Two Phase Induction Motors

For low power applications in control system, ac motors are some times used because of their rugged construction. Most ac motors used in control system are of the two phase induction type, which are generally rated from a fraction of a watt upto a few hundred watts i.e., fractional horse power. The frequency of the motor is normally rated at 50, 60, 400, 500, or 1000Hz. The use of high frequency ac actuators is often preferred in airborne system owing to the immunization from noise. More over the size of the motors decreases as the frequency increases.

A schematic of the two phase induction motor is shown in fig. 1. The motor consists of a stator with two distributed windings displaced 90 electrical degrees apart. Under normal operating conditions in control applications, a fixed voltage from a constant voltage source applied to one phase called the fixed or the reference phase.

The other phase called the control phase, is energized by a voltage which is 90 degrees out of phase with respect to the voltage of the reference phase. The control phase voltage is usually supplied from a servo amplifier, and the voltage has a variable amplitude and polarity. The direction of rotation of the motor reverses when the control phase signal Changes its sign. The rotor is squirrel cage or drag-cup type in structure.

Unlike that of a dc motor the torque-speed curve of a two phase induction motor is quite Nonlinear, see Fig. 2. As the reference phase voltage is kept fixed, the motor torque T_m. Is a function of the speed $\dot{\theta}$ and the control phase voltage E and is represented by

$$T_m = f\left(\theta, E\right)$$

Motor Specifications:-

0.2A
220V.
800 rpm.
5W.

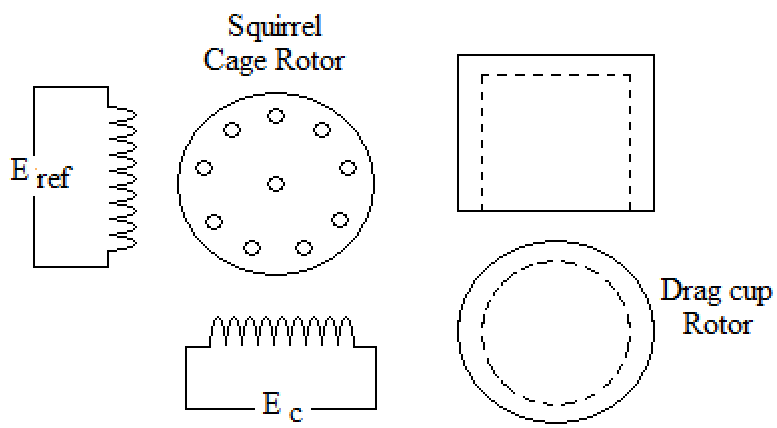


Fig.-1 Two-phase Induction motor

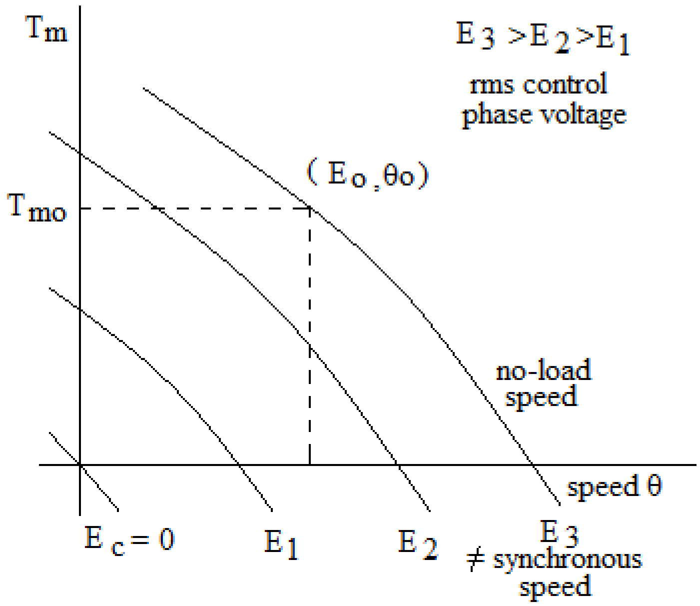


Fig.-2 Speed Torque Charteristics of an ac Servomotor

Let us choose $\left(\theta_0 E_0\right)$ be the operating point of the ac motor and consequently expanding the function f(……) about this point we have.

$$T_m = T_{m0} + \frac{\partial T_m}{\partial E}\bigg|\dot{\theta}_0\ E_0\left(E - E_0\right) + \frac{\partial T_m}{\partial \dot{\theta}}\bigg|\dot{\theta}_0\ E_0\left(\theta - \dot{\theta}_0\right) \tag{1}$$

Where the higher order terms in the Taylor series expansion are neglected. Let

J = movement of inertia of rotor and disc
F = coefficient of viscous friction
T_L = load torque

$$K = \frac{\partial T_m}{\partial E}\bigg|\theta_0\ E_0\dot{\theta}$$

$$f_0 = \frac{\partial T_m}{\partial \dot{\theta}}\dot{\theta}_0\ E_0$$

Then we can write the following equations

$$T_{m0} = J\ddot{\theta}_0 + f\dot{\theta}_0 + T_L \tag{2}$$

$$T_m = J\left(\ddot{\theta}_0 + \Delta\ddot{\theta}\right) + f\left(\theta_0 + \Delta\dot{\theta}\right)T_L \tag{3}$$

In view of (1) – (3), the torque equation in incremental notation can be written as:

$$\Delta T_m = J\Delta\ddot{\theta} + f\Delta\dot{\theta} = K\Delta E - f_0\Delta\dot{\theta}$$

Hence, the incremental motor transfer function is

$$G_M(s) = \frac{\therefore \theta(s)}{\therefore E(s)} = \frac{K}{S\left[sJ + \left(f + f_0\right)\right]}$$

$$= \frac{K_m}{s\left[T_m s + l\right]}$$

Where

$$K_m = \frac{K}{f + f_0}, T_m = \frac{J}{f + f_0}$$

For linear analysis however the torque – speed curves of a two phase induction motor are approximated by straight lines, such as those shown in Fig. 3. These curves are assumed to be straight lines parallel to the torque – speed curve at a rated control volts i.e., $E_{ref} = E_{control} =$ rated value and they are equally spaced for equal increments of the control voltage. Under these condition we have

$$K = \frac{bocked\ rotor\ torque\ at\ E_0}{rated\ control\ voltage\ E_0}$$ at constant voltage

$$f_0 = \frac{blocked\ rotor\ torque}{no\ load\ speed}$$ at rated control speed

We note that f_0 is positive for a negative slope but it is negative for a positive slope. In the letter case $f + f_0$ may become negative making the system unstable. That is why convention induction motor is unsuitable for servo motor.

Experimental Determination of Incremental transfer Function

The readings for the torque – speed characteristics for three control phase voltages E_C are tabulated as given below.

Reference phase voltage E_{ref} =220V.

E_C = 220V		E_C = 200V		E_C = 180V	
Rpm	Weight (gms)	Rpm	Weight (gms)	Rpm	Weight (gms)
918	20	914	20	913	20
891	40	885	40	880	40
880	50	856	60	769	90
854	70	819	80	754	100
820	100	792	100	739	110
796	120	760	120	718	120
771	140	741	140	697	130
748	160	699	155	662	150
734	180	720	145	643	160
715	200			634	170

Given

J (moment of inertia of the motor and disc) = 7.64 x 10^{-4} kg.m^2

F (coeff. of viscous friction) = 1.45 x 10^{-4} N-m/rad/sec

T_m (motor torque) = 1.875 W. gm – cms

W = counter weights placed on the scale pan

Incremental Transfer function at the operation point P, see. Fig. 4.

P: ($\dot{\theta}$ = 735 rpm, T_m = 187.5 gm.wt.-cm)

We know,

1 rpm = $2\pi / 60\ rad/\sec$

1 kg. wt. = 9.81 N

1 gm. wt. -cm = 10^{-3} kg. wt. –cm

= 10^{-5} Kg. wt. –cm

= 9.81 x 10^{-5} N – m

At the operating point P

Change in T_m = 20 x 1.875 gm. wt –cm for a

Change in speed = -23 rpm at constant E_c = 200V

And

change in T_m = 22 x 1.875 gm. wt. cm for a cha

change in control phase voltage E_c = 40V at constant speed 792 rpm

Therefore

$$-f_0 = \frac{20 \times 1.875}{-23} \frac{gm.wt.-cm}{rmp} = 15.268 \times 10^{-4} N-m/rad/\sec$$

$$K = \frac{22 \times 1.875}{40} \frac{gm.wt. - cm}{volt} = 1.012 \times 10^{-4} N - m / volt$$

Hence,

$$\text{Km (motor gain constant)} = \frac{1.012 \times 10^{-4}}{16.718 \times 10^{-4}}$$

= 0.0605 rad/sec/volt

$$\text{Tm (motor time constant)} = \frac{J}{f + f_0} = \frac{7.64 \times 10^{-4}}{16.718 \times 10^{-4}} \frac{kg.m^2}{N - m / rad / \sec} N - m / rad / \sec$$

= 0.457 sec,

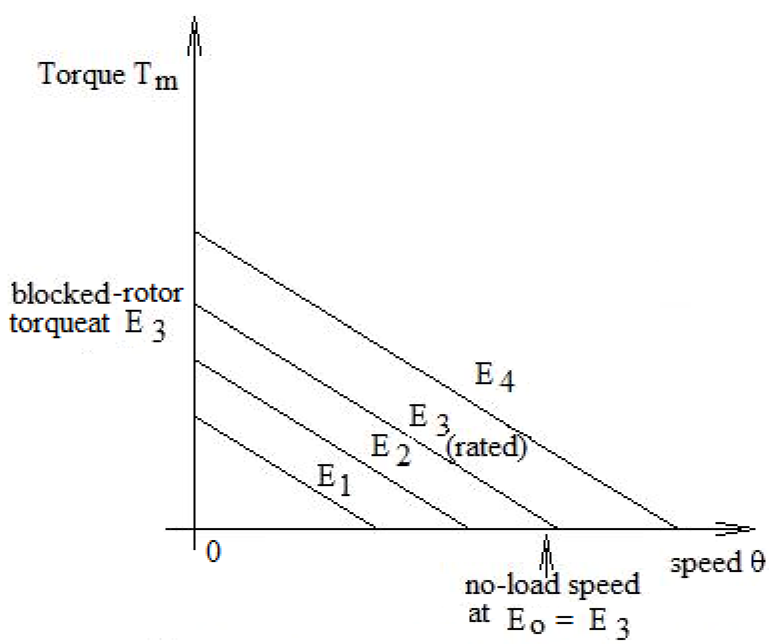
Since,

$$f = f_0 = (1.45 + 15.268) \times 10^{-4} = 16.718 \times 10^{-4} N - m / rad / \sec.$$

Consequently the incremental Transfer Function of the ac servomotor at the operating point P is

$$C_M(s) = \frac{0.0605}{s(0.457s + 1)}$$

Other operating points may be selected and the incremental transfer functions may be determined according to the procedure given above. The incremental transfer function is not a constant transfer function for this servomotor but depends on the operating point in which it is in operation.



Torque – Speed Characteristics of A Two Phase Servomotor and Its transfer Function

Introduction

An a.c. servomotor is a two phase induction motor of squirrel cage rotor. The schematic diagram of such a motor is shown in Fig. 1. In Fig. 2 typical speed -torque characteristics of such a motor are shown. The torque is large at zero speed to aid in servo static sensitivity and the slope of the characteristics is negative throughout the operating region to prevent single phasing of the servomotor. This is accomplished in an induction motor by building the rotor with a high resistance.

The above characteristics at different control winding voltages can be obtain either from a load test or may be predetermined from the equivalent circuit of the servomotor. The description of the special equipment that are used and the experimental procedure are given below.

Special Equipment

In order to conduct load test on a servomotor and to conduct no load and blocked rotor test on it the following special equipment are required.

1. Induction regu1ator to supply variable phase voltage to the control winding of the servomotor.
2. Special eddy current braking arrangement and a balance system to measure small torques of an A.C. servomotor.
3. Special Non- contact Type tachometer to measure the speed of the servomotor.
4. Multa-V-phi meter to measure the small currents and small power in a servomotor.

The above equipment is described one by one briefly below:-

Induction Regulator

The construction of the induction regulator is similar to that of a would rotor induction motor. The rotor winding terminals are brought out and can be connected to any load such as the control winding or reference winding of the servomotor. The three phase distributed winding on the stator is supplied with a three phase balanced supply of voltages. Hence a rotating magnetic field is developed and sweeps across the 3 phase rotor windings distributed along the rotor slots since the rotor windings are open and the speed of the rotating magnetic field is same as the synchronous speed, 3 phase balanced voltages of mains frequency are induced across the rotor terminals. The phase angle of the secondary voltages with respect to the primary voltages can be varied by varying the position of the rotor winding axes with respect to the stator winding axes, for which there is an arrangement in the induction regulator.

Loading Arrangement of A Servomotor

A thin aluminum disc is attached to the shaft of the servomotor. This disc is made to rotate in the air gap of an electromagnetic as shown in Fig. 3. As the aluminum disc rotates in the magnetic field produced by the electromagnet, a braking torque is produced on it because of the eddy currents induced in it. The magnitude of the braking torque can be varied by varying the D.C. current flowing in the winding of the electromagnet. The electromagnet is suspended from a special lever and ball bearing arrangement as shown in Fig. 3. When the disc rotates in one direction the electromagnet tries to deflect in the opposite direction. By adding weights in the pan attached to one of the lever arms, the magnet can be brought back to its original position. The deflection of the electromagnet from its original position and back to the position can be checked by the spirit level attached on the top of the magnet.

Speed Measuring Arrangement

The speed of the servomotor varies (i) as the braking torque applied is varied and (ii) as the voltage applied to the control winding is varied. The speed to be measured may be anywhere in the range of 0 to 90° of the synchronous speed of the motor. Usual contact type tachometer can not be used in order to measure the speed of fractional horse power motors. Stroboscopes can not be used for speed below 300 rpm. Therefore a special non-contact type tachometer making use of digital and analogue electronic circuits is used in this experiment.

In this non-contact type tachometer, another light aluminum disc is attached to the other side of the shaft of the servomotor. Eight holes are made at equal distances circumferentially on the disc. A photo transistor and a light source are arranged on other side of the disc. The photo Transistor and the light sources are aligned with the holes in the disc. When the disc is rotating the photo transistor receives 8 pulses of light per each revolution of the shaft of the servomotor. These pulses are converted in to electrical pulses by the photo transistor. The out put pulses from the photo transistor are properly shaped to rectangular pulses of definite duration and height by a schmitt's trigger circuit. These electric pulses are fed to the input terminals of the Diode-Pump Integrator. The out put voltage of this integrator is proportional to the input pulse rote and hence to the speed of the servomotor. A high resistance moving coil voltmeter or a D.C. V.T.V.M. can be used to measure this voltage and can rotated directly in terms of rpm of the motor.

Multa-V-Phi Meter

An A.C. servomotor is generally a fractional horse power motor. In order to measure the input power to the control winding and reference winding under no load and blocked rotor conditions a special instrument which works on null- balancing principle is used so as to measure the active component of the winding current. This instrument can also be used to measure the total current drawn by the winding as well as voltage applied across it by properly setting the selector switch on it. Hence this instrument is called as Multa-V-phi meter.

Experimental Procedure

1. Connect the Induction regulator, servomotor and the two Multa-V-phi meters as shown in Fig. 5. (2) Check the input 3 phase voltage to the induction regulator whether it is balanced or not.

2. If the input voltage to the regulator is balanced, then only the magnitude of the secondary voltage is constant for all positions of the rotor.
3. Measure the input voltage to the reference winding of the servomotor by keeping the selector switch of the Multa-V-Phi meter in proper voltage ranges. The reference winding is directly connected to one phase of the secondary of the induction regulator. Hence the voltage across the reference winding is constant.
4. Increase the voltage applied to the control winding of the servomotor to the rated value. The control winding voltage can be measured with the help of the second Multa-V-Phi meter connected in that phase. The voltage across the control winding can be adjusted to the required value because it is connected across a variac. The input to the variac is same as the corresponding phase voltage of the primary of the induction regulator.
5. Adjust the phase of the reference voltage to be 90° with respect to the control voltage with the help of rotor position setting mechanism of the induction regulator. The 90° position can be recognized by the maximum speed of the servomotor as the rotor is rotated.
6. Measure the no-load speed and power input to both the winding of the servomotor with the help of the tachometer and Multa-V-Phi meters respectively.
7. Load the servomotor by increasing the D.C. current in the electromagnet. The magnet deflect from its original position; which can be brought back by adding weights in the pan. Note down the weights added to balance the sprit level to its undeflected position. Note down the speed of the servomotor with the help of the tachometer.
8. Vary the control voltage to 0.8 times the rated value with the help of the variac and repeat the above procedure of noting down the weights in the pan and the speed. Likewise one can repeat the loading at various, voltages of $0.6V_R$, $0.4V_R$, $0.2V_R$ etc. The loading of the motor should be carried until the servomotor stalls, but if the electromagnet is not powerful enough one can not do this. Therefore the blocked rotor power input the motor windings can be noted by holding the rotor with the help of an handkerchief.

Observation & Calculation

Tabulate the various observations as follows

Control Winding Voltage V_C = Reference Winding Voltage V_R

S. No	Weight in the Pan W gms.	Speed in rpm N	Control Windings Current I_{RT} & I_{RC}	Reference windings Currents I_{RT} & I

Making use of the weights (W gms) added in the pan to balance the position of the magnet and the lengths of the balance of the balance arms shown in Fig. 3, the torque acting on the servomotor shaft at a given value of the electromagnet current can be calculated by making use of the following formula =

$$W \times 1_2 = F \times I_1 \quad \text{...} \quad (1)$$

$$T = F \times a \quad \text{...} \quad (2)$$

In the instrument available in the laboratory 1_2 = 15 cms, 1_1 = 32 cms, and a = 4 cms,

Hence $T = \left(W \times 15 \times 4\right)/32 = 1.875\,W \;\; gm.\,cm$ .... (3)

Since the rpm of the motor corresponding to each load torque is known at given control voltage, the torque – speed characteristics at various control voltage (Fig. 2) can be drawn.

Relationship between the Torque – Speed Characteristics and the Transfer Function of the Servomotor

As it can be seen the torque-speed characteristics are essentially non-linear except at very low control voltage, but it can be noticed from the characteristics, they are almost linear in the vicinity of stalling torque. Usually a servomotor operates at these low speeds region. But another non-linear feature of these characteristics is that they are not parallel to each other. This indicates that at a constant load torque the speed is not directly proportional to the control voltage applied. Therefore in order to derive a transfer function relating the speed of the servomotor or the out put shaft position of it and the control voltage the following assumptions are to be made.

1. "All the torque -speed control characteristics are straight lines parallel to the characteristic at rated voltage. ($V_{CR} = V_R$)".
2. "They are equally spaced torque decrements of control voltage," with the above assumptions the torque-speed characteristics can mathematically be represented by Eq. (4) given below.

$$T = m\left(d\theta m / dt\right) + kV_C \quad \text{...} \quad (4)$$

Where, m = slope of the torque – speed characteristics and is given by

$$= \frac{-Blocked\ rotor\ Torque}{No\ load\ speed} \frac{-T_0}{N_0} \quad \text{..} \quad (5)$$

k = Intercept per unit control voltage of the torque speed characteristics on the Torque axis.

$$= \frac{Blocked\ rotor\ torque\ at\ rated\ control\ voltage}{Rated\ control\ voltage} = \frac{T_{oR}}{V_C} \quad \text{..............} \quad (6)$$

When the control voltage is varied form one value to other, the speed of the servomotor and hence the output shaft position (θ) of the servomotor varies the Eq. (7)

$$T_m = J_m\left(d^2\theta_m / dt^2\right) + f_m d\theta_m / dt \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots... \quad (7)$$

Equating the rhs of the Eqns. (4) & (7) and taking the Laplace transform on both sides;

$$\beta_m\left(\theta_m(s)\right) + kV_c(s) = \left(J_m s^2 + f_m s\right)\theta_m(s) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (8)$$

From the above equation the Transfer function relating the output shaft position of the servomotor and the voltage applied to its control winding is given by equation (9).

$$\frac{\theta_m(s)}{V_C(s)} = \frac{\textit{Motor shaft displacement}}{\textit{control phase voltage}} = \frac{k}{(f_m - m)s\left(1 + s\dfrac{j_m}{f_m - m}\right)}$$

or

$$\frac{\theta_m(s)}{V_C(s)} = \frac{K}{s(1 + sJ_m)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (9)$$

Where, K = motor gain constant $= \dfrac{K}{(f_m - M)}$ $\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots...$ (10)

And τ_m = motor time constant = $\dfrac{J_m}{(f_m - m)}$ $\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$ (11)

The moment of Inertia (J_m) and Viscous friction coefficient (f_m) of motor have to be determined by Retardation test on the motor.

The torque speed characteristics could have been determined form the equivalent circuit of the servomotor. For this the no-load and blocked rotor test reading of power input to the windings and current drawn by the windings at rated voltage have to be considered. The procedure can be obtained from Ref (3).

Reference

1. B.C. Kuo, "Automatic Control System" Prentice Hall Asian Edition 1963.
2. Fitgerald & Kingsley "Electric Machinery" Mc grew hill Book Company, Second Edition 1960.
3. Gibson, J.E. & F.B. Tuteur, "Control System C

International Student Edition, Mc graw Hill 1958

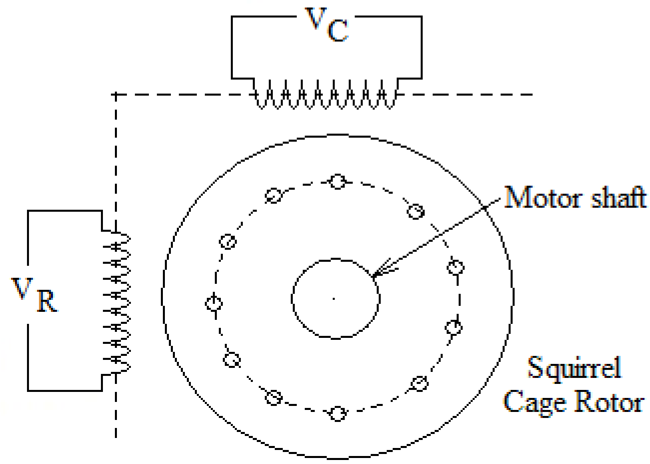
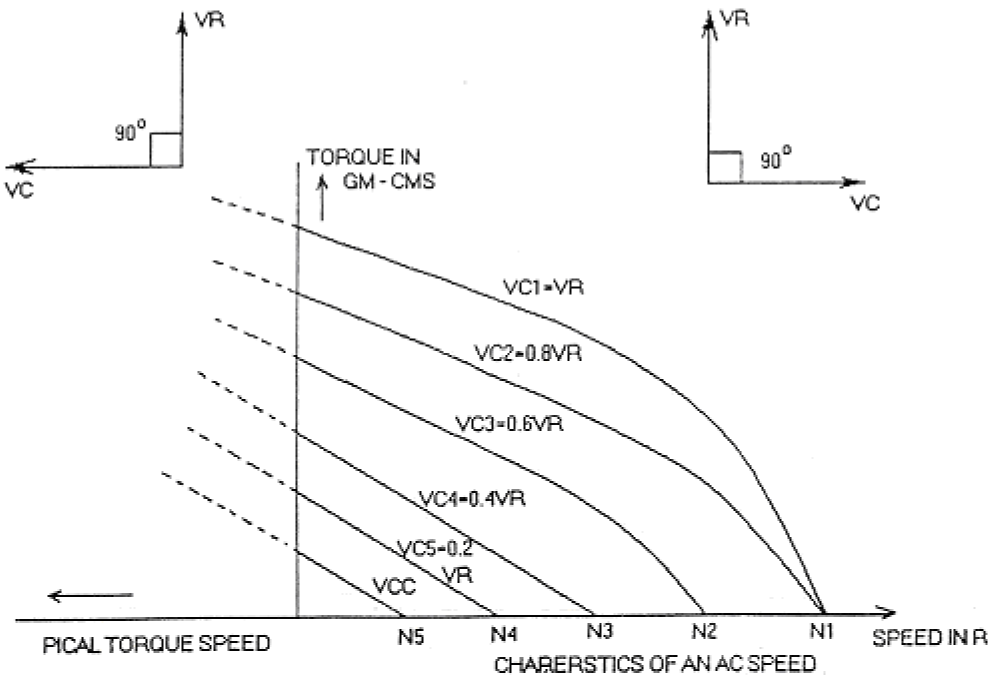


Fig.-1 Schematic diagram of a two phase servo motor



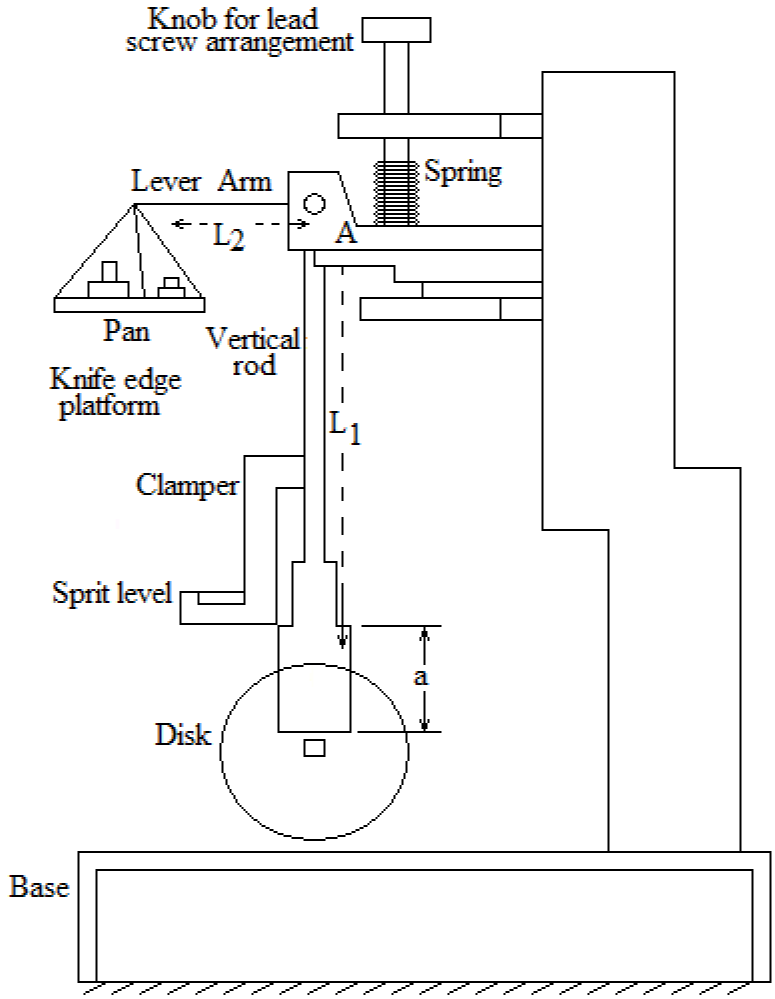


Fig.-3 LOADING ARRANGEMENT OF A SERVO MOTOR
(A) SIDE VIEW OF THE TORQUE MEASURING DEVICE

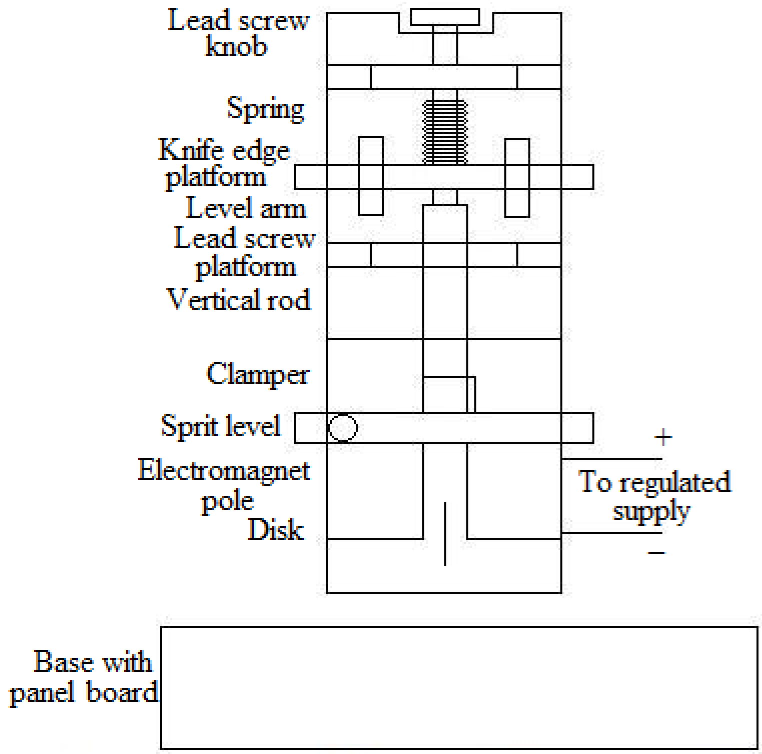


Fig.-3 LOADING ARRANGEMENT OF A SERVO MOTOR
(B) FRONT VIEW OF THE TORQUE MEASURING DEVICE

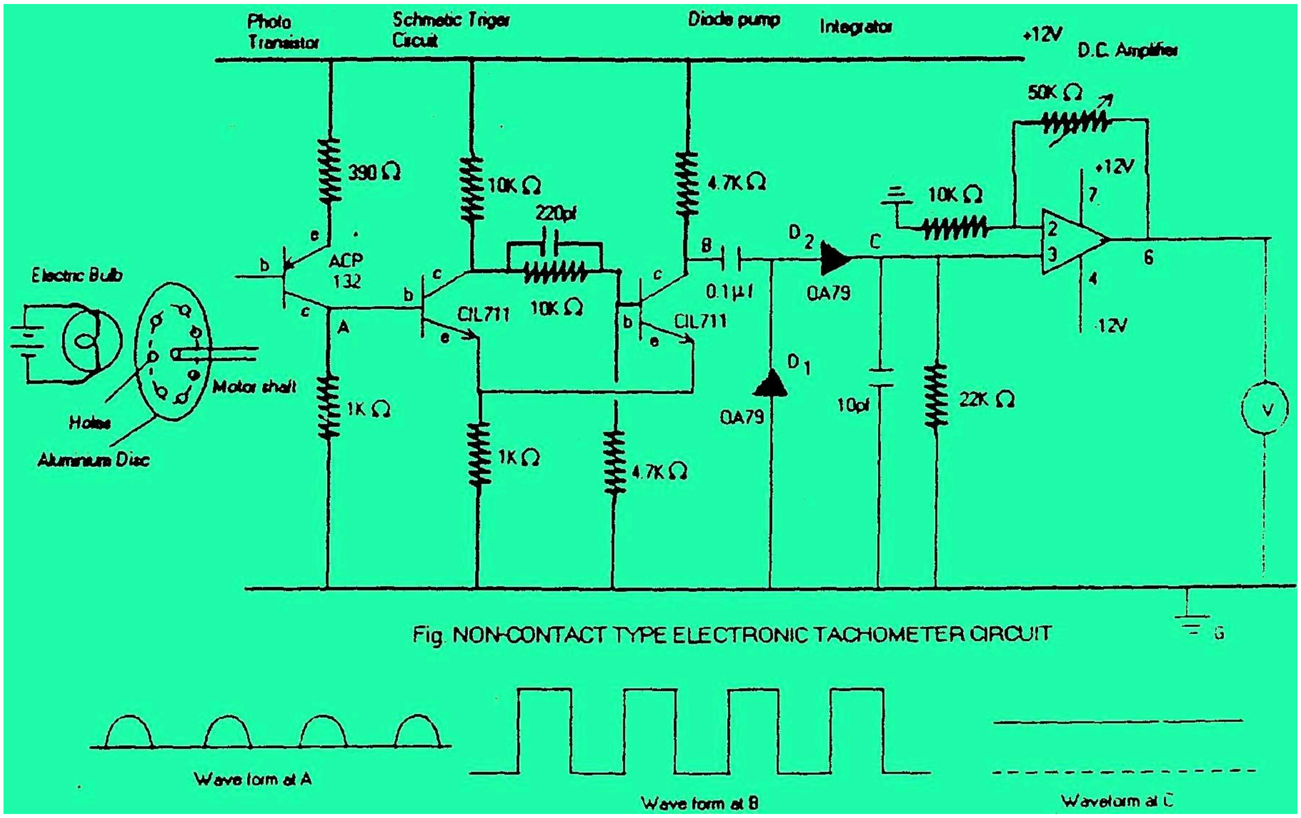
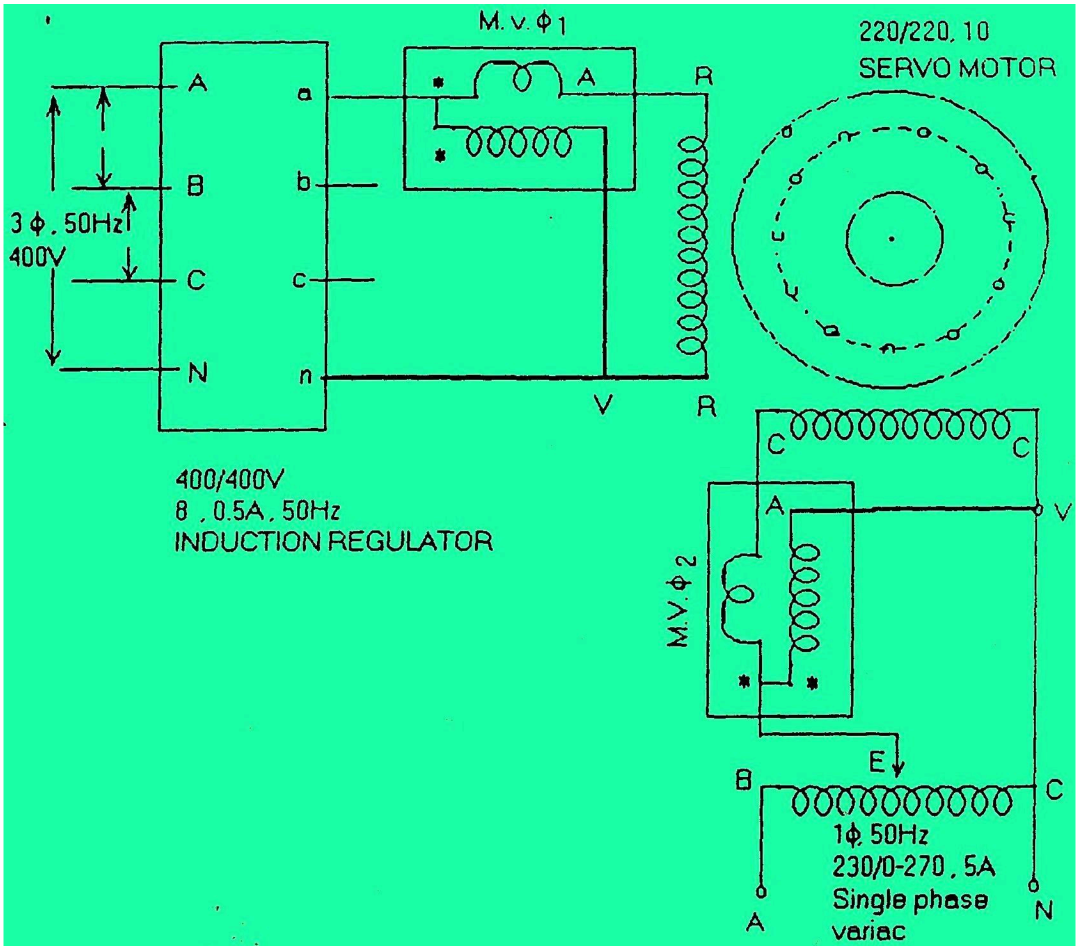
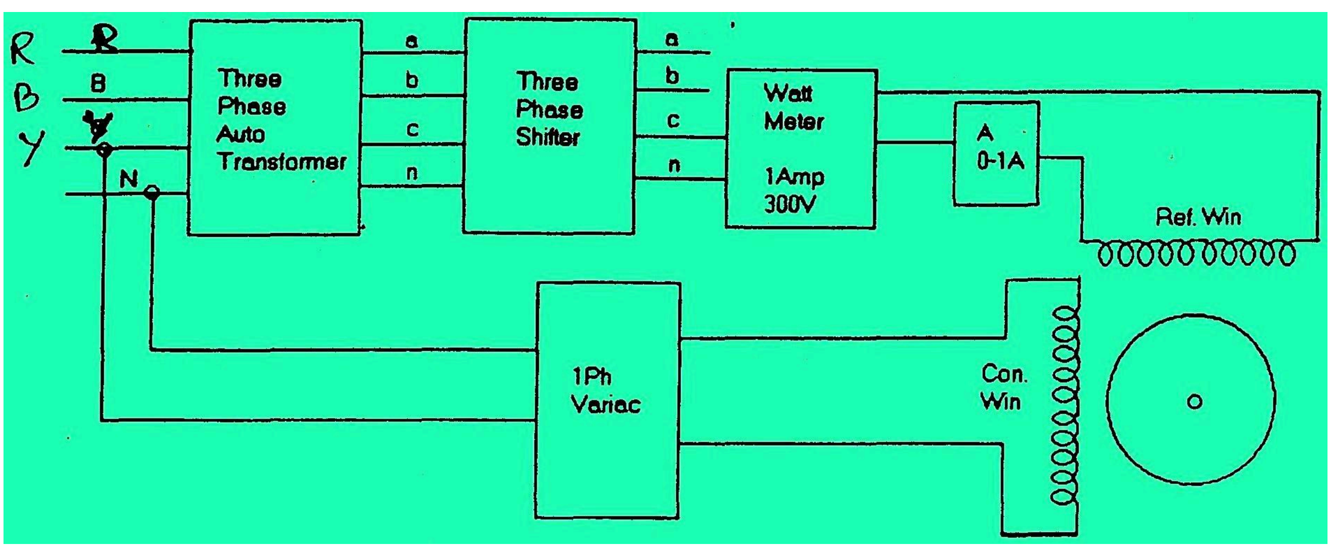


Fig. NON-CONTACT TYPE ELECTRONIC TACHOMETER CIRCUIT


M.v.ϕ1
220/220, 10
SERVO MOTOR
A
B
C
N
a
b
c
n
3 ϕ, 50Hz
400V
A
R
V
R
400/400V
8 , 0.5A, 50Hz
INDUCTION REGULATOR
C
C
A
V
M.V.ϕ2
E
B
C
1ϕ, 50Hz
230/0-270, 5A
Single phase
variac
A
N


R
B
Y
R
B
Y
N
Three
Phase
Auto
Transformer
a
b
c
n
Three
Phase
Shifter
a
b
c
n
Watt
Meter
1Amp
300V
A
0-1A
Ref. Win
1Ph
Variac
Con.
Win

Control System Laboratory
Department of Electrical Engineering
IIT, Kharagpur.

Introduction

The speed-torque curves at unbalanced voltages of an ac servomotor can be determined with the equivalent circuit parameters, Ref. J.E. Gibson and Tuteur, Control system components, Mcgrew -hill, 1963. pp. 281-291. The quasi –linear transfer functional about an operating point with a range of input and output variation small enough can be obtained from this torque-speed curve. The only experimental part is to determined the equivalent circuit from no load blocked-rotor test of the servomotor.

The connecting diagram of the experiments shown in Fig. 1

Apparatus:

(i). 3 phase Auto- Transformer.
(ii). 1 phase Auto -Transformer.
(iii). 3 phase shifter.
(iv). Ammeter
(v). watt meter.
(vi). Non contact type Tachometer.
(vii). Weights.