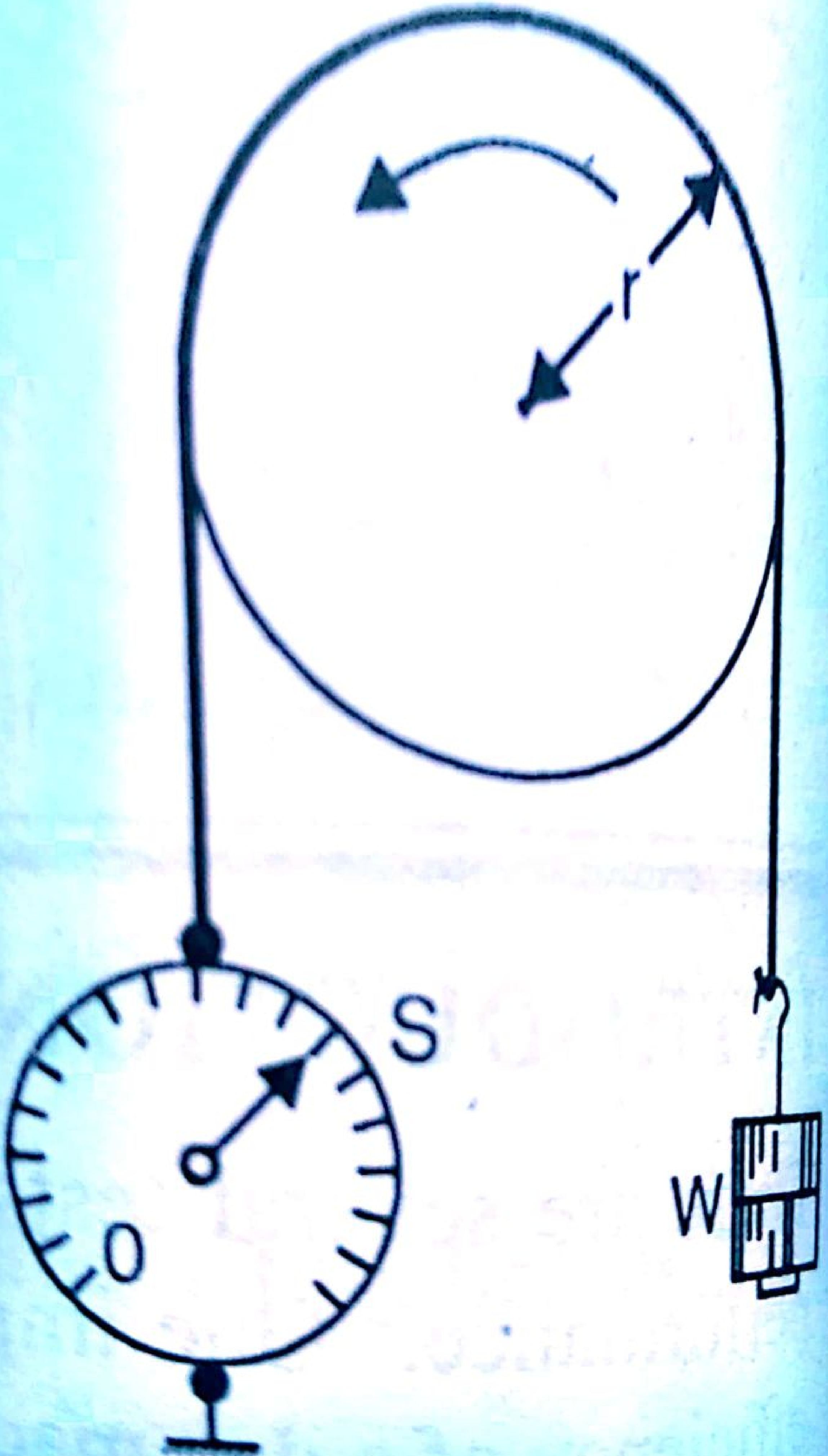
$= \frac{2\pi \times 2400}{60} \times 2.27 = 570.52\,W$

Input power, $P_{in} = VI = 120 \times 7 = 840\,W$.

Motor efficiency $\eta = \frac{P_{out}}{P_{in}} \times 100 = \frac{570.52}{840} \times 100$

$\simeq 67.9\%$

Scanned with CamScanner



Scanned with CamScanner

SWINBURNE'S METHOD FOR DETERMINING η

In this method the d.c. machine (generator or motor) is run as a motor at no-load i.e. Motor is run at no-load.

To determine η of d.c. machine (motor or generator)

(i) Motor is run at no-load.

(ii) Losses are determined.

This method is applicable to const flux motor i.e. shunt and compound machine.

Test consist of two steps.

Determination of hot resistance of winding

The R_a and R_{sh} are measured with the help of battery, voltmeter and ammeter. Since these resistances are measured when the machine is cold, they must be converted to values corresponding to the temperature at which the machine would work on full load.

fig.

Determination of Constant losses:-

The machine is run as a motor on no load with rated supply voltage and speed.

V = Supply voltage.
I_0 = No-load current by ammeter A_1
I_{sh} = Shunt field current by ammeter A_2

$I_{a0} = I_a - I_{sh}$ = No-load armature current.

No-load input power to motor $= VI_0$.
No-load input power to armature $= V(I_0 - I_{sh})$.

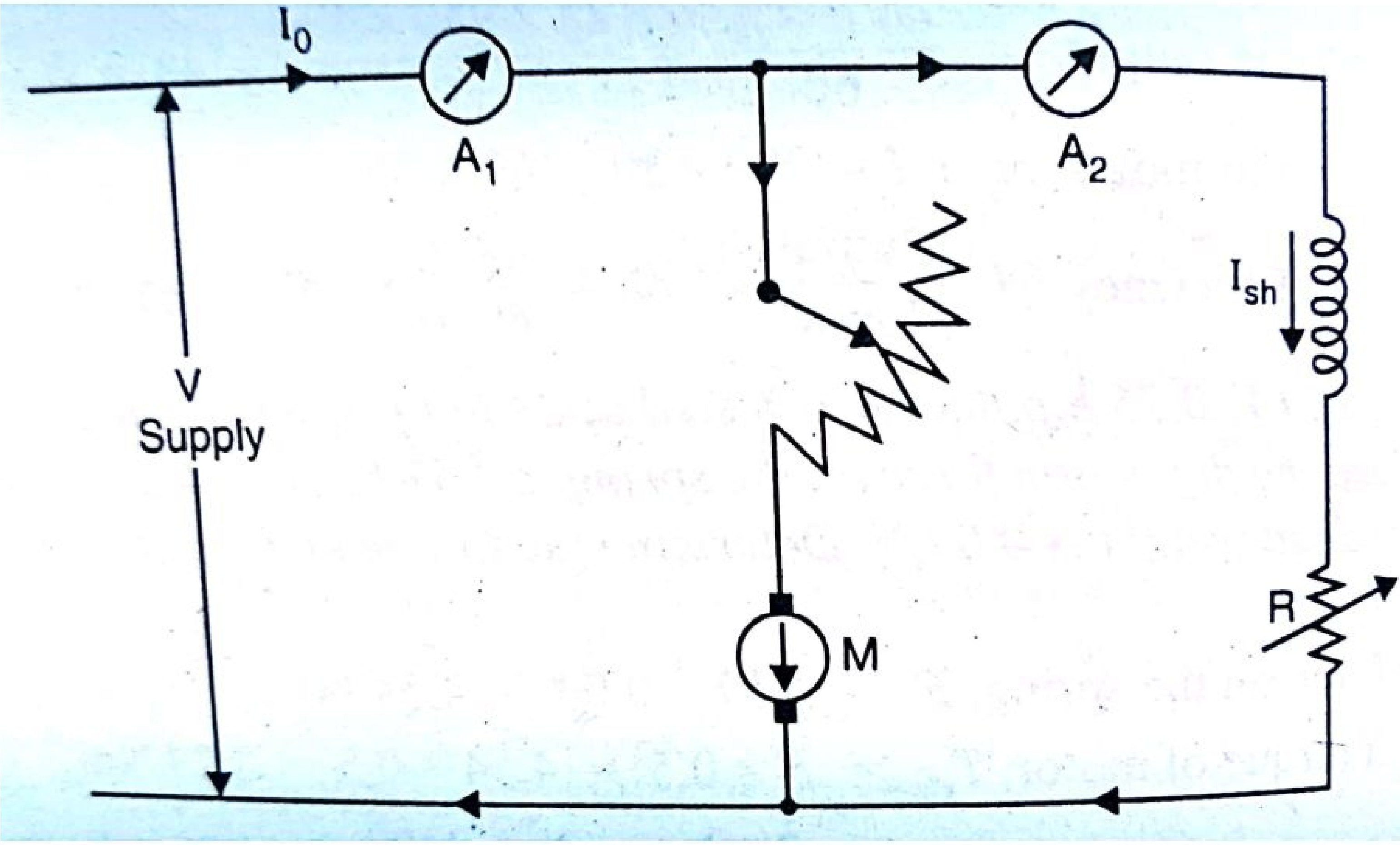
At no-load input power to armature supplies
(a) iron losses in the core.
(b) friction loss.
(c) windage loss.
(d) Cu-loss $I_{a0}^2 R_a$ or $(I_a - I_{sh})^2 R_a$.

Const. loss W_c = Input to motor − Arm. Cu. loss
$W_c = VI_0 - (I_0 - I_{sh})^2 R_a$.

<u>Efficiency when running as a motor.</u>

Input power to motor $= VI$
Arm. Cu. loss $= I_a^2 R_a = (I - I_{sh})^2 R_a$.
Const. loss $= W_c$.
Total loss $= (I - I_{sh})^2 R_a + W_c$

$$\eta_M = \frac{\text{Input} - \text{losses}}{\text{Input}} = \frac{VI - (I - I_{sh})^2 R_a - W_c}{VI}$$



I_0
A_1
A_2
I_{sh}
V
Supply
R
M

Efficiency when running as a Generator

Output of generator $= VI$

Arm. Cu. loss $= (I+I_{sh})^2 R_a$

Const. loss $= W_C$

Total loss $= (I+I_{sh})^2 R_a + W_C$

$$\eta_g = \frac{O/P}{O/P + \text{losses}} = \frac{VI}{VI + (I+I_{sh})^2 R_a + W_C}$$

Scanned with CamScanner

$V I + (I + I_{sh})^2 R_a + W_C$

Advantages of Swinburne's test

(*i*) The power required to carry out the test is small because it is a no-load test. Therefore, this method is quite economical.

(*ii*) The efficiency can be determined at any load because constant losses are known.

(*iii*) This test is very convenient.

Disadvantages of Swinburne's test

(*i*) It does not take into account the *stray load losses that occur when the machine is loaded.

(*ii*) This test does not enable us to check the performance of the machine on full-load. For example, it does not indicate whether commutation on full-load is satisfactory and whether the temperature rise is within the specified limits.

(*iii*) This test does not give quite accurate efficiency of the machine. It is because iron losses under actual load are greater than those measured. This is mainly due to armature reaction distorting the field.

Example 7.4. *A 220 V d.c. shunt motor at no-load takes a current of 2·5 A. The resistances of the armature and shunt field are 0·8 Ω and 200 Ω respectively. Estimate the efficiency of the motor when input current is 32 A. State the assumptions made.*

Solution.

$$\text{No-load input power} = V I_0 = 220 \times 2{\cdot}5 = 550 \text{ W}$$

$$I_{sh} = 220/200 = 1{\cdot}1 \text{ A}; \quad \text{No-load armature current, } I_{a0} = 2{\cdot}5 - 1{\cdot}1 = 1{\cdot}4 \text{ A}$$

$$\text{No-load armature Cu loss} = I_{a0}^2 R_a = (1{\cdot}4)^2 \times 0{\cdot}8 = 1{\cdot}6 \text{ W}$$

$$\text{Constant losses} = 550 - 1{\cdot}6 = 548{\cdot}4 \text{ W}$$

When input current is 32 A

$$\text{Armature current, } I_a = 32 - 1{\cdot}1 = 30{\cdot}9 \text{ A}$$

$$\text{Armature Cu loss} = I_a^2 R_a = (30{\cdot}9)^2 \times 0{\cdot}8 = 764 \text{ W}$$

$$\text{Total losses} = \text{Constant losses} + I_a^2 R_a = 548{\cdot}4 + 764 = 1312{\cdot}4 \text{ W}$$

$$\text{Input power} = 220 \times 32 = 7040 \text{ W}$$

$$\text{Output power} = 7040 - 1312{\cdot}4 = 5727{\cdot}6 \text{ W}$$

$$\text{Efficiency, } \eta = \frac{5727 \cdot 6}{7040} \times 100 = \mathbf{81.36\%}$$

TRANSFORMER

A Transformer is a static (or stationary) piece of device by means of which electrical power is transferred from one ckt to another ckt at const frequency.

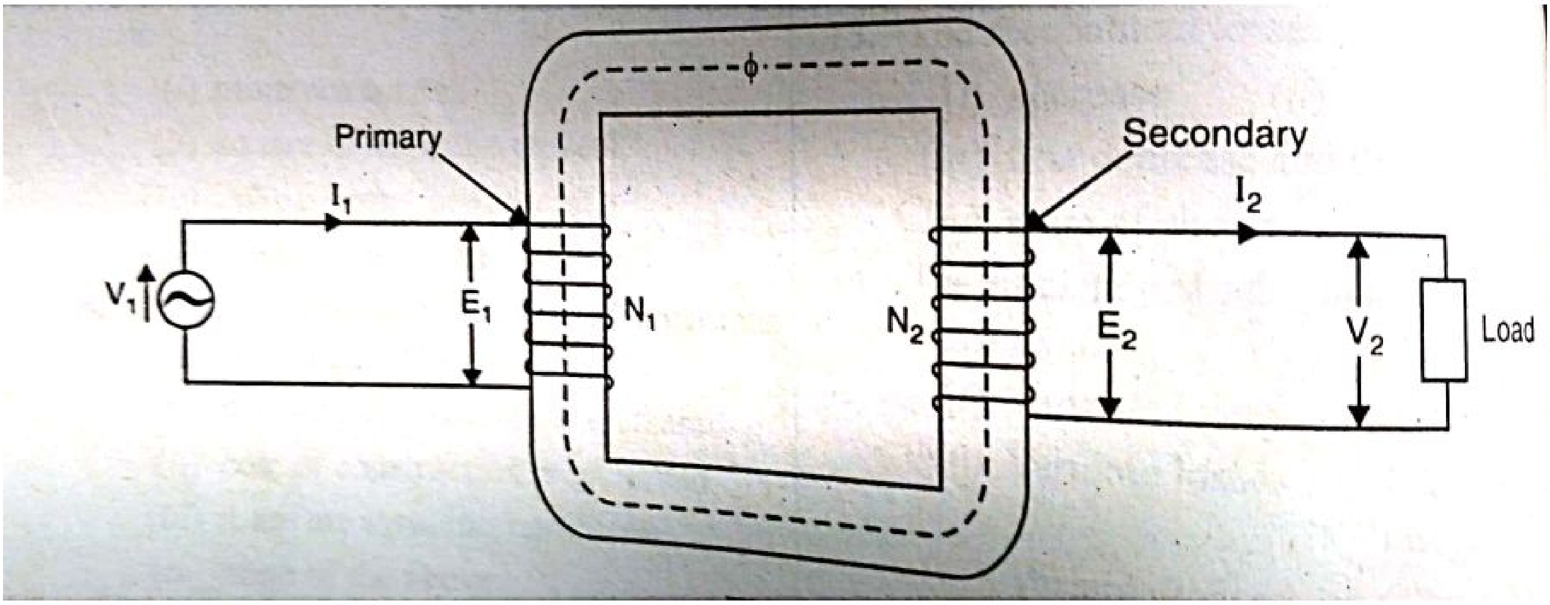
It can raise (step up) or lower (step down) the volt in a ckt but with a corresponding decrease or increase in current.

physically, a transformer is mutual induction between two ckts linked by a common magnetic flux

It consists of two inductive coils which are electrically separated but magnetically linked through a path of low reluctance.

Two coils possess high mutual inductance.
If one coil is connected to a source of AC voltage an AC flux is set up in the laminated core. Most of which linked with the other coil in which it produces mutually induced emf
According to the Faraday's Law of electromagnetic induction.

$$e = M \frac{di}{dt}$$



Scanned with CamScanner

If the second coil ckt is closed, a current flows in it and so electric energy is transferred (entirely magnetically) from the first coil to the second coil.

The first coil, in which electrical energy is fed from the AC supply main is called primary winding and other ckt from which energy is drawn out, is called secondary winding.

N_1 = No. of turns of primary.

N_2 = No. of turns of secondary.

V_1 = Alternating voltage applied to primary.

E_1 = Primary induced emf.

E_2 = Secondary induced emf.

$$E_1 = -N_1 \frac{d\phi}{dt} \; ; \; E_2 = -N_2 \frac{d\phi}{dt}$$

$$\frac{E_2}{E_1} = \frac{N_2}{N_1}$$

V_2 = Voltage across the Load.

If $N_2 > N_1$ $E_2 > E_1$ or $V_2 > V_1$

Step up Transformer

Scanned with CamScanner

If . $N_1 > N_2$ $E_1 > E_1$ $V_1 > V_2$.

Step down Transformer.

LOSSES IN A TRANSFORMER.

Core losses— eddy current and hystresis l
Copper losses — In the resistance of winding

Practically these losses are very small.
output power = Input power.

Scanned with CamScanner

IDEAL TRANSFORMER

An ideal Transformer.

(i) No winding resistance.

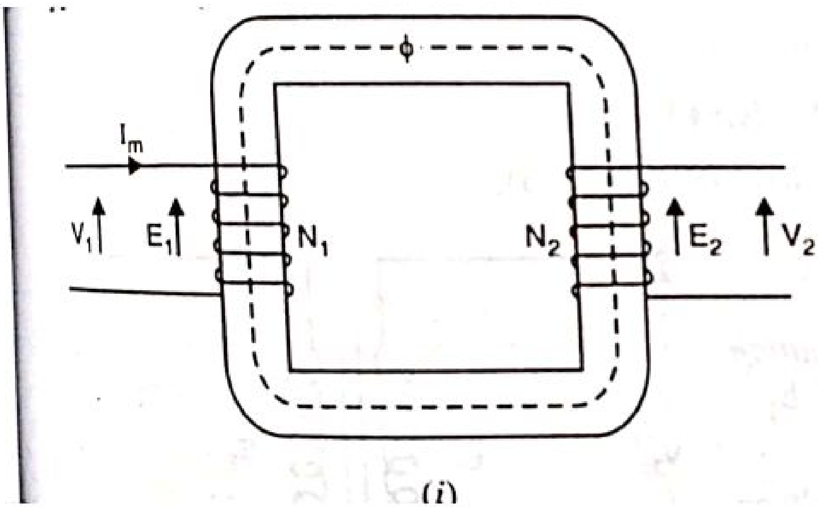
(ii) No Leakage flux

Same flux links both the winding

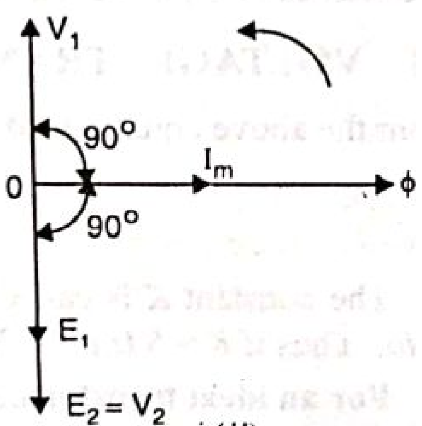
(iii) No iron losses (i.e eddy-current and hysteresis lo

Ideal Transformer can't be physically realised.

Scanned with CamScanner



(i)



(ii)

Scanned with CamScanner

VOLTAGE TRANSFORMATION RATIO (K)

$$\frac{E_2}{E_1} = \frac{N_2}{N_1} = K.$$

K = voltage Transformation ratio.

For ideal T.F.

$$E_1 = V_1 \qquad E_2 = V_2$$

$$\frac{E_2}{E_1} = \frac{V_2}{V_1} = \frac{N_2}{N_1} = K.$$

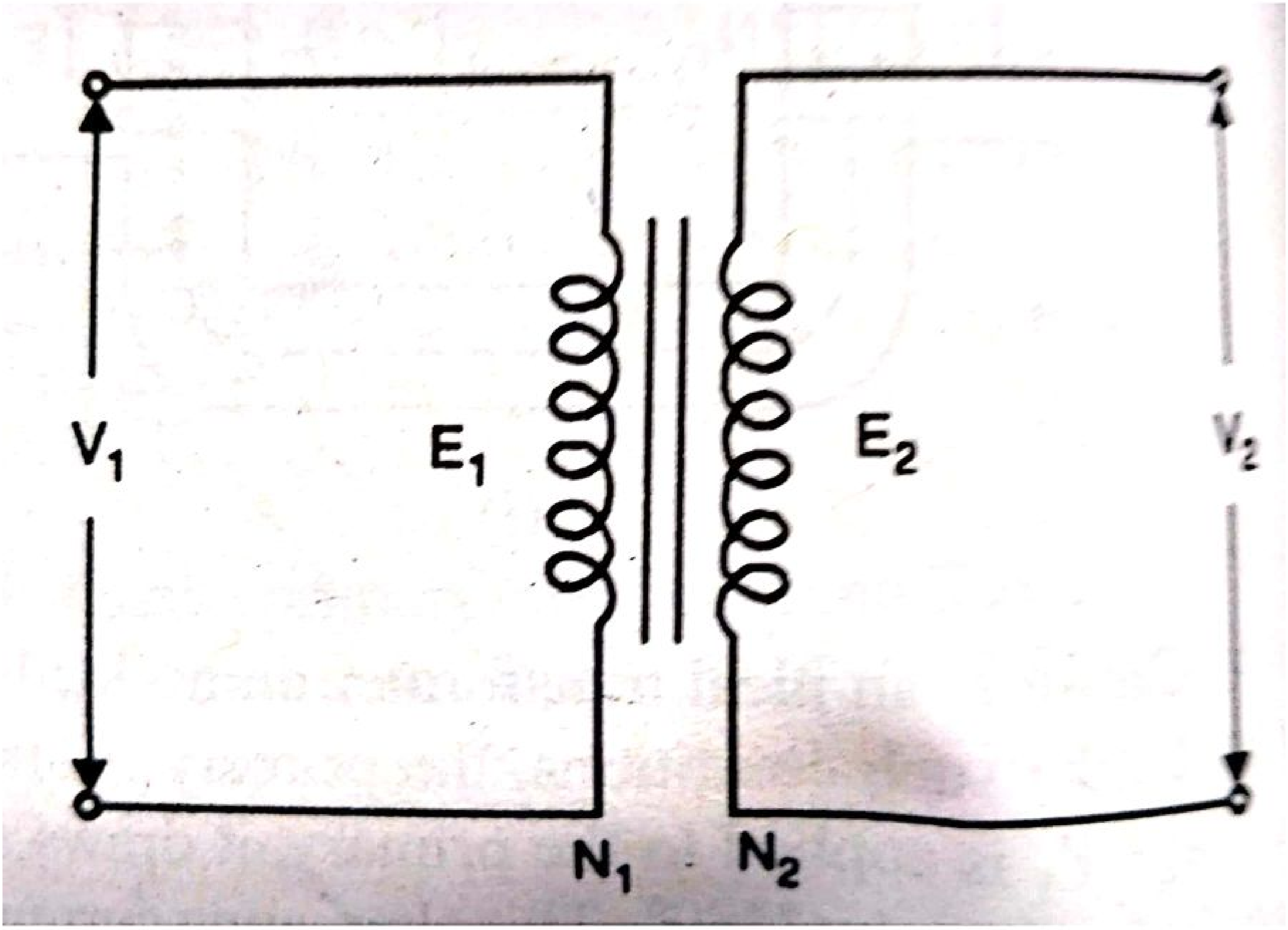
No losses.

O/p power = i/p power.

$$V_1 I_1 = V_2 I_2$$

$$\frac{V_2}{V_1} = \frac{I_1}{I_2} = K.$$

Scanned with CamScanner



Scanned with CamScanner

E. M.F. EQUATION OF A TRANSFORMER

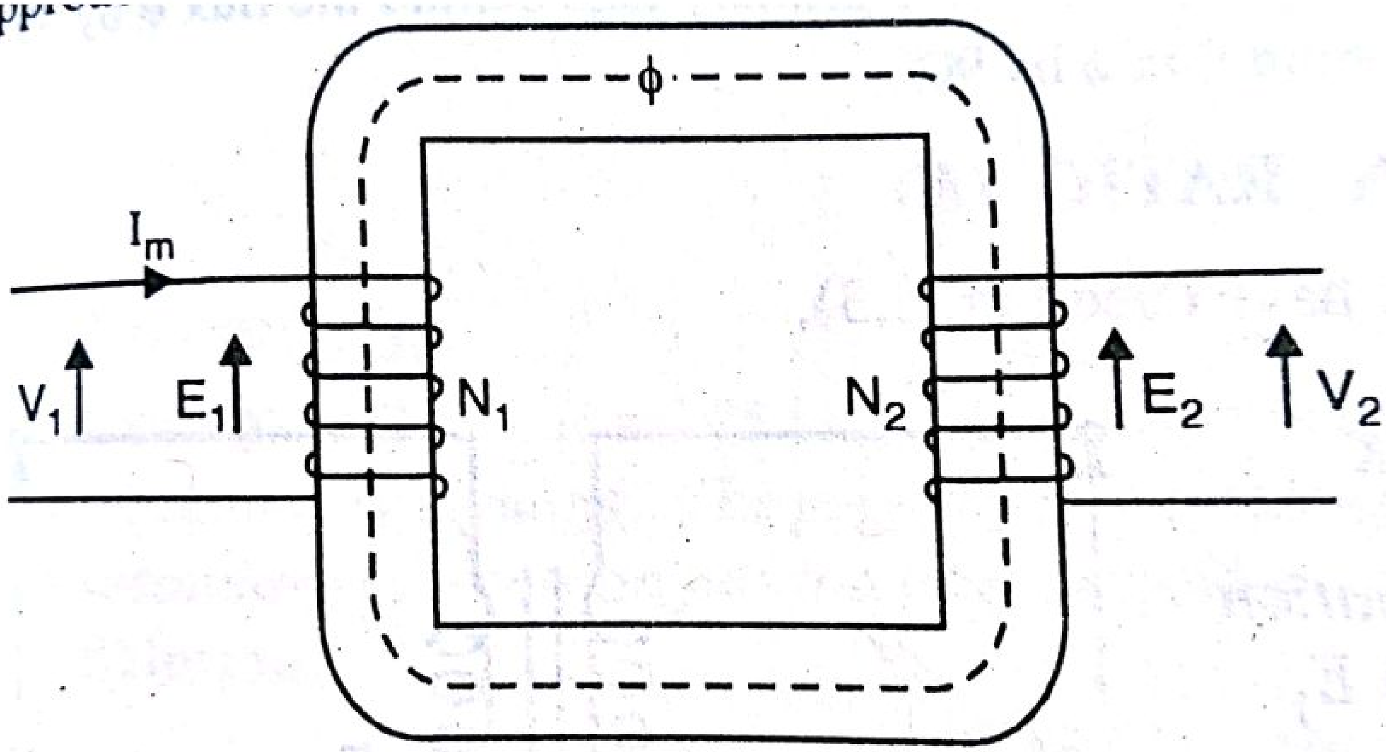
Consider an alternating voltage v_1 of frequency f is applied to primary as shown in fig. ideal Transformer

Sinusoidal flux

$$\phi = \phi_m \sin \omega t \quad \text{—— (4)}$$

Scanned with CamScanner

appr



(i)

Scanned with CamScanner

e_1 = Induced emf in the primary.

$$e_1 = -N_1 \frac{d\phi}{dt}$$

$$= -N_1 \frac{d}{dt}(\phi_m \sin\omega t) \quad [\phi = \phi_m \sin\omega t$$

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

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

$$= -N_1 \phi_m 2\pi f \; - \sin(\omega t - 90^\circ)$$

$$e_1 = 2\pi f N_1 \phi_m \sin(\omega t - 90^\circ)$$

E_{m1} = Maximum induced emf

$$= 2\pi f N_1 \phi_m$$

E_1 = r.m.s value of e_1

$$E_1 = \frac{E_{m1}}{\sqrt{2}} = \frac{2\pi f N_1 \phi_m}{\sqrt{2}}$$

Sunday 03

$$E_1 = \sqrt{2}\pi f N_1 \phi_m$$

$$E_1 = 4.44 f N_1 \phi_m \quad \text{—} \quad (5)$$

Similary $E_2 = 4.44 f N_2 \phi_m$ — (6)

For ideal Transformer $E_1 = V_1$, $E_2 = V_2$

Example:- (1) A Sinusoidal flux 0.02 Wb (max) links with 55 turns of a transformer secondary. Calculate the rms value of the induced emf in the secondary. f = 50 Hz

Solⁿ:- $\phi_m = 0.02\ Wb$, $N_2 = 55$ turns, $f = 50\ Hz$.

R.M.S value of induced emf in the secondary:

$$E_2 = 4.44 f \phi_m N_2$$
$$= 4.44 \times 50 \times 0.02 \times 55 = 244.2\ V$$

PRACTICAL TRANSFORMER

Practical Transformer has following losses.

(I) Iron losses

(II) ~~Wastage~~ Winding resistance

(III) Magnetic Leakage, giving rise to Leakage reac

Iron losses:

Since Iron core is subjected to alternating flux, hence eddy current and hysteresis Loss occurs. These two losses are known as Iron losses or Core losses.

Iron loss depends upon

(I) Supply frequency

(II) Maximum flux density.

(III) volume of the core.

Scanned with CamScanner

Winding resistances:

Winding of Transformer consists of ~~cond~~ copper conductors. Hence it is having ~~wdg~~ resistance both in primary and secondary. The resistance R_1 is in series with primary windings. The resistance R_2 ~~is~~ is in series with secondary winding.

fig.

Leakage Reactance:

Both primary and secondary current produce flux. The flux ϕ which links both the winding is the useful flux and it is called mutual flux.

But the primary current I_1 produces flux ϕ_1 which wouldn't link secondary.

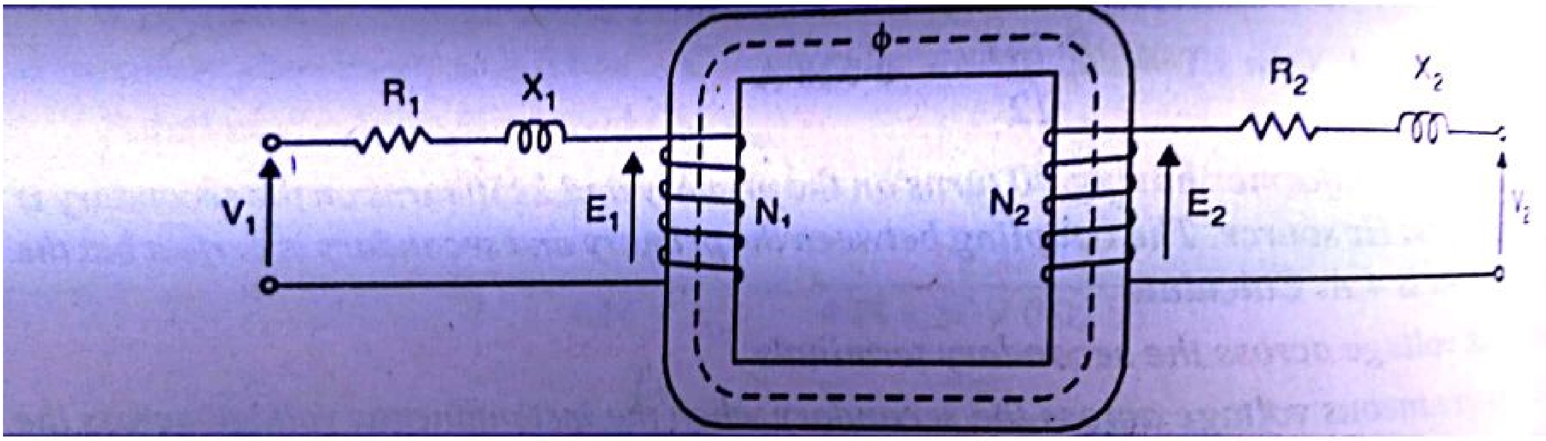
Similarly

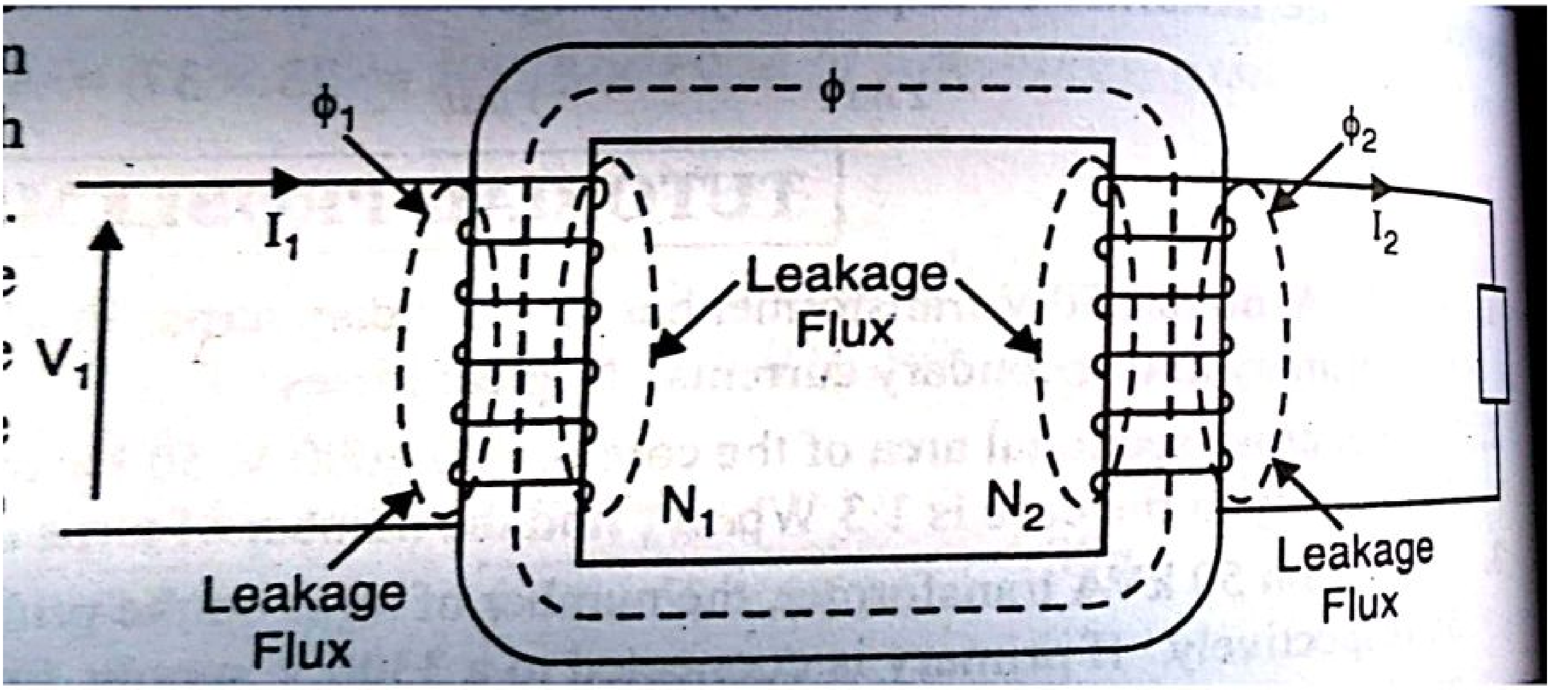
The secondary current I_2 produces flux ϕ_2 which wouldn't link primary.

The flux ϕ_1 & ϕ_2 which only link one winding is called leakage flux.

The leakage flux path through the air!

Due to leakage ~~reactance~~ flux ϕ_1 & ϕ_2, there is a leakage reactance X_1 and X_2 connected to primary and secondary winding respectively.


R1
X1
V1
E1
N1
N2
E2
R2
X2
V2
ϕ



ϕ_1
ϕ
ϕ_2
I_1
I_2
V_1
Leakage Flux
Leakage Flux
Leakage Flux
Leakage Flux
N_1
N_2

PRACTICAL TRANSFORMER ON NO LOAD :

Consider a practical transformer on no load ie. Secondary on open cct.

The primary will draw a small current I_0 to supply.

(i) Iron losses.
(ii) Very small amount of copper loss.

Hence I_0 is not exactly $90°$ lag to V_1 But I_0 lags a phase angle $\phi < 90°$.

fig.

I_0 (no load primary current) is resolved into two rectangular components.

(i) The component I_w in phase with the supply voltage V_1.

$$I_w = I_0 \cos\phi_0$$

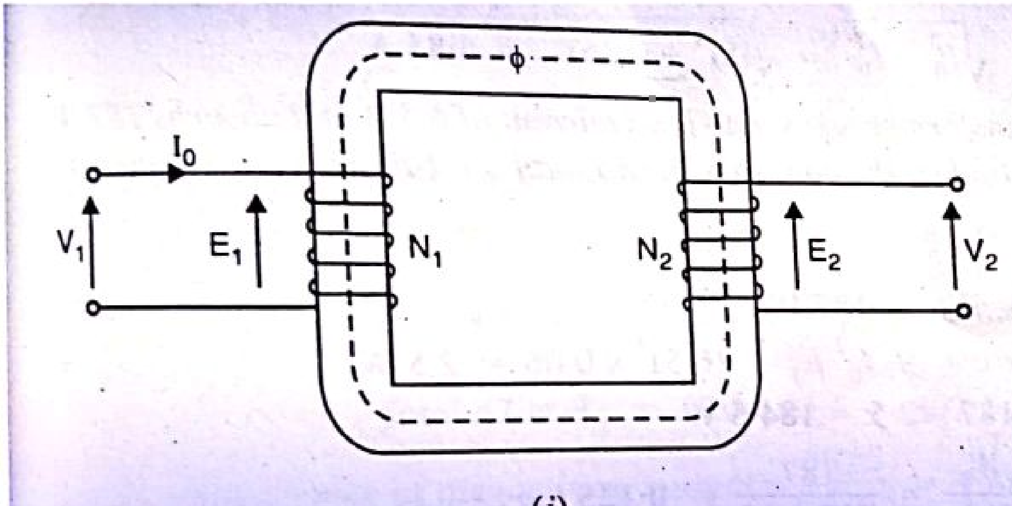
This is called Core loss compont or Active or working compond.

(ii) The component I_m lagging behind V_1 by $90°$ is called Magnetising component.

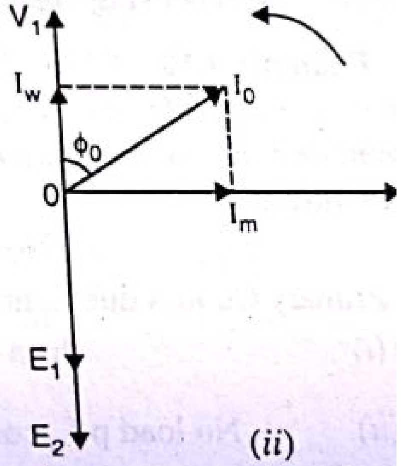
This component produces mutual flux.

$$I_m = I_0 \sin\phi_0$$

$I_0 = \sqrt{I_m^2 + I_w^2}$, $\cos\phi_0 = \frac{I_w}{I_0}$ = No Load P.f



(i)



(ii)

Scanned with CamScanner

Example 8.8. *A transformer takes a current of 0·6 A and absorbs 64 W when primary is connected to its normal supply of 200 V, 50 Hz ; the secondary being on open circuit. Find the magnetising and iron loss currents.*

Solution.

No load primary power, $W_0 = V_1 I_0 \cos\phi_0$

Iron loss component, $I_W = I_0 \cos\phi_0 = W_0/V_1 = 64/200 = \mathbf{0{\cdot}32\ A}$

No load current, $I_0 = \sqrt{I_m^2 + I_W^2}$

$\therefore$ Magnetising current, $I_m = \sqrt{I_0^2 - I_W^2} = \sqrt{(0{\cdot}6)^2 - (0{\cdot}32)^2} = \mathbf{0{\cdot}507\ A}$

Scanned with CamScanner

Example 8.10. *A 230/2300 V transformer takes a no load current of 6·5 A and absorbs 187 W. If the resistance of primary is 0·06 Ω, find (i) the core loss (ii) no load p.f. (iii) active component of current and (iv) magnetising current.*

Solution.

$$\text{No-load loss, } W_0 = 187 \text{ W}$$

$$\text{Primary Cu loss due to no-load current} = I_0^2 R_1 = (6{\cdot}5)^2 \times 0{\cdot}06 = \mathbf{2{\cdot}5\ W}$$

(*i*) $$\text{Iron loss} = 187 - 2{\cdot}5 = \mathbf{184{\cdot}5\ W}$$

(*ii*) $$\text{No load p.f., } \cos\phi_0 = \frac{W_0}{V_1 I_0} = \frac{187}{230 \times 6{\cdot}5} = \mathbf{0{\cdot}125}\ \textit{lag}$$

(*iii*) $$\text{Active component, } I_W = \frac{W_0}{V_1} = \frac{187}{230} = \mathbf{0{\cdot}81\ A}$$

(*iv*) $$\text{Magnetising current, } I_m = \sqrt{I_0^2 - I_W^2} = \sqrt{(6{\cdot}5)^2 - (0{\cdot}81)^2} = \mathbf{6{\cdot}4\ A}$$

Scanned with CamScanner

$$N_1 I_1 = N_2 I_2$$

$$I_1 = \frac{N_2}{N_1} I_2$$

$$I_1 = K I_2$$

Scanned with CamScanner

Example 8.13. *An ideal transformer having 90 turns on the primary and 2250 turns on the secondary is connected to 200 V, 50 Hz supply. The load across the secondary draws a current of 2 A at a p.f. of 0·8 lagging. Calculate (i) the value of primary current and (ii) the peak value of flux linked with the secondary. Draw the phasor diagram.*

Solution. The conditions of the problem are represented in Fig. 8.11 (*i*).

$$K = N_2/N_1 = 2250/90 = 25$$

(*i*) $$I_1 = KI_2 = 25 \times 2 = \mathbf{50\ A}$$

(*ii*) $$E_1 = 4{\cdot}44 f N_1 \phi_m$$

or $$200 = 4{\cdot}44 \times 50 \times 90 \times \phi_m$$

$$\therefore \quad \phi_m = \frac{200}{4{\cdot}44 \times 50 \times 90} = \mathbf{0{\cdot}01\ Wb}$$

This flux links both the windings.

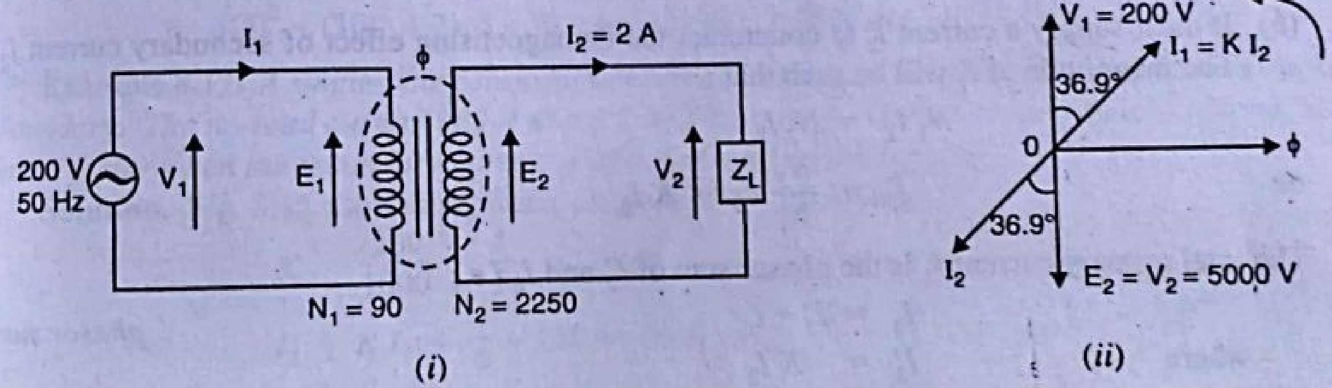


Fig. 8.11

Phasor diagram. Fig. 8.11 (*ii*) shows the phasor diagram (not to scale) of the transformer.

$$E_2 = KE_1 = 25 \times 200 = 5000 \text{ V}$$

$$\phi_2 = \text{phase angle between } V_2 \text{ and } I_2$$

$$= \cos^{-1} 0{\cdot}8 = 36{\cdot}9°$$

The phase angle between V_1 and I_1 is also 36·9°.

Example 8.14. *An ideal transformer has 1000 turns on its primary and 500 turns on its secondary. The driving voltage on the primary side is 100 V and the load resistance is 5 Ω. Calculate V_2, I_1 and I_2.*

Solution.

$$K = N_2/N_1 = 500/1000 = 1/2$$

$$V_2 = KV_1 = (1/2) \times 100 = \mathbf{50\ V}$$

$$I_2 = V_2/R_2 = 50/5 = \mathbf{10\ A}$$

$$I_1 = KI_2 = (1/2) \times 10 = \mathbf{5\ A}$$

Example 8.15. *A single-phase transformer having a core of cross-sectional area of 150 cm^2*

PRACTICAL TRANSFORMER ON LOAD.

When Practical Transformer Loaded.
Two cases arises.
(1) No Winding resistance and Leakage flux.
(11) Transformer has winding resistance and Leakage flux.

(1.) No Winding resistance and leakage flux.

Practical Transformer has no winding resistance and Leakage reactance.

$V_2 = E_2$, $V_1 = E_1$.

Take inductive Load.
I_2 Lag ϕ_2 to secondary volt V_2

I_1 = primary current
I_2 = secondary current.

Scanned with CamScanner

Scanned with CamScanner

I_1 must have two components, $I_1 = I_0 + I_2'$

(a) I_0 = No-Load current to meet iron losses in the transformer and ~~meet produce~~ provide flux in the core.

(b) I_2' to counteract the demagnetising effect of secondary current I_2.

$$N_1 I_2' = N_2 I_2$$

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

$$I_2' = K I_2$$

fig:

E_1 & E_2 lag behind the mutual flux ϕ by

$I_2' = K I_2$ antiphase.

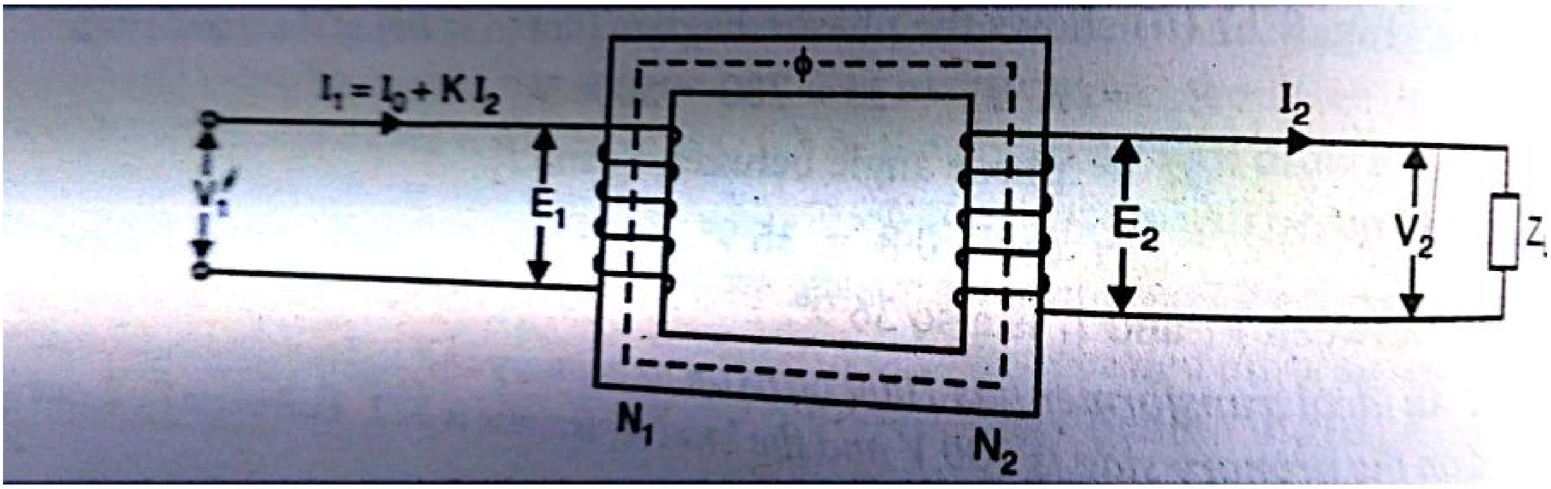
Sunday 10

I_0 makes ϕ_0 with V_1

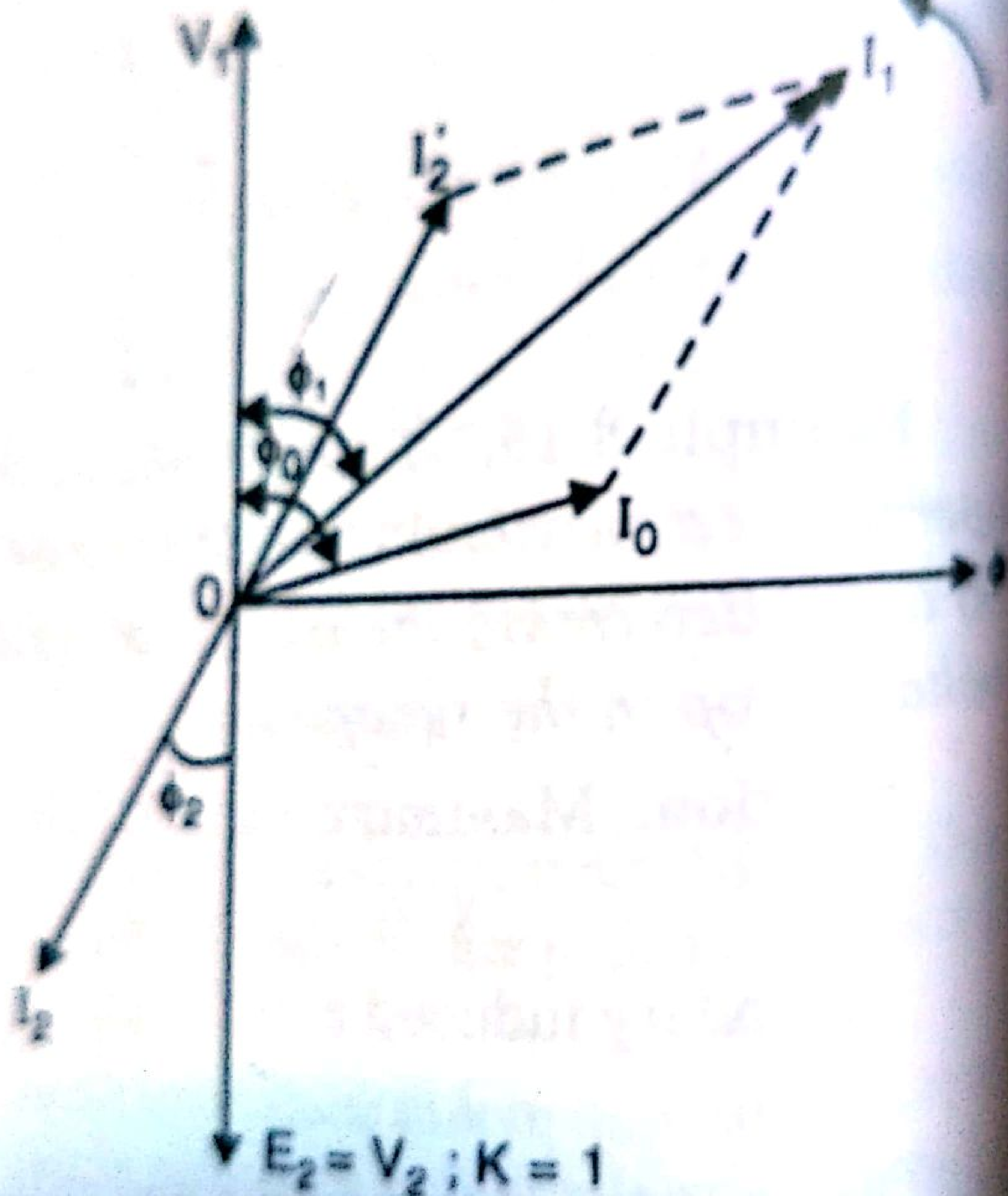
I_1 makes ϕ_1 with V_1

I_2 makes ϕ_2 with V_2

Scanned with CamScanner



Scanned with CamScanner



Scanned with CamScanner

PRACTICAL TRANSFORMER ON LOAD.

(ii) With winding resistance & Leakage reactance,

Fig Below shows a practical transformer having winding resistance and Leakage reactance.
This is the actual conditions of a practical Transformer.

$E_1 < V_1$ - As voltage drop across R_1 and X_1

$V_2 < E_2$ As voltage drop across R_2 & X_2.

Consider an inductive Load.
I_2 Lags behind V_2 by ϕ_2.

Total primary current
$$I_1 = I_0 + KI_2 = I_0 + I_2'$$

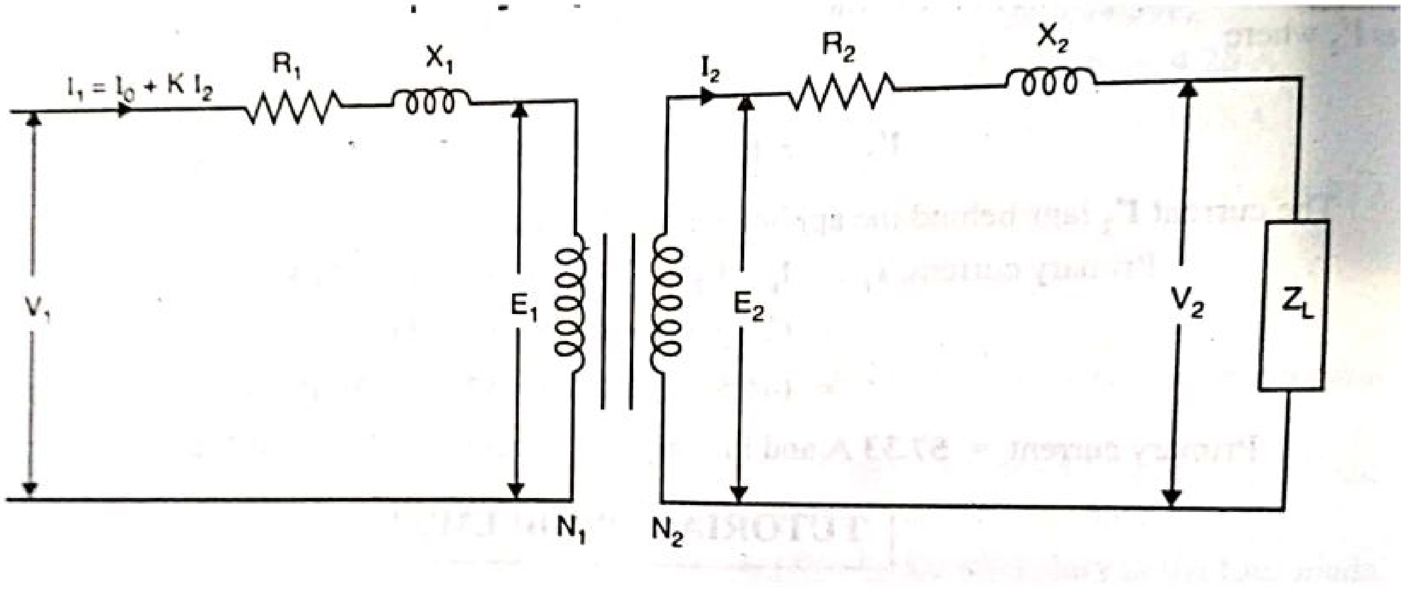
(a) I_0 is the no-Load current to meet the iron losses in the transformer and provide the flux in the core.

(b) I_2' is the part of primary current to counteract the demagnetising effect of secondary current I_2.

$$N_1 I_2' = N_2 I_2$$

$$I_2' = \frac{N_2}{N_1} I_2 = K I_2 \quad I_2' = KI_2.$$

Scanned with CamScanner



Scanned with CamScanner

$I_1 =$ phasor sum of I_0 and I_2'

$I_1 = I_2' + I_0$ $\quad$ $I_2' = -KI_2$

fig.

$V_1 = -E_1 + I_1(R_1 + jX_1)$

$$\boxed{V_1 = -E_1 + I_1 Z_1}$$

$V_2 = E_2 - I_2(R_2 + jX_2)$

$$\boxed{V_2 = E_2 - I_2 Z_2.}$$

Phasor diagram (Lagging p.f)

Load power factor $= \cos\phi_2$

Primary power factor $= \cos\phi_1$

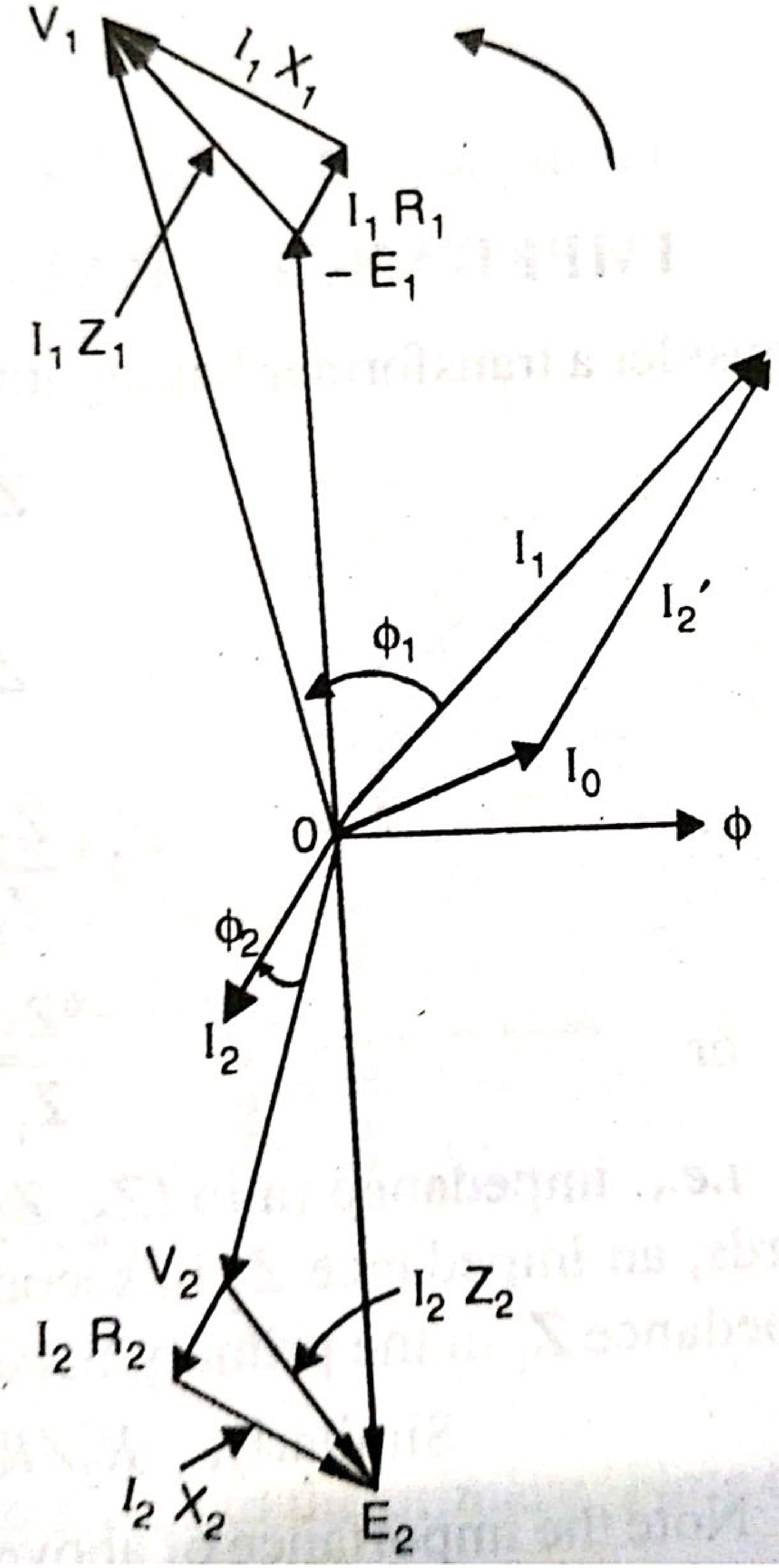
Input power to transformer, $P_1 = V_1 I_1 \cos\phi$

output power of transformer $P_2 = V_2 I_2 \cos\phi$

phasor Diagram

Scanned with CamScanner

Scanned with CamScanner

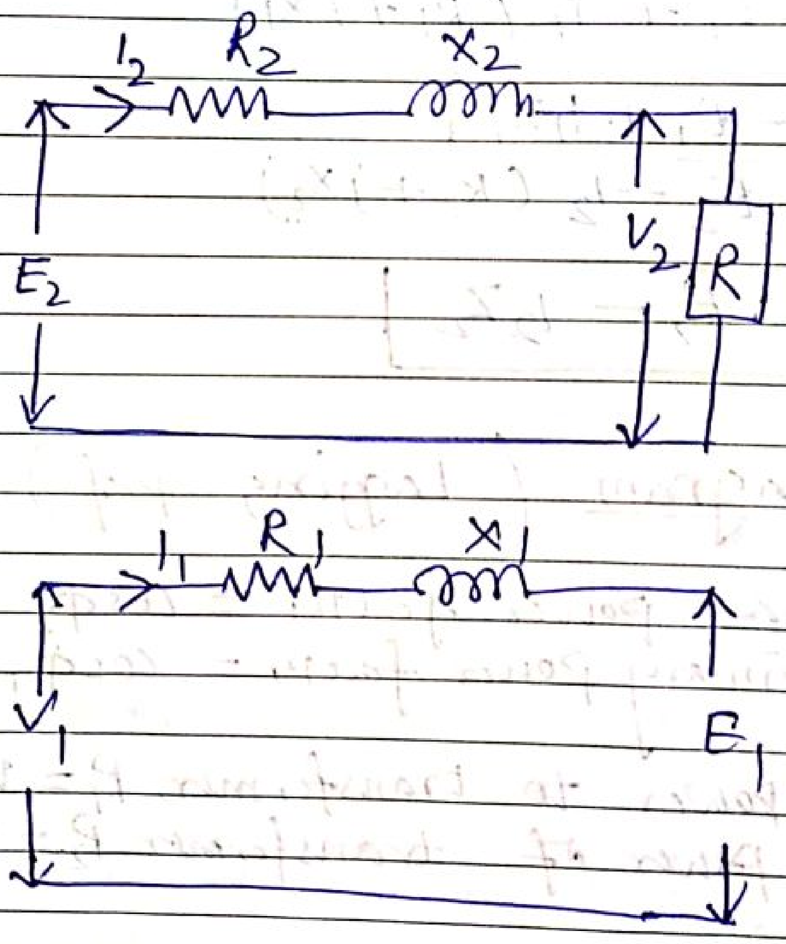


Scanned with CamScanner

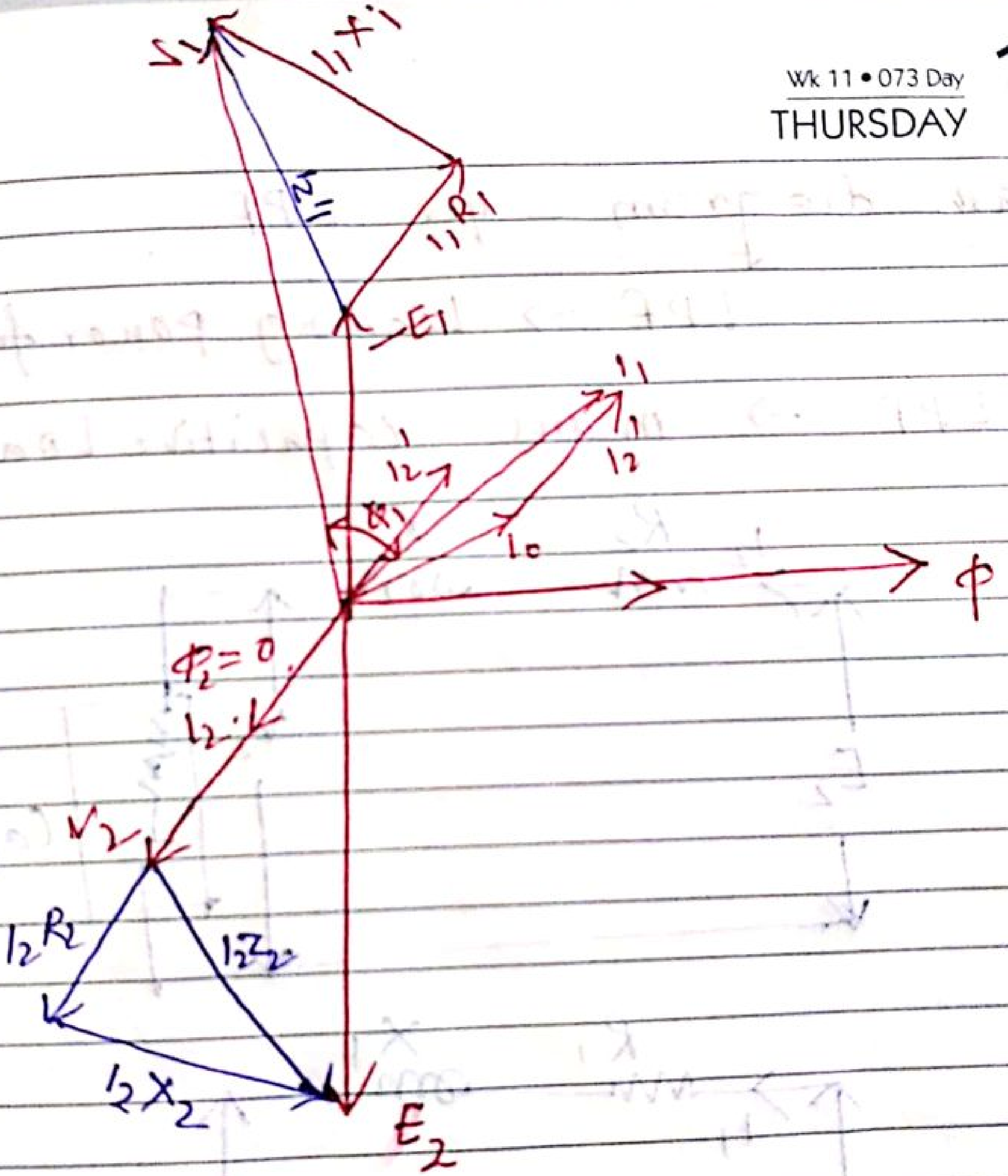
phasor diagram for UPF

UPF = Unity Power factor Load

UPF Load mean Resistive Load.



Scanned with CamScanner



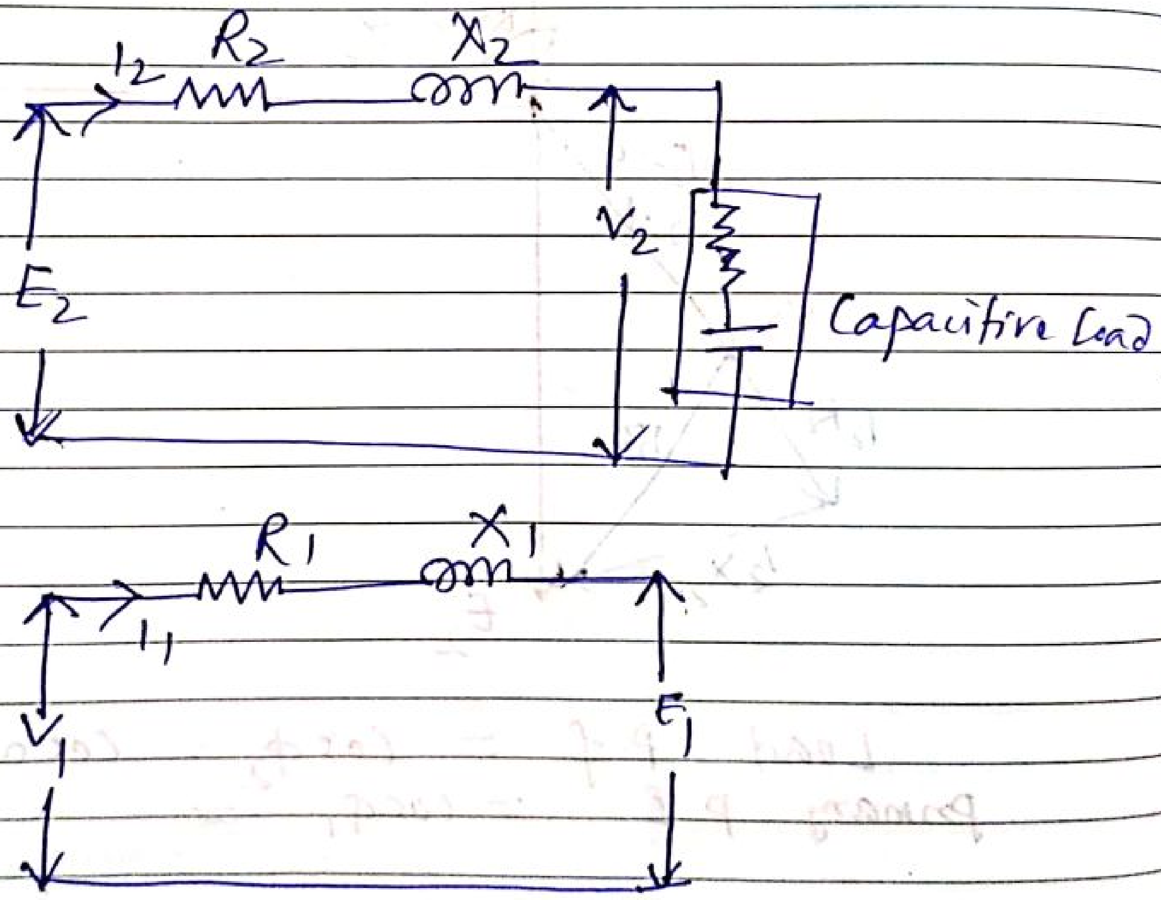
Load p.f $= \cos\phi_2 = \cos 0 = 1$

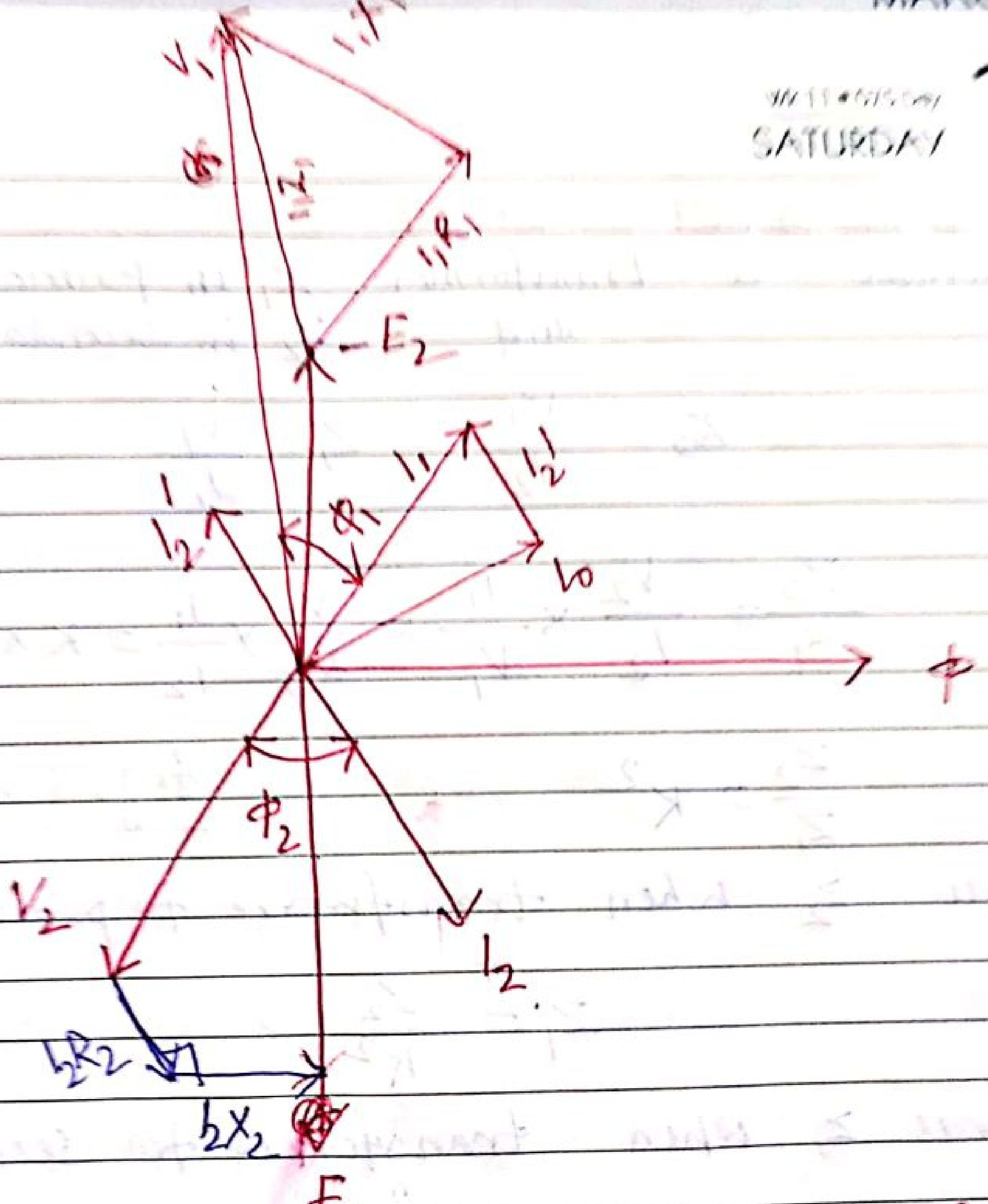
Primary p.f $= \cos\phi_1 =$

Phasor diagram for LPF

LPF → Leading power factor load,

LPF → means capacitive Load.





Phasor diagram for LPF Load

Scanned with CamScanner

IMPEDANCE RATIO

Consider a transformer Z_1 in primary
and Z_2 in Secondary.

$$Z_2 = \frac{V_2}{I_2}, \quad Z_1 = \frac{V_1}{I_1}$$

$$\frac{Z_2}{Z_1} = \frac{V_2}{I_2} \times \frac{I_1}{V_1} = \frac{V_2}{V_1} \times \frac{I_1}{I_2} = K \times K.$$

$$\frac{Z_2}{Z_1} = K^2$$

fig. 8.19

Impedance Z_2 when transformed to primary becomes

$$Z_1 = \frac{Z_2}{K^2}.$$

Impedance Z_1 when transferred to secondary becomes

$$Z_2 = K^2 Z_1$$

Similarly $\frac{R_2}{R_1} = K^2$ $\quad \frac{X_2}{X_1} = K^2$

Resistance R_1 in primary becomes $K^2 R_1$ when transformed to Secondary.

Resistance R_2 in secondary becomes $\frac{R_2}{K^2}$ when transferred to primary.

Similarly X_1 & X_2.

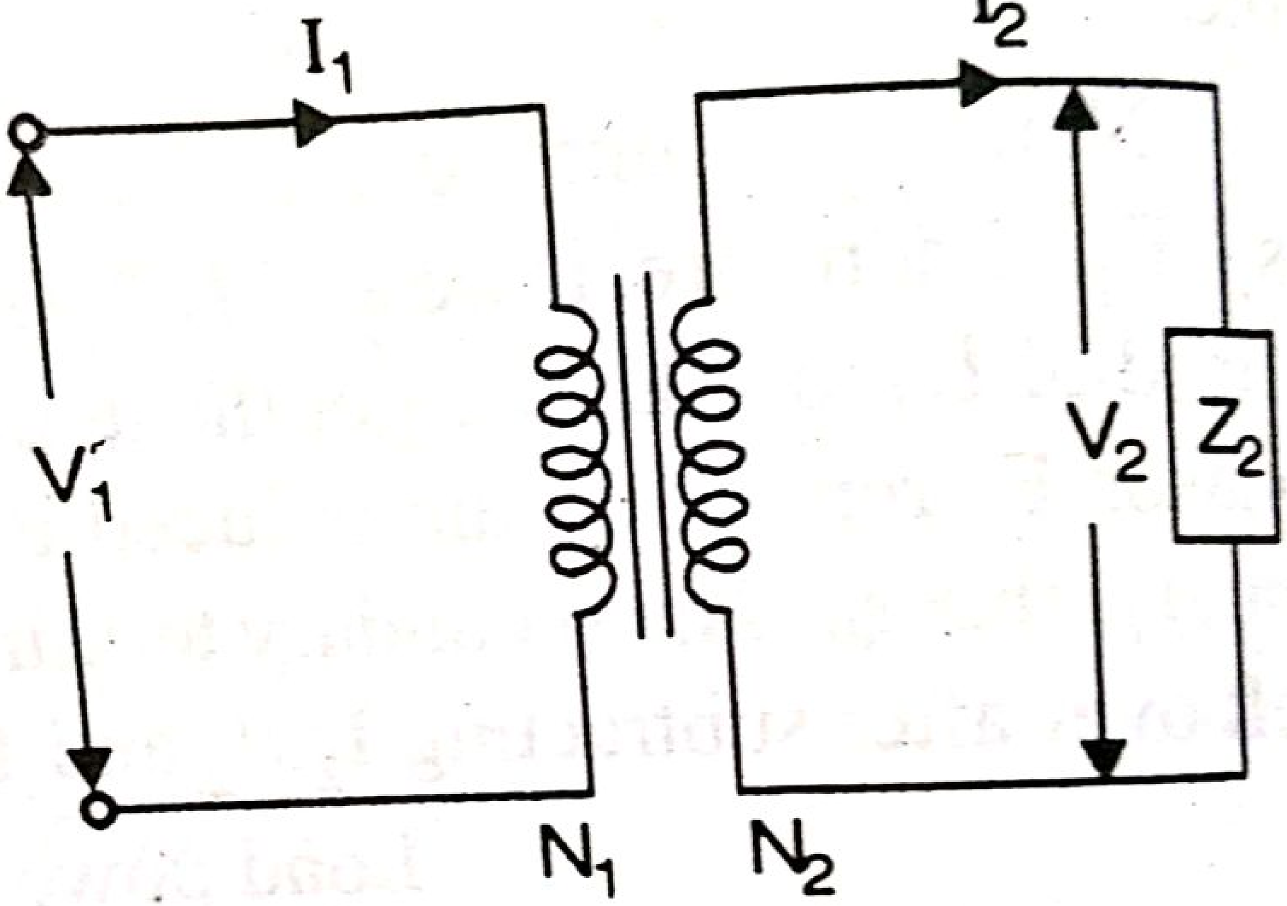


Fig. 8.19

Scanned with CamScanner

SHIFTING IMPEDANCE IN A T.F.

Fig. 8.20

Referred to primary

When secondary resistance or reactance is transferred to primary, it is divided by K^2.

Fig. 8.21

Equivalent resistance of transformer referred to primary

$$R_{01} = R_1 + R_2' = R_1 + \frac{R_2}{K^2}$$

Equivalent reactance of tranformer ref. to primary

$$X_{01} = X_1 + X_2' = X_1 + \frac{X_2}{K^2}$$

Equivalent impedance of T.F ref. to primary

$$Z_{01} = \sqrt{R_{01}^2 + X_{01}^2}$$

Scanned with CamScanner

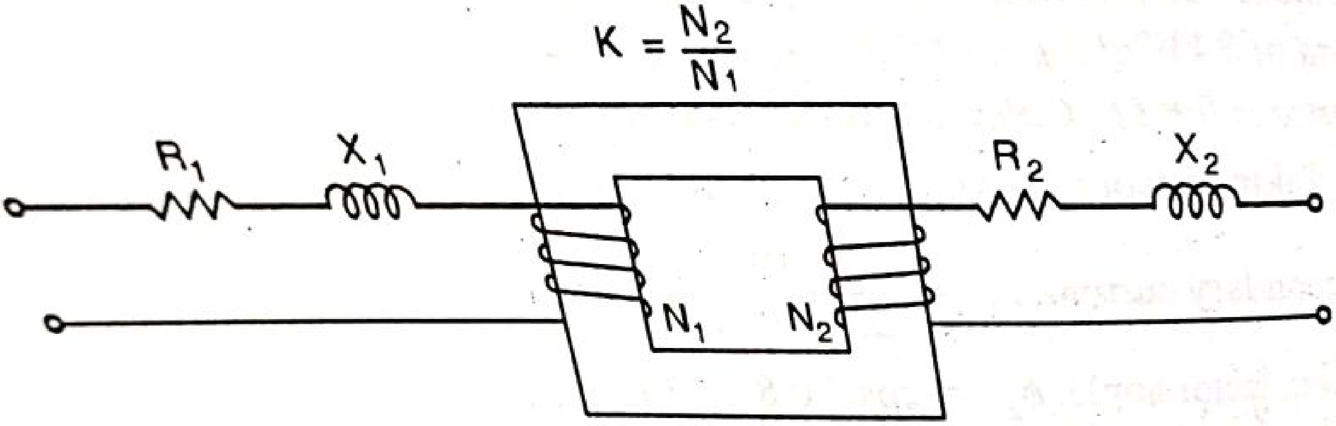


Fig. 8.20

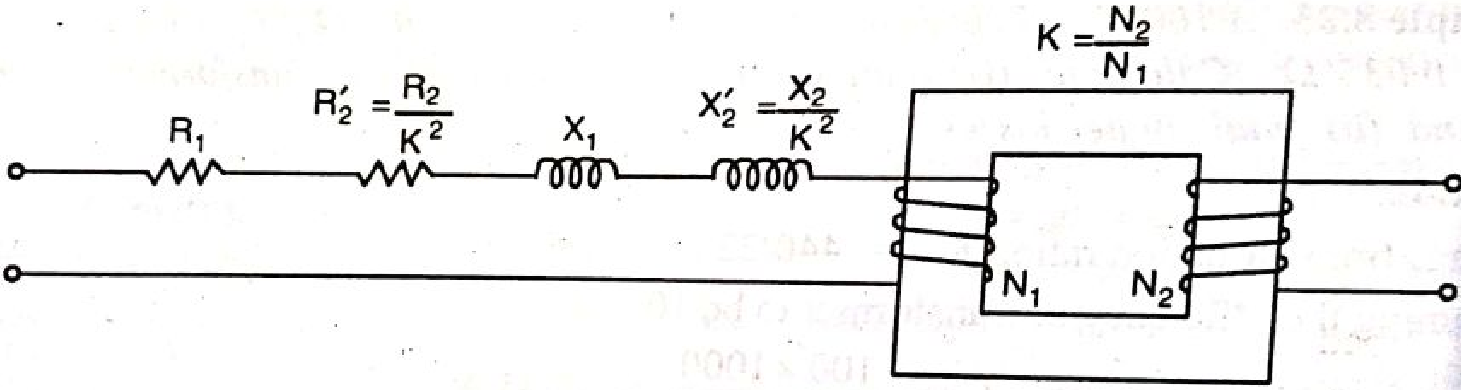


Fig. 8.21

Scanned with CamScanner

Referred to Secondary

When primary resistance or reactance is transferred to secondary, it is multiplied by K^2.

[Fig. 8.22]

Scanned with CamScanner

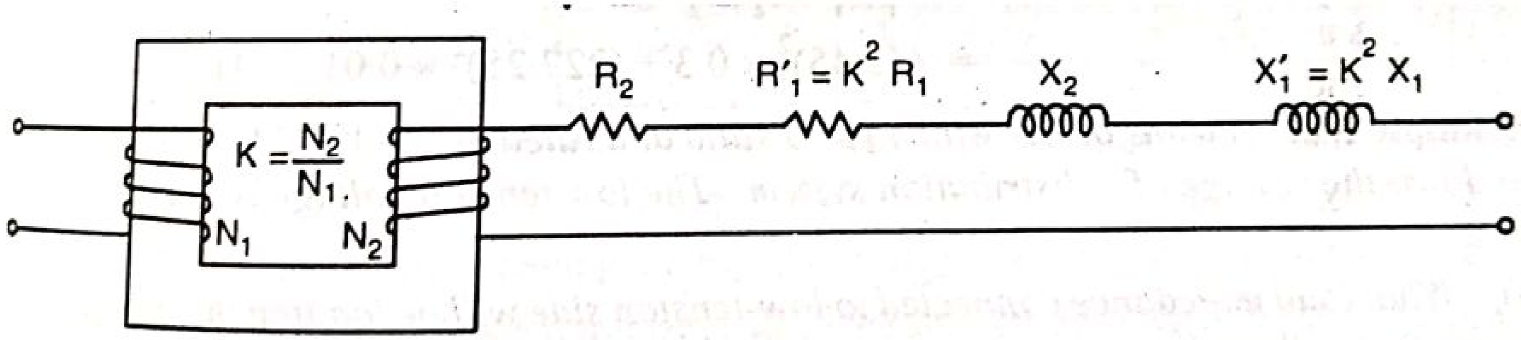


Fig. 8.22

Scanned with CamScanner

Equivalent resistance of T.F ref. to secondary is

$$R_{02} = R_2 + R_1' = R_2 + K^2 R_1$$

Equivalent reactance of T.F ref. to secondary is

$$X_{02} = X_2 + X_1' = X_2 + K^2 X_1$$

Equivalent impedance of T.F ref to secondary is

$$Z_{02} = \sqrt{R_{02}^2 + X_{02}^2}$$

~~Examp. 8.24.~~

EXACT EQUIVALENT CKT OF A LOADED T.F.

$\boxed{\text{fig. 8.28}}$

R_1 = Primary winding resistance.

R_2 = Secondary winding resistance.

X_1 = Leakage reactance of primary.

X_2 = Leakage reactance of secondary.

Scanned with CamScanner

The parallel ckt $R_0 - X_0$ is the no-Load equivalent ckt of the transformer.

R_0, resistance represent core loss so I_w current pass through it.

X_0, reactance represent Loss free coil. so I_m current pass through it.

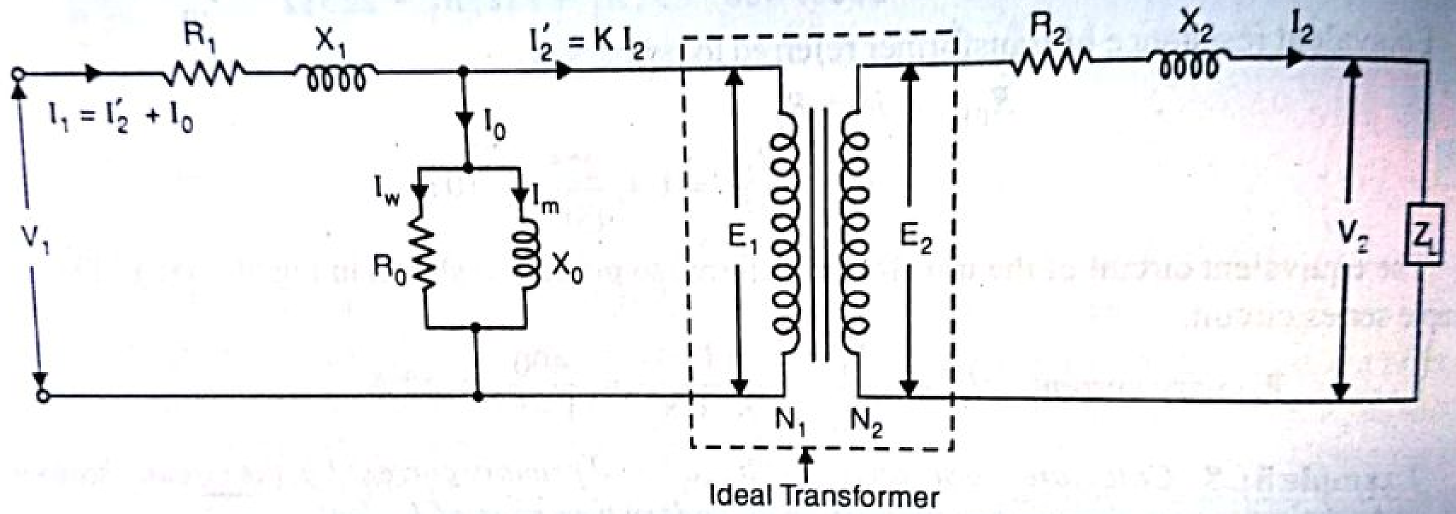
I_0 is the phasor sum of I_w and I_m.

SIMPLIFIED EQUIVALENT CKT OF A LOADED T.F.

No-Load current I_0 of T.F is small compared to rated primary current.
Voltage drop in R_1 & X_1 due to I_0 are neglected

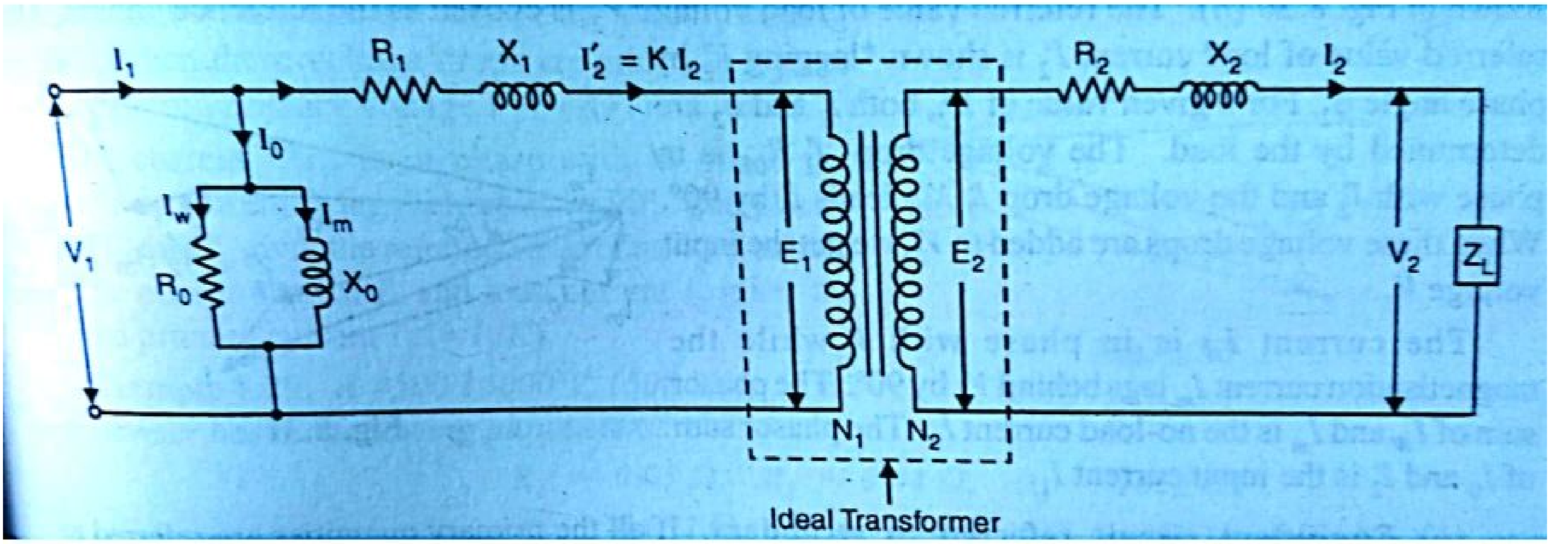
Fig. 8.29

Scanned with CamScanner



R1
X1
I'2 = K I2
R2
X2
I2
I1 = I'2 + I0
I0
Iw
Im
V1
R0
X0
E1
E2
V2
ZL
N1
N2
Ideal Transformer

Fig. 8.28



Scanned with CamScanner

(a) Equivalent ckt ref. to primary.

All secondary quantities are referred to primary

$$R_2' = \frac{R_2}{K^2}, \quad X_2' = \frac{X_2}{K^2}, \quad Z_L' = \frac{Z_L}{K^2}.$$

$$V_2' = \frac{V_2}{K}, \quad I_2' = K I_2.$$

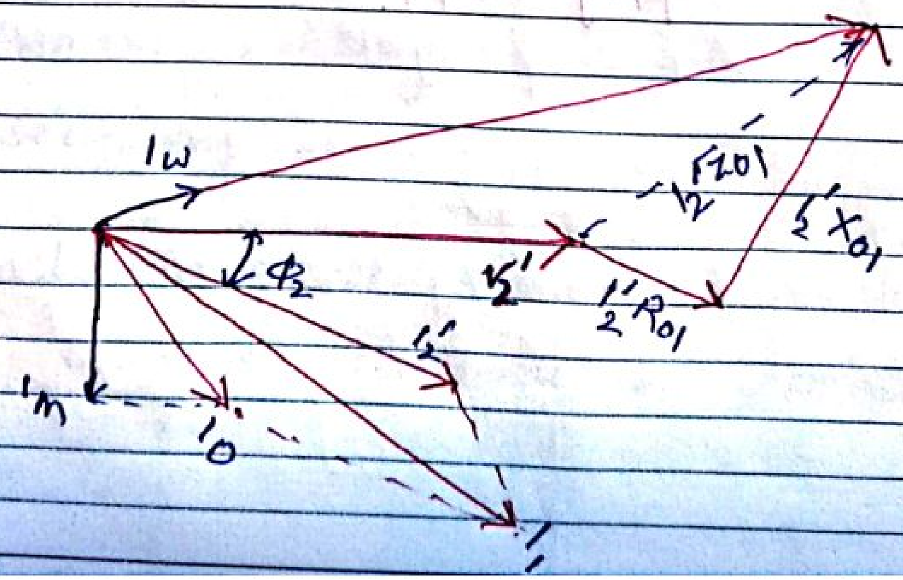
$$R_{01} = R_1 + R_2' \qquad X_{01} = X_1 + X_2'$$

$$|Z_{01}| = \sqrt{R_{01}^2 + X_{01}^2} \qquad \{Z_{01}\} = R_{01} + jX_{01}$$

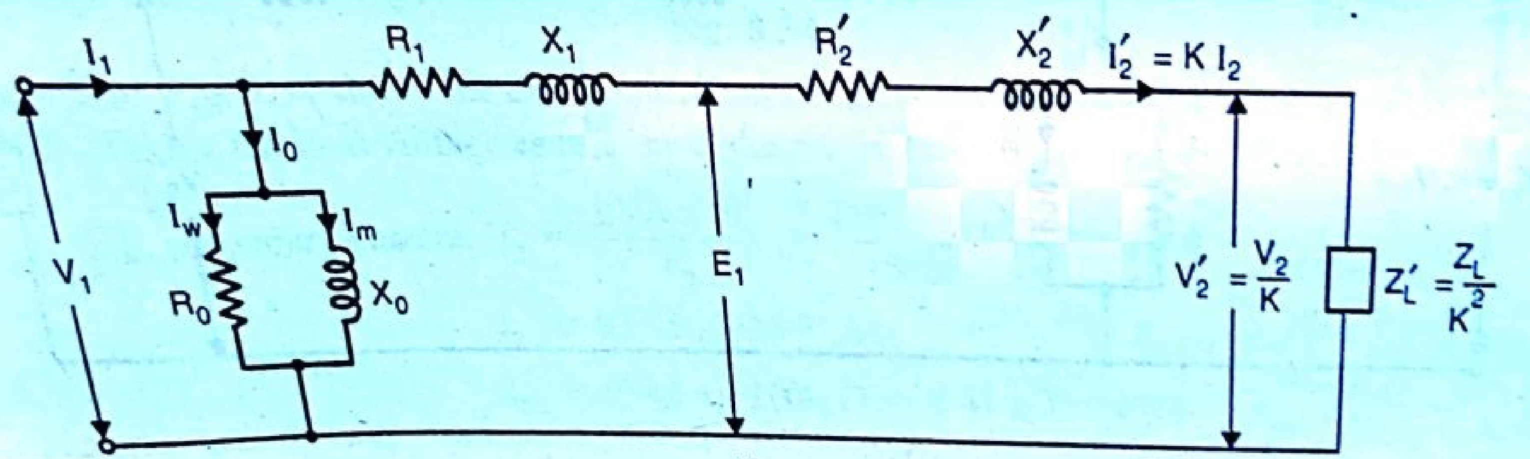
$\boxed{\text{Fig } 8.29\,(i)}$

$\boxed{\text{Fig. } 8.29\,(ii)}$

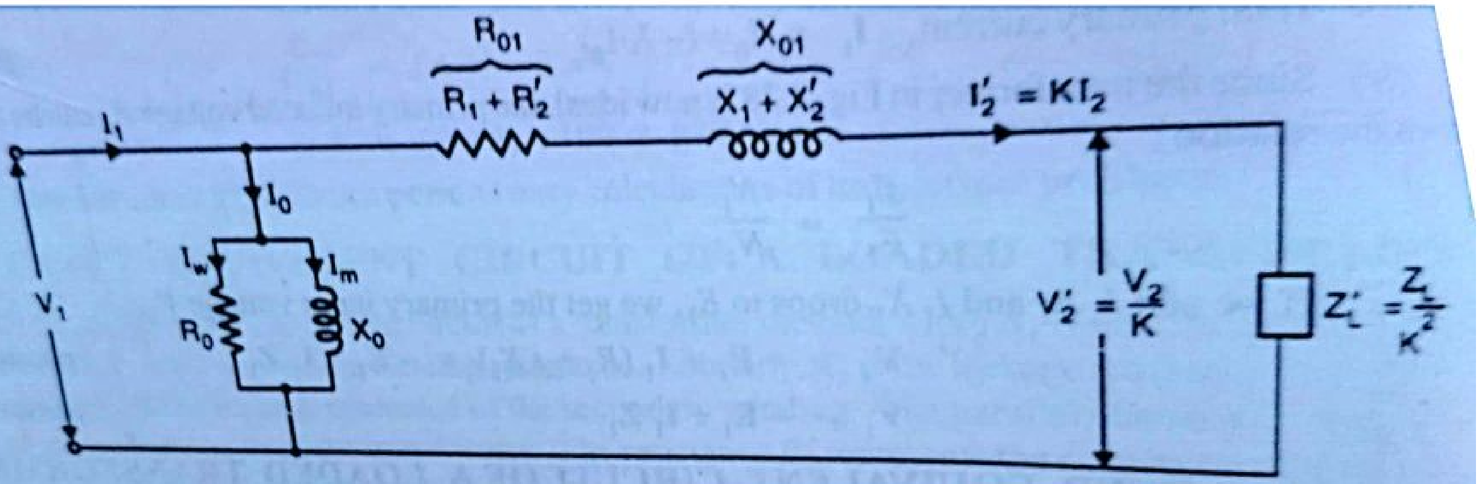
Phasor diagram.



Scanned with CamScanner



(i)



(*ii*)

Fig. 8.30

Scanned with CamScanner

(b) Equivalent ckt referred to secondary.

All primary quantities are referred to secondary.

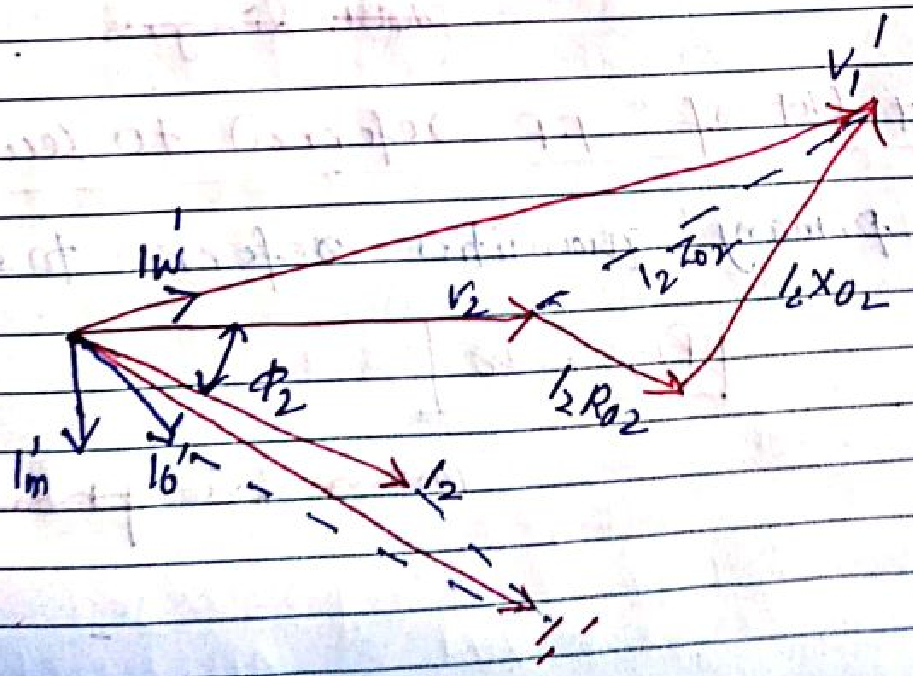
$R_1' = K^2 R_1$, $X_1' = K^2 X_1$, $V_1' = K V_1$, $I_1' = I_1/K$.

$R_{02} = R_2 + R_1'$ | $X_{02} = X_2 + X_1'$

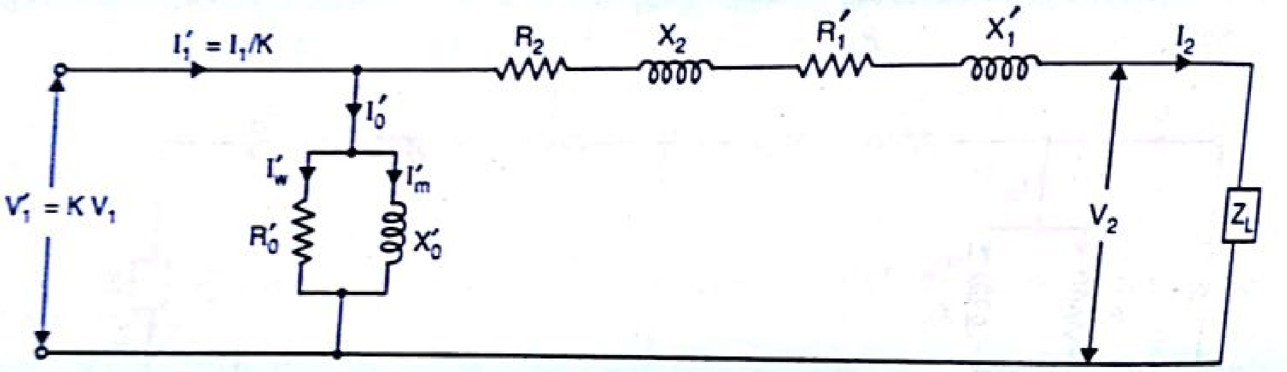
$Z_{02} = R_{02} + j X_{02}$ $|Z_{02}| = \sqrt{R_{02}^2 + X_{02}^2}$

fig. 8.32 (i)
fig. 8.32 (ii)

phasor diagram.

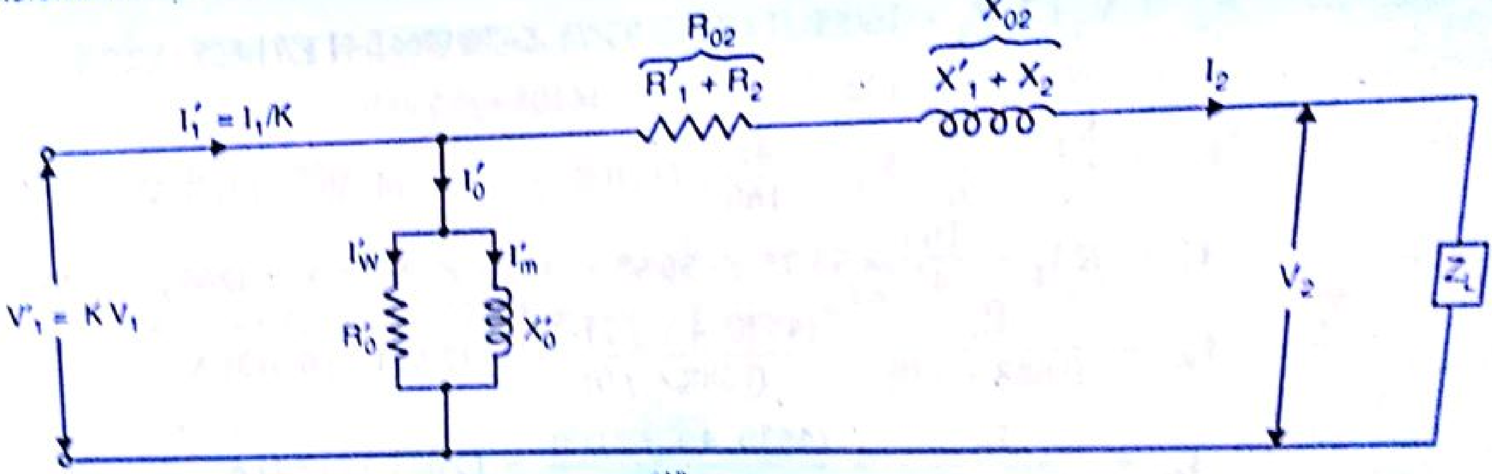


Sunday 24



(i)

Scanned with CamScanner



(*ii*)

Fig. 8.32

Scanned with CamScanner

APPROXIMATE EQUIVALENT CKT OF LOADED T.F.

As no-Load current I_0 in a Transformer is only 1–3% of the rated primary current, it may be neglected.

$\boxed{\text{Fig. 8.36}}$

(a) Equivalent ckt of T.F. referred to primary

All secondary quantities referred to primary.

$\boxed{\text{Fig. 8.37}}$

~~Phasor diagram~~

(b) Equivalent ckt of T.F referred to secondary.

All primary quantities referred to secondary.

$\boxed{\text{Fig. 8.28.}}$

~~Phasor diagram~~

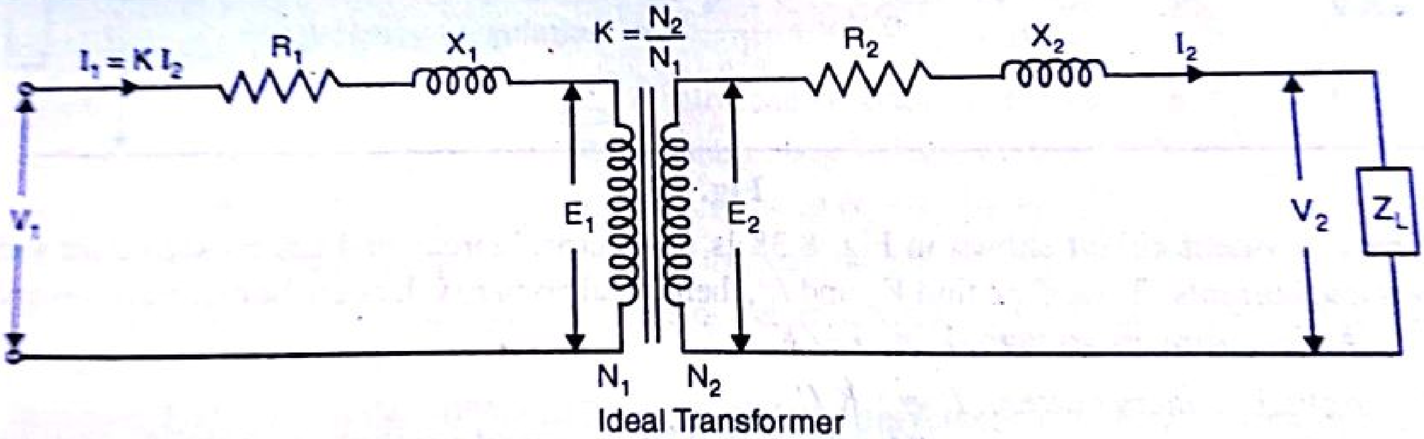


Fig. 8.36

Scanned with CamScanner

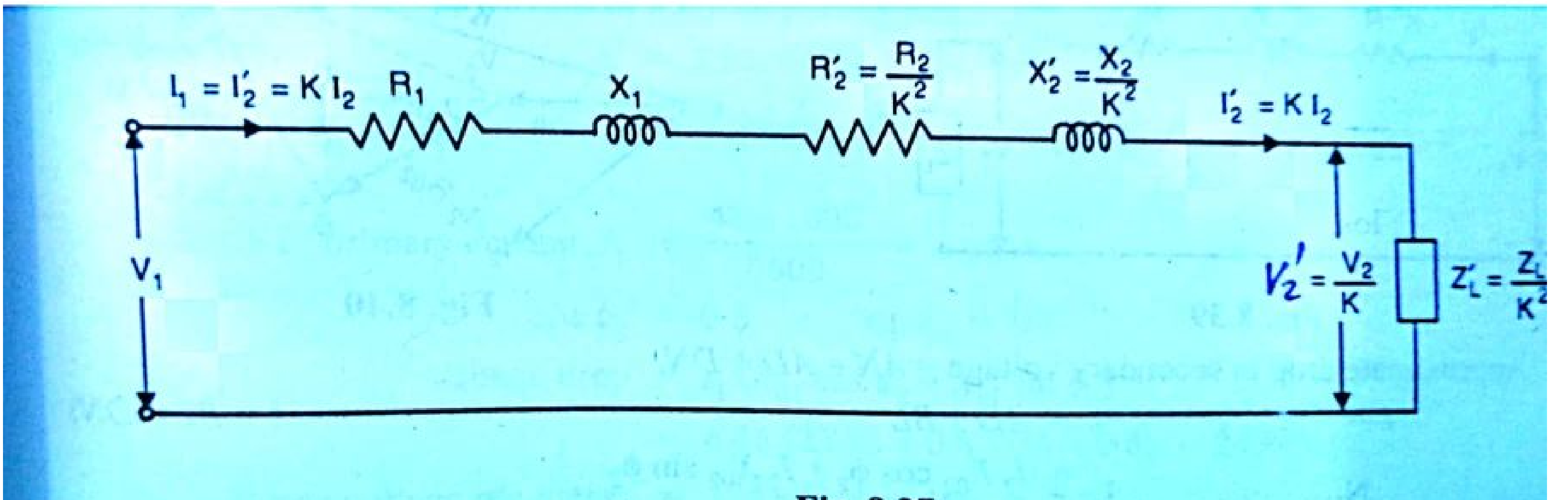


Fig. 8.37

Scanned with CamScanner

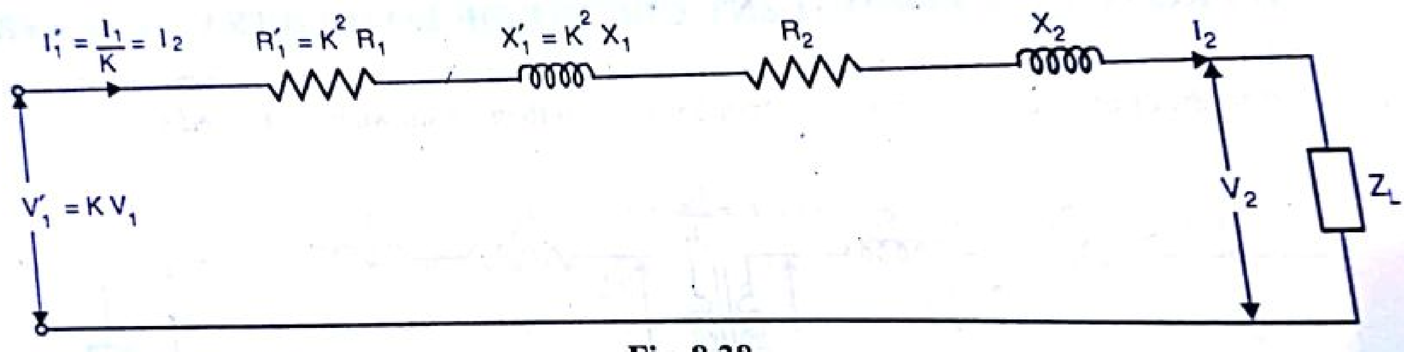


Fig. 8.38

Scanned with CamScanner

Imp

APPROXIMATE VOLTAGE DROP IN A TRANSFORMER

The approximate equivalent ckt of a transformer referred to secondary is shown in fig below, 8.39.

Primary quantities	becomes in secondary
V_1	KV_1
R_1	K^2R_1
X_1	K^2X_1

Voltage drop from KV_1 to V_2.

Let I_2 Lags ϕ_2 to voltage V_2 (Lagging p.f)

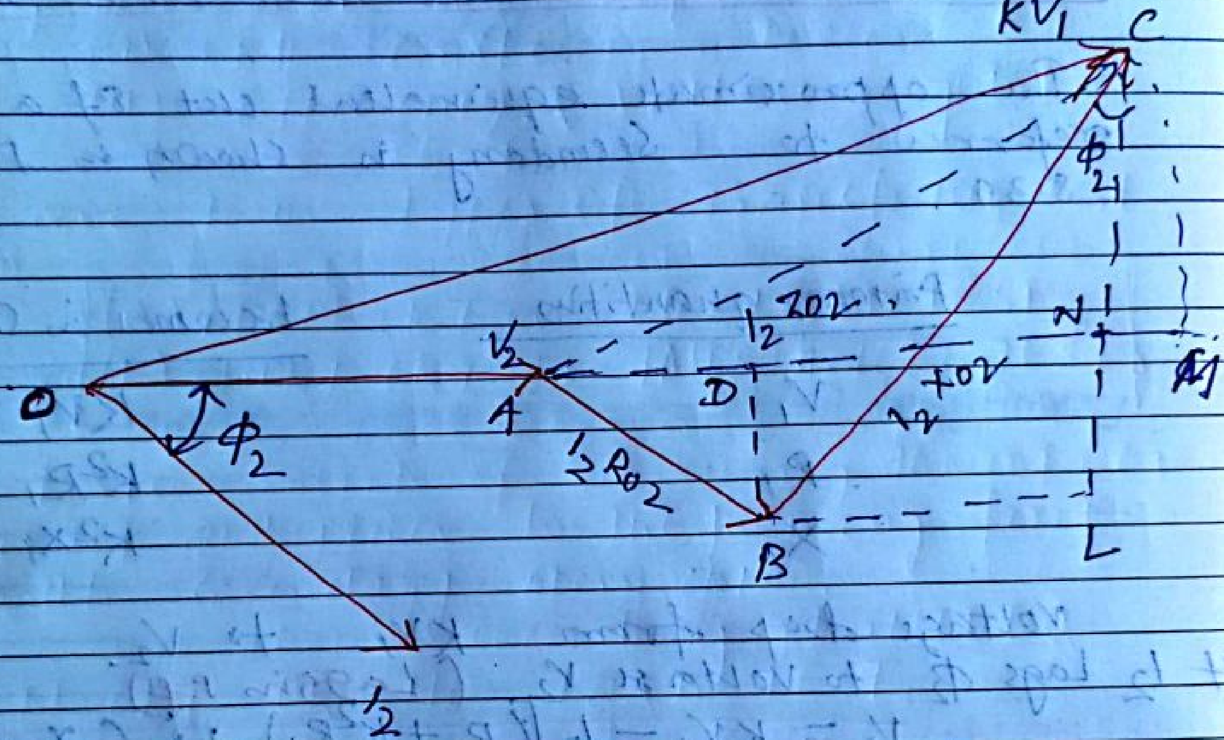
$$V_2 = KV_1 - I_2\left[(R_2+K^2R_1) + j(X_2+K^2X_1)\right]$$

$$= KV_1 - I_2\left[R_{02} + j\,X_{02}\right]$$

$$= KV_1 - I_2 Z_{02}$$

Drop in secondary voltage $= KV_1 - V_2 = I_2 Z_{02}$.

Imp



From phasor diagram, it is clear that $AC = I_2 Z_{02}$.
It is found that O is centre. OC as radius. draw an arc cutting OA produced at M.

So $AC = AM \simeq AN$

$BD \perp OA$ produced, $CN \perp OM$.

$BL \parallel OM$.

Approximate drop in secondary voltage

$= AN = AD + DN$.

$= AD + BL$.

$= I_2 R_{02} \cos\phi_2 + I_2 X_{02} \sin\phi_2$.

Scanned with CamScanner

For a Load of Leading p.f $\cos\phi_2$

$$\boxed{\text{Approximate voltage drop} = I_2 R_{02} \cos\phi_2 - I_2 X_{02} \sin\phi_2}$$

VOLTAGE REGULATION

The voltage regulation of a transformer is the arithmetic difference betw^n the no-load secondary voltage $({}_0V_2)$ and secondary voltage on load (V_2). expressed as % of no-load voltage.

$$\% \text{ Voltage regulation} = \frac{{}_0V_2 - V_2}{{}_0V_2} \times 100.$$

$${}_0V_2 = \text{No-Load Secondary voltage} = KV_1$$

$$V_2 = \text{Secondary voltage on Load}$$

$${}_0V_2 - V_2 = I_2 R_{02} \cos\phi_2 \pm I_2 X_{02} \sin\phi_2$$

+ve sign for lagging p.f.
-ve sign for leading p.f.

$$V_r = \frac{100 \times I_2 R_{02}}{{}_0V_2} = \text{percentage resistive drop.}$$

$$V_x = \frac{100 \times I_2 X_{02}}{{}_0V_2} = \text{percentage reactive drop.}$$

LOSSES IN A TRANSFORMER

The power losses in a transformer are two types
1) Core losses or Iron losses.
2) Copper losses.

1) CORE OR IRON LOSSES: (P_i)

(i) Core or Iron losses consists of hysteresis and eddy current Losses.
(ii) These losses occurs in the transformer core due to alternating flux.

(iii) These losses Can be determined by open-ckt Test.

$$\text{Hystresis losses} = K_h f B_m^{1.6} \ \text{watt}/m^3.$$

$$\text{Eddy current Loss} = K_e f^2 B_m^2 t^2 \ \text{watts}/m^3.$$

Since Transformer operated at const frequency and const supply voltage, f, B_m are const This core or Iron losses is called const loss

Scanned with CamScanner

2) Copper Losses (P_c)

i) These losses occur in both the primary and secondary windings due to their ohmic resistance.

ii) These losses can be determined by short-ckt Test

Total Cu losses, $P_c = I_1^2 R_1 + I_2^2 R_2$.

$= I_1^2 R_{01}$ or $I_2^2 R_{02}$.

Total Losses in a transformer $= P_i + P_c$.

$=$ Const losses $+$ Variable losses.

SEPARATION OF COMPONENTS OF CORE LOSSES.

The core or Iron losses consists of hysteresis and Eddy current losses.

Hysteresis losses, $P_h = K_h f B_m^{1.6}$ watts/m^3.

Eddy Current loss $P_e = K_e f^2 B_m^2 t$ watts/m^3.

B_m = Max. flux density, f = frequency

K_h, K_e = Const.

$P_h \propto f$ and $P_e \propto f^2$

$P_h = af$ $\quad$ $P_e = bf^2$

Scanned with CamScanner

The total losses, $P_i = af + bf^2$

$$\frac{P_i}{f} = a + bf.$$

plotting a graph $\frac{P_i}{f}$ vs f, we can calculate a and b.

by knowing a & b we can found out P_h, P_e

Examp 8.50

WHY TRANSFORMER RATING IN KVA.

We know that Copper loss in a transformer depends upon current and Iron Loss depends upon voltage

Total loss depends upon the Volt-ampere product not the phase angle betw voltage and current, i.e it is independent of Load P.f

For this reason, the rating of a transformer is in KVA and not KW.

Scanned with CamScanner

TRANSFORMER TEST.

Transformer Tests are required to determine.
(i) Ckt consts.
(ii) Efficiency & voltage regulation.

There are two types of Transformer Test.

(a) OPEN CKT or NO-LOAD TEST.
(b) SHORT CKT or IMPEDANCE TEST.

These tests consists of measuring the input voltage, current and power to the primary first with secondary open ckted, and then secondary short ckted.

(a) OPEN CKT OR NO-LOAD TEST.

This test is conducted to determine
(i) Iron losses (core losses)
(ii) Parameter of R_0 and X_0.

In this test rated voltage is applied to primary (L.V. winding) and secondary is open ckted.

Applied Rated voltage V_1 is measured by voltmeter.
No-load current I_0 by ammeter.
No-load input power W_0 by wattmeter.

As normal rated voltage is applied to primary normal iron losses will occur.

As no-load current I_0 is 2–10% of rated current, Cu-losses in primary under no-load condition are neglected.

Wattmeter reading practically gives the iron losses in the transformer.

Iron losses are same at all loads.

Fig. 8.41

Iron losses, P_i = Wattmeter reading $= W_0$

No-load current = Ammeter reading $= I_0$

Applied voltage = Voltmeter reading $= V_1$

Input power $= V_1 I_0 \cos\phi_0$

$$\text{No-load P.f} = \frac{W_0}{V_1 I_0} = \cos\phi_0$$

Sunday 31

$$I_W = I_0 \cos\phi_0 \qquad I_M = I_0 \sin\phi_0$$

$$R_0 = \frac{V_1}{I_W}, \quad X_0 = \frac{V_1}{I_M}$$

Scanned with CamScanner

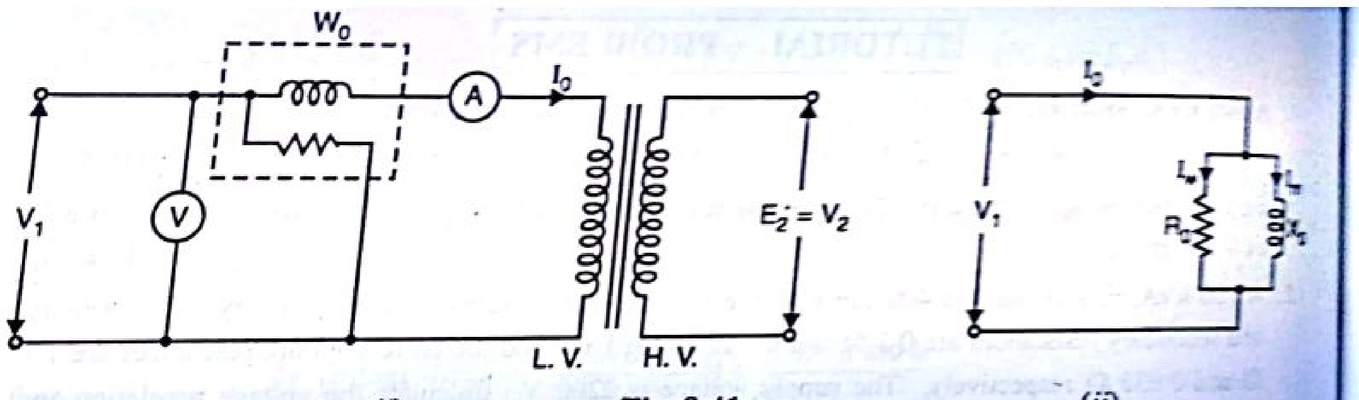


Fig. 8.41

Scanned with CamScanner

SHORT - CIRCUIT OR IMPEDANCE TEST

This test is conducted to determine
(i) R_{01} (or R_{02}), X_{01} (or X_{02}).
(ii) Full-load copper losses.

L.V. side is short ckted.
A voltage is applied to primary ~~till~~ gradually till full load current to short ckt side.

The input power loss is entirely copper losses because iron loss is negligible.

fig 8.42

Wattmeter reading will give the full load copper loss.

Full load copper losses, P_c = Wattmeter reading $= W_s$
Applied voltage = Voltmeter reading $= V_s$.

F.L primary current = Ammeter reading $= I_1$

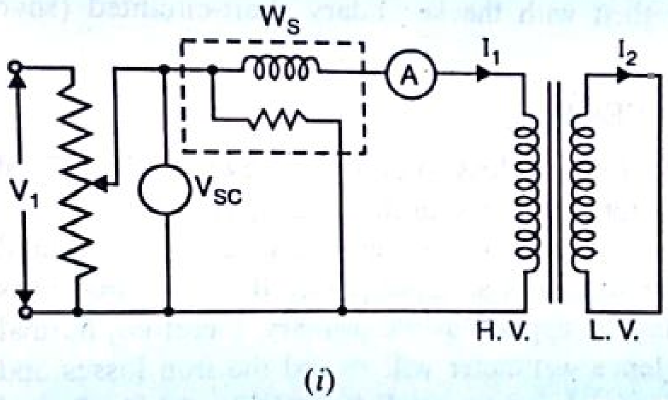
$$P_c = I_1^2 R_1 + I_1^2 R_2' = I_1^2 (R_1 + R_2')$$

$$P_c = I_1^2 R_{01}$$

$$\boxed{R_{01} = \frac{P_c}{I_1^2}}$$

Scanned with CamScanner

Scanned with CamScanner



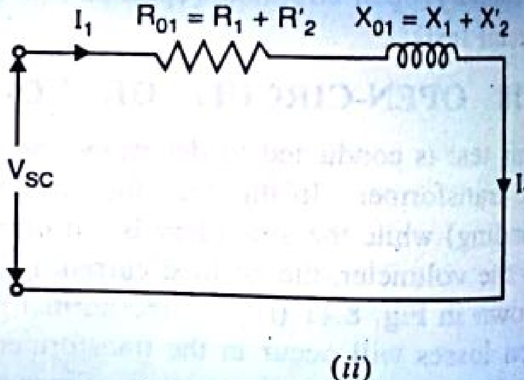


Fig. 8.42

$$Z_{01} = \frac{V_{SC}}{I_1}$$

$$X_{01} = \sqrt{Z_{01}^2 - R_{01}^2}$$

$$\cos\phi_s = \frac{P_c}{V_{SC} I_1}$$

Scanned with CamScanner

EFFICIENCY OF A TRANSFORMER.

Efficiency of a transformer is defined as the ratio of ~~of~~ output power (in watts or KW) to input power (Watts or KW).

~~Efficiency~~ = ~~Output (in watts or kW)~~

$$\text{Efficiency} = \frac{\text{Output power}}{\text{Input power}}$$

$$= \frac{\text{output}}{\text{input} + \text{losses}}.$$

Direct Loading method to determine efficiency has drawback.
So direct Loading method is seldom used in practice, open ckt and short-ckt tests are carried out.

Scanned with CamScanner

EFFICIENCY FROM TRANSFORMER TESTS:

from Open ckt test,

Full Load Iron loss $= P_i$

from Short cut test

Full Load cu. loss $= P_c$.

Total full Load Losses $= P_i + P_c$.

Full-Load efficiency of T.F. at any P.f. without Loading

$$\text{F.L efficiency} = \eta_{F.L} = \frac{\text{Full Load VA} \times \text{P.f}}{(\text{Full Load VA} \times \text{P.f}) + P_i + P_c}$$

Let $x = \dfrac{\text{Any Load}}{\text{Full Load}}$

Any Load $= x \times$ Full Load.

$$\eta_x = \frac{(x \times \text{Full Load VA}) \times \text{P.f}}{(x \times \text{full Load VA} \times \text{P.f}) + P_i + x^2 P_c}$$

Where Total losses $= P_i + x^2 P_c$.

Sunday

Scanned with CamScanner

Scanned with CamScanner

CONDITION FOR MAXIMUM EFFICIENCY

Output power $= V_2 I_2 \cos\phi_2$.

R_{o2} = Total resistance of T.F referred to secondary

Total Cu loss, $P_c = I_2^2 R_{o2}$.

Total losses $= P_i + P_c$

Efficiency $\eta = \dfrac{V_2 I_2 \cos\phi_2}{V_2 I_2 \cos\phi_2 + P_i + I_2^2 R_{o2}}$

Dividing I_2 on both numerator and denominator

$$\eta = \frac{V_2 \cos\phi_2}{V_2 \cos\phi_2 + \frac{P_i}{I_2} + I_2 R_{o2}}.$$

V_2 is approximately const.

$\cos\phi_2$ is const

Numerator is const.

η is max if denominator

$V_2 \cos\phi_2 + \frac{P_i}{I_2} + I_2 R_{o2}$ is minimum

so $\dfrac{d}{dI_2}\left(V_2 \cos\phi_2 + \frac{P_i}{I_2} + I_2 R_{o2}\right) = 0.$

Scanned with CamScanner

$$\frac{d}{dI_2}(V_2\cos\phi_2) + \frac{d}{dI_2}\left(\frac{P_i}{I_2}\right) + \frac{d}{dI_2} I_2 R_{02} = 0$$

$$\Rightarrow 0 - \frac{P_i}{I_2^2} + R_{02} = 0.$$

$$\Rightarrow -P_i + I_2^2 R_{02} = 0.$$

$$\Rightarrow P_i = I_2^2 R_{02}$$

$$\boxed{P_i = P_C}$$

For max. efficiency
Iron losses = copper losses.

Hence efficiency of a transformer will be max. when copper losses are equal to constant/iron losses

$$I_2^2 R_{02} = P_i$$

$$\boxed{I_2 = \sqrt{\frac{P_i}{R_{02}}}}$$

Scanned with CamScanner

WEDNESDAY

OUTPUT KVA CORRESPONDING TO MAX η

Let P_i = Iron losses.

P_C = copper losses at full load KVA.

x = Fraction of full load KVA at which efficiency is max

$x^2 P_c = P_i$ for max. efficiency

$$x = \sqrt{\frac{P_i}{P_C}} = \sqrt{\frac{\text{Iron loss}}{\text{Full load Cu loss}}}$$

Output KVA corresponding to max. efficiency

$= x \times$ Full Load KVA

$= \text{Full Load KVA} \times \sqrt{\frac{\text{Iron loss}}{\text{F.L Cu loss}}}$

ALL-DAY (OR ENERGY) EFFICIENCY

The ordinary or Commercial efficiency of T.F.

$$\text{Commercial efficiency} = \frac{\text{Output power}}{\text{Input power}}$$

But Transformer performance can't be judged by this efficiency.

For distribution Transformer used for supplying lighting loads.

Their primaries energised all the 24-hours a day. But the secondary supply little or no-load during major portion of the day.

That is const loss occur whole day. But copper losses occur when T.F is loaded.

The performance of such Transformer is judged on the basis of energy consumption during whole day (24-hours)

$$\boxed{\eta_{\text{all-day}} = \frac{\text{KWh output in 24 hours}}{\text{KWh input in 24 hours}}}$$

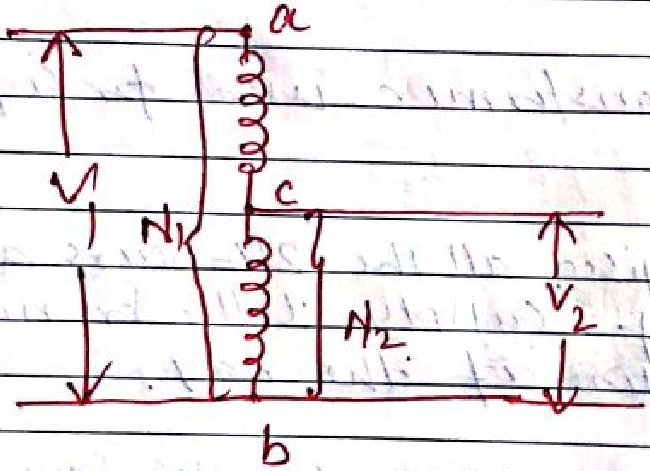
Scanned with CamScanner

Scanned with CamScanner

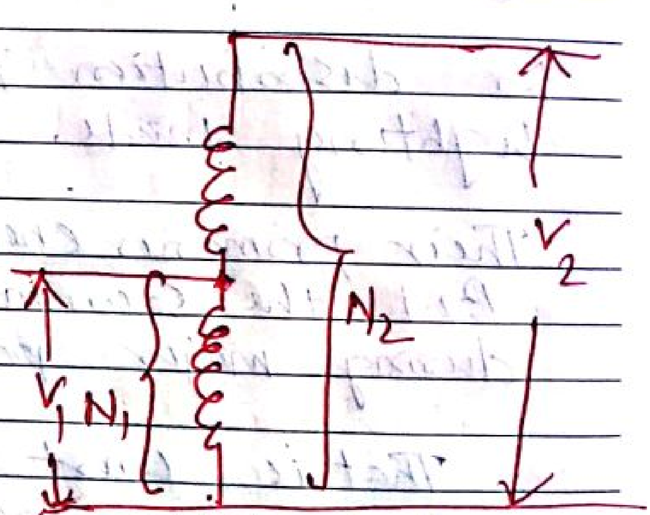
AUTOTRANSFORMER.

1) An autotransformer has a single winding on an iron core

2) A part of winding is common to both primary and secondary circuits.



Step-down Transformer
Fig(I)



Step-up Transformer.
Fig(II)

In both cases the winding ab having N_1 turns is primary winding.

Winding bc having N_2 turns in secondary windings.

Primary and secondary windings are connected electrically as well as magnetically.

Scanned with CamScanner

Therefore, Power from the primary is transferred to the Secondary conductively as well as inductively (transformer action).

$I_1 \rightarrow$ Input Current
$I_2 \rightarrow$ Output or Load current.

The difference in current $I_1 - I_2$ or $I_2 - I_1$ will flow the portion common to both primary and secondary.

In step down ~~Tran~~ Auto Transformer.

$I_2 > I_1$

$I_2 - I_1$ will flow the common portion

fig. 8.52

In step up Auto Transformer.

$I_1 > I_2$

$I_1 - I_2$ will flow the Common portion

fig 8.52

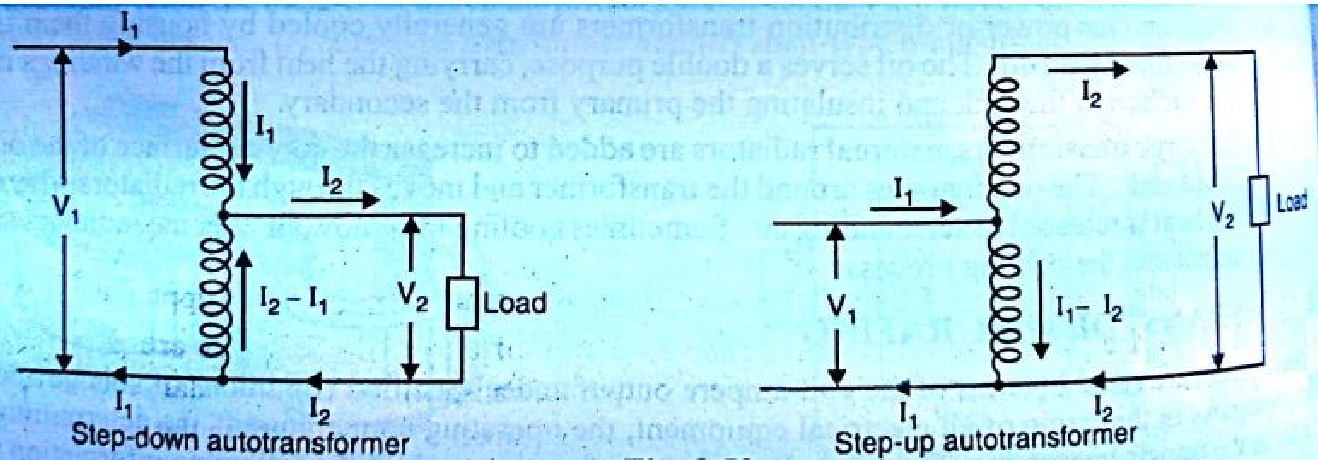


Fig. 8.52

Scanned with CamScanner

THEORY (WORKING PRINCIPLE) OF AUTOTRANSFER

Fig Below shows an ideal step-down Autotransfor on-load.

Winding 1-3 having N_1 turns is the primary winding.

Winding 2-3 having N_2 turns is the secondary winding.

Input current I_1

Output load current I_2 $\quad I_2 > I_1$ ($\because$ step down A.T)

Winding 1-2 having $N_1 - N_2$ turns and voltage $V_1 - V_2$.

Current through the common winding $I_2 - I_1$

fig 8.53

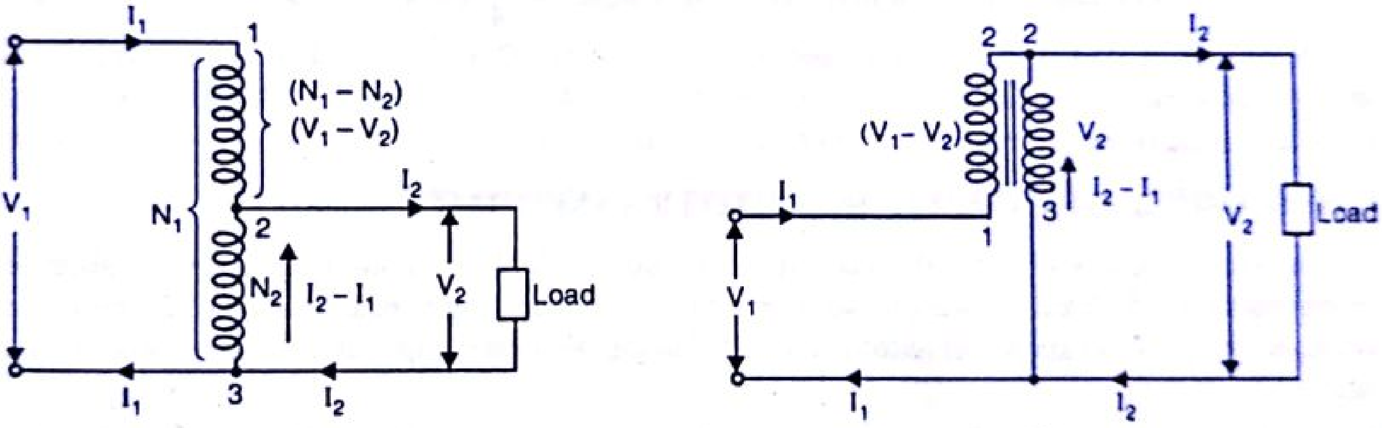
$$\frac{V_2}{V_1 - V_2} = \frac{N_2}{N_1 - N_2}$$

$$\Rightarrow V_2(N_1 - N_2) = N_2(V_1 - V_2)$$

$$\Rightarrow V_2N_1 - V_2N_2 = V_1N_2 - V_2N_2$$

$$\Rightarrow V_2N_1 = V_1N_2$$

$$\Rightarrow \frac{V_2}{V_1} = \frac{N_2}{N_1} = K.$$



(i) **Fig. 8.53** *(ii)*

Scanned with CamScanner

Also $(V_1 - V_2) I_1 = (I_2 - I_1) V_2$.

$\Rightarrow V_1 I_1 - V_2 I_1 = V_2 I_2 - V_2 I_1$

$\Rightarrow V_1 I_1 = V_2 I_2$

$\Rightarrow \frac{V_2}{V_1} = \frac{I_1}{I_2}$

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

$$V_1 I_1 = V_2 I_2$$

Input apparent power = Output apparent power

power is transferred from primary to secondary both inductively and conductively.

App. power transferred inductively $= V_2 (I_2 - I_1)$

$= V_2 (I_2 - K I_2)$

$= V_2 I_2 (1 - K) = V_1 I_1 (1 - K)$

$\boxed{\text{power transferred inductively} = \text{Input power} \times (1 - K)}$

power transferred conductively = Input − Power transferred inductively

$= \text{Input power} - \text{Input power}(1 - K)$

$= \text{Input}(1 - 1 + K)$

$= K \times \text{input power}.$

Power transferred conductively $= K \times$ Input power.

Scanned with CamScanner

COMPARISON OF AUTO TRANSFORMER WITH AN TWO WINDING TRANSFORMER

SAVING OF COPPER

Consider a two winding Transformer and an auto transformer having same $K = \frac{N_2}{N_1}$.

Fig 8.54 (i) & (ii)

The length of copper is proportional to number of turns.
Area of ~~cross~~ cross section of winding proportional to current rating.

$$l \propto N \quad , \quad A \propto i$$

$LA \propto V$ (volume) Volume hence Weight.

Weight of cu required in a winding $\propto$ Current × turns.

2 - Winding transformer.

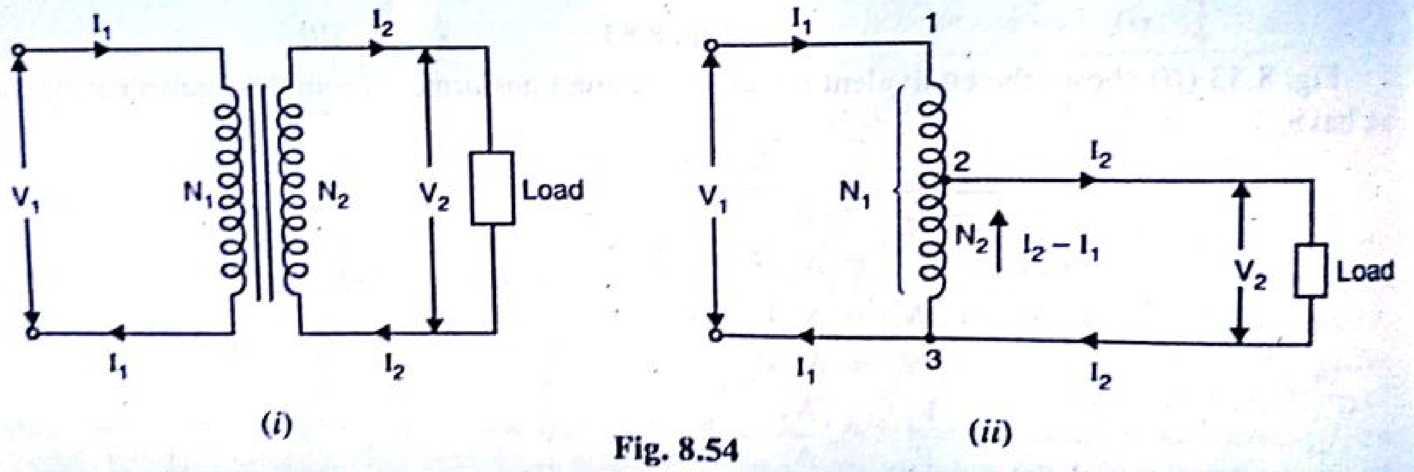
Weight of copper required $\propto (I_1 N_1 + I_2 N_2)$.

Auto - Transformer.

Weight of copper required in section 1-2 $\propto I_1 (N_1 - N_2)$

Weight of copper required in Section 2-3 $\propto (I_2 - I_1) N_2$.

Scanned with CamScanner



I1
I2
V1
N1
N2
V2
Load
I1
I2
(i)
I1
1
N1
2
I2
V1
N2
I2 – I1
V2
Load
I1
3
I2
(ii)

Fig. 8.54

∴ Total weight of copper required $\propto I_1(N_1-N_2)+(I_2-I_1)N_2$.

$$\frac{\text{Weight of Cu. in auto transformer}}{\text{Weight of Cu. in ordinary transf.}} = \frac{I_1(N_1-N_2)+(I_2-I_1)N_2}{I_1N_1+I_2N_2}$$

$$= \frac{I_1N_1 - I_1N_2 + I_2N_2 - I_1N_2}{I_1N_1 + I_2N_2}$$

$$= \frac{I_1N_1 + I_2N_2 - 2I_1N_2}{I_1N_1 + I_2N_2}$$

$$= \frac{(I_1N_1 + I_2N_2)}{(I_1N_1 + I_2N_2)} - \frac{2I_1N_2}{I_1N_1 + I_2N_2}$$

$$= 1 - \frac{2I_1N_2}{2N_1I_1} \quad (\because N_1I_1 = N_2I_2)$$

$$= 1 - \frac{N_2}{N_1}$$

$$\boxed{\frac{\text{Wt. of Cu. in autotransf.}(W_a)}{\text{Wt. of Cu. in ordinary tr.}(W_o)} = 1-K.}$$

Wt. of Cu. in autotransformer $(W_a) = (1-K)$ Wt. of Cu. in ordi. tr. (W_o)

$$W_a = (1-K)W_o$$

Saving of Cu. $= W_o - W_a = W_o - (1-K)W_o$

$= KW_o$

Saving of copper $= K \times$ Wt. of copper in ordinary tr.

Scanned with CamScanner

Scanned with CamScanner

APPLICATION OF AUTOTRANSFORMER

1) Autotransformers are used to compensate for voltage drops in transmission and distribution lines. When used for this purpose, they are known as booster transformers.

2) Autotransformers are used for reducing the voltage supplied to a.c motors during the starting period.

3) Autotransformers are used for continuously variable supply.

Scanned with CamScanner

TAP CHANGER

A tap changer is a mechanism in transformers which allows for variable turn ratios to be selected in distinct steps.

This is done by connecting to a number of access points known as taps along either the primary or secondary winding.

Tap changers exist primary two types.

(a) no-Load tap changer (NLTC)

(b) On-Load tap changer (OLTC)

NO-Load tap changer.

(i) NO-Load tap changer (NLTC) is also called as Off-circuit tap changer (OCTC) or De-energized tap charegpr (DETC).

(ii) In this situation transformer turn ratio doesn't require frequent changing.

(iii) Permissible to de-energize the transformer before tap changing.

(iv) This type of transformer is frequently employed in Low power, Low voltage transformer.

(v) No-Load tap changer also employed in high voltage distribution type transformer.

Scanned with CamScanner

On- Load tap changer.

(i) On- Load tap changer (OLTC) also known as On- Circuit tap Changer (OCTC)

(ii) This type tap changer used where a supply interruption during a tap changer is unacceptable

(iii) This mechanism is more expensive and Complex.

(iv) On-Load tap changers may be classified as (a) mechanical, electronically assisted.
(b) Fully electronic.

Scanned with CamScanner

INSTRUMENT TRANSFORMER.

CURRENT TRANSFORMER (C.T)

(i) A current transformer is used to measure high alternating current in a power system.

(ii) The primary of this transformer has a few turns of thick wire where as the secondary has many turn of fine wire.

(iii) Current transformer is a well designed step-up transformer.
Since voltage is stepped up, the current is stepped down which can be measured with a low range a.c. ammeter.

The primary of current transformer is connected in series with the line whose current is to be measured.

The secondary of transformer is connected across a low range (0-5) a.c. ammeter

We know that

$$N_p I_p = N_s I_s$$

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

~~CURRENT TRANSF~~

The primary to secondary current ratio $\left(\frac{I_p}{I_s}\right)$ is called C.T. ratio (Current Transformation ratio)

$$\frac{I_p}{I_s} = \text{C.T. ratio}$$

$$I_p = I_s \times \text{C.T. ratio}.$$

Line current (I_p) = A.C ammeter reading × C.T. ratio

If a.c. ammeter reading is 1A.

C.T. ratio 1000.

Line current $(I_p) = 1A \times 1000 = 1000A$.

Fig. 8.81, 8.82.

Relationships in a Current Transformer (C.T)

n = turns ratio = $\dfrac{\text{number of secondary winding turns}}{\text{number of primary winding turns}}$

r_s = resistance of secondary winding

x_s = reactance of secondary winding.

r_e = resistance of external burden.

x_e = reactance of external burden.

E_p = primary winding induced voltage

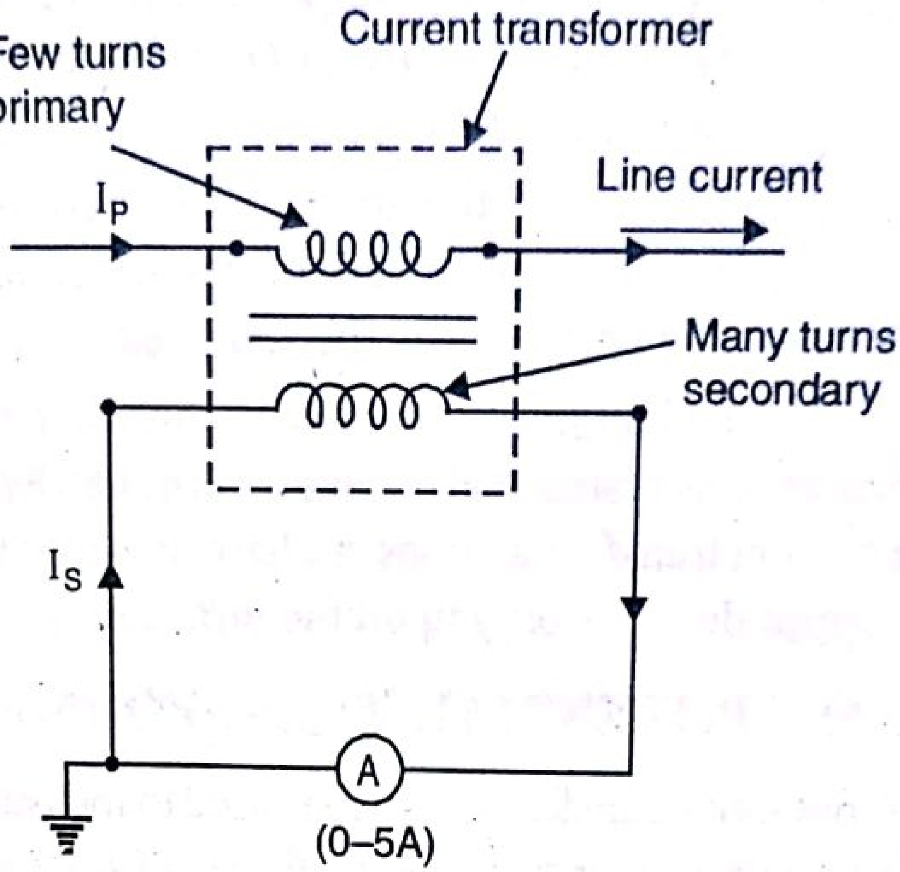
E_s = secondary winding induced voltage.

N_p = Number of primary turns

N_s = Number of secondary turns.

Scanned with CamScanner

r is
s to
y of
nge
a.c.



$_P/I_S)$

Fig. 8.81

C.T. ratio

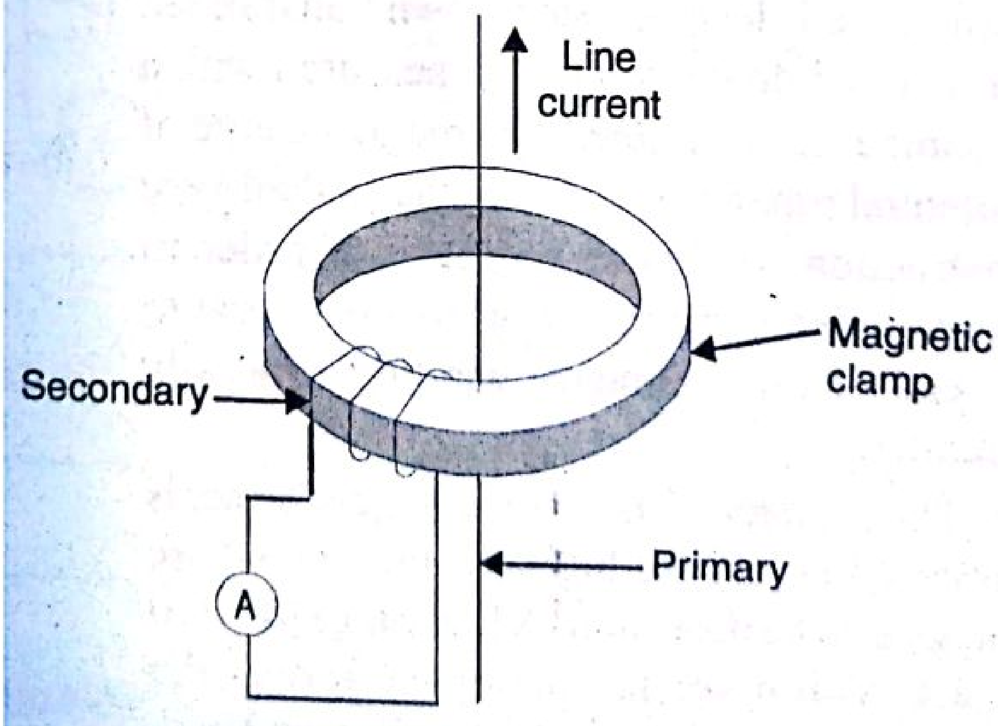


Fig. 8.82

Scanned with CamScanner

V_s = voltage at the secondary winding terminals.

I_s = secondary winding current.

I_p = primary winding current.

θ = phase angle of transformer.

ϕ = working flux of the transformer.

δ = Angle betwⁿ E_s & I_p. $= \tan^{-1}\left(\frac{x_s + x_e}{r_s + r_e}\right)$ - Total Burden

Δ = Angle betwⁿ V_s & I_s = External burden $= \tan^{-1}\left(\frac{x_e}{x_e}\right)$

I_0 = exciting current.
I_m = magnetising component of I_0.
I_w = Loss component of exciting current.

α = Angle betwⁿ I_0 & ϕ.

Fig. 10.4, Fig. 10.5

TRANSFORMATION ~~ERROR~~ RATIO: (K)

$$K = n + \frac{I_0}{I_s}(\sin\delta . \cos\alpha + \cos\delta \sin\alpha)$$

$$\simeq n + \left(\frac{I_m \sin\delta + I_w \cos\delta}{I_s}\right).$$

$I_m = I_0 \cos\alpha$, $I_w = I_0 \sin\alpha$.

Scanned with CamScanner

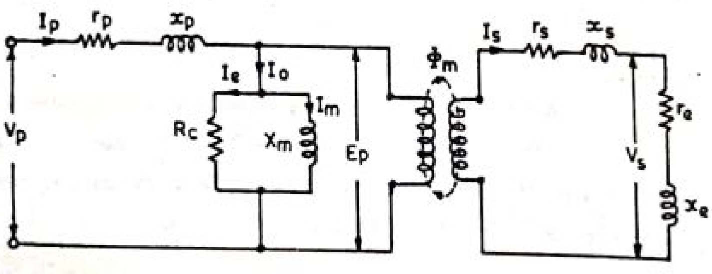


Fig. 10.4. Equivalent circuit of a C.T.

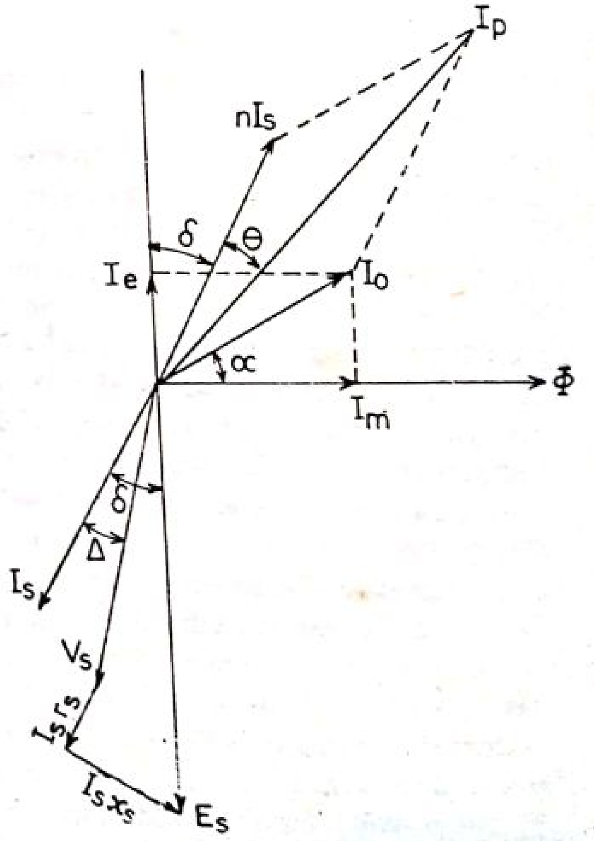


Fig. 10.5. Phasor diagram of a C.T.

PHASE ANGLE:

The angle by which the secondary current phasor, when reversed, differs in phase from the primary current, is known as phase angle of the Transformer.

The angle betw I_s reversed and I_p is θ.

$$\tan\theta = \frac{bc}{ob} = \frac{bc}{oa+ab}$$

$$\theta \simeq \frac{180}{\pi}\left(\frac{I_m \cos\delta - I_e \sin\delta}{nI_s}\right) \text{degree.}$$

RATIO ERROR

Ratio Error is defined as.

$$\text{percentage ratio error} = \frac{\text{nominal ratio} - \text{actual ratio}}{\text{actual ratio}} \times 100$$

$$= \frac{K_n - K}{K} \times 100.$$

PHASE ANGLE ERROR

Phase angle error

$$\theta = \frac{180}{\pi}\left(\frac{I_m \cos\delta - I_w \sin\delta}{nI_s}\right) \text{degree}$$

Phase of Secondary winding current shall be displaced by exactly 180^0 from that of primary winding current.

But, for power measurement in instrument transformer, phase difference is different form 180° by an angle θ.

BURDEN:-

The Secondary Load of a current transformer is termed the "burden" to distinguish it from the primary load.

The burden in a C.T. metering electrical network is largely resistive impedance presented to its secondary winding.

POTENTIAL TRANSFORMER (P.T.)

(i) A potential transformer is used to measure high alternating potential difference (voltage) in a power system.

(ii) The primary has many turns while the secondary has few turns.

(iii) Potential Transformer is a well designed step-down transformer.

(iv) The step down voltage is measured with a low range a.c. voltmeter.

Scanned with CamScanner

Fig. 8.23.

The primary of the potential transformer is connected across the high voltage line whose voltage is to be measured.

A low range (0–100) a.c. voltmeter is connected across the secondary.

$$\frac{V_p}{V_s} = \frac{N_p}{N_s}$$

$\frac{V_p}{V_s}$ = Potential transformation ratio.

$$V_p = V_s \times \text{P.T. ratio}$$

Line voltage (V_p) = A.C. voltmeter reading × P.T. ratio

If a.c. voltmeter reading is 50 V.
P.T. ratio is 100 : 1
Then line voltage = 50 × 100 = 5000 V = 5 kV.

Fig. 10.20, 10.21.

Actual transformation ratio (voltage)

$$= K = \frac{V_p}{V_s} = n + \frac{n I_s (R_p \cos\Delta + X_p \sin\Delta) [illegible]}{V_s}$$

phase angle $\theta = \frac{I_s}{V_s}(X_p \cos\Delta - R_p \sin\Delta) + \frac{[illegible]}{n V_s}$

R (P.T.)

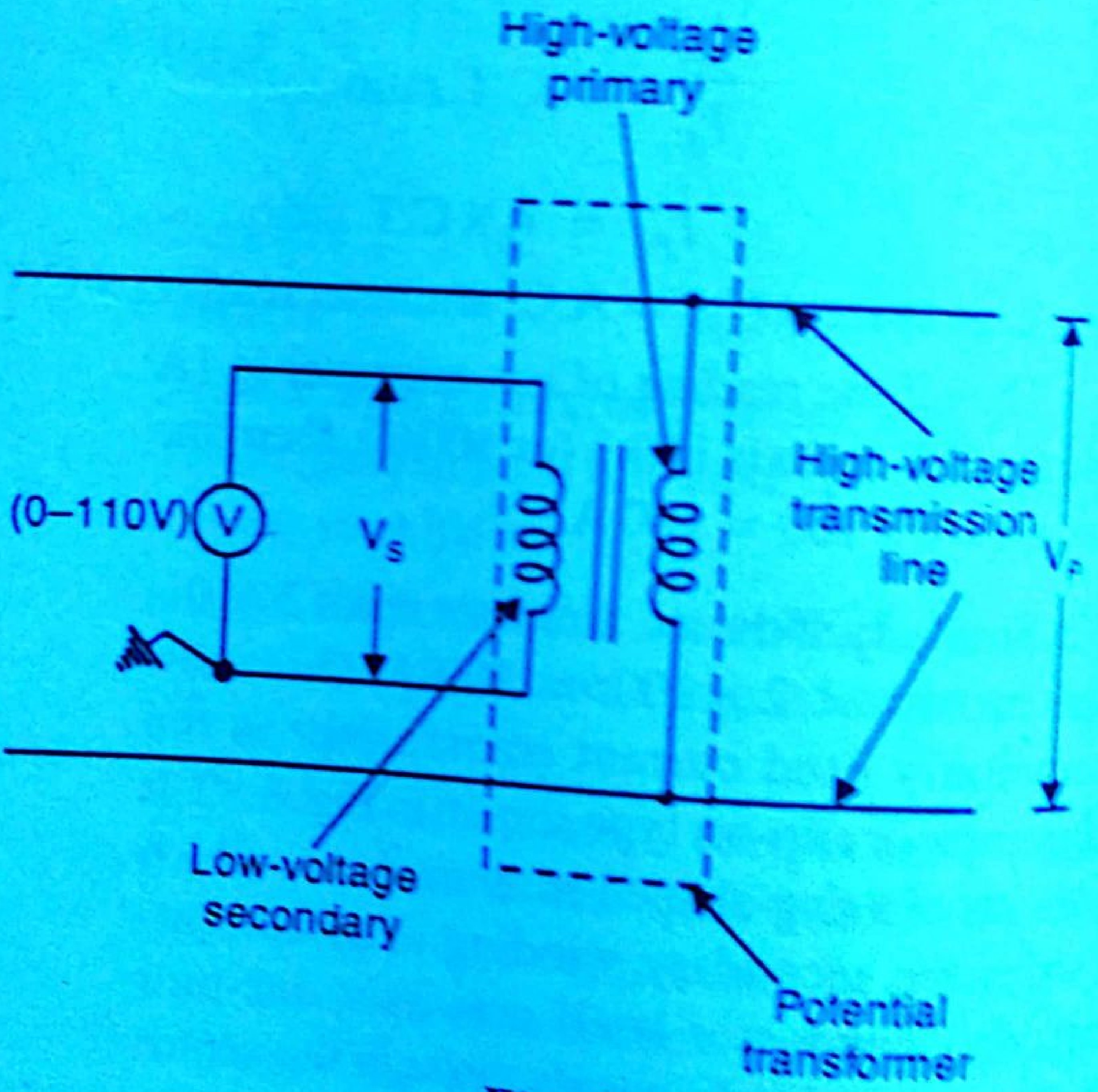

High-voltage
primary
(0–110V)
V
V_s
High-voltage
transmission
line
V_P
Low-voltage
secondary
Potential
transformer

Fig. 8.83

transformer.

Φ = working flux,

I_m = magnetizing component of no load (exciting) current,

I_e = iron loss component of no load (exciting) current,

I_0 = no load (exciting) current,

E_s = secondary winding induced voltage,

V_s = secondary winding terminal voltage,

N_p = primary winding turns

N_s = secondary winding turns,

I_s = secondary winding current,

r_s = resistance of secondary winding,

x_s = reactance of secondary winding,

r_e = resistance of secondary load circuit,

x_e = reactance of secondary load circuit

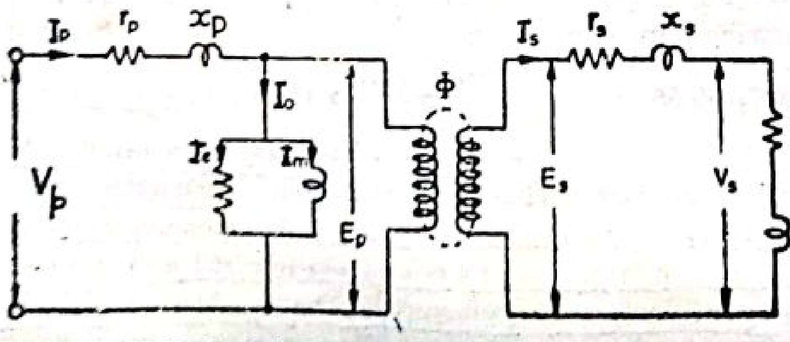


Fig. 10.20. Equivalent circuit of a potential transformer.

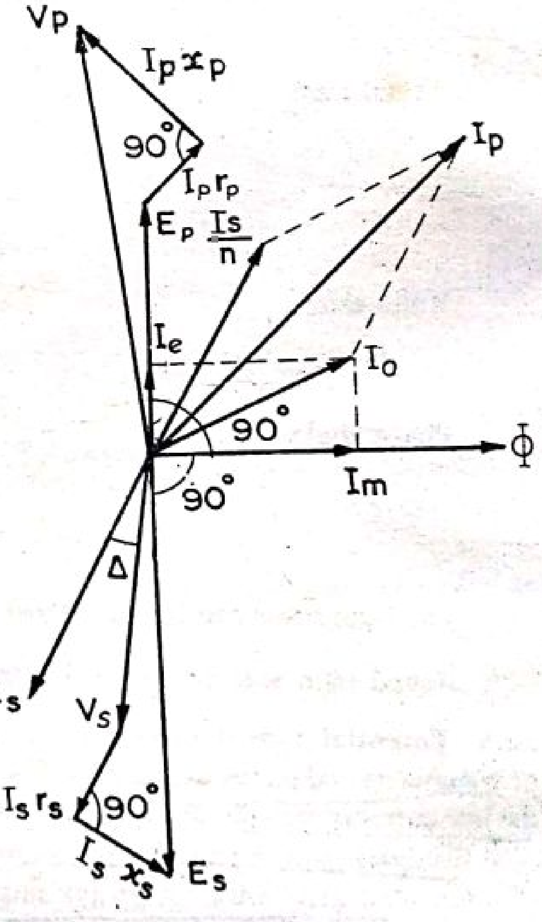


Fig. 10.21. Phasor diagram of a potential transformer.

Δ = phase angle of secondary load circuit

RATIO (VOLTAGE) ERROR.

Percentage ratio error = $\frac{K_n - K}{K} \times 100$.

PHASE ANGLE ERROR.

In an ideal voltage transformer there shouldn't be any phase difference between primary winding voltage and secondary winding voltage reversed. However, in an actual transformer there exist a phase difference between V_p and V_s reversed.

phase angle $\cdot$ $\theta = \dfrac{\frac{I_s}{n}(X_p \cos\Delta - R_p \sin\Delta) + I_e X_p - I_m r_p}{n V_s}$ rad.

BURDEN:-

The burden is the total external volt-amp Load on the secondary at rated secondary voltage.

Scanned with CamScanner