

**Dronacharya Group of Institutions Greater Noida**  
**Department of Electrical and Electronics**

**Control System Lab Manual (EEE – 552)**

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**Expt. No: 1**

**DETERMINATION OF TRANSFER FUNCTION OF  
AC SERVO MOTOR**

**AIM:**

To derive the transfer function of the given AC Servomotor.

**APPARATUS / INSTRUMENTS REQUIRED:**

S. No	Description	Range	Type	Quantity
1.	AC servo motor trainer kit	-		1
2.	AC servo motor			1
3.	Ammeter	(0-1) A	MC	1
		(0-100) mA	MI	1
4.	Voltmeter	(0-300) V	MC	1
		(0-75) V	MI	1
5.	Patch cords	-		As required

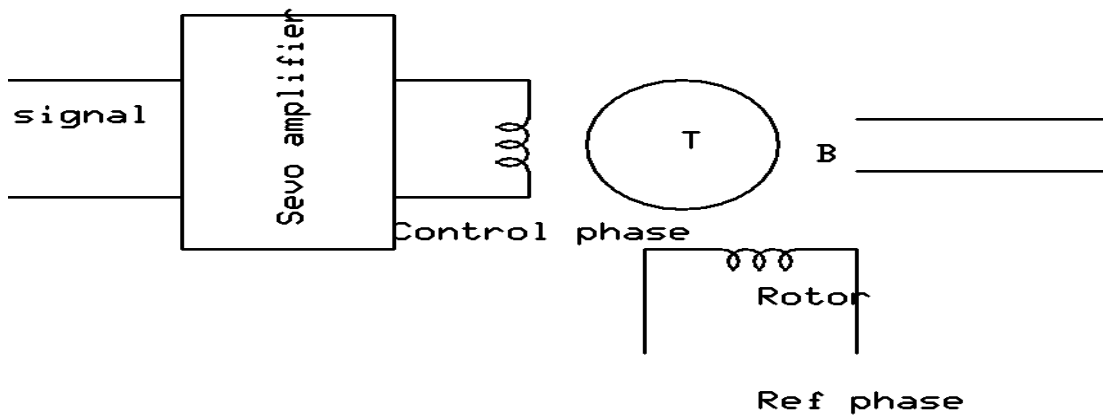
**THEORY:**

An AC servo motor is basically a two phase induction motor with some special design features. The stator consists of two pole pairs (A-B and C-D) mounted on the inner periphery of the stator, such that their axes are at an angle of  $90^\circ$  in space. Each pole pair carries a winding, one winding is called reference winding and other is called a control winding. The exciting current in the winding should have a phase displacement of  $90^\circ$ . The supply used to drive the motor is single phase and so a phase advancing capacitor is connected to one of the phase to produce a phase difference of  $90^\circ$ . The rotor construction is usually squirrel cage or drag-cup type. The rotor bars are placed on the slots and short-circuited at both ends by end rings. The diameter of the rotor is kept small in order to reduce inertia and to obtain good accelerating characteristics. The drag cup construction is employed for very low inertia applications. In this type of construction the rotor will be in the form of hollow cylinder made of aluminium. The aluminium cylinder itself acts as short-circuited rotor conductors. Electrically both the types of rotor are identical.

**WORKING PRINCIPLE :**

The stator windings are excited by voltages of equal magnitude and  $90^\circ$  phase difference. These results in exciting currents  $i_1$  and  $i_2$  that are phase displaced by  $90^\circ$  and have equal values. These currents give rise to a rotating magnetic field of constant magnitude. The direction of rotation depends on the phase relationship of the two currents (or voltages). This rotating magnetic field sweeps over the rotor conductors. The rotor conductor experience a change in flux and so voltages are induced rotor conductors. This voltage circulates currents in the short-circuited rotor conductors and currents create rotor flux. Due to the interaction of stator & rotor flux, a mechanical force (or torque) is developed on the rotor and so the rotor starts moving in the same direction as that of rotating magnetic field.

**GENERAL SCHEMATIC OF AC SERVOMOTOR:**



**FORMULAE USED:**

Transfer function,  $G_m(s) = K_m / (1 + s\tau_m)$

Where

Motor gain constant,  $K_m = K / F_O + F$

$K$  is  $\Delta T / \Delta C$

$F_O$  is  $\Delta T / \Delta N$

Torque,  $T$  is  $9.81 \times R (S1 \sim S2)$

$R$  is radius of the rotor in m

Frictional co-efficient,  $F = W / (2\pi N / 60)^2$

Frictional loss,  $W$  is 30 % of constant loss in Watts

Constant loss in watts = No load input – Copper loss

No load i/p =  $V (I_R + I_C)$

$V$  is supply voltage, V

$I_R$  is current through reference winding, A

$I_C$  is current through control winding, A

Copper loss in watts =  $I_C^2 R_C$

$R_C = 174\Omega$

$N$  is rated speed in rpm

Motor time constant,  $\tau_m = J / F_O + F$

Moment of inertia  $J$  is  $\pi d^4 L_R \rho / 32$

$d$  is diameter of the rotor in m ( Given  $d = 39.5$  mm)

$L_R$  is length of the rotor in m (Given  $L_R = 76$  mm)

$\rho$  is density =  $7.8 \times 10^2$  gm / m

**PROCEDURE:**

**1. DETERMINATION OF FRICTIONAL CO-EFFICIENT, F**

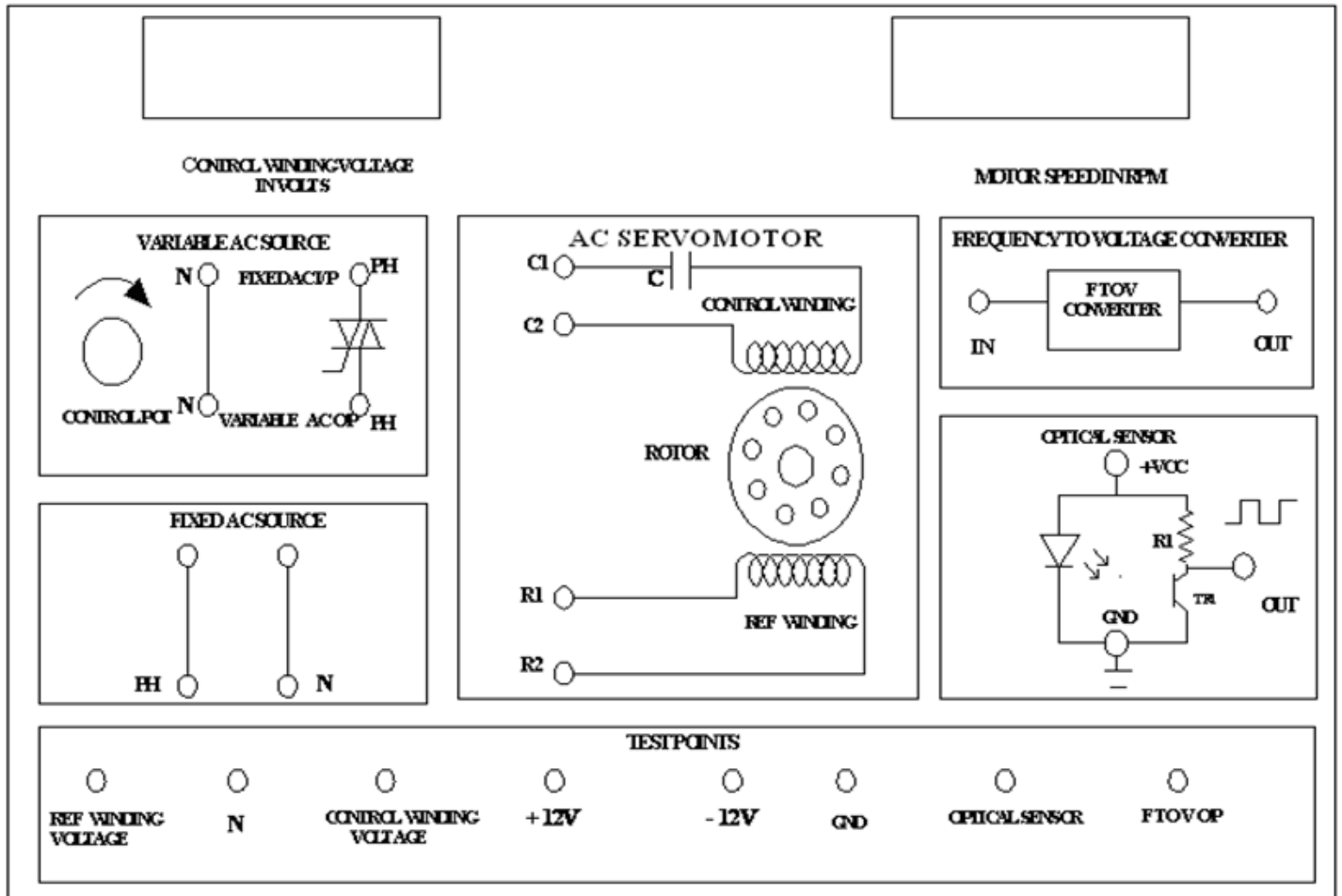
1. Check whether the MCB is in OFF position.
2. Patch the circuit using the patching diagram.
3. Switch ON the MCB
4. Vary the control pot to apply rated supply voltage
5. Note the control winding current, reference winding current, supply voltage and speed.
6. Find the frictional co-efficient using the above values

**OBSERVATIONS:**

<b>S. No.</b>	<b>Supply Voltage V (V)</b>	<b>Control winding Current <math>I_c</math> (A)</b>	<b>Reference Winding Current <math>I_r</math> (A)</b>	<b>Speed N (rpm)</b>

**CALCULATIONS:**

**DETERMINATION OF TRANSFER FUNCTION OF AC SERVO MOTOR  
PATCHING DIAGRAM TO DETERMINE FRICTIONAL CO-EFFICIENT F:**



**PROCEDURE:**

**2. To determine the motor gain constant  $K_m$**

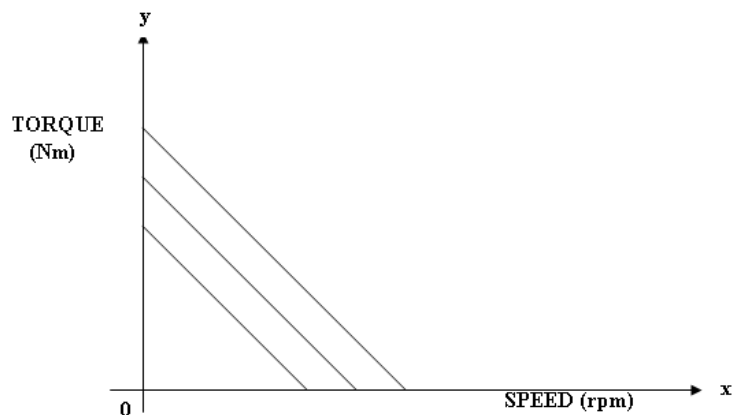
**DETERMINATION OF  $F_o$  FROM TORQUE - SPEED CHARACTERISTICS:**

1. Check whether the MCB is in OFF position.
2. Patch the circuit using the patching diagram.
3. Set the control pot in minimum position.
4. Check whether the motor is in no load condition
5. Switch ON the MCB
6. Vary the control pot and apply rated voltage to the reference phase winding and control phase winding. Note down the no load speed.
7. Apply load in steps. For each load applied note down the speed and spring balance readings. ( Take 3 or 4 sets of readings)
8. Reduce the load fully and allow the motor to run at rated speed.
9. Repeat steps 7 and 8 for 75 % control winding voltage.
10. Draw the graph between speed and torque, the slope of the graph gives  $F_o$ .

**OBSERVATIONS:**

S. No	Control voltage $V_{c1} =$				Control voltage $V_{c2} =$			
	Speed N (rpm)	Spring Balance values		Torque T (Nm)	Speed N (rpm)	Spring Balance values		Torque T (Nm)
		$S_1$ (kg)	$S_2$ (kg)			$S_1$ (kg)	$S_2$ (kg)	

**MODEL GRAPH: TORQUE - SPEED CHARACTERISTICS**



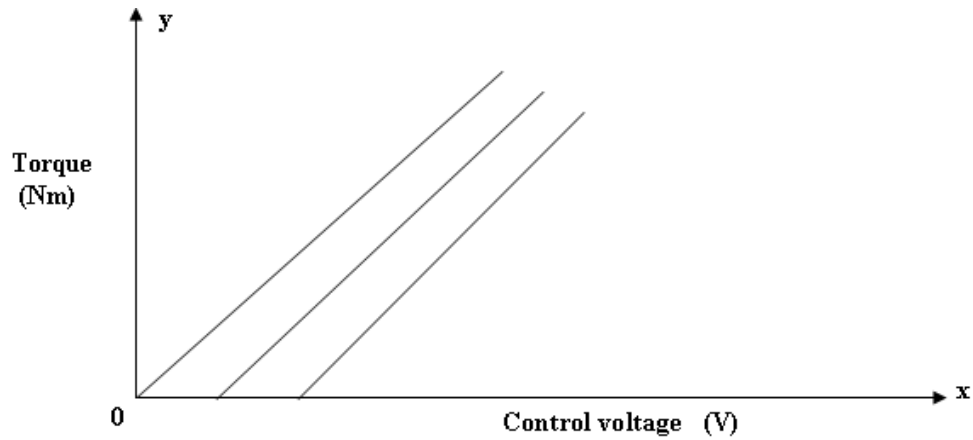
**DETERMINATION OF K FROM TORQUE - CONTROL VOLTAGE CHARACTERISTICS:**

1. Check whether the MCB is in OFF position.
2. Patch the circuit using the patching diagram.
3. Set the control pot in minimum position.
4. Check whether the motor is in no load condition
5. Switch ON the MCB
6. Vary the control pot and apply rated voltage to the reference phase winding and control phase winding. Note down the no load speed.
7. Load the motor gradually; the speed of the motor will decrease. Vary the control pot and increase the control winding voltage till the speed obtained at no load is reached. Note down control voltage and spring balance readings.
8. Repeat step 7 for various speeds and tabulate. (for 1000 rpm)
9. Plot the graph between torque and control winding voltage. The slope of the graph gives the value of K.

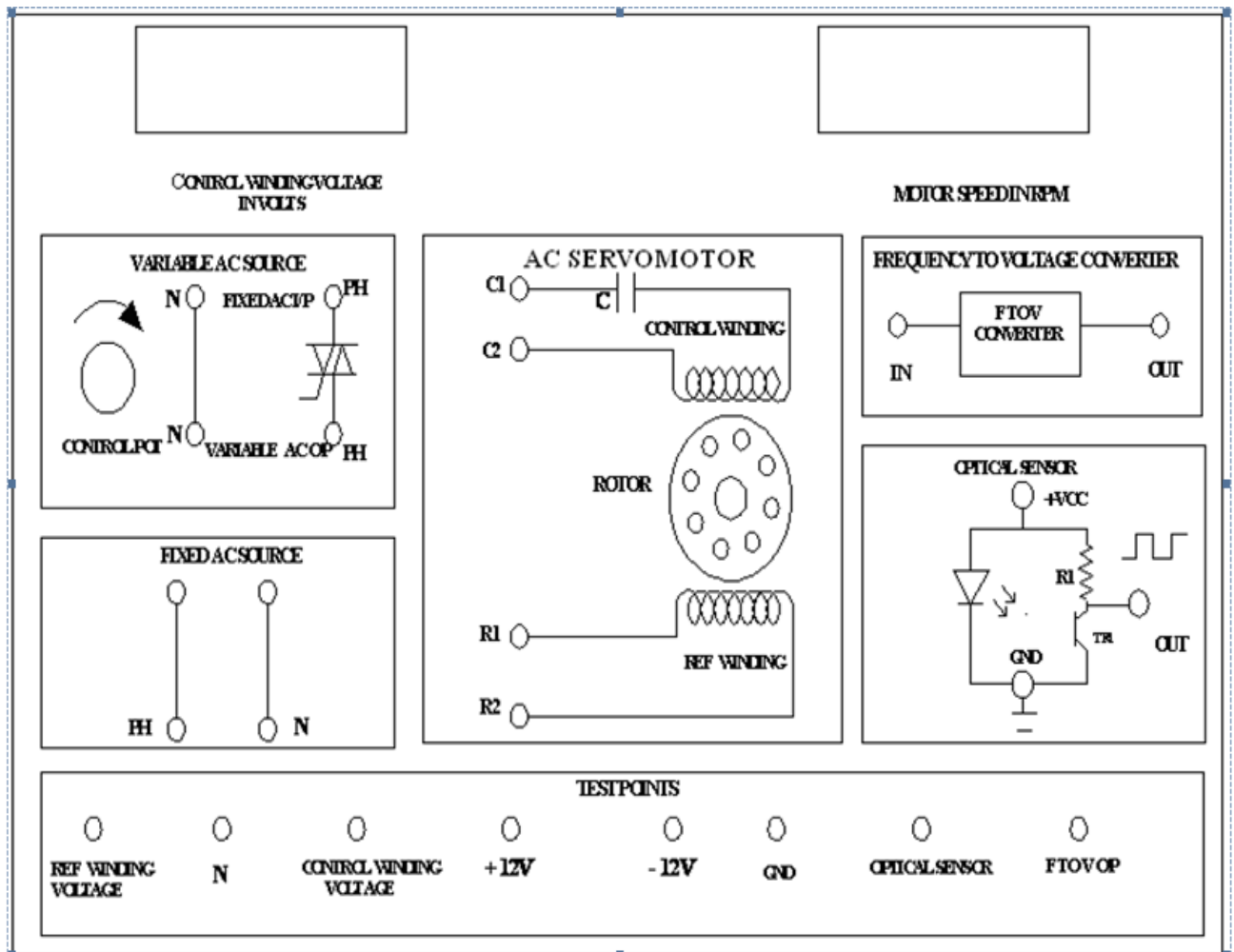
**OBSERVATIONS:**

S. No	Speed $N_1 =$				Speed $N_2 =$			
	Control Voltage $V_c$ (V)	Spring Balance values		Torque T  Nm	Speed  rpm	Spring Balance values		Control Voltage $V_c$ V
		$S_1$ (kg)	$S_2$ kg			$S_1$ $K_g$	$S_2$ $K_g$	

**MODEL GRAPH: TORQUE - CONTROL VOLTAGE CHARACTERISTICS**



**DETERMINATION OF TRANSFER FUNCTION OF AC SERVO MOTOR  
PATCHING DIAGRAM TO DETERMINE MOTOR GAIN CONSTANT  $K_M$ :**





## **CALCULATIONS:**

## **RESULT:**

The transfer function of AC servomotor is determined as

## **VIVA-VOCE QUESTIONS:**

1. What are the main parts of an AC servomotor?
2. State the advantages and disadvantages of an AC servo motor.
3. Give the applications of AC servomotor.
4. What do you mean by servo mechanism?
5. What are the characteristics of an AC servomotor?

**Expt. No: 2**

## **DC POSITION CONTROL SYSTEM**

### **AIM:**

To study the characteristics of a DC position control system.

### **APPARATUS / INSTRUMENTS REQUIRED:**

- i) DC position control kit and Motor unit
- ii) Multimeter

### **THEORY:**

A DC position control system is a closed loop control system in which the position of the mechanical load is controlled with the position of the reference shaft. A pair of potentiometers acts as error-measuring device. They convert the input and output positions into proportional electric signals. The desired position is set on the input potentiometer and the actual position is fed to feedback potentiometer. The difference between the two angular positions generates an error signal, which is amplified and fed to armature circuit of the DC motor. The tachogenerator attached to the motor shaft produces a voltage proportional to the speed which is used for feedback. If an error exists, the motor develops a torque to rotate the output in such a way as to reduce the error to zero. The rotation of the motor stops when the error signal is zero, i.e., when the desired position is reached.

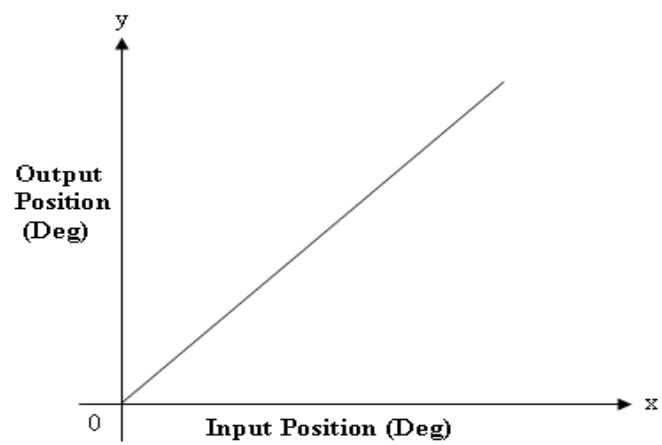
### **PROCEDURE:**

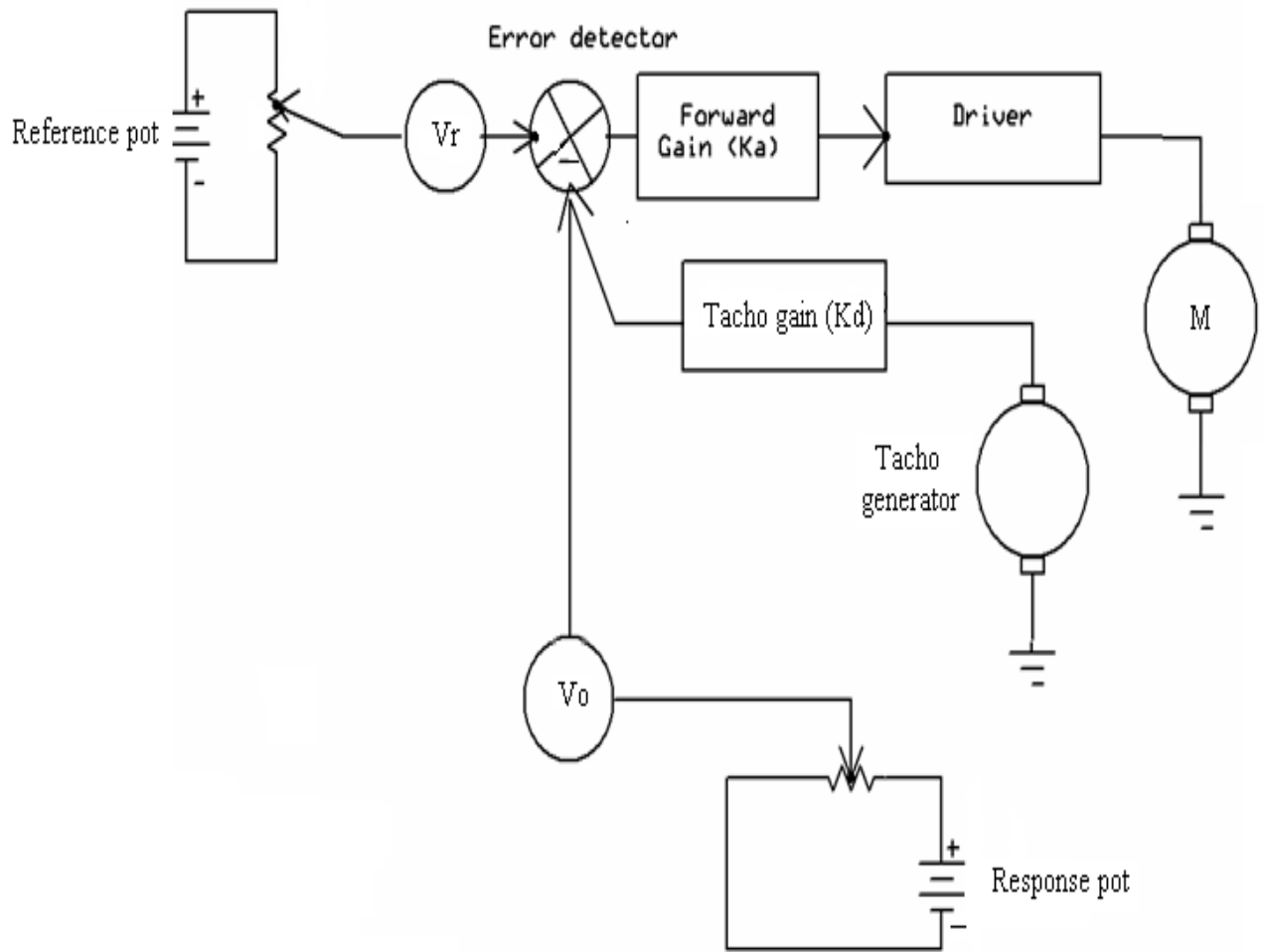
1. The input or reference potentiometer is adjusted nearer to zero initially( $\theta_R$ ).
2. The command switch is kept in continuous mode and some value of forward gain  $K_A$  is selected.
3. For various positions of input potentiometer ( $\theta_R$ ) the positions of the response potentiometer ( $\theta_0$ ) is noted. Simultaneously the reference voltage ( $V_R$ ) measured between the terminals  $V_R$  & E and the output voltage ( $V_O$ ) measured between the terminals  $V_O$  & E are noted.
4. A graph is plotted with  $\theta_0$  along y-axis and  $\theta_R$  along x-axis.

**OBSERVATIONS:**

S. No	Reference angular position, $\theta_R$ (degrees)		Output angular position, $\theta_O$ (degrees)		Reference Voltage, $V_r$ (V)		Output Voltage $V_O$ (V)	
	$K_A =$	$K_A =$	$K_A =$	$K_A =$	$K_A =$	$K_A =$	$K_A =$	$K_A =$

**MODEL GRAPH:**





**RESULT:**

The DC position control system characteristics are studied and corresponding graphs are drawn.

**Expt. No:3**

**DETERMINATION OF TRANSFER FUNCTION OF  
SEPARATELY EXCITED DC GENERATOR**

**AIM:**

To obtain the transfer function of separately excited DC generator on no load and loaded condition.

**APPARATUS / INSTRUMENTS REQUIRED:**

S. No	Description	Range	Type	Quantity

**THEORY:**

Derivation of transfer function of separately excited DC generator is as follows,

Applying KVL to the field side,

$$e_f = R_f i_f + L_f (di_f / dt) \quad \dots (1)$$

Applying KVL to the armature side,

$$e_g = R_a i_a + L_a (di_a / dt) + R_L i_a \quad \dots (2)$$

$$V_L = R_L i_a \quad \dots (3)$$

$$\text{Also since } e_g \propto i_f, \text{ let } e_g = K_g i_f \quad \dots (4)$$

Taking Laplace transform of equation (1) we get

$$E_f(s) = R_f I_f(s) + sL_f I_f(s)$$

$$E_f(s) = I_f(s) [R_f + sL_f]$$

$$I_f(s) = E_f(s) / [R_f + sL_f] \quad \dots (5)$$

Taking Laplace transform of equation (2) we get

$$E_g(s) = R_a I_a(s) + sL_a I_a(s) + R_L I_a(s)$$

$$E_g(s) = I_a(s) [R_a + sL_a + R_L] \quad \dots (6)$$

Taking Laplace transform of equations (3) and (4) we get

$$V_L(s) = R_L I_a(s)$$

Therefore,  $I_a(s) = V_L(s) / R_L \quad \dots (7)$

$$E_g(s) = K_g I_f(s) \quad \dots (8)$$

Substituting equations (7) and (8) in equation (6) we get

$$K_g I_f(s) = [R_a + sL_a + R_L] [V_L(s) / R_L] \quad \dots (9)$$

Substituting the value of  $I_f(s)$  in the above equation we get

$$K_g E_f(s) / [R_f + sL_f] = [R_a + sL_a + R_L] [V_L(s) / R_L]$$

Hence transfer function,

$$V_L(s) / E_f(s) = K_g R_L / \{[R_f + sL_f] [R_a + sL_a + R_L]\} \quad \dots(10)$$

For unloaded condition,  $I_a = 0$

$$\text{Therefore transfer function } V_L(s) / E_f(s) = K_g / [R_f + sL_f] \quad \dots (11)$$

For loaded condition

$$L_f = \sqrt{(Z_f^2 - R_f^2)} / 2\pi f$$

$$L_a = \sqrt{(Z_a^2 - R_a^2)} / 2\pi f$$

$$\text{Transfer function } V_L(s) / E_f(s) = K_g R_L / [R_f(R_a + R_L) (1+s\tau_f) (1 + s\tau_a)] \quad \dots (12)$$

where  $\tau_f = L_f / R_f$  and  $\tau_a = L_a / (R_a + R_L)$

### FORMULAE USED:

Transfer function of DC generator,

**On no load condition:**  $V_L(s) / E_f(s) = K_g / [R_f + sL_f]$

where  $K_g$  is gain constant

$R_f$  is field resistance in Ohms

$L_f$  is field inductance in Henry

**On loaded condition:**  $V_L(s) / E_f(s) = K_g R_L / [R_f(R_a + R_L) (1+s\tau_f) (1 + s\tau_a)]$

where  $K_g$  is gain constant

Field time constant  $\tau_f = L_f / R_f$

$R_f$  is field resistance in Ohms

$L_f$  is field inductance in Henry

Armature time constant  $\tau_a = L_a / (R_a + R_L)$

$R_a$  is armature resistance in Ohms

$L_a$  is armature inductance in Henry

**PROCEDURE:**

**1. To determine the gain constant  $K_g$  :**

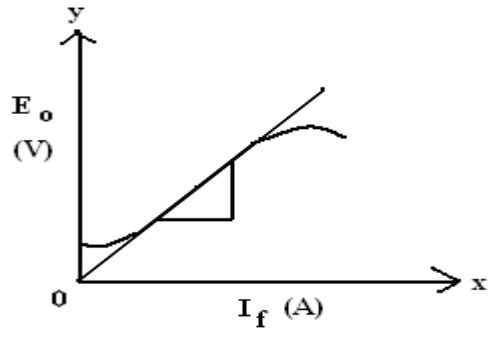
**No load or open circuit characteristics:**

1. Connections are made as shown in the circuit diagram
2. The motor field rheostat should be in **minimum resistance** position and the generator field rheostat should be in **maximum resistance position or minimum potential position** while switching ON and switching OFF the supply side DPST switch.
3. Ensure that the DPST switch on the load side is open.
4. Switch ON the supply DPST switch.
5. Using the 3- point starter the DC motor is started and it is brought to rated speed by adjusting the motor field rheostat.
6. Keeping the DPST switch on the load side open, the generated voltage  $E_g$  and field current  $I_f$  of generator is noted down by varying the generator field rheostat.
7. The above step is repeated till 125 % of rated voltage is reached.
8. A graph is plotted between  $E_g$  and  $I_f$  taking  $I_f$  along x- axis. A tangent to the linear portion of the curve is drawn from the origin and slope of this line gives  $K_g$ .

**OBSERVATIONS:**

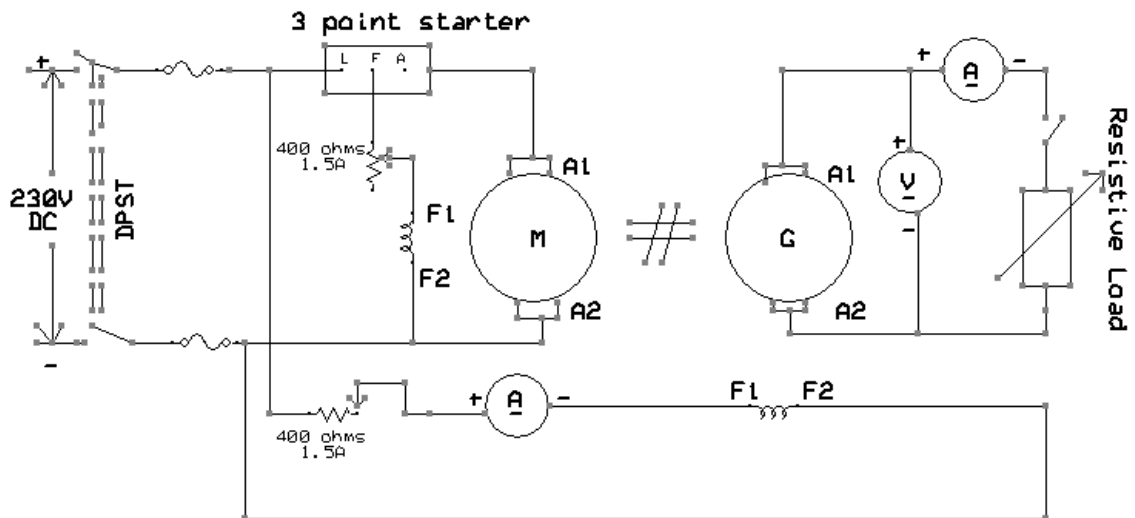
S. No.	Field current, $I_f$ (A)	Induced Voltage, $E_g$ (V)

**MODEL GRAPH:**



**CIRCUIT DIAGRAM:**

To determine gain constant,  $K_g$ :



**CALCULATIONS:**

**Load characteristics:**

1. Connections are made as shown in the circuit diagram
2. The motor field rheostat should be in **minimum resistance** position and the generator field rheostat should be in **maximum resistance position or minimum potential position** while switching ON and switching OFF the supply side DPST switch.
3. Ensure that the DPST switch on the load side is open.

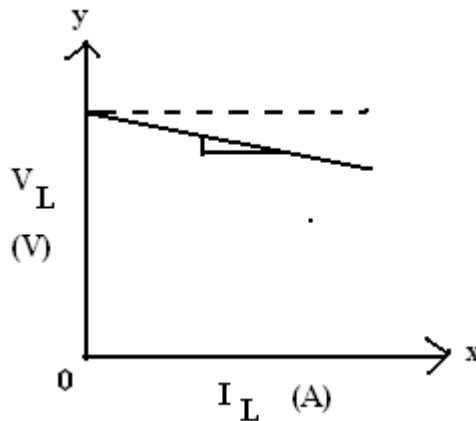


4. Switch ON the supply DPST switch
5. The generator is brought to its rated voltage by varying the generator field rheostat.
6. The DPST switch on the load side is closed, and the load is varied for convenient steps of load current up to 120 % of its rated capacity and the voltmeter  $V_L$  and ammeter  $I_a$  readings are observed. On each loading the speed should be maintained at rated speed.
7. A graph is plotted between  $V_L$  and  $I_L$  taking  $I_L$  on x- axis. The slope of the graph gives  $K_g$ .

**OBSERVATIONS:**

S. No.	Terminal Voltage, $V_L$ (V)	Load Current, $I_L$ (A)

**MODEL GRAPH:**



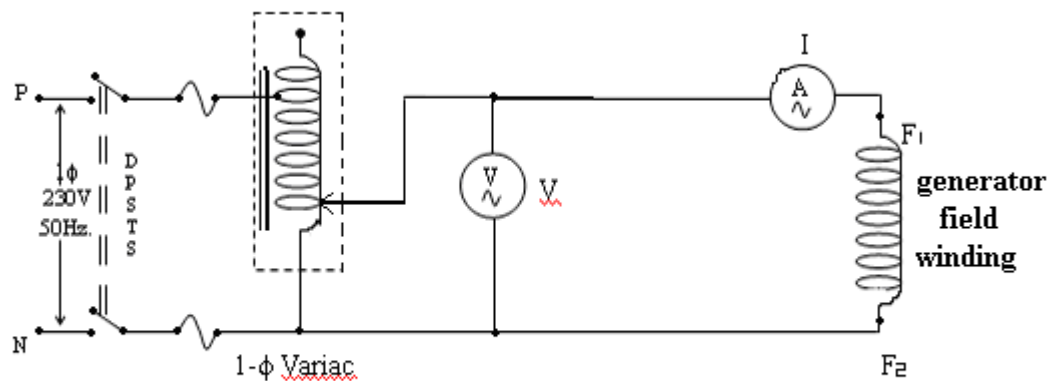
**PROCEDURE:**

**2. To determine field Inductance  $L_f$  :**

1. Connections are made as per the circuit diagram.
2. Auto transformer is varied in steps for different voltages and corresponding voltmeter and ammeter readings are noted down.
3. Field impedance  $Z_f$  is calculated as  $V/I$  and the average value of  $Z_f$  is obtained.
4. Field resistance ( $R_f$ ) is measured using multimeter.

5. Field inductance ( $L_f$ ) can be calculated using formula  
 $L_f = \sqrt{(Z_f^2 - R_f^2)} / 2\pi f$

**CIRCUIT DIAGRAM:**



**OBSERVATIONS:**

S. No	Field Voltage, V (V)	Field Current, I (A)	Field Impedance, $Z_f$ (Ohms)

**CALCULATIONS:**

**PROCEDURE:**

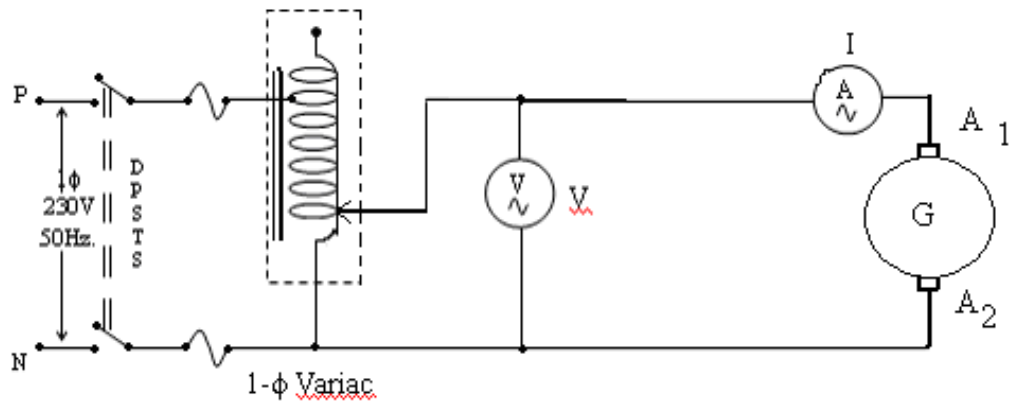
**3. Determination of armature inductance  $L_a$  :**

1. Connections are made as per the circuit diagram.
2. Auto transformer is varied in steps for different voltages and corresponding voltmeter and ammeter readings are noted down.

3. Armature impedance  $Z_a$  is calculated as  $V/I$  and the average value of  $Z_a$  is obtained.
4. Armature resistance  $R_a$  is measured using multimeter.
5. Armature inductance  $L_a$  can be calculated using formula,  

$$L_a = \sqrt{(Z_a^2 - R_a^2)} / 2\pi f$$

**CIRCUIT DIAGRAM:**



**OBSERVATIONS:**

S. No	Armature Voltage, V (V)	Armature Current, I (A)	Armature Impedance, $Z_a$ (Ohms)

**CALCULATIONS:**

**RESULT:**

**Expt. No: 4**

**Aim:-** To study synchro-transmitter and receiver and obtain output V/S input characteristics

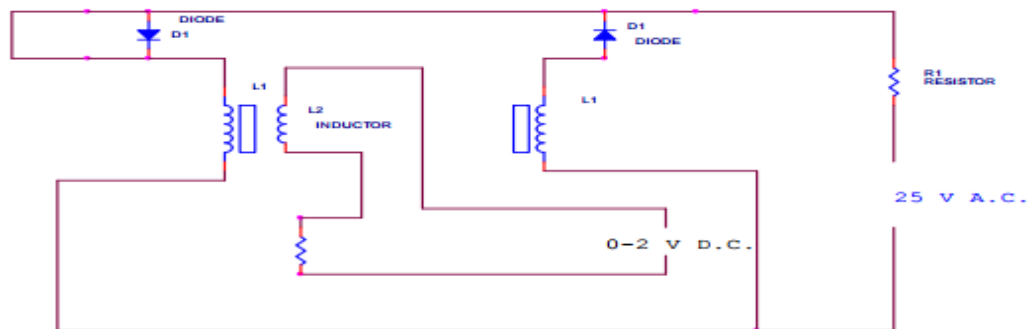
**APPARATUS REQUIRED:** Magnetic amplifier set up, digital multimeter and connecting leads.

**THEORY:** Self saturation of core is achieved by using two diodes D1 and D2 in series with L1 and L2 load coils. The successive rectified half wave saturates the core in opposite direction in few cycles. This leads to flow of current in RL greatly when control winding in open or there is no current flow. The core does not saturate completely but operates to bring the core out of saturation. DC current is made to flow in controlwinding. The control winding has more number of turns than load winding. Applying a small DC current which oppose the magnetic flux caused by self saturation tends to cut off produced mmf in load magnetic path. This causes to increase inductance in l load winding and the voltage drop across then tends to rise which result in decrease in AC current in RL.If the polarity of DC current is reversed then the saturation of core takes place in opposite direction.

**PROCEDURE:** Connect the circuit as shown in fig. keep DC voltage to minimum. Select positive direction and switch ON the power. Increase the control current slowly and note the IL, Ic and Vc in observation table. Bring DC voltage to minimum, select negative. direction and repeat the characteristics curve in both direction. Calculate power gain

$$P \text{ (gain)} = P(\text{out})/P(\text{in}) \text{ or } \Delta IL *RL/\Delta Ic *Vc$$

**CIRCUIT DIAGRAM:**



**OBSERVATION TABLE**

S.No	Ic(mA)	IL(mA)	Vc(+ve)
1.			
2.			
3.			
4.			

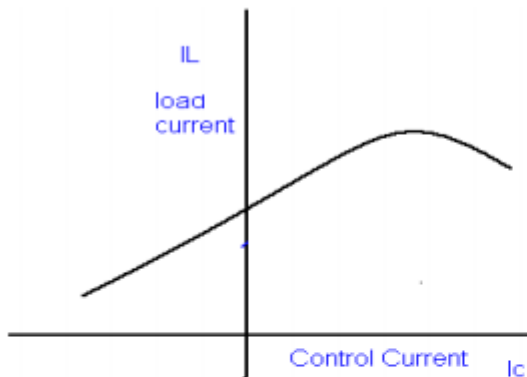
5.			
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S.No	Ic(mA)	IL(mA)	Vc(-ve)
1.			
2.			
3.			
4.			
5.			

**PRECAUTION :**

1. Apply voltage slowly to control winding as the coil may get heated up and burn.
2. Take the reading carefully and accurately.
3. Switch off the set up when not in use.

**GRAPH:-**



**DISCUSSION:-**

The graph is plotted between load current and control current. for positive polarity the Control current rises in the forward direction with rise in load current where as for negative polarity the control current decreases in the reverse direction with rise in load current .This is due to the self saturation of the magnetic core .

## Exp. No.5

**AIM: To study PID Controller for simulation**

APPARATUS:

Software: MATLAB

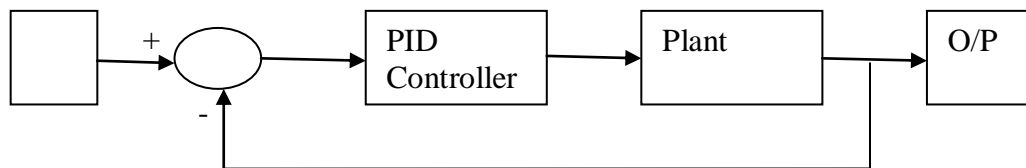
Theory:-

design and analyze plants and control systems modeled in Simulink and automatically tune PID controller gains to meet performance requirements. You can also find operating points and compute exact linearizations of Simulink models at various operating conditions. Simulink Control Design provides tools that let you compute simulation-based frequency responses without modifying your model. A graphical interface lets you design and analyze arbitrary control structures modeled in Simulink, including cascaded, prefilter, regulation, and multiloop architectures.

Let us design a PID feedback controller to control the velocity of the DC motor. Recall that the transfer function of a PID controller is:

$$C(s) = \frac{U(s)}{E(s)} = K_p + \frac{K_i}{s} + K_d s = \frac{K_d s^2 + K_p s + K_i}{s}$$

where  $u$  is the controller output (in our case the voltage  $V$ ),  $e = u_c - y$  is the controller input (the control error), and  $K_p$ ,  $K_d$ ,  $K_i$  are the proportional, derivative and integral gains, respectively. A block diagram of the closed-loop system is given in Figure



The control parameters are:

- The proportional term: providing an overall control action proportional to the error signal through the constant gain factor.
- The integral term: the action is to reduce steady-state errors through low-frequency compensation by an integrator.
- The derivative term: improves transient response through high-frequency compensation by a differentiator

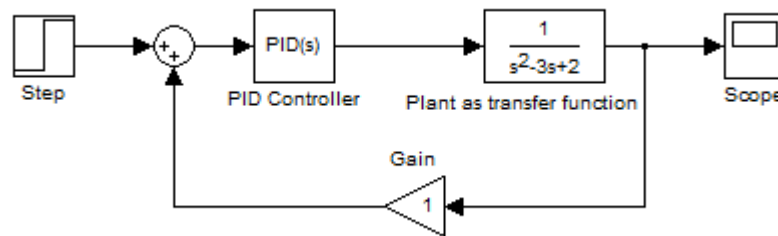
Consider a transfer function =

$$\frac{1}{s^2-3s+2}$$

Procedure:

- Open matlab Simulink Block
- Take all corresponding Simulink block per figure
- Connect as per figure
- Take output from Scope per figure. by different gain

Simulink Block



Result

## Matlab Based Experiments

### Expt. No: 6

#### TIME RESPONSE OF SECOND ORDER SYSTEM

AIM: To obtain the time response of a given second order system with its damping frequency

APPARATUS: Software: MATLAB

#### THEORY:

The time response has utmost importance for the design and analysis of control systems because these are inherently time domain systems where time is independent variable. During the analysis of response, the variation of output with respect to time can be studied and it is known as time response. To obtain satisfactory performance of the system with respect to time must be within the specified limits. From time response analysis and corresponding results, the stability of system, accuracy of system and complete evaluation can be studied easily.

Due to the application of an excitation to a system, the response of the system is known as time response and it is a function of time. The two parts of response of any system:

(i) Transient response

(ii) Steady-state response.

Transient response: The part of the time response which goes to zero after large interval of time is known as transient response.

Steady state response: The part of response that means even after the transients have died out is said to be steady state response.

The total response of a system is sum of transient response and steady state response:

$$C(t) = C_{tr}(t) + C_{ss}(t)$$

#### TIME RESPONSE OF SECOND ORDER CONTROL SYSTEM:

A second order control system is one wherein the highest power of 's' in the denominator of its transfer function equals 2.

Transfer function is given by

$$\text{Transfer function} = T(s) = \frac{\omega_n^2}{s^2 + 2\omega_n s + \omega_n^2}$$

$\omega_n$  is called natural frequency of oscillations.

$\omega_d$  is called damping frequency oscillations.

$\zeta$  = affects damping and called damping ratio.



MATLAB PROGRAM:

```
wn=input('enter value of undamped natural frequency')
z=input('enter value of damping ratio')
n=[wn*wn]
p=sqrt(1-z^2)
wd=wn*p
h=[p/z]
k=atan(h)
m=pi-k;
tr=[m/wd]
tp=[pi/wd]
q=z*wn
ts=[h/q]
r=z*pi
f=[r/p]
mp=exp(-f)
num=[0 0 n]
den=[1 2*z*wn n]
s=tf(num,den)
hold on
step(s)
impulse(s)
hold off
```

## PROCEDURE:

1. Time response of the system is being found when we give the values of natural undamped frequency and damping ratio.
2. When we give these values first rise time, peak time, peak overshoot, transfer function are being calculated.
3. Then “ step(s)” And “impulse(s)” generates time response of the system.
5. The hold function determines whether new graphics object are added to the graph or replaces objects in the graph.
6. hold on retains the current plot and certain axes properties so that subsequent graphing command add to the existing graph.
7. hold off resets axes properties to their defaults before drawing new plots. hold off is the default

## THEORETICAL CALCULATIONS:

## GRAPH

:

## Expt. No: 7

### ROOT LOCUS FROM A TRANSFER FUNCTION

AIM: To plot the root locus for a given transfer function of the system using MATLAB

APPARATUS:

Software: MATLAB

THEORY:

rlocus computes the Evans root locus of a SISO open-loop model. The root locus gives the closed-loop pole trajectories as a function of the feedback gain  $k$  (assuming negative feedback).

Root loci are used to study the effects of varying feedback gains on closed-loop pole locations.

In turn, these locations provide indirect information on the time and frequency responses.

rlocus(sys) calculates and plots the rootlocus of the open-loop SISO model sys. This function can be applied to any of the following feedback loops by setting sys appropriately.

If sys has transfer function

$$h(s) =$$

The closed-loop poles are the roots of

$$d(s) + k*n(s)=0$$

MATLAB PROGRAM:

```
num=input('enter the numerator of the transfer function')
den=input('enter the denominator of the transfer function')
h=tf(num,den)
rlocus(h)
```

PROCEDURE:

- Write MATLAB program in the MATLAB specified documents.
- Then save the program to run it.
- The input is to be mentioned.
- The syntax “h=tf(num,den)” gives the transfer function and is represented as h.

- The syntax “rlocus(h)” plots the rootlocus of the transfer function h.
- Generally the syntax is of the form

rlocus(sys)

rlocus(sys,k)

rlocus(sys1, sys2, ....)

[r,k] = rlocus(sys)

r = rlocus(sys,k)

- rlocus(sys) calculates and plots the root locus of the open loop SISO model sys.
- Now we have to solve it theoretically.
- Now we have to compare the practical and theoretical outputs to verify each other

Correctly

EXAMPLE:

Transfer function =

$$G(s) = \frac{K}{s(s+7)(s+11)}$$

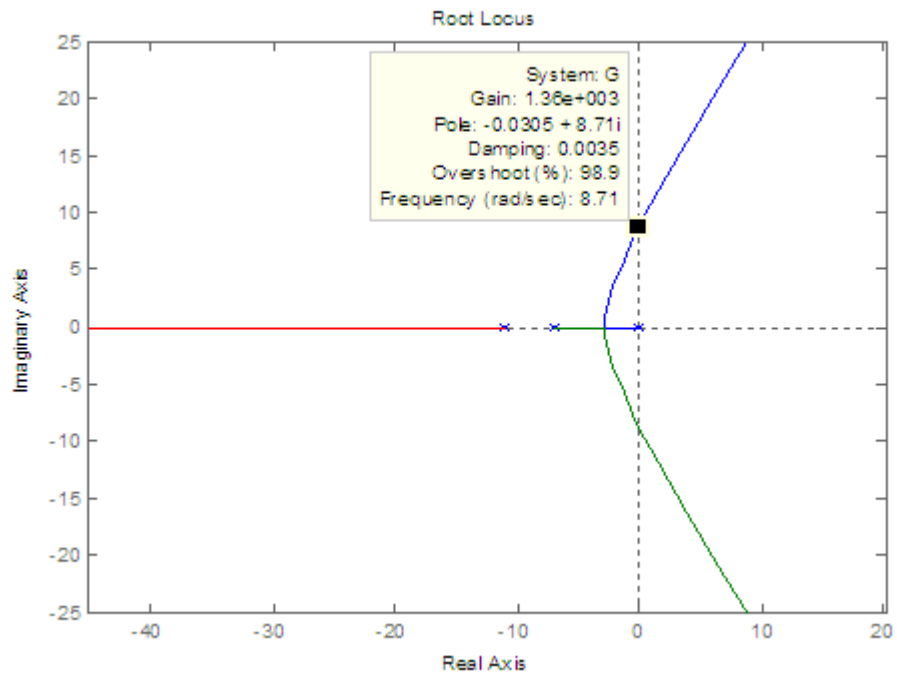
The following MATLAB script plots the root loci for

s = tf('s');

G = 1/(s\*(s+7)\*(s+11));

rlocus(G);

axis equal;



**THEORETICAL CALCULATIONS:**

enter the numerator of the transfer function

num=

enter the denominator of the transfer function

den=

Transfer function :

**RESULT:**

## Expt. No:8

### BODE PLOT FROM A TRANSFER FUNCTION

#### AIM:

To obtain bode plot for a given transfer function of the system using MATLAB.

#### APPARATUS:

Software: MATLAB

#### THEORY:

##### Get things started

1. Put the forward path transfer function in the correct form
  - a. All terms are  $(1+s/\text{something})$
  - b. Each term represents the location of a pole or zero
2. Calculate the gain in dB
  - a.  $\text{gain}=20*\log(K)$ , where K is the constant in front when in the correct form.

##### Construct Magnitude Plot

3. Calculate initial slope
  - a. For each pole at 0, subtract 20dB/dec
  - b. For each zero at 0, add 20dB/dec
  - c. The asymptote (with the defined initial slope) passes through  $0+\text{gain}$  (dB) at  $w=1\text{rad/s}$ . In other words, the slope crosses the w axis at  $w=1$ , and then is shifted up (or down) by the gain calculated in step 2 (up if  $\text{gain}>0$ , down if  $\text{gain}<0$ ).
4. At each pole location, the asymptote decreases in slope by 20dB/dec. At each zero location, the asymptote increases in slope by 20dB/dec. The location of the poles are determined from the form in step 1. Ie,  $10/(0.5s+1)$  results in a pole at  $s=-2$ . In the bode diagram, the location is at  $w=2\text{rad/s}$ .
5. Sketch the actual curve based on the asymptotes (be careful with complex pairs; see bode sample file online).

### Construct Phase Plot

6. Calculate starting position
  - a. For each pole at 0, start at an additional -90deg
  - b. For each zero at 0, start at an additional +90deg
  - c. The curve starts with a slope of zero.
7. Each pole causes the phase plot to shift down by 90deg. This transition occurs from 1 decade before to one decade after the pole location. Each zero has the opposite effect; the phase plot shifts up by 90deg (from 1 decade before to one decade after the zero location).
8. Sketch the actual curve based on the asymptotes.

### Check your plot

8. Count how many total poles and zeros you have. For each additional pole, your final magnitude slope should be -20dB/dec and your final phase value should be -90deg. For each additional zero, the results are the opposite.

### MATLAB PROGRAM:

```
num=input('enter the numerator of the transfer function')
den=input('enter the denominator of the transfer function')
h=tf(num,den)
[gm pm wcp wcg]=margin(h)
bode(h)
```

### PROCEDURE:

- Write the MATLAB program in the MATLAB editor.
- Then save and run the program.
- Give the required inputs.
- The syntax "bode(h)" solves the given input transfer function and gives the bode plot,
- where num,den are the numerator and denominator of the transfer function.

- Now plot the bode plot theoretically for the given transfer function and compare it with the plot obtained practically

EXAMPLE:

Transfer function=  $50 / (s^3 + 9 s^2 + 30 s + 40)$

THEORETICAL CALCULATIONS:

enter the numerator of the transfer function

num =

enter the denominator of the transfer function

den =

Transfer function:

gm =

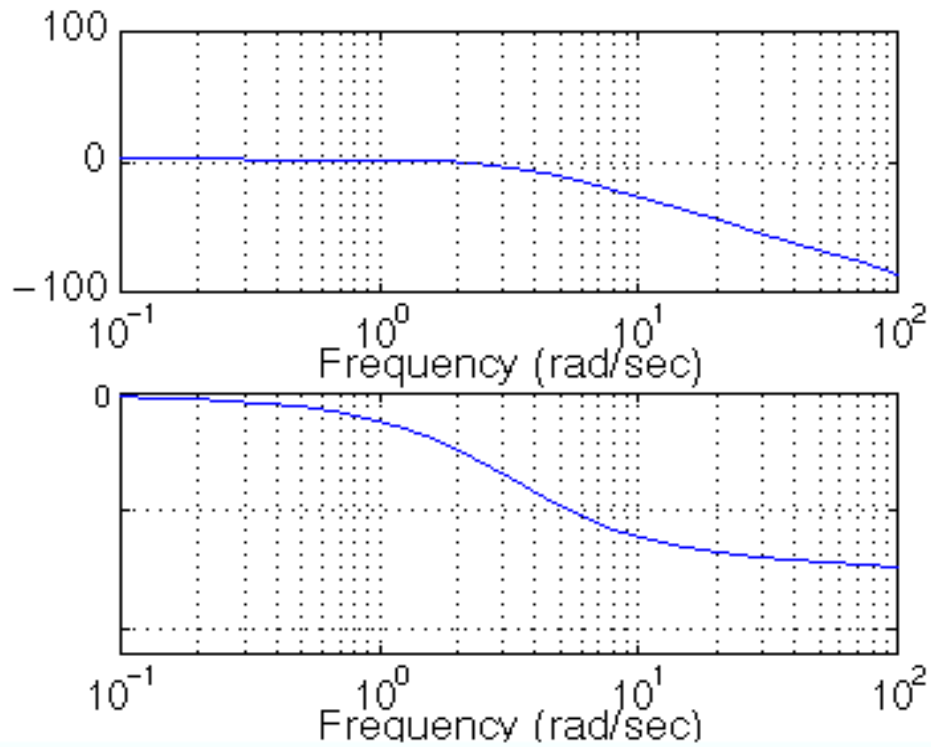
pm =

wcp =

wcg =

Graph:-





Result:-

## Expt. No: 9(a)

### .TRANSFER FUNCTION FROM STATE MODEL and VICE VERSA

#### AIM:

To obtain the transfer function from the state model.

#### APPARATUS:

Software: MATLAB

#### THEORY:

The transfer function is defined as the ratio of Laplace transform of output to Laplace transform of input. The transfer function of a given state model is given by: A state space representation is a mathematical model of a physical system as a set of input, output and state variables related by first-order differential equations. The state space representation (also known as the "time-domain approach") provides a convenient and compact way to model and analyze systems with multiple inputs and outputs. Unlike the frequency domain approach, the use of the state space representation is not limited to systems with linear components and zero initial conditions. "State space" refers to the space whose axes are the state variables. The state of the system can be represented as a vector within that space.

The input state equation is given by,

$$\dot{\mathbf{x}}(t) = \mathbf{A}\mathbf{x}(t) + \mathbf{B}\mathbf{u}(t)$$

The output equation is written as,

$$\mathbf{y}(t) = \mathbf{C}\mathbf{x}(t) + \mathbf{D}\mathbf{u}(t)$$

#### MATLAB PROGRAM:

```
A = input('enter the matrix A')
```

```
B = input('enter the matrix B')
```

```
C = input('enter the matrix C')
```

```
D = input('enter the matrix D')
```

```
Sys = ss2tf(A,B,C,D)
```

EXAMPLE:

Obtain the transfer function from the State Model given below

$$\begin{array}{cccc} A = & & B = & C = & D = \\ & -9 & -26 & -24 & & 1 & & 1 & 7 & 2 & & 0 \\ & 1 & 0 & 0 & & 0 & & & & & & \\ & 0 & 1 & 0 & & 0 & & & & & & \end{array}$$

PROCEDURE:

- Type the program in the MATLAB editor that is in M-file.
- Save and run the program.
- Give the required inputs in the command window of MATLAB in matrix format.
- The command `ss2tf(A,B,C,D)` converts the given transfer function into a state model.
- Note down the output obtained in MATLAB.
- The Transfer Function is also obtained theoretically.
- Both the state models are compared

THEORETICAL CALCULATIONS:

A=

B=

C=

D=

Result:

## Expt. No: 4(b)

### STATE MODEL FROM TRANSFER FUNCTION

AIM:

To obtain the state model from the given transfer function.

APPARATUS:

Software: MATLAB

THEORY:

There are three methods for obtaining state model from transfer function:

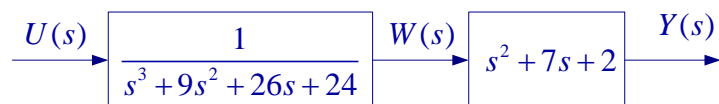
1. Phase variable method
2. Physical variable method
3. Canonical variable method

Out of three methods given above canonical form is probably the most straightforward method for converting from the transfer function of a system to a state space model is to generate a model in "controllable canonical form." This term comes from Control Theory but its exact meaning is not important to us. To see how this method of generating a state space model works, consider the third order differential transfer function:

$$\frac{Y(s)}{U(s)} = \frac{b_2s^2 + b_1s + b_0}{s^3 + a_2s^2 + a_1s + a_0}$$

- (a) Draw the simulation diagram and find the state-space representation of the above transfer function.
- (b) Use MATLAB Control System Toolbox  $[A, B, C, D] = \text{tf2ss}(\text{num}, \text{den})$  to find the state model.

- (a) Draw the transfer function block diagram in cascade form



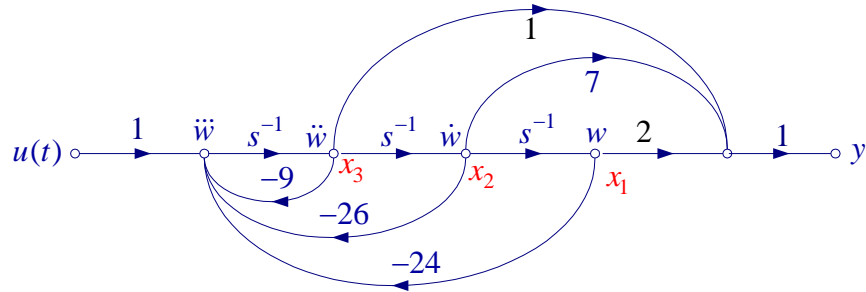
From this we have

$$s^3W(s) = -9s^2W(s) - 26sW(s) - 24W(s) + U(s) \quad \& \quad Y(s) = s^2W(s) + 7sW(s) + 2W(s)$$

or in time-domain

$$\ddot{w} = -9\ddot{w} - 26\dot{w} - 24w + u \quad \& \quad y = \ddot{w} + 7\dot{w} + 2w$$

The above time-domain equations yield the following simulation diagram



To obtain the state equation, the state variables  $x_1(t)$ ,  $x_2(t)$ , and  $x_3(t)$  are assigned to the output of each integrator from the right to the left. Next an equation is written for the input of each integrator. The results are

$$\dot{x}_1 = x_2$$

$$\dot{x}_2 = x_3$$

$$\dot{x}_3 = -24x_1 - 26x_2 - 9x_3 + u(t)$$

and the output equation is

$$y = 2x_1 + 7x_2 + x_3$$

or in matrix form

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \dot{x}_3 \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ -24 & -26 & -9 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} u(t)$$

$$y = \begin{bmatrix} 2 & 7 & 1 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \end{bmatrix}$$

**MATLAB PROGRAM:**

```
num=input('enter the numerator of the transfer function')
```

```
den=input('enter the denominator of the transfer function')
```

```
ss(tf(num,den))
```

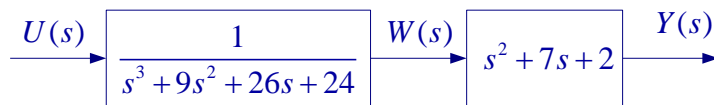
**PROCEDURE:**

- Type the program in the MATLAB editor that is in M-file.
- Save and run the program.

- Give the required inputs in the command window of MATLAB in matrix format.
- The command `ss(tf(num,den))` converts the given transfer function into a state model
- Note down the output obtained in MATLAB.
- The state model is also obtained theoretically.
- Both the state models are compared.

EXAMPLE:

Obtain the state model from the transfer function given below:



We write the following statements

```
num = [1 7 2]; den = [1 9 26 24];
```

```
[A, B, C, D] = tf2ss(num, den)
```

RESULT:

```
A =      -9  -26  -24
      1   0   0
      0   1   0

B =      1
      0
      0

C =      1  7  2
D =      0
```

## Expt. No:10

### .NYQUIST PLOT FROM TRANSFER FUNCTION

#### AIM:

To obtain the Nyquist plot for a given transfer function of the system.

#### APPARATUS:

Software: MATLAB

#### THEORY:

A Nyquist plot is used in automatic control and signal processing for assessing the stability of a system with feedback. It is represented by a graph in polar coordinates in which the gain and phase of a frequency response are plotted. The plot of these phasor quantities shows the phase as the angle and the magnitude as the distance from the origin. This plot combines the two types of Bode plot — magnitude and phase — on a single graph with frequency as a parameter along the curve. Nyquist calculates the Nyquist frequency response of LTI models. When invoked without left-hand arguments, `nyquist` produces a Nyquist plot on the screen. Nyquist plots are used to analyze system properties including gain margin, phase margin, and stability.

The Nyquist stability criterion, provides a simple test for stability of a closed-loop control system by examining the open-loop system's Nyquist plot. Stability of the closed-loop control system may be determined directly by computing the poles of the closed-loop transfer function. The Nyquist Criteria can tell us things about the frequency characteristics of the system. For instance, some systems with constant gain might be stable for low-frequency inputs, but become unstable for high-frequency inputs. Also, the Nyquist Criteria can tell us things about the phase of the input signals, the time-shift of the system, and other important information.

#### The Nyquist Contour

The Nyquist contour, the contour that makes the entire Nyquist criterion work, must encircle the entire right half of the complex  $s$  plane. Remember that if a pole to the closed-loop transfer function (or equivalently a zero of the characteristic equation) lies in the right-half of the  $s$  plane, the system is an unstable system. To satisfy this requirement, the Nyquist contour takes the shape of an infinite semi-circle that encircles the entire right-half of the  $s$  plane. Nyquist Criteria

Let us first introduce the most important equation when dealing with the Nyquist criterion:

Where:

N is the number of encirclements of the  $(-1, 0)$  point.

Z is the number of zeros of the characteristic equation

P is the number of poles of the characteristic equation.

With this equation stated, we can now state the Nyquist Stability Criterion:

Nyquist Stability Criterion

A feedback control system is stable, if and only if the contour in the  $F(s)$  plane does not encircle the  $(-1, 0)$  point when P is 0.

A feedback control system is stable, if and only if the contour in the  $F(s)$  plane encircles the  $(-1, 0)$  point a number of times equal to the number of poles of  $F(s)$  enclosed by  $\Gamma$ .

In other words, if P is zero then N must equal zero. Otherwise, N must equal P. Essentially, we are saying that Z must always equal zero, because Z is the number of zeros of the characteristic equation (and therefore the number of poles of the closed-loop transfer function) that are in the right-half of the  $s$  plane.

MATLAB PROGRAM:

```
num=input('enter the numerator of the transfer function')
den=input('enter the denominator of the transfer function')
h=tf(num,den)
nyquist(h)
[gm pm wcp wcg]=margin(h)
if(wcp>wcg)
disp('system is stable')
else
disp('system is unstable')
end
```

PROCEDURE:



- Write MATLAB program in the MATLAB editor document.
- Then save and run the program.
- Give the required input.
- The syntax “tf(num,den)” solves the given transfer function and gives poles and zeros of the function.

“nyquist(sys)”, nyquist calculates the Nyquist frequency response of LTI models. When invoked without left-hand arguments, nyquist produces a Nyquist plot on the screen. Nyquist plots are used to analyze system properties including gain margin, phase margin, and stability. “nyquist(sys)” plots the Nyquist response of an arbitrary LTI model sys. This model can be continuous or discrete, and SISO or MIMO. In the MIMO case, nyquist produces an array of Nyquist plots, each plot showing the response of one particular I/O channel. The frequency points are chosen automatically based on the system poles and zeros.

- “[Gm,Pm,Wcg,Wcp] = margin(sys)”, margin calculates the minimum gain margin, phase margin, and associated crossover frequencies of SISO open-loop models. The gain and phase margins indicate the relative stability of the control system when the loop is closed

RESULT: Nyquist Diagram

