ANNAMALAI UNIVERSITY

WITH COURAGE AND FAITH

FACULTY OF ENGINEERING AND TECHNOLOGY

DEPARTMENT OF ELECTRICAL ENGINEERING

V SEM B.E. ELECTRICAL & ELECTRONICS

CONTROL SYSTEMS LAB

Name ....

Reg. No. ....Batch ....

Class ....

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Laboratory ______________________________

Name of Student :

Register Number :

Semester : Year : 2014-2015 Course : B.E.

Branch :

Certified that this is the Bonafide Record of work done by the student named above.

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External Examiner

Annamalai University

Faculty of Engineering And Technology

Department of Electrical Engineering

EECP509 CONTROL SYSTEM LABORATORY

B.E (EEE) [V - Semester] [2020-2021]

List of Experiments

Cycle – I

1. D.C Position Control System
2. D.C Speed Control System
3. PID Controller
4. Temperature Control System
5. Lag Compensation Design

Cycle –II

6. Linear System Simulator
7. Lead Compensation Design
8. Stepper Motor Study
9. Relay Control System
10. Digital Control System

CONTROL SYSTEMS LABORATORY

S. No	Date	Name of the Experiment	Page No	Marks	Signature
1		D.C Position Control System			
2		D.C Speed Control System			
3		PID Controller			
4		Temperature Control System			
5		Lag Compensation Design			
6		Linear System Simulator			
7		Lead Compensation Design			
8		Stepper Motor Study			
9		Relay Control System			
/10		Digital Control System			

	Test No. 1	Test No. 2
Date		
Name of the Experiment		
Marks		

D.C. POSITION CONTROL

Aim:

To study the performance characteristics of a D.C. motor angular position control system.

Equipments required:

DC position control unit
CRO
Probe
Patch chords

Precaution:

1. The step command switch should be in OFF position while performing position control through continuos command
2. The Tacho generator feedback switch on the motor unit is set to negative while performing position control through STEP command.
3. The CRO must be in X - Y mode while performing position control through STEP command.

Procedure:

Part - I

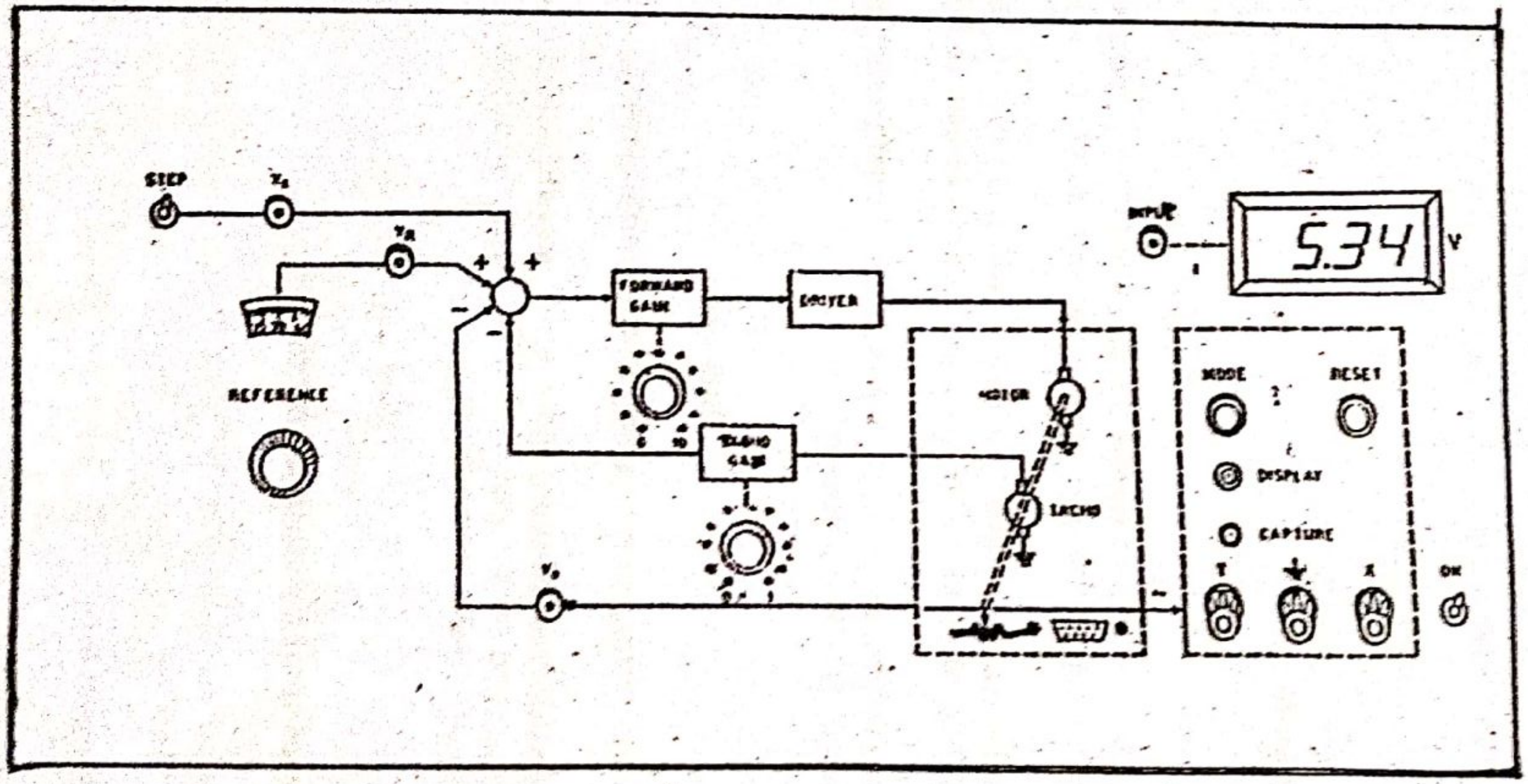
1. Connections are made as per the panel diagram.
2. The supply is effected the X input waveforms is traced (X - output connected to Y - input of CRO) and calculations are made to calibrate the X scale output.

Part - II

(a) Position control through continuos command:

1. The connections are made as per the panel diagram and the supply is effected.
2. The open loop gain K_A is set to 4.
3. The command potentiometer is adjusted in such a way to make the motor standstill (i.e. response potentiometer to read initial reading) and the voltage $V_R = 0$.
4. The potentiometer is adjusted in steps of 30° (i.e., θ_R) and the corresponding V_R, θ_0 and V_0 are tabulated.

D.C. POSITION CONTROL



5. $\Delta\theta R$ and $\Delta\theta_0$ are calculated and plotted. The errors ($\Delta\theta R$ - $\Delta\theta_0$), (ΔV_R - ΔV_0) are also calculated.

6. The above steps are repeated for various values of K_A.

(b) Position control through STEP command:

1. The connections are made as per the panel diagram and the supply is effected.

2. The reference potentiometer is adjusted to obtain $V_R = 0$.

3. The open loop gain K_A is set to 3 and the RESET switch is pressed.

4. Then CAPTURE mode switch is pressed.

5. A step input (Vs) is applied and the corresponding waveform is traced and % Mp, ess, tp, ts are calculated.

6. The above procedure is repeated for K_A = 4,5, ...

7. K_A is set to 6 the Tacho generator gain (K_D) is set to 0.1, 0.2, ... And the above procedure is repeated the corresponding waveform are traced and % Mp, ess, tp, ts are calculated.

Calculation:

i. a) Amplitude of saw tooth wave (fig.2) = --------- V

b) Time duration of the main linear part = --------- ms

c) X- output scale factor = b / a = ms / V

ii. a) Position without Tacho generator

K_D = 0 (Tacho generator channel disabled)

K_A = 5

Fig 2

Sawtooth Waveform

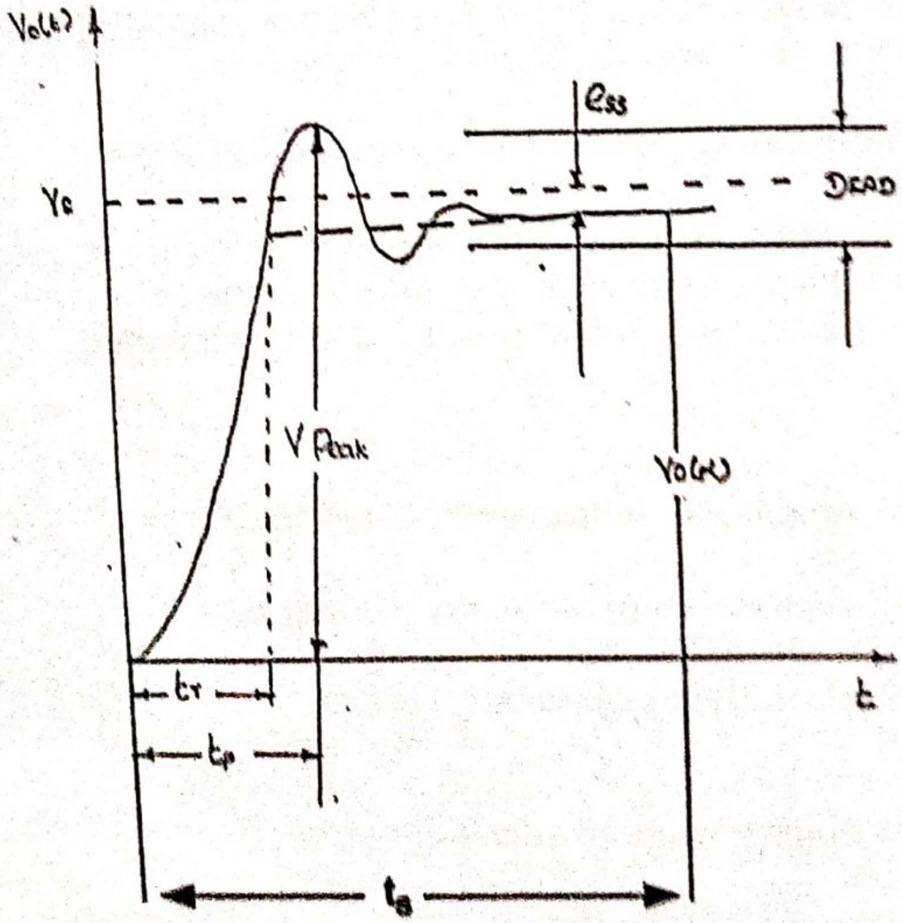


Fig 3:Typical step response of the position control system

Tabulation I:

S. No.	θ_R degrees	$\Delta\theta_R$ degrees	θ_0 degrees	$\Delta\theta_0$ degrees	$(\Delta\theta_R - \Delta\theta_0)$ degrees	V_R Volts	V_0 Volts	$(\Delta V_R - \Delta V_0)$ Volts

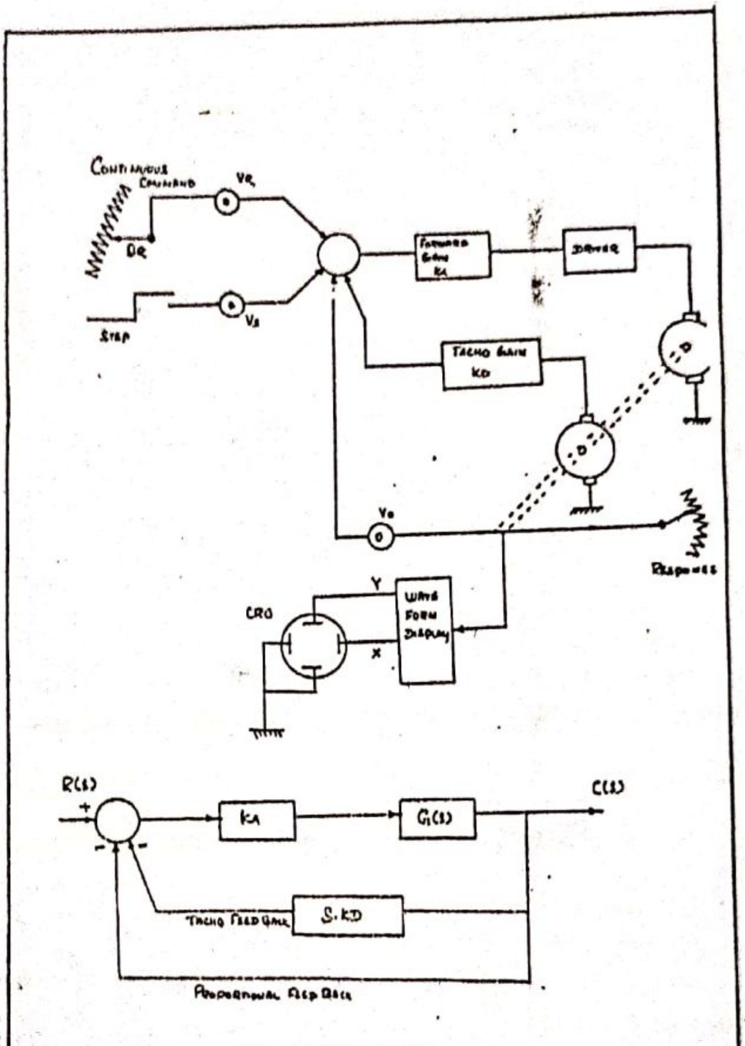
Tabulation II:

Position with without Tacho generator feedback:

Set $K_D = 0$

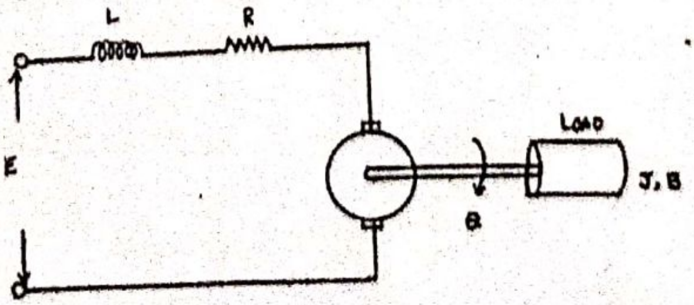
$V_S = 2.5$ V (internally set)

S. No.	K_A	M_P %	t_d ms	t_p ms	t_r ms	t_s ms	ξ	e_{ss} V	W_n rad/ sec



Simplified block diagram

Fig.1. DC Position Control System



TRANSFER FUNCTION OF A DC MOTOR $= \frac{\theta(s)}{E(s)} = \frac{K_m}{s(sT+1)}$

Fig.2.

Formula:

$E_{ss} = V_s - V_0;$ $V_s = 2.5$ V (Internally set)

$V_0 =$ V (measured for DVM)

$$\% M_p = \frac{Vpeak - V_0(\alpha)}{V_0(\alpha)} * 100$$ (from the corresponding trace)

$$ess = \frac{1}{K_A K_M}$$

$$\xi = \frac{1 + K_A K_M K_D}{2\sqrt{T K_A K_D}}$$

where T = Mech Time Constant

$t_p =$ ms , $t_r =$ ms

using the equation: $Mp = e^{-\pi\xi/\sqrt{(1-\varsigma^2)}}$

$$\text{Obtain } \xi = \sqrt{\frac{(\ln Mp)^2}{\pi^2 + (\ln Mp)^2}}$$

$$\text{Using the equation } tp = \frac{\pi}{\omega_n \sqrt{(1 - \xi^2)}}$$

calculate $\omega_n =$ rad / sec.

$$\text{Close loop transfer Function } T(s) = \frac{\omega_n^2}{s^2 + 2\xi\omega_n s + \omega_n^2}$$

(for $K_A = 5$) =

Tabulation III:

<u>Position control with Tacho generator feedback:</u>

$K_A = 5$

$V_S = 2.5$ V (internally set)

S. No.	K_D	M_P %	t_d	t_p ms	t_r ms	t_s ms	ξ	e_{ss} V	W_n rad/ sec

Open loop transfer function $G(s) = \frac{1}{K_A} \frac{\omega_n^2}{(s+2\xi\omega_n s)}$

$= \underline{\hspace{6cm}}$

Result:

For the given DC position control system the closed loop transfer function and open loop transfer functions were obtained experimentally and the transient response parameters are calculated.

Questions:

1. What are the specifications to be mentioned in specifying the transient response characteristic of a control system to a unit step input?
2. How does the forward gain affect the feed back control system output response?
3. Define dead zone.
4. How does the tacho generator gain affect the feedback control system output response?
5. What is the need to have a potentiometer in this experiment?
6. Distinguish between open-loop and closed-loop systems.

D.C. SPEED CONTROL SYSTEM

Aim:

To study the performance characteristics of a dc motor speed control system.

Equipments required:

DC speed control Unit
CRO (Storage)
Probe
Patch chords

Procedure: (open loop study)

I. Motor and Tacho-generator :

1. The connections are made as per the panel diagram the reference voltage V_R is set to 1V and open loop gain K_A is set to 3.
2. The speed N in rpm and the Tacho generator output V_T are noted.
3. The above steps are repeated with V_R = 1V and K_A = 4,5,....10 and tabulate motor voltage $V_M = (V_R K_A)$, steady state motor speed N in rpm

$$(\omega_{ss} = \frac{2\pi N}{60} \text{ rad / Sec })$$

and Tacho generator output V_T.

Calculation:

Graphs **N V_S V_M** and V_T V_S **N** are plotted, K_M and K_T from the linear region of the curves are obtained.

$$\text{Motor gain constant } (K_M) = \frac{\text{Shaft speed in rad / sec, } \omega_{ss}}{\text{Motor voltage, } V_M} \text{ rad / Volt - sec}$$

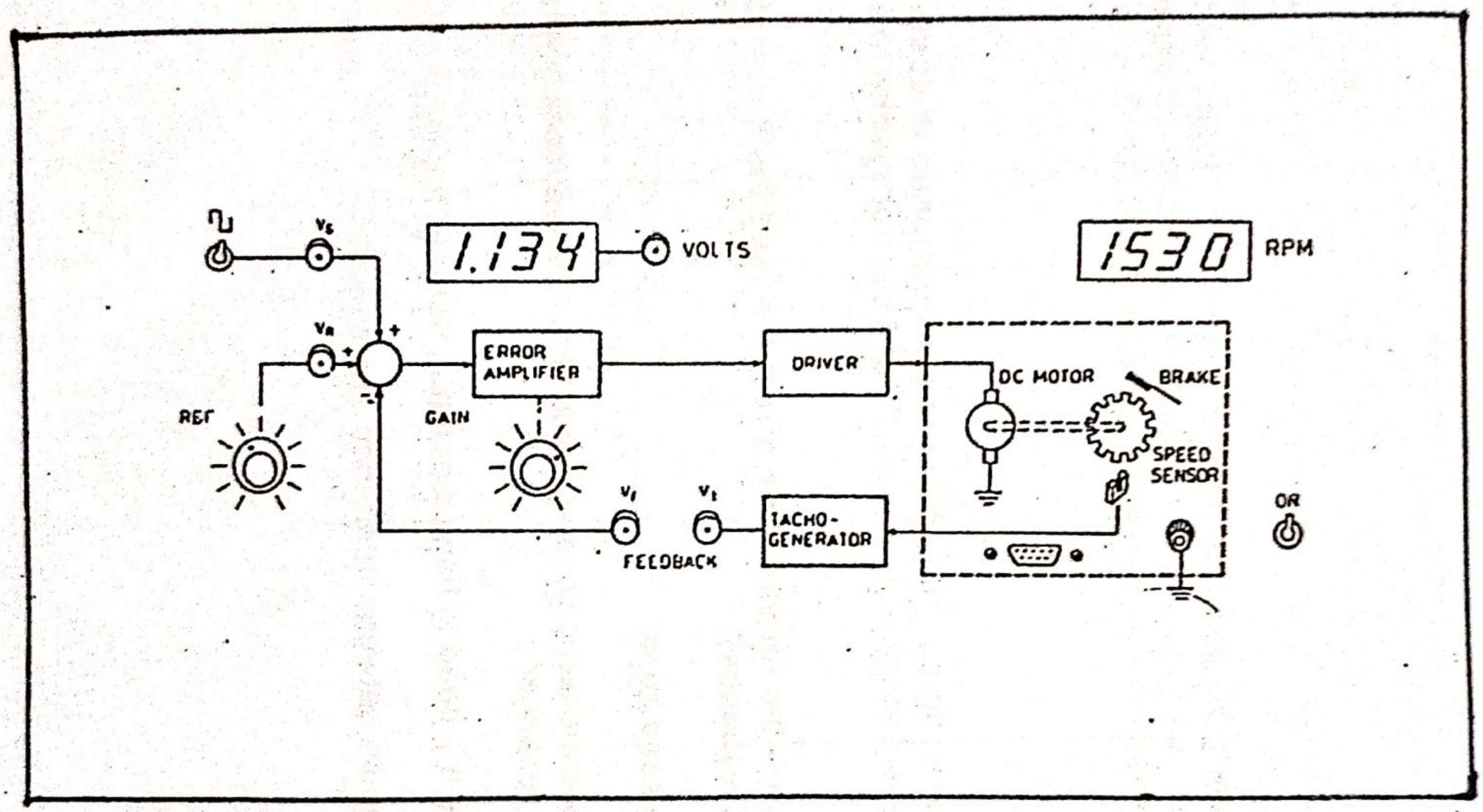
$$\text{Tacho generator gain } (K_T) = \frac{V_T}{\omega_{ss}} \text{ volt - sec / rad}$$

$$\text{The transfer function of an armature controlled dc motor} = \frac{K_M}{s(sT+1)}$$

where T is the Mech Time Constant

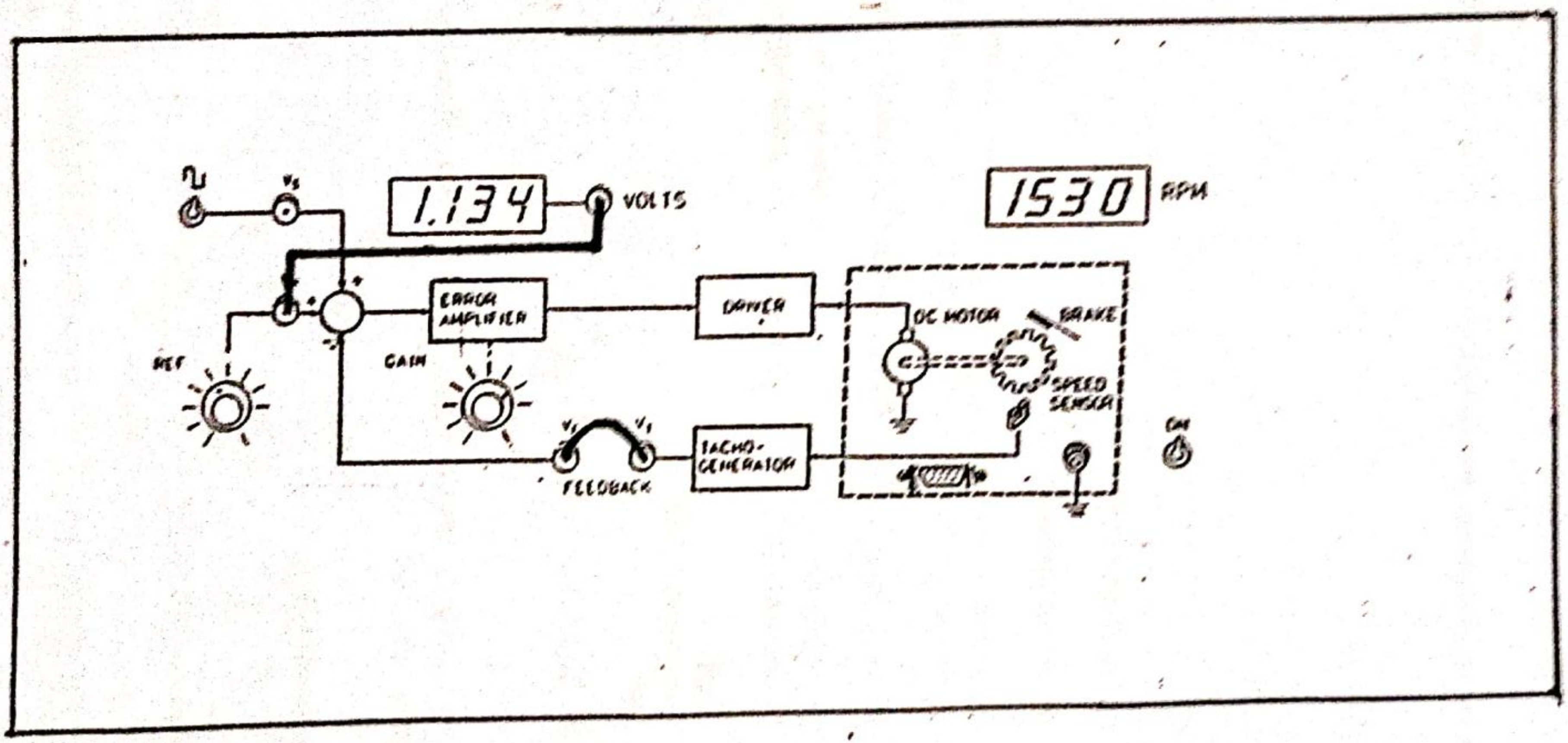
Note: The permanent magnet dc motor should behave similar to shunt motor with constant field excitation. With the motor speed (w in rad/ sec) as the output variable, the forward gain is given by

DC SPEED CONTROL



DC SPEED CONTROL(MAIN UNIT)

DC SPEED CONTROL



DC SPEED CONTROL CONNECTION DIAGRAM

$$G(s) = K_A \frac{K_M}{s(sT+1)}$$

where K_A is the gain of the amplifier

$$\text{Motor Transfer function } G(s) = \frac{K_M}{s(sT+1)}$$

II Determination of motor time constant:

1) V_R is set = 0V and K_A is set to 10
2) The square wave signal (V_S) is switched on and peak to peak amplitude of the triangular wave corresponding (V_T) is measured.

III Calculation of motor time constant:

$$\text{Motor time constant } T = \frac{V_S\,(p\text{-}p)}{V_T(p\text{-}p)} \; \frac{K_A K_M}{2f} \; K_T$$

Where f = frequency of the square wave signal =

= Hz.

$$\text{Transfer function of motor} = \frac{K_M}{(sT + 1)}$$

iv Closed loop performance :

a) Steady - state error:

1. The connections are made as per the panel diagram
2. V_R is set to IV and K_A to 3
3. Speed N in rpm and Tacho generator voltage (V_T) are measured and noted (ess = $V_R - V_T$) is calculated.
4. The above steps are repeated for K_A = (4,5, ...10).
5. Compared in each case the value of steady state error computed from the equation

$$ess = \frac{1}{1 + K_A K_M K_T}$$

Tabulation :

Motor and Tacho generator characteristics

V_R = 1 V, f = Hz

S. No.	K_A	N Rpm	V_T Volts	$V_m = K_A V_R$

Tabulation :

I. Steady state error

V_R = 1V

S. No.	K_A	N Rpm	V_T Volts	$Ess = V_R - V_T$ Experimental	$Ess = 1/[(K_A K_M K_T)+1]$ Theoretical

b) Transient performance: (System time constant Teff)

1. V_R is set to 0.5V and K_A is set to 5V.
2. V_S (p-p) and V_T (p-p) are measured.
3. The above steps are repeated & the results for K_A = 7, 10 are tabulated.

$$T_{eff} = \frac{V_s\,(p\text{-}p)}{V_T\,(p\text{-}p)} \qquad \frac{K_A K_M K_T}{K_A K_M K_T + 1} \qquad \frac{1}{2f}$$

c) Disturbance Rejection:

1. K_A is set to 5, V_R is adjusted to set a speed of 1200rpm without applying the eddy current braking.
2. Readings are noted.
3. For each and every variation of the brake settings the %decrease in speed is calculated.

General Theory:

Transfer function of armature controlled dc motor may be derived as

$$\frac{\theta\,(s)}{V(s)} = \frac{K_M}{s\,(sT + 1)}$$

Where K_M is motor gain constant

T is mechanical time constant.

The forwarded path transfer function

$$G(s) = \frac{\omega(s)}{V_E(s)} = K_A.\ \frac{K_M}{(s_T + 1)}$$

Tacho generator transfer function

$$H(s) = \frac{V_T\,(s)}{\omega(s)} = K_T$$

$$T(s) = \frac{C(s)}{R(s)} = \frac{G\,(s)}{1+G(s)\,H(s)}$$

$$\text{Closed loop Transfer function } T(s) = \frac{\dfrac{K_A K_M}{K_A K_M K_T+1}}{s\left[\dfrac{T}{K_A K_M K_T+1}\right] +1}$$

Tabulation :

I. System time constant

$V_R = 0.5V$; Vs (p-p) = R =

S. No.	K_A	V_T = C Volts	Teff. sec

III. Disturbance rejection:

Break Setting	0	1	2	3	4	5
Open loop speed in Rpm						
%decreased speed						
Closed loop speed in Rpm For $K_A = 5$						
%decreased speed						

Steady State Error:

Position error constant $K_p = \underset{s\to 0}{Lt} \; G(s)\,H(s)$

$= K_A K_M K_T$

$$\text{Steady state error } e_{ss} = \underset{s\to\infty}{Lt}(V_R - V_F) = \frac{R}{1 + Kp} = \frac{1}{1 + K_A K_M K_T}$$

e_{ss} for unit step input is given by

$e_{ss} = 1 / 1+K_p = 1 / 1+K_A K_M K_T$

Transient purpose:

For a step input $V_R(s) = 1 / s$

$$\omega(s) = \frac{1}{s} \quad \frac{K_A K_M / T}{s + (K_A K_M K_T + 1)/T}$$

on LT^{-1}

$$\omega(t) = \frac{K_A K_M}{K_A K_M K_T + 1} \left(1 - e^{\frac{(-K_A K_M K_T + 1)}{T} * t}\right)$$

$$T_{eff} = \frac{V_s\,(p\text{-}p)}{V_T\,(p\text{-}p)} \quad \frac{K_A K_M K_T}{K_A K_M K_T + 1} \quad \frac{1}{2f}$$

Result:

The performance characteristics of the given dc motor speed control is studied and the various parameters are calculated and tabulated.

1. Motor gain constant K_M = rad. / V-s
2. Tacho generator gain K_T = Volt - sec / rad.
3. Motor time constant (T) = Sec.

4. Transfer function of motor G(s) $= (K_M / sT+1) =$

5. Steady state error e_{ss} = Volt

6. Potential error constant K_P =

7. Closed loop transfer function T(s) =

Questions:

1. What is the closed loop transfer function for the system with negative feedback whose open loop transfer function is GH?

2. What are the various types of braking applied in the DC motor speed control?

3. What is the forward path transfer function of the given DC speed control system?

4. Define Steady State Error.

5. Define effective time constant of a control system.

6. What is tachogenerator? Compare the AC tacho and DC tacho.

PID CONTROLLER

Aim:

To study the performance characteristics of an analog PID controller using simulated systems.

Equipments required:

PID controller unit
CRO
Probes
Patch chords

Theory:

i. Process or plant :

a) It is that part of the system which produce the desired response under the influence of command signal

b) Usual processes are higher order, non-linear function having inherent dead time or pure time delay. Such plants are commonly modeled by transfer function of the form.

$$G(s) = \frac{K e^{\theta s}}{\tau s + 1}$$

where θ is the time delay in seconds, τ is the effective time constant and K is the dc gain

c) The system under study is an analog simulation through a ten basic building blocks which may be connected suitably to form a variety of processes or plants

Various blocks

(i) Integrator: Having an approximate transfer function of 10 / s.

This two have 180° phase shift between input and output

(ii) Simple Pole: Two identical units each having a transformer function.

$$\frac{1}{(1+0.0155s)}$$

(iii) Pure Time delay: A time delay about 5.64 m sec generated by a higher order multiple pole approximate of the delay function.

2. For a given application to have a good system performance "Compensation Design" has to be adopted (Compensation includes time, and frequency domain designs).

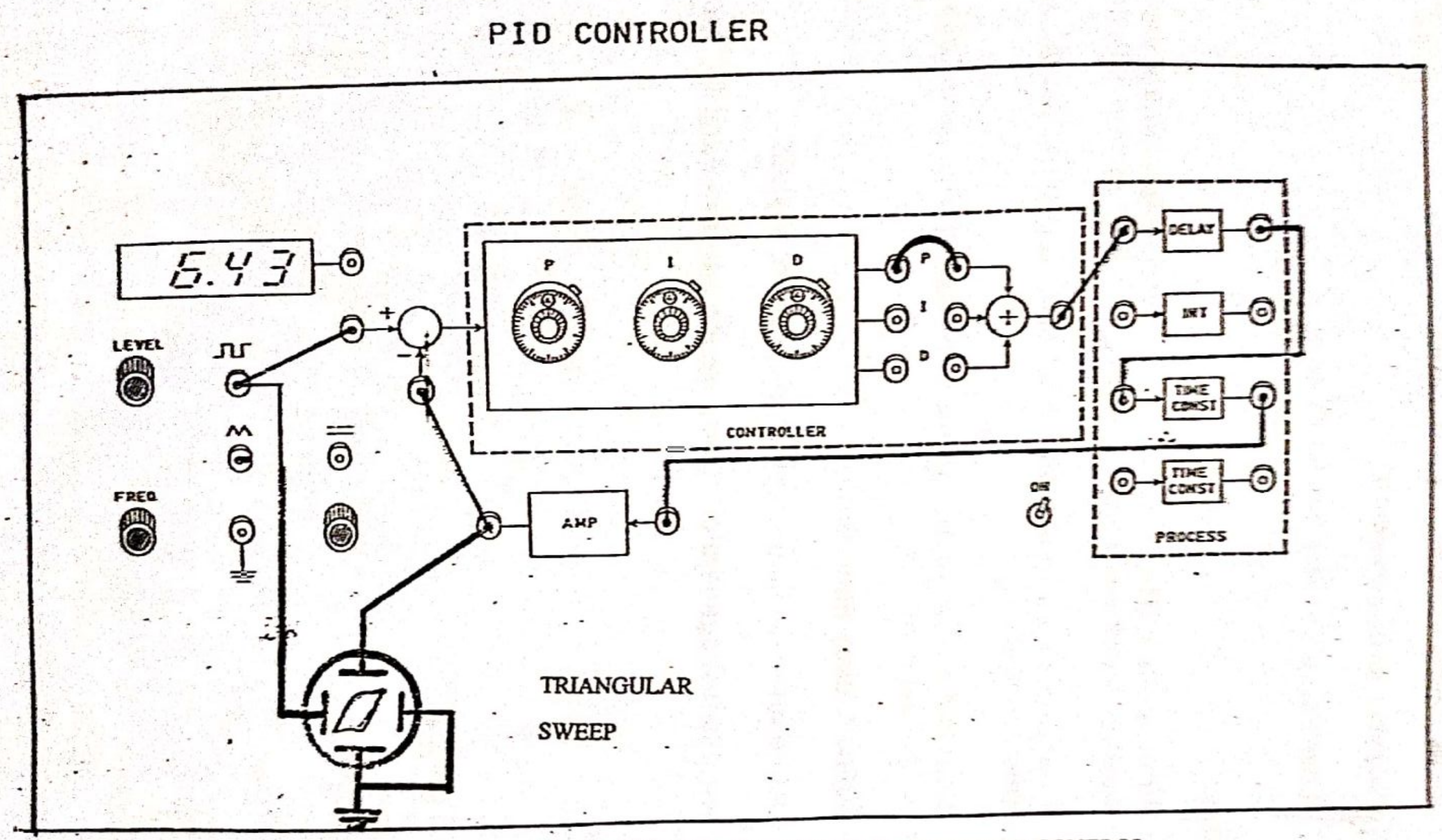


Fig 1: FIRST ORDER TIME DELAY SYSTEM: P CONTROL

Tabulation: - Controller Response

Controller type	Input wave	Output wave	Time period	Frequency Hz	Max Parameter
P	Square ____V(p-p)	Square ____V(p-p)	-	-	Kc=
I	Square ____V(p-p)	Triangular wave ____V(p-p)	___ msec		Ki =
D	Triangular ___V(p-p)	Square ___V(p-p)	___ msec		Kd =

P Control System type - 0 with time delay

S.No	Scale reading		Kc	X=two steady state value	Y=2 stdady state value	Steady state error ess	% mp over shoot
	Main	Inner					

a) The performance of the system is evaluated interns of a set of performance specification like a rise time, peak time, settling time, peak percent overshoot and steady state error in the time domain.

b) Gain margin, phase margin, closed loop bandwidth etc in frequency domain.

2. Another approach to improve the system performance through elementary control actions with controller inserted in the forward path (fig.2) of an existing control system, which has a unity feedback.

   The controller comprises of two or three of the following controls.

   a) `Proportional (P)

   b) Integral (I)

   c) Derivative (D)

   This PI, PD, PID controllers are widely used in process industries like petroleum, chemical, power, food etc.

3. PID controller

The equation of a PID controller is given by

$$M(t) = Kc\, e(t) + Ki \int e(t)\, dt + Kd \frac{de(t)}{dt} \qquad \text{———— (1)}$$

where e (t) is the error signal and M(t) is the PID output or plant output

Kc Proportional gain

Ki Integral gain

Kd Derivative gain

Equation (1) in Laplace domain

$$M(s) = Kc\, E(s) + \frac{Ki}{s} E(s) + s\, Kd\, e(s) \qquad \text{———— (2)}$$

Equation (2) represent fig.3.

Equation (2) can be rewritten as

$$M(s) = Kc\,[1 + \frac{1}{T_i} + T_d s]\; E(s) \qquad \text{———— (3)}$$

Where T_i = Integral time constant

$$= \frac{Kc}{Ki}$$

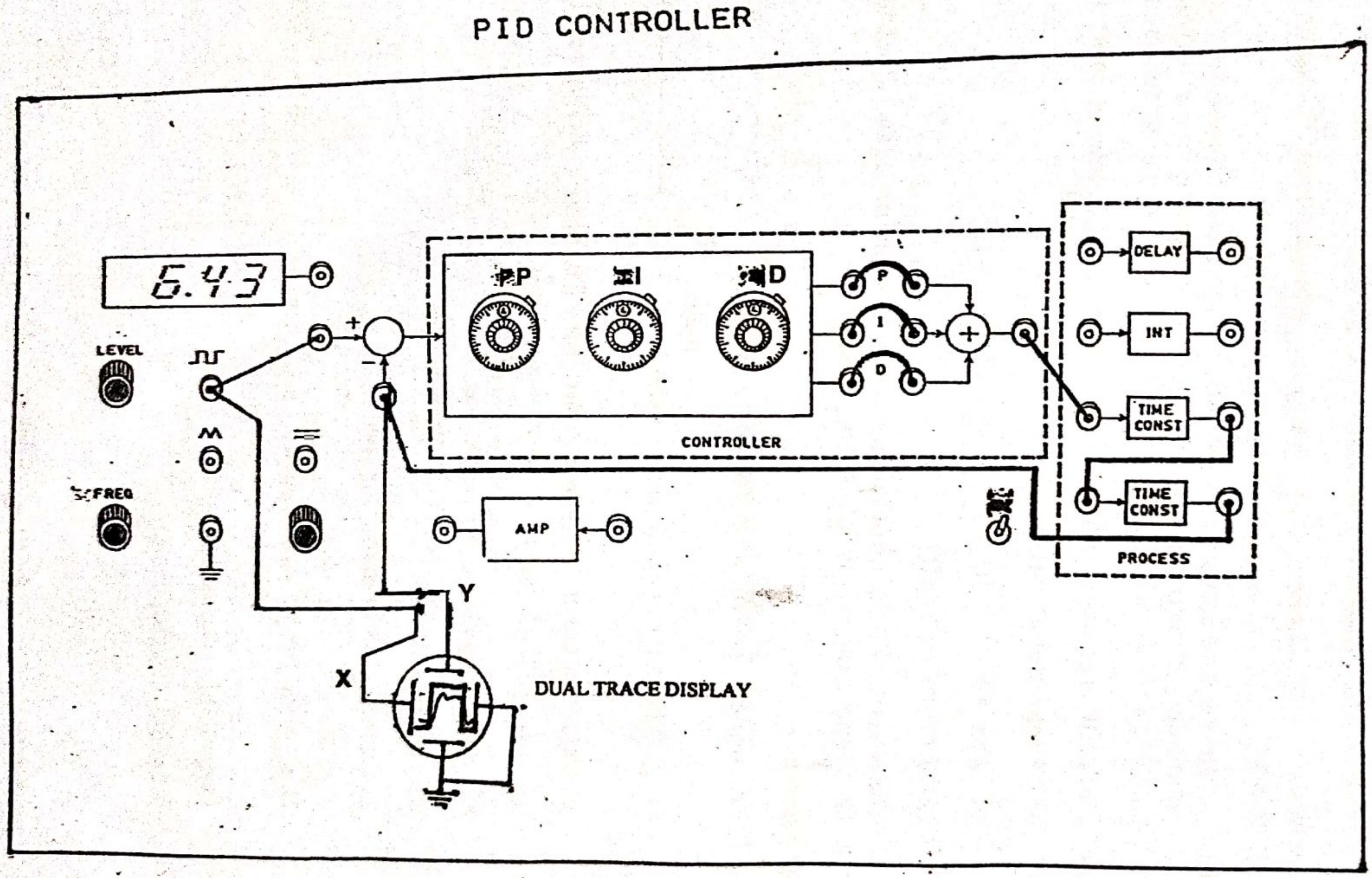


Fig :2 TWO TIME CONSTANT SYSTEM:PID CONTROL

PI Control: for Kc = 0.6; System = type -0 with time delay

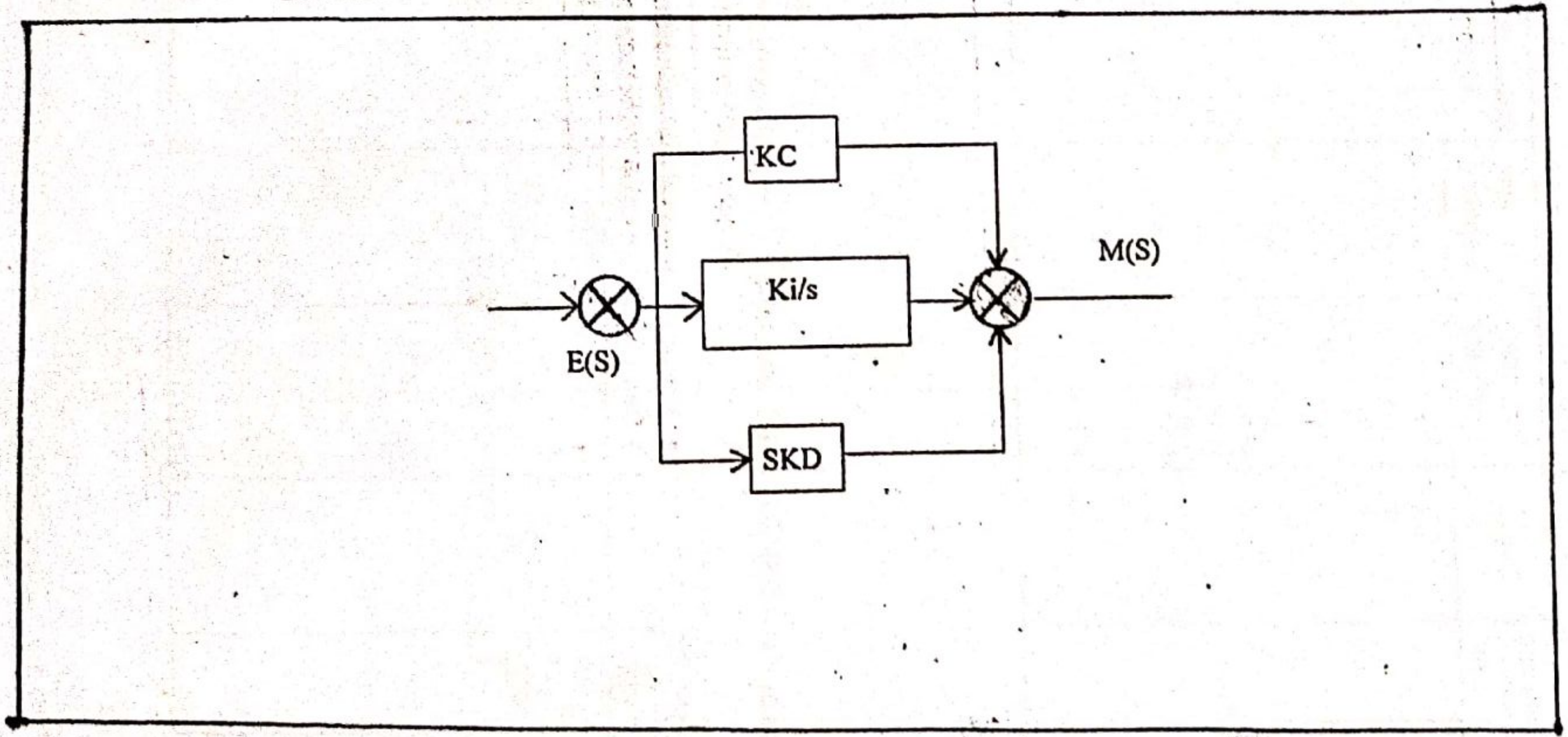
S.No	Scale reading		Ki/ Sec	X=2 steady state value	Y=2 peak response	Steady state error	% overshoot
	Main	Inner					

PID Control Kc = 0.6; KI = 100 System type = zero with time delay

S.No	Scale reading		Kc	X=2 steady state value	Y=2 stdady state value	Steady state error cess	% mp over shoot
	Main	Inner					

Fig. 3

PID
CONTROLLER



$$Td = \text{Derivative time constant} = \frac{Kd}{Kc}$$

Note: with this unit

$0 \leq Kc \leq 20$

$0 \leq Ki \leq 1000$

$0 \leq Kd \leq 0.01$

The transfer function of PID controller (from eqn.1)

$$G_{PID}(s) = \frac{M(s)}{E(s)} = \frac{K_d s^2 + K_c s + Ki}{s}$$

$$= \frac{Kd (s + \omega 1)(s + \omega 2)}{s} \qquad \text{——(4)}$$

where $\omega 1$, $\omega 2$ are the two zeros of the PID controller transfer function

PID Controller Design

(1) This can be designed both in frequency domain and in the "S" plane, through the **classical (or) trial and error** design procedure. The method needs the pole-zero locations (or) frequency - phase responses of the plant, for its implementation.

For a plant which are characterised by

(a) In complete or inaccurate plant equations

(b) Extremely slow response

(c) Presence of time delays

(d) Higher order transfer function etc.,

An alternate simple techniques of setting the controller parameters (Kc, Ti, Td) or tuning can be achieved by any of the three methods i.e.,

1. Trail and error tuning
2. Continous cycling method
3. Process reaction curve method

Trail and error tuning:

This method is simple, systematic method for on-line tuning of a PID controller. In this method Kc, Ki, Kd are available for adjustment.

PID Control: Kc = 0.6, Ki =.

Second Order, Type - 0 system with time delay & input = 1V (p-p) square wave of low frequency

S.No	Scale reading		Kd	X	Y	Steady state error	% overshoot
	Main	Inner					

Step

1. Set Ki and Kd to zero.
2. Starting from a low value increase Kc gradually till sustained oscillation sets in this condition is tested by small disturbances generated by varying the reference signal slightly. The value of proportional gain so obtained is called as **Ultimate gain** (Kcu).
3. Set to 1/2 of the value obtained in step 2.
4. Increase Ki gradually until sustained oscillations start gain set Ti to 1/3 of this value.
5. Increase Kd gradually until sustained oscillations start again. Set Td to 1/3 of this value.

Limitations of the above method

1. A number of systems, which are, or may be approximated to first or second order transfer functions without time delay do not oscillate. Therefore reducing Kc to half of its value, which was got when sustained oscillation sets in.
2. Open loop unstable system cannot be handled.
3. Tuning of very slow system is extremely time consuming.
4. Sustained oscillations may not be acceptable or may be risky in some physical processes such as a large chemical process.

Procedure:

Controller Response

Calibration of the three potentiometers used in PID controller.

1. Connections are made as per the circuit diagram.
2. A square wave signal of 100mv p-p is applied to the input of the error detector.
3. P, I, D, outputs are connected to the summer and the output of the controller was traced.
4. The p-potentiometer is set to maximum and I&D potentiometers are set to zero to obtain the maximum value of

$$Kc = \frac{\text{(p-p) square wave output}}{\text{(p-p) square wave input}}$$

$$= \frac{\text{(p - p) square wave output}}{0.1}$$

5. The I-potentiometer is set to maximum and P&D potentiometers are set to zero, (a ramp output was obtained) Maximum value of Ki was found

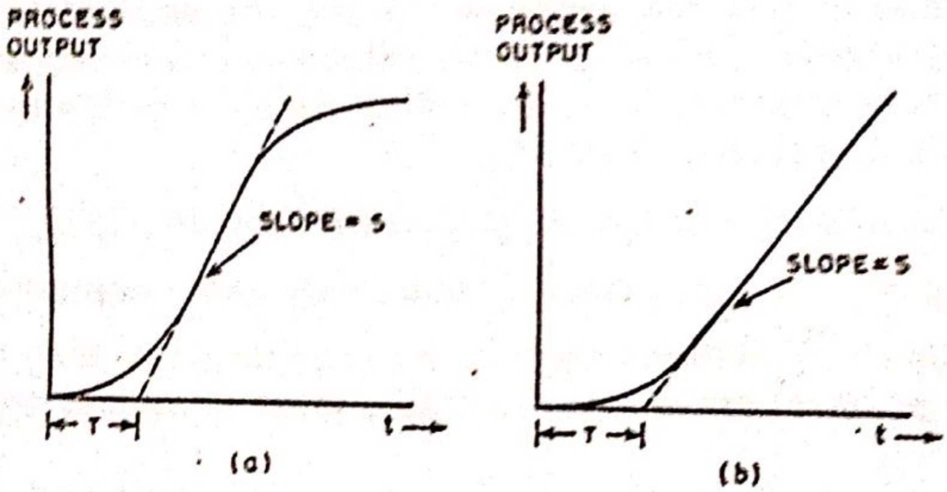


FIG. 5 STEP RESPONSE OF (a) TYPE-0, (b) TYPE-1 SYSTEMS

$$Ki = \frac{4 * f * (\text{p-p}) \text{ triangular wave output amplitude in volts}}{\text{p-p square wave amplitude Input}}$$

Where f - frequency of the input = 1 / T =

1. The D - potentiometer is set to maximum and P&I potentiometers are set to zero (a series of sharp pulses were obtained as output) As the output is not suitable for calibrating D - potentiometer, triangular wave is given (applied) as the input (& output is of square wave)

$$Kd\ max = \frac{\text{(p-p) square wave output}}{\text{4.f. (p-p) triangular wave input}}$$

where f - frequency of input

The three potentiometers P, I & D are set to maximum values and a square wave of 100mv (p-p) is applied as input. The output response was traced.

Proportional control

1. The connections are made as per the panel diagram.

2. The input amplitude is set to 1v (p-p) and frequency to a low value.

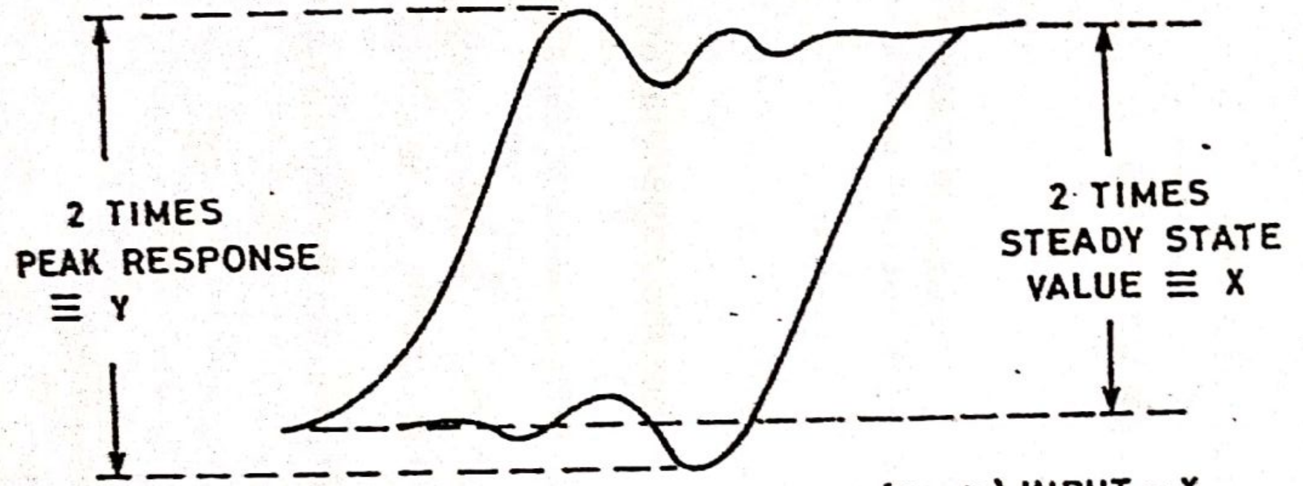
3. For various values of Kc = 0.2, 0.4, ... the peak overshoot & steady state error was obtained from the graph and readings are tabulated.

4. The above procedures are repeated for various systems with or without time delay.

Formula:

$$\text{Steady state error} = \frac{\text{(p-p) input} - X}{\text{(p-p) input}}$$

$$\text{Peak percent over shoot} = \frac{Y-X}{X} * 100$$



$$\text{S. S. ERROR} = \frac{(p-p)\ \text{INPUT} - X}{(p-p)\ \text{INPUT}}$$

$$\text{PEAK PERCENT OVERSHOOT} = \frac{Y - X}{X}\ 100\ \%$$

Fig. 4. CRO DISPLAY OF STEP RESPONSE USING TRIANGULAR TIME BASE

Proportional - Integral control

1. The connections for a first order type - 0 system with proportional and integral blocks are made.
2. The input is set to 1v (p-p) and frequency to a low value and Ki is set to zero.
3. For say Kc = 0.6 observe and record the peak overshoot & steady state error.
4. For the same Kc, Ki is increased in small steps and at each step the peak over shoot and steady state error are noted.

Proportional - Integral - Derivative control

1. The connections are made as per the panel circuit diagram with proper integral and derivative blocks connected.
2. The input is set to 1v (p-p) and frequency to a low value and also set Kc = 0.6, Ki set to low value (say scale setting of 0.05) and Kd = 0

Note:

With this the system shows a fairly large overshoot.

The peak overshoot & the steady state error are noted.

3. The above procedures are repeated for a few non zero values of Kd.
4. For Kc = 0.6, Ki, Kd are adjusted by trial and error to obtain the best overall response. Kc, Ti, Td, are noted.
5. The above procedure is repeated for Kc = 0.4, 0.2 etc...

Result :

Thus performance characteristics of PID controller were studied.

Questions:

1. What is **P - controller** and what are its characteristics?
2. What do you mean by PI - controller & what are its characteristics?
3. What is a PID - controller & what are its effects on the system performance?
4. What do you mean by "Proportional sensitivity" in a controller with proportional control action?
5. Define Peak time, rise time, and % overshoot.

TEMPERATURE CONTROL SYSTEM

Aim:

To study the performance of various types of controllers used to control the temperature of an oven.

Equipments required:

Temperature control system unit
Patch chords
Stop watch

Procedure:

i) Identification of oven parameters :

1. The oven has to be driven through P- amplifier and so set to its maximum gain of 10

2. The input to this amplifier is adjusted through the reference potentiometer (the one next to switch S_2). This input can be seen on digital display, so that if 5.0°C is set, the input to the proportional amplifier is 50mv (i.e. 10mv / °C) and its output (which is the input to the driver circuit) is 0.5v (50mv * 10)

3. The switch S1 is kept " Wait " and S2 to "Set" position and feedback terminals are opened.

4. The " P " output is connected to the actuator input and the input is switched on.

5. The potentiometer " P " is set to 1 which gives Kp =10. The reference potentiometer is adjusted to make the DVM to read 5V. (This provides an input of 0.5v to the driver).

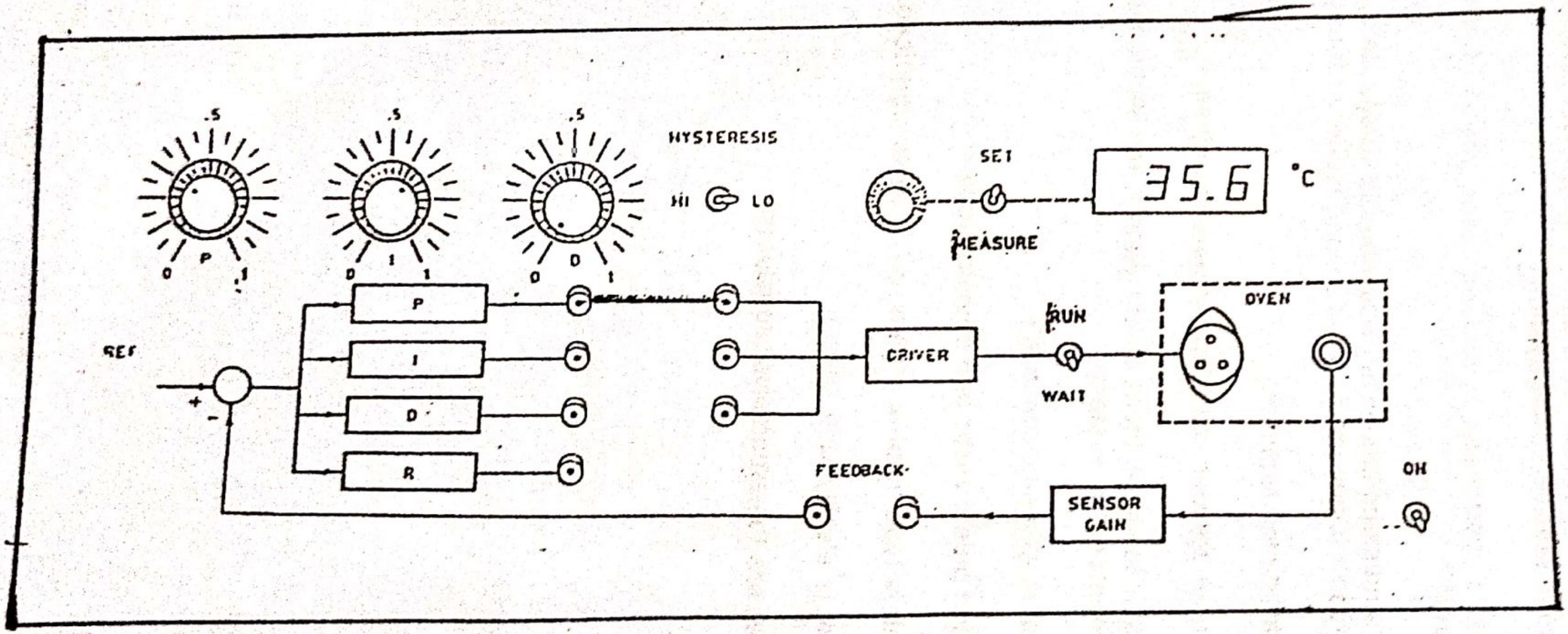
6. The switch S_2 is thrown to "Measure" position and the room temperature is measured.

7. The switch S_1 is thrown to "Run" position and the temperature readings for every 15 seconds are noted till the temperature becomes almost constant.

8. Temperature - time curve is plotted and T_1, T_2 are calculated. [fig.1] and the transfer function of the oven including its actuator were found.

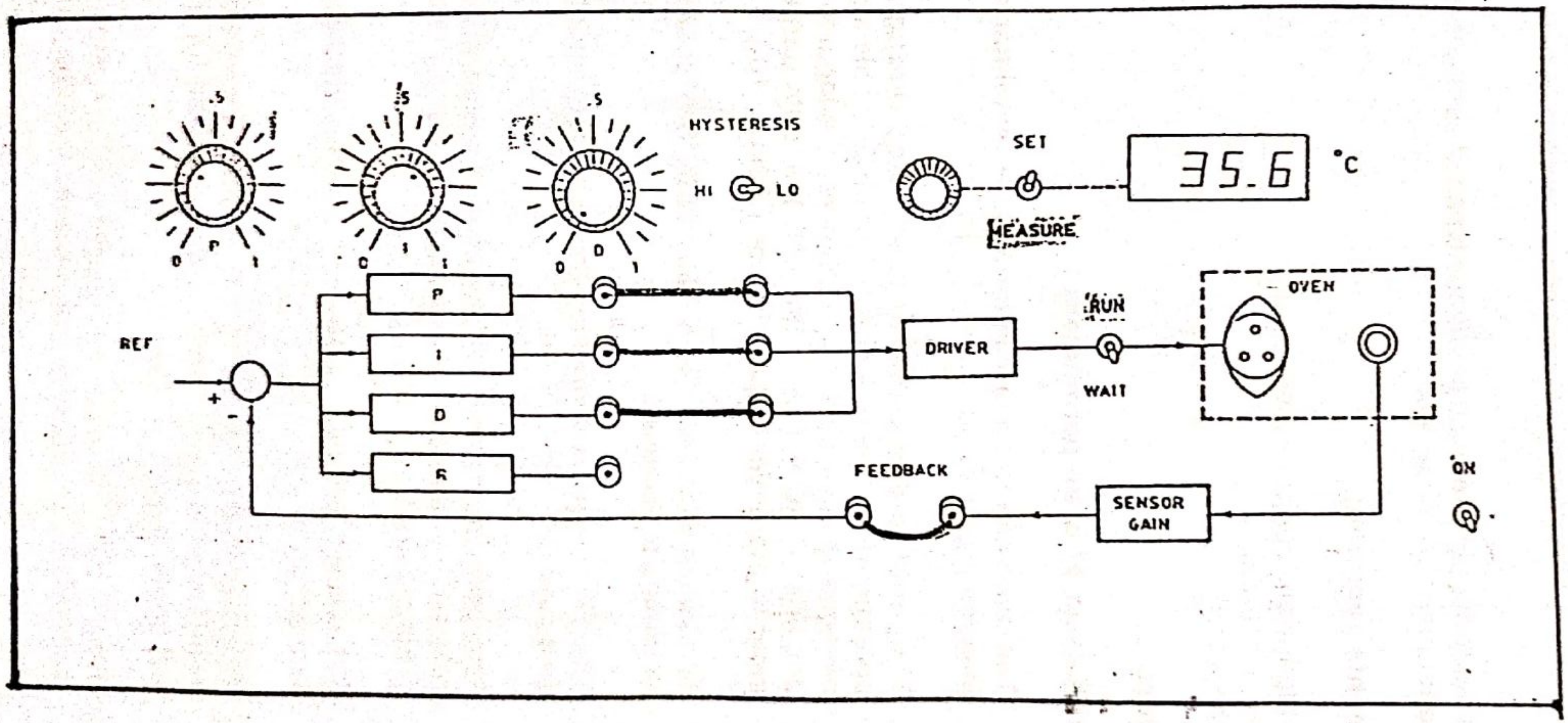
$$G(s) = K \exp^{[(-ST_2)/(1+ST_1)]}$$

OPEN LOOP RESPONSE



TEMPERATURE CONTROLLER SYSTEM

CLOSED LOOP-PID



TEMPERATURE CONTROLLER SYSTEM

P - Controller

S.No	Time in Sec.	Temperature in ° C	Rise Time	Steady State Error	% over shoot	t_p	t_s

PI - Controller

S.No	Time in Sec.	Temperature in ° C	Rise Time	Steady State Error	% over shoot	t_p	t_s

P.I.D. Controller :

S.No.	Time in Sec.	Temperature in °C	Rise Time t_r ms	Steady State Error	% over shoot	t_p ms	t_s ms

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ii) PROPORTIONAL CONTROLLER

1. Based on Ziegler and Nichols suggestion Kp is calculated using the formula

   $Kp = (1/K)\ (T_1/T_2)$

   $$\text{Where } K = \frac{\text{oven temperature at steady state}}{\text{Input (Volt)}}$$

   T_1, T_2 from previous test

2. Starting with a cool oven, the switch S_1 is thrown to "Wait" position and the "P" output is connected to the actuator input, keeping R, D and I outputs disconnected and feedback terminals are shorted.

3. The P potentiometer is set to the calculated value.
   (Note: Pmax = 10)

4. The desired temperature is set (say 55.0°C)

5. The switch S_1 is thrown to "Run" position and the temperature readings for every 15 seconds are noted till the temperature becomes constant.

6. Temperature - Time curve is plotted and the following parameters are calculated

   a) Rise Time

   b) Steady state error

   c) % overshoot

III PROPORTIONAL - INTEGRAL CONTROLLER

1. Based on Ziegler and Nichols the value of Kp and Ki are calculated using the formula

   $Kp = (0.9\ /\ K)\ T_1/T_2$

   $T_I = 1/\ K_I\ \ = 3.3T_2$ or

   $K_I = (1/3.3T_2)$

2. Starting with a cool over, the switch S_1 is thrown to "Wait". The outputs P and I are connected to the actuator input and outputs R and D are disconnected. The feedback terminals are shorted.

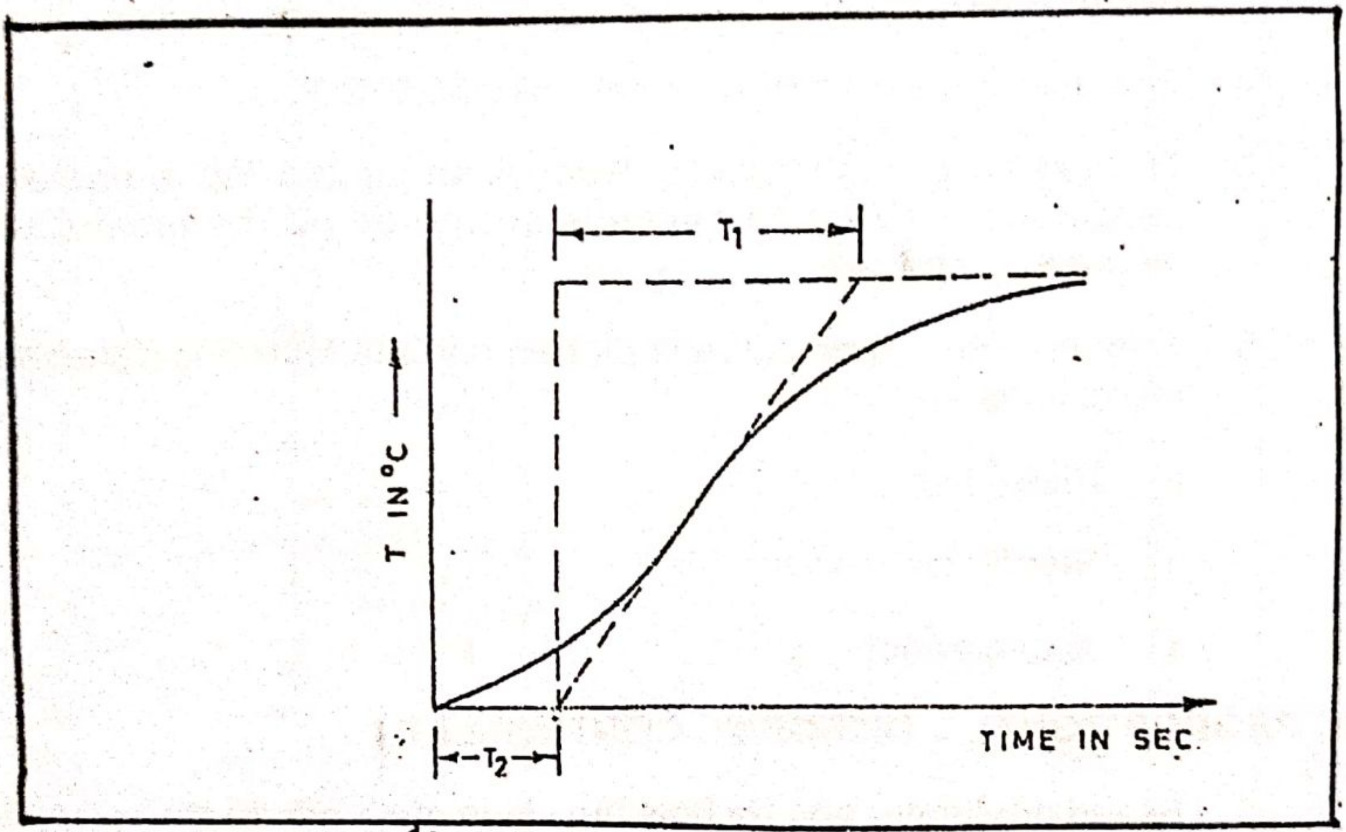


FIG. [illegible]. OPEN LOOP RESPONSE OF THE OVEN

3. P and I potentiometers are set to the above calculated value. (Note: Kp Max = 10, K_I max = 0.024)

4. The desired temperature is set (say 55° C).

5. The switch S_1 is thrown to "Run" position and the temperature readings for every 15 seconds are noted till the temperature becomes constant.

6. Temperature - Time curve is plotted and the following parameters are calculated

   a) Rise Time

   b) Steady state error

   c) % overshoot

IV Proportional Integral - Derivative Controller

1. Based on Ziegler and Nichols P, I, D values are calculated using the formula

   $Kp = (1.2 / K) T_1/T_2$

   $T_I = 1/K_I = 2T_2$ or $K_I = 1/(2T_2)$

   $K_D = T_D = 0.5T_2$

2. Starting with a cool oven, the switch "S_1" is thrown to "Wait" position. The output of P, I, D is connected to the actuator input with output R is disconnected and the feedback terminals are shorted.

3. The potentiometer P, I, D are set to the above-calculated value. (Note: $Kp_{max} = 10$, $K_{Imax} = 0.024$, $K_{Dmax} = 23.5$)

4. The desired temperature is set (say 55.0 °C)

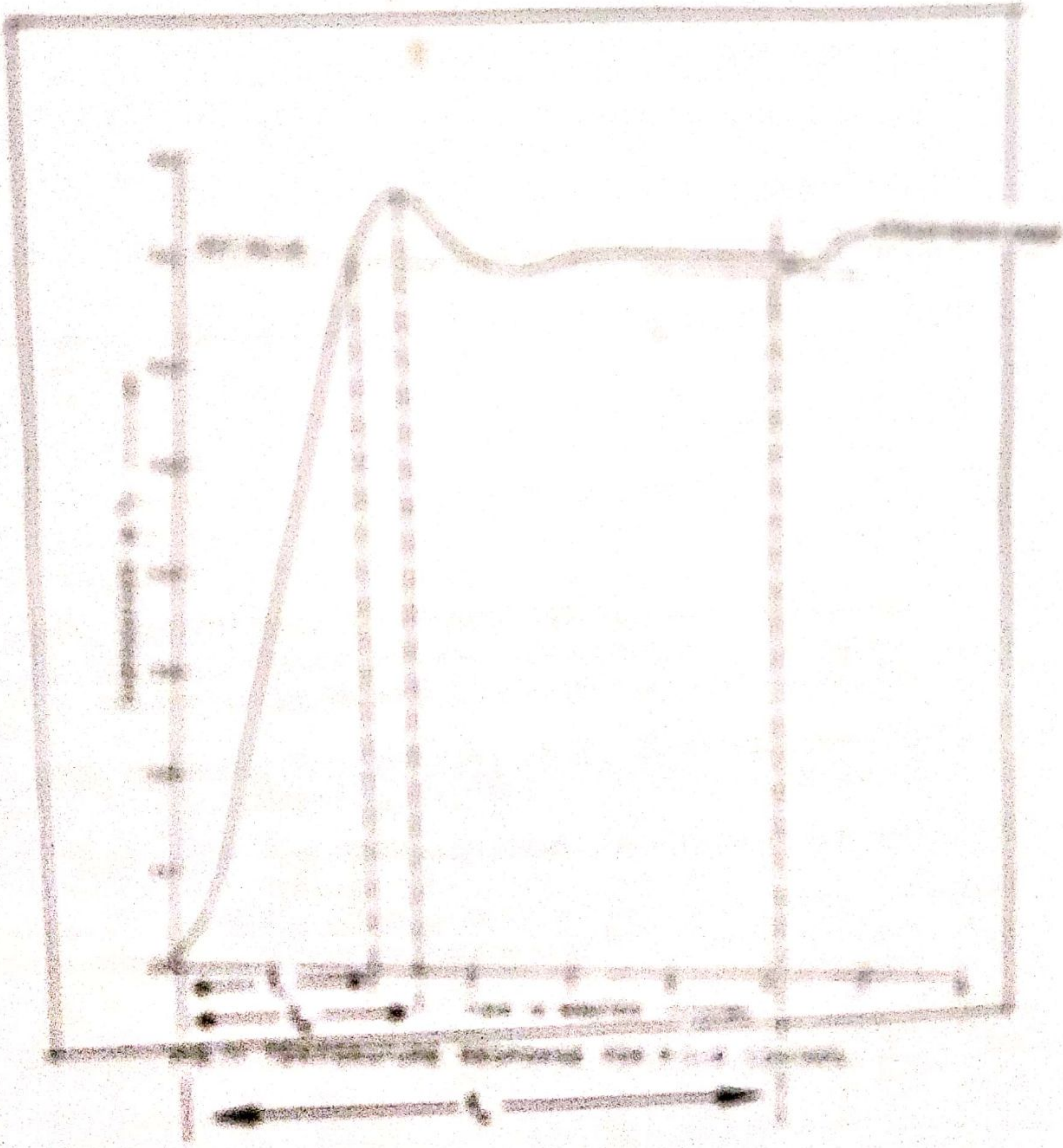
5. The switch S_1 is thrown to "Run" position and the temperature readings for every 15 seconds are noted till the temperature becomes constant.

6. Temperature - Time curve is plotted and the following parameters are calculated

   a. Rise Time

   b. Steady state error

   c. % over shoot



Formula:

I) Open loop measurement.

$$K = \frac{\text{oven temperature at steady state}}{\text{Input (Volts)}}$$

Note: Inputs is 0.5V.

From Graph

T_1 = ________ Sec, T_2 = ________ Sec,

ii) P - Controller

$Kp = (1/K)\ T_1 / T_2$ = ____________ V /C°

K_{Pmax} = 0.1 V/C°

P - Setting required for proportional control

$$= \frac{Kp}{K_{Pmax}} * 100 = \_\_\_\_\_\_\_\ \%$$

iii) P - I Controller

$Kp = (0.9 / K)\ T1/T_2$ = ________ V /C°

P - Setting required $= \frac{Kp}{K_{Pmax}} * 100$ = ________ %

$T_1 = 3.3T_2$

$$K_i = \frac{1}{T_1} = \frac{1}{3.3T_2}$$

$K_{I\ max}$ = 1/ 41 = 0.0244

I Setting required $= \frac{Ki}{K_{Imax}} * 100$ = ________ %

Controller	Rise - Time	Steady state error	% over shoot	Peak Time tp	Setting ts
P - Controller					
PI-Controller					
PID - Controller					

iv) P-I-D Controller

$Kp = (1.2 / K) T_1/T_2 =$ ________________ V/C°

P- Setting Required = $\frac{Kp}{Kpmax}$ * 100 =

$T_I = 2.0T_2$

$K_I = 1 / T_I = 1 / (2.0T_2)$

I setting = KI / K_{Imax} * 100 =

$K_D = T_D = 0.5T_2$

K_{Dmax} = 23.5 Sec.

D setting required = $K_D / K_D max$ * 100 =

Graph :

1) Temperature Vs Time for Open loop system

2) Temperature Vs Time for the system with P, PI and PID controller.

Result :

The performance of the various types of controllers for the control of the temperature of the given Oven and the results were tabulated.

Questions :

1. What is meant by "Rate Control"?
2. What is meant by "Reset Control"?
3. Discuss about the nature of the system whose steady state error is greater than the supplied input.
4. What is the transfer function of the given oven including its actuator?
5. What are the advantages of P, PI and PID controllers in this system?

Lag Compensation Design

Aim: To design, implement and study the effects of a Lag Compensation network in a given system

Equipment Required:

Compensation design unit
CRO
Probe
Patch chords
Resistance:
Capacitor:

Procedure:

a) Bode plot for the plant: Uncompensated System

1. Connections are made as per the panel diagram
2. One volt (p-p) sine wave is applied as input
3. Adjust from low frequency to high frequency of the (sine wave) applied voltage and the corresponding magnitude (db) and phase angle with respect to the frequency value are obtained.
4. The Magnitude-frequency and phase angle - frequency plots are plotted.

To obtain the plant transfer function $\frac{K}{(sT+1)^2}$ Draw a tangent in the magnitude - frequency plot to obtain the corresponding frequency and from that the plant time constant (T) is obtained and from the maximum magnitude value i.e., $20\log K = Max(G)$ the value of K can be calculated. Here K is the plant gain and T is the plant time constant. From the lissajous figure A, B, X_0 and Y_0 values are obtained

Frequency domain Performance:

Open loop bode plot is plotted $(f\ Vs\ |G|)$ and $(f\ Vs\ \angle G)$

Where $|G| = 20\log\left(\frac{B}{A}\right)$ and $\angle G = -Sin^{-1}\left(\frac{X_0}{A}\right)$ for the positive slope of the lissajous figure. For negative slope $\angle G = -180 + Sin^{-1}\left(\frac{X_0}{A}\right)$ and

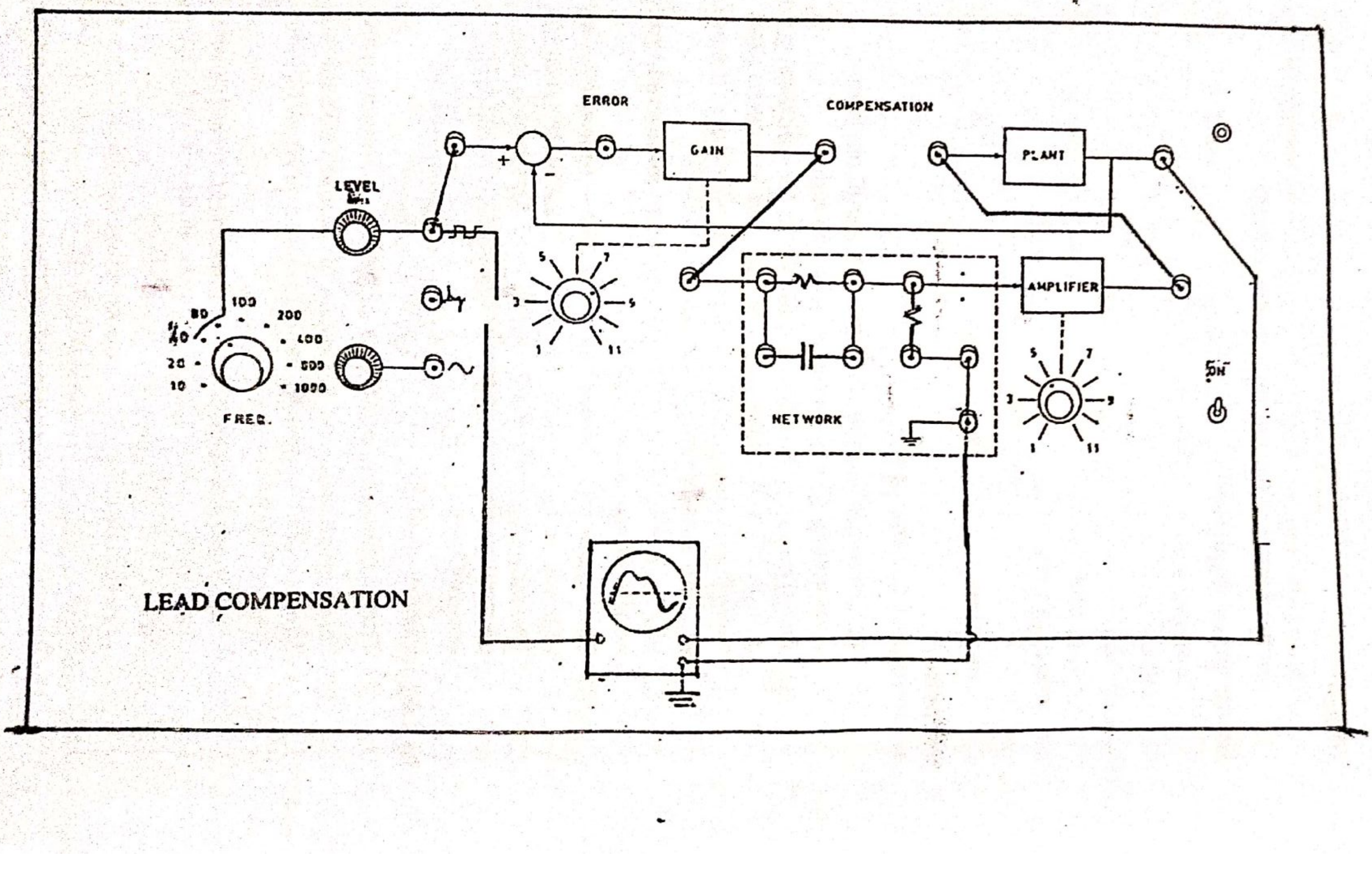
Plant Transfer function $= \frac{K}{(sT+1)^2}$

b) Lag network design

1. The connections are made as per the panel diagram.
2. For the given design specifications i.e. Phase Margin (PM) and Steady state error (ess) Let ess = 5% and Phase Margin = 50° be the design specification

Fig.2

COMPENSATION DESIGN



Note: $ess = \underset{t \to \alpha}{Lt}\left[r(t) - c(t)\right]$. Obtain the proportional gain value (K_P). Obtain $20\log\left(\frac{K_P}{K}\right)$ in db and plot

Position Error Coefficient (K_P) be obtained as follows $ess = \frac{1}{1+K_P}$ $(f\ Vs\ |G_1|)$;

where $G_1 = G + 20\log\left(\frac{K_P}{K}\right)$. i.e. the magnitude plot is shifted by $+20\log\left(\frac{K_P}{K}\right)$ in db.

3. From the gain cross over frequency find the phase margin. For the required phase margin obtain the new gain cross over frequency which will be the zero cross over frequency. The value of β can be found out from the corresponding gain margin which is found to be $20\log\beta$.

   Phase Margin to be increased (ϕ_m)= PM $_{Specified}$ - PM $_{from\ graph}$ $\pm 5^0$ (tolerance)

   Zero $Z_C = \frac{1}{T}$ is chosen approximately $0.1\,\omega_g$ i.e. one decade below the new gain cross over frequency and Pole $P_C = \frac{1}{\beta T}$ is selected accordingly.

   The Transfer Function of the Lead network can be represented as follows

$$G(s) = \frac{1}{\beta}\frac{\left(s+\frac{1}{T}\right)}{\left(s+\frac{1}{\beta T}\right)} = \frac{Ts+1}{\beta Ts+1}$$

$$G(s) = \left[\frac{R_2\left(s+\frac{1}{R_2 C}\right)}{(R_1+R_2)\left(s+\frac{1}{(R_1+R_2)C}\right)}\right] = \frac{1}{\beta}\frac{\left(s+\frac{1}{T}\right)}{\left(s+\frac{1}{\beta T}\right)}$$

   From above $T = \frac{1}{R_2 C}$ and $\beta = \frac{R_1+R_2}{R_2}$ then R_1, R_2 can be calculated.

4. The Closed loop performance of the plant is obtained by setting the amplifier gain as $\left(\frac{K_P}{K}\right)$.

5. The Phase Margin value is verified by applying sine input with the frequency equal to the new gain cross over frequency and from the corresponding lissajous figure.

6. The Steady State Error value is verified by applying square input to the system without and with compensation unit and the output responses are compared.

Note:

Delay Time (t_d): It is the time required for the output response of the system to reach 50% of the final value

Rise Time (t_r): It is the time taken for the output response of the system to reach 100% of the final value for the first time

$$t_r = \frac{\pi - \theta}{\omega_d}; \qquad \text{where } \theta = \tan^{-1}\left(\frac{\sqrt{1-\delta^2}}{\delta}\right)$$

Peak Time (t_p): It is the time taken for the output response of the system to reach its peak value.

$$t_p = \frac{\pi}{\omega_n \sqrt{1-\delta^2}}$$ where δ is the damping ratio and ω_n is the undamped natural frequency which depends on the value of δ.

Lag Compensation design

From Bode Plot

Max Gain | G | = 13

20 log K = 13

log K = 13 / 20; K = 4.47

Draw tangent to the curves and find the cross over frequency

$\omega C1 = 2\pi\ (85)$

$T = 1 / \omega C1 = 1 / 2\pi(85) = 0.00187$

Note:

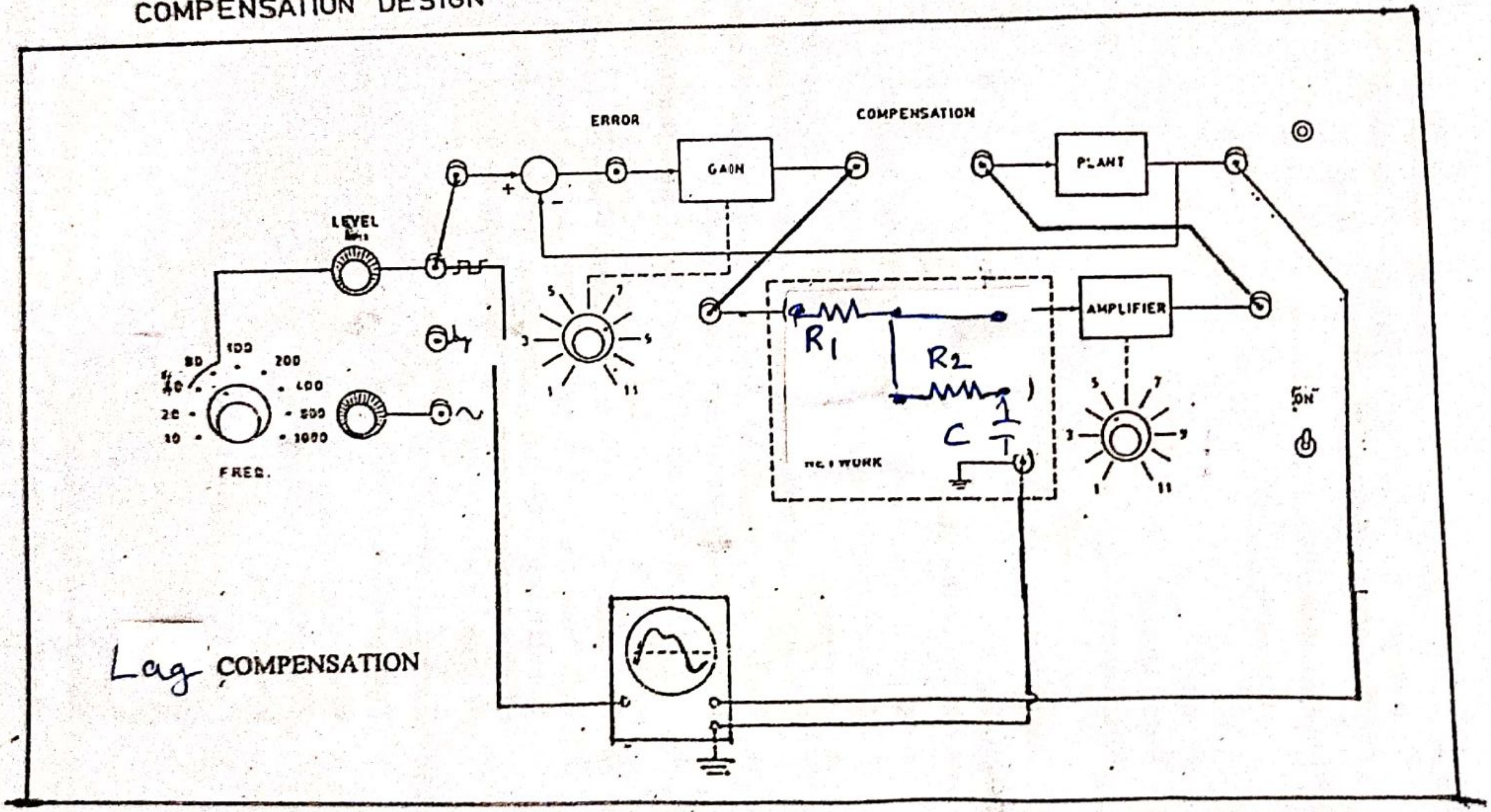
The plant is a second order dynamic system whose transfer function is given by

$$G(S) = \frac{K}{(sT + 1)^2} = \frac{4.47}{(1+s0.00187)^2}$$

Let the design requirements be ess = 0.05

Fig.2

COMPENSATION DESIGN



Tabulation: -

Fig: Phase gain measurements using CRO

Freq. Hz	A	B	X_0	Y_0	Gain dB	Phase (θ)
10						
20						
40						
80						
100						
200						
400						
800						
1000						

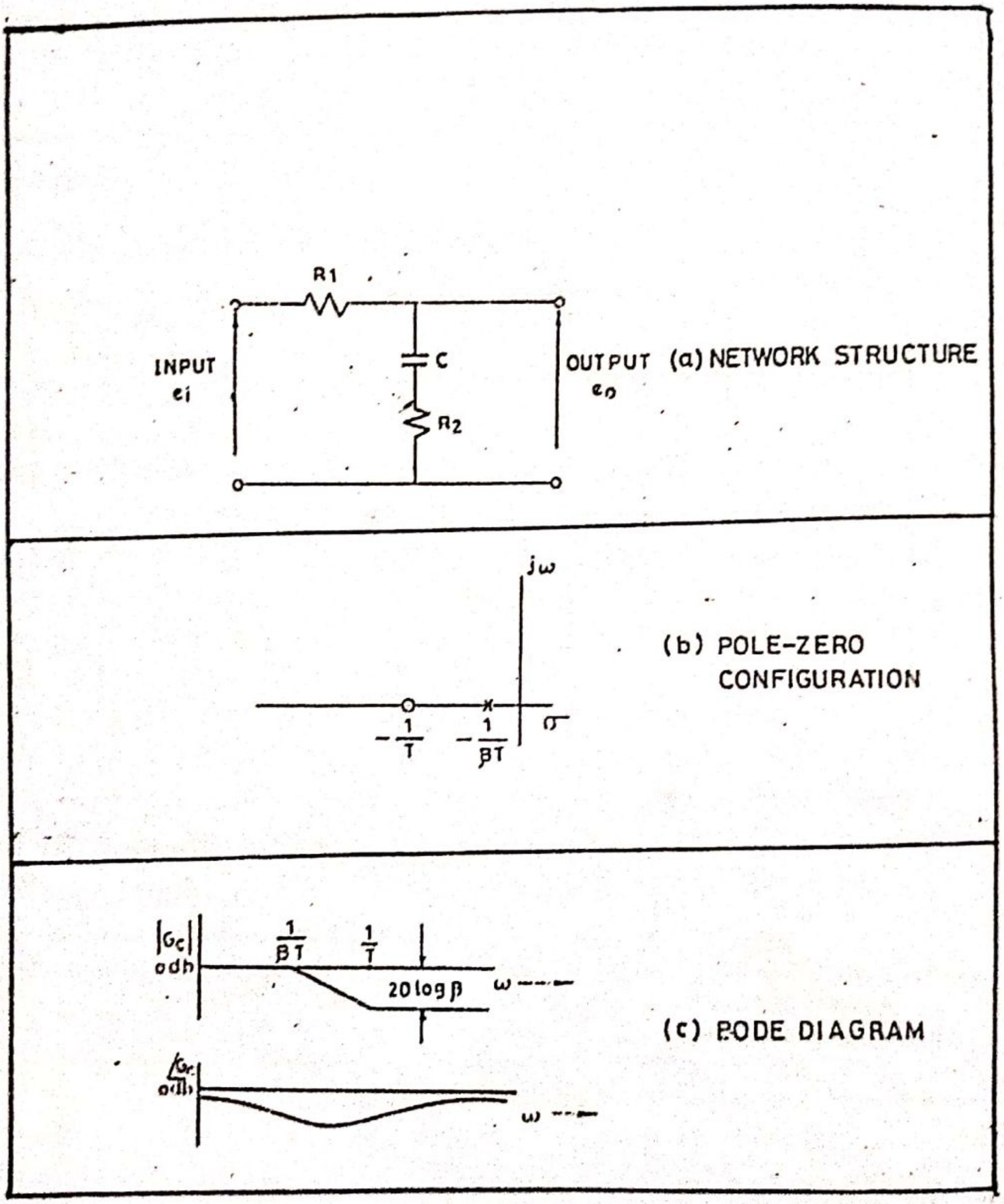


Fig. 5. LAG NETWORK CHARACTERISTICS

Table No: 1 Bode Plot: Uncompensated System

Frequency (Hz)	A	B	X_0	Y_0	Gain in db $\|G\|$	Phase Angle
20						
40						
80						
100						
200						
400						
800						
1000						

Table No: 2 Open loop system Bode Plot

Frequency (Hz)	Gain in db $\|G\|$	Phase Angle	Approximate Open Loop Transfer Function	Low Frequency Gain	Corner Frequency
20					
40					
80					
100					
200					
400					
800					
1000					

Table No: 3 Closed loop response of the system without and with compensation unit

System	Gain Value	$\%M_p$	T_r	ess	δ
Uncompensated System					
Compensated System					

Table No: 4 Closed loop system Bode Plot

Phase lead required (ϕ_m)

ϕ_m	$20\log\beta$	β	New gain crossover frequency	$G_c(s)$

The required value of error coeff Kp to ess specified; ess = 1 / 1 + Kp

$$\frac{1}{1 + Kp} = 0.05$$

$$Kp = 20 - 1 = 19$$

Therefore the gain has to be increased by 19 / 4.47 $\simeq 5$

20 log5 ≈ 14dB

The magnitude plot is shifted up by + 14 dB

From Bode plot the Gain cross over frequency

$\omega g = 2\pi \, (370)$

Phase margin = - 180 - (- 156) = 24

Phase margin required = 40°

For the above phase margin i.e. = -180 +40 = -140

$\omega g = 2\pi \, (200)$

The required high frequency attenuation = 20logβ = 9.5

β = 2.99

Chose the upper corner frequency of compensator

= 1 decade below ωg new

Zc = 1 / T = 2π(20)

Pc = 1 / βT = 125.67 / 2.99 = 42.03

For lag network

The transfer function of the above lag network is

$$Gc(s) = \frac{R2\ Cs + 1}{(R1+R2)\ Cs+1}$$

Let substitute R2C = T and $\frac{R1+R2}{R2} = \beta \ (>1)$

$$G(s) = \frac{Ts + 1}{\beta Ts+1} \qquad \text{——(1)}$$

$$= \frac{1(s+1/T)}{\beta(s+1/\beta T)} \qquad \text{——(2)}$$

Equation 1 is suitable for frequency domain design

Equation 2 with the 1/ β factor cancelled by an amplifier is suitable for root locus design.

For Lag network T = R2C

Let C = 1μf; RC = T = 1/Zc =

$$\beta = \frac{R1+R2}{R2} \Rightarrow \beta = \frac{R1+8.2}{8.2} = 2.99$$

R1= 24.52 - 8.2 = 18K

For unit step response of the system with gain set at 5(14dB)

Find %Mp = ; tp = ; ess = ;

To check weather required PM is obtained at ωg new, one-volt sine wave input is given at ωg new to the input of error detector of the compensator network and the values obtained from the graph are verified experimentally.

In X-Y mode find X_0 = ; A_0 = ;

$\phi = -\sin^{-1}(X_0 / A)$

Result:

Thus the lead and lag compensators are designed to satisfy the given requirement and the calculated parameters with the compensators are verified for the given network.

Questions:

1. Draw the various compensation schemes used for feedback control system?
2. What are the factors that affect the choice between the two compensation schemes?
3. What are the different types of electrical or electronic compensators, which are widely used?
4. Lead compensator increases the margin of stability - True or False
5. When will you select lead compensation?
6. When will you select lag compensation?
7. Lag compensation is essentially a low pass filter - True or False
8. Draw the S - plane representation of lag compensator.
9. Draw the S - plane representation of lead compensator.
10. What are the advantages of the cascade compensation?
11. Define phase margin, Gain margin
12. What is phase cross over frequency, gain cross over frequency?

LINEAR SYSTEM SIMULATOR

Aim:

To study the time response of a variety of simulated linear system and verify with theoretical values.

Equipments required:

Linear system simulator unit

CRO (Storage)

CRO probe - 2

Patch chords

Specification:

Build in sources :

Square wave	amplitude 0 - 2v (P - P)
	frequency 40 -90 Hz
Triangular wave	amplitude 0 - 2v (p-p)
	frequency 40 - 90 Hz
Trigger	amplitude +/- 5v (P - P)
	frequency 40 - 90 Hz

Procedure:

Open loop response:

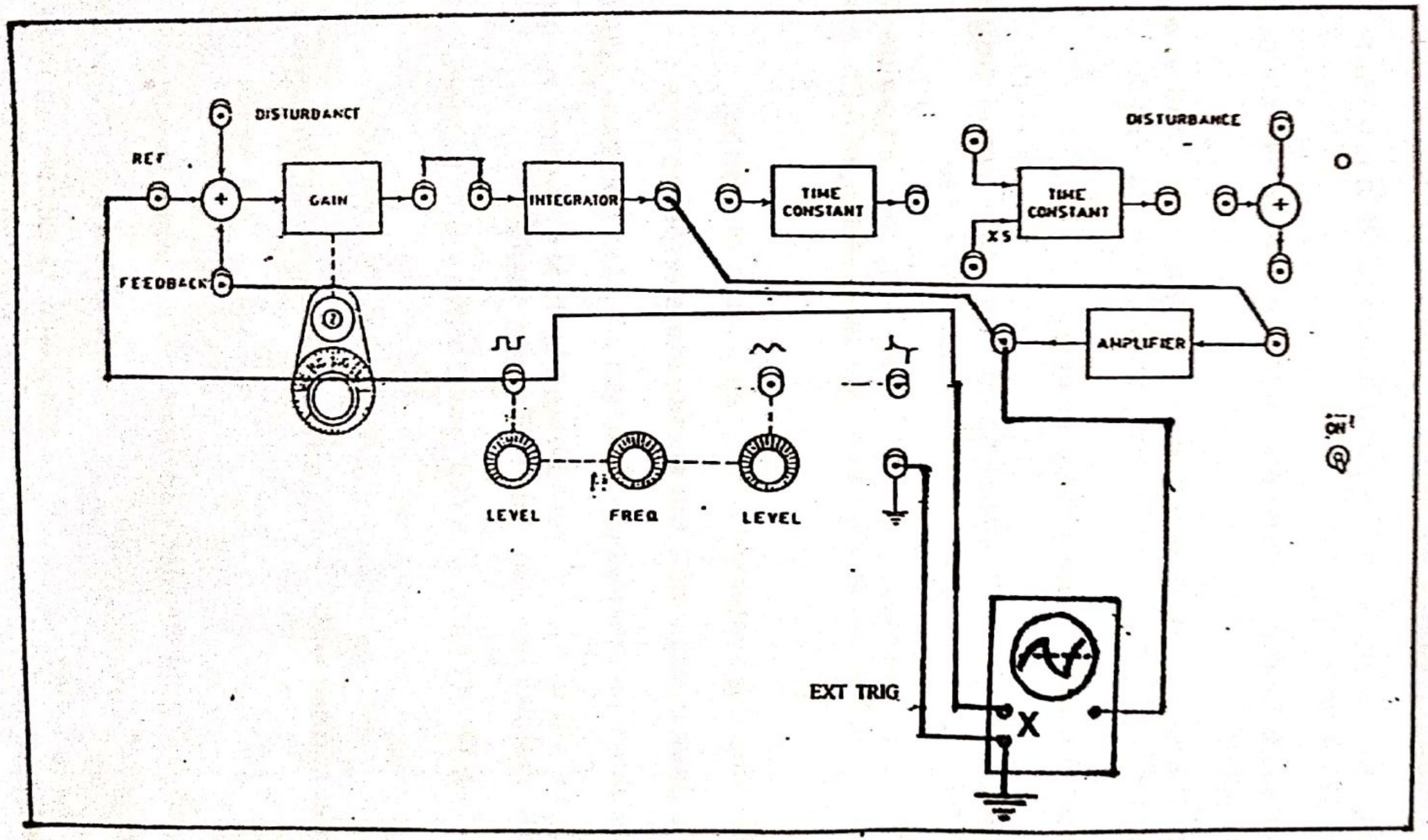
a. Error detector cum variable gain :

1. Any one of the 3 inputs is given 100 mv square wave signal
2. The gain setting potentiometer is set to 10
3. The output (p - p) voltages noted with its sign, the gain is also calculated (this is the max value of gain possible for this block)
4. The above procedure are repeated for the other inputs
5. By connecting the signal to all these inputs equation of this block was developed and verified

b. Disturbance adder

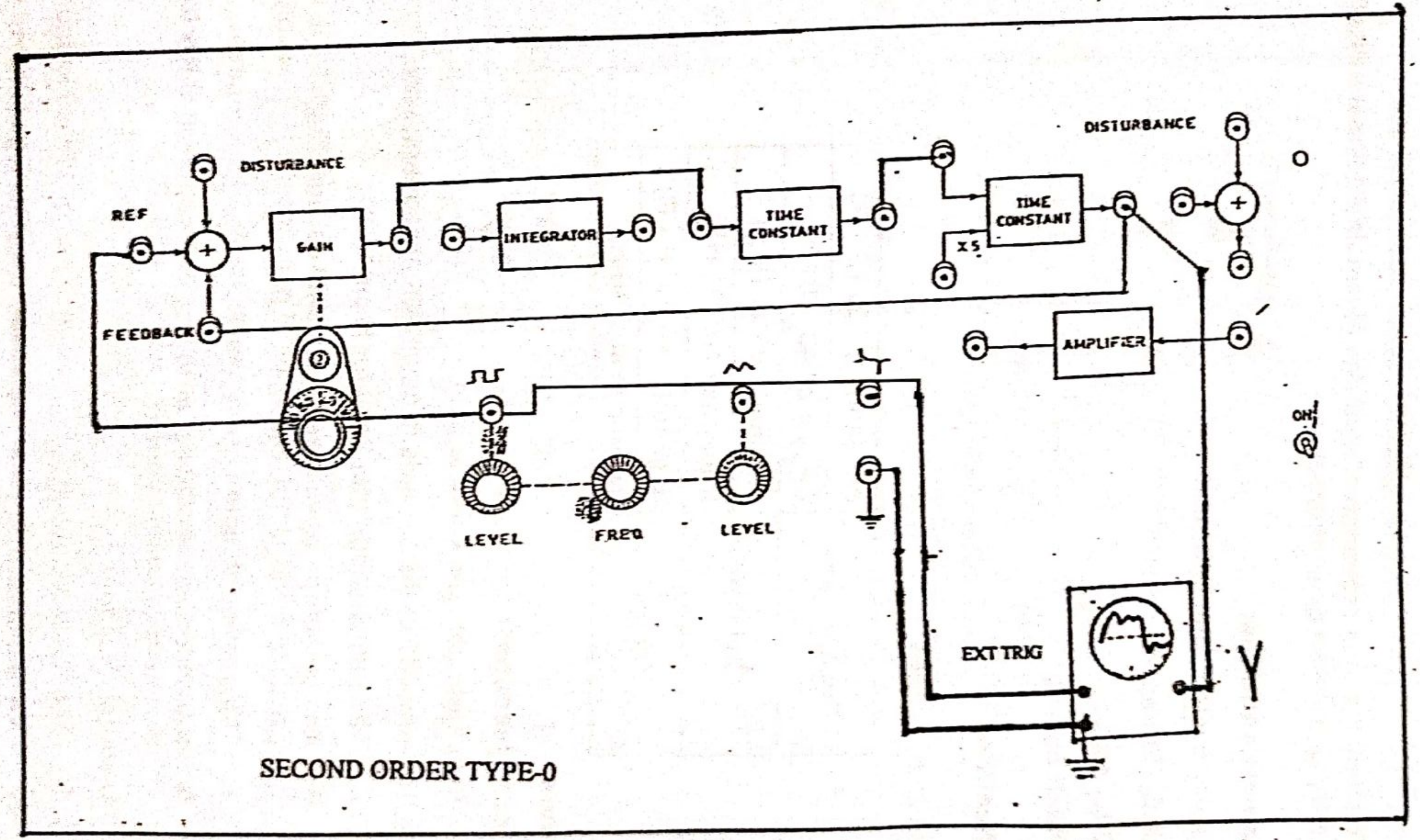
1. With the two inputs a square wave signal of 100 mv is applied
2. The output (p-p) voltage is measured and its sign is noted the gain is noted
3. The above procedure is repeated for other input.

LINEAR SYSTEM SIMULATOR



FIRST ORDER TYPE-1

LINEAR SYSTEM SIMULATOR



SECOND ORDER TYPE-0

c. Uncommitted amplifier

1. One-volt (p-P) square wave input is applied.
2. The output (p-P) voltage and its sign are noted. The equation of this block also noted.

d. Integrator

1. One volt (P-P) square wave input of know frequency is applied
2. The output (P-P) voltage of triangular wave magnitude and its phase is noted.
3. The gain constant (K) of integrator is calculated (If the square wave is of frequency "f" and peak-to-peak amplitude 4, the peak-to-peak amplitude of the triangular wave at the output of the pure integrator is given as k/4f). The transfer function of this block is also developed.

e. Time constants

1. A 100mv(P-P) square wave of know frequency is applied to the circuits.
2. Units step response of the first order transfer functions, the output is of the form

$$C(t) = k(1 - e^{-t/\tau})$$

With time t = T; the response reaches to 63.2%. This is the time constant. Where

$$K = \frac{\text{steady state output (p-p)}}{\text{Steady state input (p-p)}}$$

3. The steady state value of the response is traced and the parameters of the transfer function of the block is obtained.

Note: -

To get a properly synchronized waveform, especially for small values of signal, it will be convenient to use the built-in trigger source keeping the CRO in "external triggering" mode.

(I) Closed Loop Response First order system

Note:

The first order system is characterised by one pole and /or a zero. A pure integrator and a single time constant having transfer function of the form

$\frac{K}{s}$ and $\frac{K}{sT+1}$ are the two common forms of the first order closed loop systems.

Fig 2 unit step response of first order Transfer functions

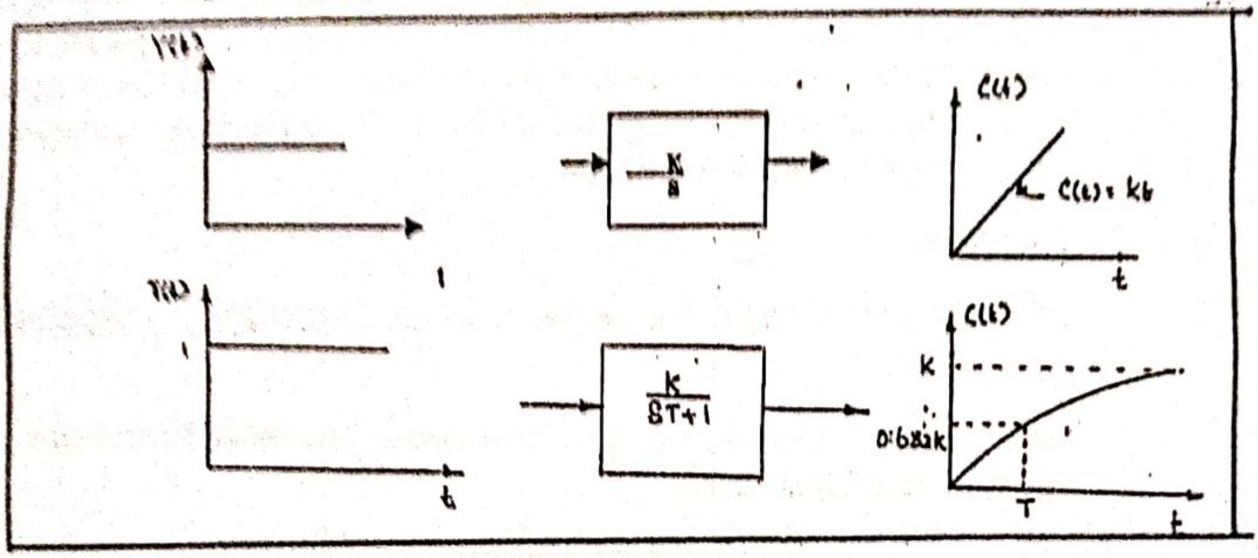
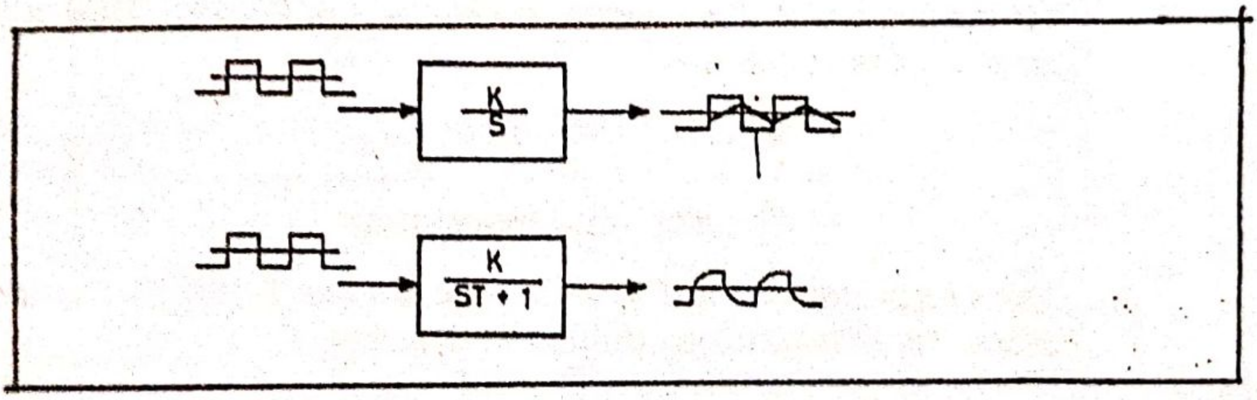


Fig 3 Square wave response of first order transfer functions



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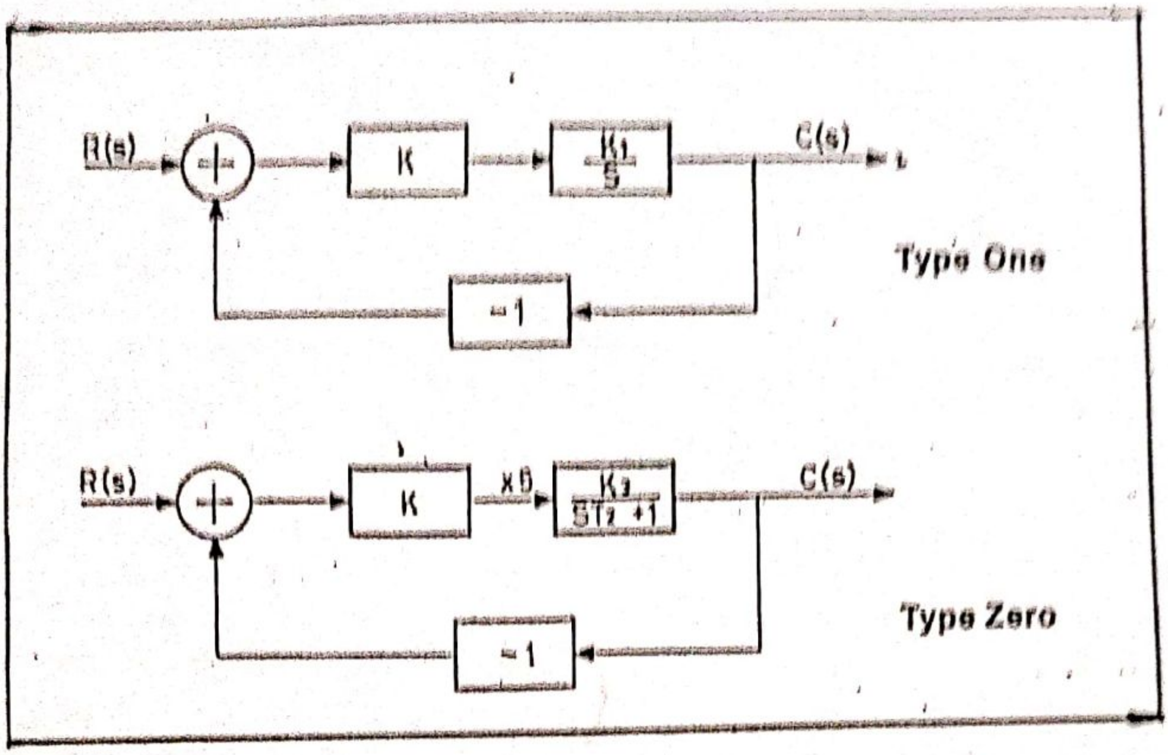

FIG. 5 CLOSED LOOP OPTIONS FOR FIRST ORDER SYSTEMS.

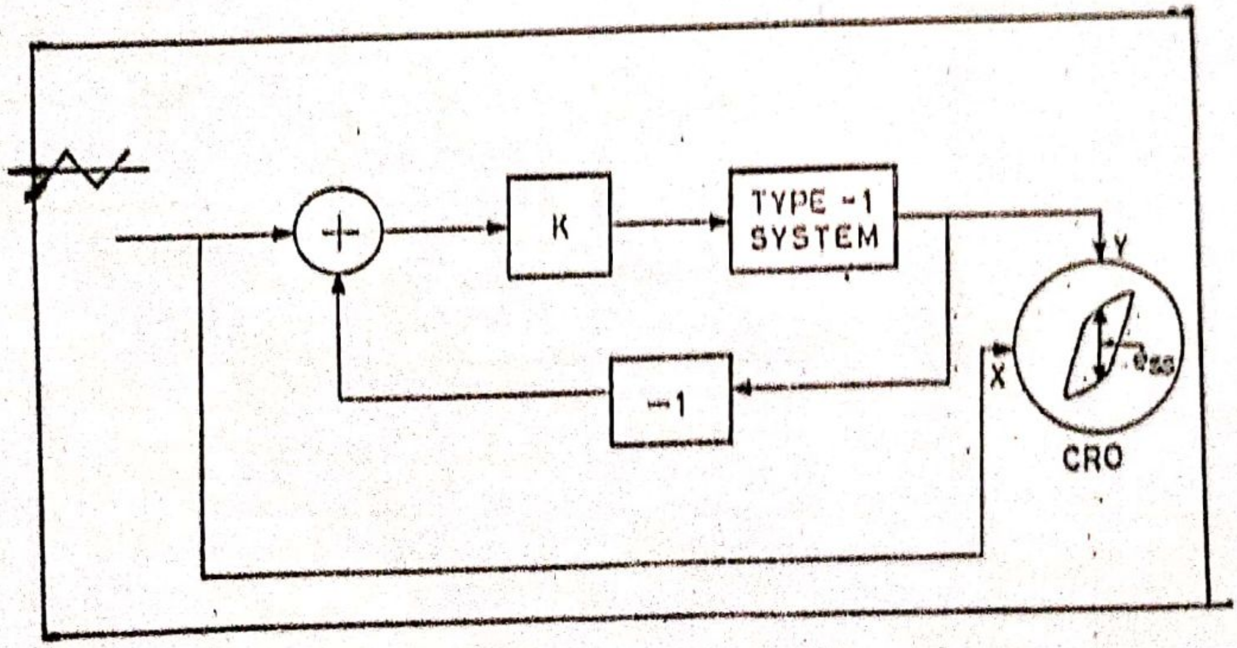

FIG. 6 STEADY-STATE ERROR FOR RAMP INPUT.

1. One volt (P-P) square wave input is applied and the output wave form for K = 0.5,1.0,1.5, ... are traced. The time constants for each case is calculated

2. The study state error are calculated for the above cases and are compared with the theoretical values

3. To study state error for ramp input:-

   (i) One volt (P-P) triangular wave is applied as input

   (ii) The CRO is kept in X - Y mode the system is connected to "X" input and output is connected to "Y" input. The wave is traced, the steady state error (ess) i.e. the vertical displacement between the two curves is noted.

   (iii) The steady state error for different values of "K" is measured & is compared with theoretical values.

(iv) Closed loop Response - Second order systems

1. Connections are made as per the block diagram..

2. One-volt (P-P) square wave is applied as input, the output waveform is traced for various values of "K".

3. The corresponding peak percentage overshoot, settling time, rise time and steady state errors, δ, ω_n are calculated

4. For type - 1 systems the steady state error was obtained using r amp input (for a step input the steady state error will be zero, the input must be of ramp nature)

Formula:

Closed loop second order type - 1 system

$$\text{Maximum over shoot (Mp)} = \frac{C\,(\text{peak}) - C\,(\alpha)}{C\,(\alpha)} \times 100$$

Settling time (ts)

$$\text{ts } (\pm 5\% \text{ tolerance band}) = \frac{3}{\delta\omega_n}$$

$$\text{ts } (\pm 2\% \text{ tolerance band}) = \frac{4}{\delta\,\omega_n}$$

Peak time (tp)

$$tp = \frac{\pi}{\omega_n(\sqrt{1 - \delta^2})}$$

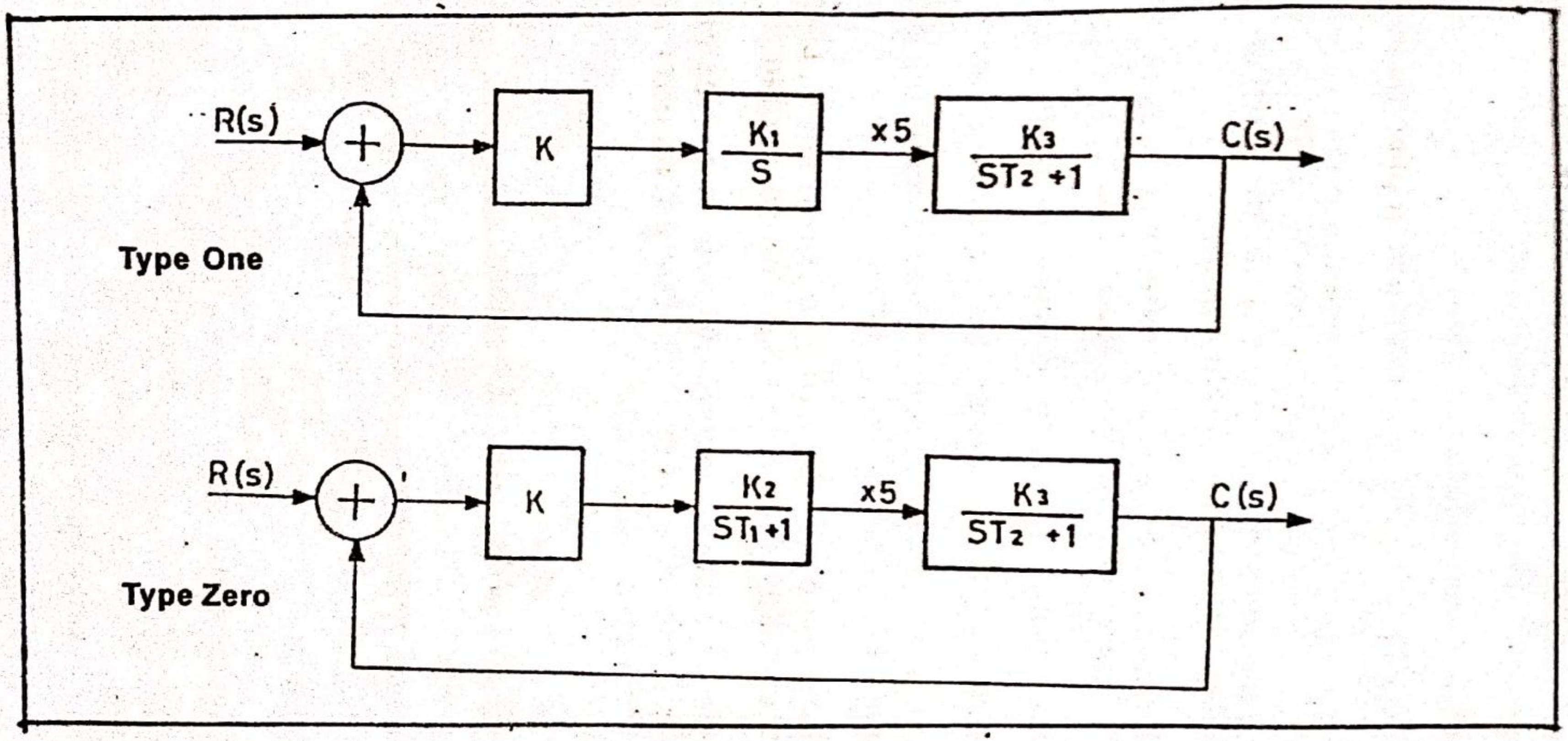

FIG. 7 CLOSED LOOP OPTIONS FOR SECOND ORDER SYSTEMS.

Rise Time (tr)

$$tr = \frac{\pi - (\tan^{-1}(\sqrt{1-\delta^2} / \delta)}{\omega d} \quad \text{Where, } wd = wn\sqrt{1-\delta^2}$$

Steady state error (ess) for unity feedback system

$$Ess = \underset{t \to \alpha}{Lt}\, e(t) = \underset{t \to \alpha}{Lt}\, (r(t) - c(t))$$

Note:

A simple wave to calculate steady state error without actually computing the time response is available in the complex frequency domain.

For an unity feed back system applying final value theorem of Laplace transform,

$$ess = \underset{t \to \alpha}{Lt}\, e(t) = \underset{s \to 0}{Lt}\, sE(s)$$

$$= \underset{s \to 0}{Lt}\, \frac{sR(s)}{1 + G(s)H(s)}$$

Open loop transformer function calculations

i) Integrator:

Input : 1 volt (p-p) square wave for time period ϑ, the integrating capacitor charges from a constant current 0.5 / R.

Output : Triangular output

$$Vp\text{-}p = \frac{0.5\,\vartheta}{R2C} = \frac{\vartheta}{4RC} = \frac{\vartheta}{4} = K_I$$

Where

$$Ki = \frac{4 \times f \times (p\text{-}p) \text{ trangular wave output amplitude in vots}}{(p\text{-}p) \text{ square wave Input amplitude}}$$

Therefore Ki = ____________

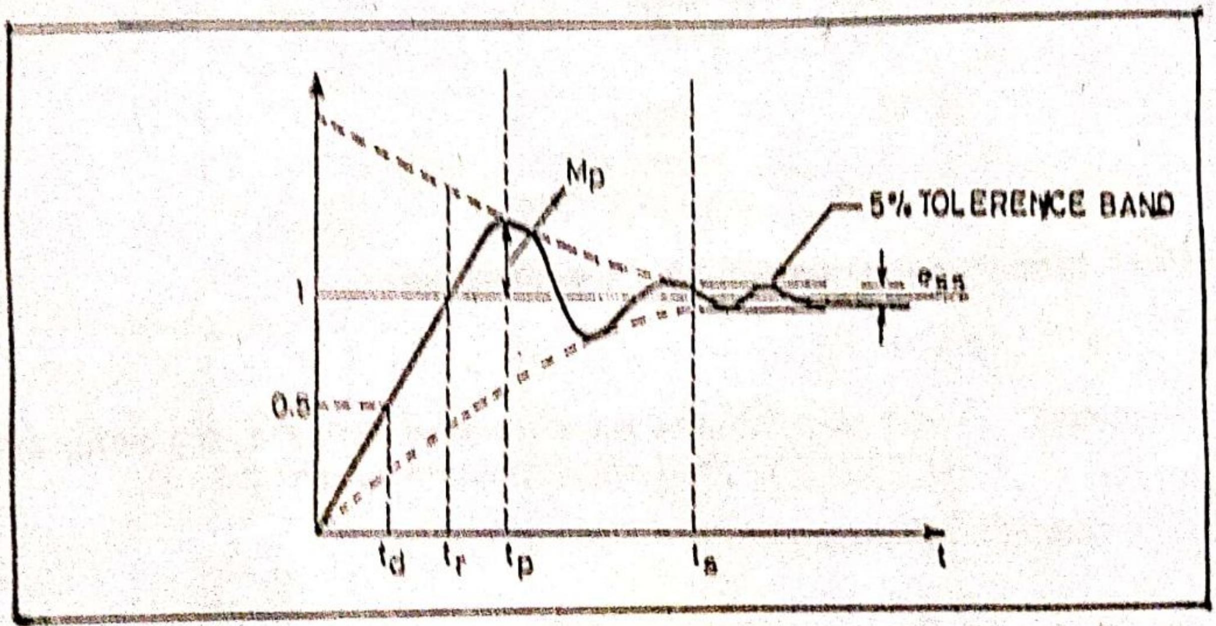

FIG. 4 STEP RESPONSE OF AN UNDERDAMPED SYSTEM.

ii) Time Constant:

The transfer function is of the form

$$\frac{K_T}{(s\,T_T + 1)}$$

From open - loop measurement

K_T = ______; T_T = ______ msec.

iii) Calculation of δ and wn from experimental values of Mp and tp

$$Mp = \exp(-\pi\delta / \sqrt{1-\delta^2})$$

$$\delta Cal = \sqrt{\frac{(\ln Mp)^2}{\pi^2 + (\ln Mp)^2}}$$

For Mp = ______;   δcal = ________;

$$\omega n\ cal = \frac{\pi}{tp\sqrt{1-(\delta_{cal})^2}}$$

iv) Calculation of δ and ωn from open loop transformer function:

Open loop transfer function of given second order system is given by

$$\frac{K_I . K_T}{s\,(sT_T + 1)} =$$

Closed loop transfer function G (S) can be written as

$$\frac{K_I\,K_T}{s^2 + sT_1 + K_I\,K_T} \qquad \text{———(1)}$$

In standard form a second order system can be repeated by

$$G(s) = \frac{\omega_n^2}{s^2 + 2\delta\omega_n\,s + \omega_n^2} \qquad \text{———(2)}$$

Comparing coefficients in the denomination in (1) & (2)

Tabulation:

a) **Open loop response error detector cum variable gain:**

Input: 1V square wave

Element	Input voltage (p-p)	Frequency	Output voltage	Transfer function parameter values
Forward Gain K				
Integrator $\frac{K_I}{s}$				
Time Constant $\frac{K_T}{sT_T + 1}$				
Time Constant $\frac{K_T}{sT_T + 1}$				
Uncommitted Amplifier				

b. **Closed loop response:**

First order with type 0 / 1 System

S.No	K	Time Constant	Steady state error	
			Theoretical	Practical
Type 0				
Type 1				

Second order type 0 System

S.No	K	%Mp	t_r	t_p	t_s	δ_{cal}	ωn_{cal}	$\delta_{open\ loop}$	$\omega n_{open\ loop}$

Second order type 1

S.No	K	%Mp	t_r	t_p	t_s	δ_{cal}	ωn_{cal}	$\delta_{open\ loop}$	e_{ss}

ω_n^2 = ; ω_n = ;

$2\omega_n\delta$ = ; δ open loop = ;
(open loop)

iii) Measurement of steady state error for ramp input

Note : A ramp is not practical, the measurement is done using a triangular input.

i) For a ramp input r (t) = Rt; where R is the slope

ii) For a triangular input, the effective slope is double due to change in slope sign so that r (t) = 2Rt

For 1 volt p-p input of a time period msec

$$R = \frac{1}{t/2}$$

Effective slope = Re = 2R =

$$\text{Steady state error (ess)} = \frac{Re}{K_I K_T} =$$

Limitations of the system performance :

1. As most of the measurement are done using CRO which may not be better than + 5%.
2. As the system is used with IC amplifies, its bias currents and other error voltage / current should also taken for calculation. But these are not included in the calculation
3. The frequency response of all the amplifiers are assumed to be flat, but may be true for a limited low frequency range only.
4. The gain of error detector cum gain block is adjustable in the range 0 - 10 (for some configurations it may be too large but for some other configuration its may be too small)

Result :

The time responses of a variety of simulated linear systems were studied and their theoretical values were verified.

Questions:

1. What are the time domain specifications required for the design of a control system?
2. What is the need to have an error detector in feedback control system?

3. Will the amount of maximum % overshoot directly indicate the relative stability of the system?

4. What do you mean by second order type -1 / first order type - 0 system?

5. For a unit step input what would be the steady state actuating error for type - 0 system, for type - 1 and higher order systems?

6. What is time response

7. What is transient and steady state response.

8. What is the Importance of test signals' and Name of the test signals used in control system.

9. What is weigning function?

10. Define poles, zeros and damping factor

11. What is type number of system? Give its significance?

12. What is steady state error?

13. What are the static error constants.

Lead Compensation Design

Aim: To design, implement and study the effects of a Lead Compensation network in a given system

Equipment Required:

Compensation design unit
CRO
Probe
Patch chords
Resistance:
Capacitor:

Procedure:

a) Bode plot for the plant: Uncompensated System

1. Connections are made as per the panel diagram
2. One volt (p-p) sine wave is applied as input
3. Adjust from low frequency to high frequency of the (sine wave) applied voltage and the corresponding magnitude (db) and phase angle with respect to the frequency value are obtained.
4. The Magnitude-frequency and phase angle - frequency plots are plotted.

   To obtain the plant transfer function $\frac{K}{(sT+1)^2}$ Draw a tangent in the magnitude - frequency plot to obtain the performance corresponding frequency and from that the plant time constant (T) is obtained and from the maximum magnitude value i.e., $20\log K = Max(G)$ the value of K can be calculated. Here K is the plant gain and T is the plant time constant. From the lissajous figure A, B, X_0 and Y_0 values are obtained

   Frequency domain Performance:

   Open loop bode plot is plotted $(f \ Vs \ |G|)$ and $(f \ Vs \ \angle G)$

   Where $|G| = 20\log\left(\frac{B}{A}\right)$ and $\angle G = -Sin^{-1}\left(\frac{X_0}{A}\right)$ for the positive slope of the lissajous figure. For negative slope $\angle G = -180 + Sin^{-1}\left(\frac{X_0}{A}\right)$ and

   Plant Transfer function $= \frac{K}{(sT+1)^2}$

b) Lead network design

1. The connections are made as per the panel diagram.
2. For the given design specifications i.e. Phase Margin (PM) and Steady state error (ess) Note: $ess = \underset{t \to \alpha}{Lt}[r(t) - c(t)]$. Obtain the proportional gain value (K_P). Obtain

   $20\log\left(\frac{K_P}{K}\right)$ in db and plot

Fig.2

COMPENSATION DESIGN

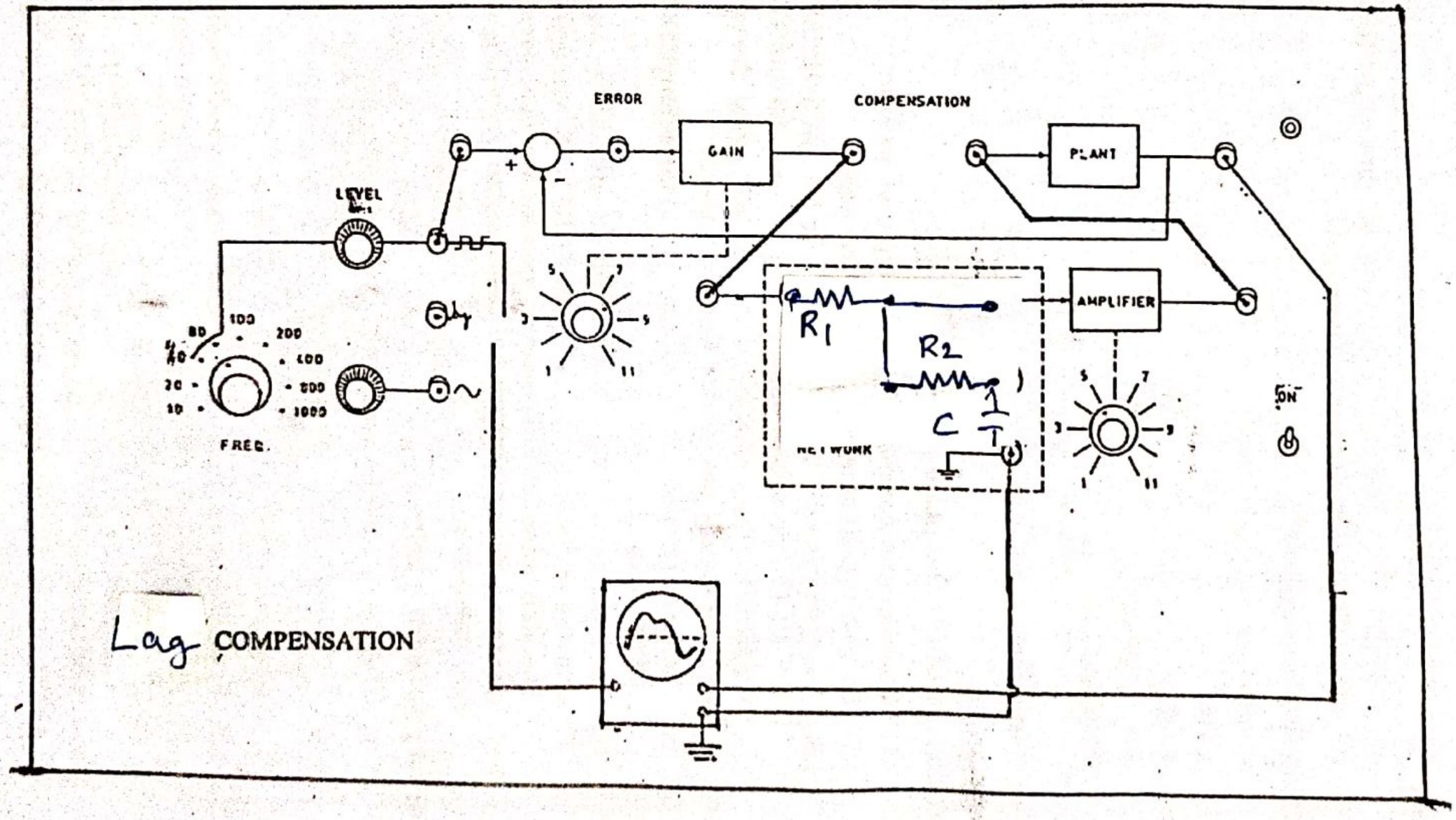

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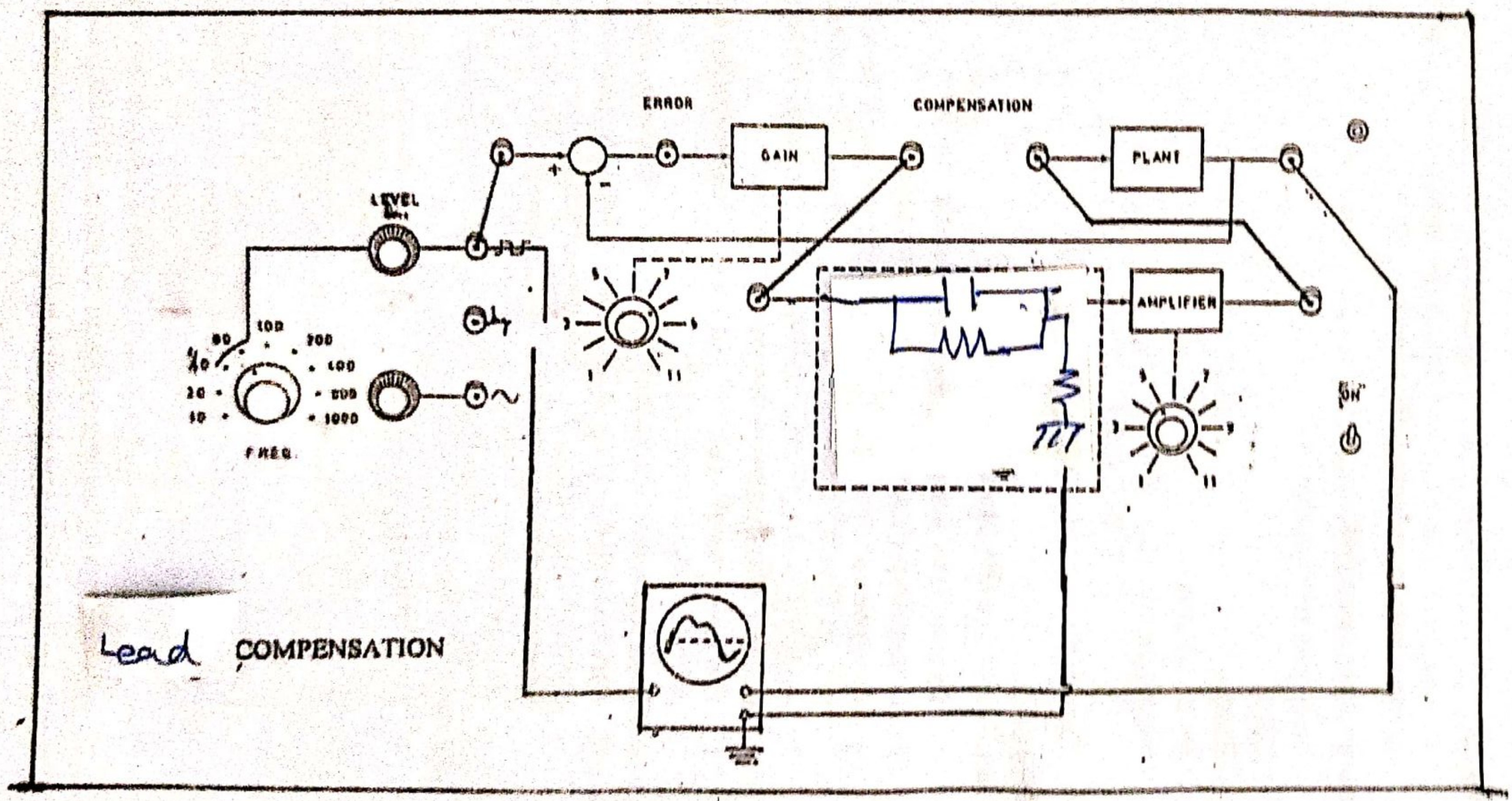
Fig.2

COMPENSATION DESIGN



Lead COMPENSATION

Position Error Coefficient (K_P) be obtained as follows

$ess = \frac{1}{1+K_P}$ $(f\ Vs\ |G_1|)$; where $G_1 = G + 20\log\left(\frac{K_P}{K}\right)$. i.e. the magnitude plot is shifted by $+20\log\left(\frac{K_P}{K}\right)$ in db.

3. The Closed loop performance of the plant is obtained by setting the amplifier gain as $\left(\frac{K_P}{K}\right)$.

4. From the gain cross over frequency find the phase margin. For the required phase margin obtain the new gain cross over frequency which will be the zero cross over frequency.
Let ess = 5% and Phase Margin = 50° be the design specification
Phase Margin to be increased (ϕ_m)= PM $_{Specified}$ - PM $_{from\ graph}$ $\pm$ 5° (tolerance) The Transfer Function of the Lead network can be represented as follows

$$G(s)=\frac{\alpha(sT+1)}{(s\alpha T+1)}=\frac{\left(s+\frac{1}{T}\right)}{\left(s+\frac{1}{\alpha T}\right)} \qquad \text{where } \alpha=\frac{1-\sin\phi_m}{1+\sin\phi_m}$$

The new gain cross over frequency = $|G_1|\ \omega_{g.new}=10\log\alpha$ which is from the phase angle plot.

$T=\frac{1}{\omega_{C1}}$

Corner frequencies are calculated from $\frac{1}{T}=\omega_m\sqrt{(\alpha)}$ and $\frac{1}{\alpha T}=\frac{\omega_m}{\sqrt{\alpha}}$

$$G(s)=\left[\frac{s+\frac{1}{R_1C}}{s+\frac{1}{R_2C}+\frac{1}{R_1C}}\right]=\frac{\alpha(sT+1)}{(s\alpha T+1)}=\frac{\left(s+\frac{1}{T}\right)}{\left(s+\frac{1}{\alpha T}\right)}$$

From above $T=R_1C=\frac{1}{\omega_{C1}}$ and $\alpha=\frac{R_2}{R_1+R_2}$

then R_1, R_2 can be calculated.

5. The Phase Margin value is verified by applying sine input with the frequency equal to the new gain cross over frequency and from the corresponding lissajous figure.

6. The Steady State Error value is verified by applying square input to the system without and with compensation unit and the output responses are compared.

Note:

Delay Time (t_d): It is the time required for the output response of the system to reach 50% of the final value

Rise Time (t_r): It is the time taken for the output response of the system to reach 100% of the final value for the first time

$$t_r = \frac{\pi - \theta}{\omega_d}; \quad \text{where } \theta = \tan^{-1}\left(\frac{\sqrt{1-\delta^2}}{\delta}\right)$$

Peak Time (t_r): It is the time taken for the output response of the system to reach its peak value.

$$t_p = \frac{\pi}{\omega_n \sqrt{1-\delta^2}}$$ where δ is the damping ratio and ω_n is the undamped natural frequency which depends on the value of δ.

Table No: 1 Bode Plot

Frequency (Hz)	A	B	X_0	Y_0	Gain in db $\lvert G \rvert$	Phase Angle
20						
40						
80						
100						
200						
400						
800						
1000						

Table No: 2 Open loop system Bode Plot

Frequency (Hz)	Gain in db $\lvert G \rvert$	Phase Angle	Approximate Open Loop Transfer Function	Low Frequency Gain	Corner Frequency
20					
40					
80					
100					
200					
400					
800					
1000					

Table No: 3 Closed loop response of the system without and with compensation unit

System	Gain Value	$\%M_p$	T_p	ess	δ
Uncompensated System					
Compensated System					

Table No: 4 Closed loop system Bode Plot

Phase lead required (ϕ_m)

ϕ_m	α	New gain crossover frequency	|Gain| at $10\log\alpha$	Corner Frequencies	$G_{C}(s)$

c) Lead Network Design

1. The connections are made as per the panel diagram.
2. For the required ess and phase margin the phase lead is calculated by (ϕm) = Phase margin specified - Phase margin available ±10° safety margin.
3. The value of a for the lead network is calculated from

$$\alpha = \frac{1-\sin\phi m}{1+\sin\phi m}$$

4. The new gain cross over frequency wg, new is calculated such that $|G|\ \omega g$, new = 10 logα

Note:

This step ensures that maximum phase lead shall e added at the new gain cross - over frequency.

5. The corner frequencies are calculated fror /T = $\sqrt{\alpha}\ \omega m$ and $1/\alpha T = \omega m / \sqrt{\alpha}$
6. The transfer function is obtained Gc(s' $\dfrac{+\ 1/T}{s + 1/\alpha T}$
7. The above value of Gc(s) is implemented with the help of the amplifier provided with a few passive elements.
8. The compensator is inserted and the phase margin of the plant with compensator is determined experimentally.
9. The step response of the compensated system is observed and the values of Mp, tp, δ and ess are obtained.

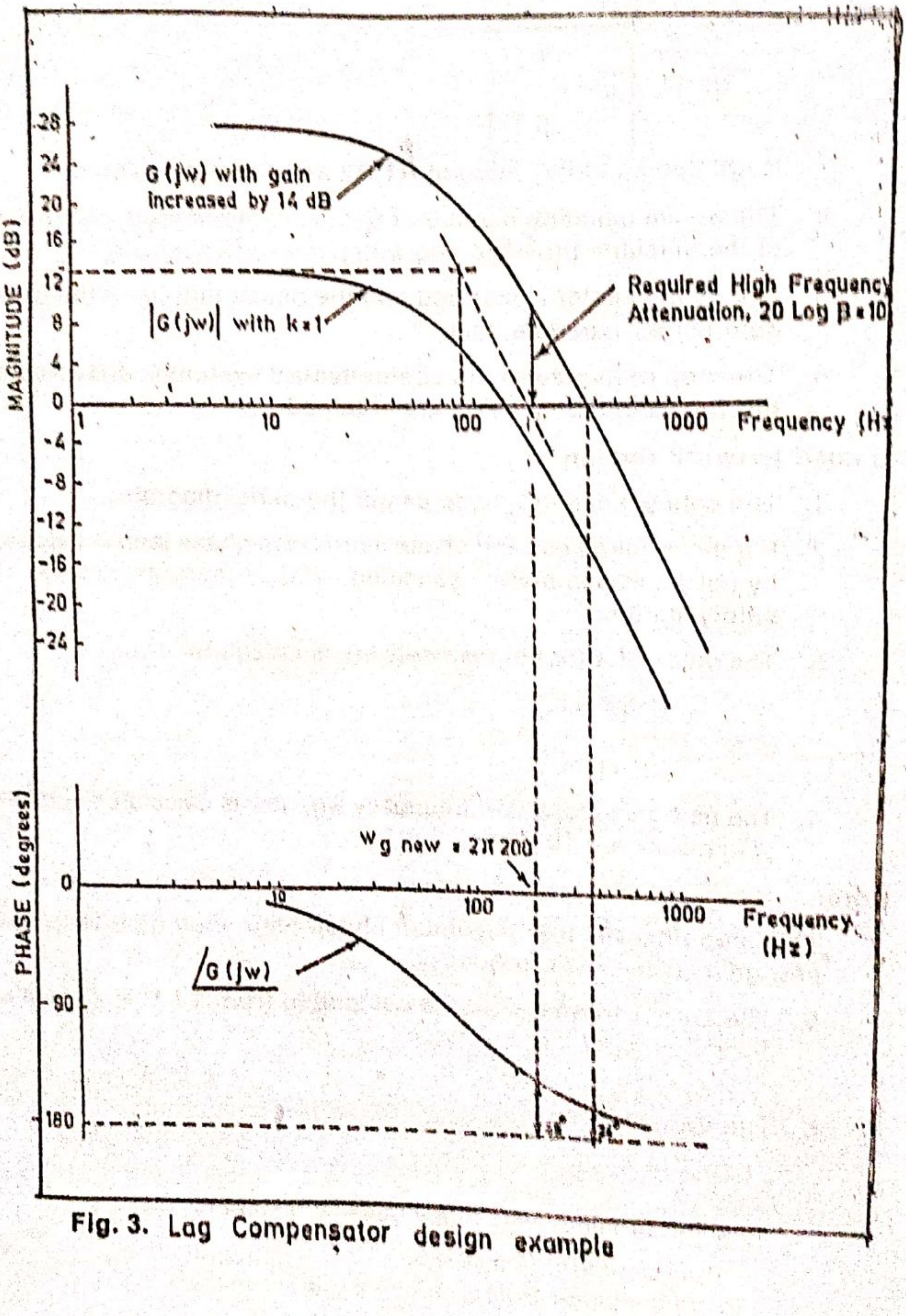


Fig. 3. Lag Compensator design example

Graph:

I Frequency domain performance

a) Open loop Bode plot

ω Vs | G |

<G

b) Closed loop frequency response

ω Vs $\frac{|C(s)|}{|R(s)|}$

II Lag network characteristics

a) Pole - Zero characteristics

b) Bode diagram

ω Vs | G(s) |

Vs < Gc

III Lead network characteristics.

a) Pole - zero configuration

b) Bode diagram

ω Vs | Gc | with & without amplifier

Vs < Gc

Note:

1. All measurements are carried out using CRO therefore accuracy will be about + 5% tolerance.
2. Errors caused by non-zero bias current requirement of the operational amplifiers are unavoidable.
3. The gain setting of the system & compensation amplifier must be accurately measured for better results.
4. R1 and R2 not to exceed 22KΩ approxi & polyester cannot be used.

Design:

(i) Lead Compensation:

ess = 5%

Phase margin = 50°

From Bode plot,

20 log K = 13

K = 4.47

Transfer function of the plant $= \frac{K}{(sT + 1)^2}$

Therefore the gain K needs to be increased by 19 / 4.466 = 5(say).
Therefore the gain margin is to increased by 20 log 5 ≃dB

With this value of open loop gain, step response of closed loop system was found as Mp = 48%; Tp = 1.5msec; Ess = 5%

The magnitude plot

a) Frequency response measurements

Input: 1-Volt (p-p) Sine wave

CRO in x - y mode

All measurements are in volts (p-p) the measurements are carried out by Ellipse method if a system input is X = A Cos (ωt - θ) are fed to the X-Y plates of CRO respectively, the resulting trace is an ellipse given by

$$Y^2 + (B^2 / A^2) X^2 - 2 (B/A) xy \cos\theta = B^2 \sin^2\theta$$

$$\text{Gain} = B / A = Y_0 / X_0 \text{ (or) } 20 \log (B/A) \text{ dB}$$

$$\text{Phase } (\theta) = -\sin^{-1} (X_0/A) = -\sin^{-1} (Y_0 / B)$$

Note:

For 90 < θ < 180° the major axis of the ellipse (fig) has a negative slope & the phase angle is given by

$$\theta = -180 + \sin^{-1} (X_0 / A)$$

$$G(s) = \frac{4.47}{(1+s0.00187)^2}$$

$$\text{Phase lead needed } (\phi m) = PM_{specl} - PM_{avail} + 5^\circ$$

$$= 50 - 24 + 5^\circ = 31^\circ$$

Gain cross over frequency w1new at PM =-180 +31 = -149

= 2π(270)

$$\alpha = \frac{1 - \sin\phi m}{1 + \sin\phi m} = 0.32$$

New gain cross over frequency | G | ωg new = 10 logα

= | - 4.95 |

Max phase lead shall be added at the new gain cross over freq.

140 + (-4.95) = 135.05

$$T = \frac{1}{\omega C1} = \frac{1}{2\pi\,(135.05)}$$

= 1.18* 10-3

Corner frequency is calculated from 1 / T = $\sqrt{\alpha}\ \omega m$

(or) 1 / αT = $\omega m / \sqrt{\alpha}$

$$\omega n = \frac{1}{\sqrt{\alpha} + T} = \frac{1}{\sqrt{0.32}\ (1.18*\ 10\text{-}3)}$$

= 1498

For Lead network

$$G(S) = \frac{R2}{R1+R2} \quad \frac{R1+Cs+1}{\dfrac{R1R2Cs}{R1+R2}+1}$$

This can be written as

$$G(S) = \frac{\alpha\,(sT+1)}{(s\alpha T+1)}$$

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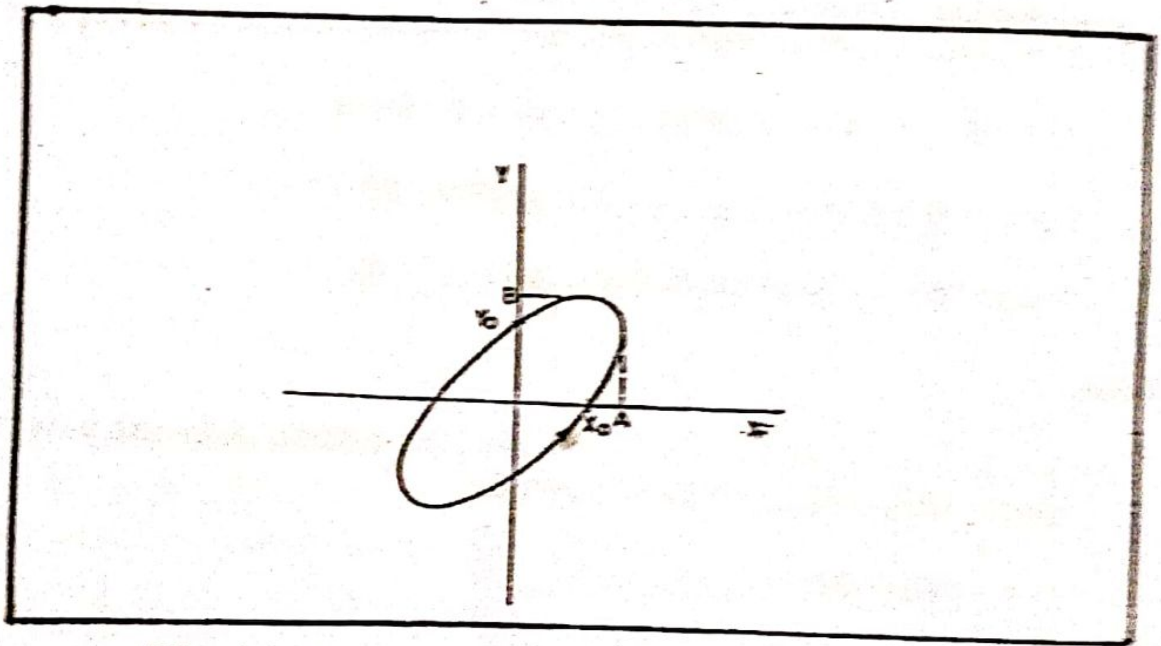


Fig. 4. PHASE AND GAIN MEASUREMENTS ON CRO

Tabulation: -

Fig: Phase gain measurements using CRO

Freq. Hz	A	B	X_0	Y_0	Gain dB	Phase (θ)
10						
20						
40						
80						
100						
200						
400						
800						
1000						

$$= \frac{(s + 1/T)}{(s + 1/\alpha T)}$$

R1C = T;   Let C = 1 μF

$$R1 = \frac{T}{C} = \frac{1.18 * 10\text{-}3}{1 * 10\text{-}6} = 1180 \simeq 1.2K$$

$$\alpha = \frac{R2}{R1 + R2}$$

$$0.32 = \frac{R2}{1180 + R2}$$

377-6.1.1   = R2 - 0.32 R2

$$R2 = \frac{377.6}{0.6} = 553.2 \simeq$$

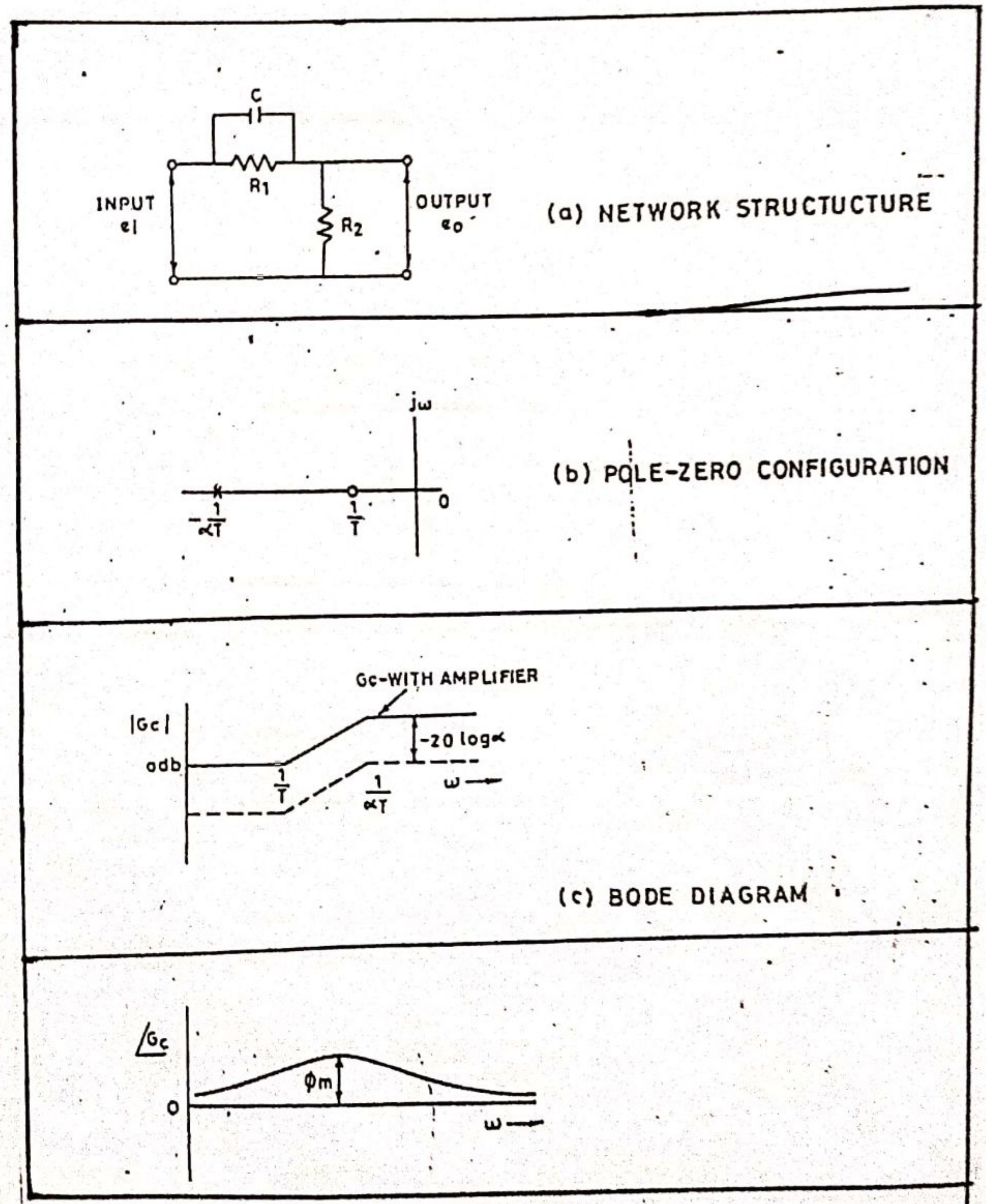


Fig. 6. -LEAD NETWORK CHARACTERISTICS.

Result:

Thus the lead and lag compensators are designed to satisfy the given requirement and the calculated parameters with the compensators are verified for the given network.

Questions:

1. Draw the various compensation schemes used for feedback control system?
2. What are the factors that affect the choice between the two compensation schemes?
3. What are the different types of electrical or electronic compensators, which are widely used?
4. Lead compensator increases the margin of stability - True or False
5. When will you select lead compensation?
6. When will you select lag compensation?
7. Lag compensation is essentially a low pass filter - True or False
8. Draw the S - plane representation of lag compensator.
9. Draw the S - plane representation of lead compensator.
10. What are the advantages of the cascade compensation?
11. Define phase margin, Gain margin
12. What is phase cross over frequency, gain cross over frequency?

STEPPER MOTOR STUDY

Aim:

To conduct an experimental study of the operating characteristics and its controller

Equipments required:

Stepper motor unit
CRO (Storage)
Microprocessor Unit
Probe
Patch chords

Procedure:

i) Basic step angle measurement

1. The connections are made as per the panel diagram. i.e. All phases to the corresponding drivers are connected
2. The switch S1 is kept at manual stepping
3. Clockwise (CW) rotation is selected
4. Ten pulses are applied manually and note the change in angular position from the dial.

$$\text{Basic step angle} = \frac{\text{Change in angular position for 10 phases}}{10}$$

= ________________ =

ii) Speed and direction control:

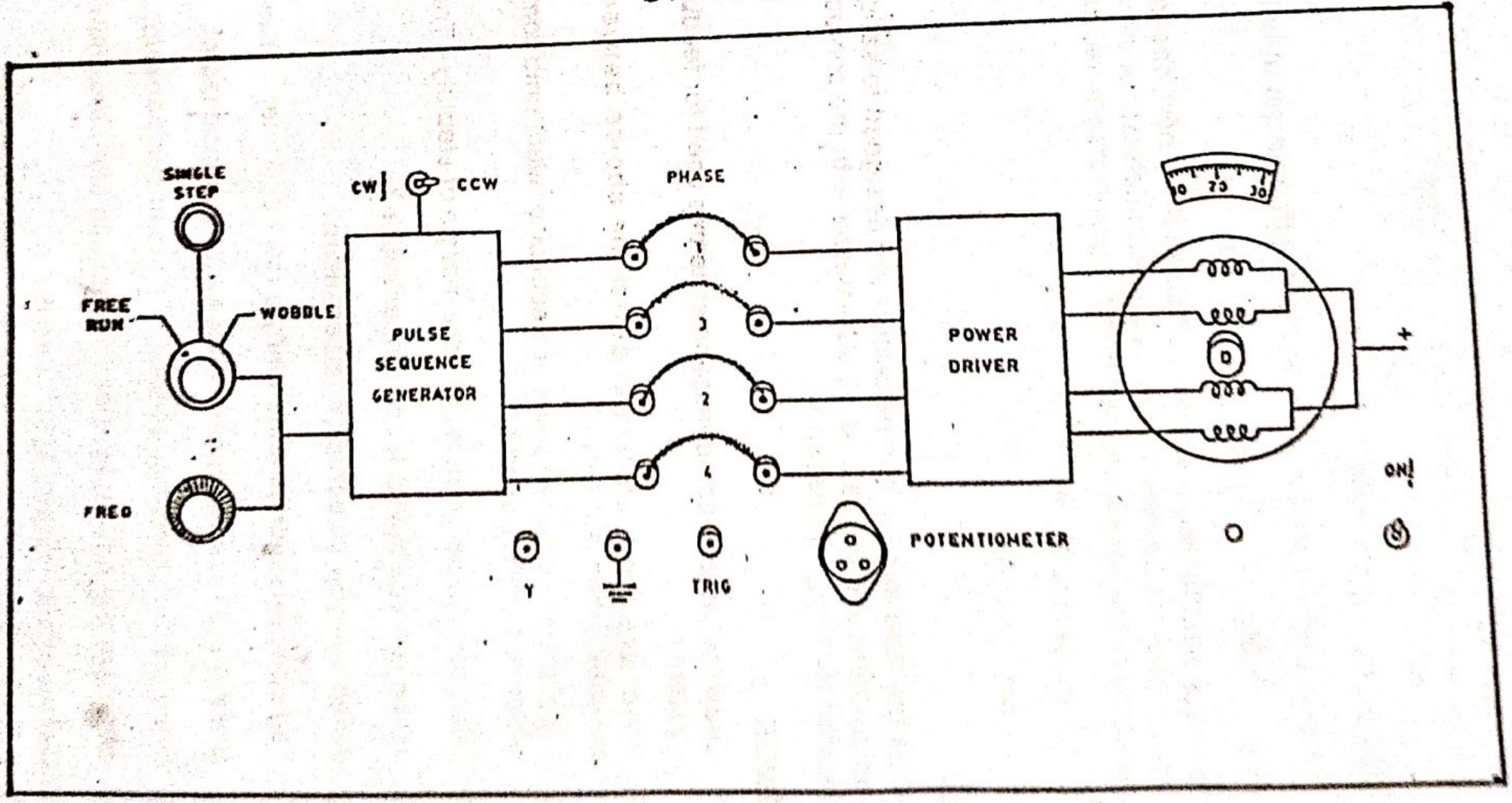
1. The connections are smade as per the panel diagram
2. The switch S1 is kept at free run position
3. The supply is effected.
4. The pulse frequency is set to about 10 Hz and measure its value accurately using the CRO
5. All phases to the corresponding drives are connected.
6. Shaft rotation speed and time are noted.
7. Steps per revolution is calculated
8. The above procedure is repeated at other frequencies and an average value of steps per revolution is found.
9. The above steps are repeated with direction of rotation reversed

iii) Low frequency dynamic resonance:

Caution: This test must be conducted at low permissible frequency to avoid excessive vibration

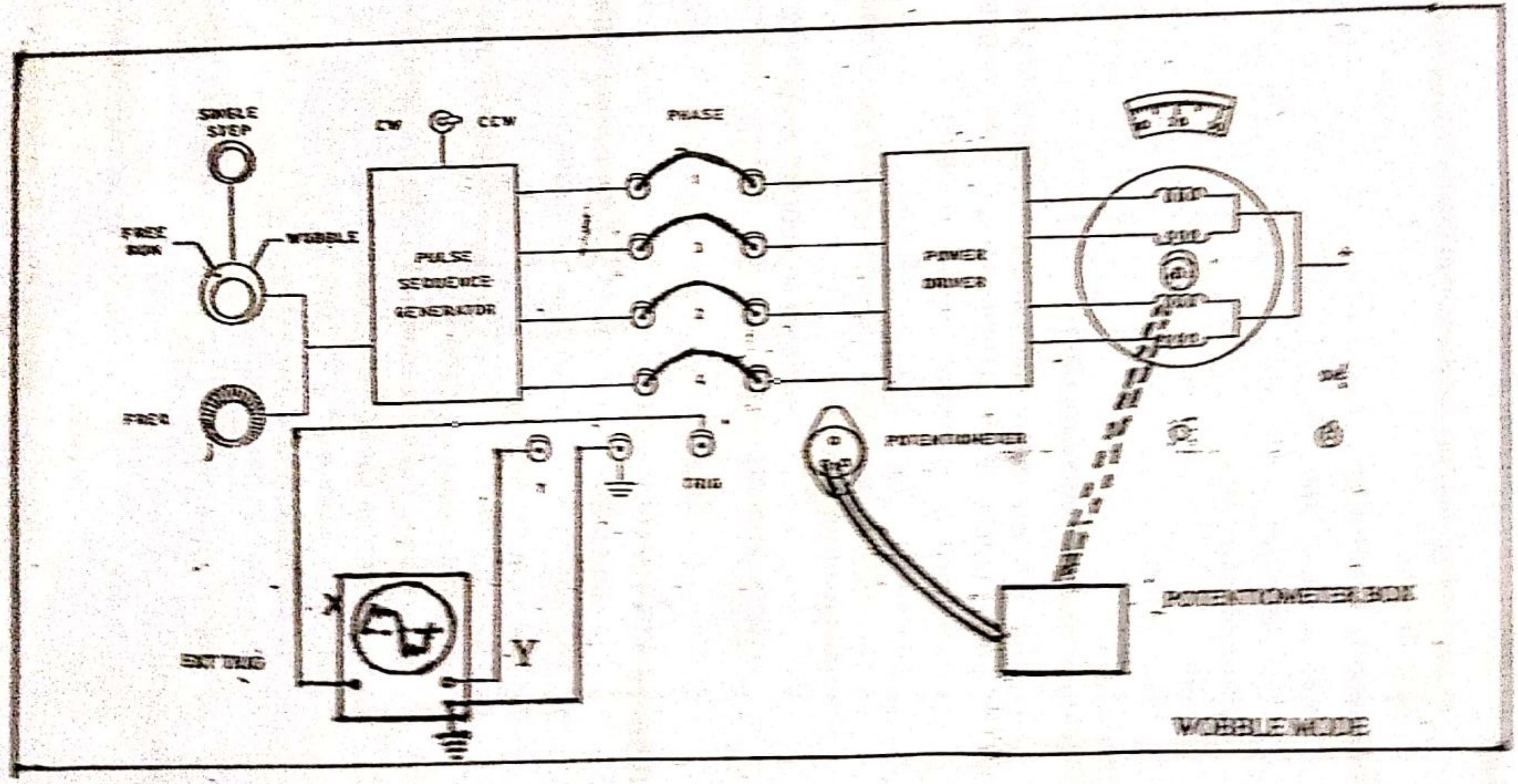
1. The connections are made as per the panel diagram.

STEPPER MOTOR



FREE RUN/SINGLE STEP

STEPPER MOTOR



Tabulation:

Steps / rev

Pulse between freqency	No. of steps Rad / rev	
	CW	CCW
10		
20		
30		
Average		

Average value of steps / rev.

Tabulation:

Parameter from the characteristics	Mode A	Mode B	Mode AB
% M_p			
δ			
T_p in sec.			
T_s in sec.			
Stepping rate			
tr in sec.			

2. The potentiometer shaft is engaged to the shaft of the stepper motor
3. The switch S1 is kept at wobble position
4. The drive circuit if stepper motor is connected in **Mode - A.** **Phase -2 to drives - 1 and Phase - 4 to drives - 4.**
5. Y output of the panel is connected to the storage oscilloscope.
6. The supply is effected and a very low frequency is applied the waveforms are traced.
7. The supply is switch off
8. The drive circuit for **Mode - B** operation is connected. i.e. **Phase -1 to drives - 1**

   Phase -2 to drives - 2

   Phase -3 to drives - 3

   Phase -4 to drives - 4.
9. The supply is effected and the above procedure is repeated and the waveforms are traced
10. The supply is switched off
11. The drive circuit for **Mode - AB** operation is connected.

    Phase 1 - drives 1

    Phase 4 - drives 4
12. The supply is effected and the above procedure is repeated and the waveforms are traced
13. The supply is switched off

Formula:

$$\%M_p = \frac{C(t_p) - C(\alpha) * 100}{C(\alpha)}$$

$$\%M_p = \exp\left(\frac{-\Pi\delta}{\sqrt{1-\delta^2}}\right) \times 100$$

$$\text{From this } \delta = \sqrt{\frac{(\ln Mp)^2}{\pi^2 + (\ln Mp)^2}}$$

$$tp = \frac{\pi}{\omega n \sqrt{1-\delta^2}} = \quad \text{sec.}$$

$$\omega n = \frac{\pi}{t_p \sqrt{1-\delta^2}} = \quad \text{rad / sec.}$$

t_s = (+/ - 2% tolerance) = $4 / \delta\omega n$ = sec.

Maximum single stepping rate = $1 / t_s$ Hz.

Sample Program : 1

Aim : To make the motor take 1.5 revolution in clockwise direction at a speed of 30 rpm.

Address	Code	Label	Mnemonic	Comments
2000	31FF21		LXI SP. FFH	: Stack initialisation
2003	0E01		MVI C, 01	: One revolution
2005	1600		MVI D,00	: Clockwise Direction
2007	1E1E		MVI E, 1E	: 30 rpm Speed
2009	CD4040		CALL FREERUN18	: Take one revolution
200C	01B400		LXI B, 00B4	: 180⁰ For 1/2 revolution more
200F	CDF040		CALL ANGLE RUN18	: rotate by 180⁰
2012	EF		RST 5	: return to monitor

Note : The angular position after executing this program and check that motor made 1.5 revolution in clockwise direction from the starting position

Sample Program : 2

Aim : To Program the motor for making 10 cycle of to and fro motion with span of 36⁰ and a time peried of 1 second.

Address	Code	Label	Mnemonic	Comments
2000	31FF21		LXI SP. 21FFH	: Stack Initialisation
2003	012400		LXI B, 0024H	: 36⁰ Span
2006	1600		MVI D,00	: Start Clockwise
2008	1E18		MVI E, 18	: Speed required 1 sec period
200A	2E0A		MVI L, 0A	: Counter for 10 Cycle
200C	CDF040	Cycle	CALL ANGLE RUN 18	
200F	16FF		MVI D,FF	: Reverse Direction
2011	CDF40		CALL ANGLERUN 18	
2014	1600		MVI D, 00	: Reverse Direction
2016	2D		DCR L	: Decrement Cycle Counter
2017	C20C20		JNZ CYCLE	: If over
201A	EF		RST5	: Return to Monitor

Result

From the various tests conducted on stepper motor the following performances are found.

1. Step angle =

2. Steps / rev. =

3. Dynamics response performances =

4. Stepping rate =

Questions:

1. Mention the various types of stepper motor.

2. Why 3 phase / 4 phase stepper motors are preferable than 2 phase stepper motor?

3. What are the various modes available in the given stepper motor & how will they affect the performance of the motor?

4. What is the use of the potentiometer in this experiment?

5. Define 'Stepping Rate'.

6. What is stepper motor?

7. What are various application of stepper motor?

8. What is full step, half step, micro step?

RELAY CONTROL SYSTEM

Aim:

To study the dynamic characteristics of system under study with an intentional non-linearity namely a simulated relay.

Equipments required:

Relay control system unit

C.R.O (Storage)

Patch chords

Probe

Procedure:

Phase Plane studies:

(i) Linear system:

1. The connections are made for the closed loop system without the relay. The two outputs X and X° are connected to X and Y input of the CRO which is kept in X - Y mode with dc coupling.

2. A square wave input of 1-volt (p-p) at 10 - 40 Hz is applied and the equilibrium points on CRO is observed.

   Note:

   The two trajectories and equilibrium points correspond to positive and negative step inputs.

3. The gain K is varied (to say 5,10) the equilibrium point variation is observed and the values of Mp and number of overshoot / undershoots from the phase plane trajectories are obtained.

(ii) Non linear system:

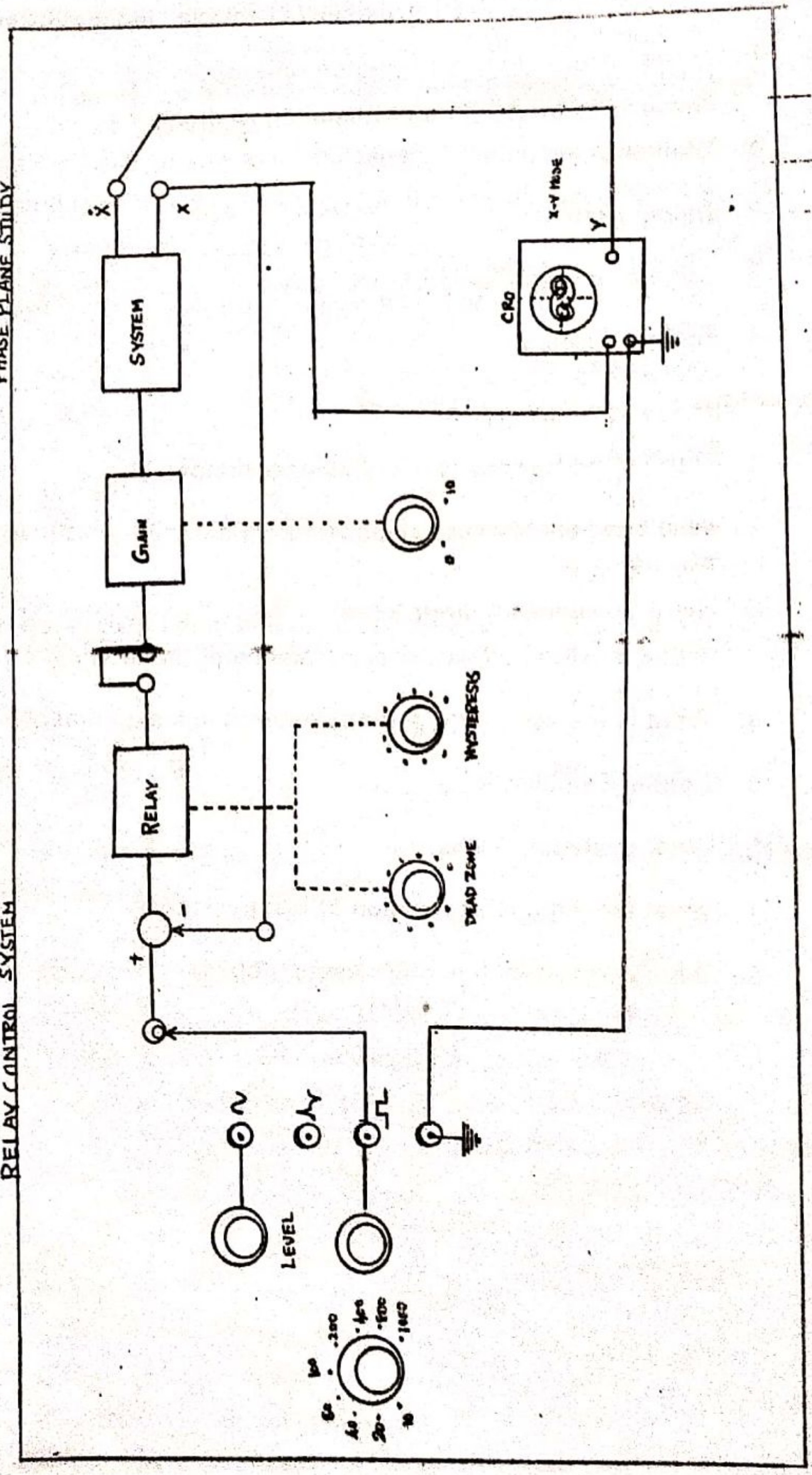
Note:

When the relay is inserted in the forward path of the system, the equilibrium point and shape of the trajectory have various changes like (with positive step input).

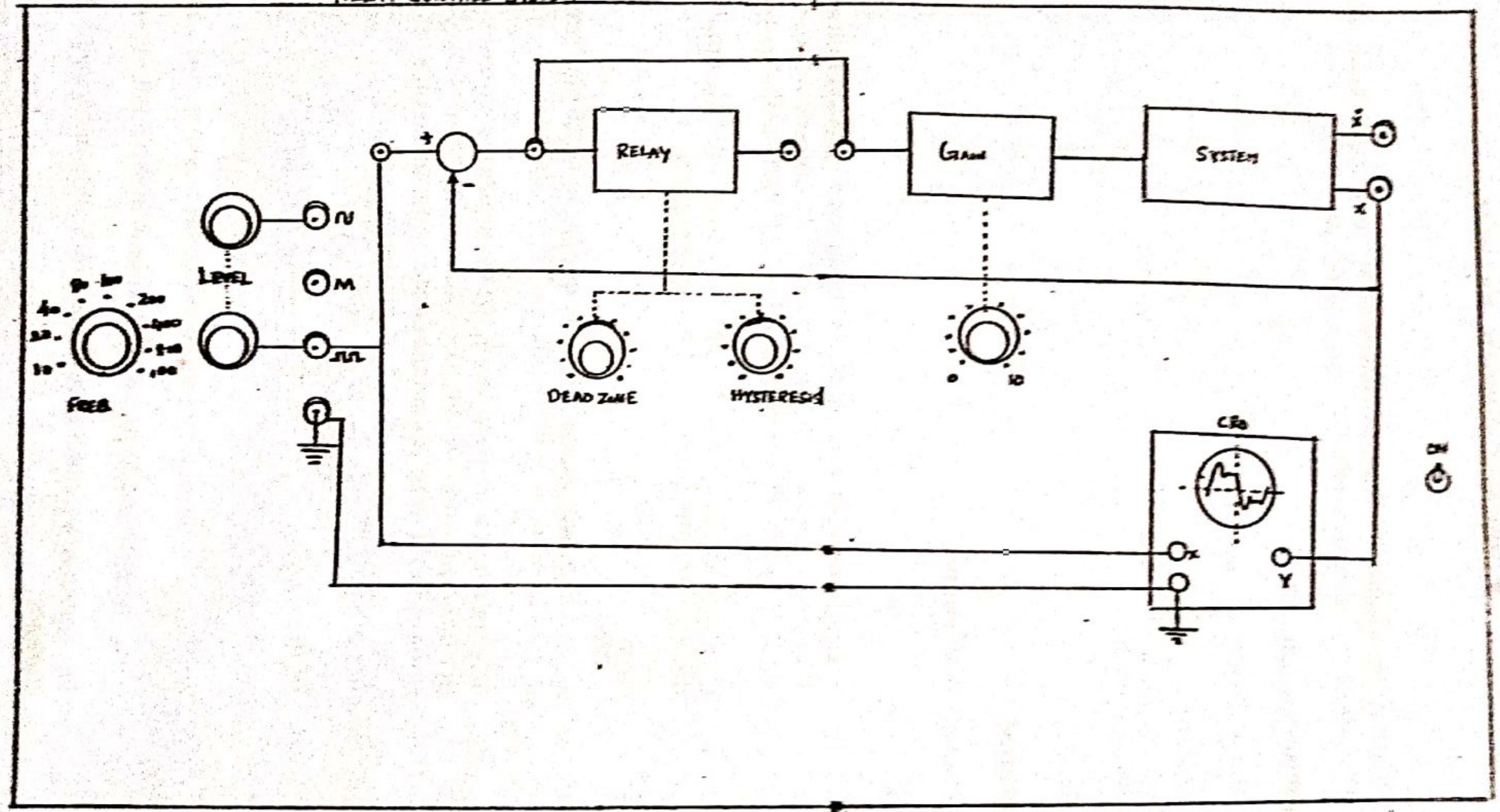
i. The trajectory becomes discontinuous at the point of switching

ii. No inputs are available to the system with in the dead zone, if present

iii. Unsymmetrical switching results in the presence of hysteresis.


RELAY CONTROL SYSTEM
PHASE PLANE STUDY
SYSTEM
GAIN
RELAY
HYSTERESIS
DEAD ZONE
LEVEL
CRO
X-Y MODE
X
Ẋ
Y
0
10

RELAY CONTROL SYSTEM



1. The gain "K" is set to 10 and H = 0 and the dead zone is increased to make the system stable .(this can be judged by the absence of a "centre" on CRO)

2. A square wave of 10 - 40 Hz, 1V (p-p) is applied and the trajectory and equilibrium point are observed Mp and number of overshoot are noted and compared with linear system results.

3. The dead zone is increase further and the effects on the singular point and from that the transient response are noted.

4. The dead zone is decreased to zero and H is set to a low value of 0.2 say. A square wave input of 10 - 40 Hz, 1V(p-p) is applied and the phase trajectory is observed. The stability of the system from the nature of the singular point is found.

5. The above step is repeated for H = 0.4 (medium) and H = 0.6 (high the readings are tabulated. The effect of the increasing hysteresis is noted.

Result:

The dynamic characteristics of system under study with an intentional non-linearity namely a simulated relay is studied.

Questions:

1. How non-linearities are introduced in the system? How are they classified?

2. What is dead zone?

3. What is hystersis and backlash?

4. Draw the input - output characteristic of a relay with dead zone and hystersis.

5. What is phase trajectory?

6. What is singular point?

7. What are the methods available for constructing phase trajectories?

8. What is a non linear system? state its disadvantages and limitation?

. DIGITAL CONTROL SYSTEM

Aim:

To study the digital control of a simulated system using an 8 bit microcomputer i.e., to study

a) the effect of sample delay on the output
b) PID control
c) An uncompensated system &
d) Lag compensation with the given software package

Equipments required:

Digital Control System Unit
Microprocessor kit
Storage Oscilloscope
Probe
Patch chords

Procedure:

a) Process Identification:

1. Connections are made as per the figure 2.
2. Square wave input is applied to the process-input terminal.
3. The output response and the input response are traced.
4. The process parameters (K), (a) are calculated.

Note: For proper time measurements, the time base should be synchronized with the square wave input.

b) Digital System - Closed loop response

(i) Fixed Forward Gain - Variable sampling rate

1. The connections are made as per the figure 3.
2. The program (DELEFF) to study the effect of sample delay on the output which is available in the address 5000h is executed for a forward gain ('P') = 4 (say) and a delay setting of 0 (say).
3. The 'CLK OUT' pulse on the CRO is observed and the time between any two pulses are measured. This is the actual sampling period.
4. The system response is also observed and the peak overshoot is obtained from the peak and steady state (Css) values.
5. The above steps from 2 to 4 are repeated for different forward gains (P) and delay settings (1,2,...) and the results are tabulated.

(ii) PID Control

1. The connections are made as per the figure 3.
2. The program to study the effect of PID Control on the output, which is available in the address 5030h, is executed for various gains selected out of 16 levels as listed below.

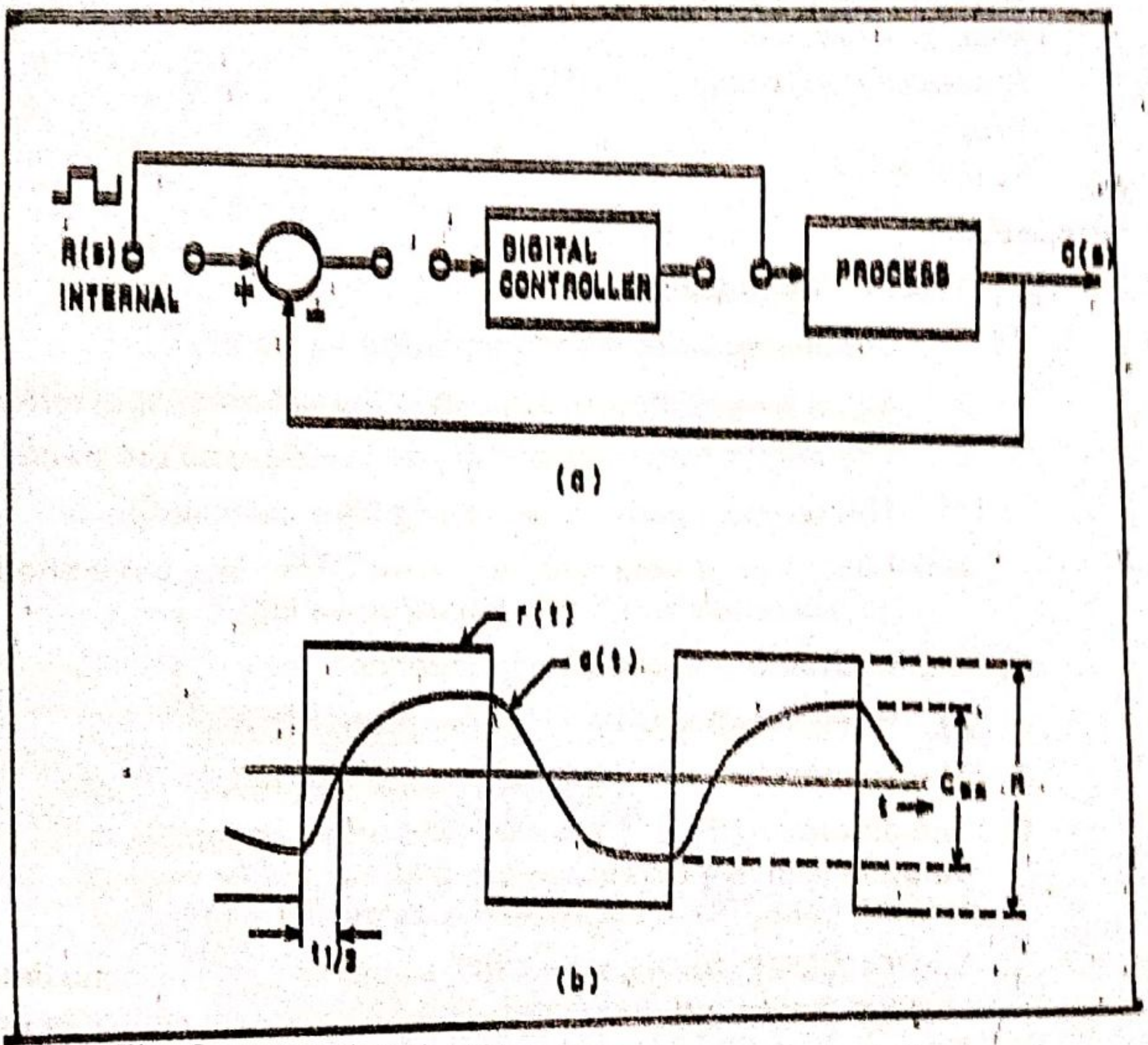
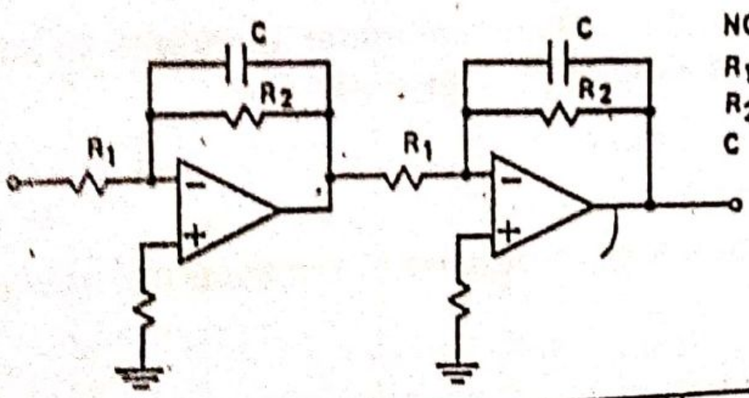


Fig. 2. CONNECTIONS FOR PROCESS IDENTIFICATION (a), AND RESPONSE MEASUREMENTS (b)



NOMINAL VALUES
R_1 = 12K
R_2 = 10K
C = 0·47 μF

Fig. 1. CONTROLLED PROCESS STRUCTURE

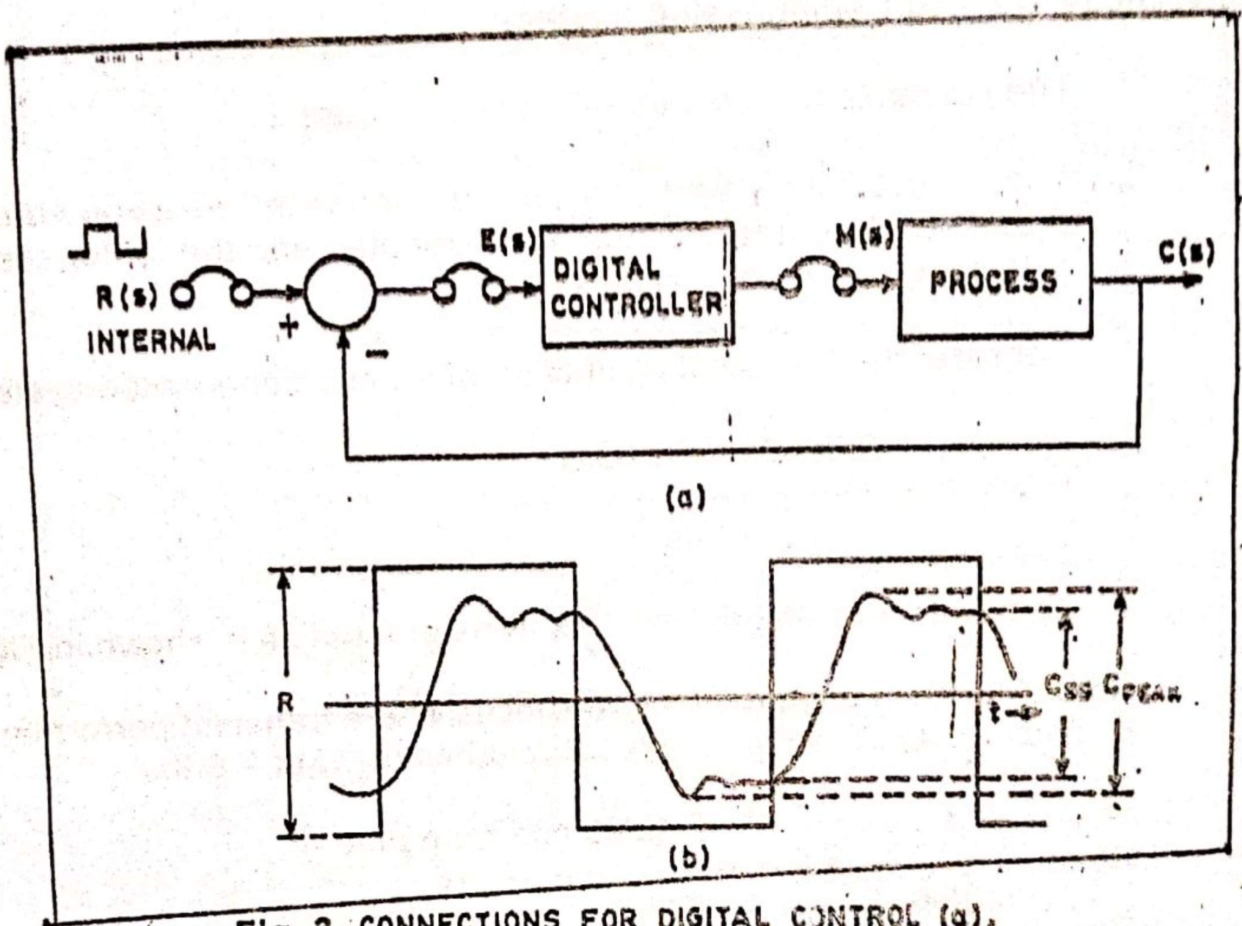


Fig. 3. CONNECTIONS FOR DIGITAL CONTROL (a), AND RESPONSE MEASUREMENTS (b)

Transfer Function :

$$G(s) = \left[\frac{(R_2 / R_1)}{1 + sCR_2}\right]^2 = \left[\frac{Ka^2}{(s+a)^2}\right]$$

$$= \frac{(R_2 / R_1)}{\left[\frac{1}{CR_2} + s\right] CR_2} = \frac{Ka^2}{(s+a)^2}$$

$$= \left[\frac{R_2 / CR_2R_1}{s + \frac{1}{CR_2}}\right]^2$$

$$= \frac{\left[1/CR_1\right]^2}{\left[s + \frac{1}{CR_2}\right]^2} \qquad a = \frac{1}{CR_2} \;;\; Ka^2 = \left[\frac{1}{CR_1}\right]^2$$

$$k = \left[\frac{1/CR_1}{1/CR_2}\right]^2 = \left[\frac{CR_2}{CR_1}\right]^2 = \left[\frac{R_2}{R_1}\right]^2 = \left[\frac{10\ K}{12\ K}\right]^2 = 0.694$$

$$a = \frac{1}{CR_2} = \frac{1}{0.47 \times 10^{-6} \times 10K} = 212.76$$

Formula :

$$K = \frac{\text{Steady state O/p C(p) P-P value}}{\text{I/p amplitude R (P-P) value}}$$

$$a = \frac{1.678}{\text{time for the response to reach } \frac{1}{2}\, C(\alpha)}$$

$$G(s) = \frac{Ka^2}{(s+a)^2}$$

P control with delay Kp =

$$mp = \frac{Cpeak - Css}{Css} \times 100$$

S. No.	Delay Setting	Cpeak	Css	$mp = \frac{Cpeak - Css}{Css} \times 100$	ts	e_{ss}	δ

PID control with delay Kp = ________ KI = ________ KD = ________

S. No.	Delay Setting	Cpeak	Css	$mp = \frac{Cpeak - Css}{Css} \times 100$	ts	e_{ss}	δ

Uncompensated system

S. No.	Cpeak	Css	$mp = \frac{Cpeak - Css}{Css} \times 100$	tr	tp	ts	e_{ss}	δ

Lag compensated system

S. No.	K	Cpeak	Css	$mp = \frac{Cpeak - Css}{Css} \times 100$	tr	tp	ts	e_{ss}	δ

Result:

Thus with the digital controller the effect of sample delay on the output, study of PID controller, implementation of lag compensation in the given simulated system and %Mp and ess are tabulated.

Questions:

1. What is the need to use Digital Control?
2. Draw the basic structure of a digital control system.
3. What do you mean by **Zero Order Hold?**
4. What are the factors limiting the gain of the feedback system?
5. What is the need for using Z - **transform** for digital control system? Can Laplace transform be used?
6. What is meant by **sampling**