Transformers:

A transformer is a static ~~piece~~ piece of apparatus by means of which an electrical power is transformed from one alternating current (A.C) circuit to another without any change in frequency.

The two circuits are magnetically coupled.

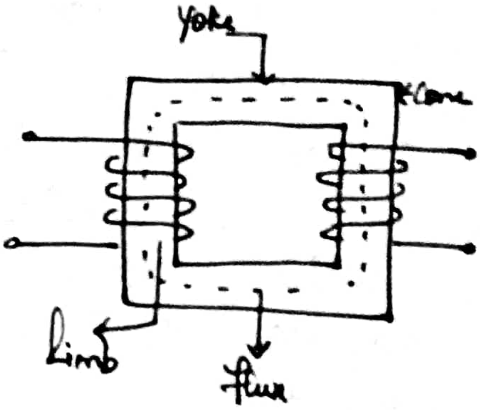
Principle:

The transformer works on the principle of electromagnetic induction. In this case, the conductors are stationary & the magnetic flux is varying with respect to time. Thus the induced emf comes under the classification of statically induced emf

Construction:

The essential requirements of transformer are

⇒ A good magnetic core
⇒ Two windings
⇒ A time varying flux



→ The core of the transformer is either square or retangular in size.

→ Core is made up of laminations. Because of laminated type of construction, eddy current losses get minimized.

→ Generally, high grade silicon steel laminations are used. Such a material has high relative permeability and low hysteresis loss. These laminations are insulated from each other.

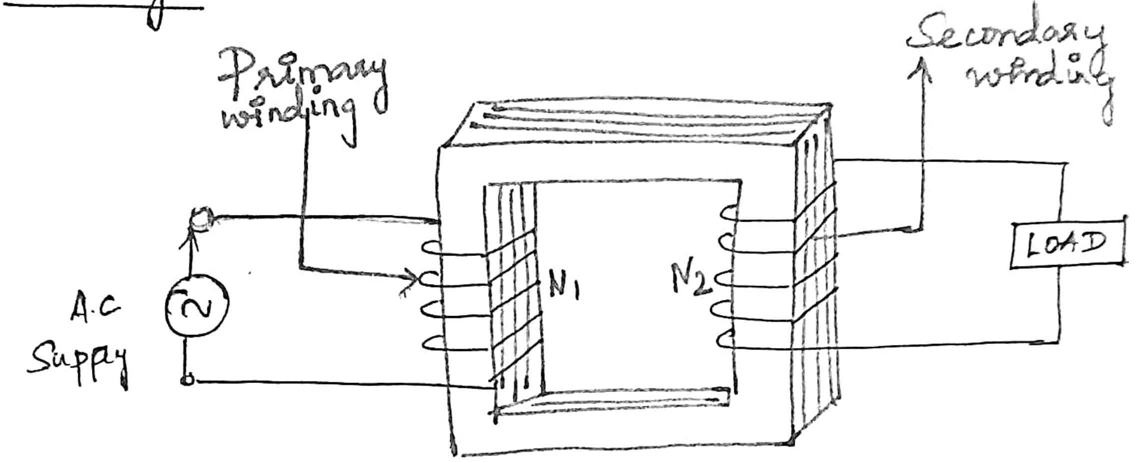
→ Laminations are overlapped so that to avoid the air gap at the joints. For this generally 'L' shaped or 'T' shaped laminations are used.

→ The coils used are wound on the limbs and are insulated from each other. To decrease the leakage flux and to have high mutual inductance, the two windings are split into number of coils and are wound adjacent to each other on the same limb.

→ The coils are made of conducting material like Copper

→ The core provides the low reluctance path to the flux produced by the primary while the winding carry currents for the functioning of the transformer.

Working:



When two coils are inductively coupled and if current in one coil is uniformly changed then an emf is gets induced in the other coil is called mutual inductance

It consists of two inductive coils which are electrically separated but linked through a common magnetic circuit. These two coils have high mutual inductance.

One of the two coils is connected to a source of alternating voltage. The coil in which electrical energy is fed with the help of source is called primary winding.

The other winding is connected to load. The electrical energy transformed to this winding is connected to the load. This winding is called secondary winding.

The primary winding has N_1 number of turns while the secondary winding has N_2 number of turns.

When primary winding is excited by an

alternating voltage, it circulates alternating current. This current produces flux (ϕ) which complete its path through common magnetic core. Thus an alternating flux links with the secondary winding.

As the flux is alternating, according to Faradays law of electromagnetic induction, mutually induced emf gets developed in the secondary winding.

Let the induced voltages (emfs) in the primary & secondary be E_1 & E_2 respectively

In any transformer $k = \frac{N_2}{N_1}$, defines the transformation ratio

Three categories of transformer action are possible

1. $E_2 < E_1$ (ie $V_2 < V_1$) $\Rightarrow$ Step down transformer
2. $E_2 = E_1$ (ie $V_2 = V_1$) $\Rightarrow$ 1:1 (or) equal ratio transformer
3. $E_2 > E_1$ (ie $V_2 > V_1$) $\Rightarrow$ Step up transformer

In any transformer, the primary ampere turns is equal to secondary ampere turns

$$E \propto N$$

$$N_1 I_1 = N_2 I_2$$

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

Types of Single phase Transformer:-

The types of 1ϕ transformer based on the construction are

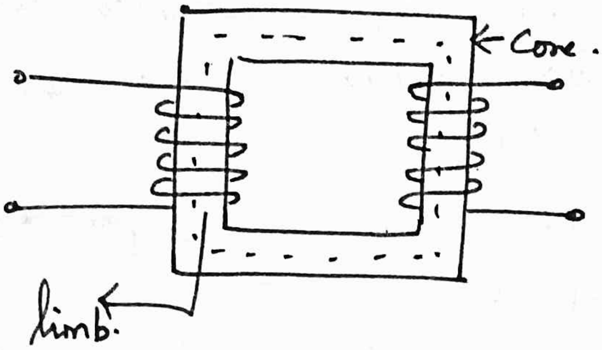
1. Core type
2. Shell type

Core type transformer:-

It has a single magnetic circuit. The core is rectangular having two limbs. The winding encircles the core.

The coils used are of cylindrical type, wound in helical layers with different layers insulated from each other by paper or mica

Both coils are placed on both the limbs. The low voltage coil is placed inside near the core while high voltage coil surrounds the low voltage coil.



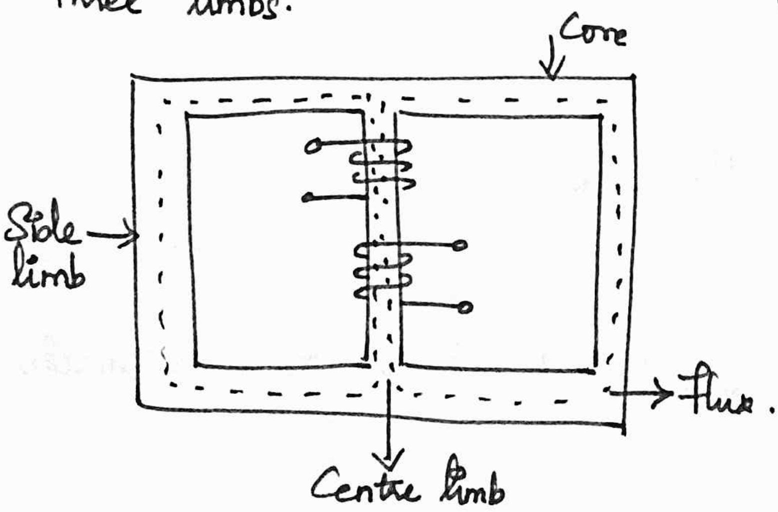
Core is made up of large ~~this~~ number of thin laminations.

As the windings are uniformly distributed over the two limbs, the natural cooling is more effective.

The coils can be easily removed by removing the laminations of the top yoke, for maintenance

Shell type transformer:-

It has a double magnetic circuit. The core has three limbs.



Both the windings are placed in central limb. The core encircles most part of the windings.

Generally for very high voltage transformers, the shell type construction is preferred.

As the windings are surrounded by core, the ~~naturn~~ natural cooling does not exist

For removing any winding for maintenance, large number of laminations are required to be removed.

E.M.F Equation of a transformer:

When the primary winding is excited by an alternating voltage V_1, it circulates alternating current, producing an alternating flux ϕ.

The primary winding has N_1 number of turns. The alternating flux ϕ linking with the primary winding induces an emf E_1

The flux links with secondary winding through the common magnetic core. It produces induced emf E_2 in the secondary winding. This is mutually induced emf.

ϕ = Flux. , ϕ_m = Max. value of flux.

N_1 = Number of primary turns winding turns

N_2 = Number of secondary turns

f = Frequency of supply voltage.

E_1 = R.M.S value of the primary induced emf

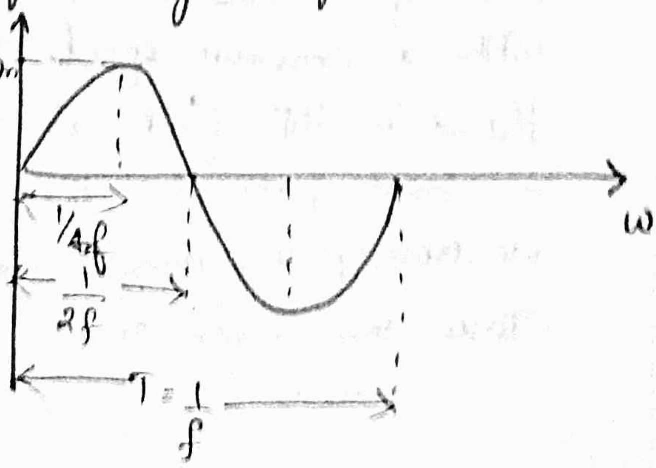
E_2 = R.M.S value of the secondary induced emf

From Faradays law of of electromagnetic induction the average emf induced in each turn is proportional to the average rate of change of flux.

$\therefore$ Average emf per turn = Average rate of change of flux $= \frac{d\phi}{dt}$

$$\frac{d\phi}{dt} = \frac{\text{Change in flux}}{\text{Time required for change in flux}}$$

Consider 1/4th cycle of the flux. Complete cycle gets completed in 1/f seconds.



In 1/4th ~~ϕ~~ time period, the change in flux is from 0 to ϕ_m.

$$\frac{d\phi}{dt} = \frac{\phi_m}{\frac{1}{4f}} = 4f\phi_m \quad Wb/sec.$$

Average emf per turn = $4f\phi_m$

for sinusoidal Quantity,

$$\text{form factor} = \frac{\text{R.M.S Value}}{\text{Average Value}} = 1.11$$

$$\text{R.M.S value} = \text{form factor} \times \text{Avg. Value}$$

$$= 1.11 \times 4f\phi_m.$$

$$= 4.44 f\phi_m$$

There are N_1 number of turns hence the R.M.S value of induced emf of primary denoted as

$$E_1 = N_1 \times 4.44 f\phi_m.$$

In N_2 number of turns in secondary, the R.M.S value of induced emf in secondary is denoted as

$$E_2 = N_2 \times 4.44 f\phi_m.$$

$$E_1 = 4.44 f\phi_m N_1$$

$$E_2 = 4.44 f\phi_m N_2$$

Three Phase Induction Motor:-

3ϕ Induction motor is extensively used as an industrial drive in variety of applications.

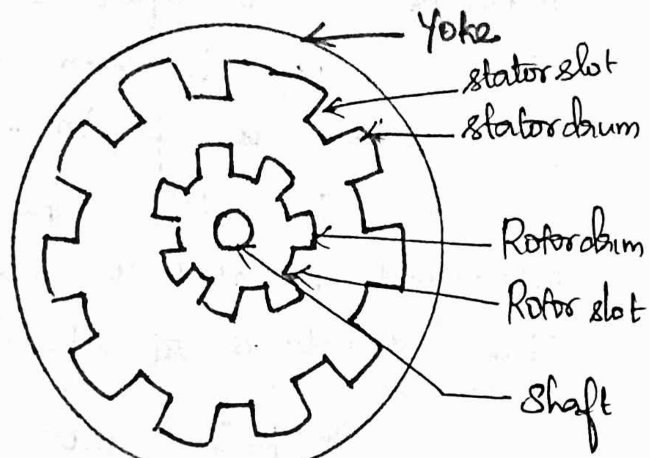
Principle:-

When a 3ϕ balanced voltage is applied to a 3ϕ balanced winding, a rotating magnetic field is produced. This field has a constant magnitude and rotates in space with a constant speed. If a stationary conductor is placed in this field, an emf is induced in it. By creating a closed path for the induced current to flow an electromagnetic torque can be exerted on the conductor. Thus the conductor is put in rotation.

Construction:-

The main parts of 3ϕ induction motor are stator & rotor

Stator:



⇒ The stator has a laminated type of construction made up of stampings which are 0.4 to 0.5 mm thick. The stampings are slotted on its periphery to carry the stator windings.

⇒ The stampings are insulated from each other. Such a construction essentially keeps the iron losses to a minimum value.

⇒ The slots on the periphery of the stator core carries a 3ϕ winding, connected either in star or delta. This 3ϕ winding is called stator winding.

⇒ The choice of number of poles depends on the speed of the rotating magnetic field required.

Rotor:

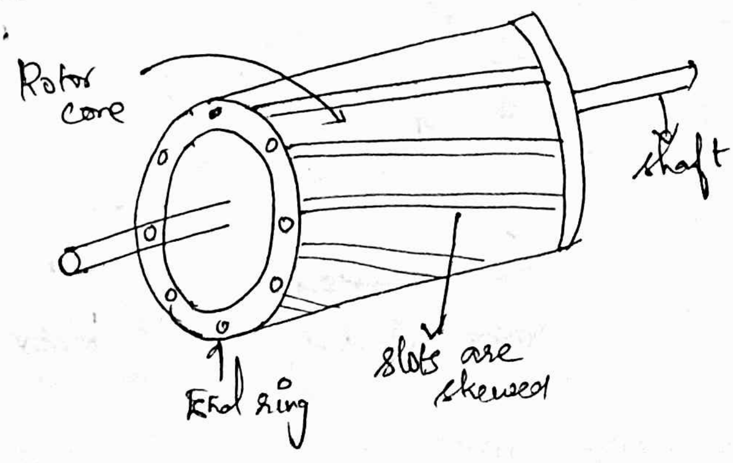
The rotor is placed inside the stator. The rotor core is also laminated in construction & uses cast iron.

In case of induction motors, the rotors are of two types namely

① Squirrel Cage rotor

② Slip ring rotor.

Squirrel Cage Rotor:



The rotor consists of uninsulated copper or Al bars called rotor conductors.

These bars are permanently shorted at each end with the help of conducting copper ring called end rings.

Fan blades are generally provided at the ends of rotor core. This circulates the air through the machine while operation, providing the necessary cooling. The air gap between stator & rotor is kept uniform and small as possible.

In this type of rotor, the slots are not arranged parallel to shaft axis but are skewed.

The advantages of skewing are:

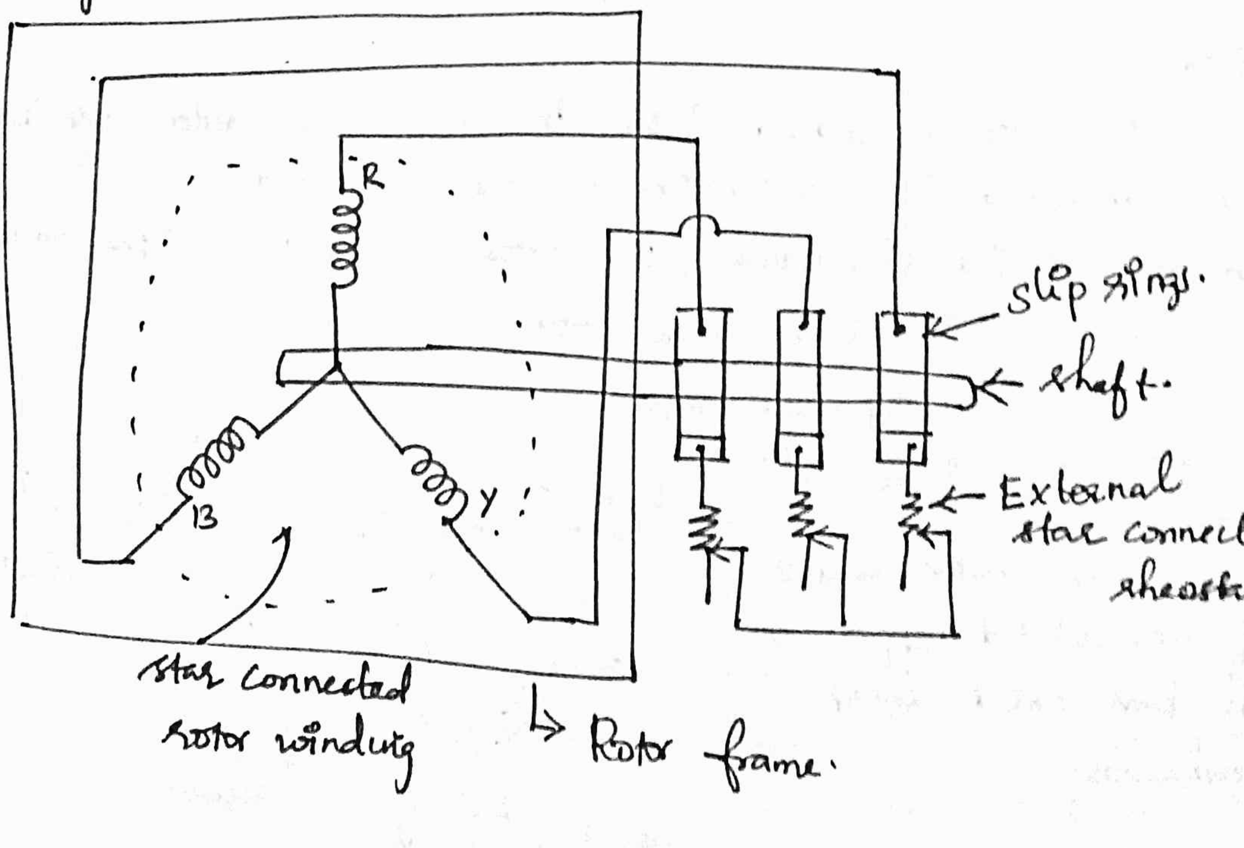
⇒ Noise gets reduced due to skewing

⇒ It makes the motor operation smooth.

⇒ Tendency of magnetic locking gets reduced due to skewing.

Slip Ring or wound Rotor:

This type of rotor is employed when high values of starting torque is required. The windings can be connected in star or delta and the three ends are brought out at the three slip rings.



In order to increase the starting torque or reduce the starting current or to control the speed, resistance can be connected through slip rings.

Working:

When a the stator of 3ϕ Induction motor is energised with 3ϕ supply, a magnetic flux of constant magnitude but revolving with certain speed in obtained. The speed of the revolving stator magnetic flux is called 'synchronous speed' given by

$$N_s = \frac{120f}{P}$$

P ⇒ No. of stator poles

f ⇒ Supply frequency is Hz.

This revolving flux while passing through the air gap, sweeps past the stationary rotor conductors. According to Faraday's laws of electromagnetic Induction, the relative speed between the rotating the rotating magnetic field and flux of the stator & the stationary rotor conductors, induces an emf in rotor conductors.

The magnitude of emf induced depends upon the relative speed & the direction is given by Flemings right hand rule. As the rotor conductors form a closed circuit, emf induced in the circuit causes the current flow through them.

The direction of flow is given by Lenz's law which is to oppose the cause of it. Hence, the cause of production is relative speed. Hence, to reduce the relative speed, the rotor starts rotating in same direction as that of revolving stator flux.

Advantages of 3ϕ Induction Motor:

- Simple design
- Rugged Construction
- Low Cost
- Reliable operation
- Minimum maintenance
- Sufficiently high efficiency.
- Simple starting arrangement

~~Single phase Induction Motor:-~~

Slip (S):

The difference between the speed of the stator magnetic flux (synchronous speed, N_s) and rotor speed (N) is known as slip.

$$S = \frac{N_s - N}{N_s}$$

$$S \cdot N_s = N_s - N$$

$$N = N_s - S \cdot N_s$$

$$N = N_s(1-S)$$

Single phase Induction Motor:

1ϕ Induction Motors are widely used in domestic, industrial and machine tool applications.

Construction:

1ϕ Induction Motor has basically 2 parts namely stator and rotor.

The stator has laminated construction, made up of stampings. The stampings are slotted on its periphery to carry the winding called stator winding or main winding. This is excited by 1ϕ A.C supply.

The laminated construction keeps iron losses to minimum. The stampings are made up of silicon steel which minimises the hysteresis loss.

The stator winding is wound for certain definite number of poles means when excited by 1ϕ AC supply, stator produces the magnetic field which creates the effect of certain definite number of poles.

$$N_s = \frac{120f}{P} \text{ r.pm}$$

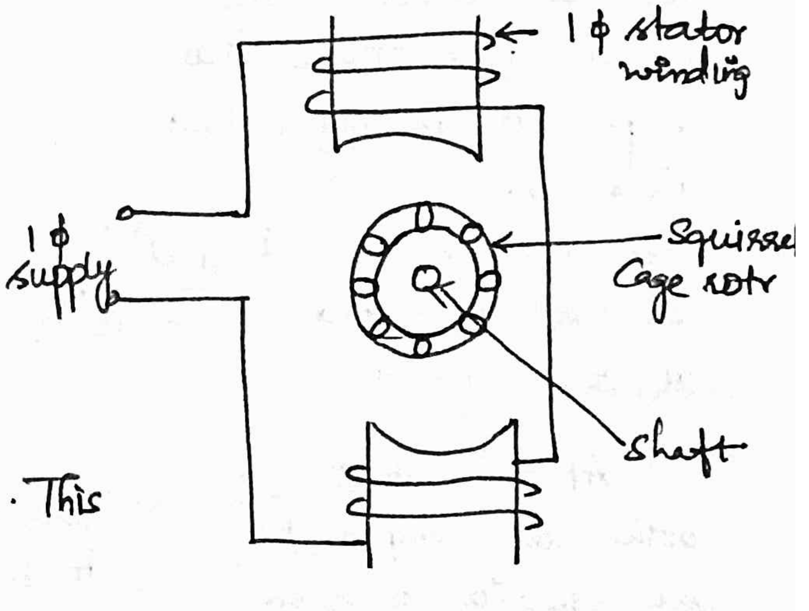
The induction motor never rotates with synchronous speed but rotates at a speed which is slightly less than synchronous speed.

The rotor construction is of squirrel cage type. In this type, rotor consists of uninsulated copper or Al bars, placed in the slots. The bars are permanently shorted at both the ends with the help of conducting rings called end rings. The entire structure looks like cage hence called squirrel cage rotor.

The air gap between stator & rotor is kept uniform & as small as possible. The main feature of this rotor is that it automatically adjusts itself for same number of poles as that of the stator winding.

<u>Working</u>:

In 1ϕ Induction motor, 1ϕ supply is given to the stator winding. The stator winding carries an alternating current which produces flux which is also alternating in nature. This flux is called <u>main flux</u>.



This flux links with the rotor conductors and emf is induced in the rotor. The induced emf drives current through rotor as rotor circuit is closed circuit.

The rotor ~~flux~~ current produces another flux called rotor flux. required for motoring action.

The second flux is produced according to induction principle due to induced emf hence the motor is called induction motor.

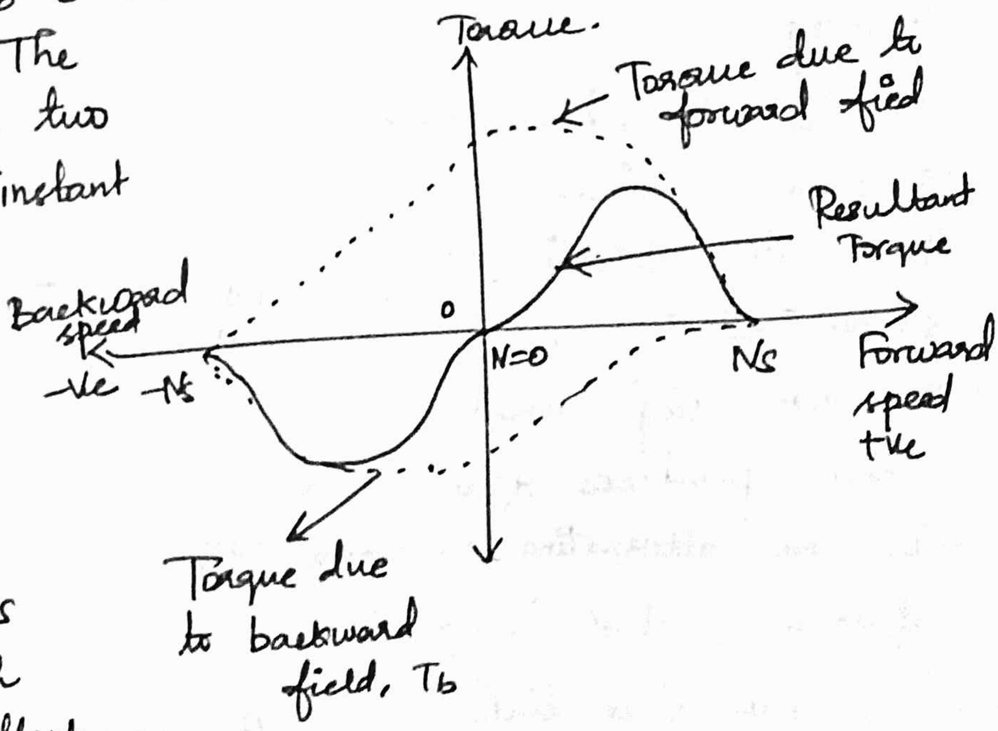
The 1ϕ induction motors are not self starting because of double revolving field theory.

Double Revolving field theory :-

According to this theory, any alternating quantity can be resolved into two rotating components which rotate in opposite direction as half of the max. magnitude of alternating quantity.

According to double revolving field theory, consider two components of the stator flux, each having magnitude half of max. magnitude of stator flux. Both components are rotating in opposite directions at the synchronous speed Ns which is dependent on frequency & stator poles.

Let ϕ_f is forward component rotating in anticlockwise direction while ϕ_b is the backward component rotating in clockwise direction. The resultant of these two components at any instant gives the instantaneous value of stator flux at that instant



At the start both the components are opposite to each other. Thus the resultant $\phi_R = 0$.

After 90°, the two components are rotated in such a way that both are pointing in the same direction.

$$\phi_R = (\phi m/2) + (\phi m/2) = \phi m.$$

The rotor current produces rotor flux. This flux interacts with forward component produces a torque in one particular direction [anticlockwise direction]. While rotor flux interacts with backward component produces a torque in clockwise direction. Anticlockwise torque is +ve then clockwise torque is -ve

At the start two torques are equal in magnitude but opposite in direction. The net torque experienced by rotor is zero at start. Hence the 1ϕ induction motors are not self starting.

Types of 1ϕ Induction Motor:-

Based on the method of starting, these motors are classified into following types.

→ Split - phase motors
→ Shaded pole motors.

Split phase Induction motors:-

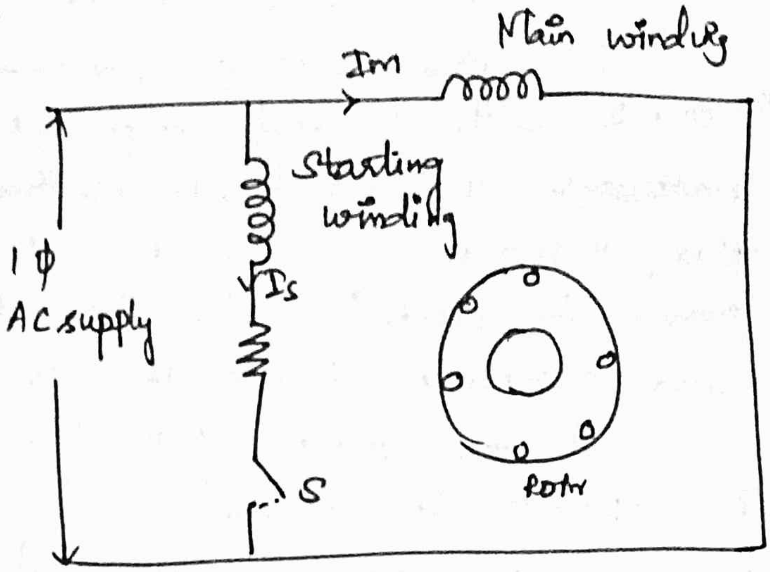
Since 1ϕ Induction motor is not self-starting, additional arrangement has to be made to make it self-starting. This could be achieved by using two windings with large phase difference between the currents carried by them. This arrangement produces revolving flux and hence makes the motor self-starting.

Depending on the circuit element connected in series with auxillary or starting winding, the split phase motor are classified as.

① Resistance - start Induction Motor
② Capacitance - start IM

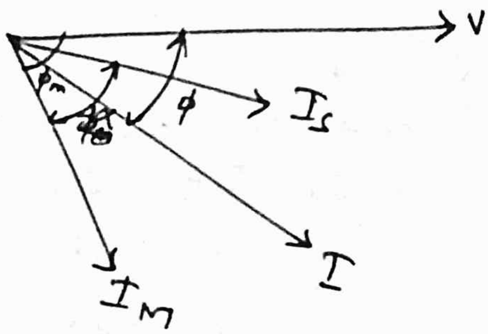
3. Capacitance start capacitance run IM.
4. Two value Capacitor run IM.

Resistance – start IM:-



The starting winding has high resistance connected in series with it. The current flowing through resistance is I_S.

The Centrifugal switch S disconnects the starting winding when the motor reaches 80% of its full load speed.



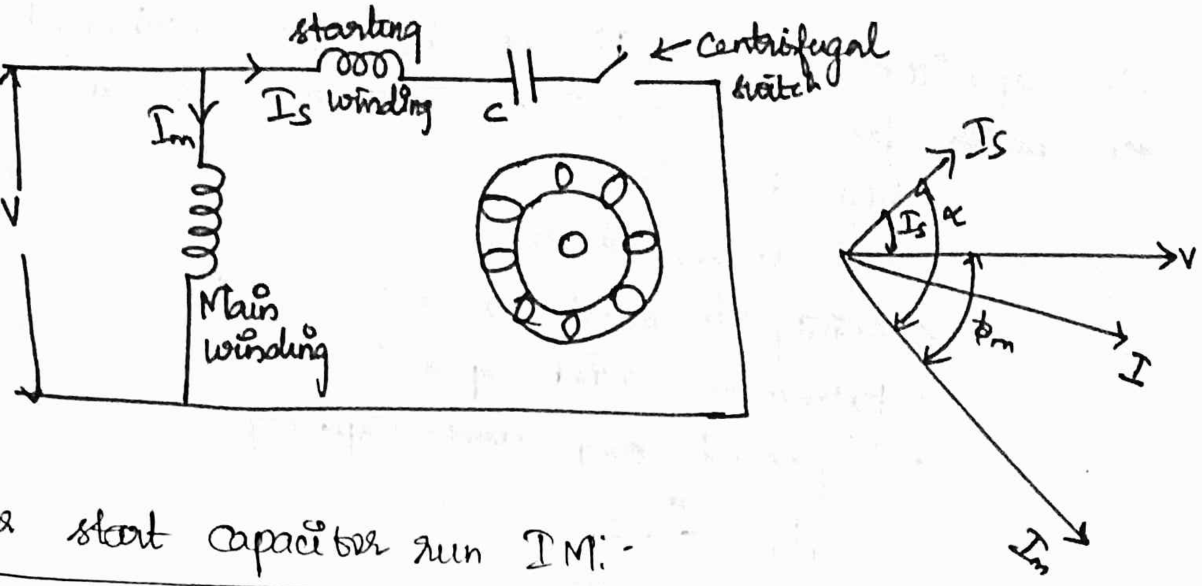
The main winding has low resistance & high reactance & it carries a current of I_M.

The torque developed by the motor is proportional to sin α, where α is the angle between I_M & I_S. Thus for obtaining high torque, α should be as high as possible.

Capacitance – start Induction Motor.

Here the Capacitor C is connected in Series with the starting winding to increase starting torque and to have a better starting power factor.

The Capacitor used is generally electrolytic type and is mounted on the surface of the motor as a separate unit.

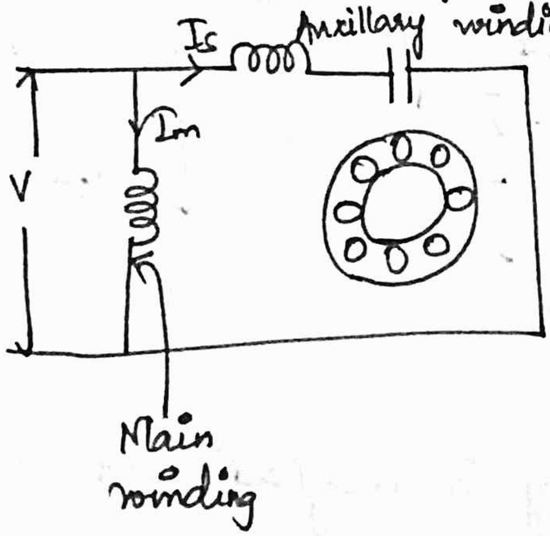


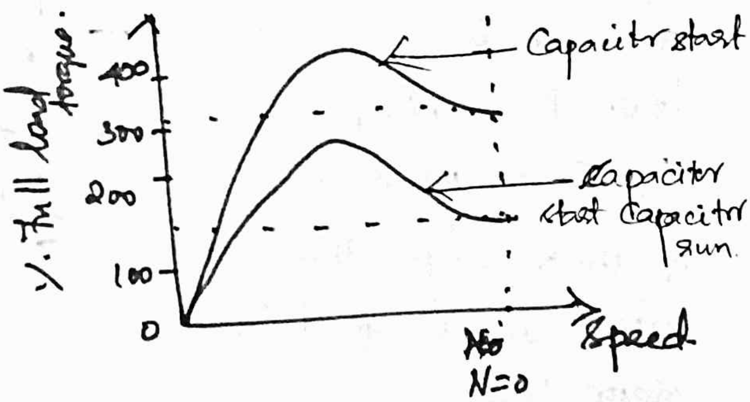
Capacitor start capacitor run IM:-

The arrangement for start and run motor is similar to that of Capacitor start motor except that the starting winding and the capacitor connected in the circuit through out of the operation of the motor.

The advantages of this type of motor are

→ Low noise in the motor while running
→ Higher power factor
→ High efficiency and
→ Improved over-load capacity of the motor





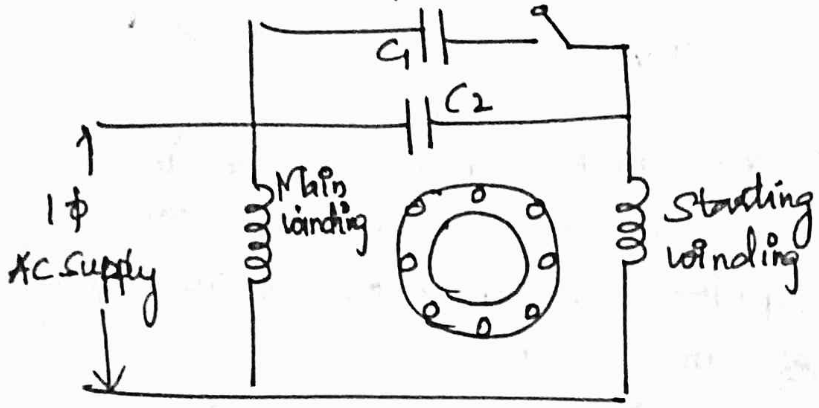
Two Value Capacitor-run motor:-

The arrangement of two value Capacitor run motor is shown below. This motor makes use of a high capacity electrolytic capacitor in series with the starting winding to produce high starting torque

During running conditions, a low value

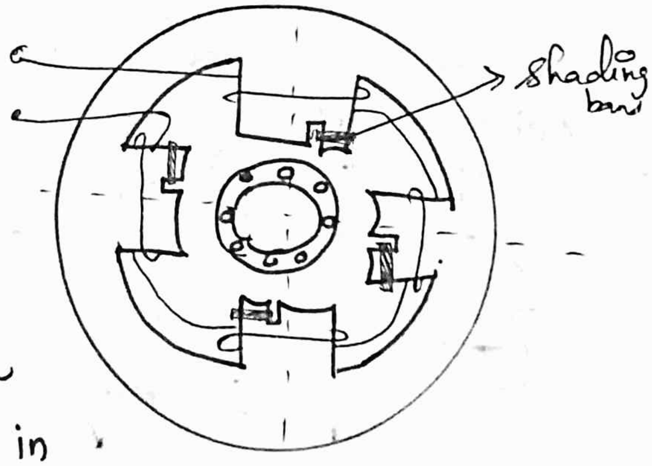
oil capacitor is substituted by the centrifugal switch for better power factor. The advantages of this motor are

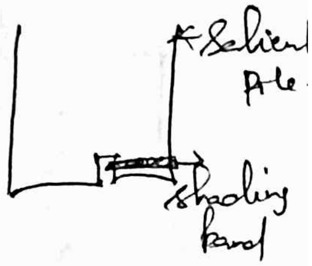
→ High Efficiency
→ High power factor.
→ Ability to start on heavy load
→ Extremely quiet operation.
→ Improved over load capacity



Shaded pole motor:-

It is employed, where the starting torque requirement of the load is very low. The shading coils is in the form of thick single turn ring. It is fixed in stator pole.



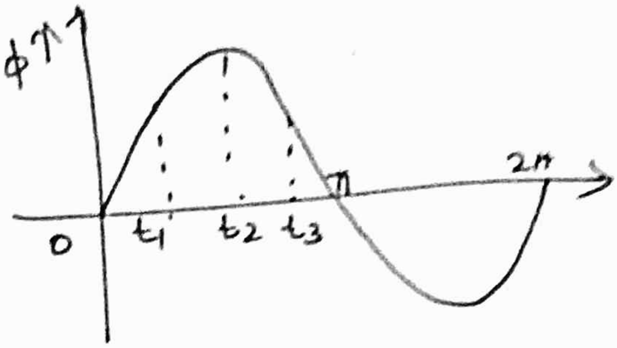


Whenever the ~~star~~ stator ring is energised with 1ϕ A.C supply, an alternating flux is created.

The effect of shading ring could be ~~understand~~ understood by considering of the magnetic flux distribution at three distances namely t_1, t_2 and t_3.

At the instant t_1, the rate ~~of~~ change of flux is high which induces an emf in the shaded ring.

According to Lenz's law, this emf induced will oppose the pole flux created by the stator current in the shaded area of the pole.



At the instant t_2, the rate of change of flux is minimum. The induced emf in the shaded ring is negligible. Hence no opposition from it for the distribution of flux in the pole. Thus, the flux distribution will be uniform & the ~~magnetic neutral axis~~

At the instant t_3, the rate of change of flux is high and emf induced in the shading coil which will oppose the reduction of flux in the pole in the shaded area.

Thus, the shifting of magnetic neutral axis from non-shaded to shaded area of the pole takes place at every half cycle. This gives a rotating magnetic field effect sufficient to provide starting torque to the rotor.

The important features of shaded pole motor are:

1. Smaller size
2. Rugged Construction
3. Harmless stalling condition