SINGLE PHASE INDUCTION MOTORS

Introduction

- The motors which work on single phase ac supply are called **single phase induction motors**.
- The power rating of these motors are very small. Some of them are of fractional horse power.
- Are used in applications like small toys, small fans, hair driers etc.

Types of Single Phase Motors

- **Single Phase Motors**
  - **Induction Motor**
    - Split Phase Type
    - Capacitor Type
    - Shaded Pole Type
  - **Universal motors**
  - **Repulsion Motors**
    - Repulsion Start Induction-run Motor
    - Repulsion Induction Motor
  - **Synchronous Motors**
    - Reluctance motor
    - Hysteresis Motor

Construction

- Single phase induction motors has
  - One rotating (rotor) and
  - Other stationary (stator)
- .

Single Phase Induction Motor

- As the name suggests, this type of motor **has only one stator winding** (**main winding**) and **operates with a single-phase power supply**.
- In all single-phase induction motors**, the rotor is the squirrel cage type**.
- The single-phase induction motor is **not self-starting**.
- When the motor is connected to a single-phase power supply, **the main winding carries an alternating current**. This current produces a pulsating magnetic field. **Due to induction, the rotor is energized**.
- As the main magnetic field is pulsating, the torque necessary for the motor rotation is not generated. This will cause the rotor to vibrate, but not to rotate. **Hence, the single phase induction motor is required to**

Single Phase Induction Motor

- The single-phase induction motor operation can be described by two methods:
  - Double revolving field theory; and
  - Cross-field theory.

Double field revolving theory

- A single-phase ac current supplies the main winding that produces a pulsating magnetic field.

- Mathematically, the pulsating field could be divided into two fields, which are rotating in opposite directions.

- The interaction between the fields and the current induced in the rotor bars generates opposing torque.

- According to this theory any alternating quantity can be resolved into two rotating components which rotate in opposite direction and each having magnitude as half of the maximum

Double field revolving theory

- Under conditions, with only the main field energized the motor will not start.
- However, if an external torque moves the motor in any direction, the motor will begin to rotate.
- The pulsating filed is divided a forward and reverse rotating field
- Motor is started in the direction of forward rotating field this generates small (5%) positive slip

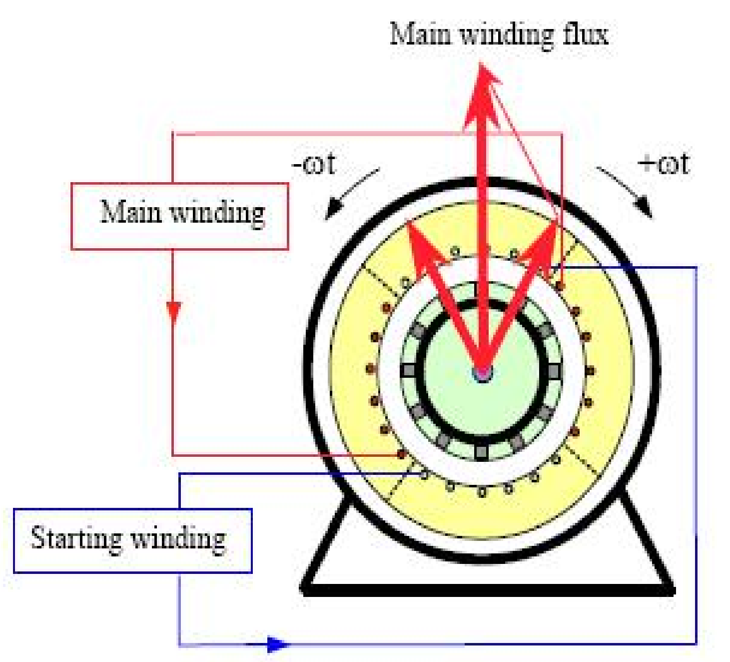


Figure 43 Single-phase motor main winding generates two rotating fields, which oppose and counter-balance one another.

Starting torque

- The single-phase motor starting **torque is zero** because of the pulsating single-phase magnetic flux.
- The starting of the motor requires the generation of a rotating magnetic flux similar to the rotating flux in a three-phase motor.
- Two perpendicular coils that have currents 90° out of- phase can generate the necessary rotating magnetic fields which start the motor.
- Therefore, single-phase motors are built

- The phase shift is achieved by connecting

– a resistance,

– an inductance, or

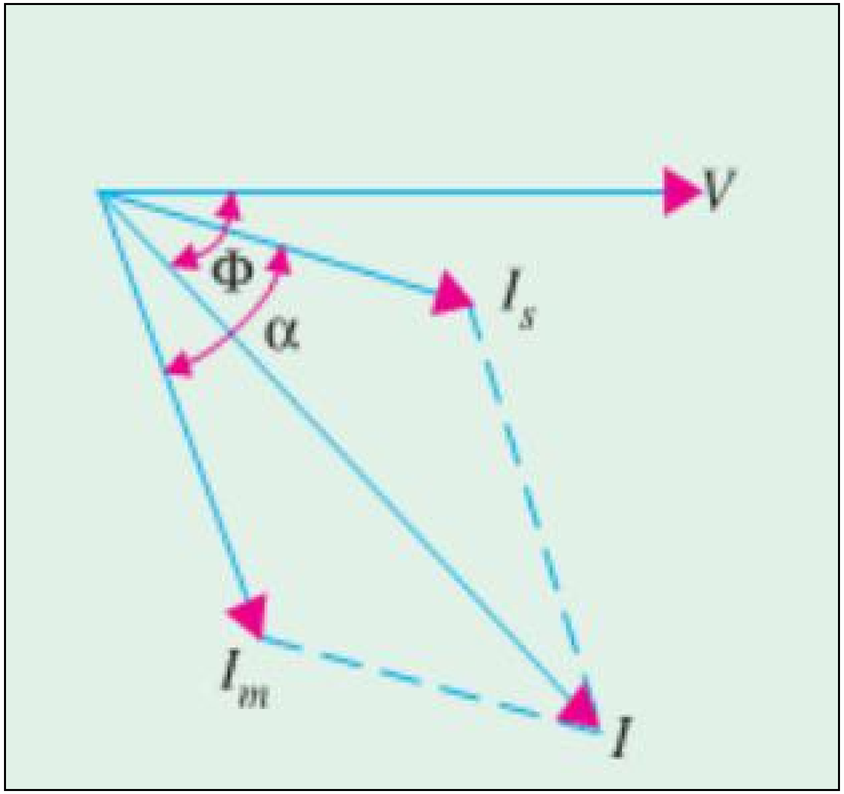
– a capacitance in series with the starting winding.

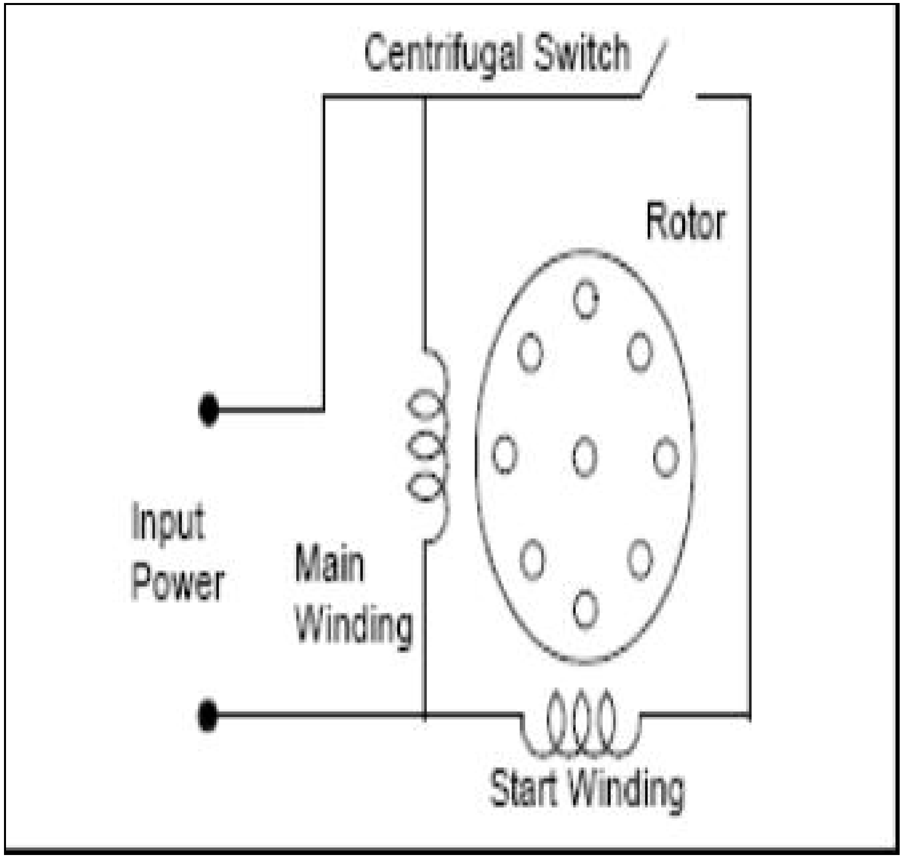
- Most frequently used is a capacitor to generate the starting torque.

Split-Phase AC Induction Motor

- **The split-phase motor is also known as an induction start/induction run motor.**
- It has two windings: **a start and a main winding**.
- The start winding is made **with smaller gauge wire and fewer turns**, relative to the main winding to create more resistance, thus putting the start winding's field at a different angle than that of the main winding which causes the motor to start rotating.
- The main winding, which is of a **heavier wire**, keeps the motor running the rest of the time.

Split-Phase AC Induction Motor





Split-Phase AC Induction Motor

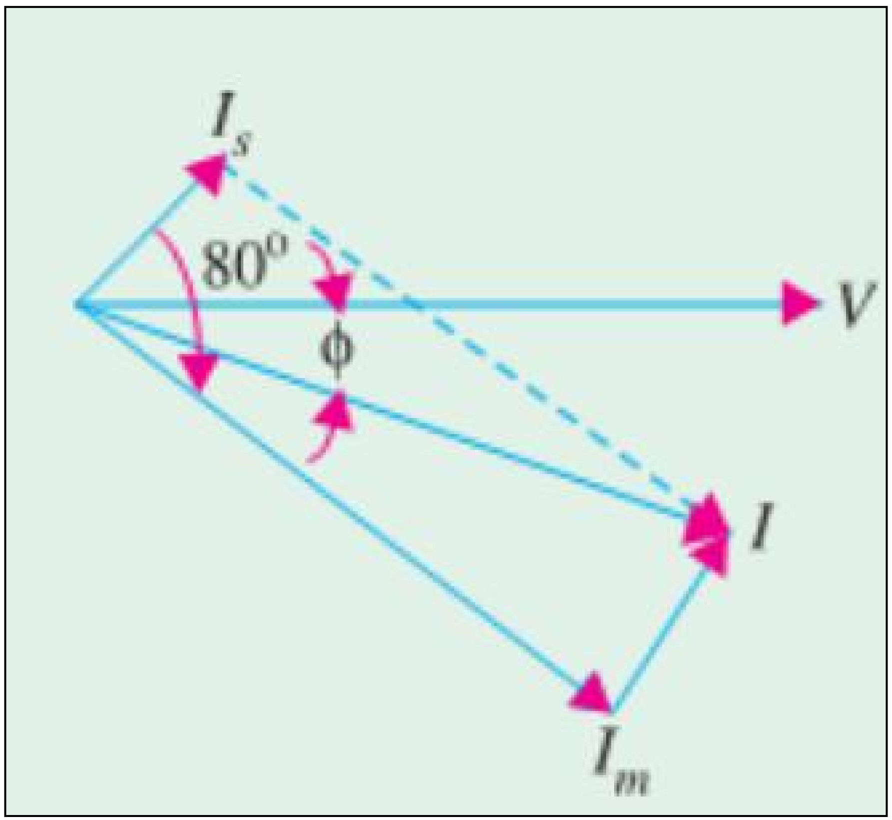
- The **starting torque** is 1.5 to 2 times of the full load torque with a starting current of 6 to 8 times the full load current.

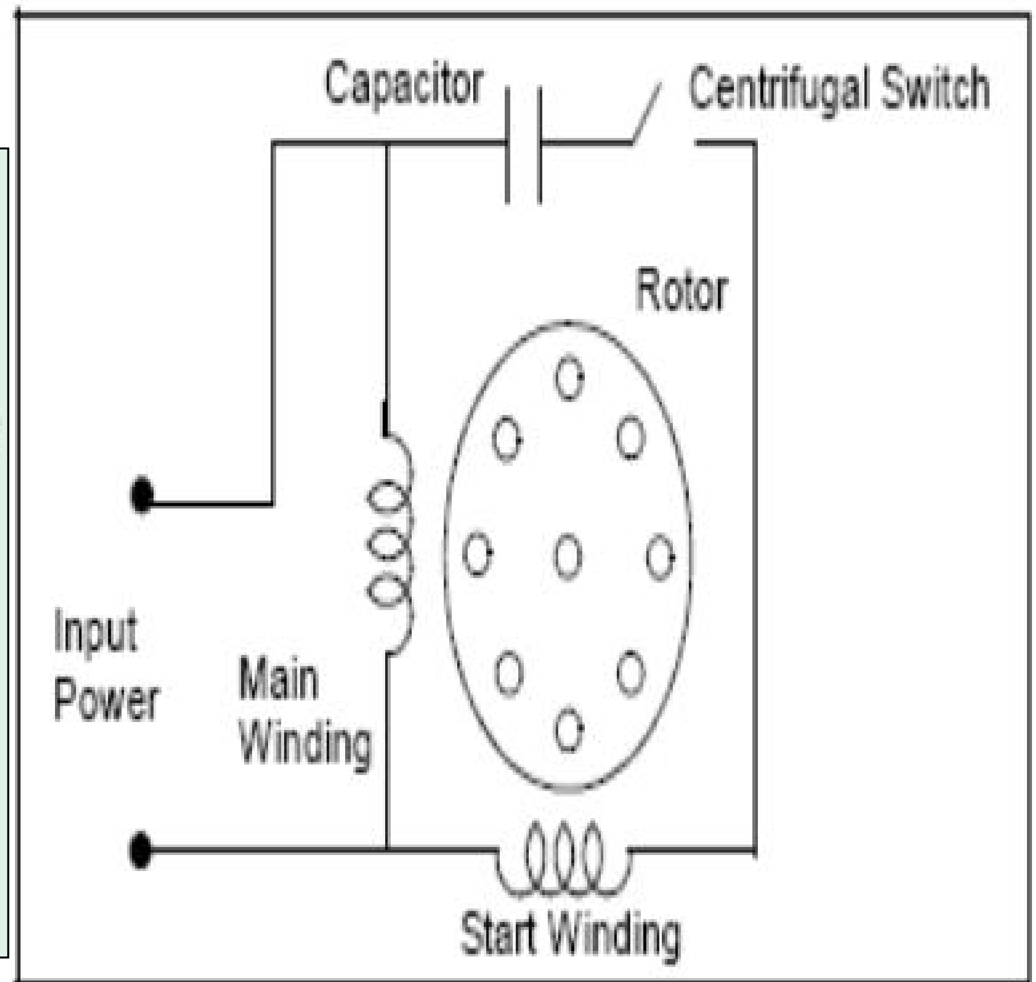
- Since the starting winding is made up of fine wires, the current density is high and the winding heats up quickly. If the starting period exceeds 5 sec. , the winding may burn out unless the motor is protected by built-in thermal relay.
- These are constant speed motors, speed variation is 2-5% from no load to full load.
- Applications for split-phase motors include small grinders, small fans and blowers and other low starting torque applications.

Capacitor Start AC Induction Motor

- This is a modified split-phase motor with a **capacitor in series** with the start winding to provide a start "boost."
- Like the split-phase motor, the capacitor start motor also has a **centrifugal switch which disconnects the start winding and the capacitor when the motor reaches about 75% of the rated speed.**
- Since the capacitor is in series with the start circuit, it creates more starting torque, typically **200% to 400% of the rated torque**.

Capacitor Start AC Induction Motor





Capacitor Start AC IM

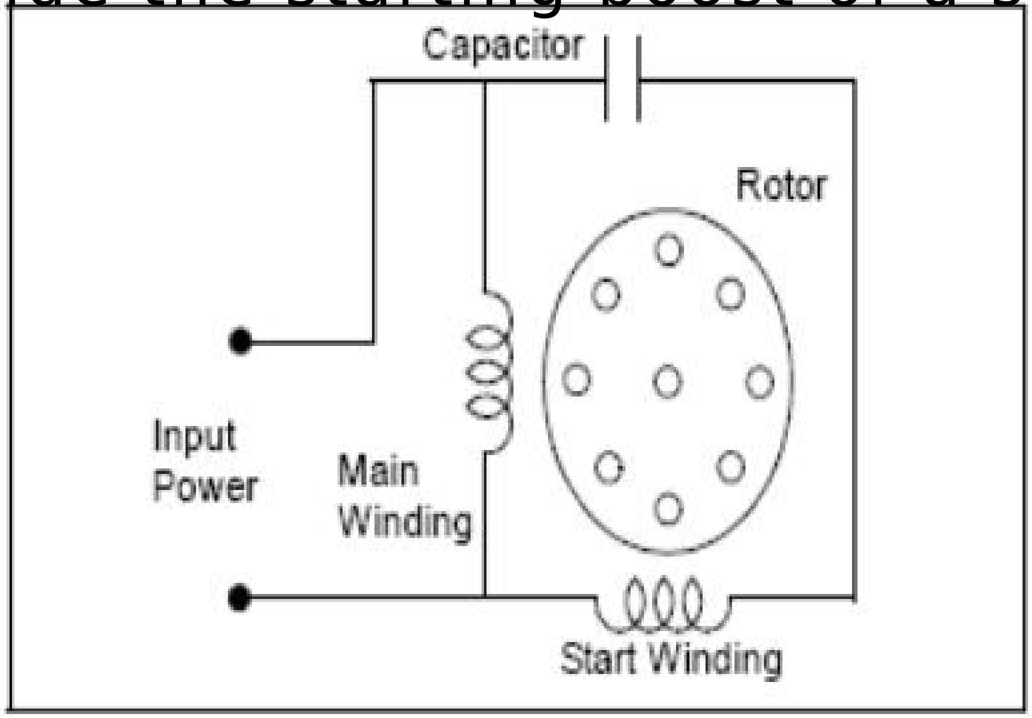
- And the starting current, is much lower than the split-phase due to the larger wire in the start circuit.

- They are used in a wide range of belt-drive applications like **small conveyors, large blowers and pumps, as well as many direct-drive or geared applications.**

Permanent Split Capacitor (Capacitor Run) AC IM

A permanent split capacitor (PSC) motor has a run type capacitor permanently connected in series with the start winding.

- The run capacitor must be designed for continuous use, it cannot provide the starting boost of a starting capacitor.



Permanent Split Capacitor (Capacitor Run) AC IM

- The typical starting torque of the PSC motor is low, from 30% to 150% of the rated torque.
- PSC motors have **low starting current**, usually **less than 200%** of the rated current, making them excellent for **applications with high on/off cycle rates**

Permanent Split Capacitor (Capacitor Run) AC IM

The PSC motors have several advantages:

- The motor design can easily be altered for use with speed controllers.
- They can also be designed for optimum efficiency and High-Power Factor (PF) at the rated load.
- They're considered to be the most reliable of the single-phase motors, mainly because no centrifugal starting switch is required.

Applications of permanent split capacitor (PSC)

- Permanent split-capacitor motors have a wide variety of applications depending on the design.

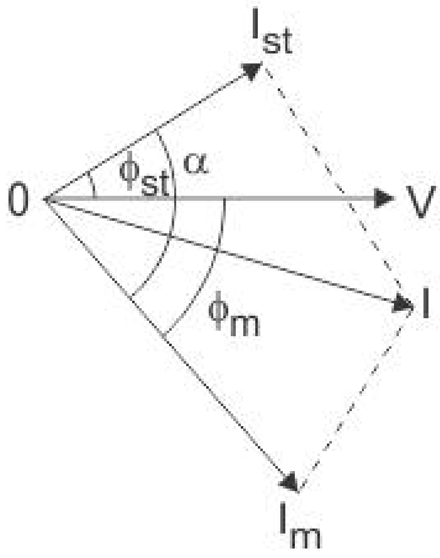
- These include **fans, blowers with low starting torque, washing machines, oil burners, small machine tools etc**.

- **Power rating of these motors lies between 60W and 250W**

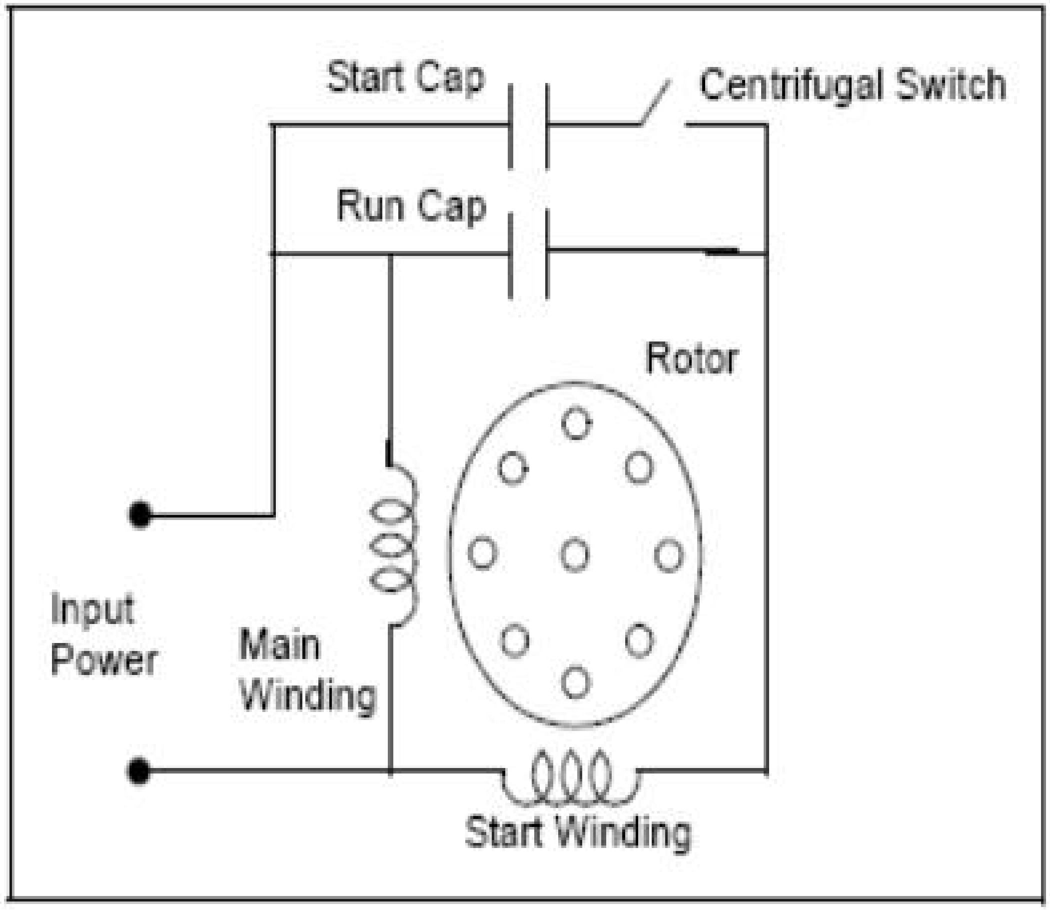
Capacitor Start/Capacitor Run AC Induction Motor

- This motor has a **start type capacitor in series** with the auxiliary winding like the capacitor start motor for high starting torque.
- Like a PSC motor, it also has a run type capacitor that is in series with the auxiliary winding after the start capacitor is switched out of the circuit. This allows high overload torque.
- This type of motor can be designed for lower full-load currents and higher efficiency.
- This motor is costly due to start and run capacitors and centrifugal switch.

Capacitor Start/Capacitor Run AC Induction Motor



Phasor diagram



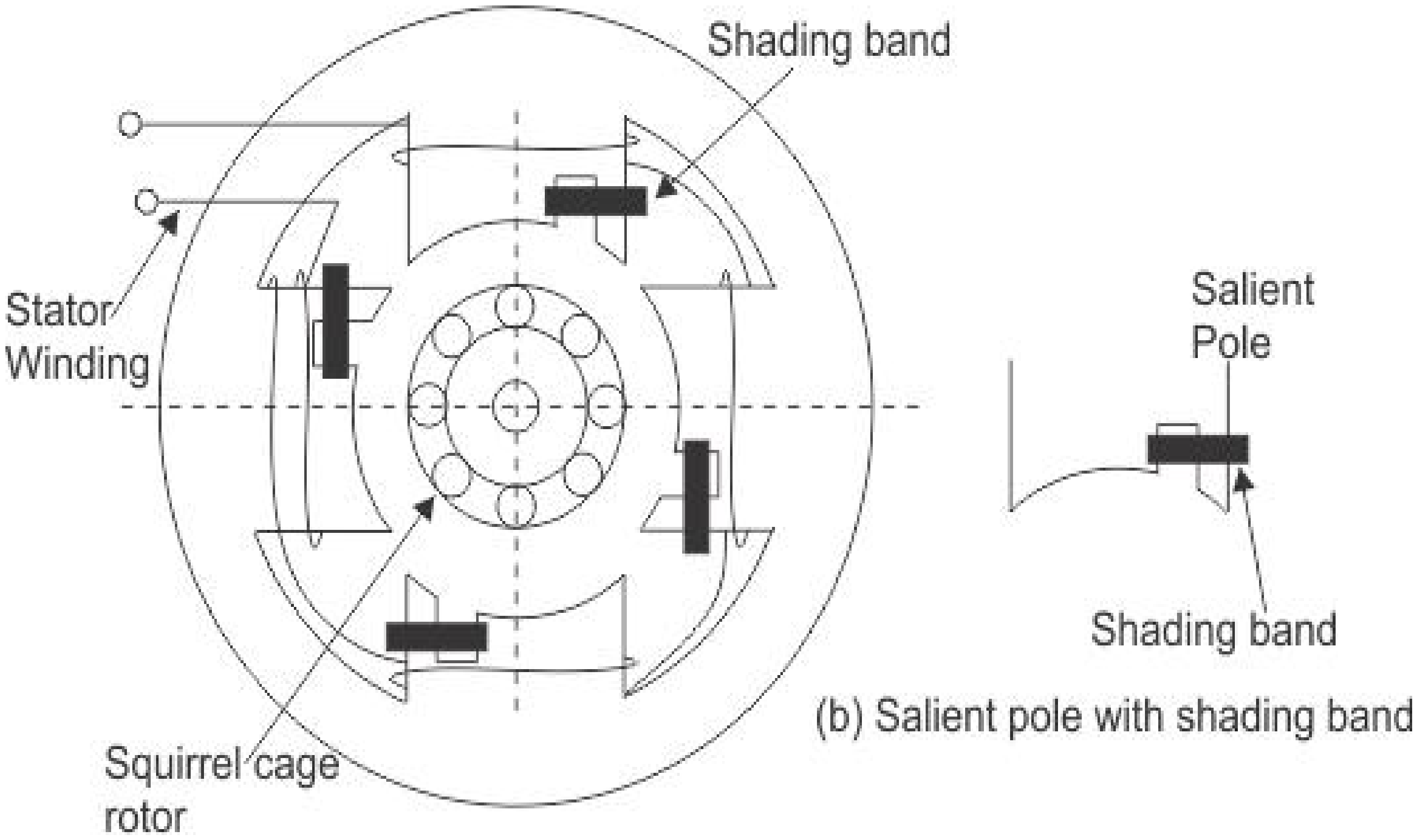
Capacitor Start/Capacitor Run AC Induction Motor

- It is able to handle applications demanding for any other kind of single-phase motor.
- These include **woodworking machinery, air compressors, high-pressure water pumps, vacuum pumps and other high torque applications requiring 1 to 10 hp.**

Shaded-Pole AC Induction Motor

- Shaded–pole motors have only one main winding and no start winding.
- Starting is by means of a design that rings a continuous copper loop around a small portion of each of the motor poles.
- This “shades” that portion of the pole, causing the magnetic field in the shaded area to lag behind the field in the unshaded area.
- The reaction of the two fields gets the shaft rotating.

Shaded-Pole AC Induction Motor



(b) Salient pole with shading band

(a) 4-pole shaded pole construction

Advantages

- Because the shaded-pole motor lacks a start winding, starting switch or capacitor, it **is electrically simple and inexpensive**.

- Also, the speed can be controlled merely by varying voltage, or through a multi-tap winding. Mechanically, the shaded-pole motor construction allows high-volume production.

- In fact, these are usually considered as "**disposable" motors**, meaning they are much cheaper to replace than to repair.

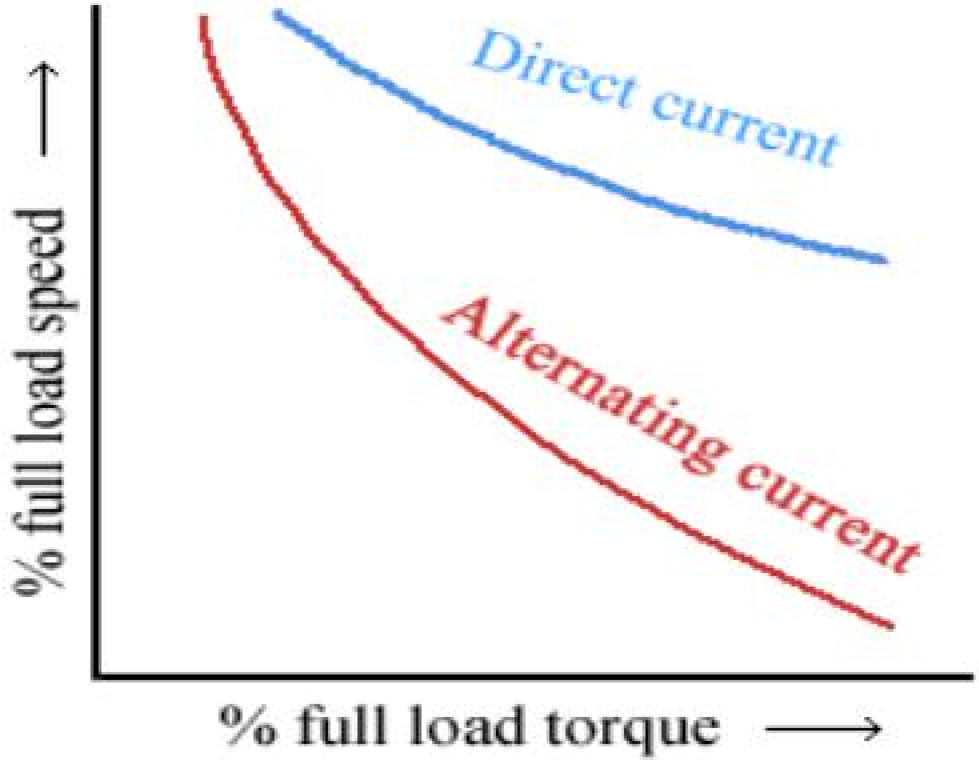
Disadvantages

- It's low starting torque is typically **25% to 75% of the rated torque.**
- It is a high slip motor with a running speed **7% to 10% below the synchronous speed.**
- Generally, efficiency of this motor type is very low **(below 20%).**

AC SERIES MOTOR

- A series ac motor is the same electrically as a dc series motor but construction differs slightly.
- Special metals, laminations, and windings are used which reduce losses caused by eddy currents, hysteresis, and high reactance.
- Dc power can be used to drive an ac series motor efficiently, but the opposite is not true.
- The characteristics of a series ac motor are similar to those of a series dc motor. It is a varying-speed machine.
- It has low speeds for large loads and high speeds for light loads.

SPEED –TORQUE CHARACTERISTICS OF AC AND DC SERIES MOTORS



Universal motor

- The motors which can be used with a single phase AC source as well as a DC source of supply and voltages are called as **Universal Motor**. It is also known as **Single Phase Series Motor**.
- A universal motor is a commutation type motor.

Construction of the universal motor

- The construction of the universal motor is same as that of the series motor.
- In order to minimize the problem of commutation, high resistance brushes with increased brush area are used.
- To reduce Eddy current losses the stator core and yoke are laminated.
- The Universal motor is simple and less costly.
- It is used usually for rating not greater than 7 5 0 W .

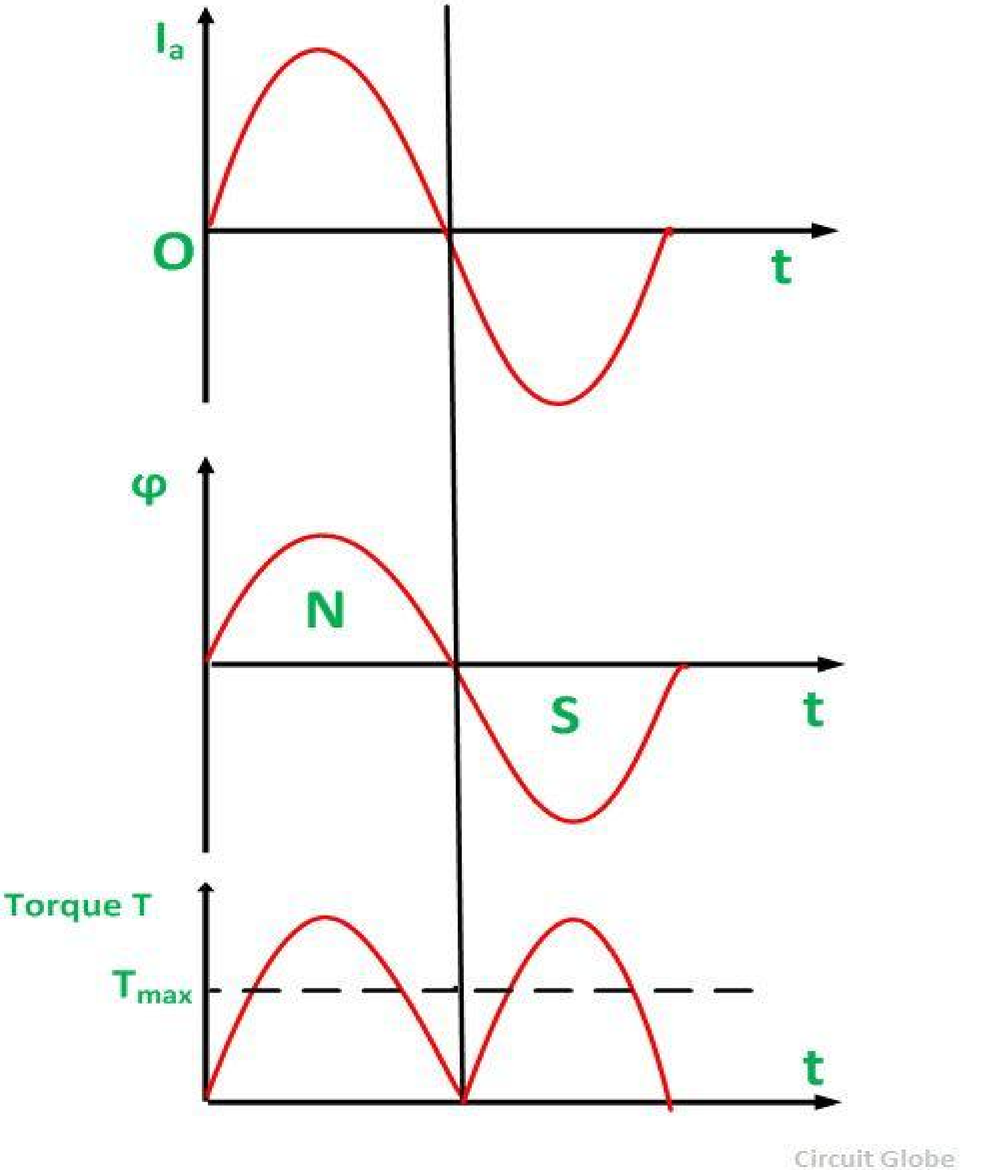
Characteristic of Universal motor

- The characteristic of Universal motor is similar to that of the DC series motor.
- When operating from an AC supply, the series motor develops less torque.
- By interchanging connections of the fields with respect to the armature, the direction of rotation can be altered.

Universal motor

- The direction of the developed torque will remain positive, and direction of the rotation will be as it was before.

- The nature of the torque will be pulsating, and the frequency will be twice that of line frequency as shown in the waveform.



Universal motor

Thus, a Universal motor can work on both AC and DC. However, a series motor which is mainly designed for DC operation if works on single phase AC supply suffers from the following drawbacks.

- The efficiency becomes low because of hysteresis and eddy current losses.
- The power factor is low due to the large reactance of the field and the armature windings.
- The sparking at the brushes is in excess.

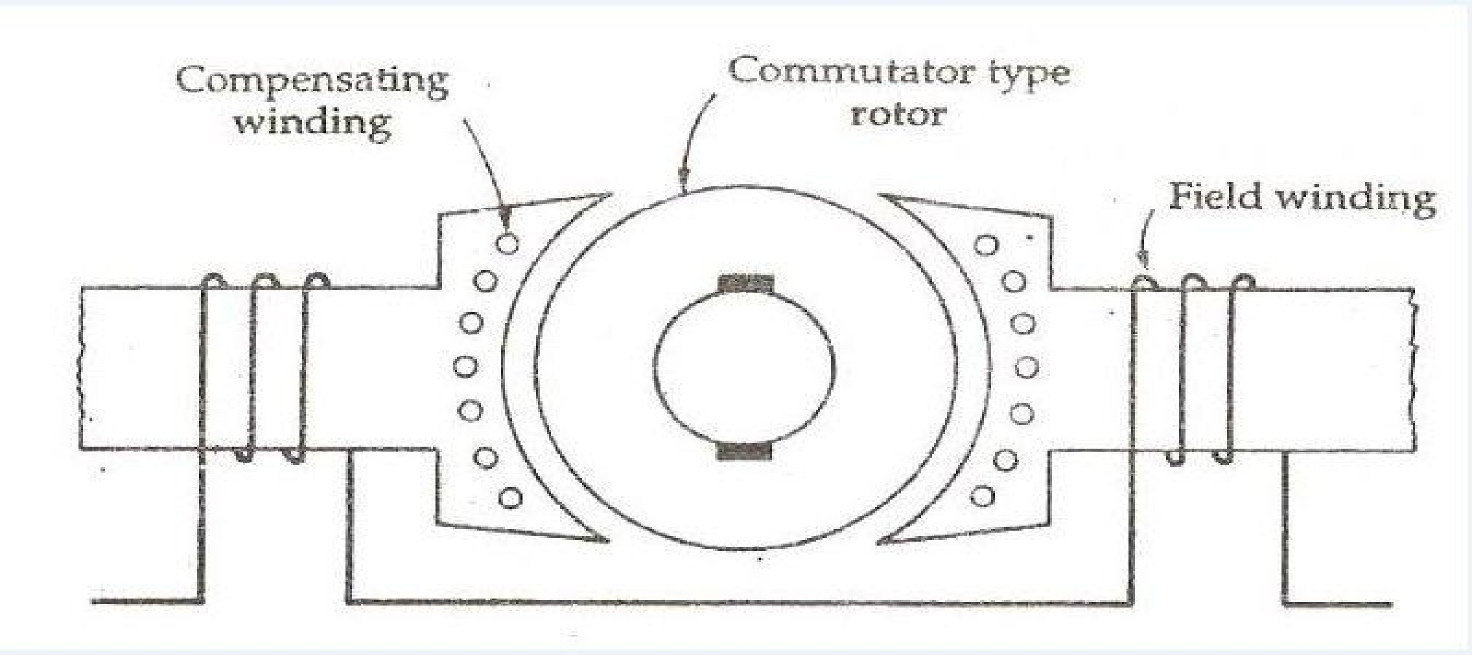
Universal motor

In order to overcome the following drawbacks, certain modifications are made in a DC series motor so that it can work even on the AC current. They are as follows:–

- The field core is made up of the material having a low hysteresis loss. It is laminated to reduce the eddy current loss.
- The area of the field poles is increased to reduce the flux density. As a result, the iron loss and the reactive voltage drop are reduced.
- To get the required torque the number of conductors in the armature is increased.

Universal motor

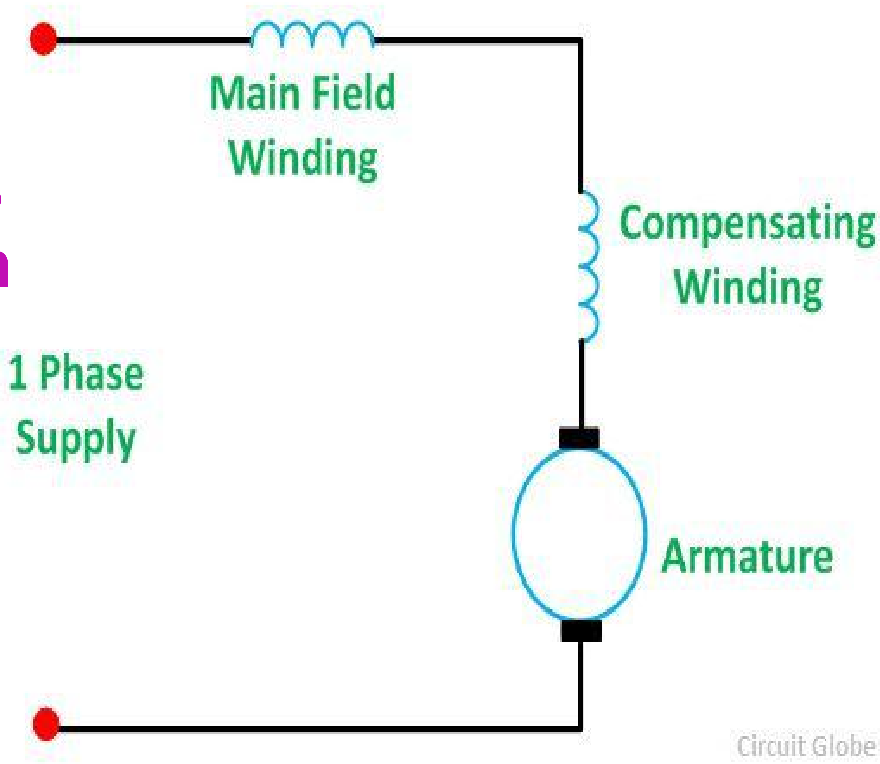
- A compensating winding is used for reducing the effect of the armature reaction and improving the commutation process.
- The winding is placed in the stator slots as shown in the figure below.



Universal motor

- The series motor with the compensated winding is shown in the figure below.

The winding is put in the stator slot. **The axis of compensating winding is 90 degrees with the main field axis.**



The compensating winding is connected in series with both the armature and the field, hence, it is called Conductively compensated.

Advantages &Disadvantage

Advantages

- High starting torque
- Very compact design if high running speeds are used.

Disadvantage

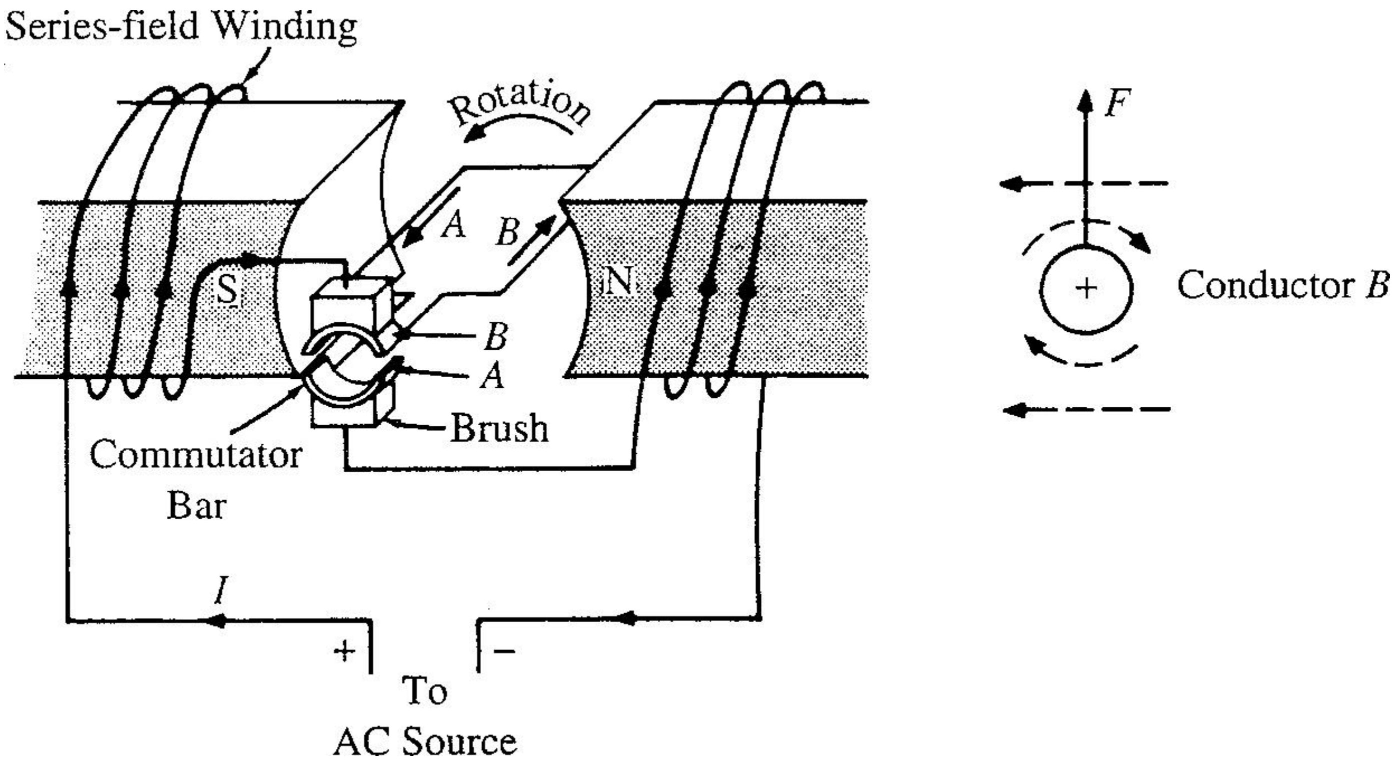
- Requires maintenance
- and short life problems caused by the commutator.

As a result, such motors are usually used in AC devices such as **food mixers and power tools which are used only intermittently, and often**

UNIVERSAL MOTOR

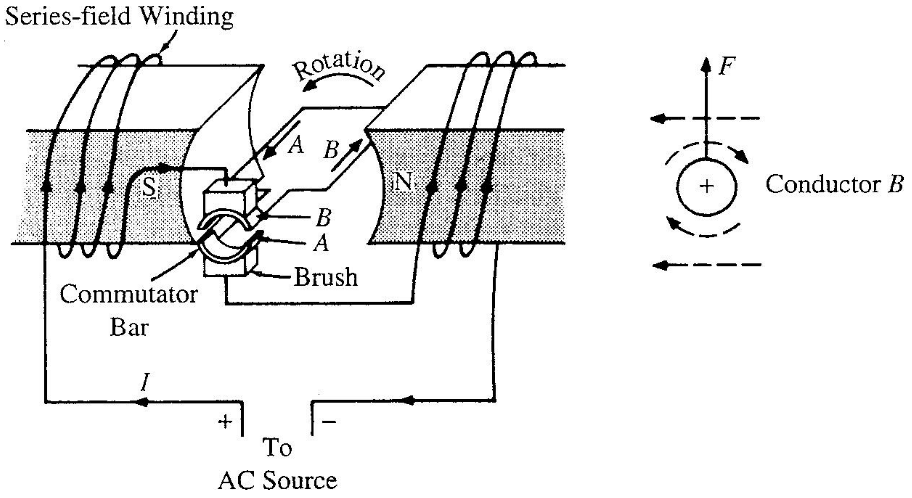
- Motor that can be used with a single– phase ac source as well as a dc source of supply voltages are called universal motor.
- The stator and rotor windings of the motor are connected in series through the rotor commutator.
- The universal motor is also known as an AC series motor or an AC commutator motor.

Universal Motor

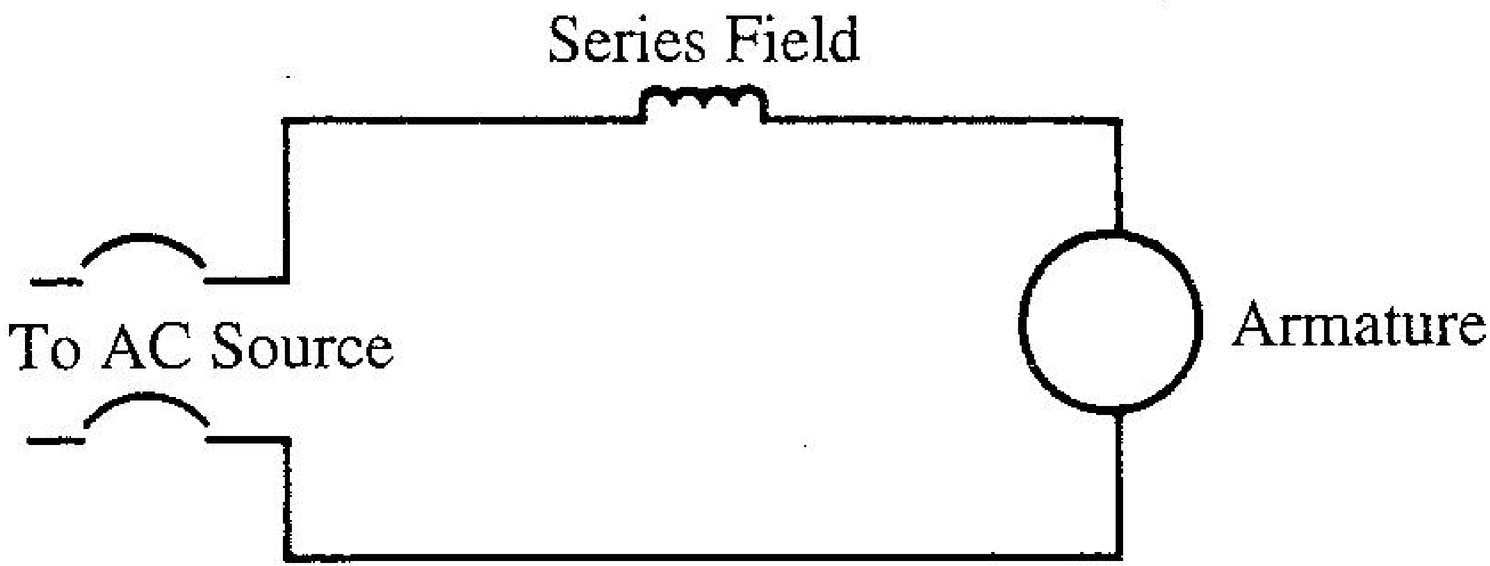


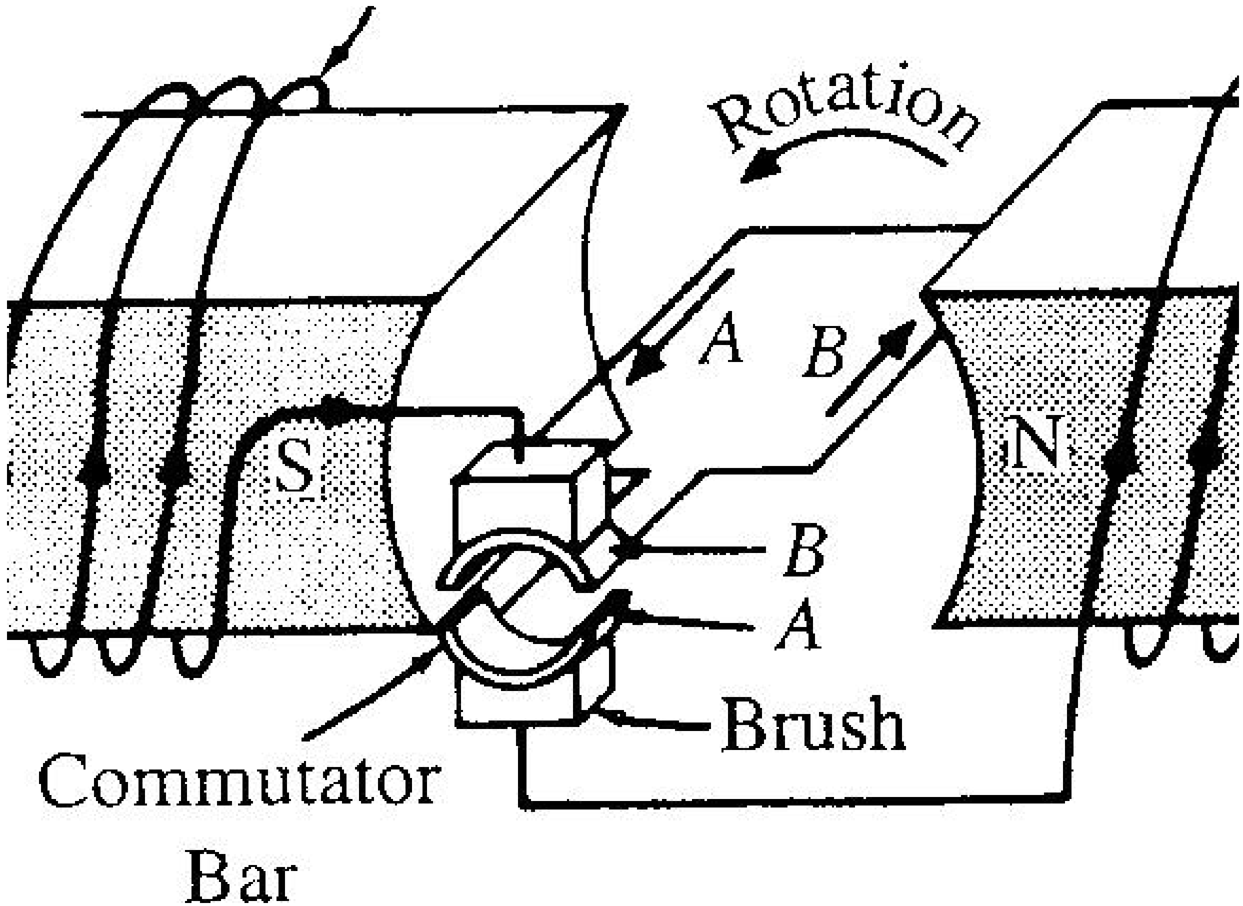
Universal Motor

- Series-connected
- Rotor and Stator are connected in series
- Operates on either
- ac or dc



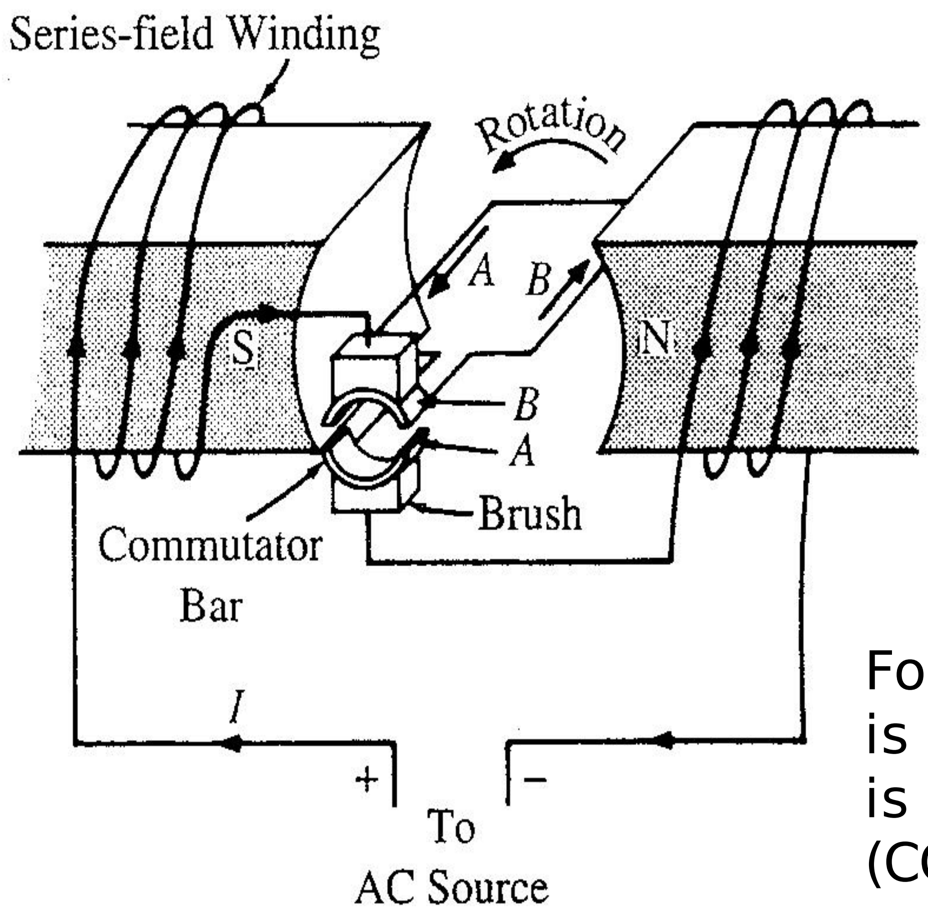
Equivalent Circuit

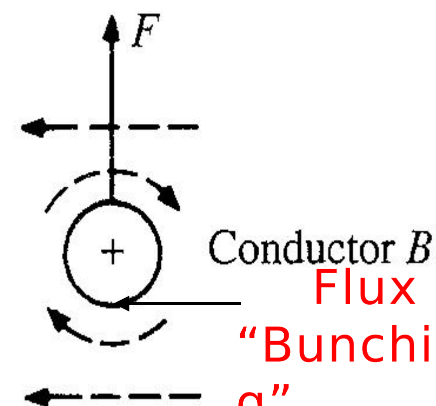




The Commutator Bar and Brushes are a switch that reverses the current in the armature coil as it rotates

Check the Direction of Rotation



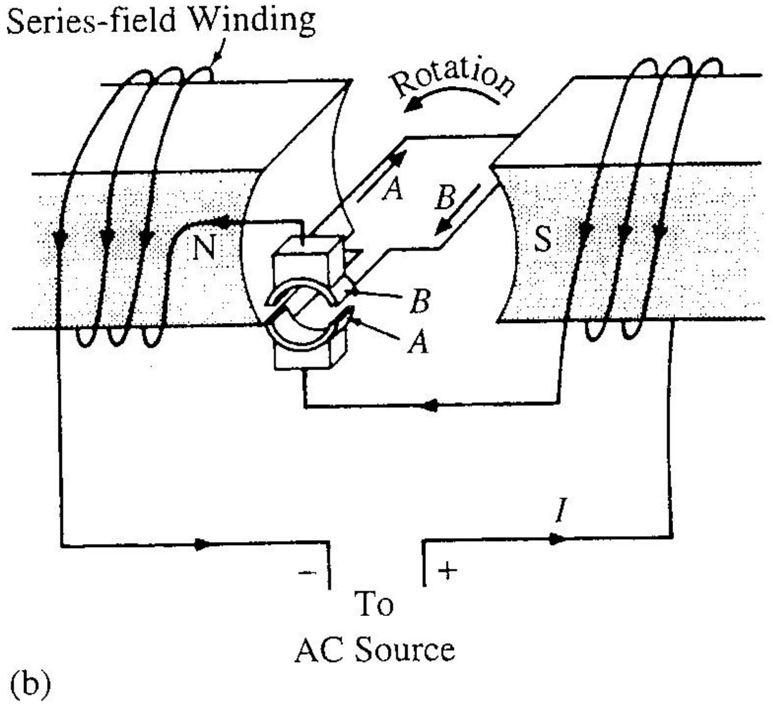


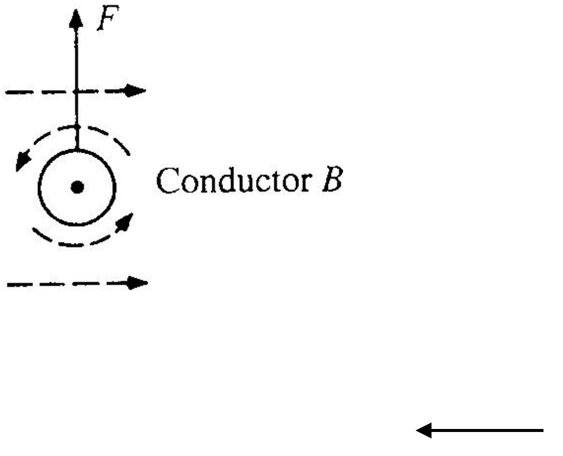
Flux "Bunching"

Force on conductor B is upwards, rotation is counter-clockwise (CCW)

+Positive Half

Opposite Half-Cycle





Flux "Bunching"

-Negative Half-Cycle-

Force on Conductor B is upwards, rotation is counter-clockwise (CCW)

REPULSION MOTORS

Repulsion motors are classified under single phase motors. In magnetic repulsion motors the stator windings are connected directly to the ac power supply and the rotor is connected to commutator and brush assembly, very similar to that of DC armature.

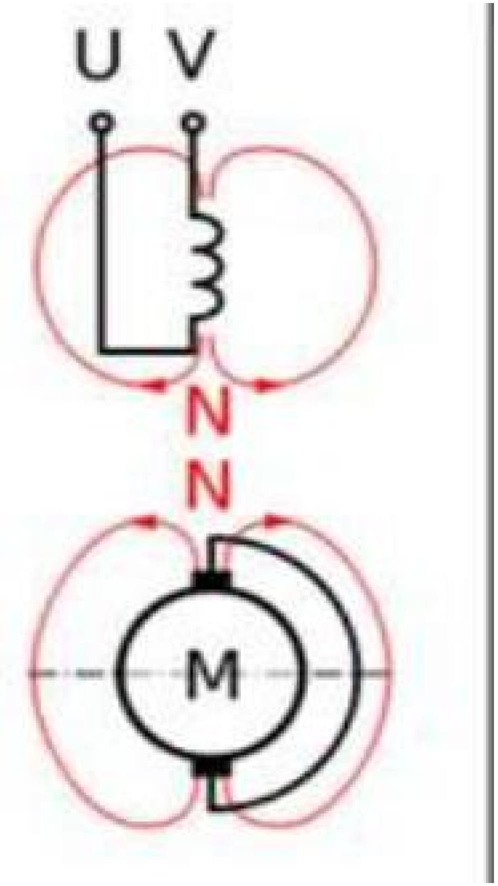
Repulsion Motor

REPULSION MOTORS

Repulsion motors are based on the principle of repulsion between two magnetic fields. Consider a 2-pole motor with a vertical magnetic axis. The armature is connected to a commutator and brushes. The brushes are short circuited using a low-resistance jumper. When alternating current is supplied to the field (stator) winding, it induces an electromotive force (emf) in the armature.

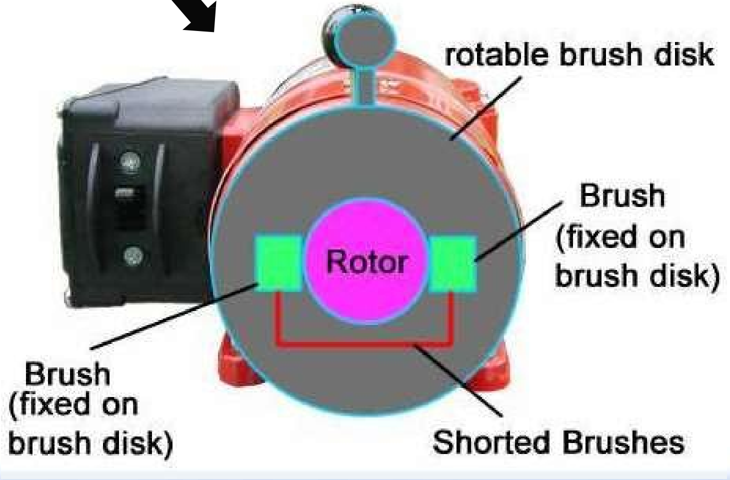
REPULSION MOTORS

- The direction of alternating current is such that it creates a north pole at the top and a south pole at the bottom. The direction of induced emf is given by Lenz's law, according to which the direction of induced emf opposes the cause producing it. The induced emf induces current in the



Application of Repulsion motors :

- high speed lift
- fans & pumps



Application of Repulsion motors :

- Hoists

- Mining Equipment

- Air Compressors

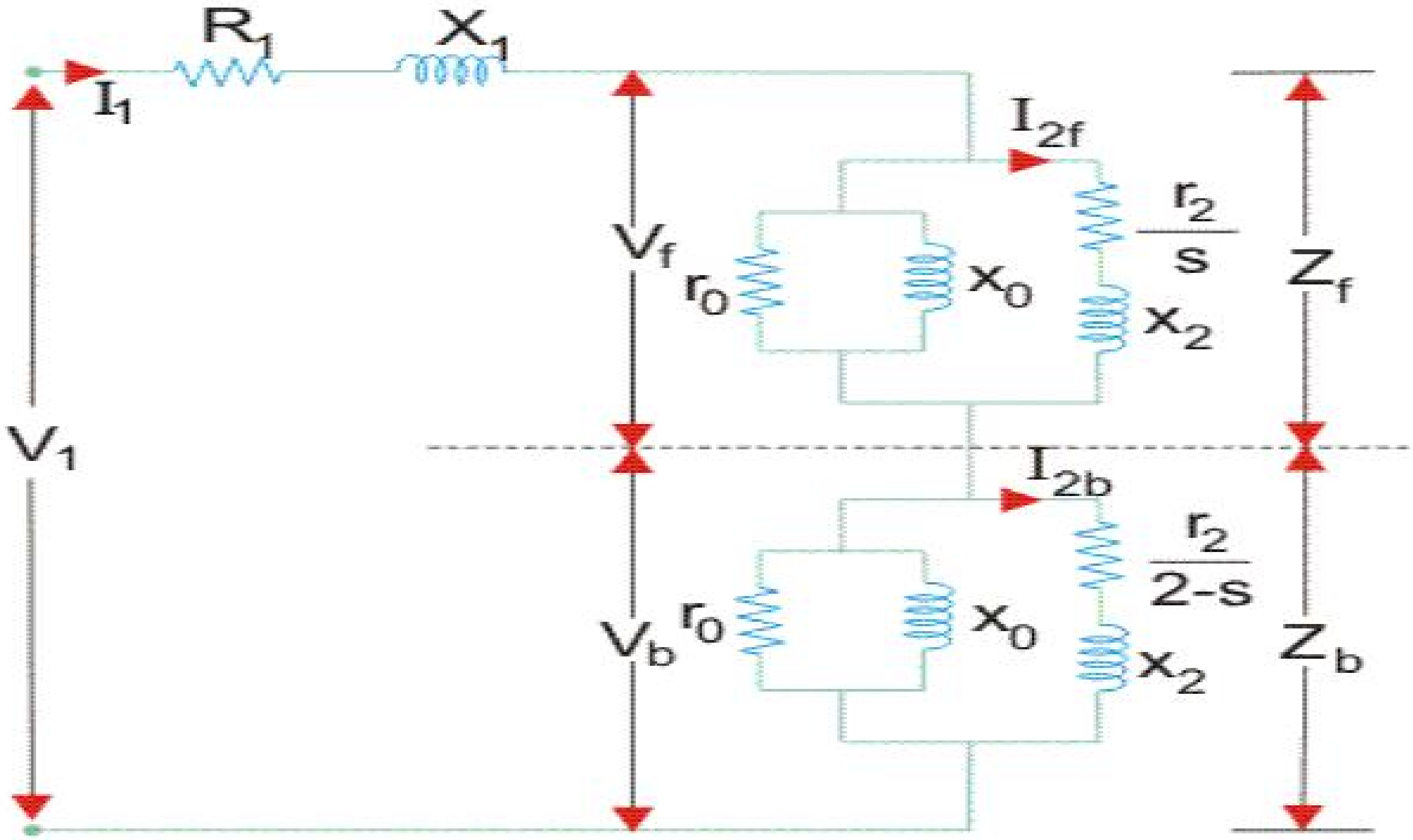
Applications of Single Phase IM

- The low initial cost suits the shaded-pole motors to low horsepower or light duty applications.

- Its Largest use is in multi-speed fans for household use.

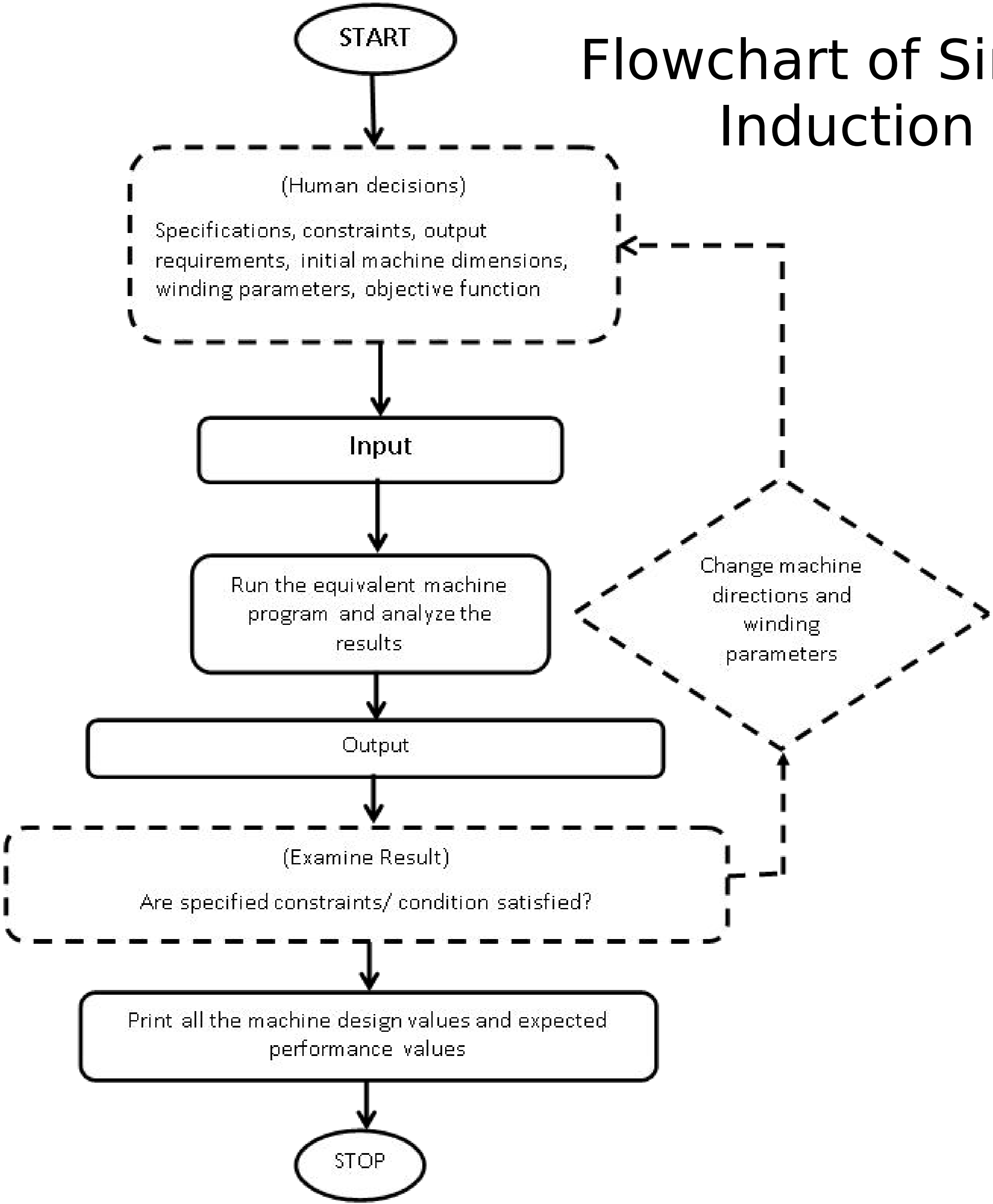
- But **the low torque, low efficiency and less sturdy mechanical features** make shaded-pole motors impractical for most industrial or commercial use, where higher cycle rates or continuous duty are the norm.

Equivalent Circuit of a Single Phase Induction Motor



Induction motor (single phase) equivalent circuit referred to the stator

Flowchart of Single phase Induction Motor



The Design Procedure

The main specifications for a single phase induction motor for design purposes are:-

1. Rated output in W or K.W.
2. Rated Voltage V
3. Rated current A
4. Rated speed r.p.m.
5. Frequency HZ
6. Poles, P
7. Pull out torque Nm
8. Starting torque Nm
9. Efficiency %

10. Power-factor %

11. Motor – type : split phase

a) Resistance start induction run (low starting torque)

b) Capacitor start induction run (medium starting torque)

c) Capacitor start capacitor run (High starting torque)

I. One capacitor

II. Two capacitor

Output Equation

The output equation relates the desired output characteristics of the induction motor to the machine's main determining specifications to which the motor should be designed based on.

F = Flux per Pole

K_w=Winding Factor

f=Frequency

V=Rated voltage

I=Full load current in the main winding, A

T_m=Number of turns of the main winding

P=Number of poles

D=stator bore diameter, m

L=Stator core length, m

τP=Pole Pitch

n_s=Synchronous speed, r.p.s

B_{av}=Average value of flux density in the air gap, Wb/m^2 (Specific

magnetic loading

ac= Ampere-conductor per meter of arm. Periphery, ac/m

(specific electric loading

η=Full load efficiency

Cos F= Full load power factor

The KVA rating of a single phase induction motor is given by;

$$KVA = V\, I*10^{-3} \quad \text{-------------------------(1)}$$

$$V = 4.44\ K_W f\ \phi\ T_{ph}$$

$$\phi = B_{av}\ L\ (\pi D/p)$$

$$ac = (2T_{ph}\ I_{ph})/\ (\pi\ D)$$

$$f = n_s\, P/2$$

Substituting for the value of V in equation (1); then

$$KVA = 4.44\ K_w\ f\ \phi\ T_{ph}\ I*10^{-3}$$

Substituting for the values of f, ϕ and T_{ph}

$$KVA = 4.44\ K_W\,(n_s\,P/2)\ \ (B_{av}\ \pi \frac{D}{P} L)\ \ (\frac{ac\,\pi D}{2})*10^{-3}$$

$$= (1.11\ \pi^2\ K_W\ B_{av}\ ac*10^{-3})\ D^2\ Ln_s$$

Again this can be expressed as;

$$KVA = C_O\ D^2\ \ Ln_s$$

Where;

$$C_o = 1.11\ \ \pi^2\ K_W\ B_{av}\ ac*10^{-3}$$

Design of Main Dimensions

$$D^2 L = \frac{\text{h}.p \times 0.746}{Co.\eta.Cos\ \phi.\eta_s}$$

To separate D and L from D^2L

L= pole pitch (0.6 to 2)

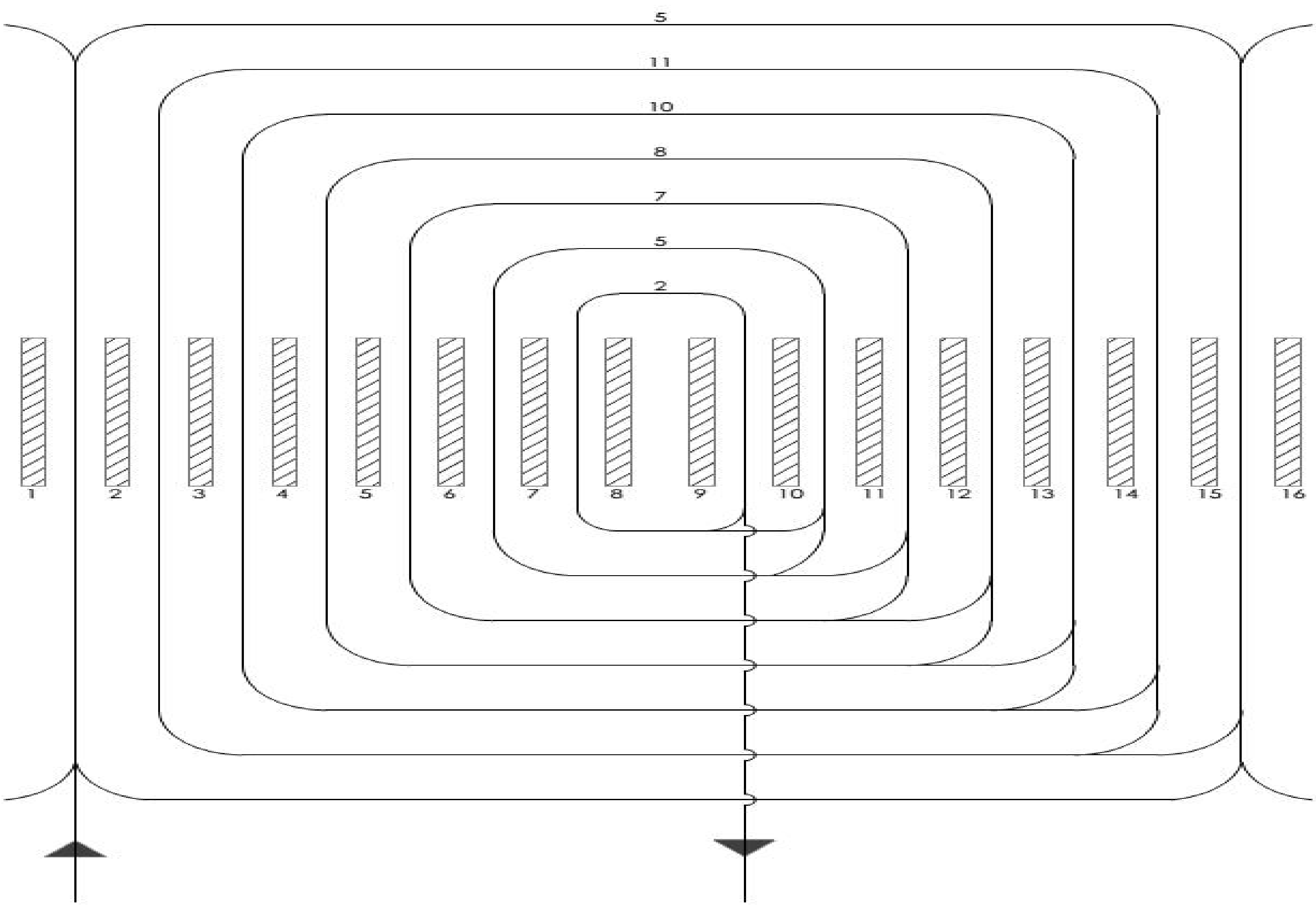
Choice of Specific Loadings

The value of B_{av} lies between 0.35 – 0.55 Tesla.

The value of ac varies between 5000 – 15000 ampere conductors per meter.

DESIGN OF STATOR

COIL ARRANGEMENT FOR STATOR WINDING



For sinusoidal distribution the number of turns of each coil are calculated as;

$$Coil\ 7-9;\ Sin\ of\ ½\ coil\ span\ =\ sin\left(\frac{2}{14}\times 90^0\right) = 0.2225$$

$$Coil\ 6-10;\ Sin\ of\ ½\ coil\ span\ =\ sin\left(\frac{4}{14}\times 90^0\right) = 0.4339$$

$$Coil\ (5-11);\ Sin\ of\ ½\ coil\ span\ =\ sin\left(\frac{6}{14}\times 90^0\right) = 0.6235$$

$$Coil\ (4-12);\ Sin\ of\ ½\ coil\ span\ =\ sin\left(\frac{8}{14}\times 90^0\right) = 0.7818$$

$$Coil\ (3-13);\ Sin\ of\ ½\ coil\ span\ =\ sin\left(\frac{10}{14}\times 90^0\right) = 0.9009$$

$$Coil\ (2-14);\ Sin\ of\ ½\ coil\ span\ =\ sin\left(\frac{12}{14}\times 90^0\right) = 0.9749$$

$$Coil\ (1-15);\ Sin\ of\ ½\ coil\ span\ =\ sin\left(\frac{14}{14}\times 90^0\right)=0.5000$$

= 4.4375

Percentage of turns in coil 7-9

$$\left(\frac{0.2225}{4.4375} \times 100\right) = 5.014$$

Percentage of turns in coil 6-10

$$\left(\frac{0.4339}{4.4375} \times 100\right) = 9.778$$

Percentage of turns in coil 5-11

$$\left(\frac{0.6235}{4.4375} \times 100\right) = 14.051$$

Percentage of turns in coil 4-12

$$\left(\frac{0.7818}{4.4375} \times 100\right) = 17.618$$

Percentage of turns in coil 3-13

$$\left(\frac{0.9009}{4.4375} \times 100\right) = 20.302$$

Percentage of turns in coil 2-14

$$\left(\frac{0.9749}{4.4375} \times 100\right) = 21.9696$$

Percentage of turns in coil 1-15

$$\left(\frac{0.500}{4.4375} \times 100\right) = 11.2676$$

The turns in each coil will be

$$Coil\ 7-9 = (0.05014 \times 48)$$
$$= 2.406 \qquad \approx 2$$
$$Coil\ 6-10 = (0.09778 \times 48)$$
$$= 4.693 \qquad \approx 5$$
$$Coil\ 5-11 = (0.1405 \times 48)$$
$$= 6.744 \qquad \approx 7$$
$$Coil 4-12 = (0.17618 \times 48)$$
$$= 8.456 \qquad \approx 8$$
$$Coil\ 3-13 = (0.20302 \times 48)$$
$$= 9.745 \qquad \approx 10$$
$$Coil\ 2-14 = (0.219696 \times 48)$$
$$= 10.545 \qquad \approx 11$$
$$Coil\ 1-15 = (0.112676 \times 48)$$
$$= 5.40 \qquad \approx 5$$

Total **48**

Amended value of $\tau_m = 2 \times 48 \ = 96$

The winding factor is calculated as;

$$\frac{\left\{\begin{array}{c}(2 \times 0.2225) + (5 \times 0.4339) + (7 \times 0.6235) + (8 \times 0.7818) \\ + (10 \times 0.9009) + (11 \times 0.9749) + (5 \times 0.500)\end{array}\right\}}{96}$$

$$= 0.3695 \qquad \approx 0.4$$

(1) **Running Winding (Main Winding)**

The stator windings of single phase induction motors are concentric type .There are usually 3 or more coils per pole each having same or different number of turns.

$$T_m = \frac{E}{4.44\ K_{wm}\ f\emptyset_m}$$

(2) Conductor size

Main winding full current is given by

$$I = \frac{H.p \times 746}{v.\eta.Cos\ \varphi}$$

Watt/r.p.s	3.6	7.2	12	18
$Co.\eta.Cos$	9.5	12	15.5	18

(**3) Area of running winding**

$$A_m = \frac{I_m}{\delta_m}$$

(4) **Number of Stator Slots**

The number of stator slots per pole is usually between 9 to 12.The no. of slots should be divisible by the number of poles so that a balanced ,regular winding can be used .A large number of slots reduces the leakage reactance by reducing the slot and zigzag leakage .A large number of slots also reduces troubles due to field harmonics .It also reduces the intensity of magnetic noise increasing the pitch of noise components .

A small number of slots reduces the cost of winding and gives a better space factor .

(5) Size of Stator Slots

All the stator slots do not have the same number of conductors and some contain both running winding and starting winding conductors. The starting winding has a small cross sectional area and its effect upon the size of slot is small. The running winding coil with largest number of turns will determine the size of slot. The ratio of insulated conductor area to slot area should never exceed 0.5.

Suppose Z_s is the total number of conductors per slot and d_1 mm is the diameter of insulated conductor.

Area required for insulated conductors =

$$Z_s \times \left[\frac{\pi}{4}\right] \times d_1^2$$

Minimum slot area required $= \left[\frac{1}{0.5}\right] \times Zs \times \left[\frac{\pi}{4}\right] \times d_1^{2}$

The slot area provided in the stamping is calculated by ,multiplying the mean width by the depth of slot.

The average slot width $W_{s\,(av)} = \left[\frac{\pi(D + d_{ss})}{S_s}\right] - W_{ts}$

d_{ss}= depth of stator slot

W_{ts}= width of stator tooth

S_s- Number of stator slots

Area of each slot = $W_{s(av)} \times d_{ss}$

(6) Stator Teeth

The stator tooth density can be generally from 1.4 to 1.7 Wb/m2 .
For general purpose machine a flux density of 1.45 Wb/m2 is taken while for high torque machines it is 1.8 Wb/m^2 .

Net iron length $L_i = 0.95\ L$

Flux density in the stator teeth =

$$B_{ts} = \frac{\Phi_m}{(S_s / p) \times W_{ts} \times L_i}$$

7) Stator Core

The flux density in the stator core should not exceed 1.5 Wb/m^2. It lies between 0.9 to 1.4 Wb/m^2.

Flux in the stator core

$$\phi_c = \frac{\phi_m}{2}$$

Flux density in the stator core

$$B_{cs} = \frac{\phi_m}{2 \times d_{cs} \times L_i}$$

d_{cs} = depth of stator core

(8) Length of mean turn

The length of mean turn for each of the coils per pole of a concentric winding .

$$L_{mt} = \frac{8.4\ (D + d_{ss})}{S_s} \times slots\ spanned + 2L$$

DESIGN OF ROTOR

(1)Number of Rotor Slots

The number of rotor slots is so chosen that there is no noise producing combinations. The number of rotor slots are divisible by number of poles. The number of rotor slots S_r differ from S_s by 20 % or more .Die cast aluminum rotor construction is used.

(2)Area of Rotor Bars

The cage rotor winding may be either of copper bars and end rings are of cast aluminum. Manufacturing is cheaper with cast aluminium.With cast rotors ,the joints between bars and end rings are eliminated.

Total stator copper section for main winding $A_m = 2 T_m a_m$ mm^2

The total rotor copper section is 0.5 to 0.8 of total

Total cross section of rotor bars $A_r = S_r \, a_b$

Where a_b = area of each bar, mm^2

For Copper ,

$$\frac{A_r}{A_m} \; 6 \; 0.5 \; to \; 0.8$$

For Aluminum,

$$\frac{A_r}{A_m} \; 6 \; 1 \; to \; 1.6$$

(3) Area of End Rings

$I_e = (S_r * I_b)/\pi p$

Area of each end ring $A_e = I_e / \delta_e$ mm²

Area of the rotor bars can be calculated as

$A_b = I_b / \delta_b$ mm²

$$a_e \; 6 \; \frac{I_e}{d_e} \; 6 \; \frac{S_r I_b}{p \, p \, d_e} \; 6 \; \frac{S_r a_b d_b}{p \, p \, d_e}$$

$$6 \; \frac{0.32 \; A_r}{p} \; ħ \; \frac{d_b}{d_e}$$

I_b= current in each bar = $d_b \, a_b$

$d_b \, d_e$ = current density in bars and end rings

If we take, $d_b \;6\; d_e$

Area of each end ring $6 \quad \dfrac{0.32 \, A_r}{p}$

(4) Rotor Resistance

It should be as low as possible to keep the rotor copper loss minimum and to maintain high efficiency ,high full load speed and minimum temperature rise. In single phase motors ,rotor resistance effects the maximum torque for a given flux and a high value of pull out torque is obtained with rotor resistance.

For split phase motors = 0.45 to 0.55

For capacitor start motors = 0.45 to 0.8

(5) Rotor Teeth

Flux density in the stator teeth =

$$B_{tr} = \frac{\phi_m}{(S_s / p) \times W_{tr} \times L_i}$$

(6) Rotor Core

Flux density in the stator core

$$B_{cr} \; 6 \; \frac{f_m}{2 \;\hbar\; d_{cr} \;\hbar\; L_i}$$

d_{cs}= depth of stator core

(7) Length of the air gap

L_g *is given by*

$$L_g = 0.2 + 2\sqrt{DL} \; mm$$

Calculation of Operating Characteristics

(1)Mmf for Air Gap

The flux produced by stator mmf is passes through the following parts :
(a)Air gap (2) stator teeth (c) stator core (d) rotor teeth (e) rotor core

The value of flux density at 60 ° from interpolar axis is 1.57 times B_{av} for single phase machines

$$B_{60} = 1.57\ B_{av}$$

Mmf required for air gap $AT_{60} = 800{,}000\ B_{g\ 60}\ K_g\ l_g$

(2) Iron loss

The iron loss in stator teeth is found by calculating their flux densities and weights .
The total iron loss for induction motors is 1.5 to 2.5 times the sum of stator tooth and core loss due to fundamental frequency flux.

(3) Friction and Windage loss

The bearing friction and windage loss will depend upon the type of bearing to be used whether ball bearings or sleeve bearings .For sleeve bearings and a speed of 1500 rpm ,it is usually from 4 to 8 % of the watt output.

(4) Main winding Resistance

$$r_{sm} \; 6 \; \frac{r \, E_{mtm} \, T_m}{a_m}$$

(5) **Stator Resistance**

$$r_s = \rho \frac{L_{mts} \times T_s}{a_s}$$

(6) **Rotor Resistance**

$$r_r = \rho \frac{L_{mtr} \times T_r}{a_r}$$

The value of rotor resistance referred to running winding ;

$$r_{rm} = 8 T_m K_{wm}^2 \rho \left[\frac{L_b}{S_r a_b} + \frac{2}{\pi} \frac{D_s}{p^2 a_e} K_{ring} \right]$$

Design of Starting Winding for Split phase Motors

The starting winding is designed for maximum torque per ampere of starting current .In order that starting winding can produce a revolving field the flux set up by it must be out of phase with flux set up by the main winding. With resistance split phase motors the required resistance is obtained by using a small section wire i.e. about 25 % of main winding. The phase angle between starting winding current and the line voltage should be about 0.4 of main winding.