UNIT-V: AC MACHINES

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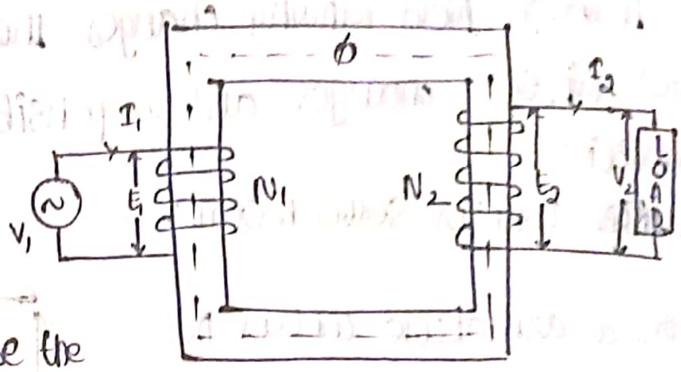
Transformer:

A transformer is a static device which transfer the power from one side to other side without changing the frequency.



Working principle:

The transformer is based on principle of mutual induction. This equipment is used to increase or decrease the voltages with corresponding decrease or increases the current.

V_1 - supply voltage
I_1 = primary current
E_1 = Emf induced in primary
N_1 - no. of turns in primary.
N_2 - no. of turns in secondary.
E_2 = Emf induced in secondary
I_2 = Secondary current
V_2 - voltage across the load.

It consists of two windings.

i, Primary winding
ii, secondary winding.

Both are wounded on a common laminated magnetic core. The winding connected to AC source is called as primary winding and winding connected to load is called as secondary winding. Depending upon the no. of turns of primary and secondary winding; the alternating emf is induced in the transformers.

If $V_2 > V_1$, then it is said to be step-up transformer ($N_2 > N_1$)

If $V_2 < V_1$, then it is said to be step-down transformer ($N_2 < N_1$)

Working:

When an alternating voltage is applied to primary, an alternating flux is set up in core. which links the primary and secondary winding. The emf induced in primary and secondary is E_1 and E_2

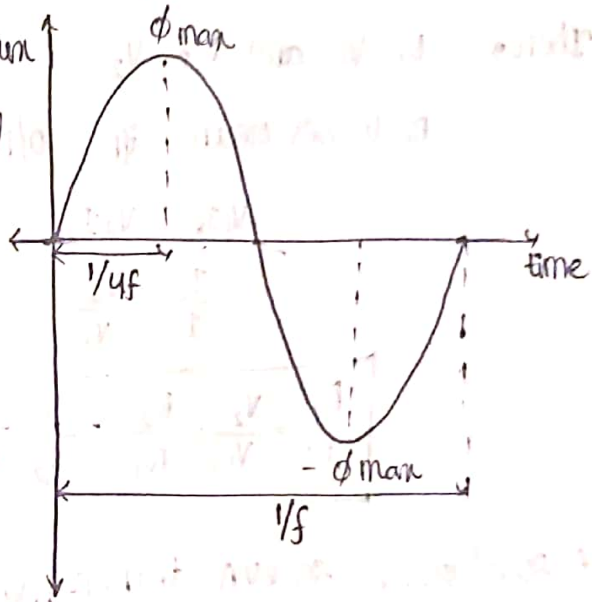
where $E_1 = \frac{N_1 d\phi}{dt}$, $E_2 = \frac{N_2 d\phi}{dt}$

Important points of transformer:

- The transformer action is based on laws of electromagnetic induction.
- There is no electrical connection b/w primary and secondary winding.
- The AC power is transfer from primary to secondary through magnetic flux

EMF equation of transformer:

When an alternating voltage is applied to the primary winding of the transformer, then alternating flux is produced in the core which links the both winding.



Let ϕ_{max} = maximum value of ϕ in Wb

f = frequency (Hz)

The magnetic flux increases from 0 to ϕ_{max} in $1/4^{th}$ of a cycle

So, the average rate of change of flux is $\frac{d\phi}{dt}$

i.e; $$\frac{d\phi}{dt} = \frac{\phi_{max} - 0}{1/4f} = 4f\phi_{max}$$

Since flux varies sinusodially, the emf having form factor 1.11

$\therefore$ rms value of induced emf per turn $= 1.11 \times 4f\phi_{max}$ $\left[\text{form factor} = \frac{\text{rms } \cancel{\text{avg}} \text{ value}}{\text{avg value}}\right]$

$= 4.44 f\phi_{max}$

If N_1 and N_2 are no. of turns in primary and secondary winding.

The emf induced in primary, $E_1 = 4.44 f\phi_{max} N_1$ —— ①

The emf induced in secondary, $E_2 = 4.44 f\phi_{max} N_2$ —— ②

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Voltage transformation Ratio:

From eq ① and eq ②

$\frac{E_2}{E_1} = \frac{N_2}{N_1} = k$ (voltage transformation ratio).

Ideal transformer:

In a ideal transformer, there is no winding resistance and reactance and no voltage drop and no losses in the transformer.

Then, $E_1 = V_1$ and $E_2 = V_2$

no losses means i/p = o/p

$$V_1 I_1 = V_2 I_2$$

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

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

Q) A 2000/200 V 20 kVA transformer has 66 turns in secondary calculate the Primary turns and secondary full load current

Sol: given, $\frac{V_1}{V_2} = \frac{2000}{200} \Longrightarrow V_1 = 2000V$

$V_2 = 200.V$

20kVA

$N_2 = 66.$

$k = \frac{V_2}{V_1} = \frac{200}{2000} = 0.1$

$\boxed{k = 0.1}$

$\frac{N_2}{N_1} = k \Longrightarrow N_1 = \frac{66}{0.1}$

$\boxed{N_1 = 660}$

$V_2 I_2 = 20kVA$

$200 \times I_2 = 20000$ VA

$\boxed{I_2 = 100A}$

(8) An Ideal 20KVA has 500 turns on primary and 40 turns in secondary winding. Primary is connected to 300 V and 50 Hz calculate the primary and secondary emf and full load currents and maximum flux

Sol: $N_1 = 500$, $N_2 = 40$

$V_1 = 300\,V$, $f = 50\,Hz$.

in Ideal transformer

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

$$V_2 = \frac{N_2}{N_1} \times V_1 = \frac{40}{500} \times 300$$

$$V_2 = 24\,V$$

$E_1 = V_1$

$$E_1 = 4.44 f \phi_{max} N_1 \Rightarrow 300 = 4.44 \times 50 \times \phi_{max} \times 500$$

$$\phi_{max} = \frac{3}{44.4 \times 25} = 2.702\,m.Wb.$$

$V_1 I_1 = 20 \times 10^3$ $\quad$ $V_2 I_2 = 20000$ $\quad$ 2500

$$I_1 = \frac{20000}{300} = 66.66\,A \qquad I_2 = \frac{\cancel{20000}\ 5000}{\cancel{24}\ 6\ 3} = 833.33\,A$$

(9) the net crossection area of 4000/3000, 50 Hz transformer is 600 cm^2, the flux density is 1.3 Wb/m^2. Find N_1 and N_2

Sol: $V_1 = 4000\,V$; $V_2 = 3000\,V$

$f = 50\,Hz$

$a = 600\,cm^2 = 600 \times 10^{-4}\,m^2$

$B = 1.3\,Wb/m^2$

$\phi_{max} = B \times a$

$= 1.3 \times 600 \times 10^{-4}$

$\phi = 78\,m.Wb$

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

$$\frac{4000}{3000} = \frac{N_1}{N_2}$$

$$N_2 = \frac{3}{4} \times 231$$

$N_2 = 173$

$N_1 = 231$

$E_1 = 4.44 f \phi_{max} N_1$

$$\cancel{4000}\ 1000 = \cancel{4.44}\ 1.11 \times 50 \times 78 \times 10^{-3} \times N_1$$

$$N_1 = \frac{1000 \times 10^3}{11.1 \times 5 \times 78} = 231$$

Equivalent circuit of transformer:

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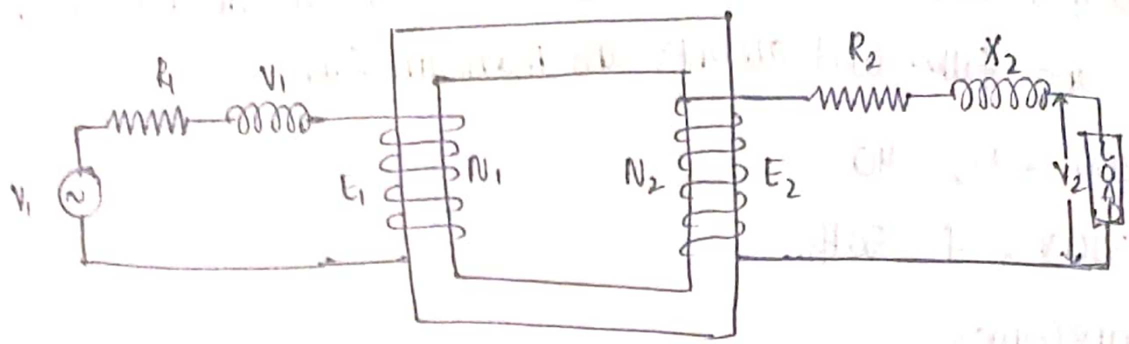


Voltage Regulation:

consider a transformer having primary and secondary winding parameters we can transfer the parameters from one side to another side

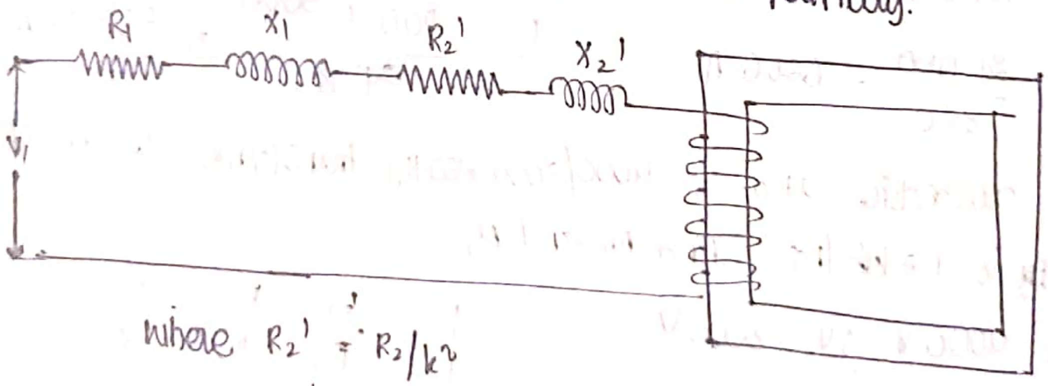
i. Resistance R_1 in primary becomes $k^2 . R_1$ when resistance transefered to secondary

ii, the resistance R_2 in secondary becomes R_2/k^2 when transefered to primary

iii, Reactance in secondary becomes x_2/k^2 when transefered to primary

iv, Reactance x_1 in primary becomes $k^2 x_1$ when transefered to secondary

from equivalent circuit of transformer refered to primary.



where $R_2' = R_2/k^2$

$x_2' = x_2/k^2$

$R_{01} = R_1 + R_2' = R_1 + R_2/k^2$

$x_{01} = x_1 + x_2' = x_1 + x_2/k^2$

Total impedence,

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

Equivalent circuit of transformer refered to secondary.

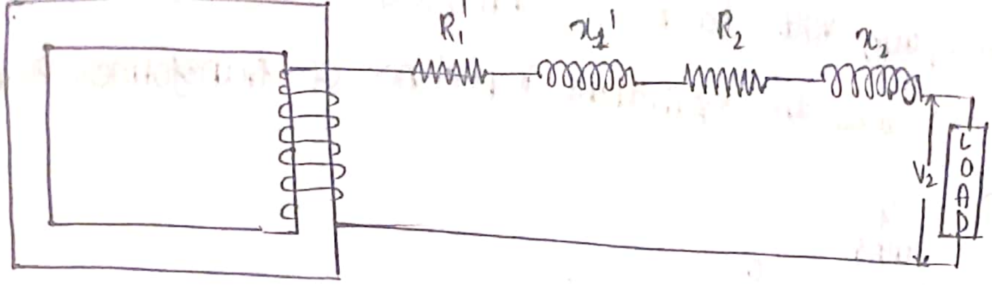
$R_1' = k^2 R_1$; $x_1' = k^2 x_1$

$R_{02} = R_1' + R_2 = k^2 R_1 + R_2$

$x_{02} = x_1' + x_2 = k^2 x_1 + x_2$

Total impedence,

$Z_{02} = \sqrt{R_{02}^2 + x_{02}^2}$



(9) A 10 kVA 2000/400 volts a single phase transformer has $R_1 = 5$ ohms, $R_2 = 0.2$ ohms, $x_1 = 12$ ohms, $x_2 = 0.4$ ohms. Determine the equivalent impedence of transformer refered to primary and secondary side of transformer.

Sol: $K = \frac{400}{2000} = \frac{1}{5}$
$= 0.2$.

Refered to primary,

$R_{0_1} = R_1 + R_2' = R_1 + \frac{R_2}{k^2}$

$= 5 + \frac{0.2}{(0.2)^2} = 10$ ohms.

$X_{0_1} = x_1 + x_2' = x_1 + \frac{x_2}{k^2}$

$= 12 + \frac{\cancel{0.4}}{\cancel{0.2 \times 0.2}} = 22$ ohms.
0.1

$\therefore Z_{0_1} = \sqrt{R_{0_1}^2 + X_{0_1}^2} = \sqrt{100 + 484} = \sqrt{584} = 24.1660$ ohms.

Refered to secondary,

$R_{0_2} = R_1' + R_2 = k^2 R_1 + R_2 = (0.2)^2 \times 5 + 0.2$

$= 0.04 \times 5 + 0.2$

$= 0.2 + 0.2 = 0.4$ ohms.

$X_{0_2} = x_1' + x_2 = k^2 x_1 + x_2 = (0.2)^2 12 + 0.4$

$= 0.04 \times 12 + 0.4$

$= 0.48 + 0.4 = 0.88$ ohms

$Z_{0_2} = \sqrt{R_{0_2}^2 + X_{0_2}^2} = \sqrt{(0.4)^2 + (0.88)^2} = 0.9666$ ohms

(9) A 100kVA 2200/440 volts has $R_1 = 0.3$ ohms, $x_1 = 1.1$ ohm, $R_2 = 0.01$ ohm, $x_2 = 0.035$ ohms. calculate the equivalent impedence of transformer refered to primary side.

Sol: $K = \frac{V_2}{V} = \frac{440}{2200} = 0.2$

$$R_{0_1} = R_1 + R_2'$$

$$= R_1 + \frac{R_2}{k^2} = 0.3 + \frac{0.01}{(0.2)^2} = 0.55 \text{ ohms}$$

$$X_{0_1} = X_1 + x_2'$$

$$= x_1 + \frac{x_2}{k^2} = 1.1 + \frac{0.035}{(0.2)^2} = 1.975 \text{ ohms}$$

$$Z_{0_1} = \sqrt{R_{0_1}^2 + X_{0_1}^2} = \sqrt{(0.55)^2 + (1.975)^2}$$

$$= 2.0501 \text{ ohms}$$

Voltage Regulation:

Voltage regulation of transformer is the arithmetic difference b/w the no load secondary voltage and the secondary voltage on load, expressed as % of no load

$$\% \text{ voltage Regulation} = \frac{V_{0_2} - V_2}{V_{0_2}} \times 100.$$

$$= \frac{I_2(R_{0_2}\cos\phi_2 \pm X_{0_2}\sin\phi_2)}{V_{0_2}} \times 100.$$

$$= \frac{I_1(R_{0_1}\cos\phi_1 \pm X_{0_1}\sin\phi_1)}{V_{0_1}} \times 100$$

here '+' for lagging power factor

'−' for leading power factor

⑤ The primary and secondary winding of 100 kVA transformer 2200/440 volts. The R_1 and R_2 are 0.3 and 0.1 ohm and the corresponding reactances 1.1 and 0.035Ω calculate the voltage regulation of transformer 0.8 power factor lagging and leading

Sol: for lagging

$$\% VR = \frac{I_2(R_{o_2}\cos\phi_2 + X_{o_2}\sin\phi_2)}{V_{o_2}} \times 100 \qquad k = 0.2$$

given, $R_1 = 0.3\Omega$

$R_2 = 0.1\Omega$

$x_1 = 1.1\Omega$

$x_2 = 0.035\Omega$

$\cos\phi_2 = 0.8$

$$\frac{V_1}{V_2} = \frac{2200}{440} \Rightarrow V_2 = 440V$$

$$I_2 = \frac{100\times10^3}{440} = \frac{5000}{22} = 227.27\ A$$

$$\sin\phi = \sqrt{1-0.64} = \sqrt{0.36} = 0.6.$$

$R_{o_2} = R_1' + R_2 = k^2R_1 + R_2$

$= (0.04)(0.3) + 0.1$

$= 0.112\ \Omega$

$X_{o_2} = x_1' + x_2 = k^2x_1 + x_2$

$= (0.04)(1.1) + 0.035$

$= 0.079\Omega$

for lagging,

$$\% VR = \frac{227.27(0.112\times0.8 + 0.079\times0.6)}{\frac{440}{22}}\times 100$$

$$= \frac{31.1359\times5}{22} = 7.07\%$$

for leading,

$$\% VR = \frac{227.27(0.112\times0.8 - 0.079\times0.6)}{\frac{440}{22}}\times 100$$

$$= \frac{9.5907\times5}{22} = 2.1797\%$$

$$R_{o_1} = R_1 + R_2' = R_1 + \frac{R_2}{k^2} = 0.3 + \frac{0.1}{(0.2)^2} = 2.8 \text{ ohms}$$

$$x_{o_1} = x_1 + x_2' = x_1 + \frac{x_2}{k^2} = 1.1 + \frac{0.035}{(0.2)^2} = 1.975 \text{ ohms}$$

$$V_{o_1} = 2200 \Rightarrow I_1 = \frac{100\times10^3}{2200} = \frac{1000}{22} = 45.45\ A$$

for lagging,

$$\% VR = \frac{I_1(R_{o_1}\cos\phi_1 + X_{o_1}\sin\phi_1)}{V_{o_1}} \times 100$$

$$= \frac{45.45(2.8 \times 0.8 + 1.975 \times 0.6)}{2200} \times 100$$

$= 7.07\%$

for leading,

$$\% VR = \frac{I_1(R_{o_1}\cos\phi_1 - X_{o_1}\sin\phi_1)}{V_{o_1}} \times 100$$

$$= \frac{45.45(2.8 \times 0.8 - 1.975 \times 0.6)}{2200} \times 100$$

$= 2.17\%$

(5) The primary and secondary resistances of 40 kVA, 6600/250 volts 1-ϕ transformer are 10 ohms and 0.02 ohms respectively. The reactance refered to primary is 35 ohms calculate the voltage regulation of transformer of 0.8 power factor lagging and leading

Sol: Given, $R_1 = 10$ ohms

$R_2 = 0.02$ ohms

$X_{o_1} = 35$ ohms

$\frac{V_1}{V_2} = \frac{6600}{250}$

$I_1 = \frac{40 \times 1000}{6600} = \frac{200}{33}$

$= 6.06A$

$k = \frac{250}{6600} = 0.037$

$R_{o_1} = R_1 + R_2' = R_1 + \frac{R_2}{k^2} = 10 + \frac{0.02}{(0.037)^2}$

$= 24.6092$

$\cos\phi = 0.8$; $\sin\phi = 0.6$

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lagging

$$\% VR = \frac{I_1(R_{01}\cos\phi + x_0\sin\phi)}{V_{01}} \times 100$$

$$= \frac{\overset{1.01}{\cancel{6.06}}(24.6\times0.8 + 35\times0.6)}{\underset{11}{\cancel{6600}}} \times 100$$

$$= 3.73\%$$

leading

$$\% VR = \frac{I_1(R_{01}\cos\phi - X_{01}\sin\phi)}{V_{01}} \times 100$$

$$= \frac{\overset{1.01}{\cancel{6.06}}(24.6\times0.8 - 35\times0.6)}{\underset{11}{\cancel{6600}}} \times 100$$

$$= -0.12\%$$

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⑤ The primary and secondary winding of 40 kVA, 6600/250 V single phase transformer has resistance 10 Ω and 0.02 Ω. The reactances are 1.1 and 0.035 Ω. Calculate the secondary full load voltage for lagging power factor of 0.8

Sol: given, $V_{01} = 6600V$

$V_{02} = 250V$

$R_1 = 10\Omega$

$R_2 = 0.02\Omega$

$x_{01} = 1.1\ \Omega$

$x_2 = 0.035\ \Omega$

$\cos\phi = 0.8 \rightarrow \sin\phi = 0.6$

$$I_2 = \frac{40\times10^3}{250} = \frac{\overset{160}{\cancel{800}}}{\cancel{4000}}\bigg/\cancel{25} = 160\ A$$

$$k = \frac{V_{02}}{V_{01}} = \frac{250}{6600} = 0.037$$

$$R_{02} = k^2R_1 + R_2$$
$$= (0.037)^2 10 + 0.02$$
$$= 0.0336\Omega$$

$$XO_2 = k^2x_1 + x_2$$
$$= (0.037)^2 1.1 + 0.035$$
$$= 0.0365\Omega$$

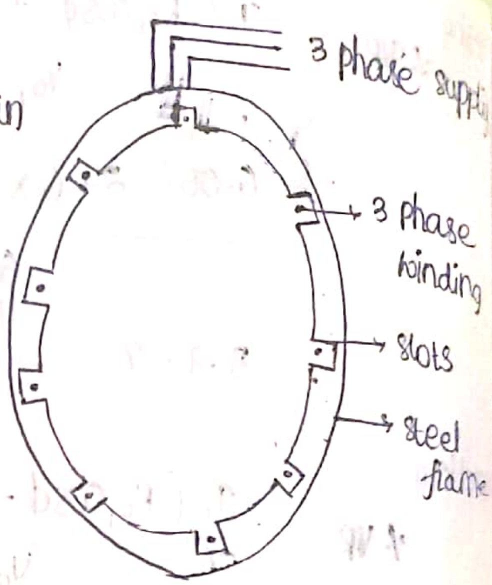
$$V_{02} - V_2 = I_2(R_{02}\cos\phi + x_{02}\sin\phi)$$

$$V_2 = V_{02} - I_2(R_{02}\cos\phi + x_{02}\sin\phi)$$

$$= 250 - 160((0.0336)(0.8) + (0.0365)0.6)$$

$$\boxed{V_2 = 242.1952\ V}$$

Three phase inductions Motors :



A 3 phase induction motor consists of 2 main parts.

1) stator
2) Rotor

1) stator :

It consists of steel frame made up of thin lamination of silicon steel to reduce eddy current and histerises loss. A no. of slots are provided in the inner periphery, the conductors are placed in the stator slots i.e; 3-phase winding. when a 3-phase supply is given to the stator winding, a rotating magnetic field is produced this rotating magnetic field induces current in the rotor by electro magnetic induction

$$N_S = \frac{120F}{P}$$

N_S = Synchronous speed

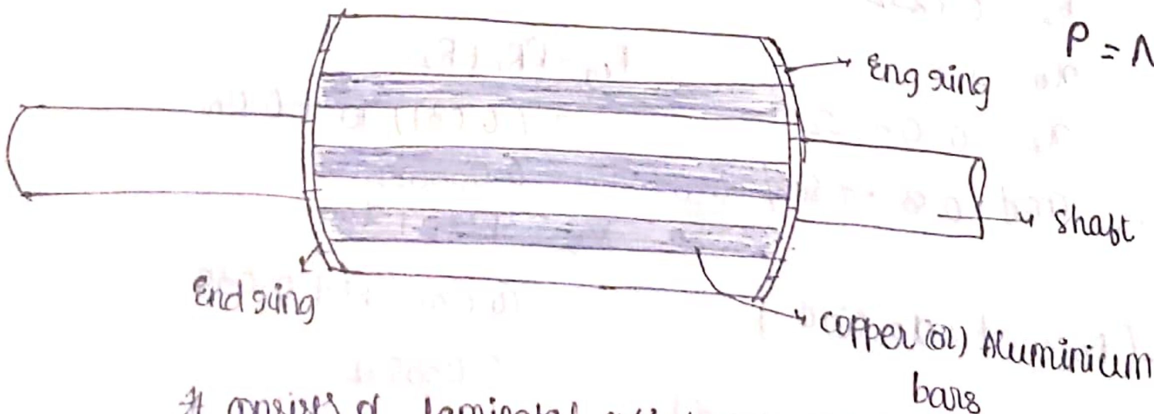
2) Rotor :

The rotor is mounted on a shaft and having the slots on its outer periphery the winding placed in the slots may be the following types

F = Supply frequency

P = No of poles

i, squirrel cage :

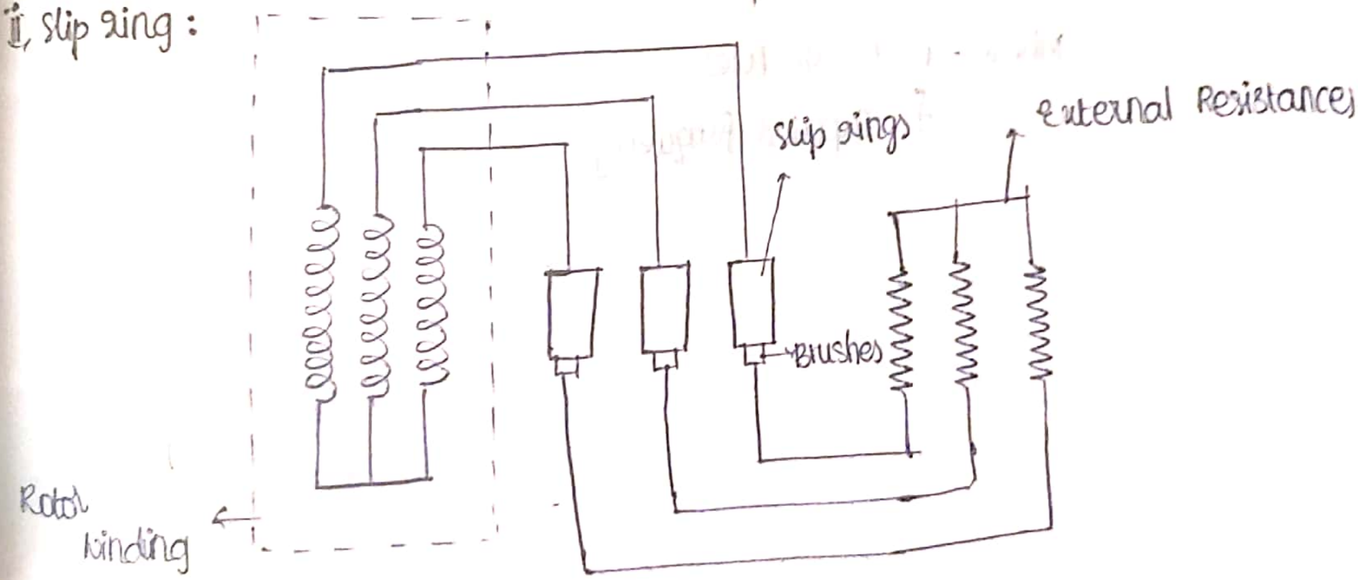


It consists of laminated cylindrical core having parallel slots on its outer periphery. copper or Aluminium bars are placed in each slot. All bars are joined at each end by end rings. They are permanently short circuited the entire construction looks like squirrel cage and hence the name. The rotor is not connected electrically, but the current induced in it by transformer action. Most of the three phase induction motors are Squirrel Cage Motors because it has robust and simple construction. It suffers from the disadvantage of low starting torque because rotor bars are permanently short circuited and it is not possible to add any external resistances to the rotor circuit to have a high starting torque.

Applications:

lathe machines, drilling machines, grinding and printing machines.

ii, Slip ring:



It consists of 3-phase winding similar to the stator. The rotor winding is uniformly distributed in the slots and connected to the slip rings and brushes. The brushes are connected to a external resistance. At starting the external resistances are included in the rotor circuit to have a high starting torque. These resistances gradually decreases to zero as the motor runs upto the speed. The external resistances are used during the starting period only. When the rotor attains the normal speed, the slip ring motor runs like a squirrel cage motor.

Rotating Magnetic field:

When a 3-phase winding is energized by 3-phase electric supply a rotating magnetic field is produced. This field is such that the poles do not remain in fixed position, they go on shifting their positions around the stator. With this reason it is called the rotating magnetic field. The speed at which the revolving flux rotates is called synchronous speed. It's value depends upon the no. of poles and supplied frequency.

$$\text{Synchronous speed, } N_s = \frac{120 \times f}{P}$$

where, P = no. of poles

f = supplied frequency.