(a) Phase Lead network

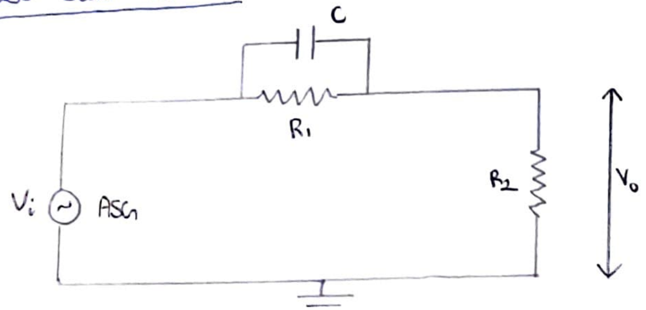


fig1 : Circuit Diagram of phase lead network

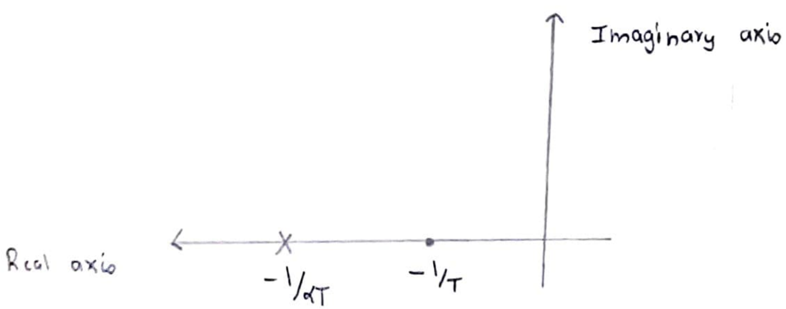


fig 2 : S-plane representation of Lead network

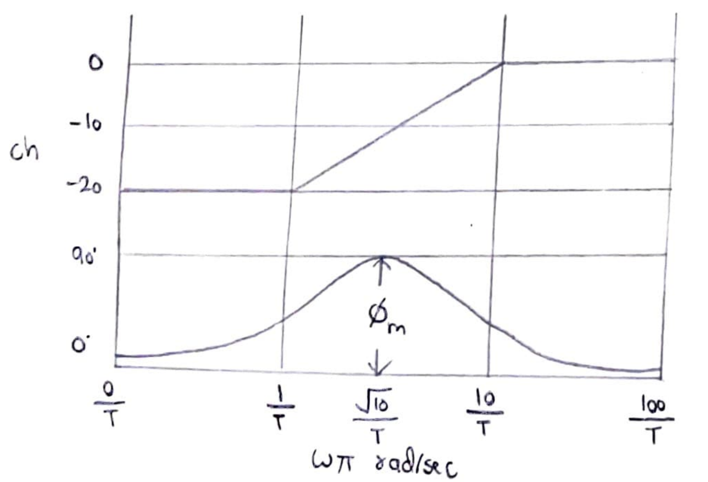


fig3 : frequency response of phase lead network

LEAD, LAG and LEAD-LAG NETWORKS

Aim :- To determine the response of lead, lag and lead-lag network using ELVIS.

Apparatus Required :-

Sl. no.	Apparatus	Range	Quantity
1.	Decade resistance box	–	2
2.	Capacitor	0.1 µf	2
3.	Signal generator	–	1
4.	Adaptor + Probes	–	2 set
5.	CRO	–	1
6.	Connecting wires	–	few
7.	NI ELVIS Board	–	1

Design :-

phase of V_o leads that of V_i. Hence the name lead compensator.

General transfer function of compensator, $G_c(s) = \frac{(s+Z_c)}{(s+P_c)}$ — ①

S plane representation of lead compensator is shown in fig(b).

Lead compensator can be realized by the circuit shown in fig (a).

From fig(a), $\frac{V_o(s)}{V_i(s)} = \frac{\alpha(1+sT)}{(1+s\alpha T)}$ — ②

where, $\alpha = \frac{R_2}{R_1+R_2}$ which is always unity

i.e., $\alpha < 1$, $T = R_1 C$

The transfer function of the compensator is then

$$\frac{V_o(j\omega)}{V_i(j\omega)} = \frac{\alpha(1+j\omega T)}{(1+j\omega\alpha T)} \quad \text{— ③}$$

This has corner frequency $\omega_{c1} = 1/T$ and $\omega_{c2} = 1/\alpha T$

Maximum phase lead ϕ_m occurs at frequency ω_m which is between ω_{c1} and ω_{c2}.

$$\omega_m = 1/\sqrt{\alpha}\,T \quad \text{— ④}$$

α in terms of ϕ_m is given by

$$\alpha = \frac{1-\sin\phi_m}{1+\sin\phi_m} \quad \text{— ⑤}$$

Zero is near to the origin of the phase lead network than the pole.

Procedure :-

1. The connections for the lead network are made on the ELVIS proto board.
2. Connect the function generator [FGEN OUT] pin socket to the input of the circuit.
3. Connect the [Ground] pin socket to the ground of the circuit.
4. From the NI ELVIS II instrument launcher strip, select Bode analyzer (Bode) icon.
5. Connect the signals, input (V_i) and output (V_o), to the analog input pins as follows:

V_i^+	AI 1$^+$ (from the FGEN o/p)
V_i^-	AI 1$^-$ (from the GROUND)
V_{out}^+	AI 0$^+$ (from the lead network o/p)
V_{out}^-	AI 0$^-$ (from the GROUND)

Design Example :- Design a phase lead compensator which provide a maximum phase angle of 30° at 500 Hz.

Given: $\phi_m = 30°$, $\omega_m = 2\pi f$, $f = 500Hz$ $\therefore T = 5.54 \times 10^{-4}$ sec

$\omega_m = 2\pi f = 2 \times \pi \times 500 = 3141.59$ r/s $T = R_1 C$

$\omega_m = \frac{1}{\sqrt{\alpha} T}$, $\alpha = \frac{R_2}{R_1+R_2}$ $T = R_1 C$ Assume, $C = 0.1\mu F$

$\sin\phi_m = \frac{1-\alpha}{1+\alpha}$, $\phi_m = 30°$ $\therefore R_1 = 5.54k\Omega$

$\therefore 0.5 = \frac{1-\alpha}{1+\alpha}$, so $\alpha = 0.33$ $\alpha = \frac{R_2}{R_1+R_2} = 0.33$

$\omega_m = 1/\sqrt{\alpha} T$ $3141.56 = \frac{1}{\sqrt{0.33} T}$ $R_2 = 2.72k\Omega$

Tabular Column :- V_{in} = 2 Volts

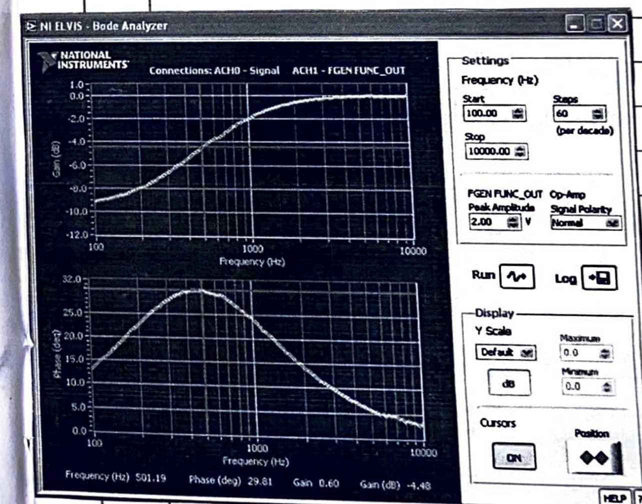
Sl. no.	Frequency in Hz	Av in dB = 20log Av	Phase angle in Degree
1.	316.228	−6.580	27.842
2.	331.599	−6.436	28.170
3.	341.455	−6.288	28.493
4.	354.813	−6.148	28.748
5.	368.695	−5.985	29.027
6.	383.119	−5.826	29.246
7.	398.107	−5.671	29.434
8.	413.682	−5.495	29.614
9.	429.866	−5.820	29.811
10.	446.159	−5.606	29.868
11.	464.159	−4.807	29.010
12.	482.318	−4.832	29.026
13.	501.187	−4.669	29.887

Name of Experiment ....01.... Date ....29/3/22....
Experiment No. ....01.... Experiment Result .... Page No. 03

6. Apply power to the photoboard.

7. Click [RUN] and observe the bode plot for the lead compensation circuit.

8. Same procedure is repeated for lag and lead lag networks.



(b) Phase Lag Network

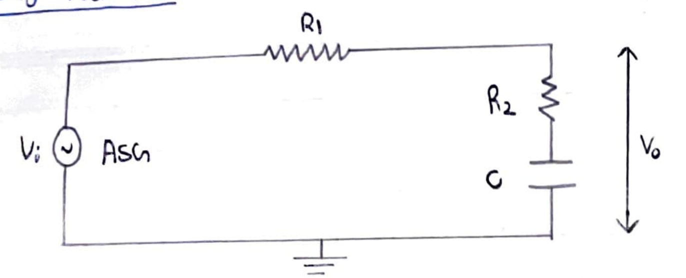


fig4 : Circuit Diagram of Phase Lag network

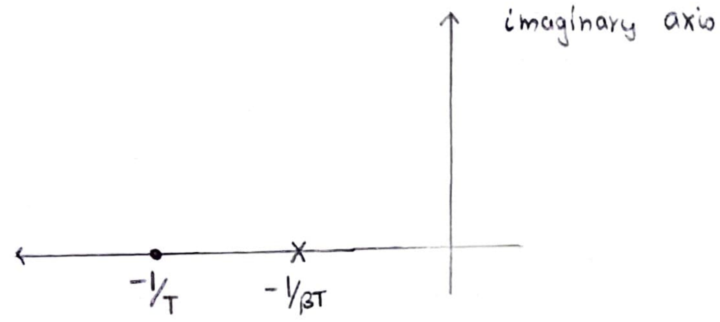


fig5 : S-plane representation of phase lag network

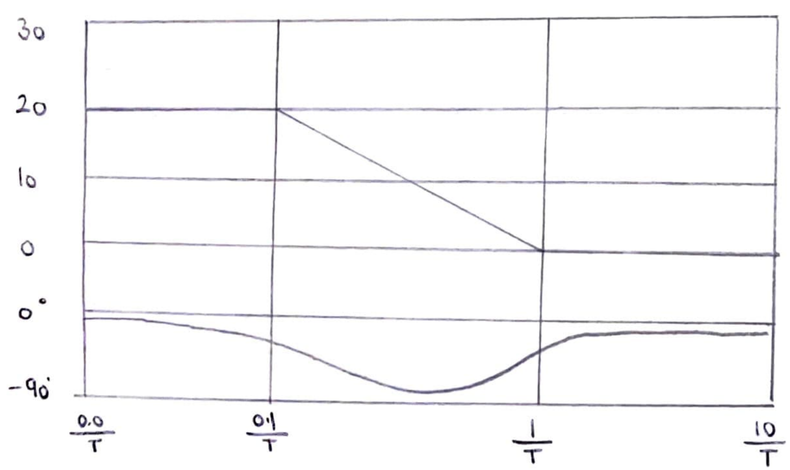


fig 6 : Frequency Response of Phase lag network

Name of Experiment......01......

Date......29/3/22......

Experiment No......01......

Experiment Result......

Page No. 04

Design :-

The transfer function of the Lag network is given by

$$\frac{V_o(s)}{V_i(s)} = \frac{Ts+1}{\beta Ts+1} \quad -①$$

where, $\beta = \frac{R_1+R_2}{R_2}$ $-②$

which is always greater than unity

$T = R_2C$ $-③$

$$\frac{V_o(j\omega)}{V_i(j\omega)} = \frac{1+j\omega\omega}{1+j\omega\beta T} \quad -④$$

Corner frequency, $\omega_{c1} = 1/\beta T$

Pole at $s = 1/\beta T$

$\omega_{c2} = 1/T$, zero at $s = -1/T$

Maximum phase lag ϕ_m occurs at frequency ω_m which is between ω_{c1} and ω_{c2}

$$\omega_m = \frac{1}{\sqrt{\beta}T} \quad -⑤$$

β in terms of ϕ_m is given by

$$\beta = \frac{1-\sin\phi_m}{1+\sin\phi_m} \quad -⑥$$

or

$$\sin\phi_m = \frac{\beta-1}{\beta+1}$$

Pole is near the origin compared to zero

Lag frequencies are allowed, high frequencies are attenuated.

Name of Experiment.....01..... Date.....29/3/22.....

Experiment No.....01..... Experiment Result..........

Page No.

Design Problem :-

Design a phase lag compensator which provides a maximum phase angle of 30° at 500Hz.

Given : $\phi_m = 30°$, $\omega_m = 2\pi f$, $f = 500Hz$

$\omega_m = 2\pi f = 2 \times \pi \times 500 = 3141.59$ r/s

$\sin\phi_m = \frac{\beta-1}{\beta+1}$ and $\phi_m = 30°$

So, $\sin 30 = \frac{\beta-1}{\beta+1}$

$\therefore 0.5 = \frac{\beta-1}{1+\beta}$

$0.5 + 0.5\beta = \beta - 1$

$\beta = 3$

$\beta = \frac{R_1+R_2}{R_2}$

$\omega_m = \frac{1}{\sqrt{\beta}T}$ $T = \frac{1}{\omega_m\sqrt{\beta}} = 1.87 \times 10^{-4} s$

$T = R_2C$

Assume , $C = 0.1\mu F$

$\boxed{R_2 = 1.83 k\Omega}$

$\frac{1.83k + R_1}{1.83k} = 3$

$\boxed{R_1 = 3.67 k\Omega}$

Tabular Column :- V_{in} = 2 volts

Sl.no.	Frequency in Hz	Av in dB = 20 log Av	Phase angle in Degree
1.	100	-0.476	-13.030
2.	158.489	-1.085	-19.028
3.	251.189	-2.219	-25.356
4.	398.107	-3.937	-29.580
5.	630.957	-5.936	-29.186
6.	1000	-7.603	-24.512

Name of Experiment....01....
Experiment No.....01....
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Experiment Result........

c) Phase Lag-Lead network

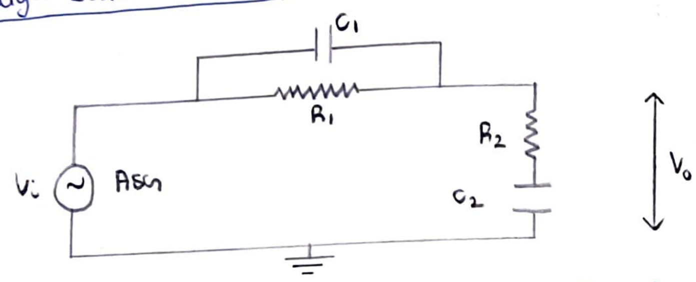


fig7 : Circuit diagram of phase Lag-Lead network

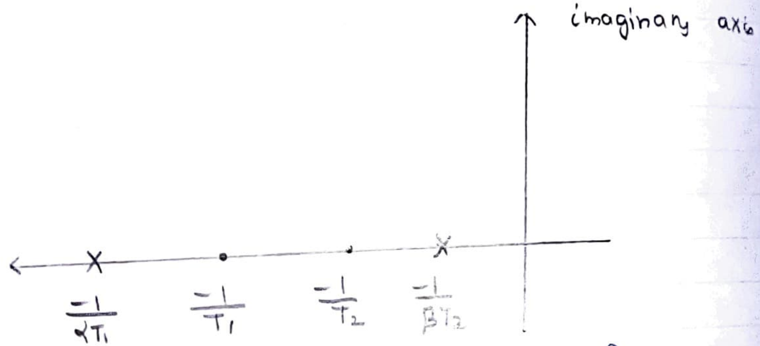


fig8 : S-plane representation of Lag-Lead network

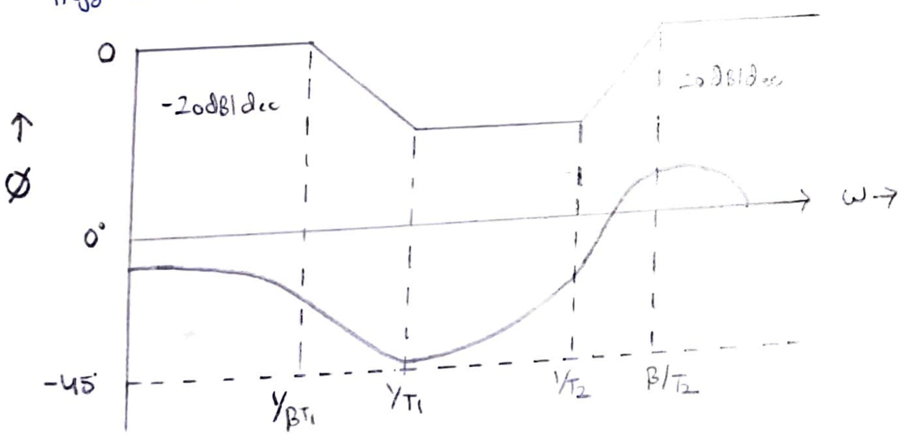
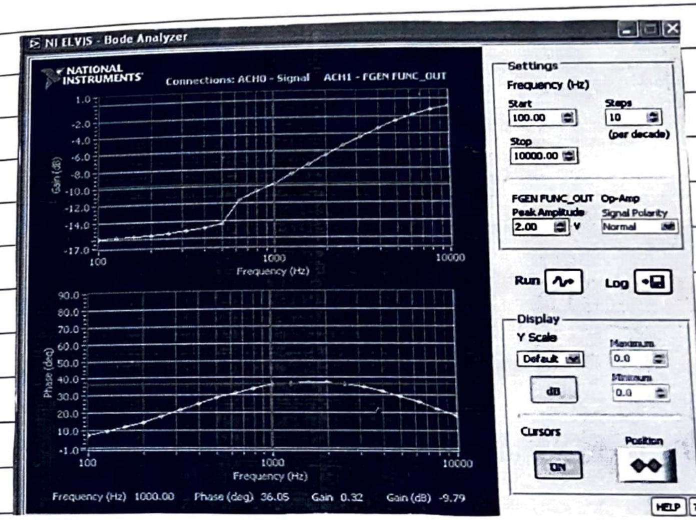


fig9 : Frequency Response of Phase Lag-Lead network

Name of Experiment.........01.........
Experiment No.........01.........

Date.........29/3/22.........
Experiment Result.........

Page No



Design :-

General transfer function of compensator

$$G_c(s) = \left\{ \frac{\left(s+\frac{1}{T_1}\right)\left(s+\frac{1}{T_2}\right)}{\left(s+\frac{1}{\beta T_1}\right)\left(s+\frac{1}{\alpha T_2}\right)} \right\}$$

Lag Lead

Where, $T_1 = R_1 C$ & $T_2 = R_2 C$

and $\alpha\beta = 1 \Rightarrow \alpha = 1/\beta$

Design Problem :-

Design a phase Lead Lag compensator which provides a maximum phase angle of 30° at 500Hz and 5KHz

Lead section :

Given $\phi_m = 30°$, $f = 5KHz$

$\omega = 2\pi f = 31415.92$ r/s

$\alpha = \frac{1}{\beta} = \frac{1-0.5}{1+0.5} = 0.333$

$\omega_m = \frac{1}{T_2\sqrt{\alpha}}$, $T_2 = 5.560 \times 10^{-5}$ s

$T_2 = R_2 C_2$, Assume $C_2 = 0.1\mu F$

$R_2 = \frac{T_2}{C_2} = 551.60\ \Omega$

Lag Section :

$\therefore \beta = 1/\alpha = 3.00$

$\omega_m = 1/\alpha = 3.00$

$\omega_m = 2\pi f = 3141.59$ r/s

$\therefore T_1 = \frac{1}{\omega_m\sqrt{\beta}} = 1.837 \times 10^{-4}$ s

$T_1 = R_1 C_1$, Assume $C_1 = 0.1\mu F$

$R_1 = \frac{T_1}{C_1} = 1.837\ k\Omega$

Name of Experiment.

Experiment No. 01

Date. 29/3/22

Experiment Result.

Page No.

Tabular Column :- V_{in} = 2 volts

Sl. no.	frequency in Hz	Av in dB = 20 log Av	Phase angle in Degree
1.	100	−0.221	−6.652
2.	158.489	−0.528	−9.897
3.	251.189	−1.141	−13.541
4.	398.107	−2.191	−15.925
5.	630.957	−3.530	−14.474
6.	1000	−4.679	−8.351

Result :-

The circuits are rigged up and and output waveform is observed in ELVIS board.

Theoretical Calculation for Lag :-

$e_{ss} = 0.2\ sec^{-1}$

$K_v = \lim_{s \to 0} [s \cdot G(s) \cdot H(s)]$

$e_{ss} = \frac{1}{K_v}$

$K_v = K = 5$

$\boxed{K = 5}$

$\boxed{K_v = 5}$

$G(s) = \frac{5}{s(1+2s)}$

$\left|\frac{5}{j\omega}\right| = 20 \log \left|\frac{5}{0.1}\right| = 34\ dB$

$|G(j\omega)| = \frac{5}{j\omega(1+2j\omega)}$

Term	Corner frequency	Slope in dB/sec	Resultant dB/dec
$\frac{5}{j\omega}$	–	−20	−20
$\frac{1}{1+2j\omega}$	0.5	−20	−40

$Z_c = \frac{1}{T} = \frac{\omega_{gcm}}{10} = \frac{0.5}{10} = 0.05$

$P_c = \frac{1}{\beta T}$

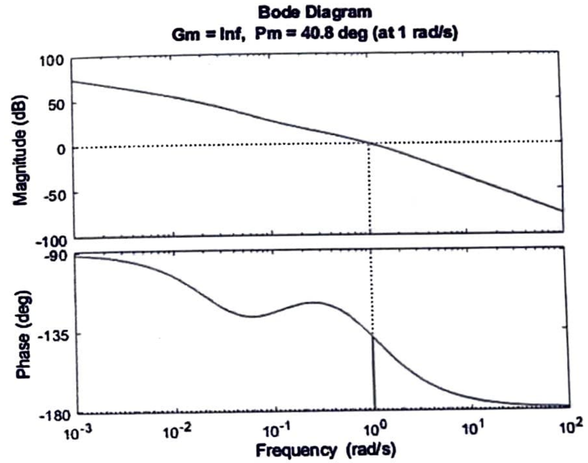
Magnitude at new gain cross over frequency $= M = 20dB$

$\beta = 10^{M/20}$

$\boxed{\beta = 10}$

Stability Analysis and compensation Bode plot with and without compensation.

Aim :- To plot the Bode diagram with and without compensation using MATLAB software for a given transfer function and verify the results using theoretical values.



...e steady state

phase plots of the

... of the uncom-

...ase margin does not

...nsation is required.

4. Determine the new phase margin

$\phi_n = \phi_d + \epsilon$, ϕ_n = new phase margin.

ϕ_d = Desired / specified phase margin

ϵ = tolerance $(5° - 12°)$

5. Determine phase angle ϕ to have a phase margin of ϕ_n.

$\phi = -180° + \phi_n$

$$G_c(S) = \frac{S+1/T}{S+1/\beta T} = \frac{\beta(ST+1)}{(S\beta T+1)}$$

$$\boxed{\frac{5}{S(1+2S)}} \rightarrow \boxed{\frac{1}{S}} \rightarrow \boxed{\frac{\beta(ST+1)}{(S\beta T+1)}}$$

$$\boxed{\frac{5}{S(1+2S)}} \rightarrow \boxed{\frac{1+20S}{1+200S}}$$

Compensated T.F $= \dfrac{5(1+20S)}{S(1+2S)(1+200S)}$

$$= \frac{5(1+20j\omega)}{j\omega(1+2j\omega)(1+200j\omega)}$$

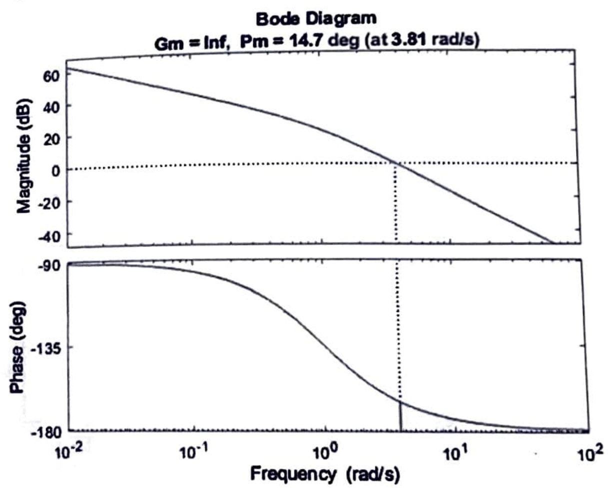
$$\phi = -90° - \tan^{-1}(2\omega) - \tan^{-1}(200\omega) + \tan^{-1}(20\omega)$$

at $\omega = \omega_{gcm} = 0.5$

$$\boxed{\phi = -140°}$$

6. Determine the frequency ω_c at which the phase angle of the uncompensated system is from the Bode plot. Choose this frequency as the new given cross over frequency.

7. Determine the β of compensator. The value of β is given by the magnitude of $G(j\omega)$ at new gain cross over frequency. Find the gain in dB at new gain cross over frequency.
Therefore, $M = 20\log\beta$ So $\beta = m/20$ (10)



g Compensator.

$= 1/T$

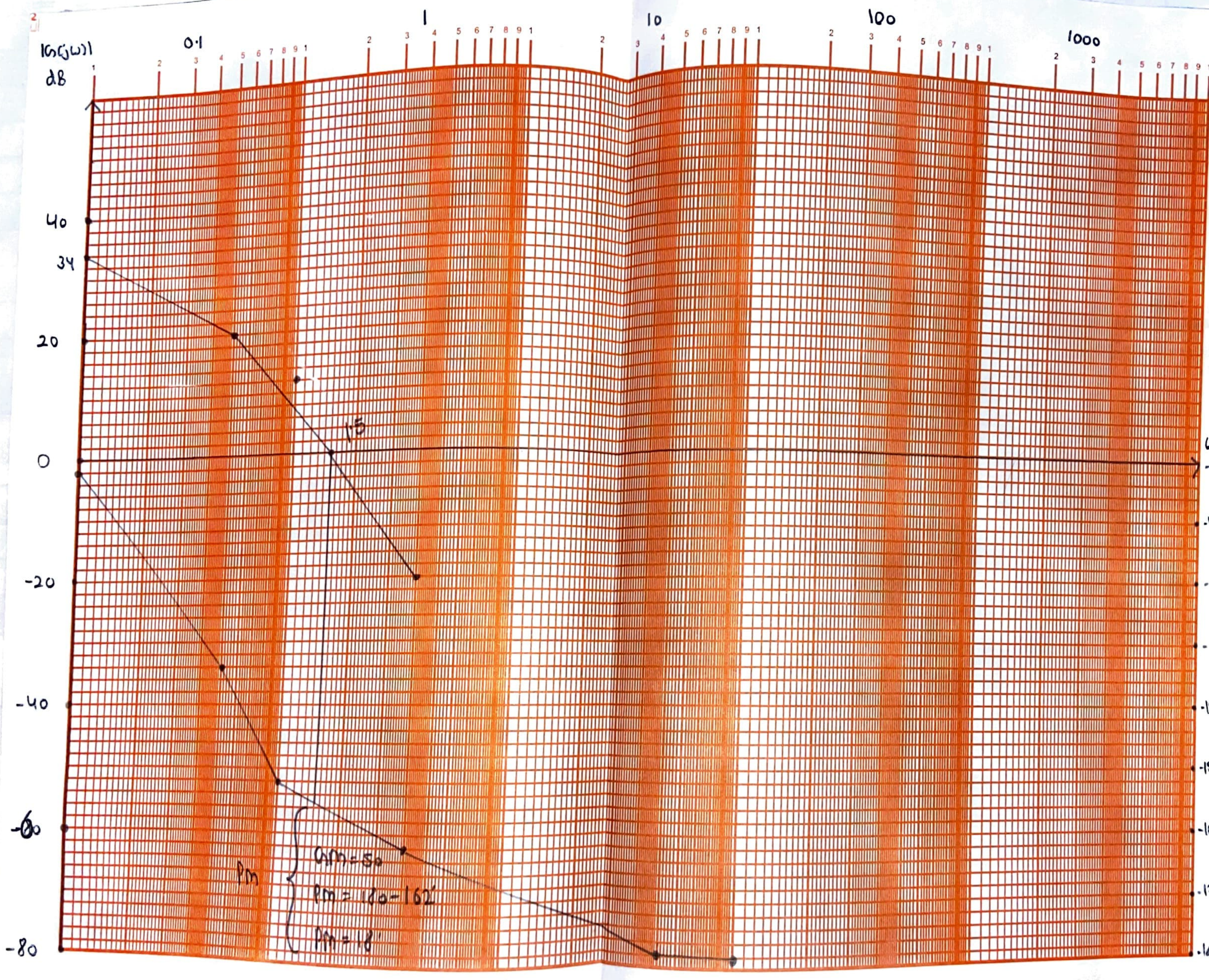
$= 1/\beta T$

$\dfrac{S+Z_c}{S+P_c} = \dfrac{S+1/T}{S+1/\beta T} = \beta\boxed{\dfrac{1+ST}{1+\beta ST}}$

```
d = conv ([1,0].[2,1])
g = tf (n,d)
S = tf ([1,0], 1)
sys = S*g
sys = minreal (sys)
k = dcgain (kv/sys)
```

Name of Experiment..............................

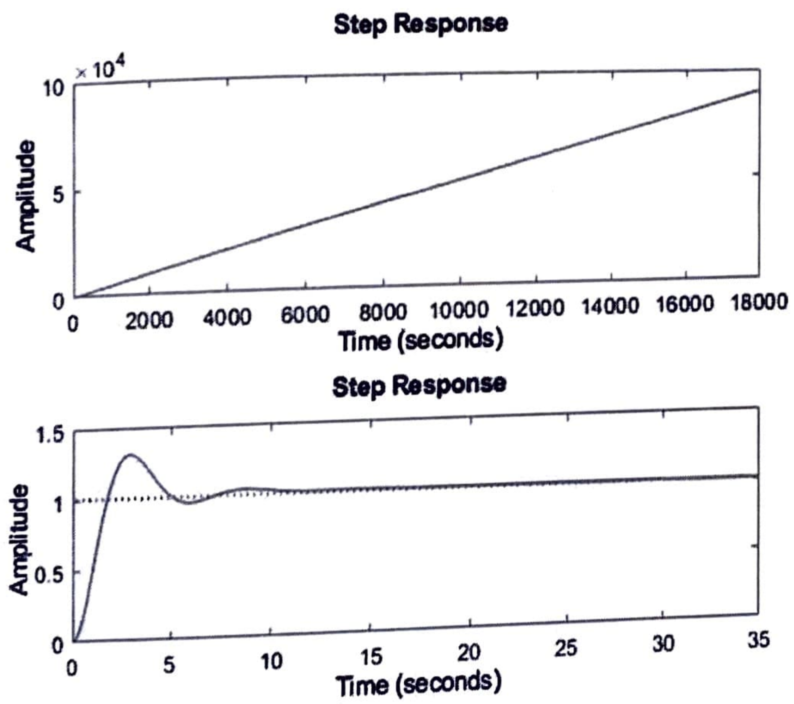
Experiment No..........02..........



Name of Experiment.. Date.....12/4/22..................... Page No. 12

Experiment No.........02................................ Experiment Result...................................

```
N = [K]
D = d
G = tf (N, D)
rpm = [40]
S = S
figure (1)
bode (N, D)
```




```
end
t = 10 / freq
m1 = 20 * log10(m)
m2 = m1/20
b1 = 10^m2
nc = [t 1]
dc = [(b1*t) 1]
```

Theoritical calculation for lead :-

$e_{ss} = \frac{1}{ka}$

$\frac{1}{15} = 1/ka$

$\boxed{ka = 15}$

$Ka = \lim_{s \to 0} [s \cdot G(s) \cdot H(s)]$

$15 = \lim_{s \to 0} \left[s \cdot \frac{k}{s(s+1)} \right]$

$\boxed{k = 15}$

$|G(j\omega)| = \left| \frac{15}{j\omega} \right| = 20 \log_{10} (15) = 23.52 \text{ dB}$

$\angle G(j\omega) = -90' - \tan^{-1}(\omega)$

Term	Corner frequency	Slope in dB/dec	Resultant slope
$\frac{15}{j\omega}$	—	-20	-20
$\frac{1}{1+j\omega}$	1	-20	-40

$\angle G(j\omega) = 90' - \tan^{-1}(\omega) = -135'$

$\omega = 1$, $\angle G(j\omega) = -135'$

$\omega = 10$, $\angle G(j\omega) = -174.28'$

$\omega = 12$, $\angle G(j\omega) = -176'$

$\omega = 16$, $\angle G(j\omega) = -177'$

$\omega = 20$, $\angle G(j\omega) = -178'$

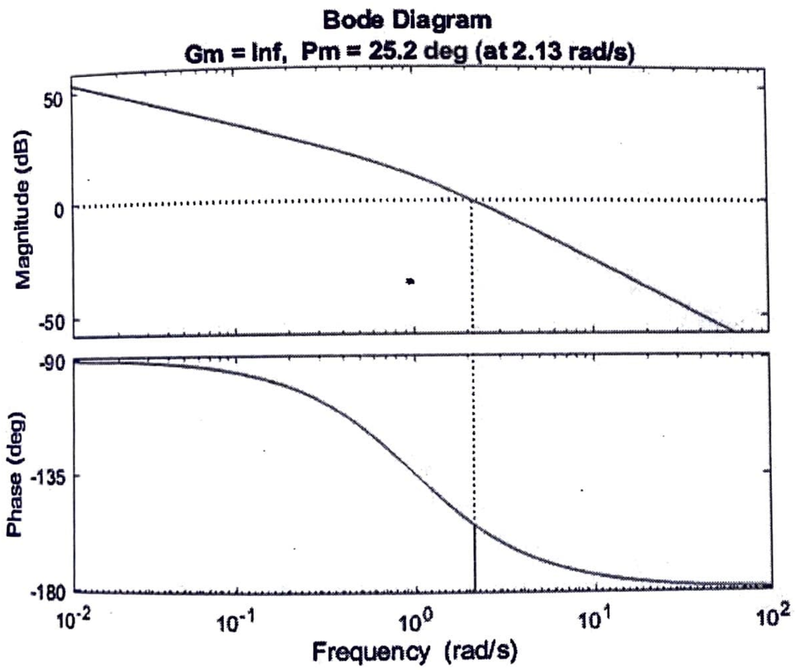
$\omega = 21$, $\angle G(j\omega) = -179'$

$\omega = 28$, $\angle G(j\omega) = -179.4'$

Name of Experiment.. Date.......12/4/22.......................

Experiment No.............02.............................. Experiment Result..................................


```
[no do] = series (N,D,nc,dc)
figure (2)
bode (no,do)
margin (no,do)
figure (3)
Subplot (2,1,1)
Step (no,do)
[n1 d1] = cloop (no,do,-1)
Subplot (2,1,2)
```



...ly state error

magnitude and

of the uncompensated

does not satisfy

is required.

3. Determine the phase margin of the uncompensated system from the plot.

4. Determine the phase lead ϕ_m to be provided by the lead compensator using the relation

$$\phi_m = \phi_s - \phi_u + \epsilon$$

$P_m = 13 - 18$

$\omega_{gc} = 4 \, r/s$

$\phi_m = \phi_s - \phi_u + \epsilon$

$\phi_m = 45 - 13 + 5$

$\boxed{\phi_m = 37^\circ}$

$$\alpha = \frac{1 - \sin\phi_m}{1 + \sin\phi_m}$$

$\boxed{\alpha = 0.248}$

$$A = -20 \log_{10}\left[\frac{1}{\sqrt{\alpha}}\right] = -20 \log_{10}\left[\frac{1}{\sqrt{0.248}}\right] = -6.05 \text{ dB}$$

$\boxed{A = -6.05 \text{ dB}}$

$\omega_m = 5 \, r/s$

$$\omega_m = \frac{1}{T\sqrt{\alpha}}$$

$$T = \frac{1}{5\sqrt{0.248}}$$

$T = 0.401 \text{ sec}$

$\alpha T = 0.1$

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

$$G_c(s) = \frac{0.25(0.4s+1)}{(0.1s+1)} = \frac{0.1s + 0.25}{0.1s + 1}$$

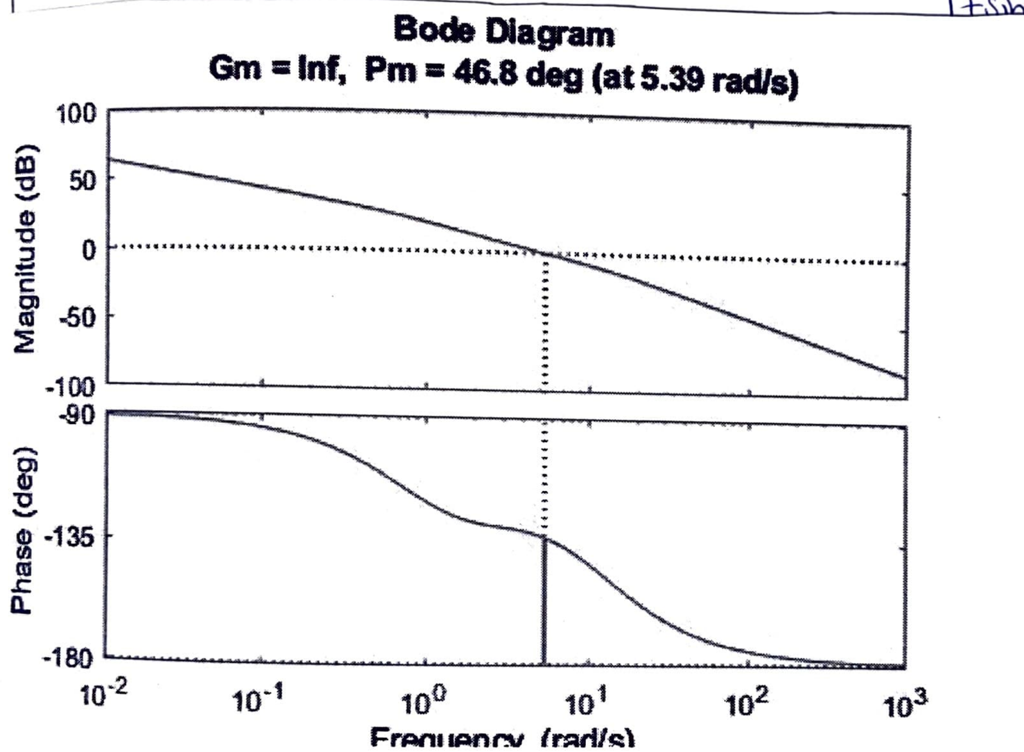
$$\longrightarrow \boxed{G(s) = \frac{k}{s(s+1)}} \longrightarrow \boxed{\frac{1}{\alpha}} \longrightarrow \boxed{G_c(s) = \frac{0.25(0.4s+1)}{(0.1s+1)}} \longrightarrow$$

ϕ_m = Specified or desired phase margin

ϕ_s = phase margin of the uncompensated system G(S)

ε = the margin of safety to account for the increase phase lead of G(S) due to increase in gain cross over frequency.

5. Determine the attenuation 'α', $\alpha = \frac{1-\sin\phi_m}{1+\sin\phi_m}$



... of the uncomp- ... is selected as the ... quency corresponds ... produces a phase

... determined,

8. The system gain is increased by a factor $1/\alpha$ to account for the attenuation due to lead network.

Transfer function, $G(s) = \dfrac{k\,(0.4s+1)}{s\,(s+1)(0.1s+1)}$

$$G(j\omega) = \frac{15\,(0.4j\omega+1)}{j\omega\,(j\omega+1)\,(0.1j\omega+1)}$$

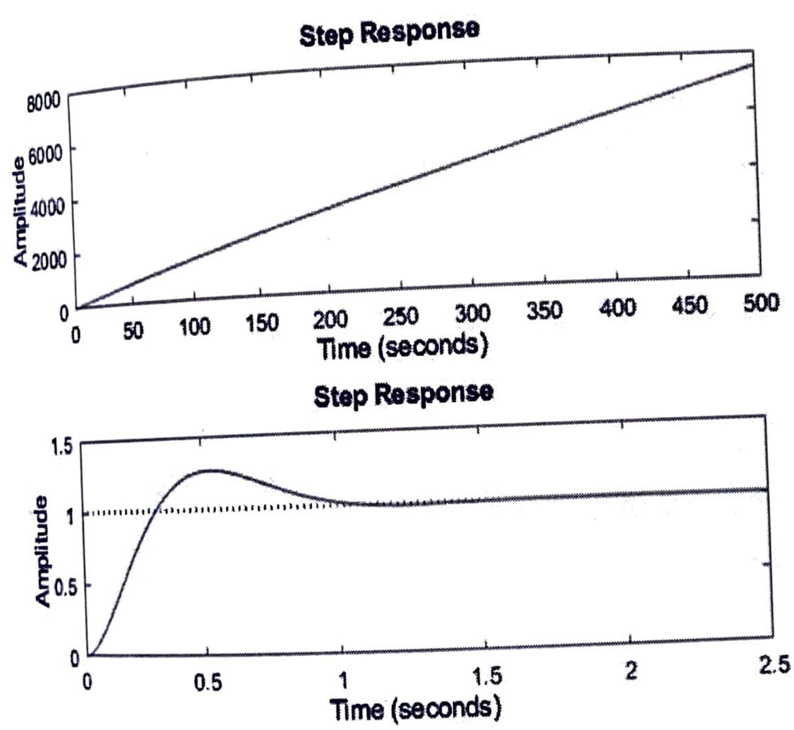
$\underline{\angle G(j\omega)} = -90^\circ - \tan^{-1}\omega - \tan^{-1}0.1\omega + \tan^{-1}0.4\omega$

When $\omega = \omega_m = 5\,r/s$

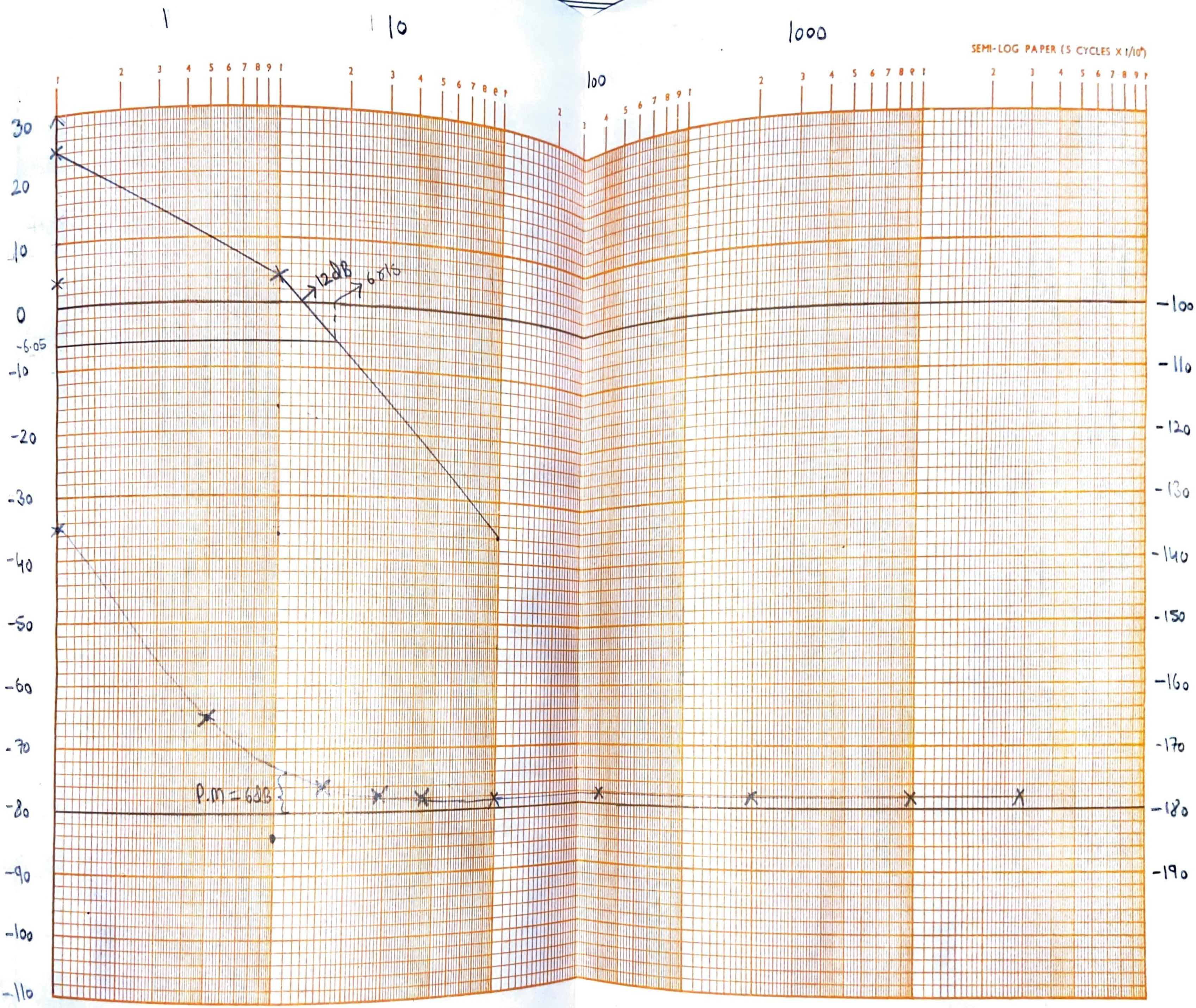
$\underline{\angle G(j\omega)} = -131.82^\circ$

Program :-

```
ess = input ('Enter steady state error')
kv = 1/ess
n=1
d = conv ([1,0] [1,1])
g = tf (n,d)
```




```
[gm, pm, wcp, wcg] = margin (mag, phase, w)
pm
dpmd = dpm - pm +5
dpmr = (dpmd * pi)/180
a = (1-sin (dpmr)) / (1+sin(dpmr))
a1 = -20 * log10 (1/sqrt(a))
w=100
```



SEMI-LOG PAPER (5 CYCLES X 1/10")
1
10
100
1000
30
20
10
0
-6.05
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
-110
-100
-110
-120
-130
-140
-150
-160
-170
-180
-190
12dB
6dB
P.M = 6dB

...iment
... 02

```
i = 0 : 0.01 : w)
    [mag, phase] = bode (N,D,i)
    m1 = 20 * log10 (mag)
    if  m1 <= a1
        freq = i
        break
    end

1/(freq * sqrt (a)]
[t 1]
[a*t 1]
] = series (N, D, nc, dc)
tf (no, do)
(2)
(no, do)
(no, do)
(3)
(2,1,1)
o, do)
] = cloop (no, do, -1)
(2,1,2)
, d1)
```

- Successfully coded the matlab program for lead and lag compensator and verified the result.

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Experiment No.......03.............. Experiment Result..........................

PD, PI and PID controller

Aim :- Design a PD/PI/PID controller in frequency domain for a given specification. Verify the result using MATLAB.

Procedure :-

The following procedure can be followed to design a PD/PI/PID controller when the given specifications are desired phase margin, γ_d at a gain crossover frequency ω_1.

Step 1 :- Determine the magnitude and phase of uncompensated open loop sinusoidal transfer function (i.e. $G(j\omega)$)

Let, $A_1 = |G(j\omega)|$ at $\omega = \omega_1$

$\phi_1 = \angle G(j\omega)$ at $\omega = \omega_1$

Step 2 :- Determine the phase margin of uncompensated system and the angle to be contributed by the controller to achieve the desired phase margin.

Let, γ_u = Phase margin of uncompensated system

γ_d = Desired phase margin at ω_1

θ = Phase angle of the uncompensated at $\omega = \omega_1$

Now, $\gamma_u = 180^\circ + \phi_1$ and $\theta = \gamma_d - \gamma_u$

Step 3 :- Determine the transfer function of the controller.

a. PD controller.

Derivative constant, $k_d = \sin\theta / \omega_1 A_1$
Proportional constant, $k_p = \cos\theta / A_1$
Transfer function of PD controller,

$$G_c(s) = (k_p + k_D s) = k_p\left(1 + \frac{k_d}{k_p} s\right)$$

b. PI controller

Integral constant, $k_i = -\omega_1 \sin\theta / A_1$
Proportional constant, $k_p = \cos\theta / A_1$
Transfer function of PI controller,

$$G_c(s) = (k_p + k_i/s \, \cancel{s}) = \frac{k_i\,(1 + k_p/k_i\, s)}{s}$$

c. PID controller

Transfer function of PID controller,

$$G_c(s) = (k_p + k_D s + k_i/s) = \frac{k_D\,(s^2 + k_p/k_d\, s + k_i/k_d)}{s}$$

Evaluate k_i such that the compensated system satisfies the error requirement. for example, if the compensated system is type-1 system, then $k_v = \lim_{s \to 0} s\, G_c(s)\, G(s)$ will give the value of k_i

Derivative constant, $k_d = \dfrac{\sin\theta}{\omega_1 A_1} + \dfrac{k_i}{\omega_1^2}$

Proportional constant, $k_p = \dfrac{\cos\theta}{A_1}$

Theoretical Calculation :-

PD controller :

$G_c(s) = k_p + k_D s$

$|G(j\omega)| = \dfrac{10}{\omega_1\sqrt{1+4\omega_1^2}\sqrt{1+\omega_1^2}}$

$A_1 = \dfrac{10}{1.2\sqrt{5.76}\sqrt{2.44}}$

$\boxed{A_1 = 2.227}$

$\underline{G(j\omega)} = -90^\circ - \tan^{-1}(0.5\omega_1) - \tan^{-1}\omega_1$

$\phi = -90^\circ - \tan^{-1}(0.6) - \tan^{-1}(1.2)$

$\boxed{\phi = -207.57^\circ}$

$Pm = 180^\circ + (-207.57)$

$\boxed{Pm = -27.57^\circ}$

$\theta = (Pm)_d - (Pm)_u$

$\theta = 30^\circ - (-27.57)$

$\boxed{\theta = 57.57^\circ}$

$k_p = \cos\theta / A_1$

$k_p = 0.536/2.081$

$\boxed{k_p = 0.261}$

$G(s) = \dfrac{5}{s(s+0.5)(s+1)}$

$k_D = \sin\theta / \omega_1 A_1$

$k_D = 0.844/2.4612$

$\boxed{k_D = 0.342}$

$G_c(s) = k_p\left(1 + \dfrac{k_D}{k_p}s\right)$

$= 0.261\,(1 + 1.31\,s)$

$G_o(s) = G_c(s)\cdot G(s)$

$$\boxed{G_o(s) = 0.261\,(1+1.31\,s) \times \frac{1}{s\,(2s+1)(1+s)}}$$

Verification :-

$|G_o(j\omega)| = 0.261\,(1+1.31s) \times \dfrac{10}{j\omega\,(2j\omega+1)(1+j\omega)}$

$= \dfrac{4.102}{4.8672}$

$= 0.842$

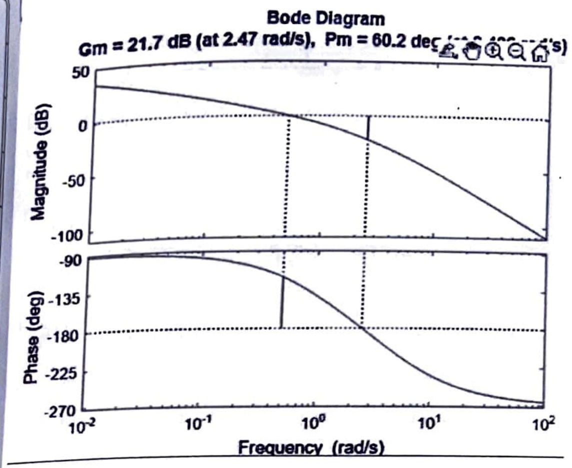
$\underline{G_o(j\omega)} = -90^\circ - \tan^{-1}(\omega_1) - \tan^{-1}(2\omega_1) + \tan^{-1}(1.31\omega_1)$

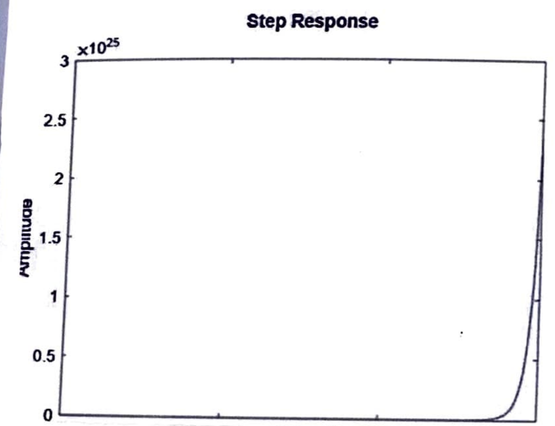
$= -150.03^\circ$

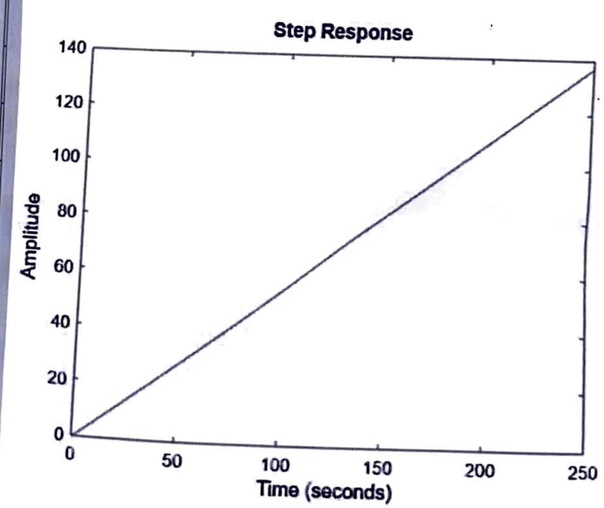
$Pm = 180 + (-150.03)$

$Pm = 180^\circ - 150.03$

$\boxed{Pm = 30.03^\circ}$







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Experiment Result

...p transfer function of compensated
of the controller is placed in
transfer function of compensated

...lculating phase margin of

compensated system

...≈1 and ...o satisfies the specifications

PI controller :

$$G(s) = \frac{100}{s(s+1)(s+2)(s+5)}$$

$$|G(j\omega)| = \frac{10}{\sqrt{1+\omega_1^2}\ \sqrt{1+(0.5\omega_1)^2}\ \sqrt{1+(0.2\omega_1)^2}}$$

$$|G(j\omega_1)| = \frac{10}{\sqrt{2.25}\ \sqrt{0.0625}\ \sqrt{1.29}}$$

$$|G(j\omega_1)| = 8.64 = A_1$$

$$\underline{|G(j\omega_1)} = -\tan^{-1}(\omega_1) - \tan^{-1}(0.5\omega_1) - \tan^{-1}(0.2\omega_1)$$

$$(PM)_u = 180° + (-46.31)$$
$$= 133.69°$$

$$\theta = (PM)_d - (PM)_u$$

$$\theta = 60° - 133.69$$

$$\boxed{\theta = -73.69}$$

$$K_p = \frac{\cos\theta}{A_1} \qquad K_I = \frac{-\omega_1 \sin\theta}{A_1}$$

$$K_p = \frac{0.28}{8.64} \qquad K_I = \frac{+0.479}{8.64}$$

$$\boxed{K_p = 0.032} \qquad \boxed{K_I = 0.05}$$

$$G_o(s) = \frac{K_p s + K_I}{s}$$

$$G_o(s) = \frac{0.05\,(1+0.64s)}{s}$$

Verification :-

$$|G_o(s)| = \frac{0.05\,(1+0.64s)}{s}$$

$$|G_o(j\omega)| = \frac{0.05\,(1+0.64j\omega)}{j\omega}$$

$$|G_o(j\omega)| = \frac{0.05\sqrt{1+(0.64\omega_1)^2}}{\sqrt{\omega^2}}$$

$$|G_o(j\omega)| = 0.104$$

$$\underline{|G_o(j\omega)} = -90° + \tan^{-1}(0.64\omega_1) - \tan^{-1}(\omega_1) - \tan^{-1}(0.5\omega_1) - \tan^{-1}(0.2\omega_1)$$

$$\underline{|G_o(j\omega)} = -119.61°$$

$$PM = 180° + (-119.61)°$$

$$PM = 180° - 119.61°$$

$$\boxed{PM = 60.39°}$$

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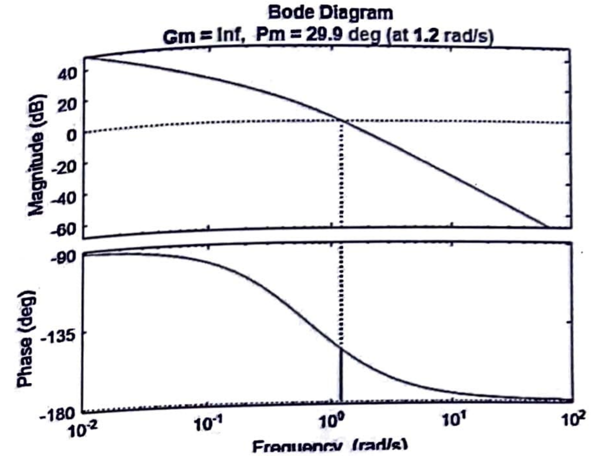
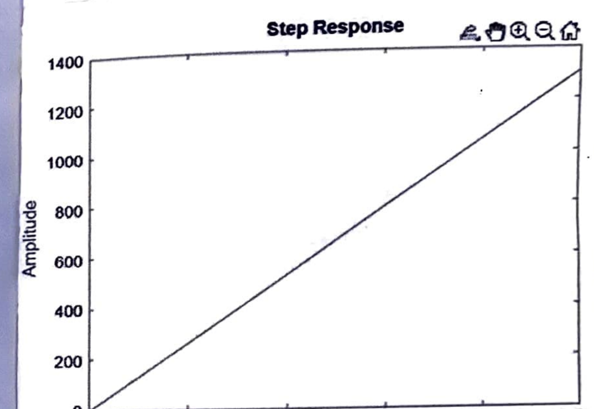
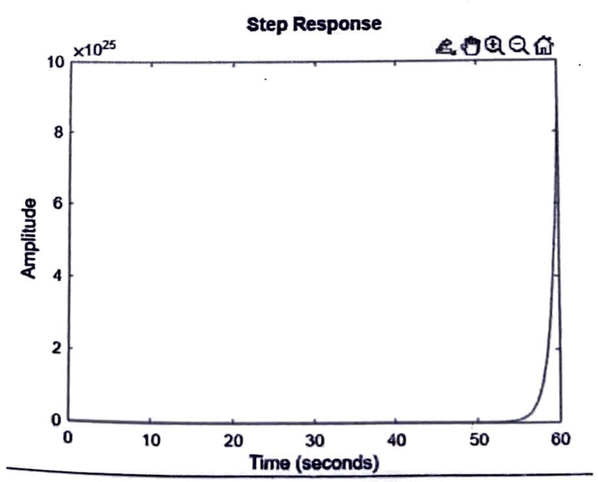
...ment Result







PID controller :

$$G(S) = \frac{100}{(S+1)(S+2)(S+10)}$$

$$e_{ss} = \frac{1}{K_v}$$

$$0.1 = \frac{1}{K_v}$$

$\boxed{K_v = 10}$

$$K_v = \lim_{S \to 0} S \cdot G(S) H(S) G_c(S)$$

$$K_v = \lim_{S \to 0} S \frac{100}{(S+1)(S+2)(S+10)} \cdot \frac{K_p S + K_I + K_D S^2}{S}$$

$\boxed{K_v = 2}$

$$|G(j\omega)| = \frac{5}{\sqrt{1+\omega_1^2}\sqrt{1+0.5\omega_1^2}\sqrt{1+0.1\omega_1^2}}$$

$$|G(j\omega)| = \frac{5}{4.1231 \cdot 2.236 \cdot 1.0770}$$

$$|G(j\omega)| = 0.50357 = A_1$$

$$\underline{/G(j\omega)} = -\tan^{-1}(\omega_1) - \tan^{-1}(0.5\omega_1) - \tan^{-1}(0.1\omega_1)$$

$$\underline{/G(j\omega)} = -\tan^{-1}(4) - \tan^{-1}2 - \tan^{-1}0.4$$

$$\underline{/G(j\omega)} = -161.2001^\circ$$

$$(Pm)_u = 180^\circ + (-161.200)$$
$$= 18.79^\circ$$

$$\theta = (Pm)_d - (Pm)_u$$
$$= 45^\circ - 18.79^\circ$$
$$= 26.201^\circ$$

$$K_p = \frac{\cos\theta}{A_1} \qquad K_D = \frac{\sin\theta}{\omega_1 A_1} + \frac{K_I}{\omega_1^2}$$

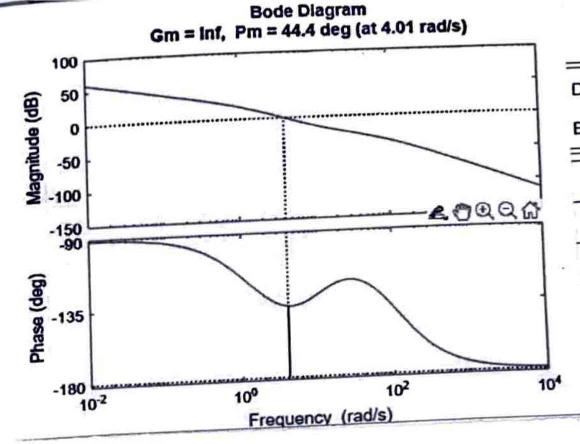
$$K_p = \frac{\cos 26.2}{0.5036} \qquad K_D = \frac{\sin 26.2}{4 \times 0.5036} + \frac{2}{4^2}$$

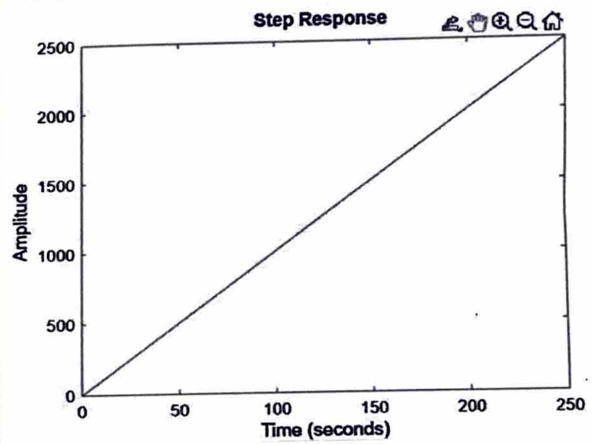
$$K_p = 1.7817 \qquad K_D = 0.344$$

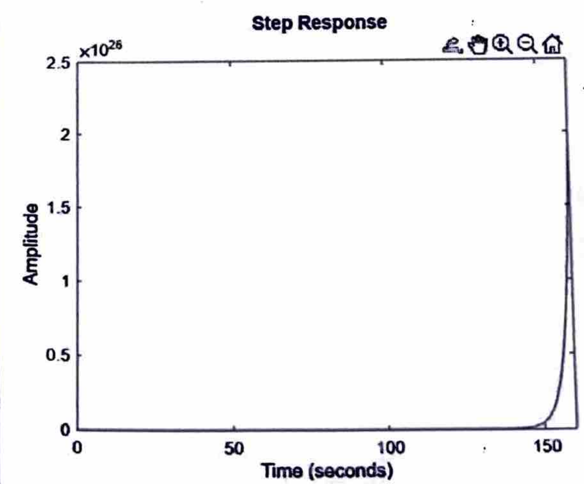
$$G_c(S) = \frac{K_p S + K_I + K_D S^2}{S}$$

$$G_c(S) = \frac{K_D\left(S^2 + \frac{K_P}{K_D} S + \frac{K_i}{K_D}\right)}{S}$$

$$G_c(S) = \frac{0.344\,(S^2 + 5.1744S + 5.813)}{S}$$







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Experiment Result

The program for PI, PD and PID
the result