Design of Compensators

Aim:- To design lead and lag compensators

Tools Required:- A PC loaded with MATLAB.

Theory:-

Compensators in control systems engineering play a crucial role in shaping the behaviour of the system to achieve desired performance. They are used to modify the input-output relationship of a control system, ensuring stability, robustness, and desired transient response. Compensators can correct errors, attenuate disturbances, and improve system performance by adjusting the gain, phase and frequency response characteristics. Essentially, compensators help engineers tailor the control system's dynamics to meet specific design requirements and performance criteria.

Program:-

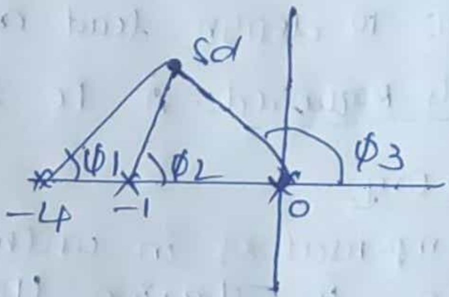
$M_P = 20\%$.

$M_P = e^{\frac{-\pi \xi}{\sqrt{1-\xi^2}}} = 0.2 \Rightarrow \xi = 0.45$

$t_s = \frac{4}{\xi \omega_n} \Rightarrow 5 = \frac{4}{0.45 \times \omega_n} \Rightarrow \omega_n = 1.75 \text{ rad s}^{-1}$

$s_d = -\xi\omega_n \pm j\omega_n\sqrt{1-\xi^2}$

$= -0.78 \pm j1.55$



$\theta = \cos^{-1}(\xi)$

$= \cos^{-1}(0.46) = 62.61°$

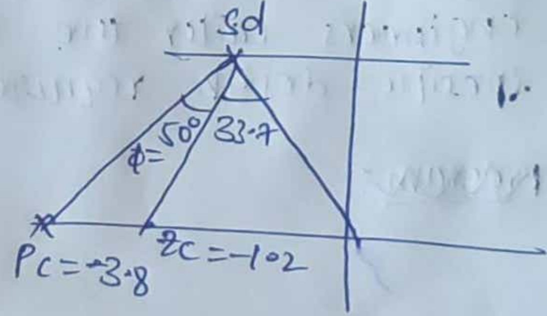
$\angle G(s) = \phi_1 + \phi_2 + \phi_3 = 230°$

$(\phi_1 = 25°;\ \phi_2 = 80°;\ \phi_3 = 125°)$

$\phi = -180° + \angle G(s) = -180° + 230° = 50°$

$\gamma = \frac{1}{2}[180° - \theta - \phi] = \frac{1}{2}[180° - 62.61° - 50°] = 33.7°$

$G_c(s) = \frac{s+1.2}{s+3.8}$



Overall transfer function

$OLTF = G_c(s)G(s)$

$= \frac{(s+1.2)k}{(s)(s+1)(s+4)(s+3.8)}$

$\alpha = \frac{z_c}{p_c} = \frac{1.2}{3.8} = 0.31$

$|G_c(s)G(s)|_{s=s_d} = 1$

$\left| \frac{k(s+1.2)}{s(s+3.8)(s+1)(s+4)} \right|_{s=s_d} = 1 \Rightarrow k = 20.78 \Rightarrow G(s) = \frac{20.78}{s(s+1)(s+4)}$

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Program :-

Q1) Design lead compensator for OLTF $G(s) = \frac{k}{s(s+1)(s+4)}$. It is desired to have a peak overshoot 20% and settling time 5 sec.

```
clc;
clear;
close all;

s = tf('s')
g = 20.78/(s*(s+1)*(s+4));
gc = (s+1.2)/(s+3.8);
k = series(g,gc);
cltf = feedback(k,1);
stepinfo(cltf)
```

Q2) Design a lag compensator for OLTF $G(s) = \frac{k}{(s+1)(s+2)(s+10)}$ to improve steady state error by a factor of 10 if the system is operating with a damping ratio 0.174

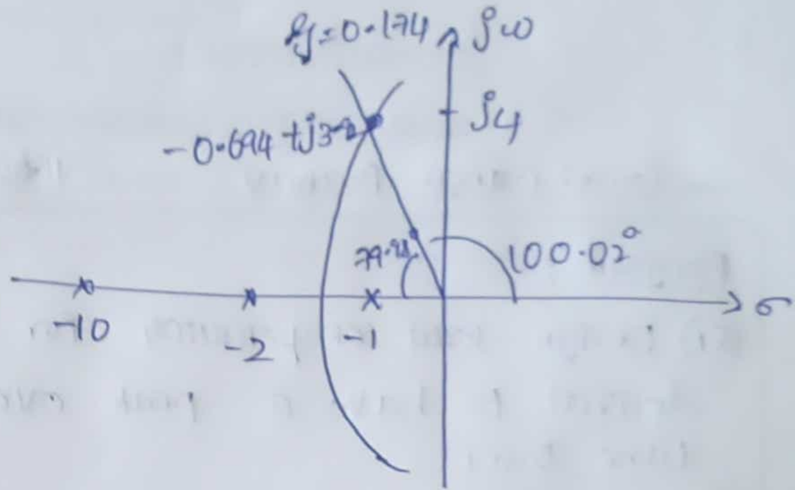
Root locus of uncompensated system:-

$\xi = 0.174$

$\cos^{-1}(\xi) = \theta = 79.98$

$s_d = -0.694 \pm j(3.926)$

At s_d, $|G(s_d)| = 1$



$$\Rightarrow \frac{k}{|(s+2)(s+1)(s+20)|_{s=s_d}} = 1$$

$$\Rightarrow k = 164.6$$

$$K_p = \lim_{s\to 0} G(s) = \lim_{s\to 0} \frac{k}{(s+1)(s+2)(s+10)} = \frac{164.6}{20} = 8.23$$

$$e_{ss} = \frac{1}{1+K_p} = 0.108$$

Ten fold improvement in e_{ss} means $e_{ss}(new) = 0.0108$

$$\Rightarrow K_{p\,new} = \frac{1}{e_{ss\,new}} - 1 = 91.59$$

$$\frac{z_c}{p_c} = \frac{K_{p\,new}}{K_{p\,old}} = \frac{91.59}{8.23} = 11.13$$

$\Rightarrow$ Let $p_c = 0.01 \Rightarrow z_c = 0.111$

$$\text{Overall OLTF} = \frac{k}{(s+2)(s+1)(s+10)} \times \left[\frac{s+0.111}{s+0.01}\right]$$

By drawing Root locus for this OLTF, we get $s_d = -0.678 \pm j3.8$

$$|OLTF|_{s=s_d} = 1 \Rightarrow K = 158.1$$

$$\Rightarrow K_p = \lim_{s\to 0} G(s)\,G_c(s) = \frac{158 \times 0.111}{20 \times 0.01} = 87.69$$

$$\Rightarrow e_{ss\,(new)} = \frac{1}{1+K_p} = 0.011$$

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```
clc;
close;
Clear all;
s=tf('s');
~~t = -3:0.01:3~~
~~vasavi~~
gs = 164.6/((s+2)*(s+1)*(s+10))
k=feedback(gs,1)
rlocus(k)
figure
stepplot(k)
figure
gs1=0.97*(s+0.111)/(s+0.01);
k1=series(gs,gs1)
cltf=feedback(k1,1)
lsim(cltf,x,t)
stepplot(cltf)
figure
rlocus(cltf)
```

Result:- Designed lead and lag compensators according to given specifications.