UNIT-II

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Single Phase Induction Motors

Single phase induction motor has basically two parts, one rotating and other stationary. The stator has laminated construction, made up of stampings. The stamping are slotted on it's periphery to carry the winding stator winding or main winding. this is excited by single phase a. c. supply. The stamping are made up of terminal like silicon , steel which minimizes the hysteresis loss.

Single phase Induction motors perform a great variety of useful services at home, office, farm, factory and in business establishments. Single phase motors are generally manufactured in fractional HP ratings below 1 HP for economic reasons. Hence, those motors are generally referred to as fractional horsepower motors with a rating of less than 1 HP. Most single phase motors fall into this category. Single phase Induction motors are also manufactured in the range of 1.5, 2, 3 and up to 10 HP as a special requirement.
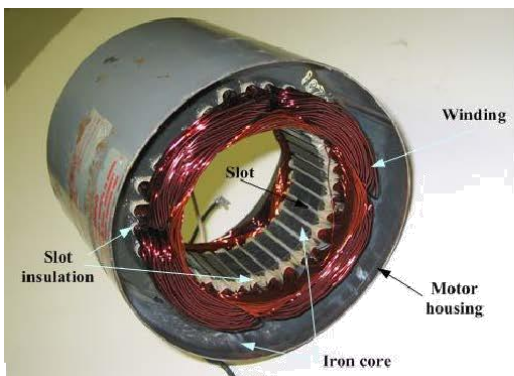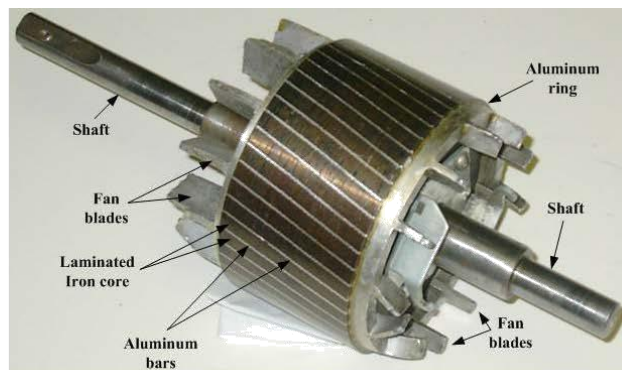

Fig: 4.1(a) Stator   Fig: 4.1(b) Squirrel cage rotor

4.1 working principle

A single phase induction motor is similar in construction to that of a polyphase induction motor with difference that its stator has only one winding. If such a stator is supplied with single phase alternating current, the field produced by it changes in magnitude and direction sinusoid ally. Thus the magnetic field produced in the air gap is alternating one but not rotating as a result these kind of motors are *NOT SELF STARTING*.

In below Fig: 4.2 (a) shows the torque-speed characteristic of single phase induction motor.
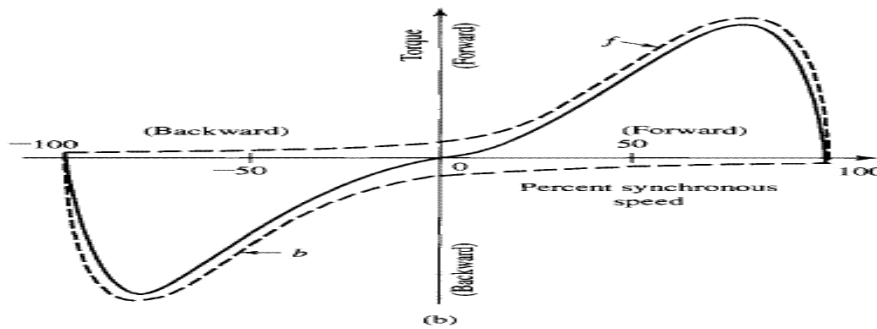
Such an alternating filed is equivalent to two fields of equal magnitude rotating in opposite directions at equal speed as explained below:

4.1.1 *Double Revolving Field Theory of Single Phase Induction Motor*

Consider two magnetic fields represented by quantities OA and OB of <u>equal</u> magnitude revolving in opposite directions as shown in fig: 4.1.
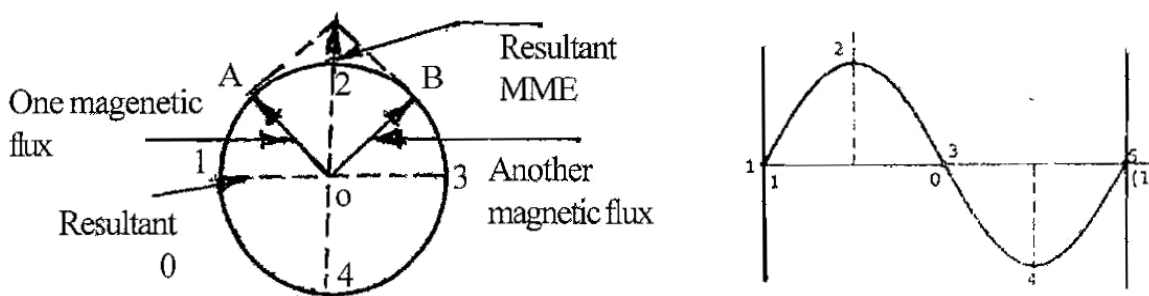

Fig: 4.2 (b)

The resultant of the two fields of equal magnitude rotating in opposite directions is alternating. Therefore an alternating current can be considered as having two components which are of equal in magnitude and rotating in opposite directions.

From the above, it is clear that when a single phase alternating current is supplied to the stator of a single phase motor, the field produced will be of alternating in nature which can be divided into two components of equal magnitude one revolving in clockwise and other in counter clockwise direction.

If a stationary squirrel cage rotor is kept in such a field equal forces in opposite direction will act and the rotor will simply vibrate and there will be no rotation.

But if the rotor is given a small jerk in any direction in this condition, it will go on revolving and will develop torque in that particular direction. It is clear from the above that a single phase induction motor when having only one winding is not a self-starting. To make it a self-starting anyone of the following can be adopted.

        (i)   Split phase starting.
        (ii)   Repulsion starting.
        (iii)   Shaded pole starting.

4.2 EQUVALENT CIRCUIT OF SINGLE PHASE INDUCTION MOTOR

The equivalent circuit of single phase induction motor is shown below (Fig: 4.3)
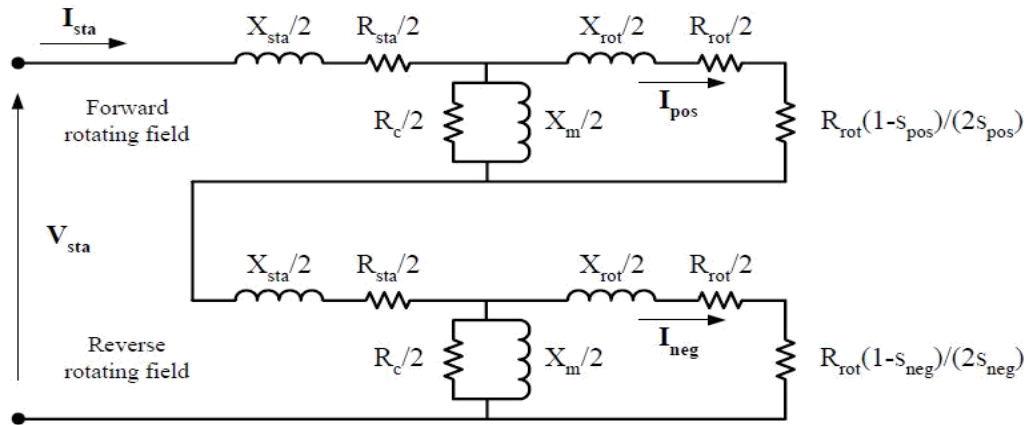

Fig: 4.3

4.2.1 Determination of Equivalent Circuit Parameters of Single Phase Induction motor

It is possible to find the parameters of the equivalent circuit of the single phase induction motor experimentally as shown in Fig.4.4. For this purpose, three tests should be conducted:

1- The DC Test:

The DC resistance of the stator can be measured by applying DC current to the terminals of the main winding and taking the reading of the voltage and the current (or using ohmmeter) and determine the DC resistance as follows:

$$R_{DC} = \frac{V_{DC}}{I_{DC}}$$

Then, the AC resistance is given by:

$$R_{AC} = 1.25 \ R_{DC}$$

2-The Blocked Rotor Test:

When the rotor is locked (i.e. prevented from running), $S_b = S_f = 1$. The secondary impedances become much less than the magnetizing branches and the corresponding equivalent circuit becomes that of Fig: 4.5.
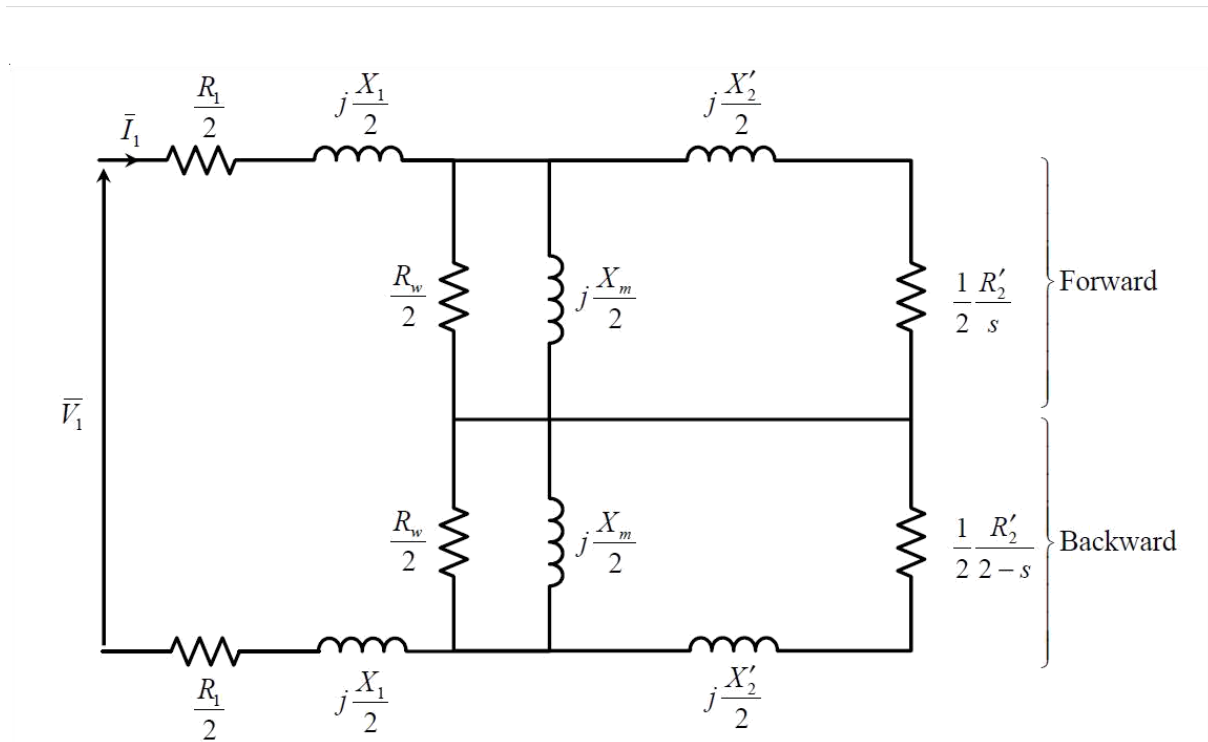
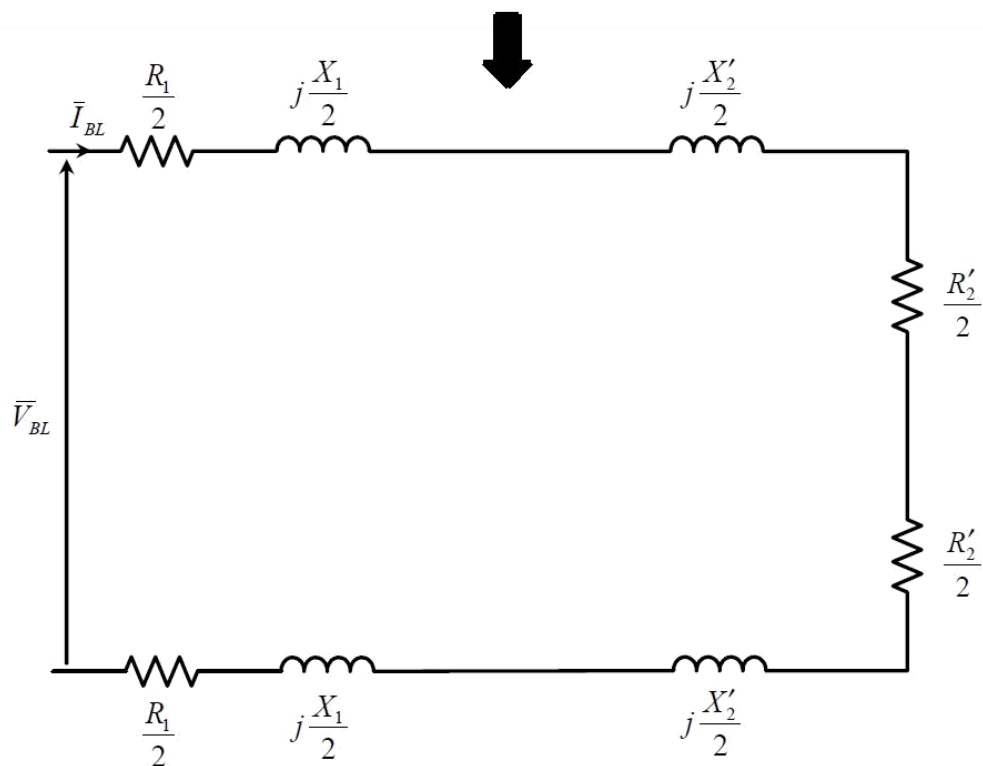Fig: 4.4 Equivalent circuit of single phase induction motor.

Fig: 4.5(a) Approximate equivalent circuit of the single phase induction motor at standstill.

The circuit in Fig: 4.5 (a) can be rearranged to the equivalent circuit that is shown in Fig: 4.5(b).

Fig: 4.5(b) Rearranged approximate equivalent circuit of the single phase induction motor at standstill.

The readings to be obtained from this test are:

    a) Single phase power P_{BL}

    b) Phase voltage V_{BL}

    c) Phase current I_{BL}

Then, R_{eq}, Z_{eq}, and X_{eq} can be obtained using the following equations:

$$R_{eq} = \frac{P_{BL}}{I_{BL}^2}$$

$$Z_{eq} = \frac{V_{BL}}{I_{BL}}$$

$$X_{eq} = \sqrt{Z_{eq}^2 - R_{eq}^2}$$

Separation of X_1, X_2', R_1, and R_2' can be done as follows:

$$X_1 = X_2' = \frac{1}{2} X_{eq}$$

$$R_2' = R_{eq} - R_1$$

3-The No Load Test:

When the induction motor is allowed to run freely at no load, the forward slip S_f approaches zero and the backward slip S_b approaches 2 ($S_f = s$, $S_b = 2\text{-}s$). The secondary forward impedance becomes very large with respect to the magnetizing branch, while the secondary backward impedance becomes very small if compared with the magnetizing branch. Accordingly, the equivalent circuit corresponding to these operating conditions can be approximated by that of Fig: 4.6.

The readings to be obtained from this test are:

    d) Single phase power P_{NL}

    e) Phase voltage V_{NL}

    f) Phase current I_{NL}

Fig: 4.6 (a) Approximate equivalent circuit of the single phase induction motor at no load.

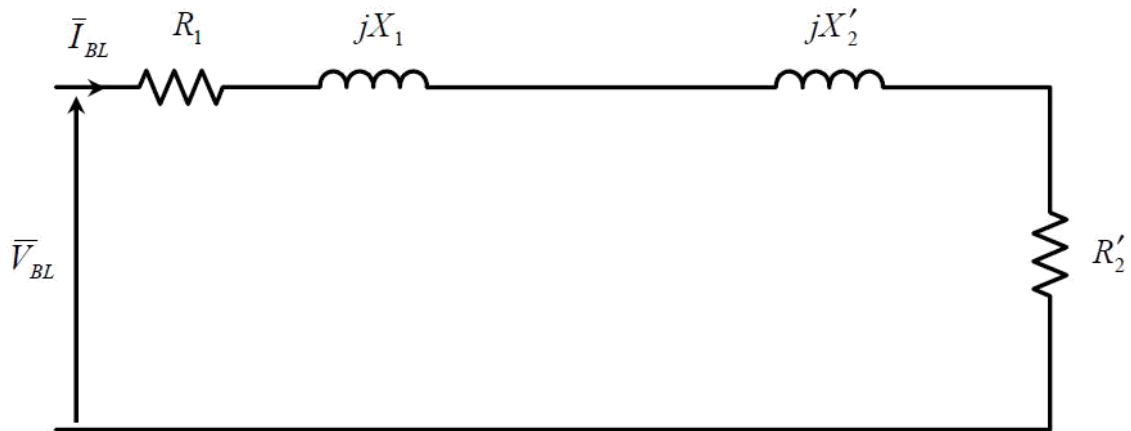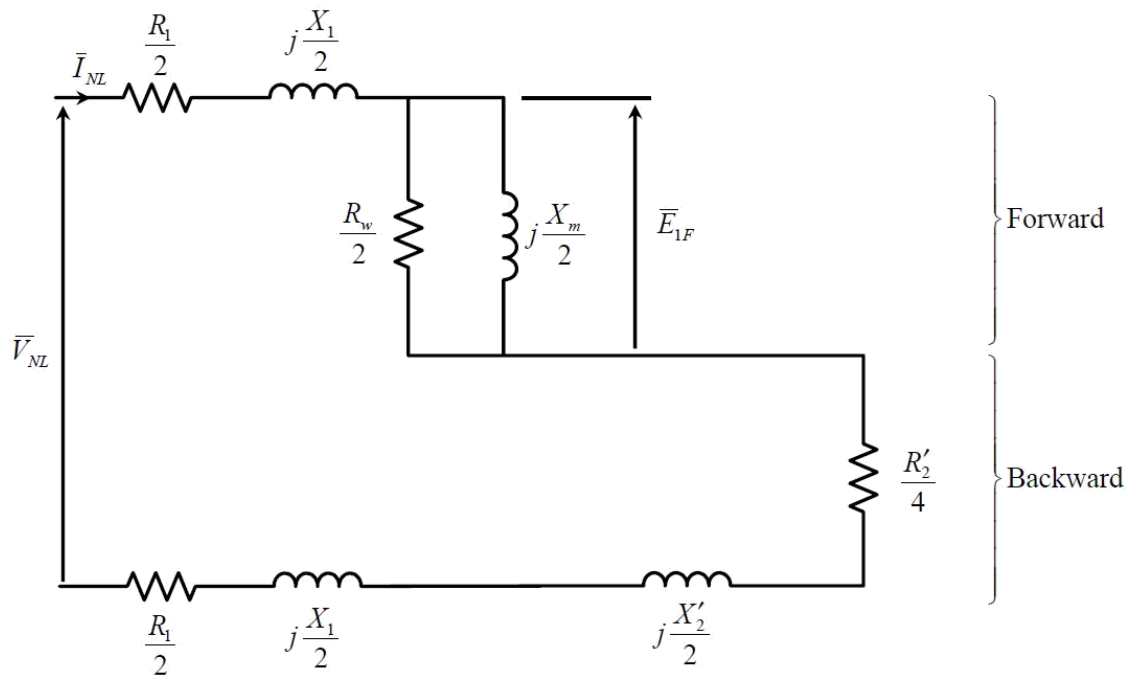The circuit in Fig: 4.6 (a) can be rearranged to the equivalent circuit that is shown in Fig: 4.6 (b)
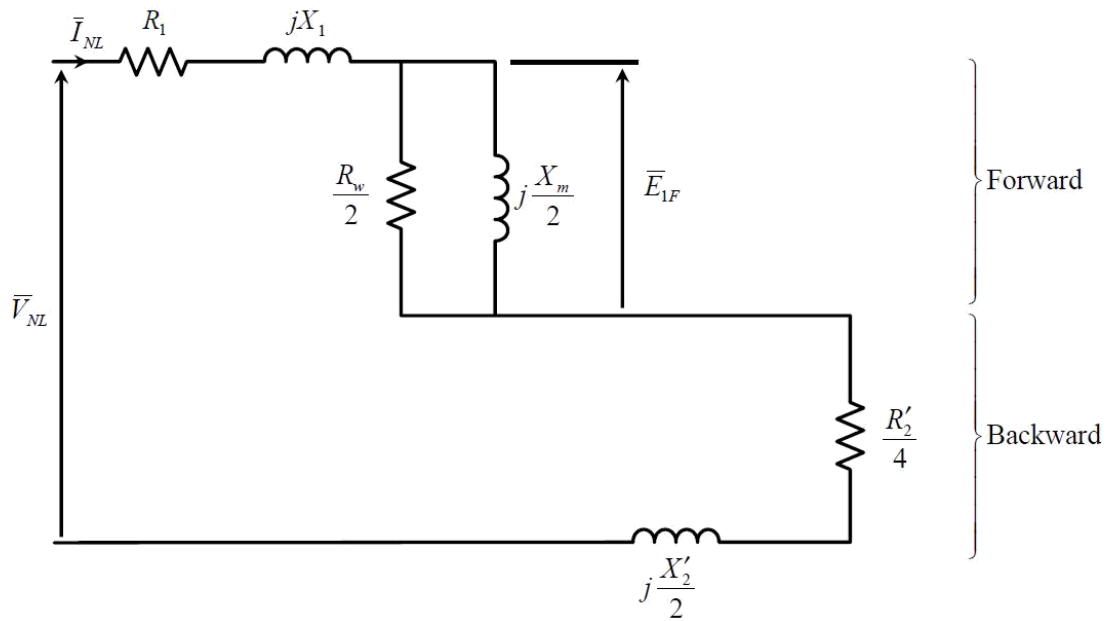
Fig: 4.6 (b) Rearranged approximate equivalent circuit of the single phase induction motor at no load

Then, R_w, and X_m, can be obtained as fallows:

$$P_{core+mechanical} = P_{NL} - I_{NL}^2 \left(R_1 + \frac{R_2'}{4} \right)$$

$$\overline{E}_{1F} = \overline{V}_{NL} - \overline{I}_{NL} \left(\left(R_1 + \frac{R_2'}{4} \right) + j \left(X_1 + \frac{X_2'}{2} \right) \right)$$

Note: $(\overline{I}_{NL} = I_{NL} \angle -\theta, \quad \theta = \cos^{-1} \frac{P_{NL}}{V_{NL} I_{NL}})$

$$R_w = 2 \frac{|E_{1F}|^2}{P_{core+mechanical}}$$

$$I_w = \frac{|E_{1F}|}{\left(\frac{R_w}{2} \right)} = 2 \frac{|E_{1F}|}{R_w}$$

$$I_m = \sqrt{I_{NL}^2 - I_w^2}$$

$$X_m = 2\frac{|E_{1F}|}{I_m}$$

4.3 **Methods of Starting**

It is clear from previous discussion that a single phase induction motor when having only one winding and it is not self-starting. To make it a self-starting anyone of the following can be adopted.

(1)   Split phase starting.

(2)   Repulsion starting.

(3)   Shaded pole starting.

4.3.1 PRINCIPLE OF SPLIT PHASE INDUCTION MOTOR

The basic principle of operation of a split phase induction motor is similar to that of a polyphase induction motor. The main difference is that the single phase motor does not produce a rotating magnetic field but produces only a pulsating filed.

Hence, to produce the rotating magnetic field for self-starting, phase splitting is to be done to make the motor to work as a two phase motor for starting.

4.3.1 *Working of Split Phase Motor*

In split phase motor two windings named as main winding and starting winding are provided. At the time of starting, both the main and starting windings should be connected across the supply to produce the rotating magnetic field.

The rotor is of a squirrel cage type and the revolving magnetic field sweeps part the stationary rotor, inducing emf in the rotor. As the rotor bars are short-circuited, a current flows through them producing a magnetic field.

This magnetic field opposes the revolving magnetic field and will combine with the main filed to produce a revolving filed. By this action, the rotor starts revolving in the same direction of the rotating magnetic field as in the case of a squirrel cage induction motor.

Hence, once the rotor starts rotating, the starting winding can be disconnected from the supply by some mechanical means as the rotor and stator fields from a revolving magnetic field. There are several types of split phase motors.

4.3.2 TYPES OF SPLIT-PHASE INDUCTION MOTORS

1.   Resistance-start, induction-run motors

2.   Capacitor-start, induction-run motors

3.   Capacitor-start, capacitor-run motors

4.   Shaded pole motors.

1. RESISTANCE-START, INDUCTION-RUN MOTORS

As the starting torque of this type of motor is relatively small and its starting current is high, these motors are most commonly used for rating up to 0.5 HP where the load could be started easily. The essential parts are shown in Fig: 4.7.

•   Main winding or running winding.

•   Auxiliary winding or starting winding

•   Squirrel cage type rotor.

•   Centrifugal switch.

CONSTRUCTION AND WORKING

The starting winding is designed to have a higher resistance and lower reactance than the main winding. This is achieved by using small conductors in the auxiliary winding than in the main winding. The main winding will have higher inductance when surrounded by more iron, which could be made possible by placing it deeper into the stator slots, it is obvious that the current would split as shown in Fig: 4.7(b).
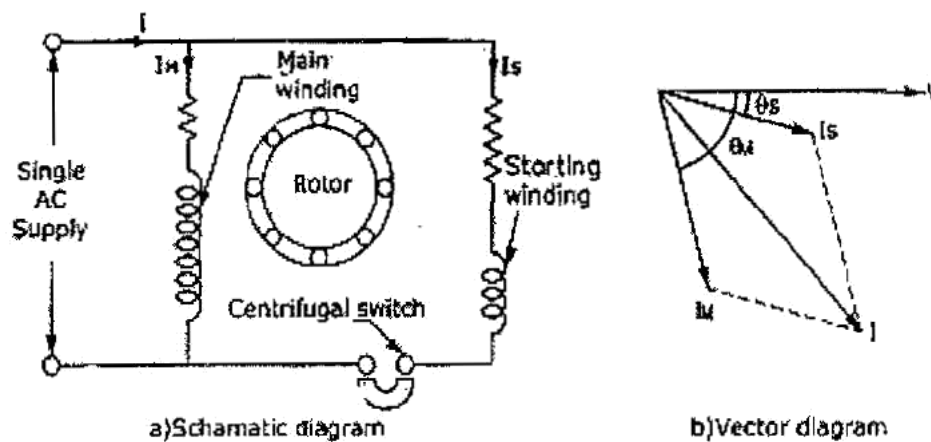

Fig: 4.7

The starting current "I" start will lag the main supply voltage "V" line by 15 degree and the main winding current. "I" main lags the main voltage by about 80 degree. Therefore, these currents will differ in time phase and their magnetic fields will combine to produce a rotating magnetic field.

When the motor has come up to about 75 to 80% of synchronous speed, the starting winding is opened by a centrifugal switch and the motor will continue to operate as a single phase motor.

CHARACTERISTICS

At the point where the starting winding is disconnected, the motor develops nearly as much torque with the main winding alone as with both windings connected. This can be observed from, the typical torque-speed characteristics of this motor, as shown in Fig: 4.8.
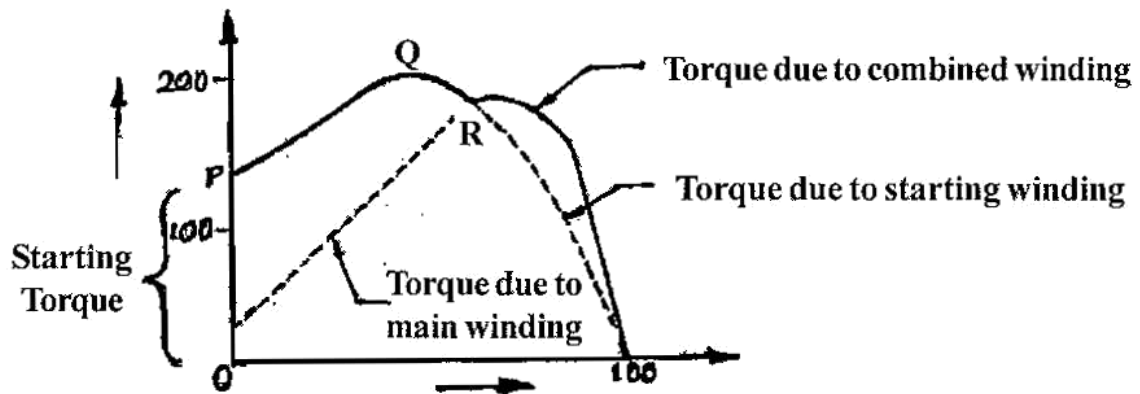

Fig: 4.8

The direction of rotating of a split-phase motor is determined by the way the main and auxiliary windings are connected. Hence, either by changing the main winding terminals or by changing the starting winding terminals, the reversal of direction of rotating could be obtained.

APPLICATIONS

These motors are used for driving fans, grinders, washing machines.

2. CAPACITOR-START, INDUCTION-RUN MOTOR

A drive which requires a large starting torque may be fitted with a capacitor-start, induction-run motor as it has excellence starting torque as compared to the resistance-start, induction-run motor.

CONSTRUCTION AND WORKING

Fig: 4.9(a) shows the schematic diagram of a capacitor-start, induction-run motor. As shown, the main winding is directly connected across the main supply whereas the starting winding is connected across the main supply through a capacitor and centrifugal switch.

Both these windings are placed in a stator slot at 90 degree electrical apart, and a squirrel cage type rotor is used.

As shown in Fig: 4.9(b), at the time of starting the current in the main winding lags the supply voltages by 90 degrees, depending upon its inductance and resistance. On the other hand, the current in the starting winding due to its capacitor will lead the applied voltage, by say 20 degrees.

Hence, the phase difference between the main and starting winding becomes near to 90 degrees. This in turn makes the line current to be more or less in phase with its applied voltage, making the power factor to be high, thereby creating an excellent starting torque.

However, after attaining 75% of the rated speed, the centrifugal switch operates opening the starting winding and the motor then operates as an induction motor, with only the main winding connected to the supply.
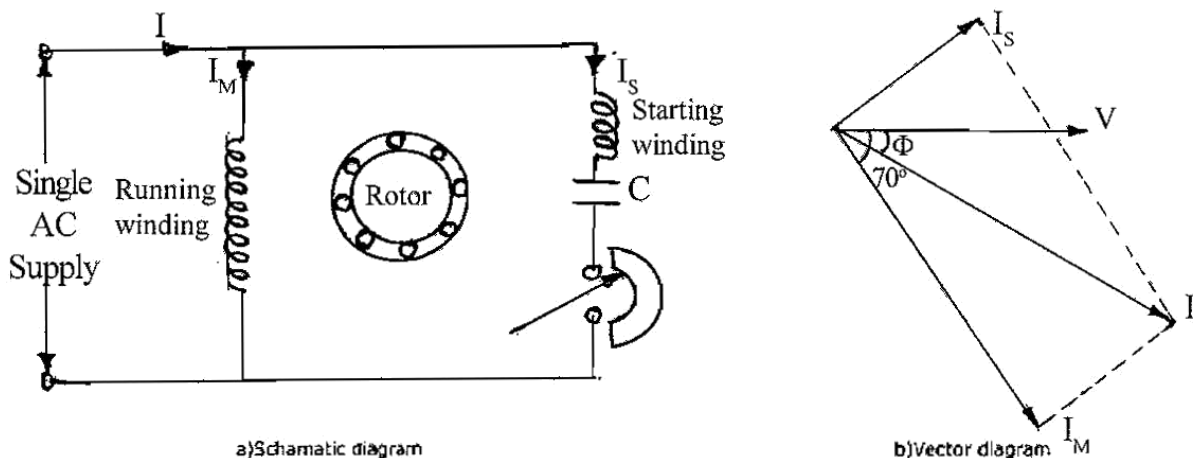

Fig: 4.9

As shown in Fig: 4.9(b), the displacement of current in the main and starting winding is about 80/90 degrees, and the power factor angle between the applied voltage and line current is very small. This results in producing a high power factor and an excellent starting torque, several times higher than the normal running torque as shown in Fig: 4.10.

CHARACTERISTICS

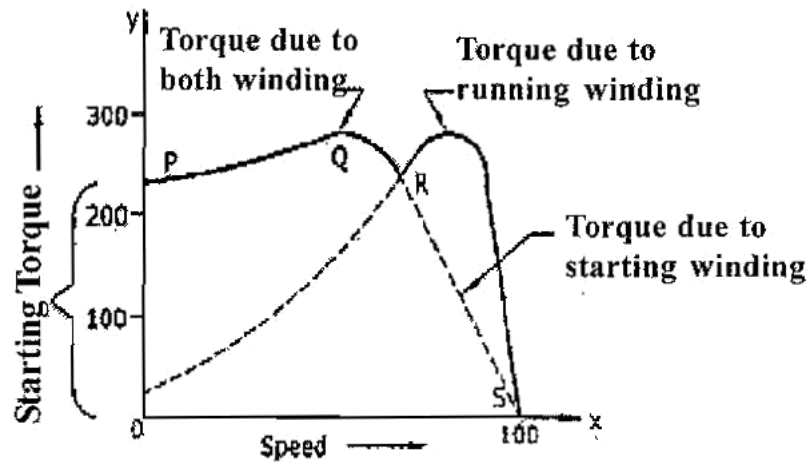The torque-speed characteristics of this motor is shown in Fig: 4.10.

Fig: 4.10

In order to reverse the direction of rotation of the capacitor-start, induction-run motor, either the starting or the main winding terminals should be changed.

This is due to the fact that the direction of rotation depends upon the instantaneous polarities of the main field flux and the flux produced by the starting winding. Therefore, reversing the polarity of one of the field will reverse the torque.

APPLICATIONS

Due to the excellent starting torque and easy direction-reversal characteristics,

- Used in belted fans,
- Used in blowers dryers,
- Used in washing machines,
- Used in pumps and compressors.

3. CAPACITOR-START, CAPACITOR-RUN MOTORS

As discussed earlier, one capacitor-start, induction-run motors have excellent starting torque, say about 300% of the full load torque and their power factor during starting in high.

However, their running torque is not good, and their power factor, while running is low. They also have lesser efficiency and cannot take overloads.

CONSTRUCTION AND WORKING

The aforementioned problems are eliminated by the use of a two valve capacitor motor in which one large capacitor of electrolytic (short duty) type is used for starting whereas a smaller

capacitor of oil filled (continuous duty) type is used for running, by connecting them with the starting winding as shown in Fig:4.11. A general view of such a two valve capacitor motor is shown in Fig: 4.11.
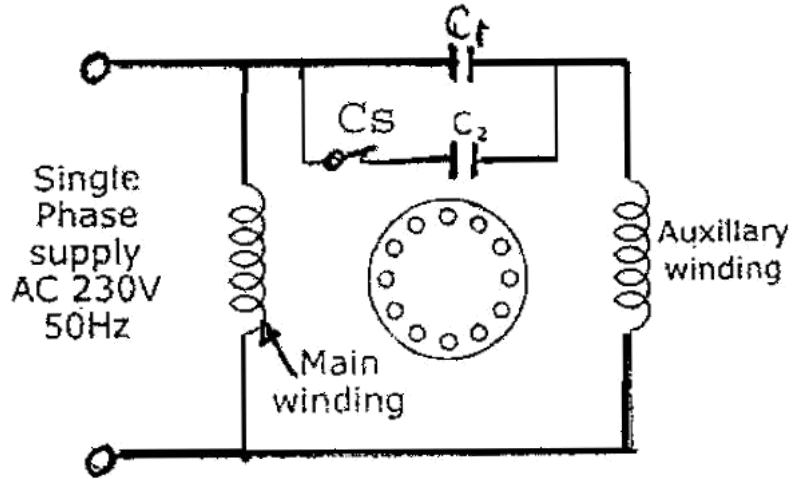

Fig: 4.11

This motor also works in the same way as a capacitor-start, induction-run motor, with exception, that the capacitor C1 is always in the circuit, altering the running performance to a great extent.

The starting capacitor which is of short duty rating will be disconnected from the starting winding with the help of a centrifugal switch, when the starting speed attains about 75% of the rated speed.

CHARACTERISTICS

The torque-speed characteristics of this motor are shown in Fig: 4.12.
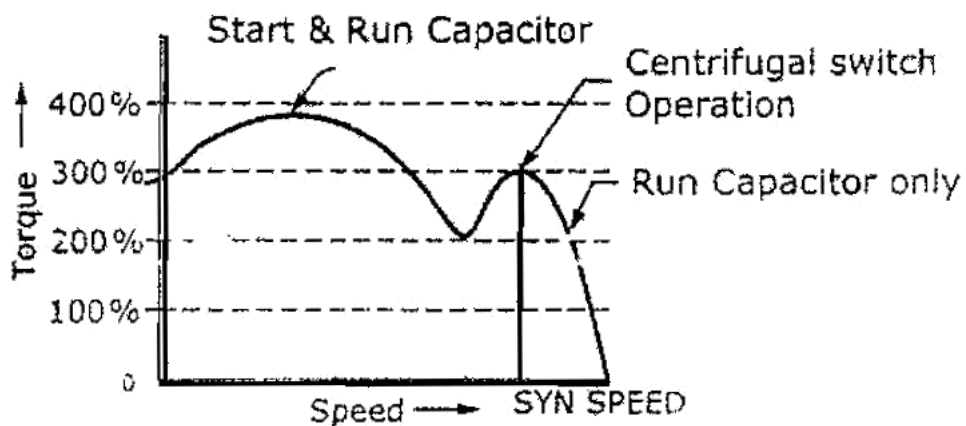

Fig: 4.12

This motor has the following advantages:

- The starting torque is 300% of the full load torque

- The starting current is low, say 2 to 3 times of the running current.

- Starting and running power factor are good.

- Highly efficient running.

- Extremely noiseless operation.

- Can be loaded upto 125% of the full load capacity.

APPLICATIONS

- Used for compressors, refrigerators, air-conditioners, etc.

- Higher starting torque.

- High efficiency, higher power factor and overloading.

- Costlier than the capacitor-start — Induction run motors of the same capacity.

4.3.2 REPULSION STARTING
4.3.3

This type of starting need a wound rotor with brush and commutator arrangement like a dc armature Fig 4.13(a). The starting operation is based on the principle of repulsion and hence the name.

CONSTRUCTION AND WORKING

Repulsion starting, though complicated in construction and higher in cost, are still used in certain industries due to their excellent starting torque, low starting current, ability to withstand long spell of starting currents to drive heavy loads and their easy method of reversal of direction.

Now there is a condition that the rotor north pole will be repelled by the main north pole and the rotor south pole is repelled by the main south pole, so that a torque could be developed in the rotor. Now due to the repulsion action between the stator and the rotor poles, the rotor will start rotating in a clockwise direction. As the motor torque is due to repulsion action, this starting method is named as repulsion starting.
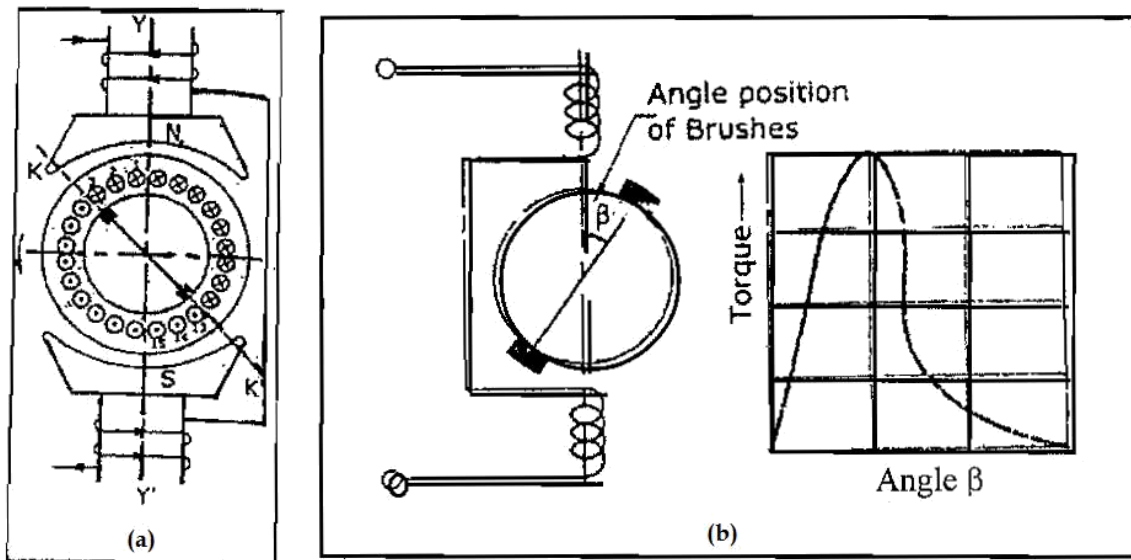

Fig: 4.13

To change the direction of rotation of this motor, the brush axis needs to be shifted from the right side as shown in Fig:4.13(b) to the left side of the main axis in a counter clockwise direction as shown in Fig:4.13(b).

CHARACTERISTICS

The torque developed in a repulsion motor will depend upon the amount of brush shaft as shown in Fig: 4.13 (b), whereas the direction of shift decides the direction of rotation.

Further, the speed depends upon the amount of brush shift and the magnitude of the load also on the relationship between the torque and brush-position angle.

Though the starting torque from 250 to 400% of the full load torque, the speed will be dangerously high during light loads. This is due to the fact that the speed of the repulsion motor start does not depend on frequency or number of poles but depends upon the repulsion principle.

Further, there is a tendency of sparking in the brushes at heavy loads, and the PF will be poor at low speeds. Hence the conventional repulsion motor start is not much popular.

4.3.3 SHAPED POLE STARTING

The motor consists of a yoke to which salient poles are fitted as shown in Fig: 4.14(a) and it has a squirrel cage type rotor.
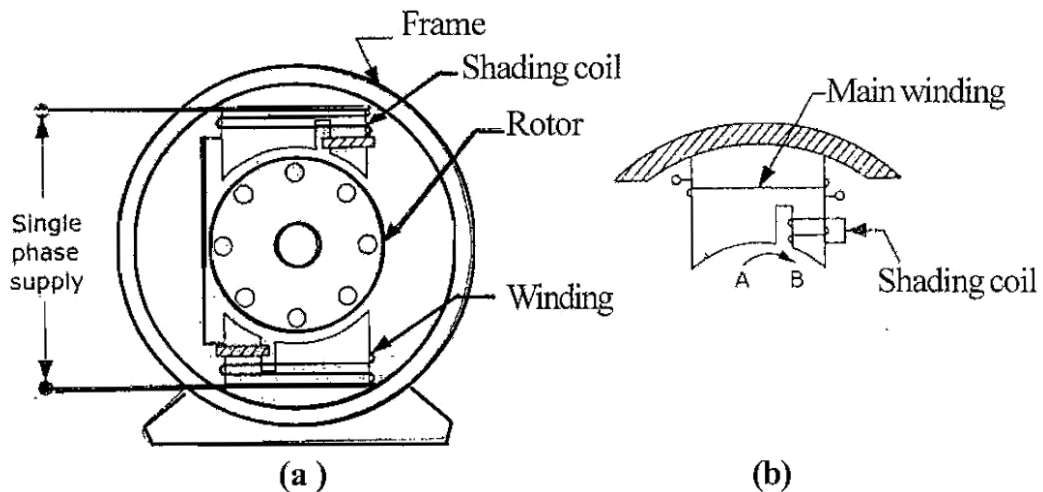

Fig: 4.14

A shaded pole made of laminated sheets has a slot cut across the lamination at about one third the distance from the edge of the pole.

Around the smaller portion of the pole, a short-circuited copper ring is placed which is called the shading coil, and this part of the pole is known as the shaded part of the pole. The remaining part of the pole is called the unshaded part which is clearly shown in Fig: 4.14(b).

Around the poles, exciting coils are placed to which an AC supply is connected. When AC supply is effected to the exciting coil, the magnetic axis shifts from the unshaded part of the pole to the shaded part as will be explained in details in the next paragraph. This shifting of axis is equivalent to the physical movement of the pole.

This magnetic axis, which is moving, cuts the rotor conductors and hence, a rotational torque is developed in the rotor.

By this torque the rotor starts rotating in the direction of the shifting of the magnetic axis that is from the unshaded part to the shaded part.

THE MAGNETIC FLUX SHIFTING

As the shaded coil is of thick copper, it will have very low resistance but as it is embedded in the iron case, it will have high inductance. When the exciting winding is connected to an AC supply, a sine wave current passes through it.

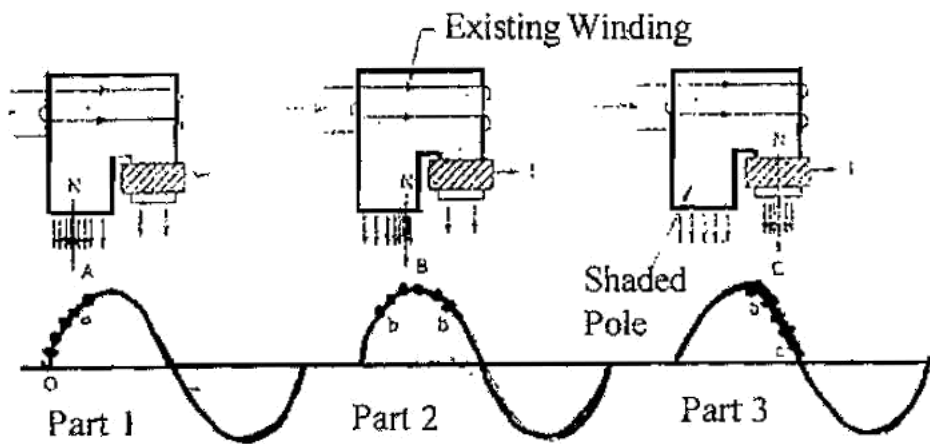Let us consider the positive half cycle of the AC current as shown in Fig: 4.15.

Fig: 4.15 Shifting of magnetic flux

When the current raises from "Zero" Value of point "0" to a point "a" the change in current is very rapid (Fast). Hence, it reduces an emf in the shaded coil on the basis of Faraday's law of electromagnetic induction.

The induced emf in the shaded coil produces a current which, in turn, produces a flux in accordance with Lenz Law. This induced flux opposes the main flux in the shaded portion and reduces the main flux in that area to a minimum value as shown in Fig: 4.15.

This makes the magnetic axis to be in the centre of the unshaded portion as shown by the arrow in part of Fig: 4.15. On the other hand as shown in part 2 of 3 when the current raises from point "a" to point "b" the change in current is slow the induced emf and resulting current in the shading coil is minimum and the main flux is able to pass through the shade portion.

This makes the magnetic axis to be shifted to the centre of the whole pole as shown in by the arrow in part 2 of Fig: 4.15.

In the next instant, as shown in part 3 of Fig: 4.15. When the current falls from "b" to "c" the change in current is fast but the change of current is from maximum to minimum.

Hence a large current is induced in the shading ring which opposes the diminishing main flux, thereby increasing the flux density in the area of the shaded part. This makes the magnetic axis to shift to the right portion of the shaded part as shown by the arrow in part.

From the above explanation it is clear the magnetic axis shifts from the unshaded part to the shaded part which is more or less a physical rotary movement of the poles.

Simple motors of this type cannot be reversed. Specially designed shaded pole motors have been constructed for reversing operations. Two such types:

  a. The double set of shading coils method

  b. The double set of exciting winding method.

Shaded pole motors are built commercially in very small sizes, varying approximately from 1/250 HP to 1/6 HP. Although such motors are simple in construction and cheap, there are certain disadvantages with these motor as stated below:

  • Low starting torque.

  • Very little overload capacity.

  • Low efficiency.

APPLICATIONS

  • Record players

  • Fans

  • Hair driers.

Two Phase A C Servomotors

Construction:- it is basically a two phase induction motor having a squirrel cage rotor . the rotor has high resistance to ensure a negative slope for the torque-speed characteristics over the entire operating range . This characteristics is needed for the positive damping & good stability. the rotor has small diameter-to-length ratio to minimize the moment of inertia and to give a good accelerating characteristics. Servo motor is commonly used feed back control system.
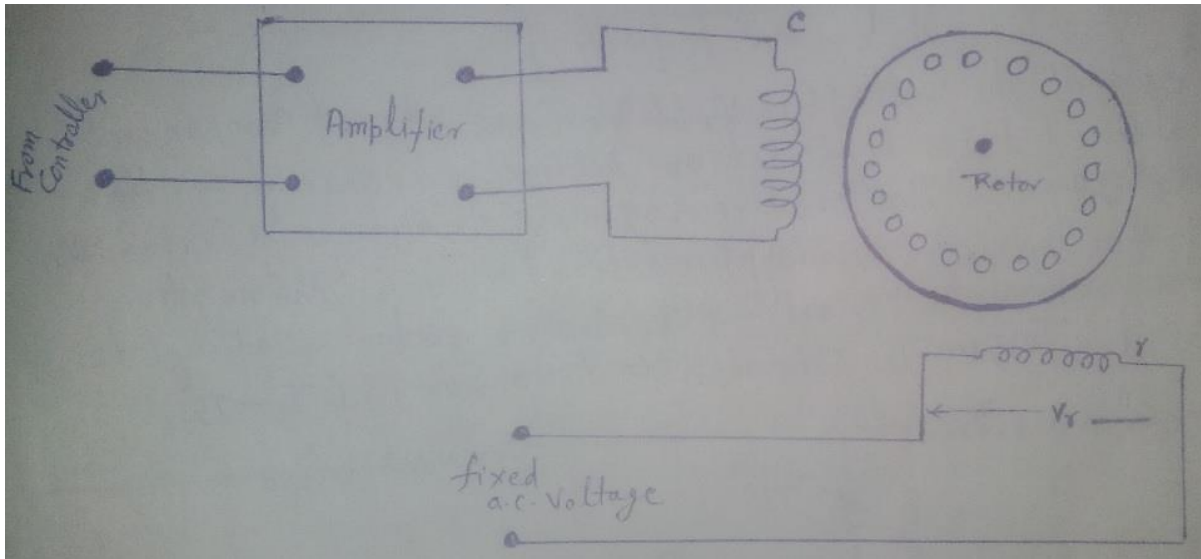
form above fig shows the connection diagram. One of the stator winding is excited by a fixed a.c. voltage V_r, while the second winding c is excited by a fixed a.c. voltage V_c The two voltages be in synchronism , which is a necessary condition for production of torque. The control voltage is fed to the motor through an amplifier . Phase difference between voltages is 90^0. The 90^0 phase shift can be obtained by phase shifting network in the amplifier circuit . when V_c leads by 90^0, rotation in one direction is obtained . The torque is function of both V_r & V_c changing the magnitude of V_c changes the torque developed.

Analysis using Symmetrical Components:- (Performance)

Symmetrical component to developed the equivalent circuit analysis the performance of single phase induction motor. It is use for analysis of a two phase servomotor. The voltage Vr & Vc can br resolved in to symmetrical component Vr_1 & Vr_2.

$$\begin{bmatrix} V_r \\ V_c \end{bmatrix} = \begin{bmatrix} 1 & 1 \\ -J & J \end{bmatrix} \begin{bmatrix} V_{r_1} \\ V_{r_2} \end{bmatrix}$$

$$\begin{bmatrix} V_{r_1} \\ V_{c_2} \end{bmatrix} = \frac{1}{2}\begin{bmatrix} 1 & J \\ 1 & -J \end{bmatrix} \begin{bmatrix} V_r \\ V_c \end{bmatrix}$$

Thus each of the voltage Vr & Vc consists of components of balance two phase set,

one positive sequence & another negative sequence. the positive sequence components V_{r1} &

Equivalent Circuit of two phase seromotor
(a) positive sequence   (b) negtive sequence
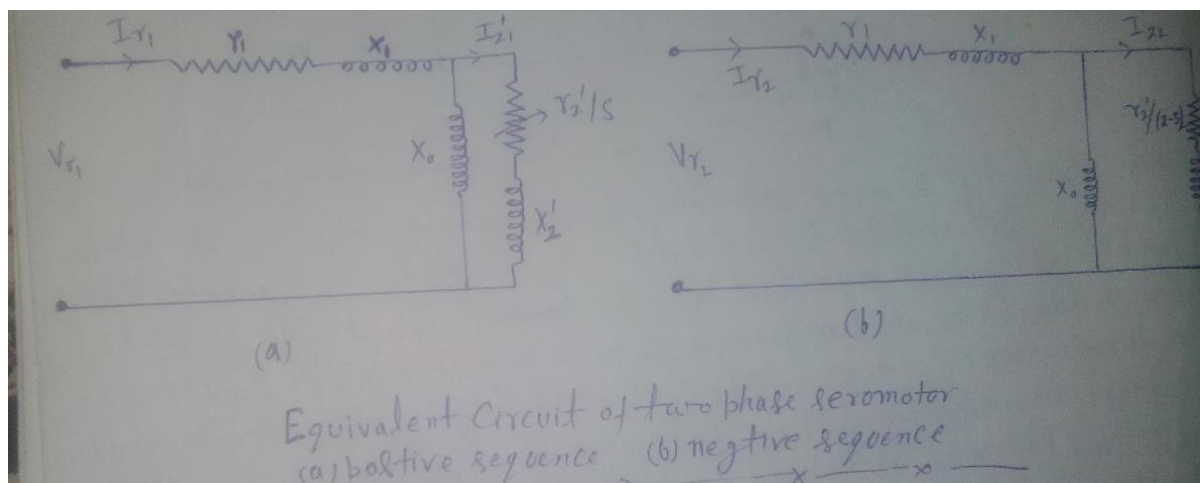
V_{r2} set up . then the rotor winding produce a torque T_1. The negative sequence components V_{r2} & + V_{r2} set up rotor winding to produced a torque T_2. The resultant torque is $(T_1 - T_2)$.

The above fig. (a) shows the per phase equivalent circuit of two phase servomotor for positive sequence set. The applied voltage is the positive sequence voltage V_{r1}.

In the above fig (b) shows the equivalent circuit for negative sequence set. The applied voltage is the negative sequence voltage V_{r2}. The total rotor resistance as referred to stator is $r_2 / (2\text{-s})$. the performance can be evaluated from the equivalent circuit.