Unit – 5 (BEE) R19&R20 Regulations – I ECE II Semester

Special Machines: Principle of operation and construction - single phase induction motor - shaded pole motors – capacitor motors and AC servomotor.

SINGLE PHASE MOTORS

- As the name suggests, these motors are used on single – phase supply. Single phase motors are the most common type of electric motors, which finds wide domestic, commercial and industrial applications.
- Single phase motors are small size motors of fraction – kilowatt ratings. Domestic applications like fans, hair driers, washing machines, mixers, refrigerators, food processors and other kitchen equipment employ these motors.
- These motors also find applications in air – conditioning fans, blower's office machinery etc.

Single phase motors may be classified into the following basic types:

1. Single phase induction motors
2. AC. Series motor (universal motor)
3. Repulsion motors
4. Synchronous motor

Single Phase Induction Motor

- A single phase induction motor is very similar to 3 – phase squirrel cage induction motor. It has a squirrel – cage rotor identical to a 3 - phase squirrel cage motor and a single – phase winding on the stator. Unlike 3 – phase induction motor, a single phase induction motor is not self starting but requires some starting means.
- Figure (1) shows 1 – phase induction motor having squirrel cage rotor and single phase distributed stator winding.

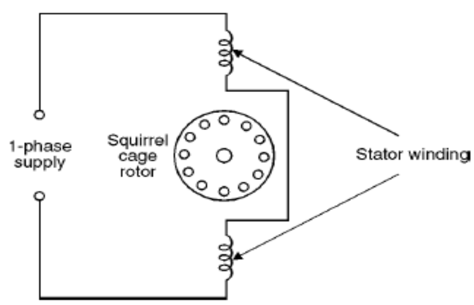


Fig. (1) Single – phase induction motor

- If the stator winding is connected to single – phase a.c. supply, the stator winding produces a magnetic field that pulsates in strength in a sinusoidal manner.
- The field polarity reverses after each half cycle but the field does not rotate. Consequently, the alternating flux cannot produce rotation in a stationary squirrel cage rotor.
- However, if the rotor is started by auxiliary means, the motor will quickly attain the final speed. The behavior of single – phase induction motor can be explained on the basic of double – field revolving theory.

Double – Field Revolving Theory

- The pulsating field produced in single phase AC motor is resolved into two components of half the magnitude and rotating in opposite directions at the same synchronous speed.
- Let Φ_m be the pulsating field which has two components each of magnitude $\Phi_m/2$ Both are rotating at the same angular speed ω rad/sec but in opposite direction as shown in the Figure (2-a).
- The resultant of the two fields is $\Phi_m \cos\theta$. Thus the resultant field varies according to cosine of the angle θ. The wave shape of the resultant field is shown in Figure (2-b).

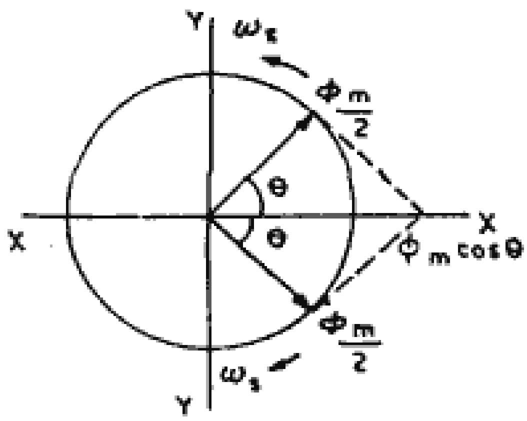


Fig. (2-a)

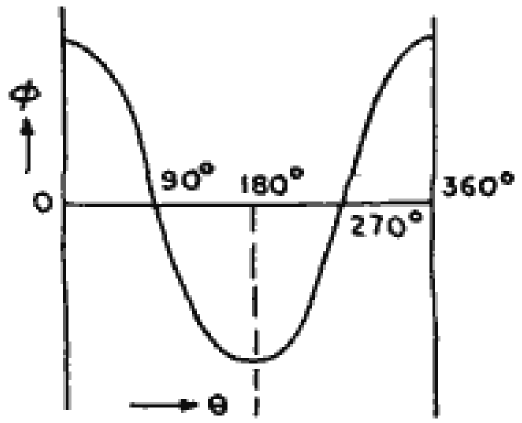


Fig. (2-b)

- Thus the alternating flux produced by stator winding can be presented as the sum of two rotating fluxes Φ_1 and Φ_2 each equal to one half of the maximum value of alternating flux and each rotating at synchronous speed in opposite directions.
- Let the flux Φ_1 (forward) rotate in anticlockwise direction and flux Φ_2 (backward) in clockwise direction. The flux Φ_1 will result in the production of torque T_1 in the anticlockwise direction and flux Φ_2 will result in the production of torque T_2 in the clockwise direction.

- At standstill, these two torques are equal and opposite and the net torque developed is zero. Therefore, single – phase induction motor is not self – starting. This fact is illustrated in fig. (3)

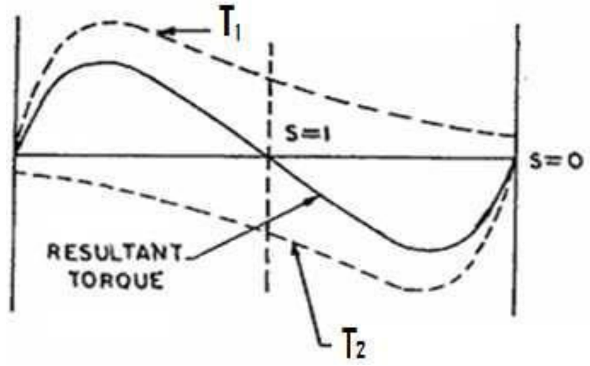


Fig. (3) Torque – slip characteristic of 1- phase induction motor

Rotor Running

- Assume that the rotor is started by spinning the rotor or by using auxiliary circuit, in say clockwise direction.
- The flux rotating in the clockwise direction is the forward rotating flux Φ_f and that in the other direction is the backward rotating flux Φ_b.
- The slip with respect to the forward flux will be $s_f = \frac{N_s - N}{N_s}$

Where

N_s = synchronous speed

N = speed of rotor in the direction of forward flux

- The rotor rotates opposite to the rotation of the backward flux. Therefore, the slip w.r.t the backward flux will be

$$s_b = \frac{N_s - (-N)}{N_s} = \frac{N_s + N}{N_s} = \frac{2N_s - N_s + N}{N_s} = \frac{2N_s}{N_s} - \frac{(N_s - N)}{N_s} = 2 - s$$

- Thus for forward rotating flux, slip is *s* (less than unity) and for backward rotating flux, the slip is 2-s (greater than unity) since for usual rotor resistance/reactance ratios, the torque at slips of less than unity are greater than those at slips of more than unity, the resultant torque will be in the direction of the rotation of the forward flux.
- Thus if the motor is once started, it will develop net torque in the direction in which it has been started and will function as a motor.

Starting of Single Phase Induction Motors

The single phases induction motors are classified based on the method of starting method and in fact are known by the same name descriptive of the method.

1. **Split – phase Induction Motor**

- The stator of a split – phase induction motor has two windings,
  1. Main winding
  2. Auxiliary winding.

These windings are displaced in space by 90 electric degrees as shown in figure (4-a).

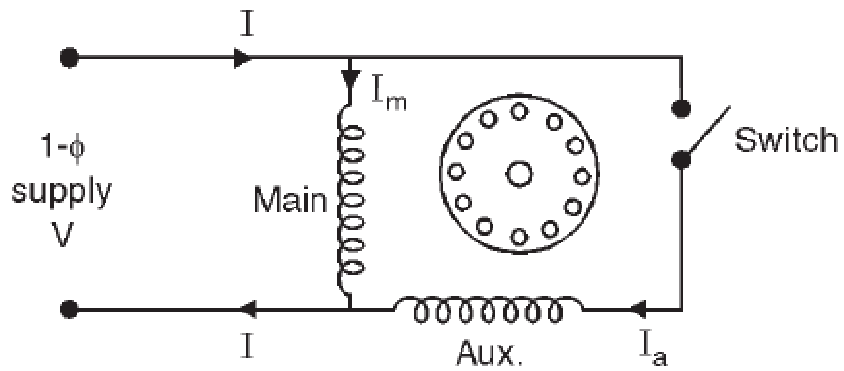


Fig.(4-a) split phase I.M.

- The auxiliary winding is made of thin wire so that it has a high R/X ratio as compared to the main winding which has thick super enamel copper wire.
- When the two stator windings are energized from a single – phase supply, the current I_m and I_a in the main winding and auxiliary winding lag behind the supply voltage V, and I_a leading the current I_m as shown in figure (4-b).

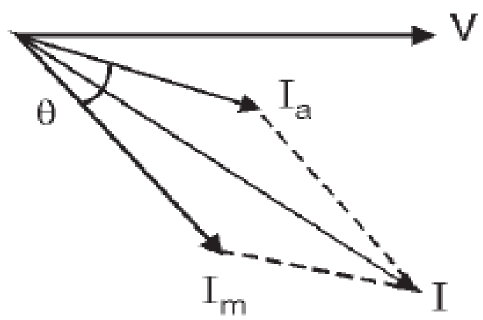
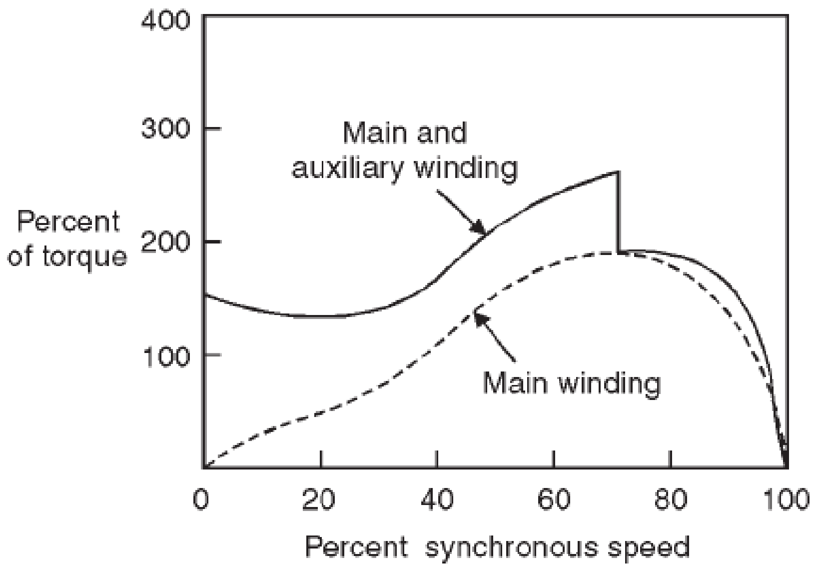


Fig.(4-b) Phasor diagram at starting

- This means the current through auxiliary winding reaches maximum value first and the mmf or flux due to I_a lies along the axis of the auxiliary winding and after some time the current I_m reaches maximum value and the mmf due to I_m lies along the main winding axis.
- Thus the motor becomes a 2 – phase unbalanced motor. Because of these two fields a starting torque is developed and the motor becomes a self starting motor.
- After the motor starts, the auxiliary winding is disconnected usually by means of centrifugal switch that operates at about 75% of synchronous speed. Finally the motor runs because of the main winding.
- Since this being single phase some level of humming noise is always associated with the motor during running. The power rating of such motors generally lies between 60- 250W.
  The typical torque – speed characteristic is shown in fig (4-c).



Characteristics

- Due to their low cost, split – phase induction motors are most popular single – phase motors in the market
- Since the starting winding is made of thin wire, the current density is high and the winding heats up quickly. If the starting period exceeds 5 seconds, the winding may burn out unless the motor is protected by built – in thermal relay. This motor is, therefore, suitable where starting periods are not frequent.

2. Capacitor – Start Motor

- Capacitors are used to improve the starting and running performance of the single phase inductions motors.
- The capacitor – start motor is identical to a split – phase motor except that the starting winding has as many turns as the main winding.
- Moreover, a capacitor C is connected in series with the starting winding as shown in fig (5-a).

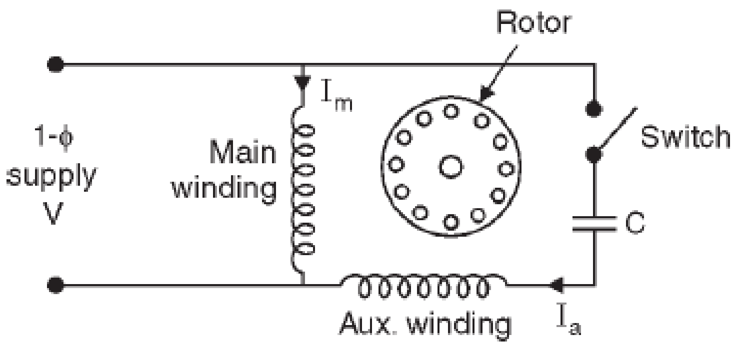
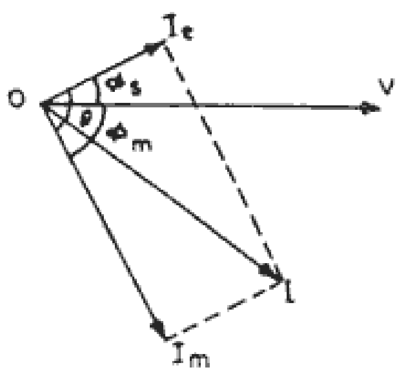


Fig.(5-a) Capacitor Start Motor

- The value of capacitor is so chosen that I_a leads I_m by about 90^o (Fig.5-b) so that the starting torque is maximum for certain values of I_a and I_m.
- Again, the starting winding is opened by the centrifugal switch when the motor attains about 75% of synchronous speed.
- The motor then operates as a single – phase induction motor and continues to accelerate till it reaches the normal speed.



The typical torque – speed characteristic is shown in fig (5-c).

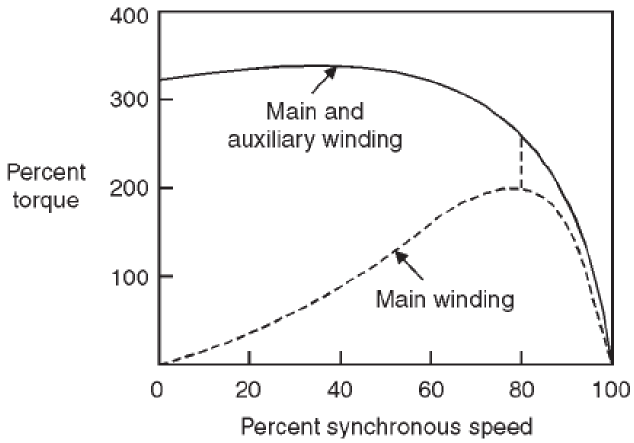


Fig. (5-c)

Characteristics

- Although starting characteristics of a capacitor – start motor are better than those of a split – phase motor, both machines possess the same running characteristics because the main windings are identical.
- The phase angle between the two currents is about 90 compared to about 25^{o} in a split – phase motor. Consequently, for the same starting torque, the current in the starting winding is only about half that in a split – phase motor.
- Therefore, the starting winding of a capacitor start motor heats up less quickly and is well suited to applications involving either frequent or prolonged starting periods.
- Capacitor – start motors are used where high starting torque is required and where high starting period may be long e.g. to drive:

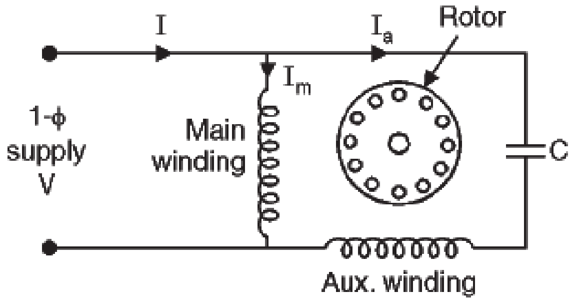
a) Compressors b) large fans c) pumps d)high inertia loads

The power rating of such motors lies between 120W and 0.75 kW.

www.Jntufastupdates.com

3. Permanent – Split Capacitor Motor

- In this motor, as shown in fig.(6-a), the capacitor that is connected in series with the auxiliary winding is not cut out after starting and is left in the circuit all the time.
- This simplifies the construction and decreases the cost because the centrifugal switch is not needed.
- The power factor, torque pulsation, and efficiency are also improved because the motor runs as a two – phase motor. The motor will run more quietly.
- The capacitor value is of the order of 20 – 50F and because it operates continuously, it is an ac paper oil type.
- The capacitor is compromise between the best starting and running value and therefore starting torque is sacrificed. The typical torque – speed characteristic is shown in fig (6-b).



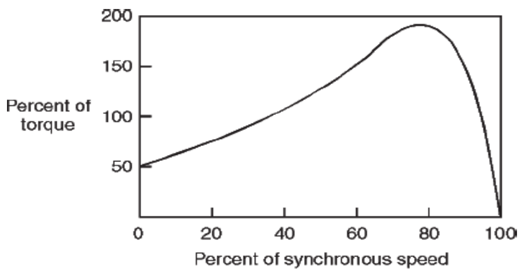


Fig.(6-a) Permanent – Split Capacitor Motor

Fig.(6-b) torque – speed characteristic

Characteristic

- These motor are used where the required starting torque is low such as air – moving equipment i.e. fans, blowers and voltage regulators and also oil burners where quite operation is particularly desirable.

4. Capacitor - Start Capacitor - Run

Two capacitor, one for starting and one for running, can be used, as shown in fig.(7-a).

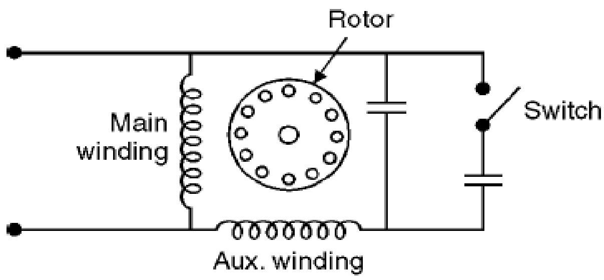


Fig. (7-a) Capacitor - Start Capacitor – Run motor

Theoretically, optimum starting and running performance can be achieved by having two capacitors. The starting capacitor is larger in value and is of the ac electrolytic type. The running capacitor permanently connected in series with the starting winding, is of smaller value and is of the paper oil type. Typical values of these capacitors for a 0.5 hp are C_s =300µF, C_r =40µF. The typical torque – speed characteristic is shown in fig. (7- b).

Characteristic

- Ability to start heavy loads
- Extremely quiet operation
- Higher efficiency and power factor

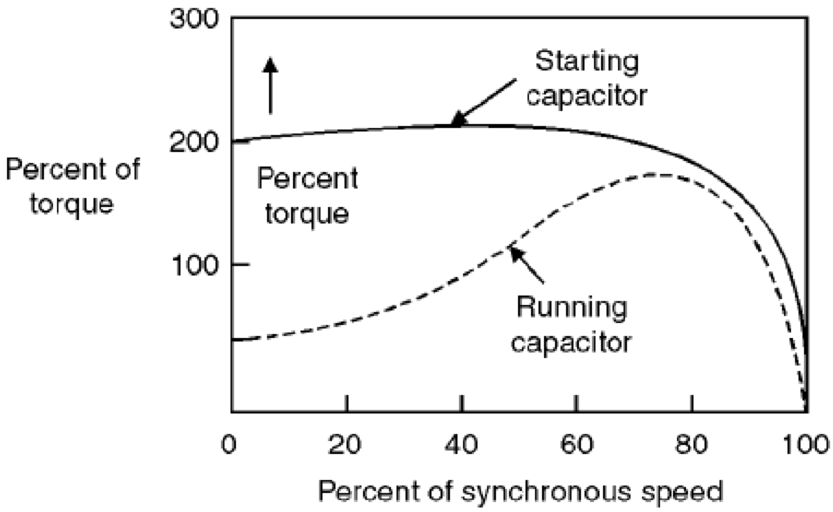


Fig.(7-b) torque – speed characteristic

- Ability to develop 25 per cent overload capacity. Hence, such motors are ideally suited where load requirements are severe as in the case of compressors and conveyors etc.

5. **Shaded Pole Induction Motor**

- These motors have a salient pole construction. A shaded band consisting of a short – circuited copper turn, known as a shading coil, is used on one portion of each pole, as shown in fig(8-a).
- When alternating current flow in the field winding, an alternating flux is produced in the field core. A portion of this flux links with the shading coil, which behaves as short – circuited secondary of a transformer.
- A voltage is induced in the shading coil, and this voltage circulates a current in it. The induced

current produces a flux called the induced flux which opposes the main core flux.

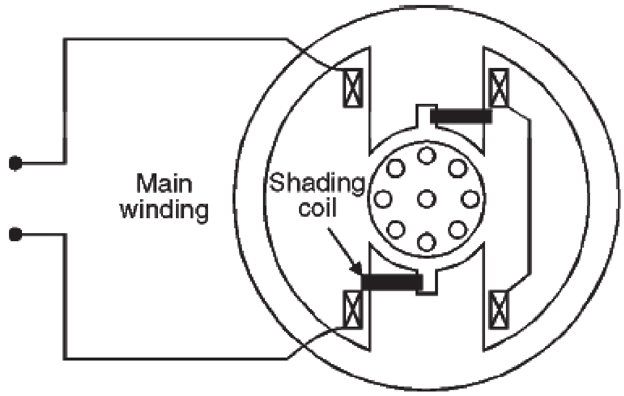


Fig (8-a) Shaded Pole Induction Motor

- The shading coil, thus, causes the flux in the shaded portion to lag behind the flux in the unshaded portion of the pole.
- At the same time, the main flux and the shaded pole flux are displaced in space. This displacement is less than 90^{o}. Since there is time and space displacement between the two fluxes, the conditions for setting up a rotating magnetic field are produced.
- Under the action of the rotating flux a starting torque is developed on the cage rotor. The direction of this rotating field (flux) is from the unshaded to the shaded portion of the pole.

The typical torque-speed characteristic is shown in fig. (8-b).

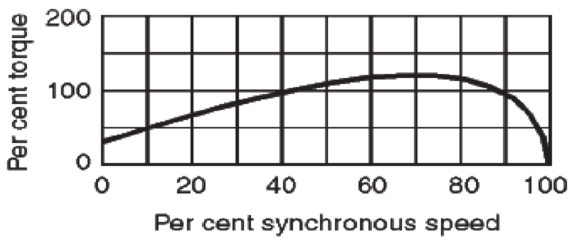


Fig.(8-b) torque – speed characteristic

<u>Characteristic</u>

- The salient features of this motor are extremely simple construction and absence of centrifugal switch
- Since starting torque, efficiency and power factor are very low, these motors are only suitable for low power applications e.g. to drive: Small fans b) toys c) hair driers. The power rating of such motors is up to about 30 W.

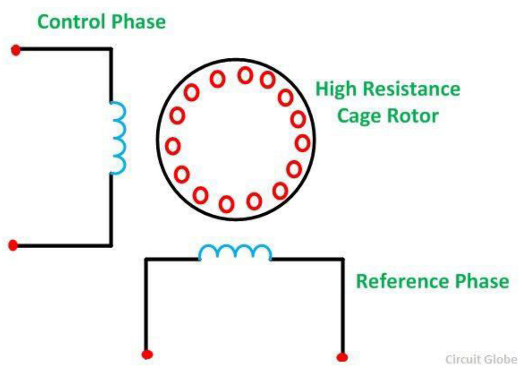
www.Jntufastupdates.com

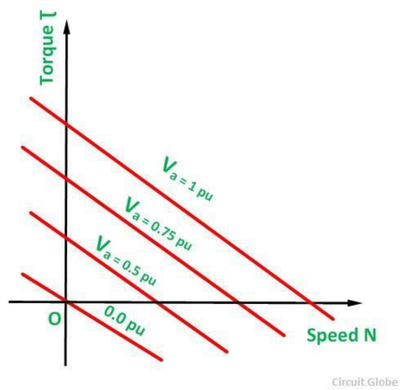
AC SERVO MOTOR

Most of the ac servo motors are of the two – phase squirrel cage induction type and are used for low power applications. However recently three phase induction motors have been modified for high power servo systems which had so far been using high power dc servo motors.

Two – Phase AC Servo motor

- Such motors normally run on a frequency of 60Hz or 400Hz (for airborne systems). The stator has two distributed windings which are displaced from each other by 90^0 (electrical).
- The main winding (also called the reference or fixed phase) is supplied from a constant voltage source $V_m \angle 0^0$.
- The other winding (also called the control phase) is supplied with a variable voltage of the same frequency as the reference phase but is phase – displaced by 90^0 (electrical).
- The control phase voltage is controlled by an electronic controller. The speed and torque of the rotor are controlled by the phase difference between the main and control windings.
- Reversing the phase difference from leading to lagging reverses the motor direction
- Since the rotor bars have high resistance, the torque – speed characteristic for various armature voltages are almost linear over a wide speed range particularly near the zero speed.
- The motor operation can be controlled by varying the voltage of the main phase while keeping that of eh reference phase constant.





11