DC Generator

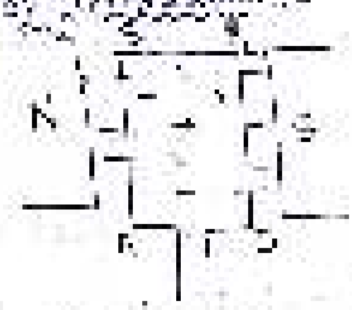
Definition:-

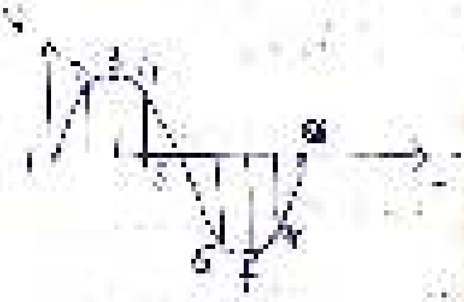
→ Electrical generator is a machine that converts mechanical energy into electrical energy.

→ An electrical generator is based on the principle that whenever a flux is cut by a moving conductor, emf is induced in it as it is flux cut.

→ And the direction is of induced emf is given by Fleming's right hand rule.

Principle of Generator:-





(i) When the loop is at position no 1 the generated emf is 0 because the side of coil does is not cut any flux. The flux lines are parallel to the conductor making the loop.

(ii) When the loop is at position no 2 the coil sides are moving at an angle to the flux and therefore low emf is generated as indicated at point 2 in the figure.

(iii) When the loop is at position no 3 the coil sides (AB and CD) are at right angle to the flux lines, so the flux cutting is maximum and the emf generated is maximum.

(iv) When the loop at position no. 4 the generated emf is less because the coil sides are cutting the flux at an angle less than 90°.

(v) At position no. 5 the flux lines are cut the emf induced is 0V.

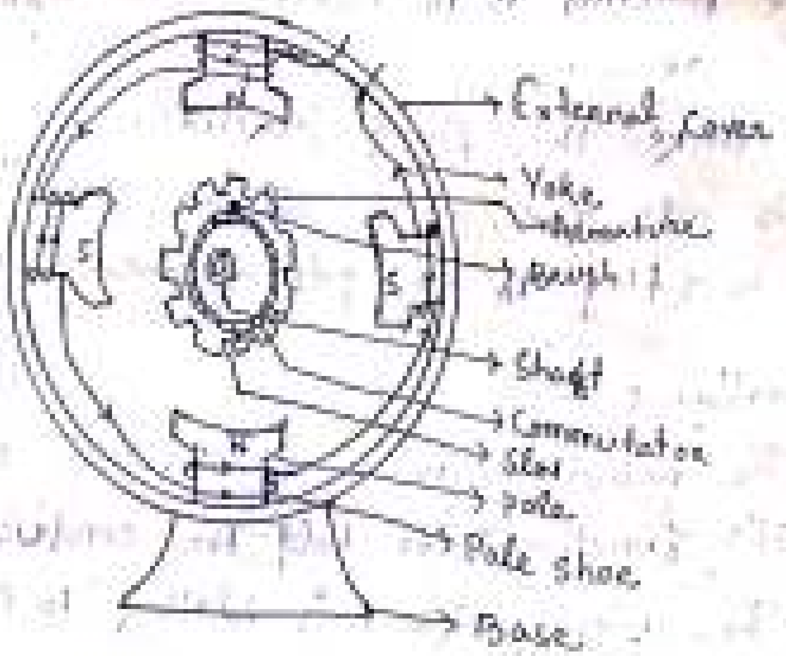
(vi) At the position no. 6 the coil sides moves under a pole of opposite polarity and hence the direction of generated emf is reversed.

(vii) The maximum emf in this direction will be at position no. 7 and 0V when the position is 9.

(viii) The cycle repeats with each revolution.

★ Parts of DC Machine Generator:-

★ Parts of DC Generator



(i) External Cover :-

→ It is made up of cast iron.
→ It protect the machine from dust and dirt.
→ It is provided with radial ventilating duct to cool the machine.

(ii) Yoke :-

→ The shape of the yoke is hollow cylinder.
→ It is made ~~of~~ up of silicon steel.
→ It supports the magnetic poles.
→ It provide a return path for magnetic flux.

(iii) Pole :-

→ It is fitted with the yoke by means of bolting.
→ The pole is laminated in structure to reduce the eddy current loss.
→ It is made up of silicon steel.
→ It create the magnetic flux when some current passes through it's own winding.

(iv) Pole shoe :-

→ It's function is to increase the effective pole area.

→ It makes the field parallel.

→ It is also made up of silicon steel.

→ It is fitted with the pole by screws or welding.

(v) Armature :-

→ The armature is a cylindrical body.

→ It's function is to hold the conductor.

→ The outer periphery is slotted to carry the conductor.

→ Armature is laminated to reduce the eddy current loss.

→ It is made up of CRGO cold Rolled (grain) oriented material.

(vi) Commutator :-

→ It is placed on (at) the front end of the armature.

→ It is made up of copper.

→ The whole commutator is made up of different commutator segments.

→ The shape of the commutator is circular.

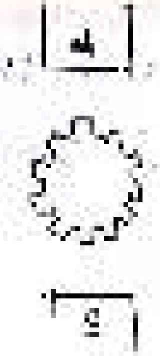
→ It convert AC to DC in case of generator and DC to AC in case of Motor.

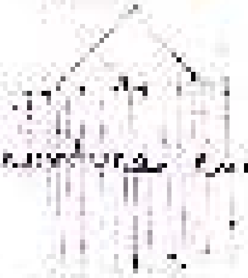
(vii) Brush :-

→ It is made up of copper or carbon.

→ It's function is to collect the current.

Pole pitch :- The [illegible] periphery of armature [illegible]





Pole pitch = $\frac{Z}{P}$

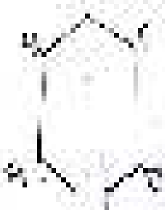
→ It is equal to no. of armature conductors are under one pole.

★ Conductor :-

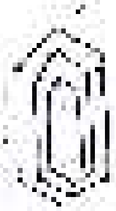
→ It is a wire in which current is flowing e.g. AB and CD.

★ Coil and winding element :-

→ The conductor AB and CD along with their end connection is called coil.



single turned



multi turned

→ The coil may be single turned and multiturned.

→ The sides of the coil is called winding elements.

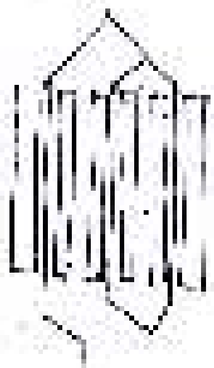
★ Coil pitch or coil span :-

→ Coil pitch is the peripheral distance between 2 sides of a coil measured in terms of no. of armature slot.

→ If coil pitch is equal to the pole pitch then it is called the [illegible] winding is called full pitch and emf induced is maximum.

→ If coil pitch is less than pole pitch then the armature winding is called short pitch.

★ Back pitch (Y_b):-



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

The distance measured in terms of armature conductors which a coil advances on the back end of the armature is called back pitch. Is denoted by Y_b.

★ Front pitch:- $Y_f = \frac{Z}{P} - 1$

The no. of armature conductors or element spanned by a coil on the front side is called front pitch and is denoted by Y_f

★ Resultant pitch:-

It is distance between the beginning of one coil and the beginning of the next coil to which it is connected called as resultant pitch.

★ Commutator pitch:-

It is the distance measured in commutator bars or segments between the segment to which two ends of coil is connected is known as commutator pitch.

Q. Write down the winding table for 2 layer simplex lap winding for 4 pole DC generator having 20 slots.

Ans Given Data

Pole = P = 4

Armature slots = 20

Total conductor = $20 \times 2 = 40$

$Y_b = \frac{Z}{P} + 1 = \frac{40}{4} + 1 = 10 + 1 = 11$

$Y_f = \frac{Z}{P} - 1 = \frac{40}{4} - 1 = 10 - 1 = 9$

Back Connection $Y_b = 11$	Front Connection $Y_f = 9$
$1+11 = 12$	$12-9 = 3$
$3+11 = 14$	$14-9 = 5$
$5+11 = 16$	$16-9 = 7$
$7+11 = 18$	$18-9 = 9$
$9+11 = 20$	$20-9 = 11$
$11+11 = 22$	$22-9 = 13$
$13+11 = 24$	$24-9 = 15$
$15+11 = 26$	$26-9 = 17$
$17+11 = 28$	$28-9 = 19$
$19+11 = 30$	$30-9 = 21$
$21+11 = 32$	$32-9 = 23$
$23+11 = 34$	$34-9 = 25$
$25+11 = 36$	$36-9 = 27$
$27+11 = 38$	$38-9 = 29$
$29+11 = 40$	$40-9 = 31$
$31+11 = 42 - 40 = 2$	$42-9 = 33$
$33+11 = 44 - 40 = 4$	$44-9 = 35$

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Back Connection

25 + 11 = 46 − 40 = 6

37 + 11 = 48 − 40 = 8

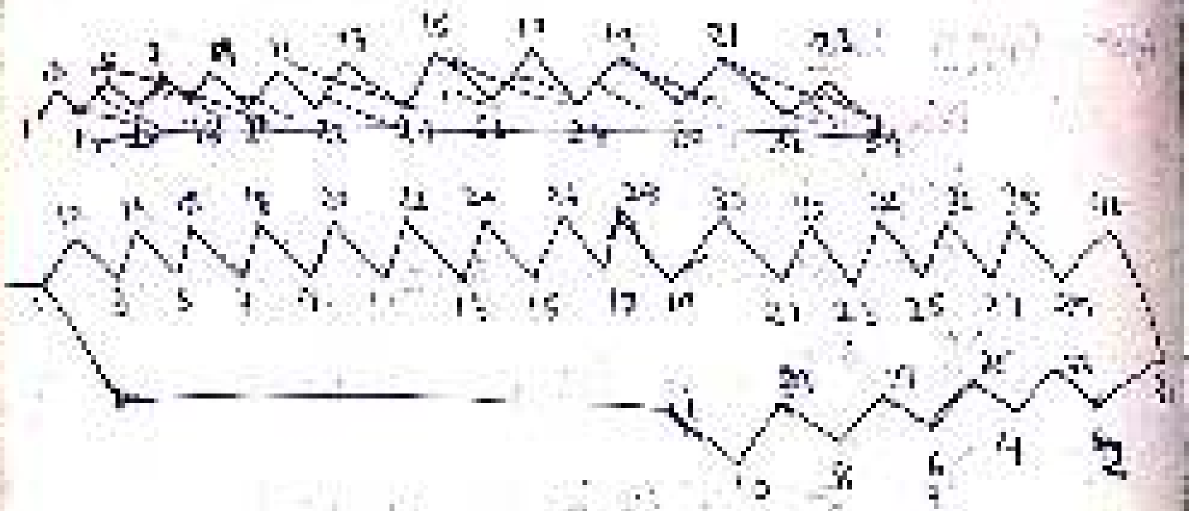
37 + 11 = 56 − 40 = 16

Front Connection

46 − 9 = 37

46 − 9 = 37

50 − 9 = 41 − 40 = 1



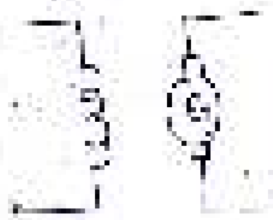
Types of DC Generators :-

DC Generators

- Separately excited DC Generator
- Self excited DC generator

(i) **Separately excited DC Generator :-**

→ In separately excited DC Generator a separate DC supply is given to the field winding.



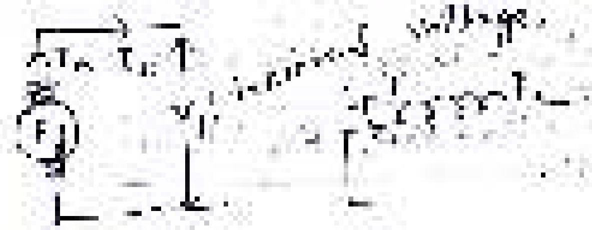
(ii) Self excited DC Generator :- [illegible]

In self excited DC generator the induced voltage itself giving supply to the field winding.

Types of DC Generator

- Separately excited DC Generator
- Self excited DC Generator
  - Series Generator
  - Shunt Generator
  - Compound Generator
    - Long shunt
    - Short shunt

(i) Separately excited DC generator :-



E_g = Generating voltage

R_a = Armature resistance

I_a = Armature current

I_L = Load current

V_t = Terminal voltage

$I_f = I_{sh}$ = Field current

R_f = Field resistance

Applying KVL to the loop,

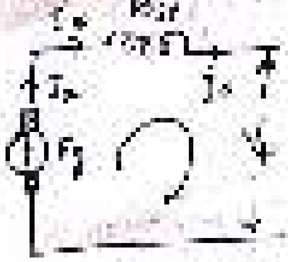
$E_g - I_a R_a - V_t - BD = 0$

Here $I_a = I_L \Rightarrow E_g = I_a R_a + V_t + BD$

$I_a = I_L$

(ii) Self excited DC Generator :-

(a) Series Generator :-



R_{se} = Series resistance

R_a = Armature resistance

$I_a = I_{se} = I_L$

i.e. Armature current = series field current = load current

V_t = Terminal voltage.

Applying KVL in the loop.

$E_g - I_a R_a - I_{se} R_{se} - V_t - B.D = 0$

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

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

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

(b) Shunt generator :-

I_{sh} = Shunt current

R_{sh} = Shunt Resistance

$I_a = I_{sh} + I_L$

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

Apply KVL in the loop.

$E_g - I_a R_a - V_t - B.D = 0$

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

(c) Compound Generator:-

1. Long Shunt Compound Generator:-

R_{se} = Series field Resistance.

R_{sh} = Shunt field Resistance.

I_{sh} = Shunt field Current

$I_a = I_{sh} + I_L$

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

Apply KVL in the loop,

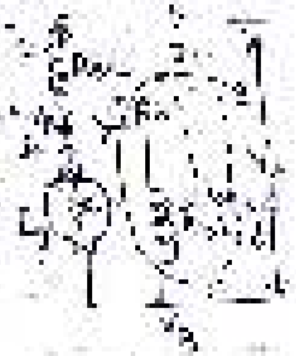
$E_g - I_a R_a - I_a R_{se} - B.D - V_t = 0$

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

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

2. Short Shunt Compound Generator:-

$I_a = I_{sh} + I_L$



~~Example~~

Apply KVL in dotted loop

$V_{sh} + V_L + I_L R_{se} - V_{sh} = 0$

$\Rightarrow V_{sh} = V_t + I_L R_{se}$

$\Rightarrow$ ~~Vrsh~~ $V_{sh} - V_t - I_L R_{se} = 0$

$\Rightarrow V_{Rsh} = V_{sh} = V_t + I_L R_{se}$

$\Rightarrow V_{Rsh} = V_t + I_L R_{se}$

$I_{sh} = \frac{V_{Rsh}}{R_{sh}} = \frac{V_t + I_L R_{se}}{R_{sh}}$

Applying KVL in the outer loop

$E_g - I_a R_a - I_L R_{se} - V_t - B.D = 0$

$\Rightarrow E_g = I_a R_a + I_L R_{se} + V_t + B.D$

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Short Shunt Generator

$I_L = 30$ Amp
$V_t = 220$ V
$R_a = 0.05\ \Omega$
$R_{se} = 0.3\ \Omega$
$R_{sh} = 200\ \Omega$
$2BD = 1$ V

$E_g = I_a R_a + I_L R_{se} + V_t + BD$.

$$I_{sh} = \frac{V_t + I_L R_{se}}{R_{sh}}$$

$$= \frac{220 + (30 \times 0.3)}{200} = \frac{220 + 9}{200}$$

$$= \frac{229}{200} = 1.145 \text{ Amp.}$$

$I_a = I_{sh} + I_L$

$= 1.145 + 30 = 31.145$ Amp

$E_g = I_a R_a + I_L R_{se} + V_t + BD$.

$= (31.145 \times 0.05) + (30 \times 0.3 + 220 + 1)$

$= 1.557 + 9 + 221$

$= 231.557$ V

Equation of EMF generation in DC Generator

ϕ = Flux per pole.
Z = no. of conductors (= no. of slot × no. of conductors in each slot)
P = no. of pole
N = no. of revolution in R.P.M.
E_g = EMF generated
$E = n \frac{d\phi}{dt}$ (if n = no. of conductor is one)
Emf generated per conductor = $\frac{d\phi}{dt}$
No. of flux cut by one conductor in one revolution $(d\phi) = P\phi$

No. of revolution per minute = N

No. of revolution per second = $\frac{N}{60}$ rps

~~Emf generated = $e = \frac{d\phi}{dt}$~~

~~1 revolution ... = ... second~~ $\frac{1}{\frac{N}{60}}$ sec.

Time taken for 1 revolution $= \frac{60}{N}$ sec.

Emf generated $= e = \frac{d\phi}{dt}$

$= \frac{P\phi}{\frac{60}{N}} = \frac{P\phi N}{60}$ $(\because d\phi = P\phi)$

~~There are~~

If total no. of conductors are Z, then,

The total emf generated $E = \frac{ZP\phi N}{60}$

There are 2 types of winding

(i) Lap winding

(ii) Wave winding

For lap winding no. of parallel path (A) is no. of poles.

For this, the generated emf $= \frac{Z\phi P N}{60A}$

For wave winding no. $A = 2$

So the generated emf $= \frac{Z P \phi N}{60 \times 2}$

Q: A 4 pole generator having wave wound armature winding having 51 slots and each ~~slot~~ slots have 20 conductors. Find ~~the emf~~ what will be the voltage generated in the machine when it is driven 500 rpm assuming flux per pole is ~~7 milli~~ 7 milli weber.

Ans. Given Data

No. of poles (P) = 4

No. of slots = 51

Conductors in each slot = 20

Total conductors (Z) = 51 × 20

= 1020

Flux per pole (ϕ) = 7 mWb

= 7×10^{-3} Wb.

No. of revolution (N) = 500 rpm.

As the armature winding is wave wound, so A = 2.

$$\therefore E_g = \frac{\phi Z N P}{60 A} = \frac{4 \times 7 \times 10^{-3} \times 1020 \times 500}{60 \times 2} = 119 \text{ V}$$

Q. An 8 pole DC shunt generator with 778 wave connected armature conductors running at 500 rpm supplies a load of 12.5 Ω resistance at terminal voltage of 250 V. The armature resistance is 0.24 Ω and field resistance is 250 Ω. Find the armature current, induced emf and flux per pole.

Ans. Given Data

$N = 500$ rpm.

$R_L = 12.5\ \Omega$

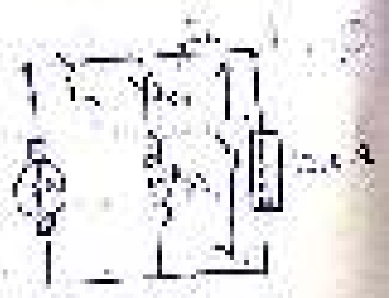
$V_t = 250$ V

$R_a = 0.24\ \Omega$

$R_{sh} = 250\ \Omega$

$A = 2$,

$Z = 778$



$$I_L = \frac{V_t}{R_L} = \frac{250}{12.5} = 20 \text{ Amp.}$$

Again,

$$I_{sh} = \frac{V_t}{R_{sh}} = \frac{250}{250} = 1 \text{ Amp.}$$

$I_a = I_{sh} + I_L = 20 + 1 = 21$ [illegible]

$E_g = I_a R_a + B.D. + V$

$= (21) \times 0.24 + 250 + 0$

$= 5.04 + 250$

$= 255.04\ V$

We know,

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

$$\Rightarrow 255.04 = \frac{8 \times \phi \times 778 \times 500}{60 \times 2}$$

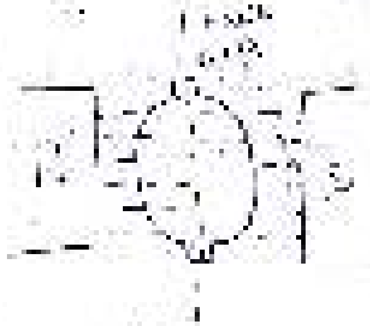
$$\Rightarrow \phi = \frac{255.04 \times 120}{8 \times 778 \times 500}$$

$\Rightarrow \phi = 9.83 \times 10^{-3}\ Wb = 9.83\ mWb$.

$\therefore$ generated emf is 255.04 V and flux per pole is 9.83 mWb.

Armature Reaction:-

The effect of armature flux lines with main magnetic flux lines.



(i) Direct of

Armature conductor.

Armature Reaction :-

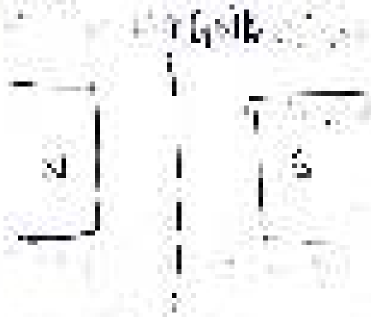
→ The action of armature flux on main flux is called armature reaction.

→ The flux arising in a DC machine is that in main poles is called main flux.

→ The current through the armature conductors create a magnetic flux called armature flux.

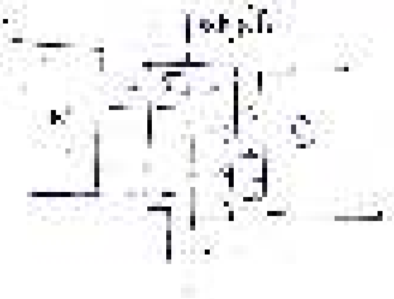
GNA (Geometrical Neutral Axis):-

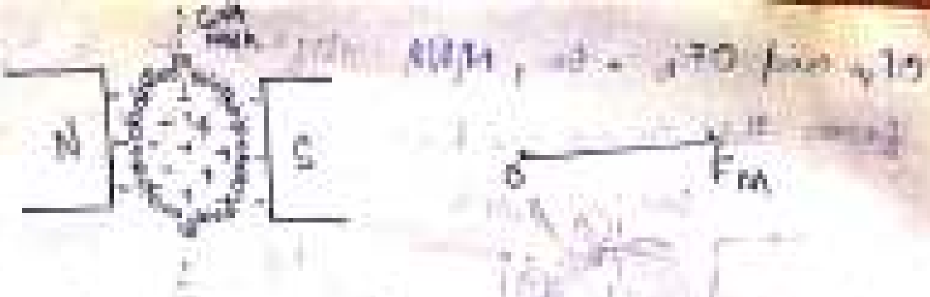
→ The Geometric neutral axis is a axis that bisects the angle between the centre line of adjacent poles.



MNA : Magnetic Neutral Axis:-

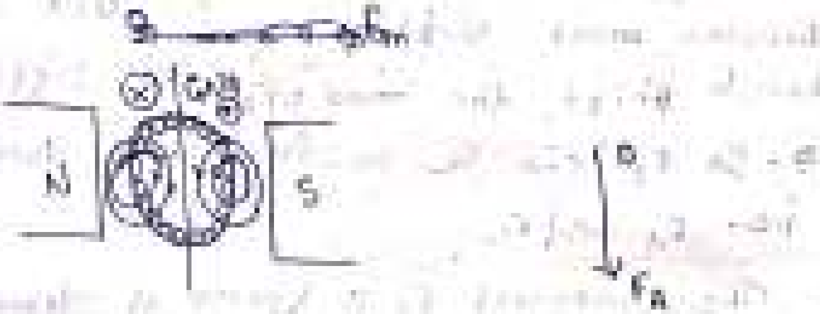
→ It is the axis drawn perpendicular to the mean direction of flux passing through the centre of the armature.





→ The above figure shows the flux due to the main flux only.

→ The MMF produced during the main flux is OF_m.

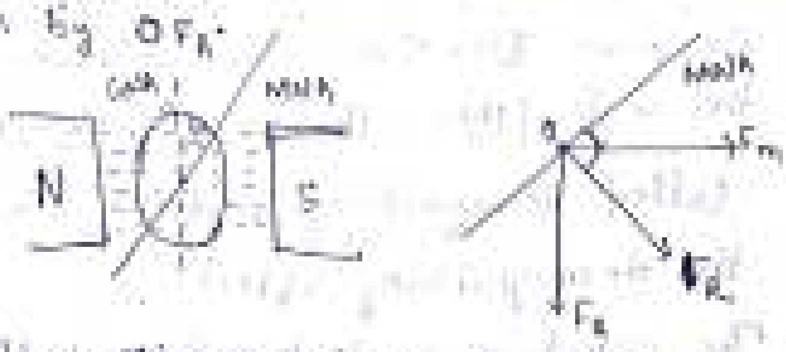


→ The above figure shows the flux due to the current flowing to the armature conductor only.

→ The armature conductor left of GNA carry current in inward direction, i.e. taken as (×) and those conductor right of the GNA carry current in outward direction i.e. taken as (•).

→ So, the direction of magnetic flux can be found out by ~~cork~~ thumb's rule.

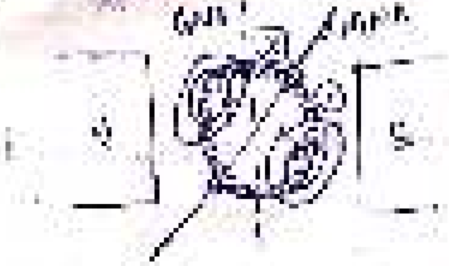
→ The mmf produced in the armature flux is given by OF_A.

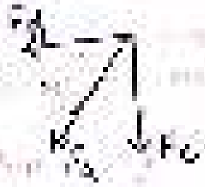


→ The above figure shows the flux due to mainpole and the armature conductor.

→ Resultant flux OF_R is the vector ~~of~~ sum of

OF_m and OF_A i.e., MNA shifted in a angle θ from the mean position on GNA axis.

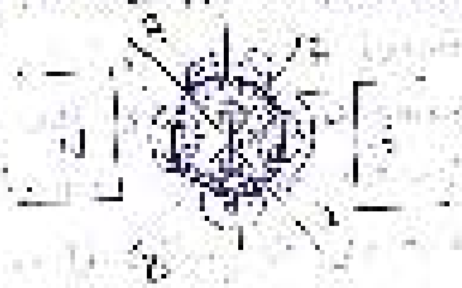




→ In order to achieve sparkless commutation, the brushes must shift along the MNA, due to brush shift some of which give the component of F_A, so F_A can be resolved into two components i.e. F_d and F_c.

→ The component F_d is known as demagnetising component and the component F_c is known as cross magnetising component.

Demagnetising and Cross-magnetising conductors:



→ The armature conductors on both sides of GNA positions lying in direct opposition to the main flux and the conductors lying within the angle |BOC| = |AOD| = 2θ are called demagnetising conductors which produces the demagnetising effect.

→ The armature conductors lying between the angle |AOC| = |BOD| constitutes cross magnetising effect. So, the conductors are called cross magnetising conductors.

Q. A separately excited DC generator has an armature circuit resistance of 0.1 Ω and total brush drop is 2V. When running at 1000 rpm it delivers a current of 100 Amp at 250V to a load of constant resistance. If the generator speed drops to 700 rpm with field current unchanged, then find the current in the load.

Ans. Given Data:

$R_a = 0.1\Omega$

$BD = 2V$

$N_1 = 1000$ rpm

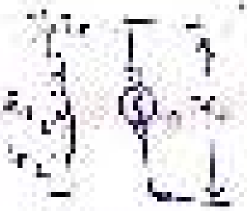
$I_{L_1} = 100$ Amp

$V_{t_1} = 250V$

$N_2 = 700$ rpm

R_L = constant

I_f = constant



$\therefore R_L = \dfrac{V_t}{I_L} = \dfrac{250}{100} = 2.5\,\Omega$

$E_{g_1} = I_a R_a + V_t + BD$

$= 100 \times 0.1 + 250 + 2$

$= 10 + 250 + 2 = 262V$

$E_{g_2} = V_t + I_{a_2} R_a + BD$ ——— eq (1)

$I_{a_2} = I_{L_2}$

$E_g = \dfrac{\phi ZNP}{60A}$

Here, P, Z and A constant;

We know $\phi \propto I_f$ = constant

So, ϕ also constant

$\therefore E_g \propto N$

$\Rightarrow \dfrac{E_{g_1}}{E_{g_2}} = \dfrac{N_1}{N_2}$

$\Rightarrow \dfrac{262}{E_{g_2}} = \dfrac{1000}{700}$ $\Rightarrow E_{g_2} = \dfrac{262 \times 7}{10} = 183.4V$

Putting E_{g_2} in Eq (i)

$E_{g_2} = I_{a_2}R_a + V_{t_2} + B.D.$

$\Rightarrow 183.4 = (I_{a_2} \times 0.1) + 250 + 2$

$\Rightarrow 183.4 - 252 = 0.1 I_{a_2}$

$\Rightarrow -68.6 = 0.1 I_{a_2}$

$\Rightarrow I_{a_2} =$

$\Rightarrow E_{g_2} = I_{a_2}R_a + (I_{a_2} \times R_L) + B.D. \quad (\because I_{a_2} = I_{L_2})$

$\Rightarrow 183.4 = I_{a_2}(R_a + R_L) + 2$

$\Rightarrow 183.4 = I_{a_2}(0.1 + 2.5) + 2$

$\Rightarrow 183.4 = 2.6 I_{a_2} + 2$

$\Rightarrow 183.4 - 2 = 2.6 I_{a_2}$

$\Rightarrow I_{a_2} = \frac{181.4}{2.6} = 69.76$ Amp

$\therefore I_{a_2} = I_{L_2} = 69.769$ Amp

Q. A 4 pole DC shunt generator with a shunt field resistance of 100 Ω and Armature Resistance of 1Ω and has a 378 wave connected conductor in it's armature. The flux per pole is 0.02 wb and ~~exists~~ a If the load Resistance is 10 Ω and ~~and~~ it is connected across the armature terminal and the generator driven at 1000 rpm calculate power ~~op~~ absorbed by the load.

Ans: Given data:

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

$P = 4$

$R_a = 1\,\Omega$

$Z = [illegible]$

$\phi = 0.02\,Wb$

$R_L = 10\,\Omega$

$N = 1000$

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

$$\Rightarrow E_g = \frac{4 \times 0.02 \times [illegible] \times 1000}{60 \times 2}$$

$$= \frac{4 \times 0.02 \times [illegible] \times 1000}{[illegible]} = 250\,V$$

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

$I_a = I_L + I_{sh}$

$I_L = \frac{V_t}{R_L} = \frac{V_t}{10}$ Amp

$I_{sh} = \frac{V_t}{R_{sh}} = \frac{V_t}{100}$ Amp

$$I_a = [illegible] \frac{V_t}{10} + \frac{V_t}{100} = V_t\left(\frac{1}{10} + \frac{1}{100}\right)$$

$$= V_t\left(\frac{10+1}{100}\right) = \frac{11 V_t}{100}$$

We know

$$E_g = I_a R_a + V_t + [illegible]$$

$$\Rightarrow 250 = \left(\frac{11 V_t}{100} \times 1\right) + V_t + [illegible]$$

$$\Rightarrow 250 = V_t\left(\frac{11}{100} + 1\right)$$

$$\Rightarrow 250 = V_t\left(\frac{111}{100}\right)$$

$$\Rightarrow V_t = \frac{250 \times 100}{111} = 225.2\,V$$

$I_L = \frac{P_L}{V_L} = \frac{227.02}{10} = 22.7?$

$P_L = V_L I_L = 227.02 \times 21.70 = 25158.967$ Watt.

Demagnetizing Ampere turns

→ Demagnetizing Ampere turn/pole $= \frac{\theta_m}{360°} \times ZI$

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

→ Cross magnetizing Ampere turn/pole

$$\boxed{AT/pole = ZI\left(\frac{1}{2P} - \frac{\theta_m}{360°}\right)}$$ where, $I = \frac{I_a}{A}$

Q. A 4 pole generator has a wave wound armature with 722 conductors and it delivers 100 Amp on full load. If the brush lead is 8°, Calculate the armature demagnetizing and cross magnetizing AT/pole.

Ans) Given Data,

$P = 4$ $\quad A = 2$

$Z = 722$

$I_a = I_L = 100$ Amp.

Brush lead angle $(\theta_m) = 8°$

Demagnetizing AT/pole $= \frac{\theta_m}{360} \times ZI$

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

$AT/pole = \frac{8°}{360} \times 722 \times 50$

$= 802.22$ AT/pole

Cross-magnetizing AT/pole $= ZI\left(\frac{1}{2P} - \frac{\theta_m}{360}\right)$

$$I = \frac{I_a}{A} = \frac{120}{4} = 30$$

$$AT/pole = 782 \times 30 \times \left(\frac{1}{2\times 4} - \frac{?}{360}\right)$$

$$= 2710.37 \ AT/pole$$

Q. A 8 pole lap connected DC shunt generator delivers an output current of 240 Amp at 500 V. The armature has 1408 conductors and 160 commutator segments. If the brushes are given a lead of 4 segments from the no-load neutral axis, find the demagnetizing and cross magnetizing AT/pole.

Ans: Given Data:

$P = 8$

$A = P = 8$

$I_L = 240$ Amp

$V_t = 500$ V

$Z = 1408$

Total commutator segments = 160

So, 160 commutators = 360°

1 commutator $= \frac{360}{160} = 2.25$

Brushes are lead by 4 seg commutator segment.

So, angle $(\theta_m) = 2.25 \times 4 = 9°$

Shunt current is not given so, $I_{sh} = 0$

So, $I_a = I_L = 240$ Amp.

Demagnetizing AT/pole $= \frac{\theta_m}{360} \times ZI$

$$I = \frac{I_a}{A} = \frac{240}{8} = 30$$

$$AT/pole = \frac{2\beta}{\frac{360}{4}} \times 1408 \times 30 = \frac{1408 \times 30}{40} = 1056$$

Cross magnetising $AT/pole = \frac{Z I}{2} \left(\frac{1}{2P} - \frac{\beta_m}{360} \right)$

$$= 1408 \times 30 \left(\frac{1}{2 \times 8} - \frac{4}{360} \right)$$

$$= 1408 \times 30 \left(\frac{1}{16} - \frac{1}{45} \right)$$

$$= 1584$$

Compensating winding :

→ The cross-magnetising effect of armature reaction can be neutralised by compensating winding.

→ A compensating winding is an auxiliary winding embedded in slots in pole face as shown in the figure. It is connected in series with the armature winding in manner so that the direction current through the compensating conductors in any pole face will be opposite to the direction of current through the adjacent armature conductors.

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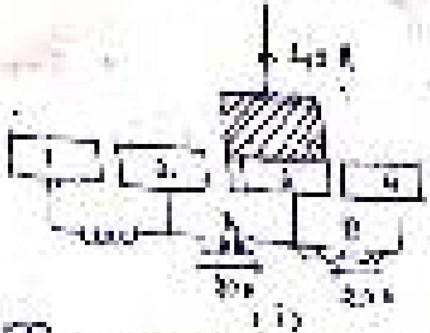
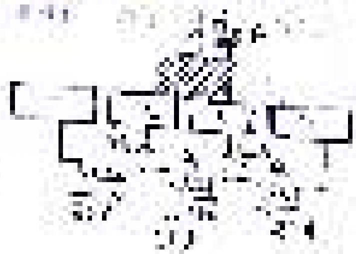
★ Commutation :-



The process by which the current [illegible] passes through the brush axis

The reversal of current in a coil as the coil passes through the brush axis is called commutation.

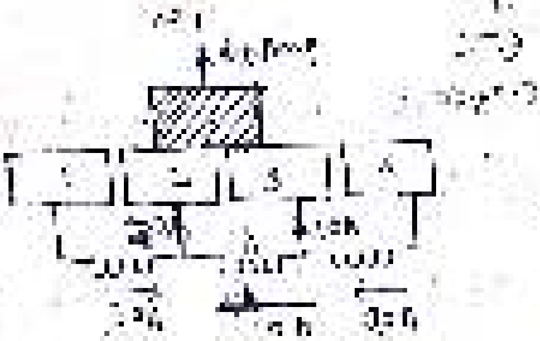
→ In figure (i) the brush is contact with segment 3 & so the total current flows through the brush is 40Amp. i.e. I_1 = 20A and I_2 = 20A



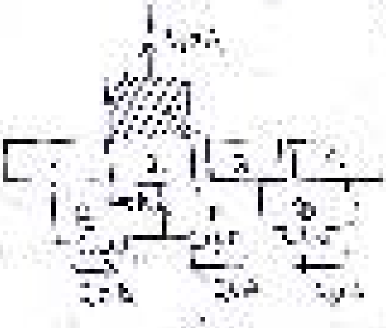
→ As the armature rotates the brush will make 3/4 contact with segment 2 and 1/4 contact with segment 3. Again the total current through the brush is 40Amp. i.e. 30Amp through segment 2 and 10Amp through the segment 3

→ The above figure shows the position when the brush is on segment 2 and 1/2

Contact with segment #3 is 0, the total current will flow through the brush i.e. 40 Amp through segment 2 and 0 Amp through segment and the current through coil A is 0 Amp.



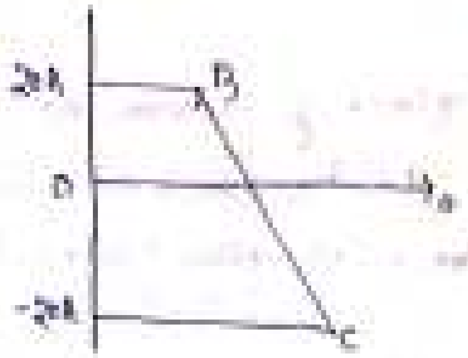
→ The above figure shows the instant when the brush is in 3/4 contact with segment 2 and 1/4 contact with segment 3 and the total current flows through the brush 40A i.e. 30A through segment 2 & 10A through segment 3 and the current in the coil is 10A but in reverse direction.



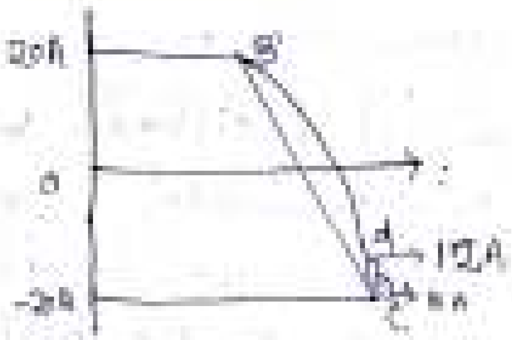
(c)

→ The above figure shows the instant when the brush is in contact with segment only. The total current through brush is 40A i.e. 20A from coil A and coil B.

Improvement in Commutation :-



If the Current Changes at a uniform rate (i.e. BC is a straight line) then it is called Ideal commutation. Under such condition no sparking will taken place between brush and commutator.



The ideal commutation can not be attend in practice because the armature coil has some inductance when the current changes in the coil so, a reactance voltage is induced in opposite direction to the current flowing through it.

This reactance voltage opposes the change of current so the commutation occurs more slowly than ideal commutation.

The curve BC represents the new current direction.

DC = 8 Amp i.e. flowing from the commutator segment to brush when the brush has no contact with the commutator segment.

So, we need to improve the commutation process.

There are 2 methods to improve the commutation,

(i) Resistance Commutation
(ii) EMF Commutation

(i) Resistance Commutation :-

→ If the contact resistance between the brush and commutator is made large, the current would divide in the inverse ratio of the contact resistance and this improves the commutation and it is achieved by carbon brush.

↳ It is called Resistance Commutation.

(ii) EMF Commutation :-

In this method an arrangement is made to neutralized the reactance voltage by producing a reversing voltage in the coil undergoing commutation. The reversing voltage act in the opposite to the reactance voltage

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and it is achieved by 2 ways

(i) ~~By~~ Brush shifting

(ii) By using Interpole

Q.- A separately excited DC generator running at 1200 rpm supply a current of 200A at 125V to circuit of constant resistance. What will be the current when the speed is drop to 1000 rpm and the field current reduced to 80%. Armature resistance is 0.01Ω and total B.D. is 2V.

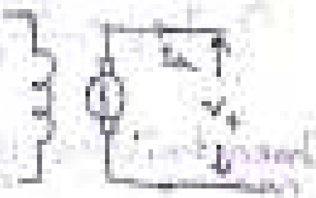
Ans:- Given Data

$N_1 = 1200$ rpm $R_a = 0.01\Omega$

$I_a = 200A$

$V_t = 125V$

$N_2 = 1000$ rpm



We know,

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

$$E_g \propto \phi N$$

$$\phi_2 = 80\% \text{ of } \phi_1 = \frac{80}{100} \times \phi_1 = 0.8\phi_1$$

$$\Rightarrow \frac{125}{E_{g_2}} = \frac{1200}{1000}$$

$$R_L = \frac{V_t}{I_L} = \frac{125}{200}$$

$$\Rightarrow E_{g_2}$$

$$E_{g_1} = I_a R_a + V_t + B.D.$$

$$= (200 \times 0.01) + 125 + 2 = 129V$$

$$E_g \propto \phi N$$

$$\Rightarrow \frac{E_{g_1}}{E_{g_2}} = \frac{\phi_1 N_1}{\phi_2 N_2}$$

$$\Rightarrow \frac{129}{E_{g_2}} = \frac{\phi_1 \times 1200}{0.8 \times \phi_1 \times 1000} \Rightarrow E_{g_2} = \frac{129 \times 0.8 \times 10}{12}$$

$\Rightarrow E_{g_2} = $ [illegible]

$E_{g_2} = V_{t_2} + I_{a_2} R_a + $ [illegible]

$\Rightarrow $ [illegible] $= V_{t_2} + $ [illegible] $I_{a_2} R_a + $ [illegible]

[illegible] known, $R_L = \frac{V_t}{I_L} = \frac{125}{[illegible]} = $ [illegible]

$\Rightarrow $ [illegible] $= I_{a_2} R_L + I_{a_2} R_a + $ [illegible]

$\Rightarrow $ [illegible] $= I_{a_2} ($[illegible]$ + $[illegible]$) + 2$

$\Rightarrow $ [illegible] $= I_{a_2} (0.125 + 0.01)$ [illegible]

$\Rightarrow $ [illegible] $= I_{a_2} R = $ [illegible]

$\Rightarrow I_{a_2} = \frac{[illegible]}{[illegible]} = $ [illegible]

Characteristics of DC generator

1. Magnetic characteristic

E_0 vs I_f

It is the relation between no-load voltage and field current.

2. Internal characteristic

E_g vs I_a

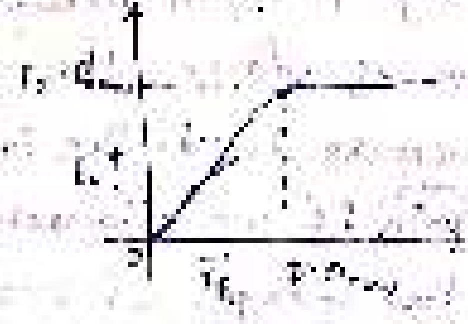
It is the relation between the voltage generated actually in the armature winding and armature current.

3. External characteristic

V vs I_L

It is the relation between terminal voltage and load current.

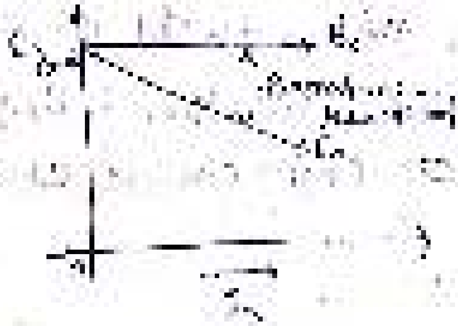
No load Characteristics (O.C.C) of Separately Exciting Gen.



$I_f \uparrow \to \phi_m \uparrow \to E_g \uparrow \to E_0 \uparrow$

ϕ_m is maximum it remains constant for increasing the field current i.e. E_g is const.

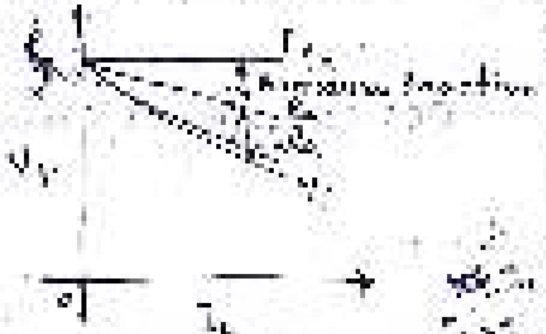
Internal Characteristics:



$I_a \uparrow \to \phi_{AR} \uparrow \to \phi_{net} \downarrow$ (armature reaction)

so $E_g \downarrow$

External characteristics:



When load increases in parallel

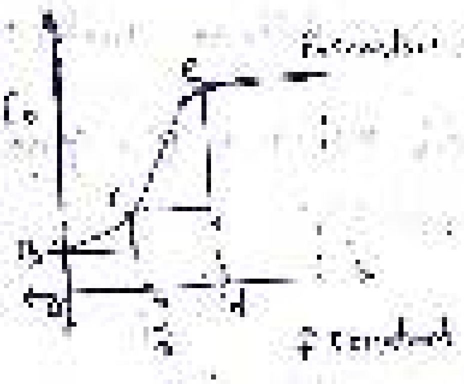
$R_L \downarrow \to I_L \uparrow \to I_a \uparrow$

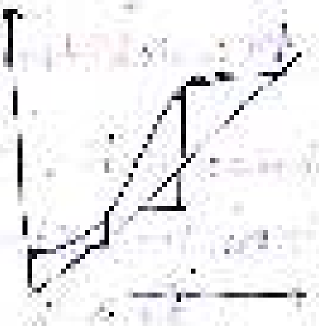
$I_a \uparrow \to \phi_{AR} \uparrow \to \phi_{net} \downarrow$

$\phi_{net} \downarrow \to E_g \downarrow \to V_t \downarrow$

Which separately excited
$I_a = I_L$ ...

Voltage building in self excited DC Generator

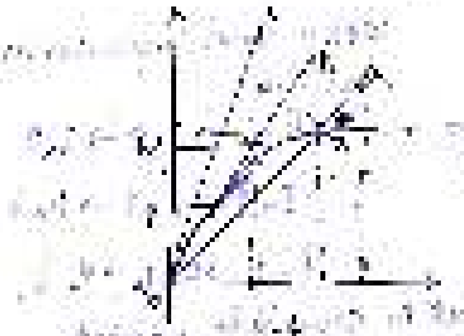




Voltage build up phenomenon means the gradual generation voltage from short ... generation. Due to the residual magnetism initially the voltage generated in a generator is OA. Due to that voltage, the field current increased to oh. Due to increase of field current the voltage is again increased to be equal to the increase of voltage. The field current is again increased to od. Thus, the increased voltage again, if we increase the field current then the voltage will [illegible] due to the saturation of field current.

So, the process voltage build up takes place and it will continue till the intersection point of R_f with OCC (open circuit characteristic).

* Critical Resistance :-



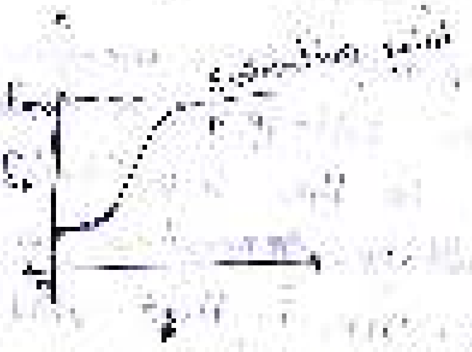
OCC (open circuit characteristic)

Critical field resistance is that resistance below which voltage build up takes place and above which there is no voltage building.

* Characteristics of DC shunt generator :-

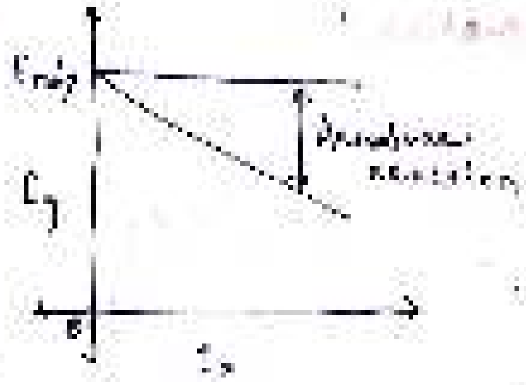
(i) No load characteristics.

E_0 vs I_f

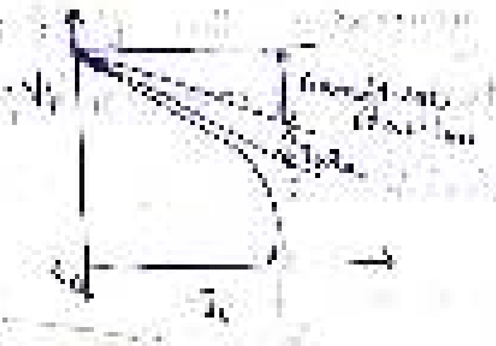


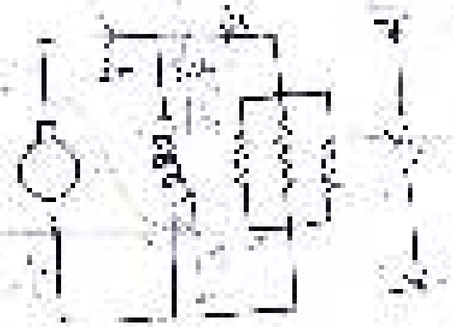
(ii) Internal Characteristics :-

E_g vs I_a



(iii) External Characteristics :-

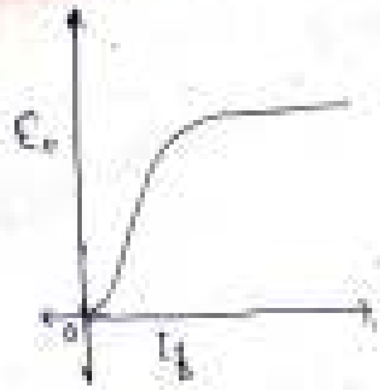




Any decrease of load resistance beyond a point instead of increasing the load current decreases the load current and external characteristics curve turn back as shown in the figure.

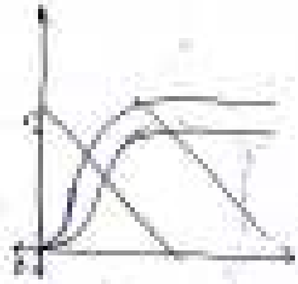
Characteristics of self excited DC series generator:

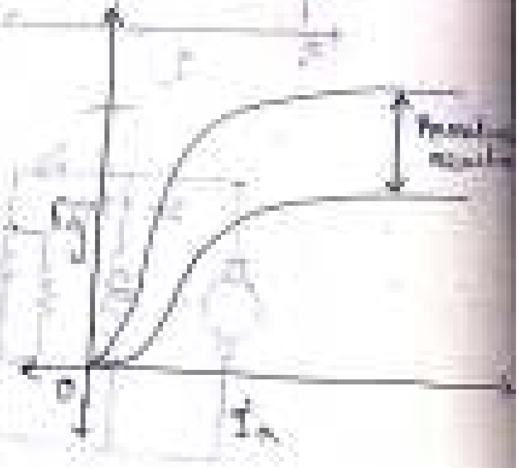
(i) No load characteristics :-



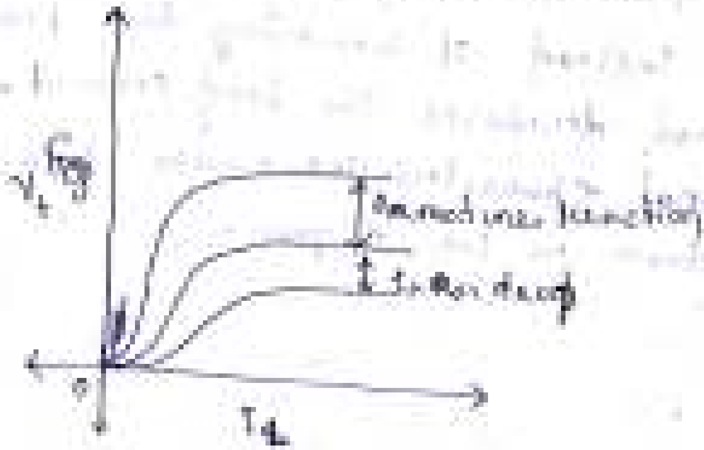
The main in series generator the field winding is separately excited for experimental purpose.

(ii) Internal characteristics :-





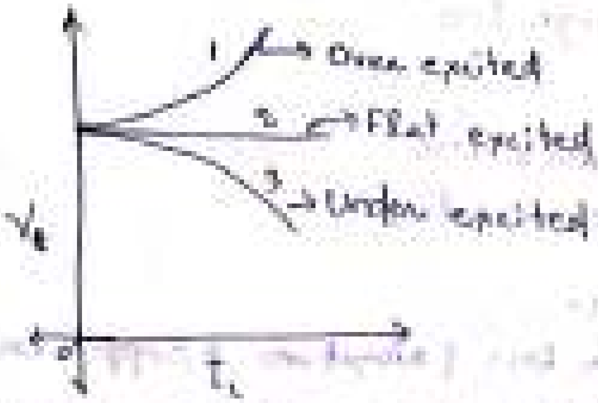
(iii) External characteristics :-



$E_g - I_aR_a = V_t$

* Characteristics of self excited DC compound generator:-

External characteristics:-



Curve-1 (Over excited):-

If the series winding turns are adjusted that with increase in load current the terminal voltage increases then it is called over excited compound generator.

Curve-2 (Flat excited):-

If the series winding turns are so adjusted that with increase in load current the voltage remains constant then it is called Flat excited DC compound generator.

Curve-3 (Under excited):-

If the series winding turns are so adjusted that with increase in load current the terminal voltage decreases then it is called Under excited DC compound generator.

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Losses in D.C. machine :-

i) Friction & winding loss :-
   a) Friction loss
   b) windage loss

ii) Iron loss :-
   a) Hysteresis loss
   b) Eddy current loss

iii) Copper loss :-
   a) $I_a^2 R_a$ loss (armature copper loss)
   b) $I_{sh}^2 R_{sh}$ (shunt field copper loss)

Friction loss :-
It occurs due to frictional part of D.C. machine.

Windage loss :-
It is also known as air friction loss. It occurs due to displacement of air inside machine.

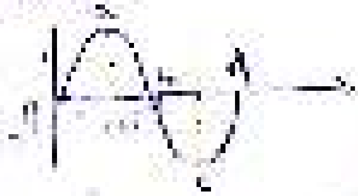
Eddy current loss :-
Whenever a magnetic flux pass through the armature body an emf is induced at the 2 ends of the armature due to Faraday's law of electromagnetic induction. This emf will circulate a current inside body of armature and this current is known as eddy current. The eddy current causes some amount of loss is produced that loss is known as eddy current loss.

$P_e = K_e f^2 B_m^2 V t^2$

where, f = frequency of rotation
B_m = magnetic flux density
V = volume of the body
t = thickness of the body
K_e = proportionality constant

Hysteresis Loss:-

In a DC machine, the armature rotates, the armature is ... direction from 'a' the current increases in OA and then decreases to 'b' and then increases in the direction to the neg... decreased in ... to 'c' and so on. With increase in current H increases and vice versa.



$\Rightarrow$ $\boxed{H = \frac{NI}{l}}$ = magnetic field intensity

The magnetic flux density 'B' undergo changes (up and down) by moving some phenomena like 'a' ... some amount of work is done on the material (B-H loop). The work done is dissipated as heat and this loss is called hysteresis loss.

$P_h = \eta B_m^{1.6} f V$

where, f = frequency of rotation
B_m = magnetic flux density
V = volume of the material
η = Steinmetz constant

Hysteresis loss $W_h = K_h f B_m^{1.6}$

Eddy current loss $W_e = K_e f^2 B_m^2 t^2$

Total loss = constant loss + variable loss

= W_c + variable loss ($I_2^2 R_{02}$)

$W_c = \underbrace{\text{Hy. loss + Eddy loss}}_{\text{Iron loss}}$ + shunt field Cu loss

Efficiency (η) = $\frac{O/P}{I/P} = \frac{O/P}{O/P + \text{losses}}$

I/P = O/P + loss

$= \frac{P_{out}}{P_{out} + W_c + I_2^2 R_{02}}$

$P_2 = V_2 I_2 \cos\phi$

$= \frac{V_2 I_2 \cos\phi}{V_2 I_2 \cos\phi + W_c + I_2^2 R_{02}}$ (... constant ...)

Condition for maximum efficiency $\frac{d\eta}{dI_2} = 0$

$\frac{d\eta}{dI_2} = 0$ (... the denominator should be minimum)

$\frac{d}{dI_2}\left[\frac{V_2 I_2 \cos\phi}{V_2 I_2 \cos\phi + W_c + I_2^2 R_{02}}\right]$

$$\frac{d}{dI_L}\left(V_t I_L + W_c + I_L^2 R_a\right) = 0$$

$$\Rightarrow \frac{d}{dI_L}\left(V_t I_L\right) + \frac{dW_c}{dI_L}$$

dividing $V_t I_L$ in both numerator and denominator

$$\frac{\frac{V_t I_L}{V_t I_L}}{\frac{V_t I_L + W_c + I_L^2 R_a}{V_t I_L}} = \frac{1}{1 + \frac{W_c}{V_t I_L} + \frac{I_L^2 R_a}{V_t I_L}}$$

$$= \frac{1}{1 + \frac{W_c}{V_t I_L} + \frac{I_L R_a}{V_t}}$$

$$\frac{d}{dI_L}\left[\frac{1}{1 + \frac{W_c}{V_t I_L} + \frac{I_L R_a}{V_t}}\right] = 0$$ or we can take $\frac{d}{dI_L}\left(\frac{1}{1 + \frac{W_c}{V_t I_L} + \frac{I_L R_a}{V_t}}\right)$

$$\Rightarrow 0 + \frac{W_c}{V_t}\left(-I^{-2}\right) + \frac{R_a}{V_t} = 0 \quad \left(\because \frac{d}{dI_L}\left(\frac{1}{I_L}\right) = -I^{-2}\right)$$

$$\Rightarrow \frac{R_a}{V_t} = \frac{W_c I_L^{-2}}{V_t}$$

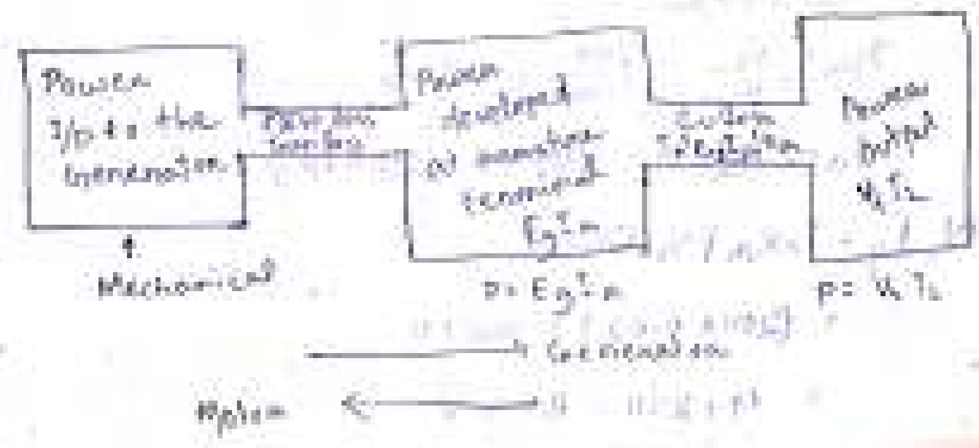
$$\Rightarrow R_a = \frac{W_c}{I_L^2}$$

$$\Rightarrow \boxed{W_c = I_L^2 R_a}$$

$\Rightarrow$ $\boxed{\text{Constant loss} = \text{Variable loss}}$

When variable loss equal to constant loss the efficiency will be maximum.

Power stages of DC Machine :-



Efficiency :-

(i) Electrical efficiency :-

$$\eta_E = \frac{C}{B} \quad \left(\frac{\text{electrical o/p}}{\text{electrical i/p}} = \eta_e\right)$$

(ii) Mechanical efficiency :-

$$\eta_m = \frac{B}{A} \quad \left(\frac{\text{Total electrical o/p}}{\text{mechanical i/p}} = \eta_m\right)$$

(iii) Overall efficiency :-

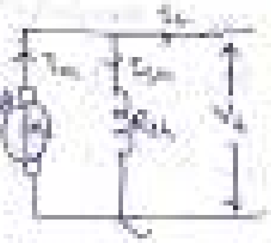
$$\eta_o = \frac{C}{A} \quad \left(\frac{\text{electrical o/p}}{\text{Mechanical i/p}} = \eta_o\right)$$

Q:- A shunt generator delivers 195 Amp. at terminal voltage 250V. The armature resistance and shunt resistance 0.02 Ω and 50 Ω respectively. The iron and friction loss is 950 watt. Find

(a) Emf generated
(b) Copper loss
(c) Output of prime mover
(d) Mechanical, electrical and overall efficiency.

Ans Given Data

$I_L = 195$ Amp.
$V_t = 250V$
$R_a = 0.02\,\Omega$
$R_{sh} = 50\,\Omega$



$$I_{sh} = \frac{V_t}{R_{sh}} = \frac{250}{50} = 5 \text{ Amp}$$

$$I_a = I_{sh} + I_L = 195 + 5 = 200 \text{ Amp}$$

(a) $E_g = I_a R_a + V_t + B.D.$

$= (200 \times 0.02) + 250 + 0$

$= 4 + 250 = 254\,V$

(b) Copper loss :-

$I_a^2 R_a = 200^2 \times 0.02 = 800$ watt

$I_{sh}^2 R_{sh} = 5^2 \times 50 = 1250$ watt

$I_a^2 R_a + I_{sh}^2 R_{sh} = 800 + 1250 = 2050$ watt

P_1 − loss = P_2

⇒ $P_1 = P_2 +$ loss [illegible]

⇒ $P_1 = E_g I_a + 750$ [illegible]

(c) Output of prime mover

= [illegible]

= [illegible]

= [illegible]

[illegible]

(d) Mechanical efficiency :-

$\eta_m = \frac{P_2}{P_1} =$ [illegible] $\times 100$ [illegible] %

(e) Electrical efficiency :

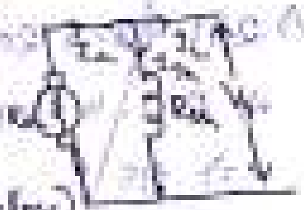
$\eta_e = \frac{P_3}{P_2} =$ [illegible] $\times 100$ [illegible] %

Overall efficiency :-

$\eta_o = \frac{P_3}{P_1} =$ [illegible] $\times 100$ [illegible]

Q. A shunt generator has a full load current of 196 Amp. at 220V. The stray losses are 720 watt and shunt field resistance is 55 Ω. If it has a full load efficiency of 88%. Find the armature resistance. Also find the load current corresponding to maximum efficiency.

Ans. Given data



$I_L = 196$ Amp.

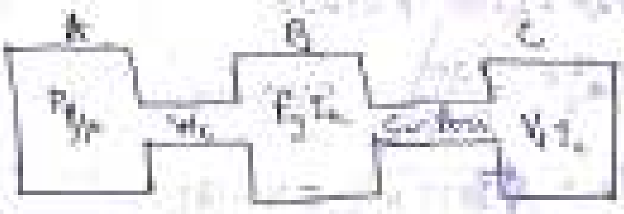
$V_t = 220$ V

Stray losses (Friction loss + Iron loss) = 720 watt

$R_{sh} = 55 \Omega$

Full load efficiency (overall efficiency)

$\frac{C}{A} = \eta_o = 88\%$



$I_{sh} = \frac{V_t}{R_{sh}} = \frac{220}{55} = 4$ Amp

$I_a = I_L + I_{sh} = 196 + 4 = 200$ Amp

~~$E_g = I_a R_a + V_t + B.D. = 200 R_a + 220 + 0$~~

$\frac{C}{A} = 88\%$

$\Rightarrow \frac{V_t I_L}{A} = \frac{88}{100}$ $\Rightarrow \frac{220 \times 196}{A} = \frac{88}{100}$

$\Rightarrow \frac{220 \times 196 \times 100}{88} = A$

$\Rightarrow A = 49000$ watt

Now, [illegible]

9000 = [illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

★ Parallel operation of D.C. generators:

Requirement of parallel operation:

(i) Continuity of service

(ii) Efficiency

(iii) Maintenance and repair purposes

(iv) Future use or additional plant.

→ Terminal voltage of the generators should be same.

→ Proper polarity should be maintained.

→ Run up the generator at rated speed then connect the generator to busbar. While connecting the 2nd generator the following procedure should be adopted.

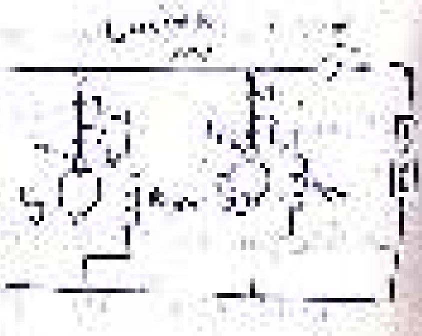
→ The armature of generator is speeded to the [illegible] prime mover.

→ The excitation of generator is changed till the voltmeter reads to zero value. Then it means that the terminal voltage is same as busbar voltage. After that the switch is closed so, the generator is parallel with the system. Under this condition the generator is not taking the load because the induced emf is same the terminal voltage. So, the generator is in floating condition.

→ When there is load requirement the induced emf of generator should be greater than the terminal voltage or system voltage.

Q) A shunt generator [illegible] with an armature resistance of 0.01 Ω and field resistance of 50 Ω are [illegible] parallelly to supply a common load of 2500 Amp. the emf are respectively [illegible]. Calculate the terminal voltage and [illegible] each machine.

Ans: Given Data



$R_{a} = 0.01\,\Omega$

$R_{f} = 50\,\Omega$

I_L = [illegible]

E_1 = 250 V?

E_2 = [illegible] V

V = ?

I_1 = ?

I_2 = ?

$E_{g_1} - I_{a_1}R_{a_1} = V_t$

$E_{g_1} = I_{a_1}R_{a_1} + V + BD$

$\Rightarrow 210 = I_{a_1} \times 0.01 + V + 2.0$

$\Rightarrow 210 = 0.01 I_{a_1} + V + 2.0$ —— Eq (1)

$E_{g_2} = I_{a_2}R_{a_2} + V + BD$

$\Rightarrow 220 = I_{a_2} \times 0.012 + V + 2.0$

$\Rightarrow 220 = I_{a_2}\, 0.012 + V + 2.0$ —— Eq (2)

We know,

$I_{a_1} = I_{L_1} + I_{sh}$

$\Rightarrow$ We know

From $I_{a_1} = I_{L_1} + I_f$

$\Rightarrow I_{a_1} = I_{L_1} + \frac{V}{R_{sh}}$

$\Rightarrow I_{a_1} = I_{L_1} + \frac{V}{25}$

and,

$I_{a_2} = I_{L_2} + I_{sh}$

$\Rightarrow I_{a_2} = I_{L_2} + \frac{V}{R_{sh}}$

$\Rightarrow I_{a_2} = I_{L_2} + \frac{V}{25}$

putting the value of I_{a_1} in eq (1)

$210 = 0.04\left(I_{L_1} + \frac{V}{25}\right) + V$

$\Rightarrow 210 = 0.04 I_{L_1} + 0.04\frac{V}{25} + V$

$\Rightarrow 210 = 0.04 I_{L_1} + \frac{V}{2500} + V$

$\Rightarrow 210 = 0.04 I_{L_1} + V + \frac{V}{2500}$

$\Rightarrow 210 = 0.04 I_{L_1} + \frac{2500V + V}{2500}$

$\Rightarrow 210 = 0.04 I_{L_1} + \frac{2501V}{2500}$ —— Eq (3)

$\Rightarrow 2000 + 2.5 I_{L_1} = [illegible]\, 25005$ —— Eq (4) putting I_{L_2} in eq (ii)

$220 - \left(I_{L_2} + \frac{V}{20}\right) 0.01 = V$

$\Rightarrow 220 - 0.01 I_{L_2} - \frac{V}{20} \times 0.01 = V$

$\Rightarrow 220 - 0.01 I_{L_2} = V + \frac{V}{20} \times 0.01$

$\Rightarrow 220 - 0.01 I_{L_2} = V + \frac{V}{2000}$

$\Rightarrow 220 - 0.01 I_{L_2} = \frac{2001V}{2000}$ ~~— eq (iv)~~

$\Rightarrow \frac{2001V}{2000} + 0.01 I_{L_2} = 220$

$\Rightarrow 2001V + 20 I_{L_2} = 220 \times 2000$

$\Rightarrow 2001V + 20 I_{L_2} = 440000$ —— eq (iv)

~~Subtracting~~

eq (iii) − eq (iv)

$\cancel{2001V} + 20 I_{L_1} = 420000$

$-\;\cancel{2001V} + 20 I_{L_2} = 440000$

$20 I_{L_1} - 20 I_{L_2} = 20000$

$\Rightarrow I_{L_1} - I_{L_2} = \frac{20000}{20} = 1000$ —— eq (v)

~~also~~ $I_{L_1} + I_{L_2} = 4000$ —— eq (vi)

$I_{L_1} + I_{L_2} = 4000$

$I_{L_1} - I_{L_2} = 1000$

$2 I_{L_1} = 5000 \Rightarrow \frac{5000}{2} = 2500$ Amp.

$I_{L_1} + I_{L_2} = 4000$

$\Rightarrow 2500 + I_{L_2} = 4000$

$\Rightarrow I_{L_2} = 4000 - 1500 = 1500$ Amp.

[illegible]

~~$I_{sh} = \frac{V}{R_{sh}}$~~ Putting I_{L_2} in eq. (vi)

$\Rightarrow 420000 = 20 I_{L_2} + 2001V$

$\Rightarrow 420000 - 20 I_{L_2} = 2001V$

$\Rightarrow 420000 - 20 \times 1500 = 2001V$

$\Rightarrow 420000 - 30000 = 2001V$

$\Rightarrow V = \frac{390000}{2001} = 194.90 \text{ V}$

~~$P_{L_1} = V \times I_{L_1} = 194.90 \times 1500$~~

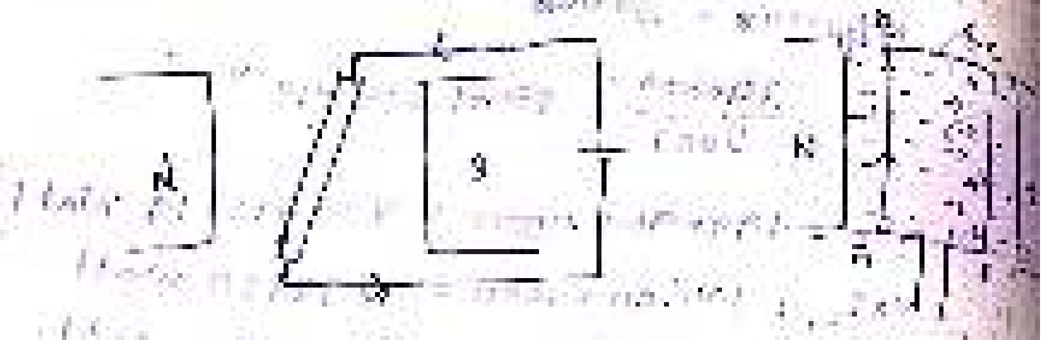
$P_{L_1} = V \times I_{L_1} = 194.90 \times 1500 = 292350$ watt

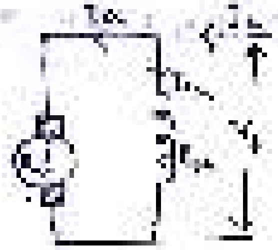
$P_{L_2} = V \times I_{L_2} = 194.9 \times 2500 = 487250$ watt

D.C. Motors

Working Principle of D.C. Motor :-

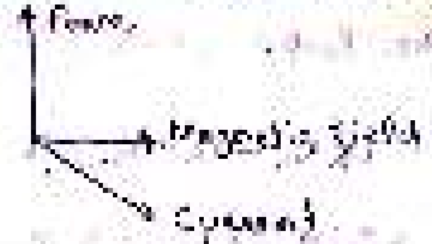
The machine which convert electrical energy to mechanical energy is called D.C. motor.



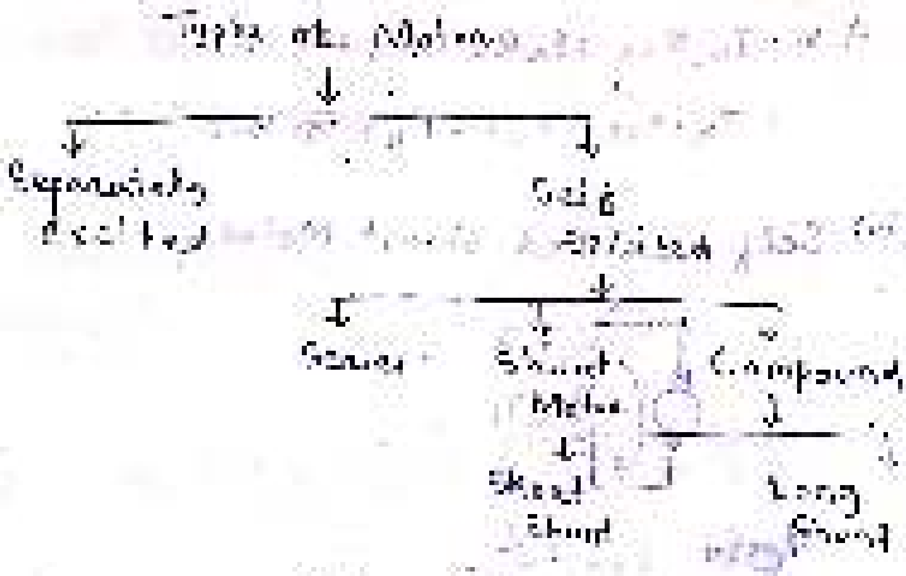


When some voltage is applied to the terminal of the motor the current in the field winding is $I_{sh} = \frac{V_t}{R_{sh}}$. Due to this field current the magnetic pole will excite and they will behave as magnet. Due to the terminal voltage V_t some current will flow in the armature winding. This is the condition of a current carrying conductor placed inside the magnetic field.

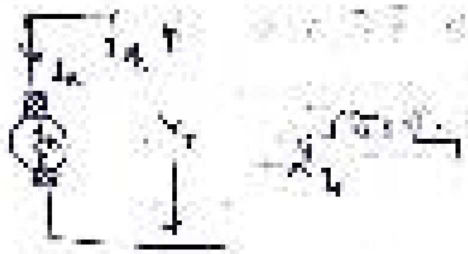
According to the basic principle of electromagnet phenomenon a current carrying conductor placed in the magnetic field it experiences a torque and the direction of torque is given by Fleming's Left hand Rule.



Types of Motor :-



(i) Separately excited Motor :-



Apply KVL in the loop,

$V_t - I_a R_a - E_b = 0$

$\Rightarrow V_t = E_b + I_a R_a$

$I_a = I_L$

(ii) Self excited Series motor :-

Apply

Apply KVL in the loop -

$V_t - I_{se}R_{se} - I_a R_a - E_b - B.D = 0$

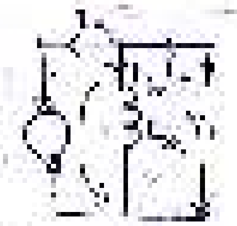
$\Rightarrow V_t = I_{se}R_{se} + I_a R_a + E_b + B.D.$

$I_a = I_{se}$

$\Rightarrow V_t = I_a R_{se} + I_a R_a + E_b + B.D.$

$= I_a(R_{se} + R_a) + E_b + B.D.$

(iii) Self excited shunt Motor -



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

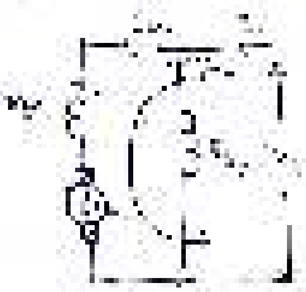
Apply KVL in the loop -

$V_t - I_a R_a - B.D - E_b = 0$

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

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

(iv) Long shunt compound Motor



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

Apply KVL in the loop

$V_t - I_a R_{se} - I_a R_a - E_b - B.D = 0$

$\Rightarrow V_t = I_a R_a + I_a R_{se} + E_b + B.D$

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

$I_a = I_L + I_{sh}$

(ii) Short Shunt Compound Motor:-

$I_{sh} = \frac{V_t - I_L R_{se}}{R_{sh}}$

Apply KVL in loop

$V_t - I_L R_{se} - I_a R_a - B.D. - E_b = 0$

$\Rightarrow \boxed{V_t = I_L R_{se} + I_a R_a + E_b + B.D.}$

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

<u>Significance of back emf (E_b)</u>:-

Since the generated emf in case of motor opposes after all the motor are completed - so, it is called back emf (E_b)

In a motor $E_b = V_t - I_a R_a$

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

At the time of starting $E_b = 0$, so that

$\therefore I_a = \frac{V_t}{R_a}$. Since the terminal voltage has a high value and armature resistance has a small value so a huge amount of armature current will flow through the armature winding which will burnt the armature winding.

Condition for Maximum efficiency :-

$E_b = V_t - I_a R_a$ ——— eq (i)

$\Rightarrow E_b I_a = V_t I_a - I_a^2 R_a$

$\frac{d}{dI_a}(E_b I_a) = 0$ $\qquad \frac{d}{dI_a}(V_t I_a - I_a^2 R_a) = 0$

$\Rightarrow V_t - 2 I_a R_a = 0$

$\Rightarrow V_t = 2 I_a R_a$

$\Rightarrow I_a R_a = \frac{V_t}{2}$ ——— eq (ii)

Putting $I_a R_a$ in eq (i)

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

$\Rightarrow \boxed{E_b = \frac{V_t}{2}}$ condition for maximum efficiency

Hence when the back emf is half of the applied voltage maximum power will be obtained.

Q. A 440 V DC shunt motor has a armature resistance of 0.8 Ω and the field resistance of 200 Ω. Determine the back emf when giving an output of 7.46 kW and 85% efficiency.

Ans Given data

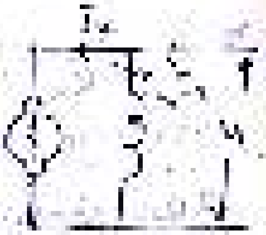
$V_t = 440$ V

$R_a = 0.8\ \Omega$

$R_{sh} = 200\ \Omega$

$P_{out} = 7.46$ kW

Efficiency $(\eta) = 85\% = 0.85$



We know

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

$\Rightarrow 0.85 = \frac{7.46 \times 10^3 \times 10}{P_{i/p}}$

$\Rightarrow P_{i/p} = \frac{7.46 \times 10^3}{0.85} = 8776.47$ watt.

$P_{i/p} = V_t \times I_L$

$\Rightarrow 8776.47 = 440 \times I_L$

$\Rightarrow I_L = \frac{8776.47}{440} = 19.94$ Amp.

$I_{sh} = \frac{V_t}{R_{sh}} = \frac{440}{200} = 2.2$ Amp.

$I_L = I_a + I_{sh}$

$\Rightarrow I_a = I_L - I_{sh} = 19.94 - 2.2 = 17.74$

Apply KVL in the loop

$V_t = I_aR_a + E_b + \ldots$

$\Rightarrow 440 = 17.74 \times \ldots + E_b$

$\Rightarrow E_b = 440 - \ldots = 433.802$ V (Ans)

Q8. A 220V DC machine has an armature resistance of 0.5 Ω. If the full load current is 20A, find the induced emf when the machine acts as (i) generator (ii) motor.

Ans) Given Data,

$V_t = 220$ V

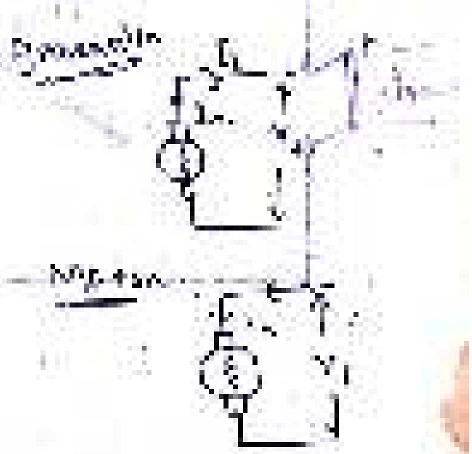
$R_a = 0.5\ \Omega$

$I_L = I_a = 20$ A.

In generator case,

$E_g = V_t + I_aR_a + \ldots$

$= 220 + (20 \times 0.5) = 230$ V



b) In Motor case

$V_t = I_a R_a + E_b$

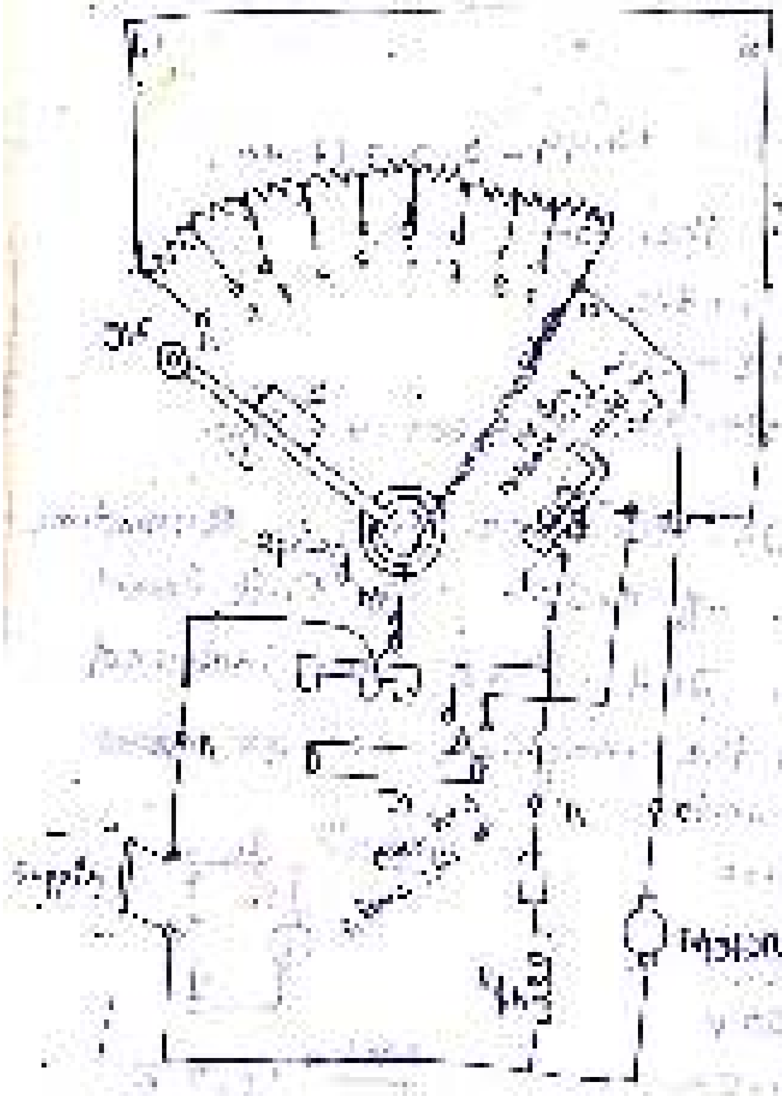
$\Rightarrow V_t - I_a R_a = E_b$

$\Rightarrow E_b = 220 - (20 \times 0.5)$

$= 220 - 10 = 210V$

$\therefore E_g = 230V,\ E_b = 210V$

3-point starter



Different types of starters used for D.C. motors:

There are 2 types of starters used for starting the D.C. shunt and compound motors.

i) D.C. three point starter.

ii) D.C. four point starter.

D.C. three point starter:

The starter has got only three terminals namely line (L), armature (A) and field (F or Z) so it is called a three point starter as shown in the figure.

Parts of a D.C. Three point starter:

The following are the main parts of a three point starter:

i) Variable resistance:

It is made of an alloy. It is connected with the armature in series. The resistance is used to limit the starting current and [illegible]. It is in the form of spiral shape and placed on the position the [illegible]. A convenient method of tapping the connections with the studs. When the motor starts, full resistance is connected in series with the armature and as the motor attains the speed, it is gradually decreased to zero value.

ii) Handle:

It is made of an iron and is insulated from the starter. A soft copper strip is placed under the handle to make contact with the studs. It has a soft iron piece which is held by the no volt coil and the handle remains in ON position as long as the current flows through the no volt coil.

(iii) Spring :-

It is wound on the handle of the starter. The function of the spring is to bring the handle in OFF position in case of supply fails. Tension of the spring is adjust with ... so that the handle comes at the OFF position immediately when the no volt coil is demagnetised.

(iv) No volt coil :-

It is an electromagnet consisting of many turns of thin wire and is connected in series with the shunt field. The coil is magnetised by the current flowing in the shunt field and holds the starter handle in the ON position. If in case of supply failure, the no volt coil gets demagnetised and the handle returns back to OFF position under the action of spring thereby disconnecting the motor from the mains.

(v) Over load coil :-

It is also an electromagnet which is connected in the line and the handle. It consists of a few turns of thick wire ... connected in the

the current flowing in the armature. If due to any reason (fault or over load) the load current is increased, the no volt coil terminals are short circuited by the over load coil lever. The no volt coil ~~terminals are short ci~~ is demagnetised and then release the handle which return to OFF position automatically by the spring action. Thus, the motor stops. So it is called over load release coil.

Function of a D.C. three point starter with no volt and over load release:

The starter is a device which is used for the safety of D.C. motor. A three point starter is used for starting the D.C. shunt motor, on the starter face plate there are three terminals which are marked as L, A, F etc. The positive wire (+ve) is connected to the L terminal. The A and F terminals are connected to armature and field respectively. This starter also consists of a variable resistance and two coils called the no volt coil (N.V.C) and over load coil (O.L.C) as shown in the figure the N.V.C is wound by many turns of thin wire and is connected in series with the shunt field. The O.L.C consists of few turns of thick wire and is connected in series with the line and handle. The handle of the starter is moved from OFF position before starting. When the handle is moved to stud number 1 the whole

Resistance is in series with the armature. As the speed of the motor goes up, the handle is moved slowly from stud number 1 (from OFF position) to the ON position. The motor should attain its normal speed, as complete resistance is cut off. In the running condition, the N.V.C. is magnetised by current flowing in the shunt field, the handle of the starter is held in the ON position. If at any time the supply goes off, the N.V.C. is de-energised and it releases the handle and goes back to the OFF position by the spring force. In case of overloads, the series winding, the motor will take heavy current, the O.L.C. is magnetised and attracts the lever thereby short circuiting of N.V.C. ... the N.V.C. will be de-magnetised and it will release the handle which comes back to OFF position by the spring force.

Function of 4 Pt. (four point) Starter:

A four point starter is used with shunt or compound motor. It has four terminals marked as L, F, A, L. A four point starter ... In this starter, the N.V.C. coil is connected directly across the line through a protecting resistance, unlike the three point starter, in which it is in series with the field. The construction is similar to that of a 3 point starter. This

starter is used at places where much speed regulation is required. For maximum variation of speed a high resistance is connected in series with the shunt field winding.
If this resistance is used in three point starter, it will reduce the shunt field winding current. It means the current passing through the N.V.C. is also decreased. Therefore, the N.V. coil will not be able to produce sufficient magnetic strength and therefore, release the handle to the OFF position. This problem has been rectified in four point starter so that N.V.C. is able to form a strong magnet.

Characteristics of DC Motor:

Series Motor:

1. Torque vs armature current

$T_a \propto \phi I_a$ before saturation

we know

$\phi \propto I_f$

In series motor

$I_f = I_a$

$\phi \propto I_a$

$T \propto \phi I_a$

$\Rightarrow T \propto I_a I_a$

$\Rightarrow T \propto I_a^2$

$T_a = F \times r$

$\Rightarrow T_a = \frac{P}{2\pi} \phi Z I_a / A$

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

After saturation, ϕ becomes maximum (i.e. constant).

So $T \propto I_a$

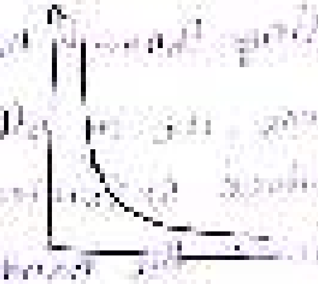
2. Speed (N) vs armature current (I_a)

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

$\phi \propto I_a$ $\uparrow$ [illegible] $I_a \uparrow$

$N \propto \frac{1}{\phi}$ $I_a \uparrow \propto \frac{1}{N\downarrow}$

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



3. Speed (N) vs Torque

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

$\therefore$ [illegible] $\frac{T}{I_a}$ [illegible] $\frac{E_b}{N}$

$\therefore \frac{T}{I_a} \propto \frac{E_b}{N}$ [illegible]

Speed Regulation:

Series motor can not run on no load. Under no load condition, the speed is dangerously high, so it is used under heavy load condition.

So it is used in traction.

Shunt motor :-

(i) Torque v/s armature current

$T \propto \phi I_a$

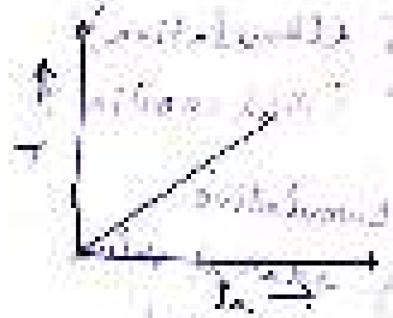
$\phi \propto I_{sh}$

If $I_a \propto I_L$

V and R_{sh} is constant

I_{sh} is constant ∴ ϕ is constant

∴ $T \propto I_a$



(ii) Speed v/s armature current

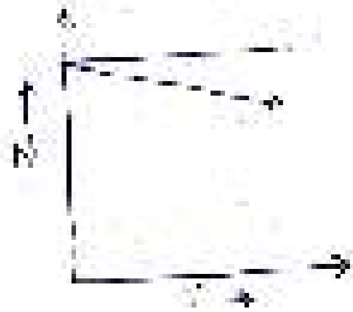
$N \propto \frac{E_b}{\phi}$

ϕ is constant (∵ I_{sh} and R_{sh} constant) ∴ I_{sh} = constant

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

(iii) Speed v/s Torque

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



Compound Motor (DC)

1. Torque V/s armature current

2. Speed V/s armature

Cumulative — $\phi_{sh} + \phi_{se}$

differential — $\phi_{sh} - \phi_{se}$

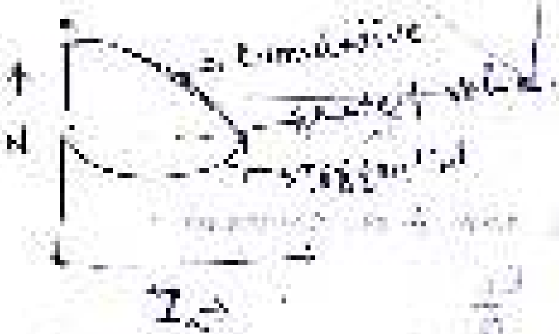
3. Speed V/s Torque (mechanical) = Speed V/s Torque

ϕ_{sh} = constant

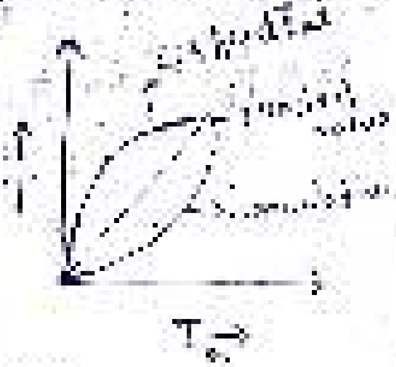
$\phi_{se} \propto I_a$

$(\phi_{sh} + \phi_{se})\uparrow \to N\downarrow$ (cumulative)

$(\phi_{sh} - \phi_{se})\downarrow \to N\uparrow$ (differential)



4. Torque V/s armature



$T \propto \phi I_a$

$\phi = \phi_{sh} \pm \phi_{se}$

ϕ_{sh} = constant

$\phi_{se} \propto I_a$

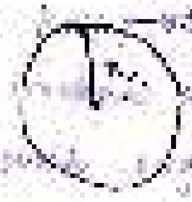
$\phi = (\phi_{sh} + \phi_{se})\uparrow$ cumulative

$\phi = (\phi_{sh} - \phi_{se})\downarrow$ differential

Torque developed by armature of DC motor

Torque is the turning effort ...

$T = F \times r$



Work done $= F \times d$
$= F \times 2\pi r$

Power developed = Work done × speed in rps

$= F \times 2\pi r \times N/60$

$= F \times r \times 2\pi N/60$

$\Rightarrow T \times \omega$ ($\because \omega$ = angular speed $= 2\pi N/60$)

$\therefore \boxed{P_a = T_a \times \omega}$

or $E_b I_a = T_a \times \omega$

$\Rightarrow E_b I_a = T_a \times \omega$ (from power equation)

$\Rightarrow \frac{\phi Z N P}{60 A} \times I_a = T_a \times \frac{2\pi N}{60}$

$\Rightarrow \frac{\phi Z N P I_a}{60 A} = T_a \times \frac{2\pi N}{60}$

$\Rightarrow \frac{\phi Z P I_a}{A} = T_a \times 2\pi$

$\Rightarrow T_a = \frac{\phi Z P I_a}{2\pi A}$

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

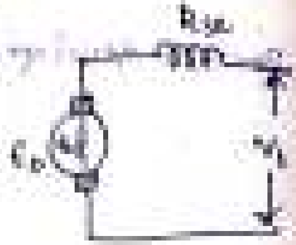
$E_b I_a = T_a \times \omega$

$\Rightarrow E_b I_a = T_a \times \frac{2\pi N}{60}$

$\Rightarrow T_a = \frac{60 E_b I_a}{2\pi N}$

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

Q. A 250V, 4 pole wave connected DC series motor has 752 conductors on its armature. It has 0.75Ω the total armature and series resistance. The motor takes a current 40 Amp. Estimate the speed & torque developed by it if it has a flux/pole of 25 mWb.



Ans. Given Data

$V_t = 250V$

$P = 4$

$A = 2$

$Z = 752$

$R_a + R_{se} = 0.75\Omega$

$I_a = I_L = 40$ Amp.

$\phi = 25$ mWb $= 25 \times 10^{-3}$ Wb.

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

$$= \frac{0.159 \times 4 \times 25 \times 10^{-3} \times 752 \times 40}{2}$$

$= 239.136$ Nm

~~$N = \frac{\cdots}{T_a} = \frac{\cdots}{239.136}$~~

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

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

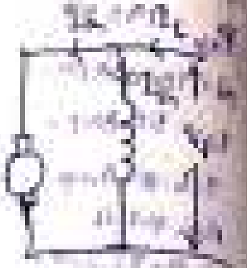
$$= 250 - 40 \times 0.75 = 220\ V$$

$$220 = \frac{4 \times 25 \times 10^{-3} \times 752 \times N}{60 \times 2}$$

$$\Rightarrow \frac{220 \times 2 \times 60}{4 \times 25 \times 10^{-3} \times 752} = N$$

$\Rightarrow N = 351.0638$ rpm

Q. A 230 V, DC shunt motor runs at 500 rpm when the armature current is 50 Amp. Calculate the speed if the torque is doubled. Given armature resistance is 0.2 Ω.



Ans Given Data:

$V_t = 230\,V$

$N_1 = 500$ rpm.

$I_{a_1} = 50$ Amp.

$R_a = 0.2\,\Omega$

$E_{b_1} = V_t - I_a R_a - B.D.$

$= 230 - (50 \times 0.2) = 230 - 10 = 220\,V$

$$T_1 = \frac{9.55 \times E_b I_a}{N} = \frac{9.55 \times 220 \times 50}{500} = 210.1$$

$T_2 = 2T_1 = 420.2\,Nm$

We know,

$T \propto I_a$ (in shunt motor)

$\Rightarrow \frac{T_1}{T_2} = \frac{I_{a_1}}{I_{a_2}}$

$\Rightarrow \frac{T_1}{2T_1} = \frac{I_{a_1}}{I_{a_2}} \Rightarrow \frac{1}{2} = \frac{50}{I_{a_2}}$

$\Rightarrow I_{a_2} = 100$ Amp.

$\therefore E_{b_2} = V_t - I_{a_2} R_a - B.D.$

$= 230 - (100 \times 0.2) = 230 - 20 = 210\,V$

We know,

$E_b \propto N$ $\left(\because E = \frac{P\phi Z N}{60A},\ \phi = \text{constant}\right)$

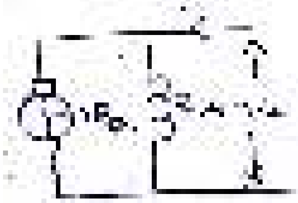
$\Rightarrow \frac{E_{b_1}}{E_{b_2}} = \frac{N_1}{N_2}$

$\Rightarrow \frac{220}{214} = \frac{230}{N_2}$

$\Rightarrow N_2 = \frac{230 \times 10^{?}}{214} = $ [illegible] $\approx$ [illegible] rpm.

Q3. A shunt D.C. machine has an armature resistance of 0.12 Ω and field resistance of 100Ω. The machine rated terminal voltage is 220 V. Find the ratio of speed as generator and motor if the current is 50 Amp in each case.

Ans. Given Data:



$R_a = 0.12\ \Omega$

$R_{sh} = 100\ \Omega$

$V_t = 220\ V$

$I_L = 50$ Amp

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

[illegible]

$I_{sh} = \frac{V_t}{R_{sh}} = \frac{220}{100} = 2.2$ Amp

generator: $I_a = I_L + I_{sh} = 50 + 2.2 = 52.2$ Amp.

motor: $I_a = I_L - I_{sh} = 50 - 2.2 = 47.8$ Amp.

$E_g = V_t + I_a R_a$

$= 220 + (52.2 \times 0.12) = 226.264\ V$

$E_b = V_t - I_a R_a$

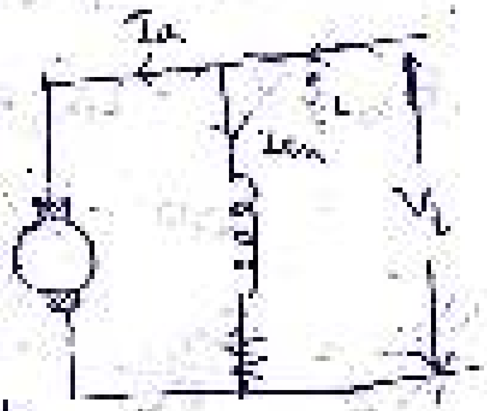
$= 220 - (47.8 \times 0.12) = 214.264\ V$

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

$\Rightarrow \frac{N_1}{N_2} = \frac{226.264}{214.264} = 1.056$

Speed ~~Flux~~ Control of shunt motor by flux control method

V_t = terminal voltage



Ia_1 = Armature current without external resistance added to the shunt field.

Ia_2 = Armature current with external resistance added to the shunt field.

N_1 = speed without external resistance is added to the shunt field.

N_2 = speed with external resistance added to the shunt field.

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ϕ_1 = flux without external resistance added to the shunt field.

ϕ_2 = flux with external resistance added to the shunt field.

$E_{b} = V_t - I_a R_a$

$\Rightarrow \frac{P\phi Z N}{60 A} = V_t - I_a R_a$

$\Rightarrow K\phi N = V_t - I_a R_a$

$\Rightarrow N \uparrow = \frac{V_t - I_a R_a}{K\phi \downarrow}$ $\Rightarrow N = \frac{E_b}{K\phi}$

$E_b = K\phi N$

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

$E_{b_1} = V_t - I_{a_1} R_a$

$E_{b_2} = V_t - I_{a_2} R_a$

$K\phi_2 N_2 = V_t - I_{a_2} R_a$

$\therefore \frac{E_{b_1}}{E_{b_2}} = \frac{K N_1 \phi_1}{K N_2 \phi_2} = \frac{V_t - I_{a_1} R_a}{V_t - I_{a_2} R_a}$

$\Rightarrow \frac{N_1 \phi_1}{N_2 \phi_2} = \frac{V_t - I_{a_1} R_a}{V_t - I_{a_2} R_a}$

Q: A 250 V DC shunt motor [illegible] armature resistance of [illegible] and [illegible] takes an armature current of [illegible] when running at [illegible] rpm. If the flux of the motor reduced by [illegible] without changing the load torque, find the new speed of the motor.

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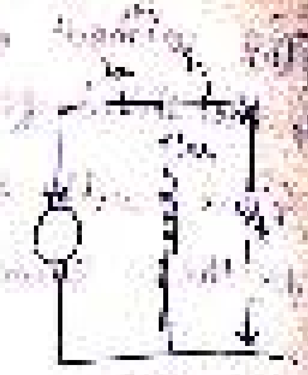
Ans: Given Data—



$N_1 = 2000$

$R_a = 0.25\,\Omega$

$I_{a_1} = 50$ Amp

$N_2 = $ [illegible] r.p.m.

$\Phi_1 = \Phi$

$\Phi_2 = $ [illegible] Φ_1

$= 0.9\,\Phi$

[illegible]

i.e. $T_1 = T_2$

$\Rightarrow \Phi_1 I_{a_1} = \Phi_2 I_{a_2}$

$\Rightarrow I_{a_2} = \frac{\Phi \times 50}{\Phi_2}$

$\therefore I_{a_2} = \frac{\Phi \times 50}{0.9\,\Phi} = 55.55$ Amp

We know

$$\frac{N_1\Phi_1}{N_2\Phi_2} = \frac{V - I_{a_1}R_a}{V - I_{a_2}R_a}$$

$\Rightarrow$ [illegible]

$\Rightarrow$ [illegible]

$\Rightarrow$ [illegible]

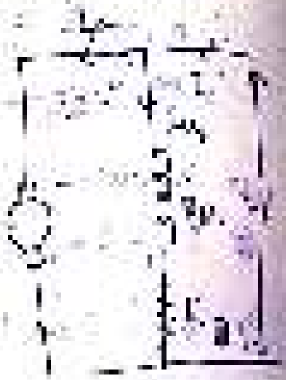
$\therefore N_2 = $ [illegible]

$\Rightarrow N_2 = $ [illegible] r.p.m.

$\Rightarrow N_2 = 1582.5$ rpm

Q_2. A 220 V shunt motor at 800 rpm takes an armature current of 50 Amp. Find resistance to be added in the shunt field circuit so that the speed will increase to 1000 rpm at an armature current of 80 Amp. Assume R_a & R_{sh} are 0.15 and 250 Ω respectively.

From given data -



$V_L = 220$ V

$N_1 = 800$ rpm

$I_{a_1} = 50$ Amp.

$N_2 = 1000$ rpm.

$I_{a_2} = 80$ Amp

$R_a = 0.15$ Ω

$R_{sh} = 250$ Ω

As we know

$$\frac{N_1 \phi_1}{N_2 \phi_2} = \frac{V_L - I_{a_1} R_a}{V_L - I_{a_2} R_a}$$

$$I_{sh_1} = \frac{V_L}{R_{sh}} = \frac{220}{250}$$

$$I_{sh_2} = \frac{V_L}{R_{sh} + R}$$

As we $\phi_1 \propto I_{sh_1}$

$$\Rightarrow \phi_1 = \frac{V_L}{R_{sh}}$$

$\phi_2 \propto I_{sh_2}$

$$\Rightarrow \phi_2 = \frac{V_L}{R_{sh} + R}$$

$$\Rightarrow \frac{N_2 \frac{\phi_2}{R_{sh}}}{N_1 \frac{250}{R_{sh}+R}} = \frac{V_t - I_{a_2} R_a}{V_t - I_{a_1} R_a}$$

$$\Rightarrow \frac{N_1 (R_{sh}+R)}{N_1 R_{sh}} = \frac{250 - (50 \times 0.15)}{250 - (80 \times 0.15)}$$

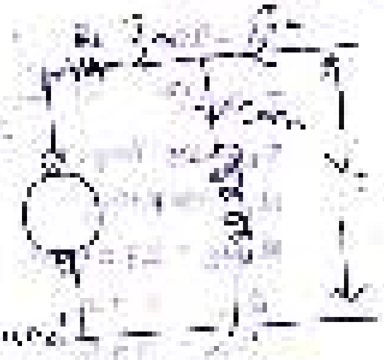
$$\Rightarrow \frac{1000 (250+R)}{1200 \times 250}$$

$$\Rightarrow 800 (250+R) = 255 \times 0.55$$

$$\Rightarrow 250+R = 318.75$$

$$\Rightarrow R = 68.75\ \Omega$$

Speed control of shunt motor by armature control method.



Case 1: Armature current without added in the armature circuit.

V_t = terminal voltage

N_1 = ~~function~~

Case 2: Armature without external resistance added in the armature circuit.

Case 3: Armature with external resistance added in the armature circuit.

Case 4: Armature current with external resistance added in the armature circuit.

R = external resistance added to the armature circuit.

$E_{b_1} = V_t - I_{a_1} R_a$

$E_{b_2} = V_t - I_{a_2} R_a$

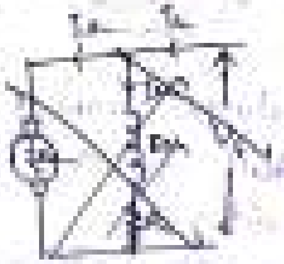
$$\frac{k N_2 \phi_1}{k N_1 \phi_1} = \frac{V_t - I_{a_2} R_a}{V_t - I_{a_1} R_a}$$

ϕ is constant because R_{sh} and V is constant.

$$\frac{N_1}{N_2} = \frac{V_1 - I_{a_1} R_a}{V_2 - I_{a_2}(R_a + R)}$$ when $I_a \uparrow$ the $N \downarrow$

Q. A DC shunt motor fed from 220V supply & the torque is proportional to the square of the speed and it takes 45 Amp when running 900 rpm. What resistance must be inserted in armature circuit in order to reduce the speed to 210 rpm. If the armature resistance and shunt field resistance 0.1 Ω and 110 Ω respectively.

Ans. Given Data



$V_1 = 220V$

$T \propto N^2 \Rightarrow \frac{T_1}{T_2} = \frac{N_1^2}{N_2^2}$

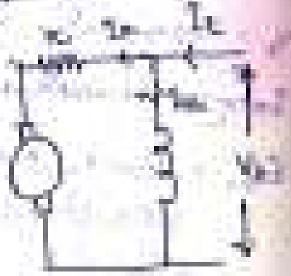
$I_L = 45$ Amp

$N_1 = 900$ rpm

$N_2 = 210$ rpm

$R_a = 0.1\Omega$

$R_{sh} = 110\Omega$



$I_{sh} = \frac{V_1}{R_{sh}} = \frac{220}{110} = 2$ Amp.

$I_L = I_a + I_{sh}$

$\Rightarrow I_{a_1} = I_L - I_{sh} = 45 - 2 = 43$ Amp

E_{b_1} at 900

$E_{b_1} = V_1 - I_{a_1} R_a$

$= 220 - (43 \times 0.1)$

$= 215.7$ V

E_{b_2} at 210

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

$\Rightarrow \frac{215.7}{E_{b_2}} = \frac{900}{210}$

$\Rightarrow E_{b_2} = \frac{215.7 \times 210}{900}$

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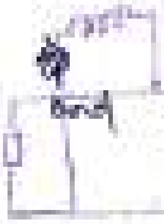
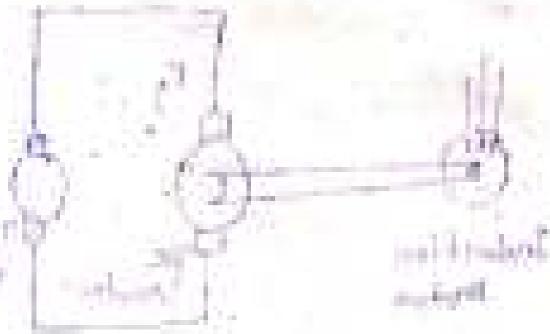
$T \propto \phi I_a$

$\Rightarrow T \propto I_a$ ($\because \phi$ is constant)

$\Rightarrow \dfrac{T_1}{T_2} = \dfrac{I_{a_1}}{I_{a_2}}$



$\dfrac{I_{a_1}}{I_{a_2}} = \dfrac{N_1^2}{N_2^2}$



$\Rightarrow \dfrac{43}{I_{a_2}} = \dfrac{(900)^2}{(700)^2}$

$\Rightarrow I_{a_2} = \dfrac{43 \times (700)^2}{(900)^2} = 26.01$ Amp

We have,

$\dfrac{N_1}{N_2} = \dfrac{V_1 - I_{a_1} R_a}{V_2 - I_{a_2}(R_a + R)}$

$\Rightarrow \dfrac{900}{700} = \dfrac{220 - (43 \times 0.1)}{220 - 26.01(0.1+R)}$

$\Rightarrow \dfrac{9}{7} = \dfrac{215.7}{220 - 26.01(0.1+R)}$

$\Rightarrow 220 - 26.01(0.1+R) = \dfrac{215.7 \times 7}{9}$

$\Rightarrow 220 - 26.01(0.1+R) = 167.76$

$\Rightarrow 26.01(0.1+R) = 220 - 167.76$

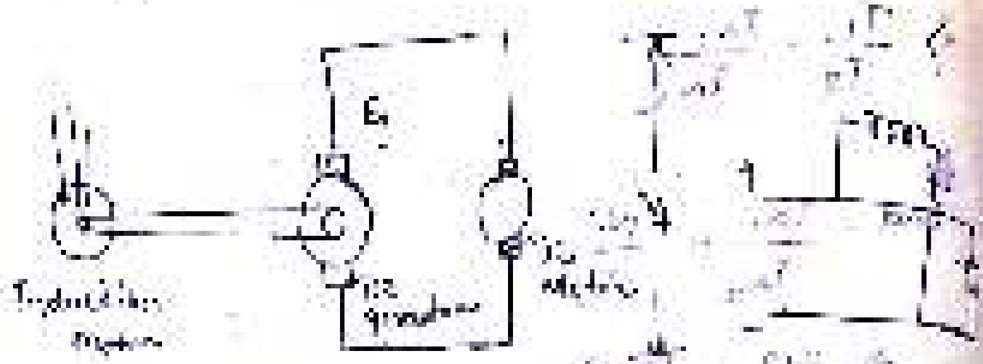
$\Rightarrow 26.01(0.1+R) = 52.23$

$\Rightarrow 0.1 + R = \dfrac{52.23}{26.01} = 2.008$

$\Rightarrow R = 2.008 - 0.1$

$\Rightarrow R = 1.908\ \Omega$ (Ans)

Speed control of DC shunt motor by using (changing) the terminal voltage



(Ward Leonard method)

The Ward Leonard method consists of induction motor, DC generator, DC motor.

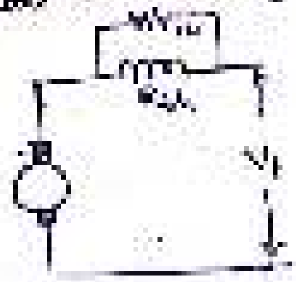
The DC motor, shaft is coupled with DC generator. The induction motor and the dc generator is called motor generator set.

A separate supply is given to the field winding of the generator.

When the induction motor runs the dc generator runs at some speed. Due to the field current emf is induced in the dc generator. The emf of the dc generator is given to the dc motor, so the motor input voltage is variable by this method.

Generally this method is used for increasing the speed.

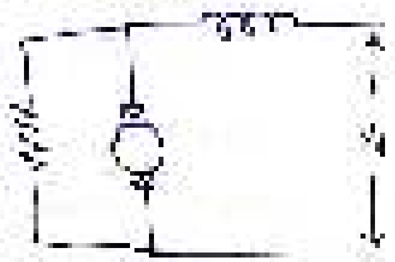
Speed control of DC series motor by flux control
Field diverter method



Current is diverted by connecting the resistance parallel to the field winding.

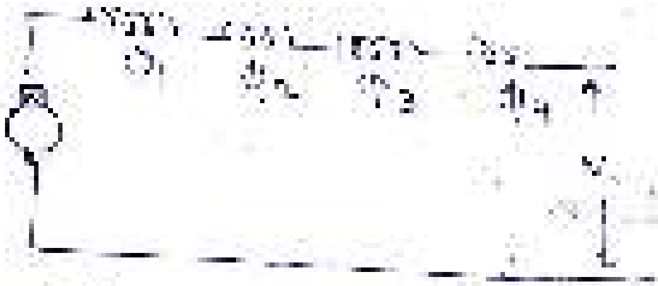
Speed

By armature diverter method :-



To maintain a constant load torque the decrease in the armature diverter the flux is increased. If flux increases speed will decrease.

Tapped control :-



Here flux are added, so speed will decrease.

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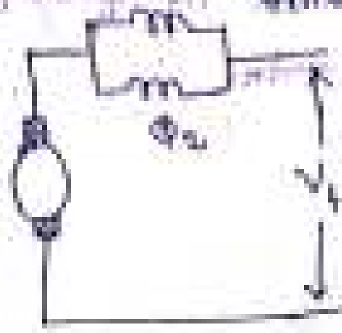
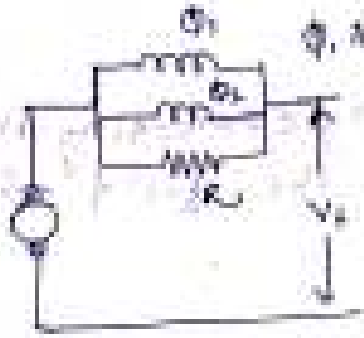


$\therefore \Phi \downarrow$ so $N \uparrow$



$\therefore \Phi \downarrow$ so $N \uparrow$

Ans: <u>Given Data</u>:

unsaturated magnetic circuit : $\Phi \propto$ constant

$R_s = 0$

$N_1 = N$

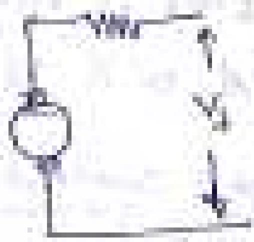
$I_{a_1} = I_{L_1} = 50$ Amp.

$V_t = 500V$

$T \propto N^3$

$N_2 = 0.75N$

$R_s = ?$



$E_{b_1} = V_t - I_{a_1}R$

We know,

$T \propto \Phi I_a$

$\Rightarrow T \propto I_a I_a$ $\quad$ ($\because \Phi \propto I_s$ in series motor, $I_s = I_a = I_L$, $\Phi \propto I_a$)

$\Rightarrow T \propto I_a^2$

$\Rightarrow \frac{T_1}{T_2} = \frac{I_{a_1}^2}{I_{a_2}^2}$

we have,

$T \propto N^3 \quad \Rightarrow \frac{T_1}{T_2} = \frac{N_1^3}{N_2^3}$

$\therefore \frac{I_{a_1}^2}{I_{a_2}^2} = \frac{N_1^3}{N_2^3}$

$\Rightarrow \frac{(50)^2}{I_{a_2}^2} = \frac{N^3}{(0.75N)^3}$

$\Rightarrow \frac{2500}{I_{a_2}^2} = \frac{N^3}{0.421 N^3}$

$\Rightarrow 2500 \times 0.421 = I_{a_2}^2$

$\Rightarrow I_{a_2}^2 = 1054.68$

$\Rightarrow I_{a_2} = \sqrt{1054.68} = 32.47$ Amp.

$E_{b_1} = V_t - I_{a_1}(R_a + R_{se})$

R_a and R_{se} are not given so neglected

$\therefore E_{b_1} = V_t = 500\,V$

we know

$E_b \propto \phi N$

$\Rightarrow \frac{E_{b_1}}{E_{b_2}} = \frac{\phi_1 N_1}{\phi_2 N_2}$

$\Rightarrow \frac{500}{E_{b_2}} = \frac{I_{a_1}}{I_{a_2}} \times \frac{N}{0.75N} \quad (\because \phi \propto I_a)$

$\Rightarrow \frac{500}{E_{b_2}} = \frac{50}{32.47} \times \frac{1}{0.75}$

$\Rightarrow E_{b_2} = \frac{500 \times 32.47 \times 0.75}{50}$

$\Rightarrow E_{b_2} = 243.525$

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We know,

$E_{b_2} = V - I_{a_2}(R_a + R_{se})$

$\Rightarrow 243.5\ldots = 500 - 32.47 \times R_{se}$

$\Rightarrow 32.47\, R_{se} = 500 - 243.5\ldots$

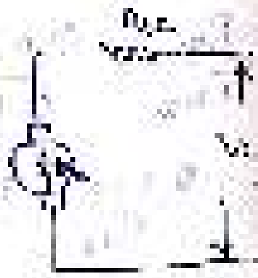
$\Rightarrow R_{se} = \dfrac{256.\ldots}{32.47}$

$\Rightarrow R_{se} = 7.8\ldots\ \Omega$ Ans

Q: A DC ~~shunt~~ series motor [illegible] with negligible magnetic circuit and [illegible]

Q: The speed of 37.3 kW series motor running on 500 V supply is [illegible] rpm at full load and the efficiency is [illegible] at full load. The full load torque is made [illegible] Nm and a resistance is connected in series with the machine. Calculate the speed of the machine with [illegible]. Assume the magnetic circuit is unsaturated and armature and field resistance is [illegible].

Ans: Given Data:



$P_o = 37.3$ kW

$V_t = 500$ V

$N_1 = 1250$ rpm

$\eta = [illegible]$

$T_L = [illegible]$ Nm.

$R_{se} = [illegible]\ \Omega$

$R = [illegible]$

$R_a + R_{se} = 0.5\ \Omega$

$P_i = [illegible]$

We have $\eta = \frac{P_{out}}{P_{i/p}}$

$\Rightarrow 0.9 = \frac{37.75 \times 10^3}{P_{i/p}}$

$\Rightarrow P_{i/p} = \frac{37.75 \times 10^3}{0.9} = 41944.44 = 41.944\ kW$

$P_{i/p} = V_t I_L \qquad \Rightarrow I_L = \frac{P_{i/p}}{500}$

$\Rightarrow I_{L_1} = \frac{41.944 \times 10^3}{500} = 83.88\ Amp$

$I_{L_1} = I_{a_1}$

$E_{b_1} = V_t - I_{a_1}(R_a + R_{se})$

$= 500 - 83.88(0.5)$

$= 500 - 41.94 = 458.06\ V$

$E_{b_2} = V_t - I_{a_2}(R_a + R_{se} + R)$

$T_1 = \frac{9.55 \times E_{b_1} I_{a_1}}{N_1} = 483.39\ Nm$

We know,

$T \propto \phi I_a$

$\Rightarrow T \propto I_a \quad (\phi = constant)$

$\Rightarrow \frac{T_1}{T_2} = \frac{I_{a_1}}{I_{a_2}}$

$\Rightarrow \frac{483.39}{345.43} = \frac{83.88}{I_{a_2}}$

$\Rightarrow I_{a_2} = \frac{83.88 \times 345.43}{483.39} = 59.94\ Amp$

$E_{b_2} = V_t - I_{a_2}(R_a + R_{se} + R)$

$= 500 - 59.94(5.5)$

$= 500 - 329.68 = 170.32\ V$

We know,

$E_b \propto \phi N$

$\Rightarrow E_b \propto N \quad (\phi = constant)$

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

$\Rightarrow \frac{458.35}{...} = \frac{450}{N_2}$

$\Rightarrow N_2 = \frac{450 \times 13.5 ...}{458.5}$

$\Rightarrow N_2 = 1314.56$ rpm (Ans)

Testing of D.C. Machine:

1. Brake Test

$P_{i/p} = V_t I_L$

$P_{o/p} = T \times \omega$

$= F \times (r + t) \times \omega$

$= M \times g \times (r+t) \times \omega$

$= (S_1 - S_2) \times 9.8 \times (r+t) \times \frac{2\pi N}{60}$

S_1 and S_2 = spring balance reading

r = radius of the shaft of pulley

t = thickness of belt

N = speed in rpm

Procedure :-

→ Loosen the belt to start the machine with zero to no load.

→ Excite the machine as a motor.

→ When the machine is at rated speed tight the belt.

→ Input power to the motor = $V_t I_L$

output power of the motor is

$P_{o/p} = T\omega$

$= F \times r \times \omega$

$= M g \times (r+t) \times \frac{2\pi N}{60}$ watt

$= (S_1 - S_2) \times 9.81 \times (R + t) \times \frac{2\pi N}{60}$

Disadvantages :-

→ Considerable amount of energy is wasted

→ It is generally performed in small machine.

→ The reading of the spring balance is not steady.

Q. A brake test on a small DC shunt motor gives the following data.

(i) Spring balance reading 25 kg and 9 kg.

(ii) Diameter of the shaft is 19.5 cm.

(iii) Thickness of the belt is 0.25 cm.

(iv) speed is 1500 rpm

(v) Applied voltage is 230 V

(vi) line current is 12.5 Amp

Calculate the shaft torque and efficiency?

Ans Given Data :-

$S_1 = 25$ kg

$S_2 = 9$ kg

$t = 0.25$ cm $= 0.25 \times 10^{-2}$ m

$D = 19.5$ cm $= 19.5 \times 10^{-2}$ m.

$R = \frac{19.5}{2} \times 10^{-2}$ m $= 9.75 \times 10^{-2}$ m.

$N = 1500$ rpm.

$V_L = 230$ V

$I_L = 12.5$ Amp.

$P_{i/p} = V_L I_L = 230 \times 12.5 = 2875$ watt

$P_{o/p} = (S_1 - S_2) \times 9.81 \times (R + t) \times \frac{2\pi \times N}{60}$

$= (25 - 9) \times 9.81 \times (9.75 \times 10^{-2} + 0.25 \times 10^{-2})$

$\times \frac{2\pi \times 1500}{60}$

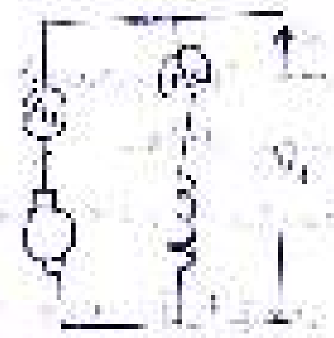
P_{cu} (full load) $= (16 \times 2.81 \times 10^{...})^2 \times$ [illegible]

P_{cu} $= 2465.52$ W

Efficiency $= \frac{P_o}{P_{i/p}} = \frac{2465.52}{[illegible] 7625} = 0.9895$

$= 98.95$ %

Swinburne Test



I_0 be the no load current

Total loss in a motor = constant loss + variable loss.

In Swinburne's test, [illegible] input = loss.

Efficiency = $\frac{output}{input} = \frac{input - loss}{input}$

In this method the machine will run at rated voltage and rated speed to know the efficiency of the motor.

Advantages:-

This test is generally used in large machines because there is no need of load to consume while performing the test.

Q. A 400V DC shunt motor takes 5 Amp at no load with armature resistance of 0.5 Ω and shunt field resistance of 200 Ω. Calculate the output and efficiency when the motor takes a load current of 50 Amp.

Ans: Given Data:

$V_L = 400\,V$

$I_{NL} = 5\,Amp$

$R_a = 0.5\,\Omega$

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

$I_L = 50\,Amp$

$I_{sh} = \frac{V_L}{R_{sh}} = \frac{400}{200} = 2\,Amp$

$I_{a_{NL}} = I_{NL} - I_{sh} = 5 - 2 = 3\,Amp$

$I_{aL} = I_L - I_{sh} = 50 - 2 = 48\,Amp$

At no load condition:

Input power = losses

$\Rightarrow P_{ip} = W_C + I_a^2 R_a$

$\Rightarrow V_L I_{NL} = W_C + 3^2 \times 0.5$

$\Rightarrow 400 \times 5 = W_C + 4.5$

$\Rightarrow 2000 = W_C + 4.5$

$\Rightarrow W_C = 2000 - 4.5$

$\Rightarrow W_C = 1995.5\,watt$

At full load condition:

Input power = O/P + losses

$\Rightarrow P_{i/p} = P_{op} + W_C + I_a^2 R_a$

$\Rightarrow V_L I_L = P_{op} + 1995.5 + 48^2 \times 0.5$

$\Rightarrow (400 \times 50) - (48^2 \times 0.5) - 1995.5 = P_{op}$

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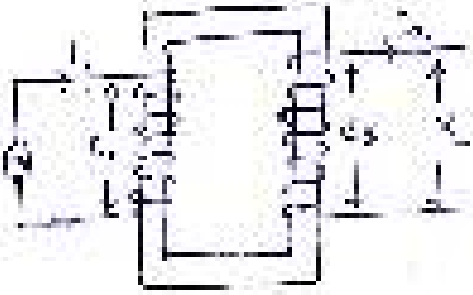
$P_{out} = 16852.5$ watts

$\eta = \frac{P_{out}}{P_{input}} = \frac{16852.5}{[illegible]} = 0.8426 \times 100 = 84$ [illegible]

TRANSFORMER



A transformer is a static device in which electrical power is transformed from one circuit to another without changing the frequency [illegible]

Principle of transformer :-

Consider an ideal transformer as shown in figure in which [illegible] [illegible] the primary winding [illegible] current [illegible] [illegible] induced in the primary winding [illegible] applied voltage [illegible] [illegible] [illegible]

Applying Fleming's right hand rule the direction of [illegible] [illegible] [illegible] [illegible] [illegible] electromagnetic induction the emf is induced in the two ends of the winding (i.e. E_1).

The flux created in the primary winding through the transformer core links with the secondary winding.

According to Faraday's law of electromagnetic induction an emf will developed in the secondary winding.

N_1 = No. of turns in the primary winding

N_2 = No. of turns in the secondary winding.

EMF equation of transformer:-

e_1 = Instantaneous voltage developed in the primary winding.

e_2 = Instantaneous voltage developed in the secondary winding.

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

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

$$= -N \phi_m \cos\omega t \cdot \omega$$

$$= \omega N \phi_m (-\cos\omega t)$$

$$= N \phi_m \omega \sin(\omega t - \frac{\pi}{2})$$

$$E_{rms} = \frac{E_m}{\sqrt{2}}$$

$$E_{rms} = \frac{N \phi_m \omega}{\sqrt{2}}$$ [∵ N [illegible]]

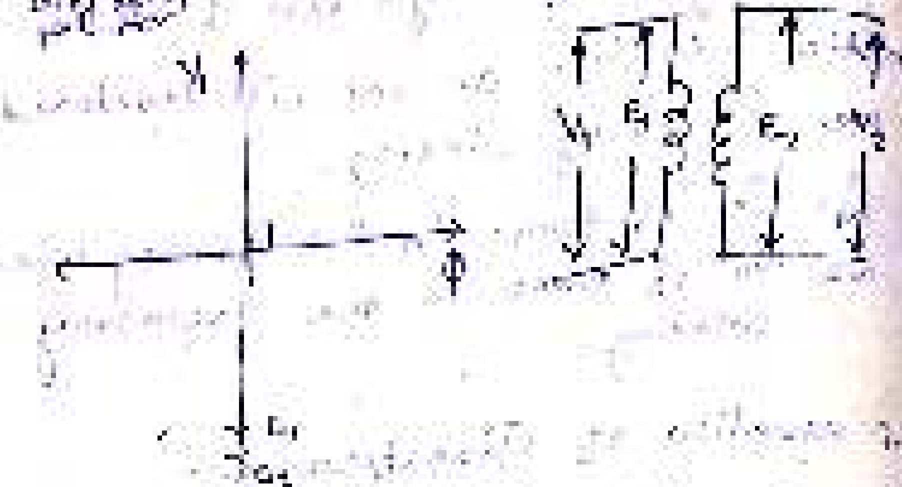
$$E_{rms} = \frac{N \phi_m 2\pi f}{\sqrt{2}}$$

$$E_{rms} = 4.44 f \phi_m N$$

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

$\Rightarrow \frac{V_1}{V_2} = \frac{N_1}{N_2}$, $\frac{V_2}{V_1} = \frac{N_2}{N_1} = K$ (Transformation ratio)

Phasor diagram of Ideal transformer on no load:



Transformer Construction:

A transformer has the following parts:

(i) Core
(ii) winding
(iii) Oil
(iv) Conservator
(v) breather
(vi) bushing
(vii) Explosion

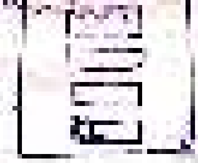
Transformers are of 2 types
(i) Core type
(ii) Shell type

Core type:

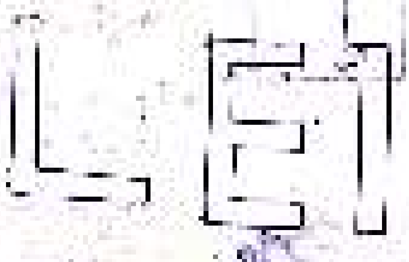
The winding surrounds the core.

Shell type:

The core surrounds the winding.



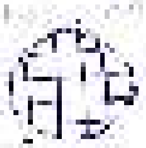
The shape of the core :



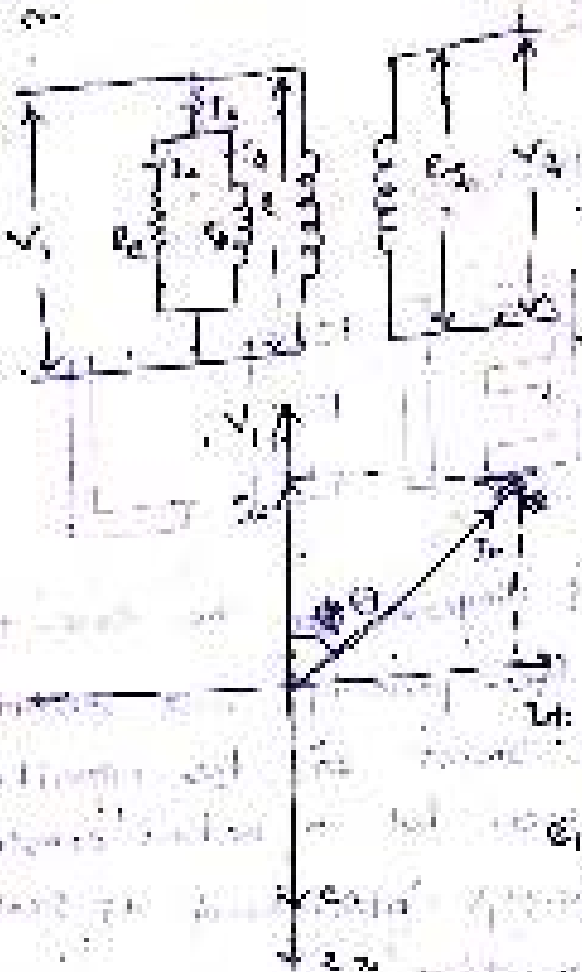
In a simplified diagram of the core type transformer the primary and secondary winding are shown on the opposite limbs of the core but in actual construction these are always interleaved to reduce the leakage flux.

Under the core [illegible] designing [illegible] it is essential to introduce [illegible] between the core [illegible].

2) [illegible] winding [illegible] [illegible] in [illegible] [illegible] [illegible] generally we will use Cross-section core.



Phasor diagram of practical transformer on no load



I_w for core loss component

I_ϕ magnetising component

I_ϕ is used to carry flux in the core

I_w is used to supply hysteresis & eddy current loss in the core

By addition of small amount of current

E_1 & E_2 in same phase lagging ϕ by $\frac{\pi}{2}$

V_1 & E_1 in phase with V_1 in opposite.

$I_w = I_0 \cos\phi_0$

$I_\phi = I_0 \sin\phi_0$

1. A transformer takes a current of 0.6 A and absorbs 64 watt when the primary is connected to its normal supply of 200 V the secondary being open circuit. Find the magnetising current and core loss current.

Ans: Given Data—

Input power = 64 watt

The load condition,

∴ I/p power = Core loss.

$\Rightarrow P_0 = V_1 I_0$

$\Rightarrow P_0 = V_1 I_0 \cos\phi_0$

$I_0 = 0.6A$

$V_1 = 200V$

$f = 50Hz$

$64 = 200 \times 0.6 \times \cos\theta$

$\Rightarrow \cos\theta = \frac{64}{200 \times 0.6}$

$I_w = \frac{\text{i/p Power}}{V_1} = \frac{64}{200} = 0.32 \text{ Amp}$

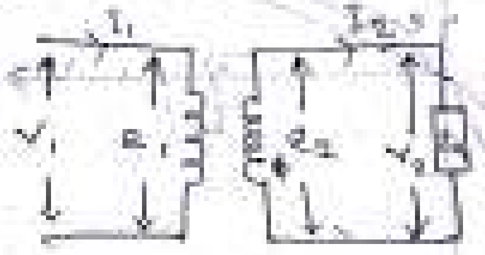
$\cos\theta = \frac{I_w}{I_0} = \frac{0.32}{0.6} = 0.53$

$\theta = \cos^{-1}(0.53) = 57.76°$

$I_\mu = I_0 \sin\theta$

$= 0.6 \sin(57.76°) = 0.507 \text{ Amp}$

Phasor diagram of Ideal transformer on load.

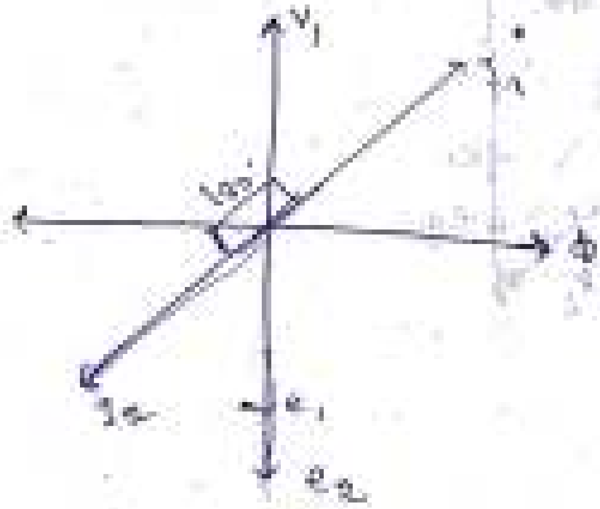


$V_1 \to I_1 \to \Phi_1 \to e_1$

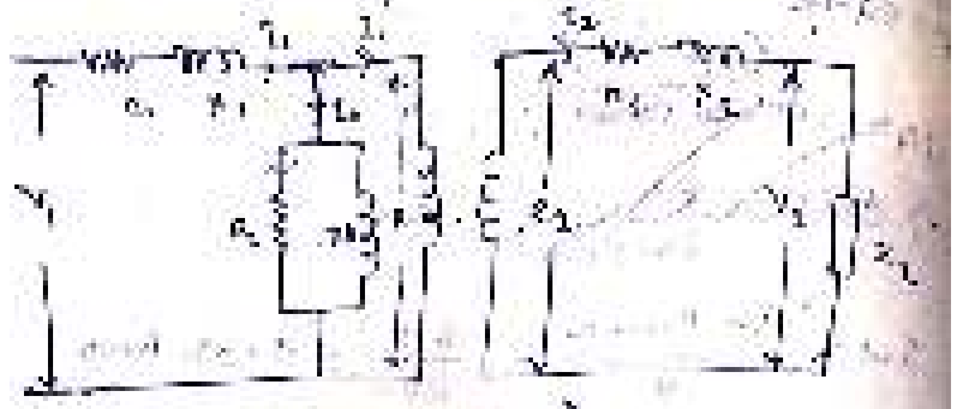
$e_2 \to I_2 \to \Phi_2$

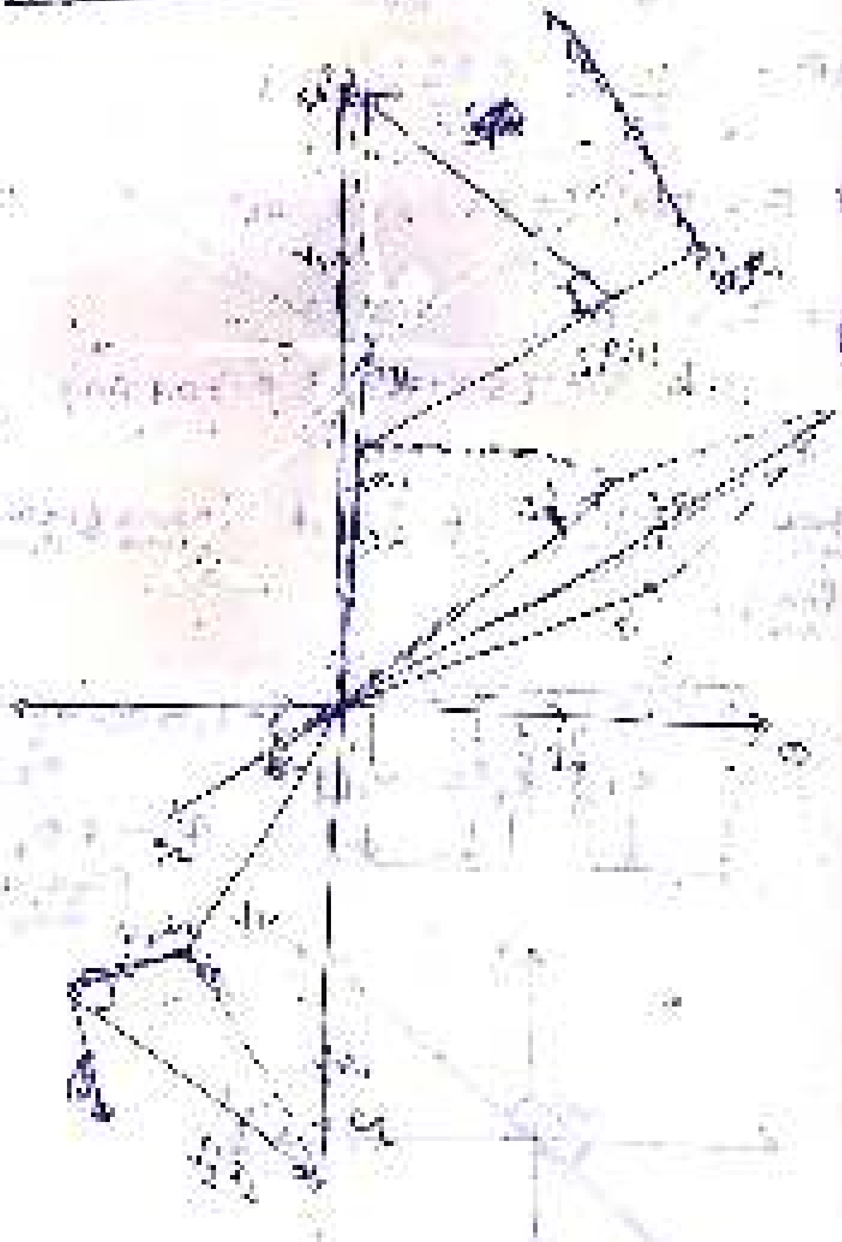
$\Phi_1 \to \leftarrow \Phi_2$

(Due to Lenz's law)

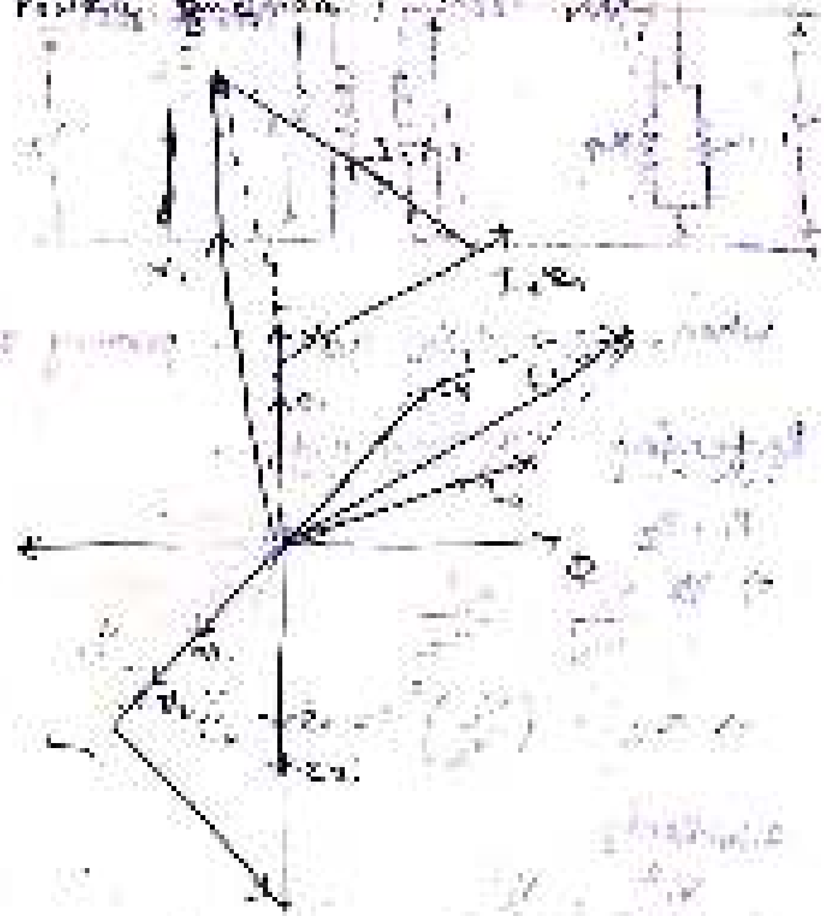


Phasor diagram of Practical transformer on load (lagging power factor)

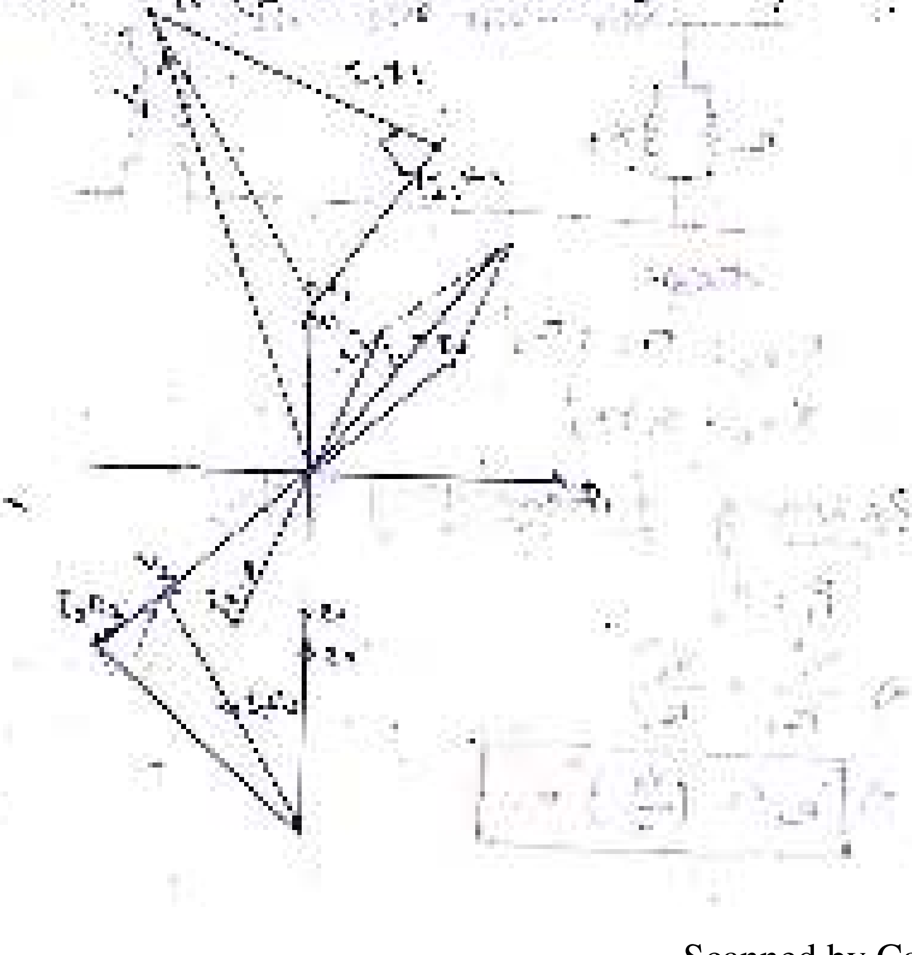




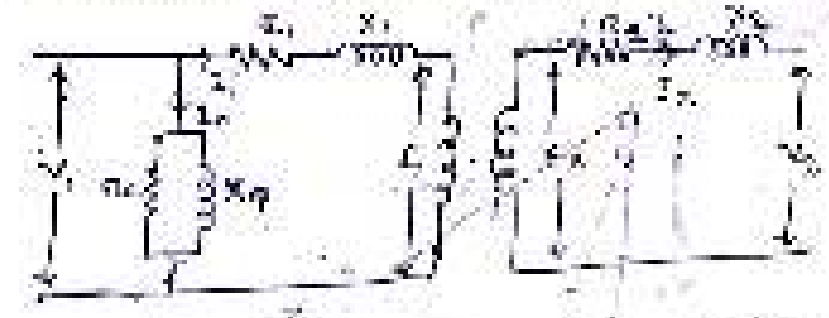
Phasor diagram of practical transformer working at (unity power factor)



Phasor diagram of practical transformer on load at (leading power factor)



Transformer equivalent circuit:



when, r_2 and x_2 goes to primary side r_2', x_2'

Referring primary side:

$P_1 = P_2$

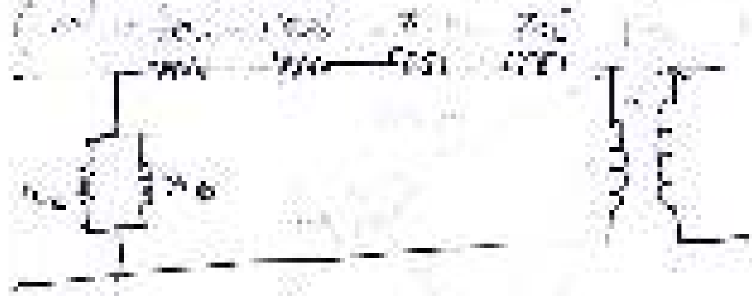
$$\Rightarrow \frac{V_1^2}{r_2'} = \frac{V_2^2}{r_2}$$

$$\Rightarrow r_2' = \left(\frac{V_1}{V_2}\right)^2 r_2$$

similarly

$$\frac{V_1^2}{x_2'} = \frac{V_2^2}{x_2}$$

$$\Rightarrow x_2' = \left(\frac{V_1}{V_2}\right)^2 x_2$$



Now,

$r_{ep} = r_1 + r_2'$

$x_{ep} = x_1 + x_2'$

Referring to secondary side:

$P_1 = P_2$

$$\Rightarrow \frac{V_1^2}{r_1} = \frac{V_2^2}{r_1'}$$

$$\Rightarrow \boxed{r_1' = \left(\frac{V_2}{V_1}\right)^2 r_1}$$

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$$\frac{V_1^2}{X_1} = \frac{V_2^2}{X_1'}$$

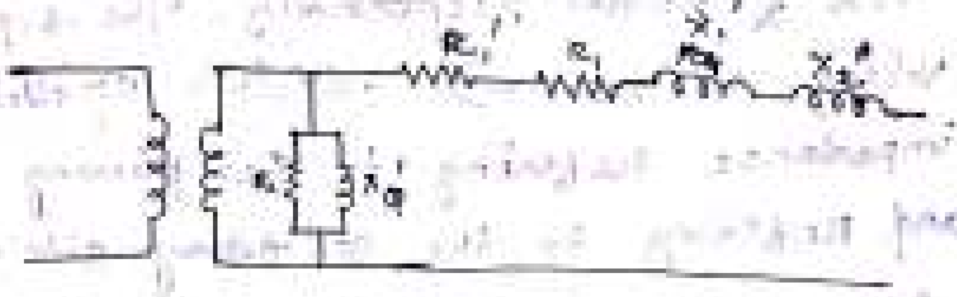
$$\Rightarrow \boxed{X_1' = \left(\frac{V_2}{V_1}\right)^2 X_1}$$

$$\frac{V_1^2}{R_c} = \frac{V_2^2}{R_c'}$$

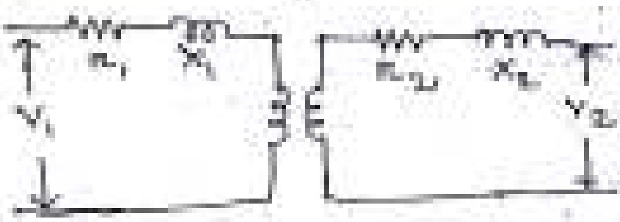
$$\Rightarrow \boxed{R_c' = \left(\frac{V_2}{V_1}\right)^2 R_c}$$

$$\frac{V_1^2}{X_\phi} = \frac{V_2^2}{X_\phi'}$$

$$\Rightarrow \boxed{X_\phi' = \left(\frac{V_2}{V_1}\right)^2 X_\phi}$$

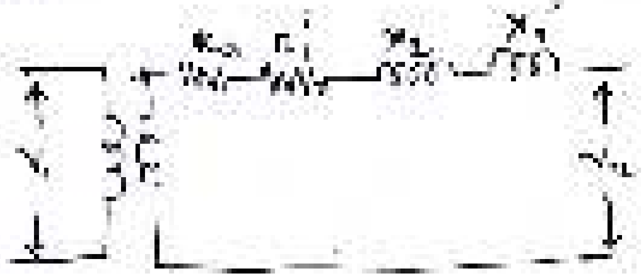


Approximate equivalent circuit:-



Approximate equivalent ckt referring to primary side

Approximate equivalent ckt referring to sec. side.



Q:- A 100kVA transformer has 400 turns on the primary and 80 turns on the secondary. The primary and secondary resistances are 0.3 Ω and 0.01 Ω respectively and corresponding leakage reactance are 1.1 Ω & 0.035 Ω respectively. The supply voltage is 2200 volt. Calculate equivalent impedance referring to the primary and referring to the secondary side.

Ans: Given Data

$T = 100\,kVA$

$N_1 = 400$ turns

$N_2 = 80$ turns

$R_1 = 0.3\,\Omega$

$R_2 = 0.01\,\Omega$

$X_1 = 1.1\,\Omega$

$X_2 = 0.035\,\Omega$

$V_1 = 2200\,V$

we know:-

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

$$\Rightarrow V_2 = \frac{80}{400} \times 2200$$

$$\Rightarrow V_2 = 440\,V$$

$P_1 = P_2$

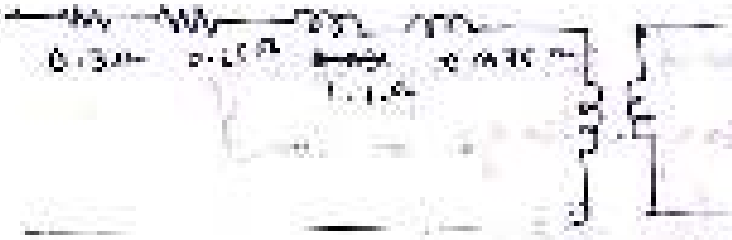
$\frac{V_1^2}{r_1} = \frac{V_2^2}{r_1}$; Referring to primary.

$r_2' = \left(\frac{V_1}{V_2}\right)^2 r_2$

$= \left(\frac{2200}{440}\right)^2 \times 0.01 = 0.25\,\Omega$

$x_2' = \left(\frac{V_1}{V_2}\right)^2 \times x_2$

$= \frac{2200}{440} \times 0.035 = 0.875$



Referring to secondary side.

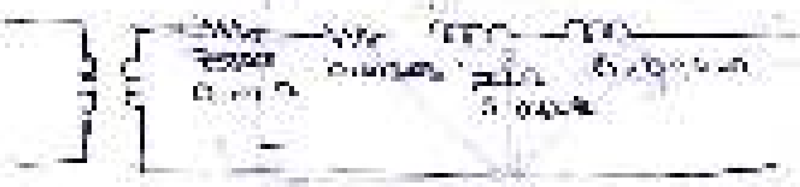
$R_{01} = r_1 + r_2'$
$= 0.3 + 0.25$
$= 0.55$
$X_{01} = 1.1 + 0.875$
$= 1.975\,\Omega$

$r_1' = \left(\frac{V_2}{V_1}\right)^2 r_1$

$= \left(\frac{440}{2200}\right)^2 \times 0.3 = 0.012\,\Omega$

$x_1' = \left(\frac{V_2}{V_1}\right)^2 \times x_1$

$\left(\frac{440}{2200}\right)^2 \times 1.1 = 0.044\,\Omega$



$R_{02} = 0.01 + 0.012$
$= 0.022\,\Omega$

$X_{02} = 0.044 + 0.035$
$= 0.079\,\Omega$

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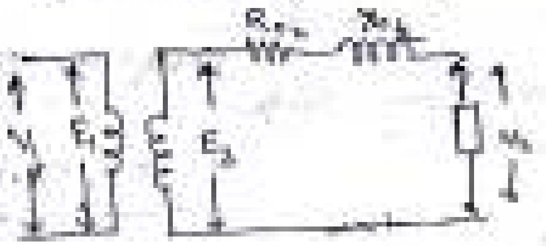
Voltage Regulation :-

The voltage regulation of a transformer is the arithmetic ~~oper~~ difference (not phasor difference) between the no load secondary voltage and secondary voltage on load expressed as percentage of no load voltage.

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

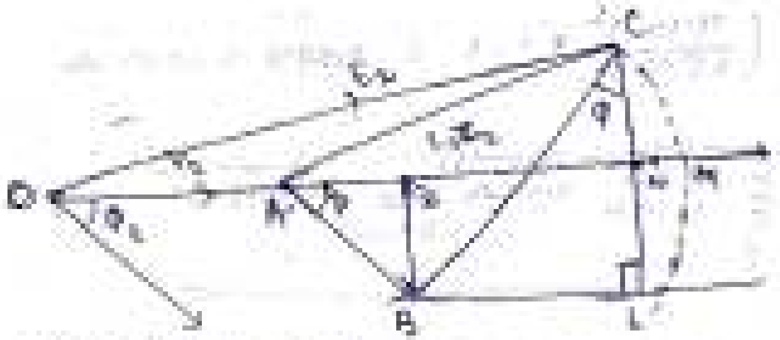
E_2 = no load secondary voltage

V_2 = Secondary voltage on load.



For lagging power factor

$$E_2 = V_2 + I_2(R_{02} + X_{02})$$



$OC = OM \cos\alpha = E_2$

$\Rightarrow E_2 - V_2 = ON - OA$

$= AN = AD + DN$

$= AD + BL$

$$\frac{E_2 - V_2}{E_2} = \frac{I_2 R_{02} \cos\phi_2 \pm I_2 X_{02} \sin\phi_2}{E_2}$$

$\Rightarrow V.R. = \frac{I_2 R_{02}\cos\phi_2 + I_2 X_{02}\sin\phi_2}{E_2}\times 100$

For leading p.f.

$V.R. = \frac{I_2 R_{02}\cos\phi_2 - I_2 X_{02}\cos\phi_2}{E_2}\times 100$

Q: A 10kVA 2000/400V single phase transformer has the following data—

$R_1 = 5\Omega$

$X_1 = 12\Omega$

$R_2 = 0.2\Omega$

$X_2 = 0.48\Omega$

Determine the voltage regulation of the T/F & the secondary voltage at full load at 0.8 p.f. (lagging).

Ans: Given data—

$R_1 = 5\Omega$

$X_1 = 12\Omega$

$R_2 = 0.2\Omega$

$X_2 = 0.48\Omega$

$\frac{E_1}{E_2} = \frac{V_1}{V_2} = \frac{2000}{400} = 5$

$\cos\phi = 0.8$ (lagging)

$S = 10$ kVA

$P_1 = P_2$

$\Rightarrow E_1 I_1 = E_2 I_2 = 10000$ VA

$\Rightarrow 10000 = 10\times 10^3 = E_2 I_2$

$\Rightarrow \frac{10\times 10^3}{400} = I_2$

$\Rightarrow I_2 = 25$ A

$R_{02} = R_2 + R_1'$

$R_1' = \left(\frac{V_2}{V_1}\right)^2 \times R_1 = \left(\frac{400}{2000}\right)^2 \times 5$

$= 0.2\,\Omega$

$R_{02} = R_2 + R_1' = 0.2 + 0.2 = 0.4\Omega$

$X_1' = \left(\frac{V_2}{V_1}\right)^2 \times X_1$

$= \left(\frac{400}{2000}\right)^2 \times 12 = 0.48$

$X_{02} = X_2 + X_1' = 0.48 + 0.48 = 0.96\Omega$

$\cos\phi = 0.8$

$\phi = \cos^{-1}(0.8) = 36.86$

$\sin\phi = \sin(36.86) = 0.6$

$$V.R. = \frac{I_2 R_{02} \cos\phi_2 + I_2 X_{02} \sin\phi}{E_2} \times 100$$

$= 5.6\%$

We know

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

$\Rightarrow \cancel{5.6 \times E_2 = E_2 - V_2}$

$\Rightarrow \cancel{5.6 \times 400 = 400 - V_2}$

$\cancel{\Rightarrow V_2 = 400 - 22.40}$

Or

$E_2 - V_2 = I_2 R_{02} \cos\phi_2 + I_2 X_{02} \sin\phi$

$\Rightarrow 400 - V_2 = 22.5$

$\Rightarrow V_2 = 400 - 22.5 = 377.48\ V$

TEST ON ~~Transf~~ TRANSFORMER

1. OPEN CIRCUIT TEST:

Why LV is energised

1. Convenience of supply voltage.
2. Because of lower voltage, easier to handle.
3. Easy measurement of current.
4. Low range voltmeter.

This test is conducted to determine the iron losses (core losses). In this test rated voltage is applied to LV winding and the HV winding is kept open circuited.

The applied primary (LV) voltage is measured by voltmeter and the no load current is measured by ammeter and the no load i/p ~~voltage~~ power is measured by wattmeter.

Since the no load current is very small (2–10 % of full load current), the copper loss in primary winding is negligible, so wattmeter only reads the iron loss.

Iron loss $= P_i = V I_0 \cos\phi_0$

wattmeter reading $= W$

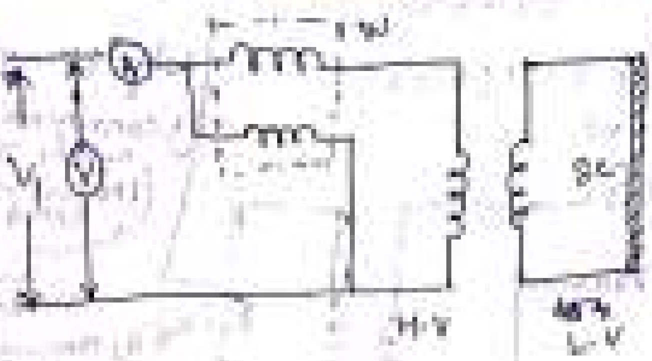
Ammeter reading $= I_0$

$$\cos\phi_0 = \frac{W}{V I_0}$$

$$R_0 = \frac{V}{I_w} = \frac{V}{I_0 \cos\phi_0}$$

$$X_0 = \frac{V}{I_\mu} = \frac{V}{I_0 \sin\phi_0}$$

2. Short circuit test:



~~Rated current~~ Reduced voltage is applied so that rated current flow through the secondary. When rated value of current flows the secondary: rated current I_2

This test is conducted to determine

Full load copper loss and R_{01} or R_{02} and X_{01} or X_{02}

In this test generally the LV winding is short circuited and in HV side the i/p voltage is gradually raised till at voltage V_{SC}, full load current I_1 flows in the primary.

In this test the total loss is only copper loss due to small i/p voltage.

Voltmeter reading $= V_{SC}$

Ammeter reading $= I_{FL} = I_1$

Wattmeter reading $= P$

$$P = I_1^2 (R_1 + R_2') = I_1^2 R_{01}$$

$$R_{01} = \frac{P}{I_1^2}$$

Total impedance referring to primary side

is $Z_{01} = \frac{V_{SC}}{I_{FL}}$

Total reactance referring to primary side

is $X_{01} = \sqrt{Z^2 - R_{01}^2}$

* measurement of voltage (for better accuracy)
rated current will flow through the P.E

Q. A 10 KVA, 200/400 V, 50 Hz single phase T/F gave the following test results:

O.C. Test : 200 V, 1.3 A, 120 W on LV side

S.C. Test : 22 V, 30 A, 200 W on HV side

Calculate magnetising current and the component corresponding to core loss at normal ~~[illegible]~~ frequency and voltage.

(ii) The magnetising branch impedance.

(iii) Percentage of VR when supplying full load at 0.8 p.f. lagging.

Ans: Given Data:

$P = 10$ KVA $= 10 \times 10^3$ VA

$E_1 = 200$ V

$E_2 = 400$ V

$f = 50$ Hz

O.C. Test = 200 V, 1.3 A, 120 W, on LV side

$V = 200$ V

$I_0 = 1.3$ A

$W_0 = 120$ W

[illegible]

$\Rightarrow \cos\phi_0 = \frac{W_0}{V I_0} = \frac{120}{200 \times 1.3} = [illegible]$

$\cos\phi_0 = [illegible]$

$\Rightarrow \phi_0 = \cos^{-1}([illegible]) = [illegible]$

(i) $I_\mu = I_0 \sin\phi_0 = 1.3 \sin([illegible]) = [illegible]$ A

$R_0 = \frac{V}{I_0 \cos\phi_0} = \frac{200}{1.3 \times [illegible]} = [illegible]\ \Omega$

$X_0 = \frac{V}{I_0 \sin\phi_0} = \frac{[illegible]}{1.3 \times \sin([illegible])} = [illegible]$

$P = I_2^2 R_{02}$ [illegible]

$\Rightarrow R_{02} = \frac{P}{I_2^2} = \frac{200}{20^2} = \frac{200}{400} =$ [illegible] Ω

$Z_{02} = \frac{V_{sc}}{20} =$ [illegible]

$X_{02} = \sqrt{Z_{02}^2 - R_{02}^2} = \sqrt{[illegible]^2 - [illegible]^2} =$ [illegible]

$P = 10\,kVA = 10 \times 10^3\ VA$

$P = E_2 I_2$

$\Rightarrow I_2 = \frac{P}{E_2} = \frac{10 \times 10^3}{[illegible]} =$ [illegible] Amp

$$V.R. = \frac{I_2 R_{02}\cos\phi_2 - I_2 X_{02}\sin\phi_2}{E_2}$$

$$= \frac{([illegible]) - ([illegible])}{400}$$

$= -$ [illegible] %

Q. A [illegible] kVA, 2000/400 V, 50 Hz, 1-φ transformer gave following test result:

O.C. test – 2000 V, [illegible] A, [illegible] kW on H.V. side

S.C. test – [illegible] V, [illegible] A, [illegible] kW on H.V. side

Determine [illegible] equivalent circuit [illegible]

Sol: Given data

$P =$ [illegible] kVA $=$ [illegible] $\times 10^3$ VA

$E_1 =$ [illegible]

$E_2 =$ [illegible] V

$F =$ [illegible] Hz

O.C. test – [illegible] kW

V = [illegible] V

$I_0 =$ [illegible]

$P_0 =$ [illegible] kW [illegible]

We know

$P_0 = V I_0 \cos\phi$

$\Rightarrow \cos\phi = \frac{V}{I_0 P_0} = \frac{2000}{1.8 \times 1.75 \times 10^3} = 0.64$

$\phi = \cos^{-1}(0.64) = 50.78^\circ$

$\sin\phi = 0.77$

$I_\phi = I_0 \sin\phi = 1.389$ Amp.

$R_0 = \frac{V}{I_0 \cos\phi} = \frac{2000}{1.8 \times 0.64} = 1736.11\ \Omega$

$X_\phi = \frac{V}{I_0 \sin\phi} = \frac{2000}{1.389} = 1438.42\ \Omega$

$P_0 = V I_0 \cos\phi$

$\Rightarrow P_0 = V I_w$

$\Rightarrow I_w = \frac{P_0}{V} = \frac{1.75 \times 10^3}{2000} = 0.875$ Amp.

$I_\phi = \sqrt{I_0^2 - I_w^2}$

$= \sqrt{(1.8)^2 - (0.875)^2} = 1.573$ Amp.

$R_0 = \frac{V}{I_w} = \frac{2000}{0.875} = 2285.71\ \Omega$

$X_0 = \frac{V}{I_\phi} = \frac{2000}{1.573} = 1271.45\ \Omega$

S.C. test : 12 V, 500 A, 1 KW

$P = I_2^2 R_{02}$

$\Rightarrow 1000 = 500^2 R_{02}$

$\Rightarrow R_{02} = \frac{10^3}{500^2} = 0.004\ \Omega$

$Z_{02} = \frac{V_{sc}}{I_2}$

$= \frac{12}{500} = 0.024\ \Omega$

$X_{02} = \sqrt{Z_{02}^2 - R_{02}^2} = \sqrt{(0.024)^2 - (0.004)^2}$

$= 0.0236\ \Omega$

$$\frac{V_2^2}{R_{02}} = \frac{V_1^2}{R_{02}'}$$

$$\Rightarrow R_{02}' = \left(\frac{V_1}{V_2}\right)^2 R_{02}$$

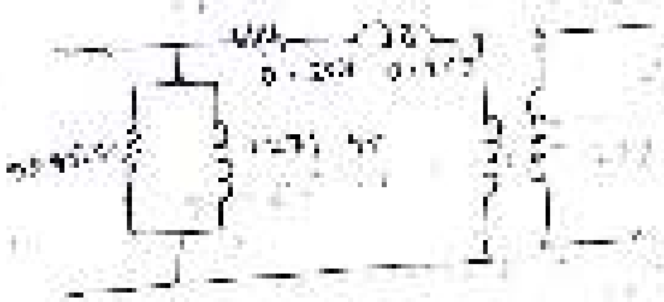
$$= \left(\frac{2050}{[illegible]}\right)^2 \times [illegible] = 0.2046\ \Omega$$

Diagram

$$\frac{V_2^2}{X_{02}} = \frac{V_1^2}{X_{02}'}$$

$$\Rightarrow X_{02}' = \left(\frac{V_2}{V_2}\right)^2 \times X_{02}$$

$$= \left(\frac{2000}{1444}\right)^2 \times 0.046 = 0.817\ \Omega$$



Losses in Transformer

Core loss / Iron loss :

1. Hysteresis loss = $K_h B_m^{1.6} f V$

2. Eddy current loss = $K_e t^2 B_m^2 f^2 V$

Copper loss = $I_1^2 R_1 + I_2^2 R_2$

$= I_1^2 R_{01}$ or $I_2^2 R_{02}$

$R_{01} = R_1 + R_2'$, $R_{02} = R_2 + R_1'$

Core loss :-

Efficiency (Full load) :-

$$\eta = \frac{O/P}{I/P} = \frac{KVA \cos\phi_2}{KVA \cos\phi_2 + P_i + P_{cu}}$$

Full load efficiency of transformer.

$$\boxed{\eta = \frac{V_2 \times I_2 \cos\phi_2}{V_2 \times I_2 \cos\phi_2 + P_i + x^2 P_{cu}}}$$

(when the transformer is x % of loaded)

Condition for maximum efficiency of transformer.

$$\eta = \frac{V_2 I_2 \cos\phi_2}{V_2 I_2 \cos\phi_2 + P_i + I_2^2 R_{02}}$$

$$\eta = \frac{V_2 \cos\phi_2}{V_2 \cos\phi_2 + \frac{P_i}{I_2} + I_2 R_{02}}$$

$$\frac{d\eta}{dI_2}\left(\frac{V_2 \cos\phi_2}{V_2 \cos\phi_2 + \frac{P_i}{I_2} + I_2 R_{02}}\right)$$

$$\eta = V_2 \cos\phi_2 \frac{d}{dI_2}\left(V_2 \cos\phi_2 + \frac{P_i}{I_2} + I_2 R_{02}\right)$$

$$\frac{d}{dI_2}\left(V_2 \cos\phi_2 + \frac{P_i}{I_2} + I_2 R_{02}\right) = 0$$

$$\Rightarrow 0 + P_i\left(-\frac{1}{I_2^2}\right) + R_{02} = 0$$

$$\Rightarrow \frac{P_i}{I_2^2} = R_{02} \quad \Rightarrow \boxed{P_i = I_2^2 R_{02}}$$

Q. [illegible] kVA transformer whose iron loss is [illegible] and full load copper [illegible]. [illegible] find the efficiency at full load and at half load at [illegible] power factor lagging.

Soln. [illegible]

[illegible]

Output KVA corresponding to Maximum efficiency

$$\eta_x = \frac{x\,KVA\cos\phi}{x\,KVA\cos\phi + P_i + P_{cu}}$$

$P_i = I_2^2 R_{02}$ [∵ condition for max^m efficiency $P_i = P_{cu}$]

$\Rightarrow P_i = (x I_2)^2 R_{02}$

$\Rightarrow P_i = x^2 I_2^2 R_{02}$

$\Rightarrow P_i = x^2 P_{cu}$

$\Rightarrow x = \sqrt{\frac{P_i}{P_{cu}}}$

output KVA corresponding to max^m efficiency
= x output KVA (F.L)

$\eta_{max} = x \times o/p\ KVA$

Q:- A 40KVA transformer has iron loss of 450 watt and full load Cu loss of 850 watt if the power factor of the load is 0.8 lagging calculate (i) full load efficiency
(ii) The KVA load at which maximum efficiency occurs
(iii) Maximum efficiency

Ans Given Data

$P = 40\,KVA = 40\times10^3\,VA$

$P_i = 450$ watt

$P_{cu} = 850$ watt

$\cos\phi = 0.8$

$$\eta_{F.L} = \frac{40\times10^3\times0.8}{(40\times10^3\times0.8) + 450 + 850} = 0.9609 = 96.09\,\%$$

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$x = \sqrt{\frac{P_i}{P_{cu}}} = \sqrt{\frac{450}{850}} = 0.727$ $\quad$ $0.727 \times 40 = 29.10$ kVA

η_{max}

At max^m efficiency

$P_{cu} = P_i = 450$

$$\eta_{max} = \frac{40 \times 10^3 \times 0.8 \times 0.727}{(0.727 \times 40 \times 10^3 \times 0.8) + 450 + 450}$$

$= 0.9626 = 96.26\%$

Q. The iron loss in a certain transformer is 80 watt at 25 Hz and 204 watt at 60 Hz, the maximum flux density being same; calculate total iron loss at 100 Hz at the same maximum flux density and find the value of Hysteresis loss and eddy current loss.

Ans: Given data

$P_i = 80$ watt (at 25 Hz)

$P_i = 204$ watt (60 Hz)

$P_h = K_h B_m^{1.6} f V$

$P_e = K_e f^2 B_m^2 t^2 V$

$P_h \propto f \Rightarrow P_h = af$

$P_e \propto f^2 \Rightarrow P_e = bf^2$

$P_i = P_h + P_e$

$\Rightarrow 80 = af + bf^2$

$\Rightarrow 80 = a \times 25 + b(25)^2$

$\Rightarrow 25a + 625b = 80$ ...... eq (i)

$204 = a\times 60 + b(60)^2$

$\Rightarrow 60a + 3600b = 204$ ——— eq (ii)

By solving eq (i) and eq (ii) we get

$a = 3.05$

$b = 5.71\times10^{-3}$

$P_h = a\times f = 3.05\times100 = 305$ watts

$P_e = b\times(f)^2 = 5.71\times10^{-3}\times100^2 = 57.1$ watts

Iron loss $= P_h + P_e = 305 + 57.1 = 362.1$ watt.

Q5: A 25 kVA 2200/220V single phase transformer has a primary resistance of 1Ω and secondary resistance of 0.01Ω. Find the full load efficiency at 0.8 power factor lagging if the iron loss is 900 watt.

Ans: Given data,

$P = 25$ kVA

$E_1 = 2200$V

$E_2 = 220$V

$R_1 = 1\Omega$

$R_2 = 0.01\Omega$

Considering lagging

Full load efficiency

$$\eta = \frac{V_2 I_2 \cos\phi_2}{V_2 I_2 \cos\phi_2 + P_i + P_{cu}}$$

$P = V_2 I_2$

$\Rightarrow 25$ kVA $= 220\times I_2$

$\Rightarrow I_2 = \frac{25\times10^3}{220} = 113.63$ Amp.

$P_{cu} = I_1^2 R_1 + I_2^2 R_2$

$= I_2^2 R_{02}$

$R_{02} = R_2 + R_1'$

$R_1' \Rightarrow$ [illegible]

$\Rightarrow \frac{V_1^2}{R_1} = \frac{V_2^2}{R_1'}$

$\Rightarrow R_1' = \left(\frac{V_2}{V_1}\right)^2 R_1 =$ [illegible] Ω

$\therefore R_{02} =$ [illegible] $+ 0.01 =$ [illegible]

$\therefore P_{cu} = (113.63)^2 \times$ [illegible]

$=$ [illegible]

$\eta =$ [illegible]

$=$ [illegible] %

All day efficiency :-

$\eta_{all\ day} = \frac{O/P \text{ in kWh in 24 hours}}{I/P \text{ in kWh in 24 hours}}$

The ratio of O/P in kWh to the I/P in kWh of a transformer over a 24 hour period is known as all day efficiency.

Q.4 5 kVA distribution transformer has a full load efficiency of 95% at which Cu loss is equal to iron loss. The transformer is loaded for 24 hrs as under: no load for 10 hrs, $1/4^{th}$ of full load for 7 hrs, $1/2$ load for 5 hrs and full load for 2 hrs. Calculate the all day efficiency of the T/F.

Since the distribution transformer supplies mainly lighting load, the power factor is unity.

Ans: Given Data:

$S = 5\,kVA$

$\eta_{max}/_{fl} = 95\% = 0.95$

$P_i = P_{cu}$

No load for 10 hrs

$1/4^{th}$ of full load for 7 hrs

$1/2$ load for 5 hrs

Full load for 2 hrs

Eqn. $\eta = \dfrac{S\cos\phi}{(S\cos\phi) + P_i + P_{cu}}$

$\Rightarrow 0.95 = \dfrac{5\times10^3}{5\times10^3 + 2P_i}$

$\Rightarrow 0.95 = \dfrac{5\times10^3}{5\times10^3 + 2P_i}$

$\Rightarrow [5\times10^3 + 2P_i]\,0.95 = 5\times10^3$

$\Rightarrow$ [illegible]

$\Rightarrow$ [illegible]

Cu loss [illegible]

Full load [illegible]

[Copper loss]

$\frac{1}{2}$ th full load [illegible]

[illegible]

$\frac{1}{4}$ th full load [illegible]

[illegible]

Iron loss [illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

⇒ Total [illegible] losses [illegible] = [illegible] watt.

$$\eta_{(all\ day)} = \frac{31.25\times10^3}{(31.25\times10^3) + [illegible]} \times 100 = 97.00\ [illegible]\%$$

Q. A [illegible] has a maximum efficiency of 98% at 15 kVA at unity power factor. During the day it is loaded as follows:

12 hours : 2 kW at power factor 0.5 lag.
6 hours : 12 kW at power factor 0.8 lag.
6 hours : 18 kW at power factor 0.9 lag.

Find all day efficiency.

Ans. Given data:

$P_{o/p} = 15$ kW

$\eta_{max} = 98\% = 0.98$

$P_i = P_{cu}$

$\eta = \frac{P_{o/p}}{P_{i/p}} \Rightarrow P_{i/p} = \frac{P_{o/p}}{\eta}$

$\Rightarrow P_{i/p} = \frac{15\times10^3}{0.98} = 15306.1224$ watt

$\Rightarrow P_{i/p} = P_{o/p} + P_i + P_{cu}$

$\Rightarrow 15306.1224 = (15\times10^3) + P_i + P_i$

$\Rightarrow 2P_i = 15306.1224 - 15\times10^3 = 306.1224$

$\Rightarrow P_i = \frac{306.1224}{2} = 153.0612$ watt

$\therefore P_i = P_{cu} = 153.0612$ (at full load)

Full load copper loss = 153.0612 watt.

Total iron loss ... $\times 24 = 3673.46$ watts

For 12 hours o/p power = ... $\cos\phi \times 12$

$= \dfrac{[illegible]}{[illegible]} \times 12 = [illegible]$

For 6 hours o/p power = ... $\times 6$

$= [illegible] \times 6 = [illegible]$

For 6 hours o/p power = $P_2 \cos\phi \times 6$

$= [illegible] = 94200$

Total o/p power = [illegible]

$= 75000 + 4200 - [illegible] = 114850$ watt

Copper loss:

12 hours = $\dfrac{[illegible]}{\cos\phi} = [illegible] = 4$ kVA

6 hours = $\dfrac{15}{\cos\phi} = \dfrac{15}{0.8} = 18.75$ kVA

6 hours = $\dfrac{18}{\cos\phi} = \dfrac{18}{0.9} = 20$ kVA

At 25 kVA, cu loss = [illegible] watt

[illegible] cu loss = $[illegible] \times \left(\dfrac{[illegible]}{[illegible]}\right)^2 = [illegible]$

4 kVA cu loss = $[illegible] \times (4)^2 = [illegible]$

18.75 kVA cu loss = $[illegible] \times (18.75)^2 = 153.068$ watt

20 kVA cu loss = $[illegible] \times (20)^2 = [illegible]$ watt

Total P_{cu} = [illegible]

$= [illegible]$ watt

Total o/p power = $(2 \times 12) + (15 \times 6) + (18 \times 6)$

$= [illegible]$ kWh

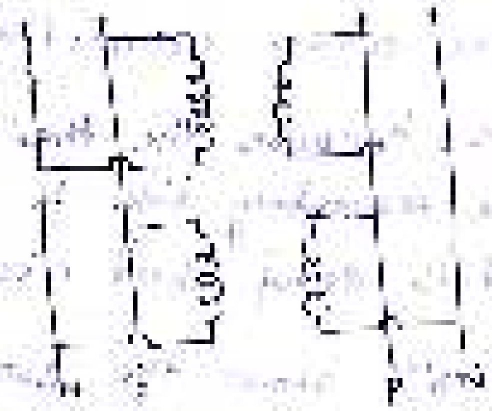
$\eta_{all\ day} = \dfrac{P_{o/p}}{P_{i/p}} = \dfrac{20000 \times [illegible]}{(20000 \times [illegible]) + 3673.45 + 2550.56} \times 100$

$= 96.97\% \approx 97\%$

Parallel operation of Transformer :-

Condition :-

1. Polarity should be properly maintained.
2. KVA, voltage ratio same.
3. Per unit impedance of both the T/F is same.
4. $\frac{R}{X}$ ratio should be same.



Requirement of parallel operation :-

→ Parallel operation is done under when there is a sudden demand of load.

→ When one T/F is not able to supply the total load.

→ When there is a continuous extension of load.

Condition for Parallel operation of T/F

(i) T/F should be properly connected with regard of their polarity.

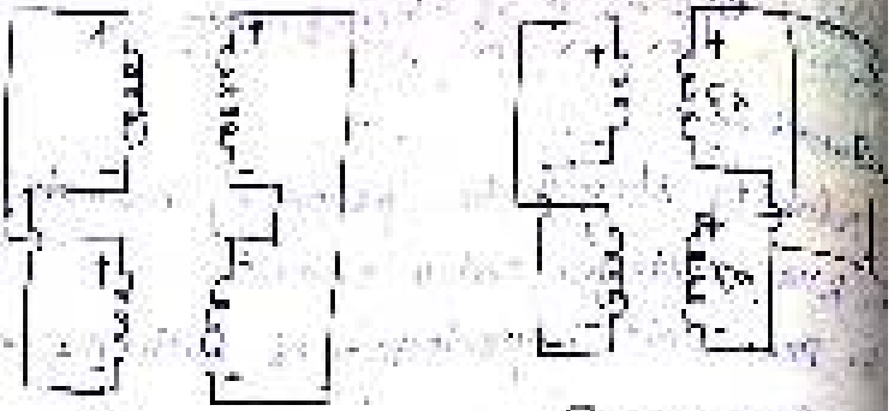
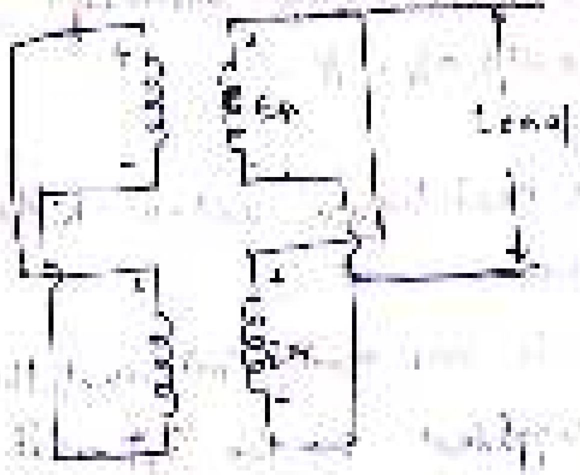


Fig (i)   Fig (ii)

Fig (i) shows the wrong connection in secondary side because the total voltage in the secondary side is additive which result in dead short circuit (?).

In Fig (ii) which shows the correct connection because the total emf in the secondary opposes each other, hence there is no circulating current. If this condition is not maintained, the transformer may damaged unless they are protected by fuse and circuit breaker.

(ii) The voltage rating and voltage ratio of the T/F should be same.



If this condition is not maintained ($E_a \neq E_b$). Even a small difference in induced secondary voltage can cause large circulating current in the secondary loop because the impedance of T/f is very low.

This causes copper loss and when the load is connected to T/f will not share the load according to their KVA rating [illegible] with standard voltage [illegible] will lead to [illegible] of the proper sharing of load.

(iii) The pu unit or the percentage of impedance should be equal.

If this condition is not maintained the T/f will not share the load according to their KVA rating. It can be corrected by inserting proper amount of inductance and resistance.

of both, in series with either primary or secondary circuits of T/F.

(iv) The reactance to resistance ratio of the T/F should be same.

If this condition is not ~~mat~~ maintained the PF of the load supplied by the T/F will not be equal.

Auto Transformer

Auto Transformer is a T/F in which a part of the winding is common to both primary and secondary.

Difference between Auto transformer and 2 winding T/F

Auto Transformer	2 winding T/F
Power transferred by Auto T/F in both conduction and induction principle	In 2 winding T/F the power transferred by induction principle only.

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Principle of Auto-transformer [illegible]

When voltage V_1 is applied to the primary winding a current I_1 is flow from A to C. Due to this current a flux will be created which is moving from C to A.

Due to this flux a voltage will be induced in winding [illegible] when a pulsating flux come in contact with the coil i.e. voltage developed i.e. V_2. When a load is applied the load current of I_2 will flow through load and the [illegible] in common winding i.e. $(I_2 - I_1)$ [illegible]

V_1 = I/p voltage
V_2 = O/p voltage
I_1 = I/p current
I_2 = O/p current

[illegible]

we have

$V_1 I_1 = V_2 I_2 = P$

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

Total O/p power of power transferred in the power of power transferred in 2 parts as

(Transfer of power by inductively) (Transfer of power by conductively)

Calculation ratio of inductively transferred power

$$\frac{\text{Inductively transferred power}}{\text{Total power}} = \frac{V_{bc} I_{bc}}{V_{ac} I_{ac}} = \frac{(V_1 - V_2) I_1}{V_1 I_1}$$

$$= \frac{V_1 I_1 - V_2 I_1}{V_1 I_1} = 1 - \frac{V_2 I_1}{V_1 I_1}$$

$$= 1 - \frac{V_2}{V_1} = 1 - K_a$$

$$\frac{\text{Inductive power}}{\text{Total power}} = 1 - K_a$$

$$\boxed{\text{Inductive power} = (1 - K_a)\ \text{total power}}$$

* Total power transferred conductively

$= \text{Total power} - \text{inductive power}$

$= V_1 I_1 - (V_1 - V_2) I_1$

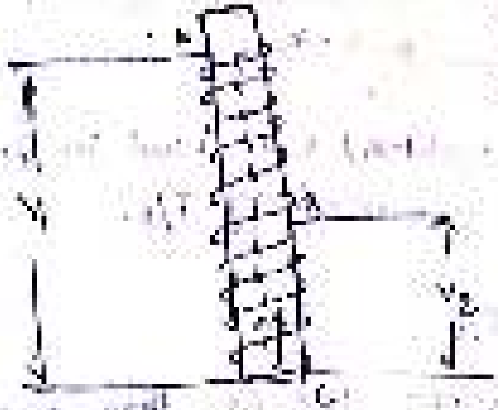
$= V_1 I_1 - V_1 I_1 + V_2 I_1$

$= V_2 I_1$

$= K_a V_1 I_1 \quad (\because K_a = \frac{V_2}{V_1} \Rightarrow V_2 = K_a V_1)$

Total power transferred conductively $= K_a \times$ total power.

Saving of copper in Autotransformer.



The length of copper required in a winding is proportional to no. of turns and area of cross-section of the winding wire.

The area of cross-section is proportional to the current rating. So the copper used is proportional to current and no. of turns.

→ Copper used in 2 winding T/F ∝ $N_1I_1 + N_2I_2$

→ Copper used in Auto T/F = copper used in the portion of winding

i.e.

Copper used in Auto T/F ∝ $(N_1 - N_2)I_1 + N_2(I_2 - I_1)$

$= N_1I_1 - N_2I_1 + N_2I_2 - N_2I_1$

$= N_1I_1 + N_2I_2 - 2N_2I_1$

$$\frac{\text{Copper used in Auto T/F}}{\text{Copper in 2 winding T/F}} = \frac{N_1I_1 + N_2I_2 - 2N_2I_1}{N_1I_1 + N_2I_2}$$

$$= \frac{N_1I_1 + N_2I_2}{N_1I_1 + N_2I_2} - \frac{2N_2I_1}{N_1I_1 + N_2I_2}$$

$$= 1 - \frac{2N_2I_1}{N_1I_1 + N_2I_2} \qquad \left(\because \frac{N_2}{N_1} = \frac{I_1}{I_2},\ N_1I_1 = N_2I_2\right)$$

$$= 1 - \frac{2 N_2 I_2}{N_1 I_1 + N_2 I_2}$$

$$= 1 - \frac{2 N_2 I_2}{2 N_1 I_1} = 1 - K$$

Cu used in auto T/F = (1-K) Cu used in two winding T/F

Advantages of auto T/F:

→ An auto T/F requires less Cu than 2 winding T/F of similar rating.

→ An auto T/F provides higher efficiency than two winding T/F of similar rating.

→ An auto T/F has better voltage regulation than 2 winding T/F of same voltage & kVA.

Disadvantages of auto T/F:

→ There is direct connection between the primary and secondary, therefore the o/p is no longer ~~electrically~~ isolated from i/p.

→ If an open circuit develops in the common portion of the winding, then full primary winding will appear across the load. This could be dangerous to both the operator and equipment.

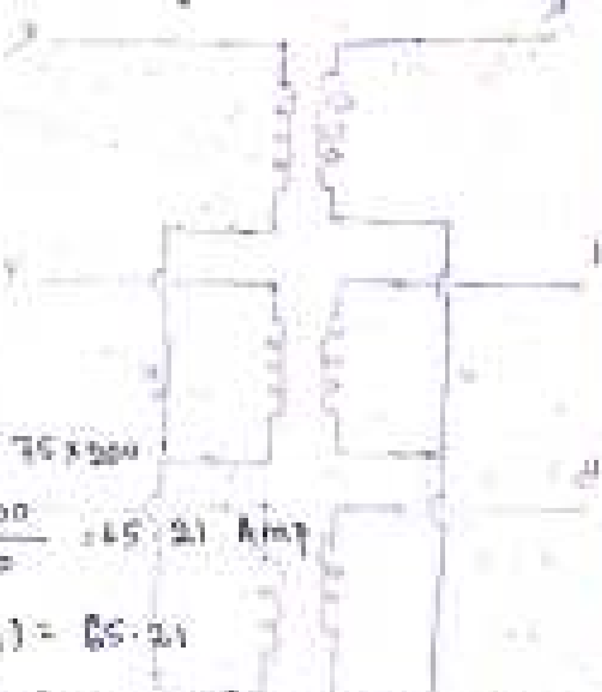
Application:-

Auto T/F are used to compensate the voltage drop for Transmission and distribution line. So, they are known as booster T/F.

→ Auto T/F are used for reducing the voltage supply to AC motor during starting period.

Q1. The primary and secondary of an Auto T/F are 230 V and 75 V respectively. Calculate the current in different parts of winding when load current is 200 Amp. also calculate the saving of copper.

Ans. Given data.



$V_1 = 230\ V$

$V_2 = 75\ V$

$I_2 = 200$ Amp.

$P = V_1 I_1 = V_2 I_2$

$\Rightarrow 230\, I_1 = 75 \times 200$

$\Rightarrow I_1 = \frac{75 \times 200}{230} = 65.21$ Amp

Current in AB $(I_1) = 65.21$

Current in BC $(I_2 - I_1) = 200 - 65.21 = 134.79$.

$K = \frac{V_2}{V_1} = \frac{75}{230} = 0.32$

Cu saving = Cu used in 2 winding T/F − (1−K) Cu used in 2 winding T/F

= Cu used in 2 winding T/F (1 − 1+K)