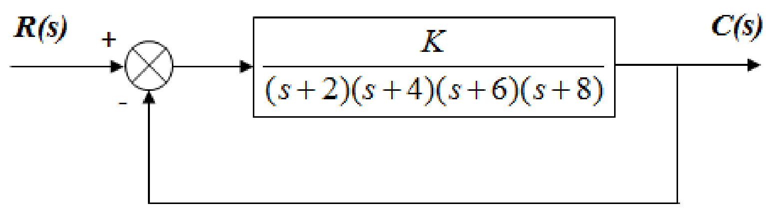
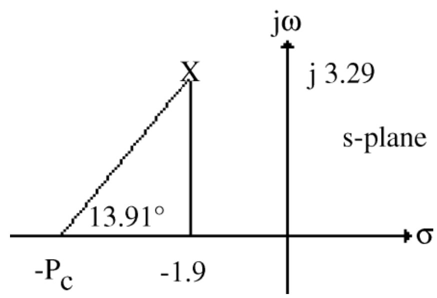
Given the system, design a **lag-lead compensator** that yields a settling time 0.5 seconds shorter than that of the uncompensated system. The compensated system also will have a damping ratio of 0.5, and improve the steady-state error by a factor of 30. The lead compensator zero is at -5, and the lag compensator pole is at 0.001. Justify the second-order approximations and verify the design through simulation.



19.

Lead compensator design: Searching along the 120^o line ($\zeta = 0.5$), find the operating point at $-1.531 + j2.652$ with $K = 354.5$. Thus, $T_s = \frac{4}{\zeta\omega_n} = \frac{4}{1.531} = 2.61$ seconds. For the settling time to decrease by 0.5 second, $T_s = 2.11$ seconds, or $Re = -\zeta\omega_n = -\frac{4}{2.11} = -1.9$. The imaginary part is $-1.9 \tan 60^o = 3.29$. Hence, the compensated dominant poles are $-1.9 \pm j3.29$. The compensator zero is at -5. Using the uncompensated system's poles along with the compensator zero, the summation of angles to the design point, $-1.9 \pm j3.29$ is -166.09^o. Thus, the contribution of the compensator pole must be $166.09^o - 180^o = -13.91^o$. Using the following geometry, $\frac{3.29}{p_c - 1.9} = \tan 13.91^o$, or $p_c = 15.18$.



Adding the compensator pole and using $-1.9 \pm j3.29$ as the test point, $K = 1417$.

Computer simulations yield the following: Uncompensated: $T_s = 3$ seconds, %OS = 14.6%.

Compensated: $T_s = 2.3$ seconds, %OS = 15.3%.

Lag compensator design: The lead compensated open-loop transfer function is

$G_{LC}(s) = \frac{1417(s+5)}{(s+2)(s+4)(s+6)(s+8)(s+15.18)}$. The uncompensated

$K_p = 354.5/(2 \times 4 \times 6 \times 8) = 0.923$. Hence, the uncompensated steady-state error is $\frac{1}{1+K_p} = 0.52$. Since we want 30 times improvement, the lag-lead compensated system must have a steady-state error of $0.52/30 = 0.017$. The lead compensated $K_p = 1417*5/(2*4*6*8*15.18) = 1.215$. Hence, the lead-compensated error is $\frac{1}{1+K_p} = 0.451$. Thus, the lag compensator must improve the lead-compensated error by $0.451/0.017 = 26.529$ times. Thus $0.451/\left(\frac{1}{1+K_{pllc}}\right) = 26.529$, where $K_{pllc} = 57.823$ is the lead-lag compensated system's position constant. Thus, the improvement in K_p from the lead to the lag-lead compensated system is $57.823/1.215 = 47.59$. Use a lag compensator, whose zero is 47.59 times farther than its pole, or $G_{lag} = \frac{(s+0.04759)}{(s+0.001)}$. Thus, the lead-lag compensated open-loop transfer function is $G_{LLC}(s) = \frac{1417(s+5)(s+0.04759)}{(s+2)(s+4)(s+6)(s+8)(s+15.18)(s+0.001)}$.

20.

Program:

```
numg=1;
deng=poly([-2 -4 -6 -8]);
'G(s)'
G=tf(numg,deng);
Gzpk=zpk(G)
rlocus(G,0:5:500)
z=0.5;
pos=exp(-pi*z/sqrt(1-z^2))*100;
sgrid(z,0)
title(['Uncompensated Root Locus with ' , num2str(z), ' Damping Ratio
Line'])
[K,p]=rlocfind(G);  %Allows input by selecting point on graphic
'Closed-loop poles = '
p
i=input('Give pole number that is operating point   ');
'Summary of estimated specifications for uncompensated system'
operatingpoint=p(i)
gain=K
estimated_settling_time=4/abs(real(p(i)))
estimated_peak_time=pi/abs(imag(p(i)))
estimated_percent_overshoot=pos
estimated_damping_ratio=z
estimated_natural_frequency=sqrt(real(p(i))^2+imag(p(i))^2)
Kpo=dcgain(K*G)
T=feedback(K*G,1);
'Press any key to continue and obtain the step response'
pause
step(T)

whitebg('w')
title(['Step Response for Uncompensated System with  ' , num2str(z),...
' Damping Ratio'],'color','black')
'Press any key to go to Lead compensation'
pause
'Compensated system'
b=5;
'Lead Zero at -b '
done=1;
while done>0
a=input('Enter a Test Lead Compensator Pole, (s+a). a =     ');
numgglead=[1 b];
dengglead=conv([1 a],poly([-2 -4 -6 -8]));
'G(s)Glead(s)'
GGlead=tf(numgglead,dengglead);
GGleadzpk=zpk(GGlead)
```