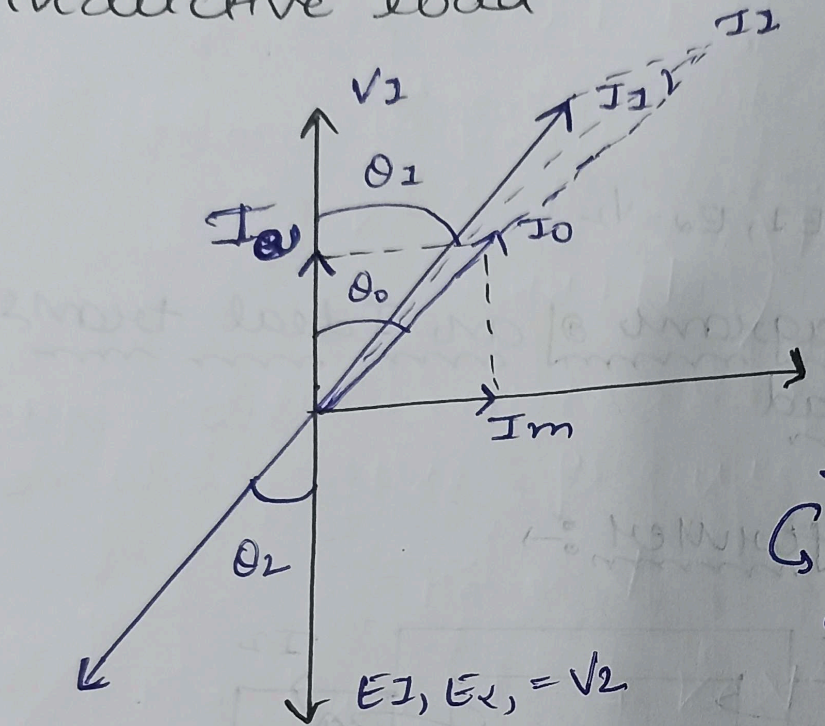
→ Practical transformers are those transformers which has core loss, hysteresis loss and other kind of losses

* Phasor diagram :→

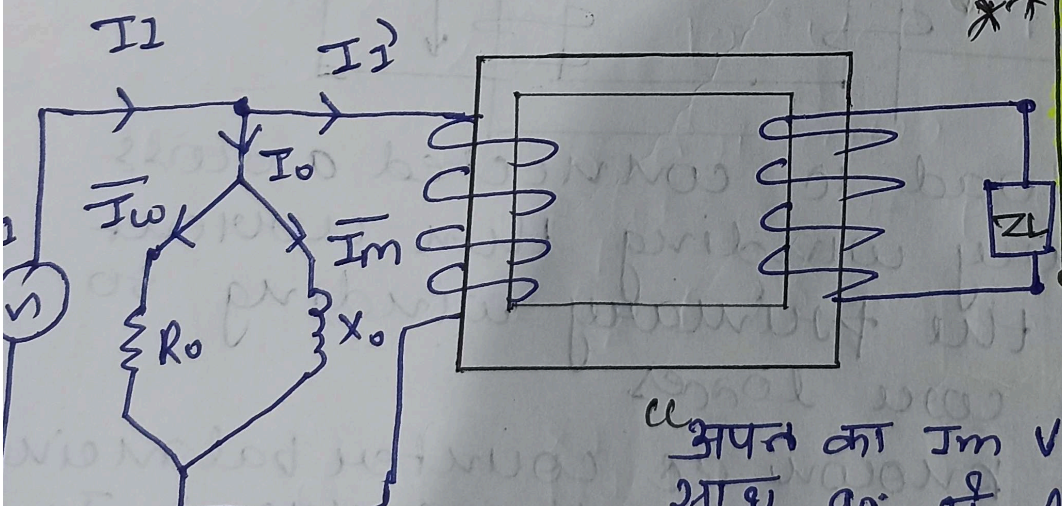
(i) inductive load



I_e = energy comp
or
I_w = Working component

$\vec{I_0} = \vec{I_m} + \vec{I_w}$
↳ No load current

* Practical transformer on load :→



** $I_0 = \sqrt{I_m^2 + I_w^2}$

$I_m = I_0 \sin\phi$

$I_w = I_0 \cos\phi$

$\phi = \tan^{-1}\left(\frac{I_m}{I_w}\right)$

** $R_0 = \frac{V_1}{I_w}$

$X_0 = \frac{V_1}{I_m}$

"अपन का Im voltage के साथ 90° से lag कर रहा है तो वो inductor से पास होगा और अपन का Im same phase में है voltage से तो वो R_0 से pass होगा।"

* **Losses in Transformer:→**

→ There are mainly two types of losses in the transformer

① Core losses / Iron losses (P_i)

② Copper losses (P_c)

→ Core losses are further classified into two categories.

① Hysterisis loss

② Eddy current loss

Hysterisis loss:→ During magnetization and demagnetization due to molecular friction material suffer from losses known as Hysterisis loss

$$\boxed{P_h = K_h V^{\eta} f^{1-x}} \quad \boxed{P_h = \eta (B_{max})^{1.6} f V}$$

$P_h \propto V_1 . f$ $\eta \rightarrow$ hysterisis cofficient

$B_{max} \rightarrow$ Max value of flux density

$V \rightarrow$ Volume of the core

$f \rightarrow$ frequency of supply

Eddy current loss:→ When an alternating flux flows in the core due to which EMF get induced in the core and we know that core is an conducting material so it has some resistance and by the combination of R and V there is current flows in the core known as Eddy current and due to Eddy current I^2R losses occur known as Eddy losses

$$\boxed{P_e = K_e (B_m)^2 f^2 t^2 V} \text{ watts}$$

K_e → eddy current cofficient

$$\boxed{P_e = K_e \left(\frac{V}{4.44 f N a}\right)^2 f^2 t^2 V}$$

→ ~~cop~~ eddy current losses are independent of the frequency

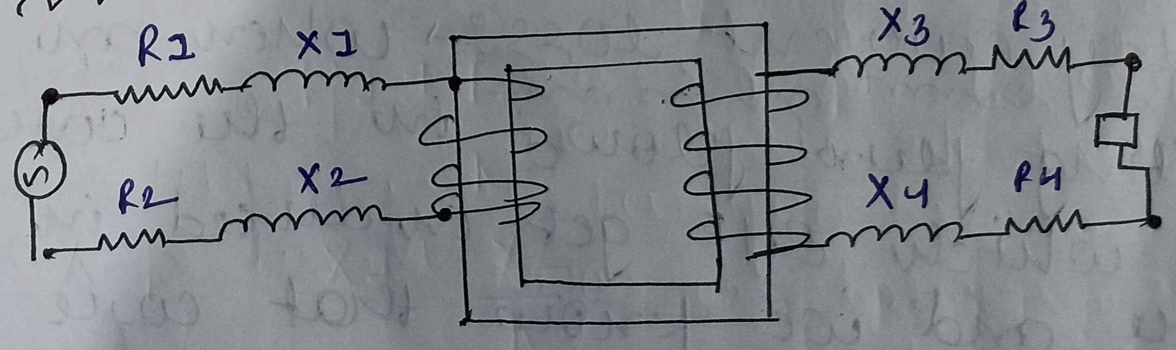
$$P_e \propto V^2$$

$$\boxed{P_i = K_h V^x f^{1-x} + K_e V^2}$$

→ To minimize the eddy current losses we have to use the lamination strips

"मतलब कम area होगा तो कम current के loop बनेंगे।"

copper losses (I^2R losses) :→



→These losses are also known as the ohmic losses

→These losses occurs due to the ohmic resistance of the transformer winding

→If I_1 is the current in primary and R_1 is the resistance than loss

$P_P = I_1^2 R_1$ — (1)

similiarly secondary

$P_S = I_2^2 R_2$ — (2)

$P_T = I_1^2 R_1 + R_2 I_2^2$

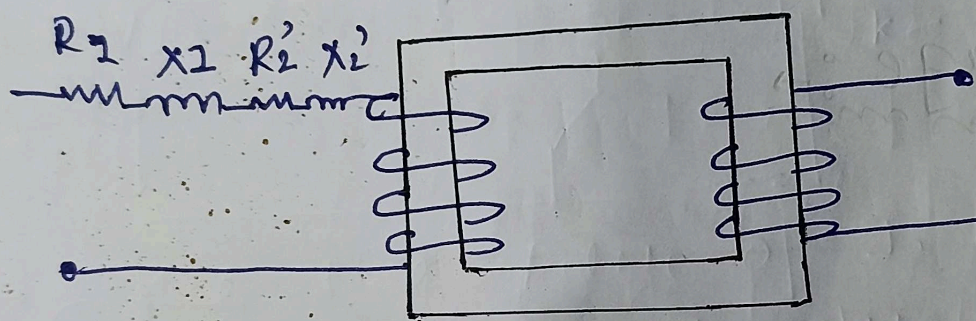
"These losses are known as the Variable loss because they depend upon the load

Magnetic lekage :→

* Equivalent circuit of Transformers:

Shifting impedence in transformer means interchanging the resistor, inductive load of primary and secondary side with each other

(i) Reffered to primary side:→

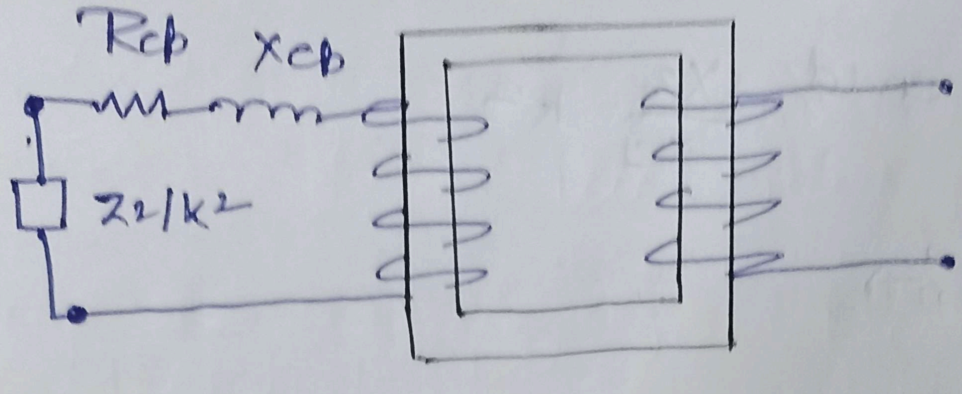


When we are shifting impedence towards primary side from secon-dary side they get reduced by k^2 factor

$$R_2' = \frac{R_2}{k^2}, \quad X_2' = \frac{X_2}{k^2}$$

$$R_{ep} = R_1 + \frac{R_2}{k^2}$$

$$X_{ep} = X_1 + \frac{X_2}{k^2}$$



(ii) Reffered to secondary side :→

→ Now we are shifting impedences towards secondary side from pr-imary side. So our reactance at pr-imary side get multiplied by k^2 fac[tor] then it get shifted to secondary side.

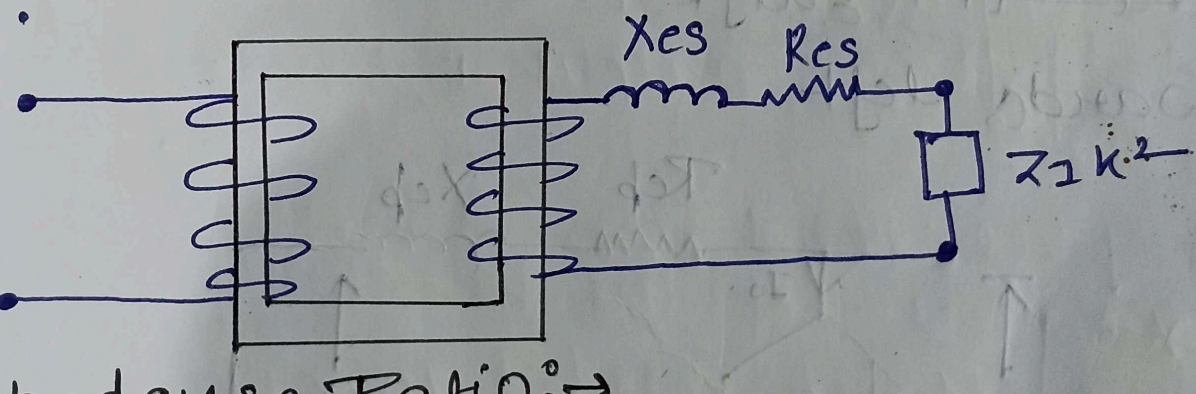
$R_1' = k^2 R_1$

$X_1' = k^2 X_1$

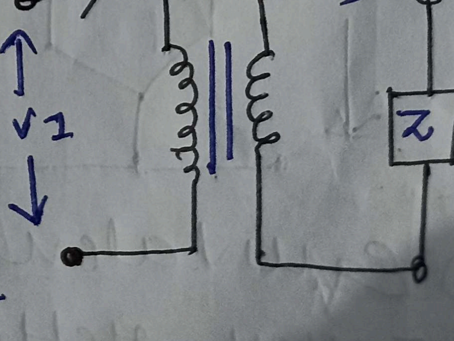
*** $X_{es} = X_1 k^2 + X_2$

$R_{es} = k^2 R_1 + R_2$

$Z = \sqrt{(R_{es})^2 + (X_{es})^2}$



* Impedence Ratio :→



$Z_2 = \frac{V_2}{I_2}$ — ①

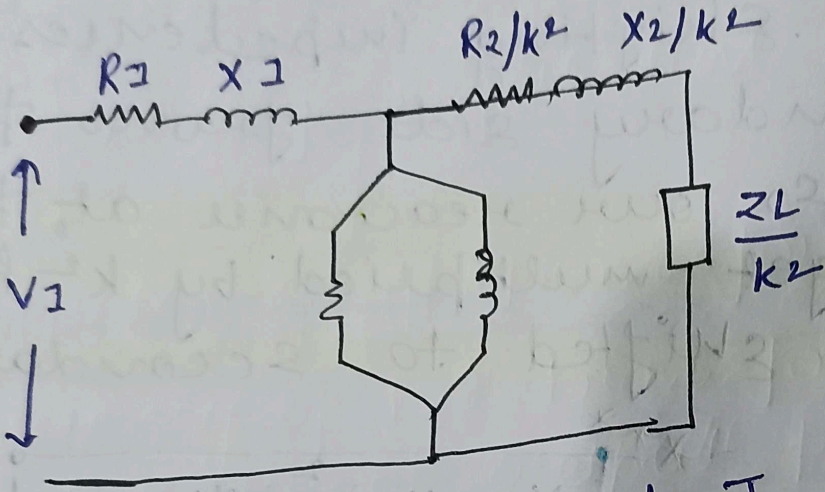
$Z_1 = \frac{V_1}{I_1}$ — ②

$\frac{Z_2}{Z_1} = \frac{V_2}{V_1} \cdot \frac{I_1}{I_2} = k^2$

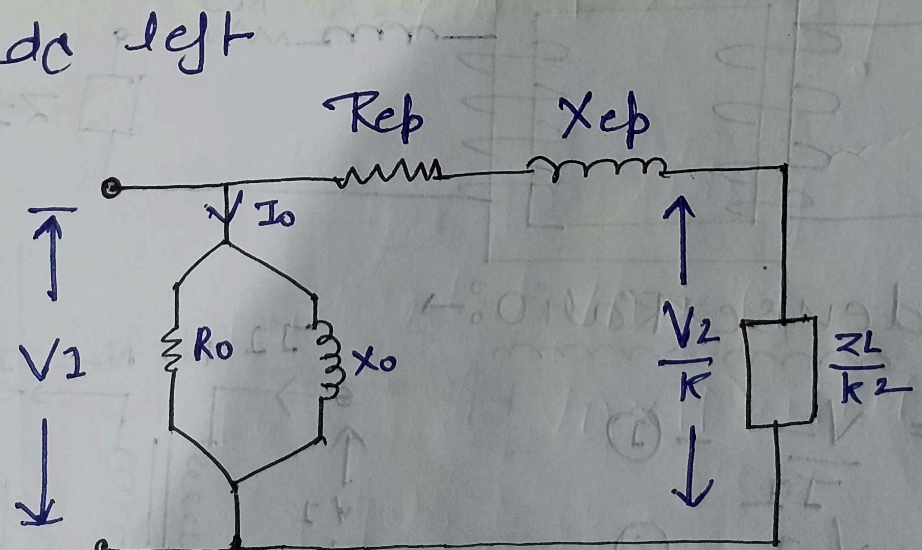
And also

$$\frac{R_2}{R_1} = k^2 \quad \text{and} \quad \frac{X_2}{X_1} = k^2$$

* Eq circuit :→



→ Since the value of I_0 (No load current) is very small which is nearly ~~3~~-5% of load current so we can ~~ignore~~ it shift the R_0 and X_0 branch towards left



(i) Equivalent circuit of transformer referred to primary

* Voltage regulation :→

→ With the increase in the load of the transformer there is a change in its secondary terminal voltage. Voltage falls if the load power factor is lagging. Voltage increases if the power factor is leading

→ "Voltage regulation is defined as the change in its secondary terminal voltage from no load to full load, the primary voltage being assumed constant"

***

$$\boxed{\text{Voltage regulation} = \frac{E_2 - V_2}{E_2}}$$

→ For inductive load :→

$$E_2 = V_2 + I_2 R_{es} \cos\phi_2 + I_2 X_{es} \sin\phi_2$$

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

***

$$\boxed{\frac{E_2 - V_2}{E_2} = \underbrace{\frac{I_2 R_{es}}{E_2} \cos\phi_2} + \frac{I_2 X_{es}}{E_2} \sin\phi_2}$$

$$\frac{I_2 R_{es} \cos\phi_2}{E_2} \times 100 = \text{\% Resistance drop}$$

$$\frac{I_2 X_{es} \sin\phi_2}{E_2} \times 100 = \text{\% Reactance drop}$$

→ For capacitive load

% regulation = % resistance drop − % reactance drop

**

$$\boxed{\text{Voltage regulation} = \frac{I_2 R_{eq}}{E_2}\cos\phi_2 - \frac{I_2 X_{eq}\sin\phi_2}{E_2}}$$

→ For reactive load:→

$$\boxed{\text{Voltage regulation} = \frac{I_2 R_{eq}}{E_2}\cos\phi_2}$$

* Efficiency of Transformer:→

→ efficiency of the transformer is defined as the ratio of output power to the input power. Both power has to be same unit

***

$$\boxed{\eta = \frac{\text{output power}}{\text{output + losses}}}$$

→ At full load

***

$$\boxed{\eta = \frac{\text{Full load VA} * \text{PF}}{(\text{Full load VA} \times \text{PF}) + P_i + P_c}}$$

At any load of fraction x

***

$$\eta = \frac{x V_2 I_2 \cos\phi_2}{x V_2 I_2 \cos\phi_2 + P_i + P_c x^2}$$

Condition for maximum efficiency

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

dividing the numerator and denomi[nator by] I_2

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

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

$$-\frac{P_i}{I_2^2} + I_2 R_{es} = 0$$

$$I_2 R_{es} = \frac{P_i}{I_2^2}$$

$$\boxed{P_i = I_2^2 R_{es}}$$

$$P_i = P_c$$

$$I_2 = \sqrt{\frac{P_i}{R_{es}}}$$

* Output KVA corresponding to max eff:→

Total cu losses $= x^2 P_c$

$$x^2 P_c = P_i$$

$$x = \sqrt{P_i / P_c}$$

Q A 500 KVA transformer have full load copper loss 4KW and iron loss 2.5 KW

(a) Determine the output KVA at which which η_{max}?

(b) η_{max} for a load with pf 0.75?

$$x = \sqrt{\frac{2.5}{4}}$$

$$x = 0.79$$

$$500 \times 0.790$$

$$= 395 \text{ KVA}$$

$$\eta = \frac{500 \times 0.75}{500 \times .75 + 4 + 2.5} = \frac{375}{381.5} \times 100 = 98.2\%$$

Q A ϕ transformer has 30 turns at primary 350 turns at secondary the net cross sectional area of the core 250 cm^2 if the primary winding is connected to 230 V, 50Hz calculate

(a) Peak Value of flux density

(b) Voltage induced in the second

(c) Primary current when the second current 100 amp

Q A ϕ trans 230/110 ... transformer has iron loss of 100 W at 60 Hz and 60 W at 40 Hz determine the hysteresis and eddy losses at 50 Hz?

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

$$\frac{350}{30} = \frac{230}{V_2}$$

$$V_2 = \frac{30 \times 230}{350}, \quad V_2 = 19.71 \text{ volt}$$

$$\frac{N_2}{N_1} = \frac{I_1}{I_2} \qquad \frac{E_2}{E_1}$$

$$\frac{350}{30} = \frac{I_2}{100}$$

$$\frac{35}{3} \qquad E_2 = 2683.$$

~~Open circuit Test/~~:→

Transformers are tested before installation at the side to determine the parameters of the transformers to compute its performance characteristic. like voltage regulation and efficiency

→ There are two test

① O C test

② S C test

① Open circuit test:→

↳ It is performed to calculate the no-load losses or the core losses or the iron losses and no load current I_0 which is helpful in finding the no load parameter R_0 and X_0 it is usually done at low voltage side.

The LV side is given the a.c supply using the Auto transformer while HV side kept open circuited from the OC test we obtain V_0, I_0, W_0. V_0 → No load Primary voltage

$W_0 = I_0 V_0$

$W_0 = I_0 V_0 \cos\phi_0$

$\left(\frac{W_0}{I_0 V_0}\right) = \cos\phi_0$

$\phi_0 = \cos^{-1}\left(\frac{W_0}{I_0 V_0}\right)$

V_0 = Rated voltage

I_0 = No load primary current whose value is very low

W_0 = No load loss or core loss

↳ copper losses occuring in the winding is very less is the value of I_0 is very low

* DC Machines:→

↳ D.C machines is actually an alternating current machine but they contains with a special device called commutator which convert a.c into d.c and vice versa

↳ There are two types of DC Machines

① D.C Motor

② D.C Generator

* Construction:→

① Mechanical frame/Yoke:→

↳ It is the outer cylinder frame to which the main poles are fixed by means of which the machine is fixed with the foundation

↳ It serves 2 following f(n)

① provide mechanical protection to the inner part of the machine

② It provides low reluctance path through which flux is setup

② Pole core and Pole shoe:→

↳ They support the field or the exciting coil

↳ They spread out the magnetic flux over the armature boundary uniformly

③ Field winding:→

↳ When DC is passed through the field winding it magnetizes the poles that produced the required flux The field

in ε of all the poles are connected in series
in such a way that opposite poles are
created on the adjacent poles.

④ Armature coil:→

It is cylindrical in shape and connected with the rotating shape at the outer boundary slots are cut in which armature winding is placed. It has following purpose

(i) It houses the armature conductor

(ii) It provides an easy path for magnetic flux (S=low)

(iii) Since armature is the rotating part reversal of flux takes place in the core therefore hysteresis loss is produced. To minimize the hysteresis loss silicon steel is used for its construction

(iv) The rotating armature cuts across the magnetic field that induced an EMF in it. The EMF circulate Eddy current resulting in Eddy current losses. Therefore armature core is laminated

⑤ Armature winding:→

Armature winding is placed in the slots present in the armature. Armature winding is the heart of the DC motor or DC machine. It is the place where energy conversion take place. The armature winding is connected in two ways

(i) LAP (A=P)

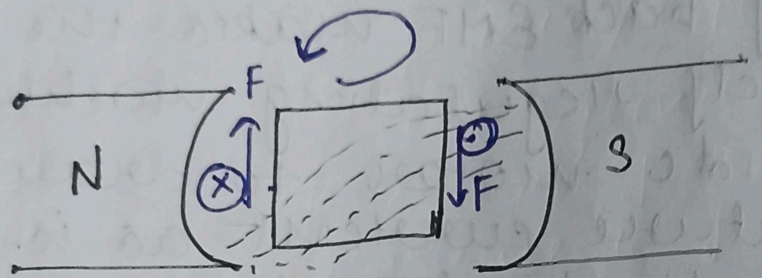
(ii) wave (A= 2)

⑥ comm

* Working Principal of DC Motor

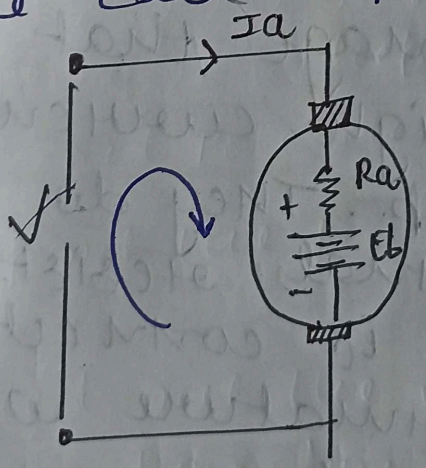
→ When a current carrying conductor is placed in a magnetic field the conductor experiences a mechanical force. The direction of force can be determined by Flemings left hand rule

$$\boxed{F = IBl \sin\theta \text{ Newton}}$$



* Back EMF or counter EMF :→

↳ Back EMF or counter EMF is the EMF of produced in the armature coil and it opposes the cause of generated flux



$V = E_b + I_a R_a$

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

$E_b \propto N$ (RPM)

↳ For No load condition Torque requir-ed is very less so motor rotates at very high speed. so our E_b is more and the armature current (I_a) is less

↳ For a loaded condition, The require
-ment of the Torque increases. So
our motor rotates slowly due to the
load due to which our Eb is less
and Ia is more. And the increase
in the armature current results in
higher electro-magnetic torque (T ∝ Ia)
when the torque which is required
to match the load torque ~~is attained~~.
the steady state is attained

"→The presence of back EMF makes the
DC motor a self regulating machine
i.e it make the dc motor to draw
as much armature current as is
just sufficient to develop the requir
-ed load torque."

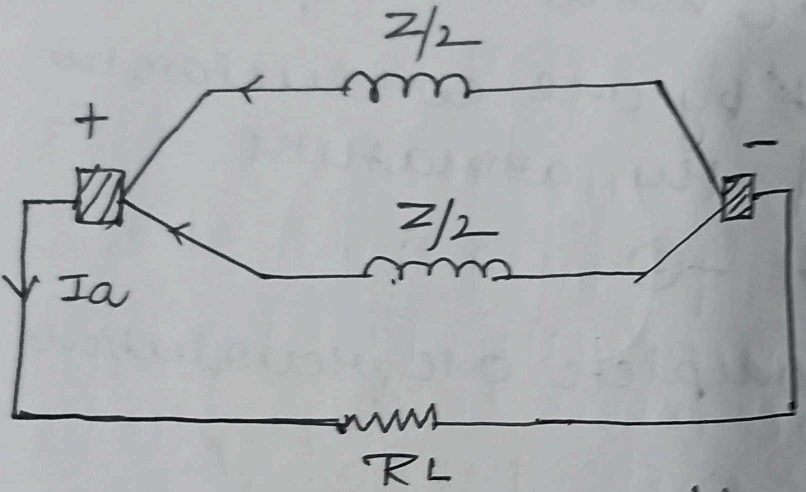
* Need of starters in DC Machine :-

↳ Starters are used to protect DC
motors from damage that can be
caused by very high current and Torqu
-e during startup. They do this by
providing external resistance to
the motor which is connected in
series to the armature winding and
restrict the current to an acceptable
level

* EMF equation of DC Machines :→

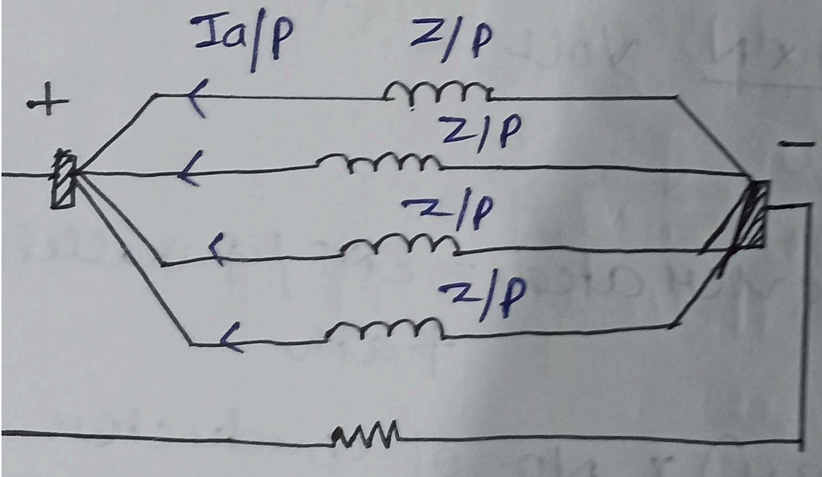
→ To understand the EMF equation first there is a need to understand types of armature winding because according the type and EMF eqn changes

→ Two types of winding
① Wave winding
② Lap winding



Z = No. of conductor
Ia = armature current
EMF generated = EMF / parallel path

(i) Wave winding
↳ It is used where we need large voltage



No. of parallel path = P

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

EMF = EMF / Parallel path

(ii) Lap winding
↳ (~~Application in motor~~)

↳ used where we need large current

→ Now derive EMF equation

ϕ = Magnetic flux per pole (Wb)

Z = No. of conductor

P = No. of poles

A = No. of parallel path

N = speed in RPM

n = speed in RPS

E = EMF of DC machine

→ Magnetic flux cut by one conductor in one revolution of the armature

$$d\phi = P\phi \text{ Wb} \quad -(1)$$

→ Time taken to complete one revolution

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

↳ EMF generated/conductor

$$\frac{d\phi}{dt} = \frac{P\phi \times N}{60} \text{ Volt}$$

↳ Now total EMF generated = EMF/parallel path

(EMF/conductor) × No. of conductor in series per parallel path

***

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

A = 2 (Wave)

A = 4 (Lap)

$E \propto \phi N \quad , \quad N \propto \frac{E}{\phi}$

→ EMF is directly proportional to the flux and rotating speed

Q

* Types of DC Motors:→

↳ There are following types of DC motor
① Permanent magnet DC motor
② Seperately Excited DC motor
③ Shunt wound DC motor
④ Series wound DC motor
⑤ compound wound DC motor

① Permanent Magnet Motor:→

↳ It consists of an armature and one or more several permanent magnets encircling the armature. Field coils are usually not required. And they have a fixed strength thus the motor can rotate at a speific speed we cannot change its speed.

② Seperately Excited DC motor:→

These motors have field coils similar but the armature and field coils are connected from different supply source

I_a = armature current

$E_b = V - I_a R_a$

$P = VI$

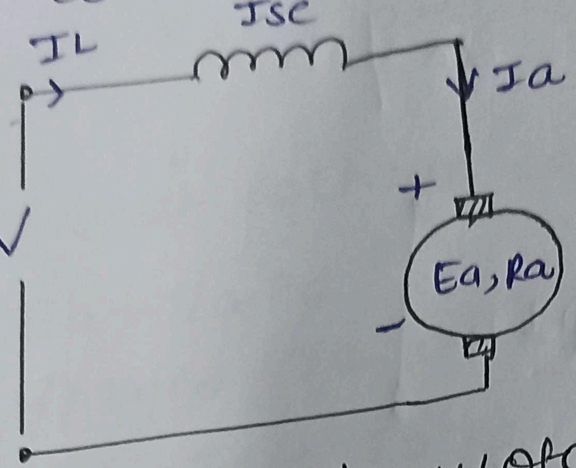
$T_m = V I_a - I_a^2 R_a$

$= I_a (V - I_a R_a)$

$= E_b \cdot I_a$

③ Series wound DC motor:→

↳ The field coils consisting of few turns of thick wire are connected in series with the armature

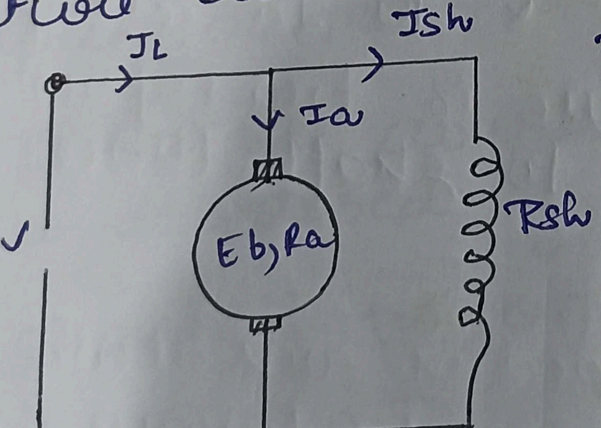


$V = E_b + I_{se}R_{se} + I_aR_a$

$E_b = V - I_aR_a - I_{se}R_{se}$

④ Shunt wound dc motor:→

↳ The word shunt means parallel. In these motors the field coils are connected in parallel with the armature. The field current is much less than armature current.



By KCL

$I_a = I_L - I_{sh}$

$V = I_aR_a + E_b$

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

⑤ Compound wound DC Motor:→

↳ A compound wound DC motor has both shunt and series field coils.

* Torque Equation :→

→ The force which is used to rotate the coil is known as Torque or we can say that the rotating force is known as Torque

→ We know that voltage equation

$$V = E_b + I_a \cdot R_a$$

Multipleying I_a on both side

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

$V \cdot I_a$ = Electrical power Input

$I_a^2 \cdot R_a$ = copper losses

$E_b \cdot I_a$ = Electromagnetic Power (output power) — ①

[Input = Output + losses]

→ Let T be the average electromagnetic torque developed by armature (N-m)

Mechanical power developed

$$P_m = \omega \cdot T$$

$$P_m = 2\pi n \cdot T$$

And from eq ①

$$E_b \cdot I_a = \omega \cdot T$$

$$E_b \cdot I_a = 2\pi n \cdot T$$

and we know

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

$$I_a \cdot \frac{P\phi \cancel{n} \cdot Z}{A} = 2\pi \cancel{n} \cdot T.$$

$$\boxed{T = \frac{PZ}{2\pi A} \cdot \phi I_a}$$

or

$$\boxed{T = K \cdot \phi I_a}$$ where $K = \frac{PZ}{2\pi A}$

$$T \propto \phi \cdot I_a$$

Hence the torque developed in the DC motor is directly $\propto$ to I_a and ϕ

when the torque is transferred from armature to shaft there are some losses.

Torque developed in armature is called Electromagnetic torque (T_e)

torque which we get at shaft is known as shaft torque

*** $$\boxed{T_e = T_{sh} + \text{losses}}$$

↳ So our $T_2 \omega < T_e$

* Losses in DC machines :→

Copper losses
↳ Armature current loss
↳ series field current loss

Iron losses
↳ Hysteresis
↳ Eddy current

Mechanical losses
↳ Friction loss
↳ windage loss

* Applications of DC motor :→

① Shunt motor :→ It is a constant speed running motor
↳ It is used in Lathe machine, drill machine, Weaving machine

② series motor :→ used in the machine where load is initially connected and we require large torque
- It is used in elevators
- It is used in Traction (Train)
- It is used in Vaccum cleaner
- It is used in hair dryer

③ compound motors :→ It is used in Presses