Project 3

Objective

Designing a control system for given plant having $PM > 40$ and settling time for 5% settling less than 1 sec. Observing effect of time delay on the system to determine sensor latency which can be tolerated for before the system goes unstable.

Introduction

Dynamic System transfer function is as below-

$$\frac{Y}{U} = \frac{50(s+4)}{s(s+6)(s^2+4s+25)}$$

Design Requirements-

Phase margin for the final system greater than 40, velocity error (K_v) for the system is greater than $\frac{20}{3}$ and step response 5% settling time is less than 1sec, with actuator force not exceeding $\pm 15N$.

Control System Design

For velocity error constant K_v to be greater than $\frac{20}{3}$.

Let us assume system have loop gain as K_c,hence the loop transfer function will become-

$$G_l(s) = \frac{50K_c(s+4)}{s(s+6)(s^2+4s+25)}$$

we have,

$$K_v = \lim_{s \to 0} s * G_l(s)$$

By substituting above values, we get,

$$K_v = \lim_{s \to 0} s * \frac{50K_c(s+4)}{s(s+6)(s^2+4s+25)}$$

$$K_v = \lim_{s \to 0} \frac{50K_c(s+4)}{(s+6)(s^2+4s+25)}$$

Hence, $K_v = \dfrac{50 * 4 * K_c}{6 * 25}$

$$K_v = \frac{4}{3}K_c$$

We have, $K_v > \frac{20}{3}$

hence, $\frac{4}{3}K_c > \frac{20}{3}$

We get, condition for loop gain as below,

$K_c > 5$

Steady state error for the system for ramp input can be obtained as below-

we have, $e_{ss} = \frac{A}{K_v}$

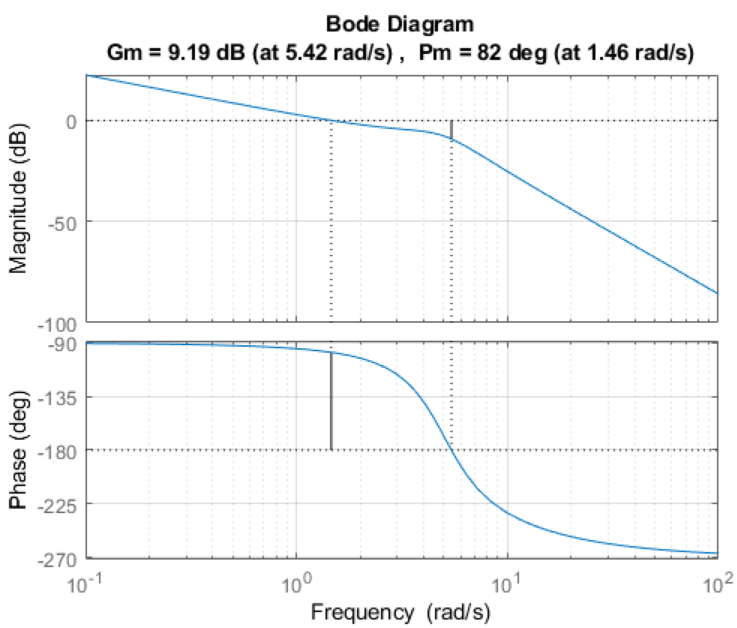
If $A = 1$ we get, $e_{ss} = \frac{1}{K_v}$

But, we have condition as, $K_v > \frac{20}{3}$

hence, we get condition for steady state error as-

$e_{ss} < \frac{3}{20}$

For initial system, phase margin observed to be 82 degrees, against the required of 40deg.

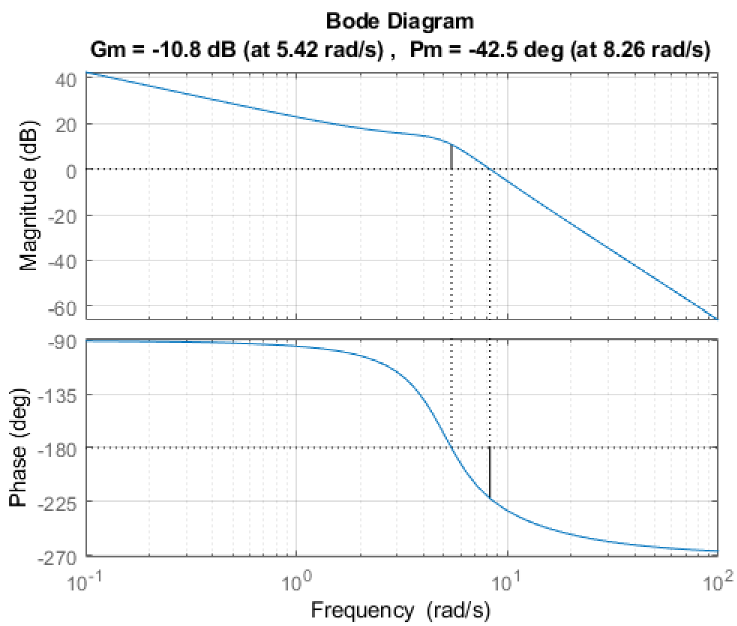


Range for stability of K from bode plot of the system can be observed as below-

For stability we get range as-

$1 < k < 2.8810$, where as to achieve steady state error requirement we require, $k > 5$

With gain for system greater than 5, initially system was designed with gain of 5.2, but for the requirement of actuator force less than $\pm 15\,Nm$, filters were required to be added to the input command in simulations, hence response by the system for settling time was delayed from the designed for 1 sec at 5% settling time, hence settling time with system design is targeted for 0.6 sec against required of 1 sec and gain value for lead compensator design to include in loop transfer function used is 10, which will satisfy the requirement for steady state error.



Phase margin of the system is -42.5 deg against required of 40deg.

Hence, lead compensator will be required to be added in system which will provide phase lead of (40+42.5 = 82.5) 83 deg, to obtain the required response from the system.

As phase required is greater than 50degree, initial decision was to use two lead compensators providing phase lead of 49 and 34 respectively.

Below were the formulas used for the design of the lead compensator

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

where, α is one of the design parameters lead compensator and ϕ_m is the phase to be added

$$|G_m(\omega_m)| = 10log_{10}\alpha$$

where, ω_m is the frequency at which the gain calculated in dB from above formula is observed, and it is the frequency which is used for adding the lead compensator.

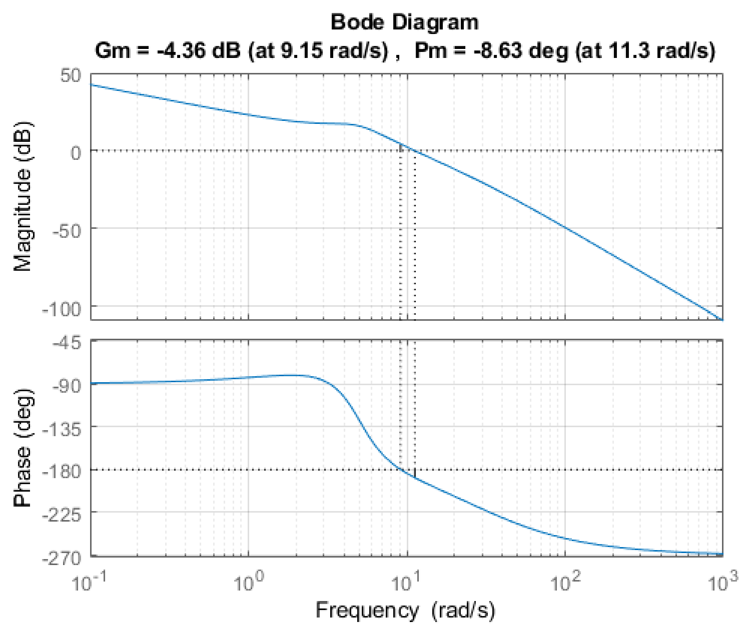
$$T = \frac{1}{\omega_m \sqrt{\alpha}}$$

where, T is the design parameter for lead compensator.

From above formulas, we get lead compensator as-

$$D(s) = \frac{Ts+1}{\alpha Ts+1}$$

From the calculations frequency for adding phase lead compensator observed to be 11.26 rad/s

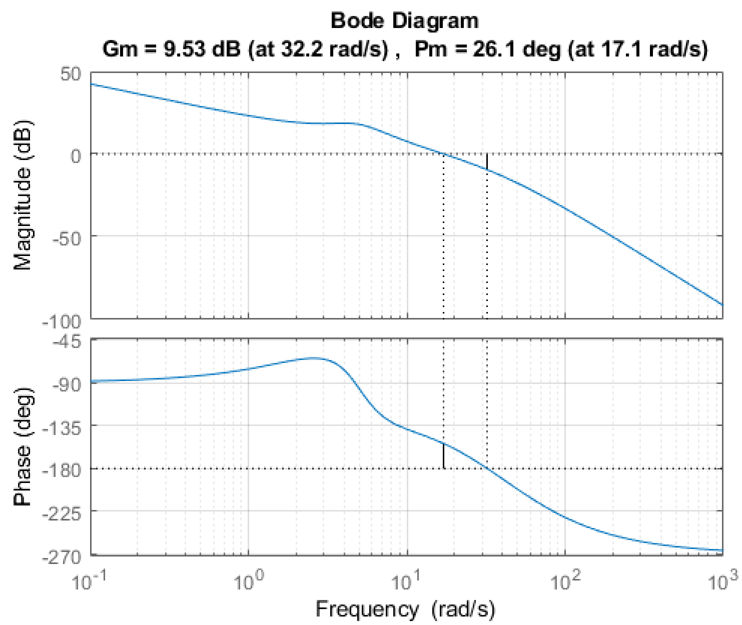


First lead compensator for designed for phase lead of 49, observed to be providing the phase lead of 33.82 deg against targeted 49deg, final PM of the system with one lead compensator designed observed to be -8.62deg. Hence for design requirement, additional phase of 48deg is required, hence second lead compensator designed to provide phase lead of 49 deg.

First compensator obtained from design is as below-

$$D_1(s) = \frac{0.2375s+1}{0.0332s+1}$$

Frequency for adding second lead compensator observed to be 17.1 rad/s

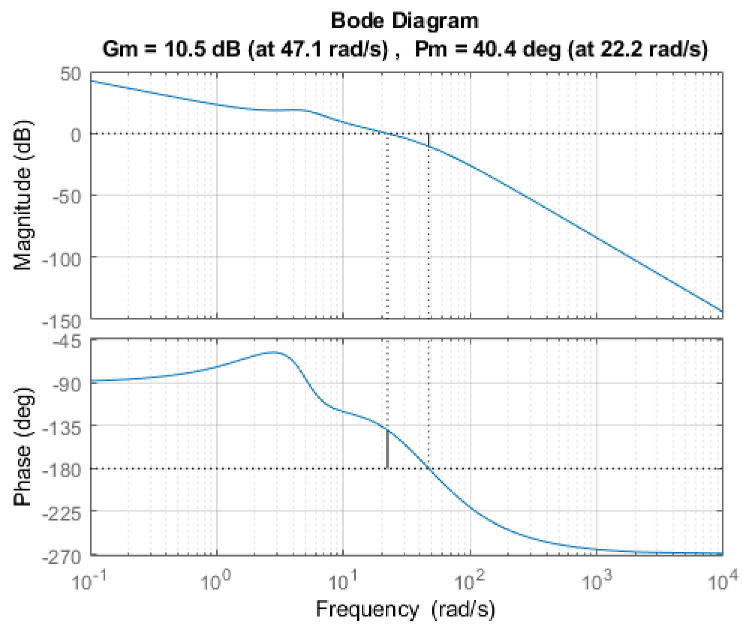


Second lead compensator for designed for phase lead of 49, observed to be providing the phase lead of 26.08 deg against targeted 49deg, final PM of the system with two lead compensators designed observed to be 26.123deg. Hence to satisfy design requirement, additional phase of 13.88deg is required, by checking phase graph the system with two compensator, phase lead compensator designed with phase lead of 23.80deg against the required 13.88deg.

Second lead compensator designed is as below-

$$D_2(s) = \frac{0.1564s + 1}{0.02186s + 1}$$

Frequency for adding third compensator observed to be 22.2 rad/s.

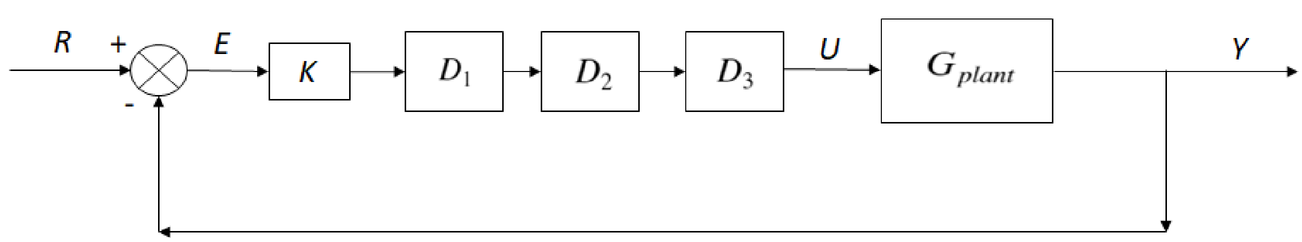


With the third lead compensator in system, total system phase margin observed to be 40.3852deg against required 40deg. Third lead compensator provided the value of 14.2463deg against targeted 23.80 deg.

Third lead compensator designed is as below-

$$D_3(s) = \frac{0.0691s + 1}{0.02936s + 1}$$

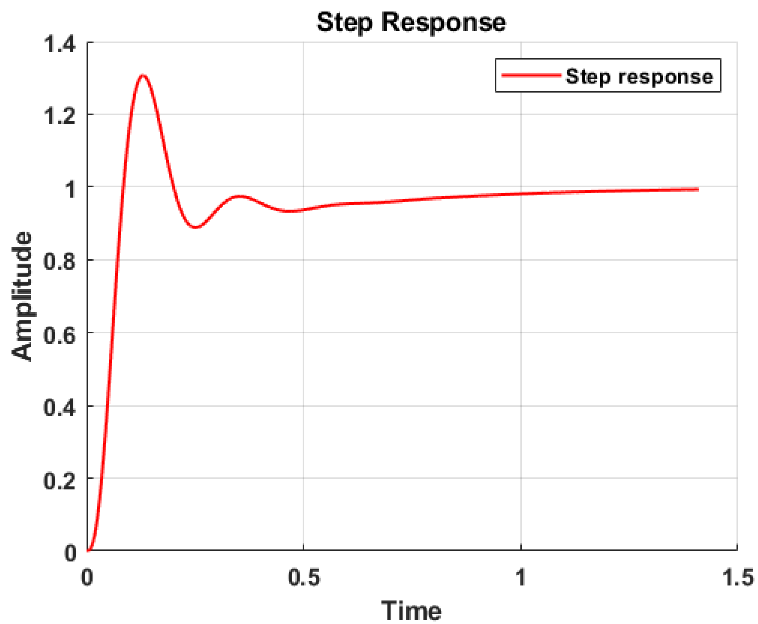
With three designed lead compensators and gain of 10, Block diagram of the system can be represented as below-



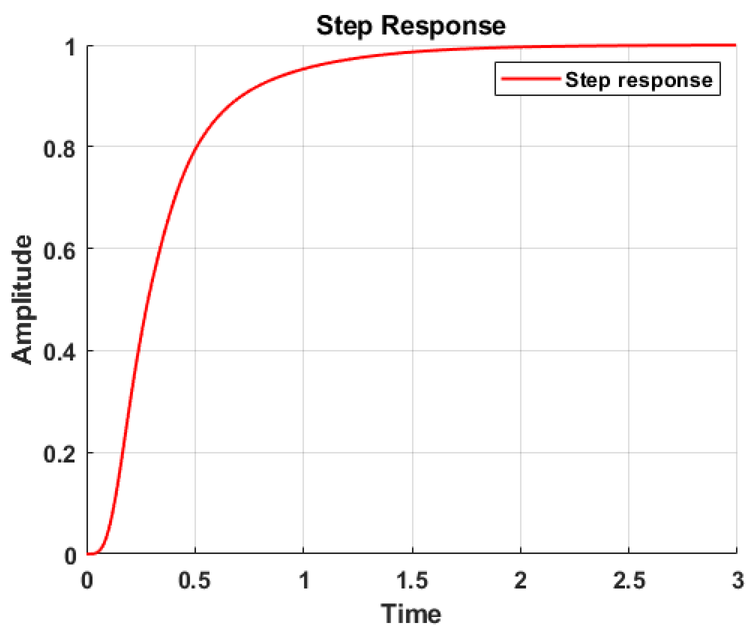
Where,

$$K_c = 10, D_1(s) = \frac{0.2375s + 1}{0.0332s + 1}, D_2(s) = \frac{0.1564s + 1}{0.02186s + 1}, D_3(s) = \frac{0.0691s + 1}{0.02936s + 1}$$

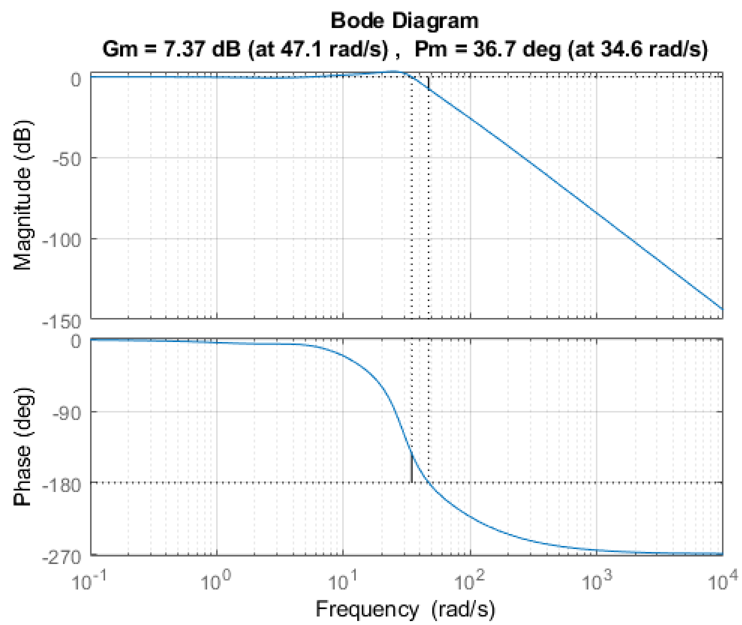
For designed system, 5% settling time observed to be 0.56sec against targeted 0.6sec. Below graph provide response of the system observed without filters.



By adding filters in the system final settling time for the system observed to be 0.9765sec for 5% settling against required 1sec. Below is the step response from the system with filters used-



Closed loop system bode plot for the final design with two phase lead compensators is as shown below-



For the closed loop system, bandwidth observed to be 39.5rad/s.

Design Verification with Root Locus

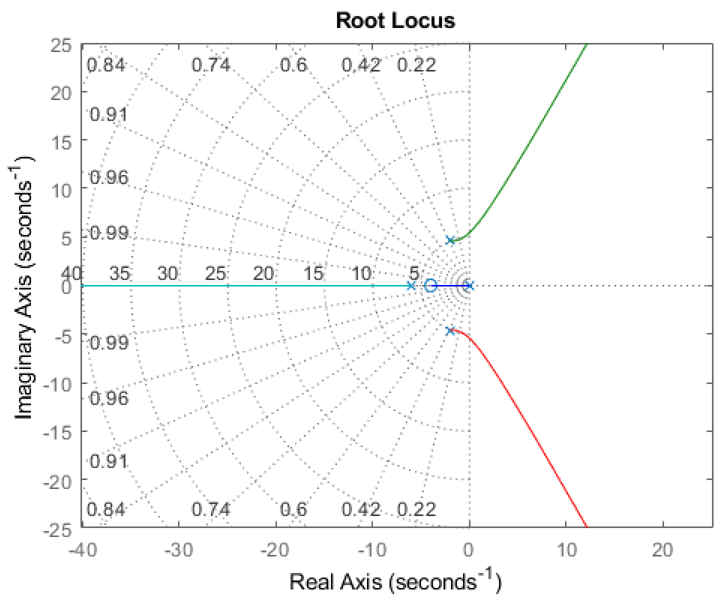
For only plant in loop, characteristic equation for the system can be represented as-

$$1 + K_c * G_{plant} = 0$$

Hence loop transfer function for root locus will be-

$$G_l = G_{plant} = \frac{50(s+4)}{s(s+6)(s^2+4s+25)}$$

For initial system root locus observed to be as below-



As from earlier design for $K_v > \frac{20}{3}$ gain value for the system observed to be required as $K > 5$. At Around $K > 2.75$ roots locus enters into the RHP making system unstable. For selected value of gain, without compensator roots for the system observed to be -3.6164 + 0.0000i, 1.7208 $\pm$ 7.5345i, -9.8253 + 0.0000i. Initially for the required gain system had two poles in RHP and system goes unstable for the high gains as seen from the bode plot earlier.

Below is the loop transfer function for the designed system, which can be represented as-

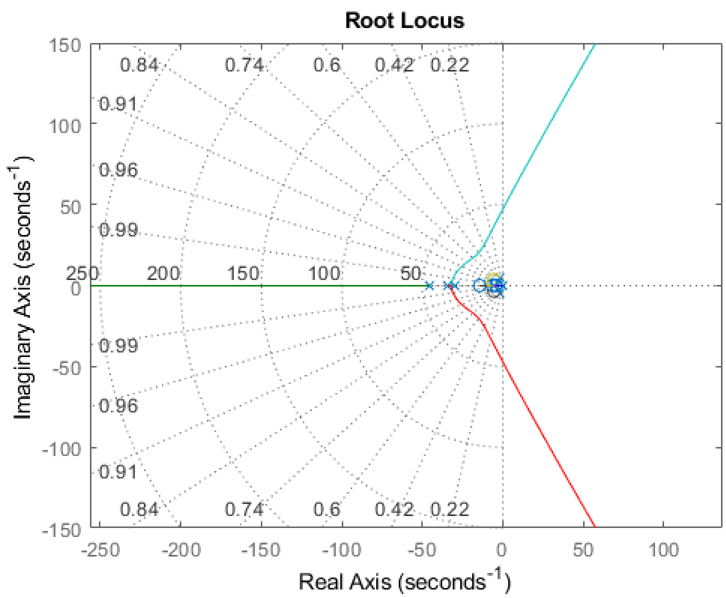
Characteristic equation for the system will be-

$1 + K_c * D_1 * D_2 * D_3 * G_{plant} = 0$

Hence loop transfer function for the system will be-

$G_l(s) = D_1 * D_2 * D_3 * G_{plant}$ and we have taken $K_c = 10$ for the final system.

Root locus for the designed system is as below-



With the designed system, system observed to have 7 poles, and all the roots for the $K_c = 10$ observed to be in LHP -2.5832, -74.2808, -9.2523 $\pm$29.3276i, -5.8286, -9.3559 $\pm$ 3.4430i against the earlier, with two poles in RHP. Designed system is stable. At $K_c = 10$ on root locus plot we get, $\zeta = 0.345$ and $\omega_n = 29.5 rad/s$. By using the time domain analysis tool, approximate settling time for the system can be observed to be as below-

$$t_s = \frac{4.6}{\zeta \omega_n}$$

After substituting values obtained from the root locus for the designed system at $K_c = 10$ we get settling time to be 0.452sec against targeted 0.6sec for the system.

Design Verification with Nyquist

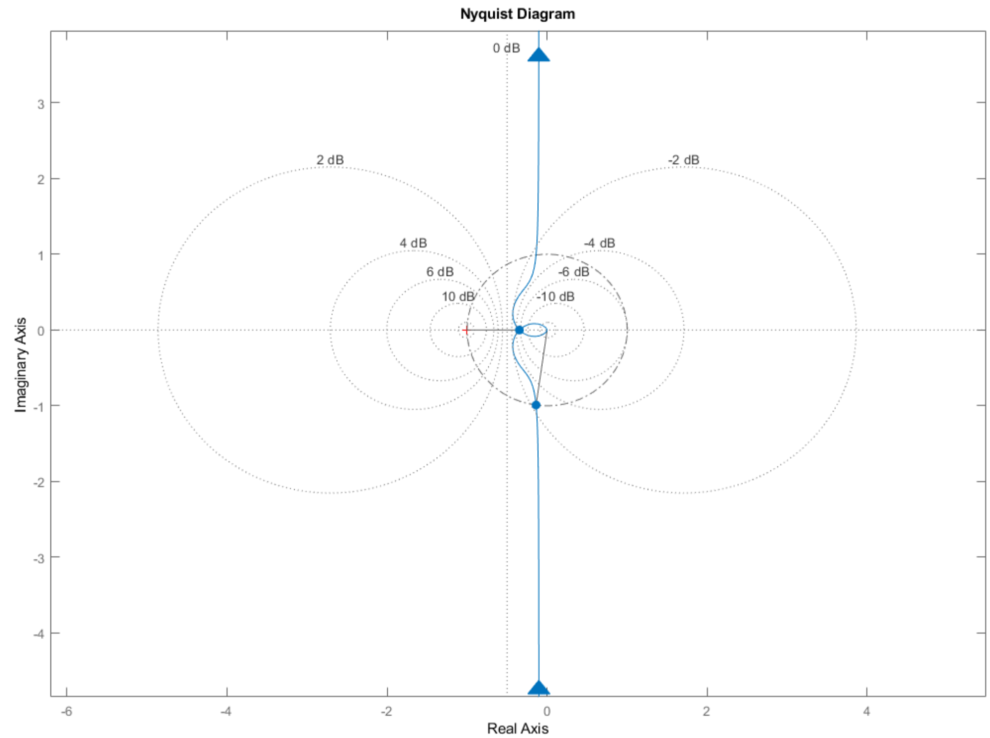
With initial system, characteristic equation for the system can be represented as-

$$1 + K_c * G_{plant} = 0$$

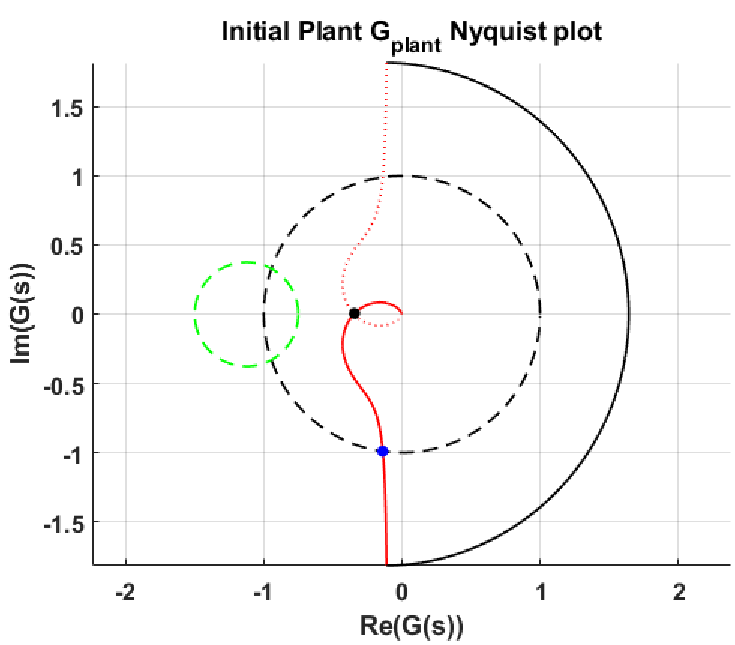
Hence loop transfer function for Nyquist plot will be-

$$G_l = G_{plant} = \frac{50(s+4)}{s(s+6)(s^2+4s+25)}$$

From the MATLAB command we get Nyquist plot as below-



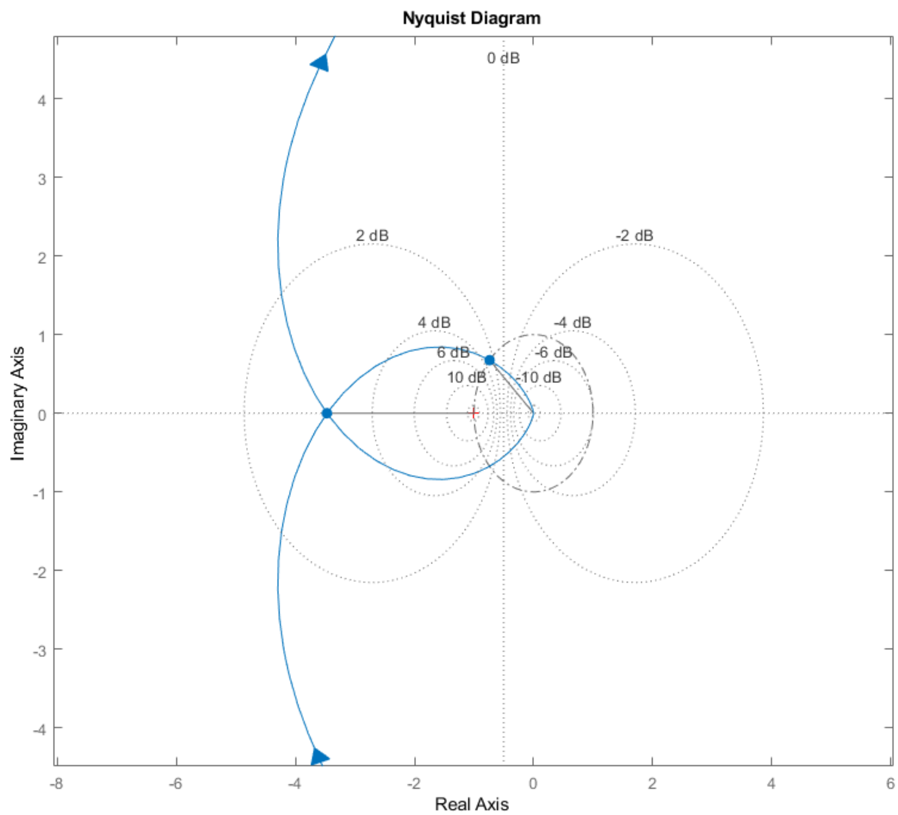
Same prepared with below MATLAB code considering maximum frequency as 50rad/sec.



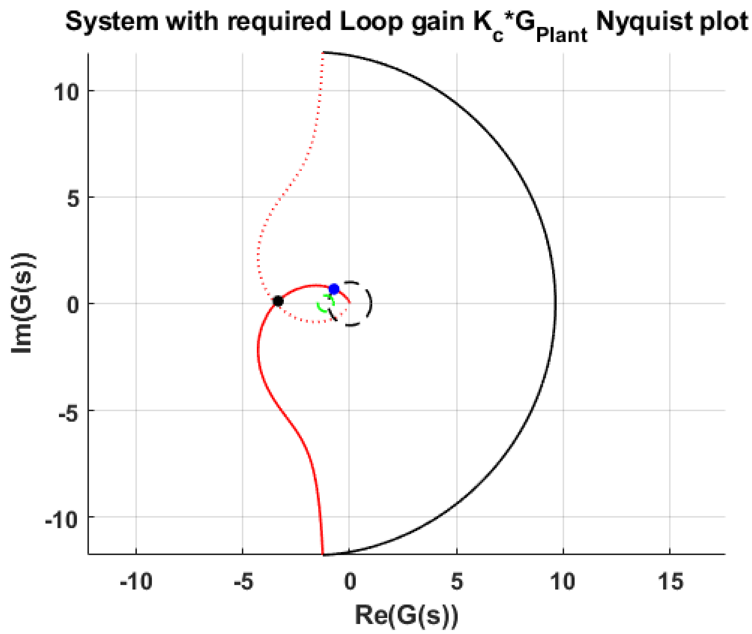
From the initial Nyquist plot available for the system, it can be observed that gain margin for the system is 9.4dB and phase margin for the system is 82.0373deg. which provide range for K_c as $0 < K_c < 2.951$

For required stead state error, we have $K_c > 5$. With selected $K_c = 10$ Nyquist plot for the system observed to be as below-

From the MATLAB command we get Nyquist plot as below-



by considering maximum frequency as $50\, rad/sec$ we get, Nyquist plot as below

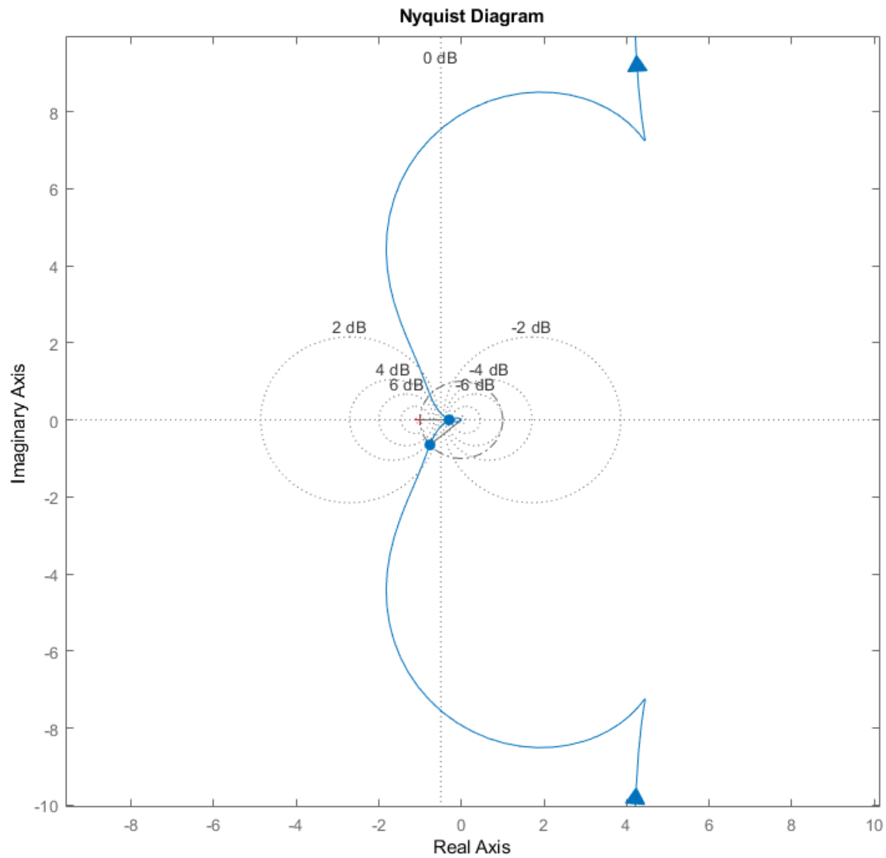


By considering the K_c required for the system, phase margin of the system observed to be -42.46deg, as observed with the bode plot and system observed to be unstable.

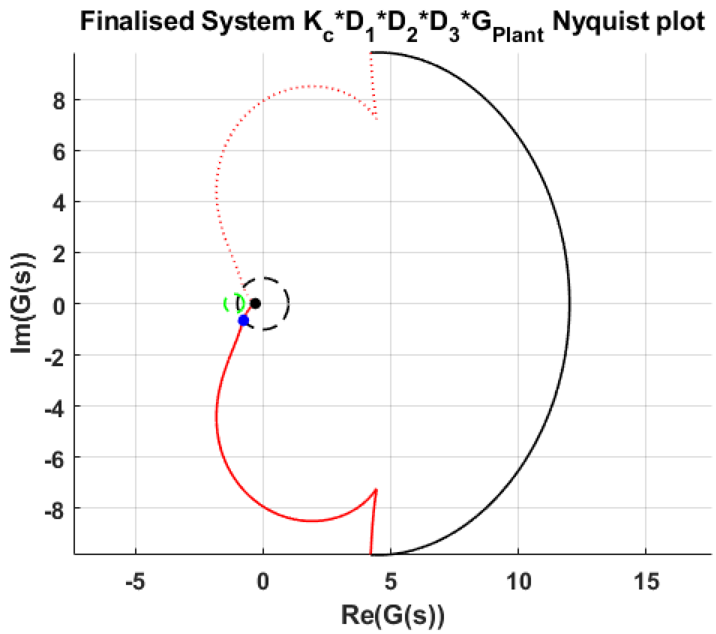
As mentioned earlier loop transfer function for the designed system is as below-

$G_l(s) = K_c * D_1 * D_2 * D_3 * G_{plant}$

From the MATLAB command we get Nyquist plot as below-



by considering the max frequency as 50 rad/s, we get Nyquist plot as below for the designed system-



From the Nyquist plot available above, phase margin for the system observed to be 40.38deg as obtained by the final bode plot details and gain margin for the system observed to be 10.49dB. From figure it can be observed that further with loop gain for the system can be used, of value for multiplication around 3 to designed system, beyond which it will go unstable.

Simulations for the designed system

With finalized gain values and lead compensator designed as per the design requirement, assumption made for system to have simulation error of less than 1%, calculated integration step size for simulation by below formula-

$e_\lambda = -e_I(\lambda T)^k$

where, $e_\lambda =$ max allowable error possible

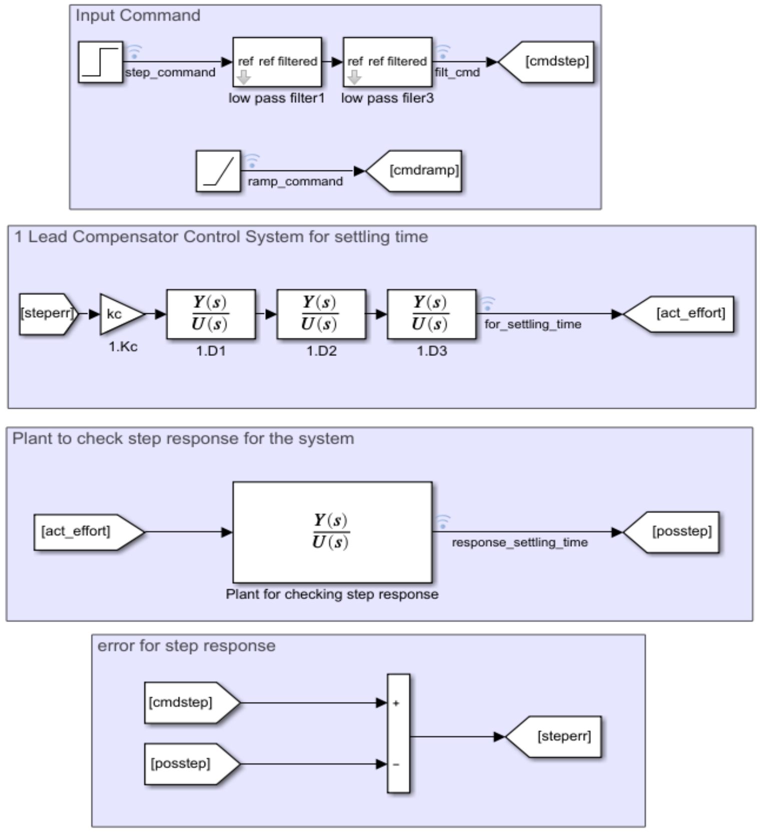
$e_I =$values corresponding to Integration method

$\lambda =$ max eigen value for the system

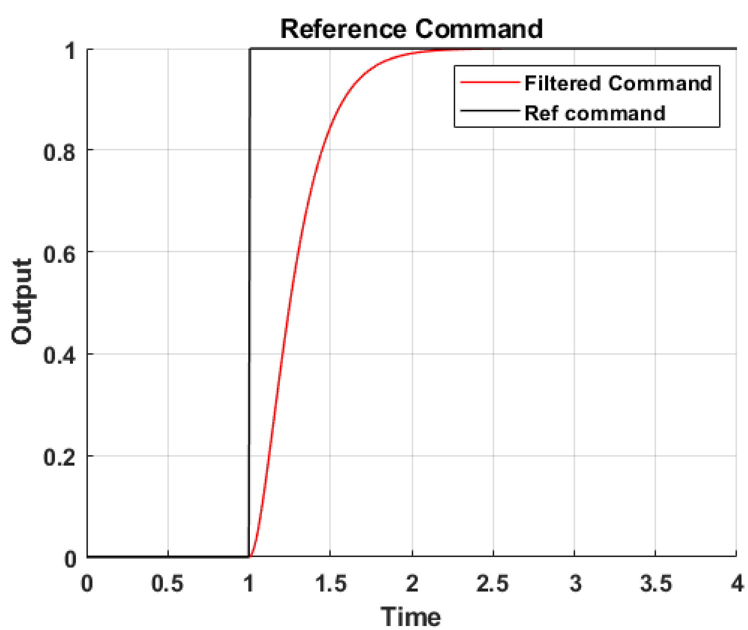
$k =$ order of integration

Integration method used is RK-4, which required integration step size T less than 0.0144sec, for error in simulation less than 1%. Hence, selecting integration step size as 0.0072 which is around 1/2 of the 0.0144 required for error less than 1%.

Below is the simulation model used for Simulation with step response details-



Results obtained from the simulation are as below-



Above figure provide the details of the reference command provided to the system. Black line represents the original step command provided and red line represent the command going to the system after band limited filters used.

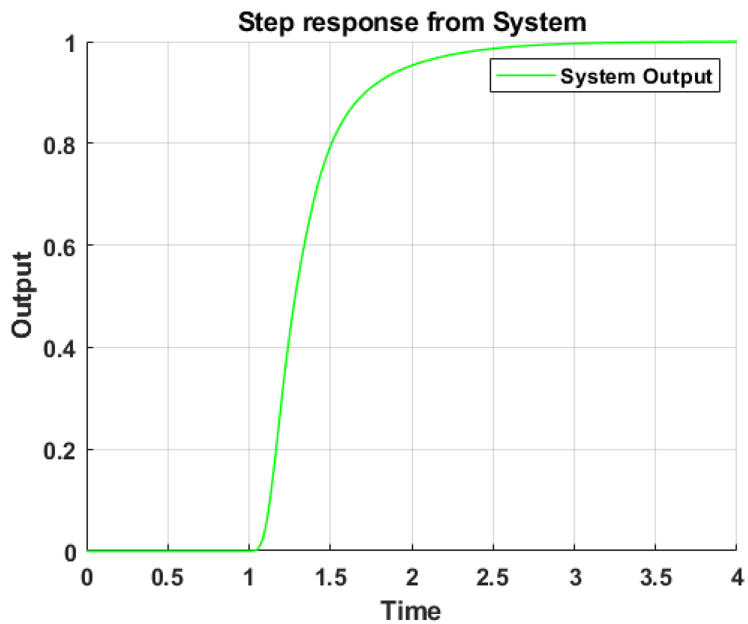
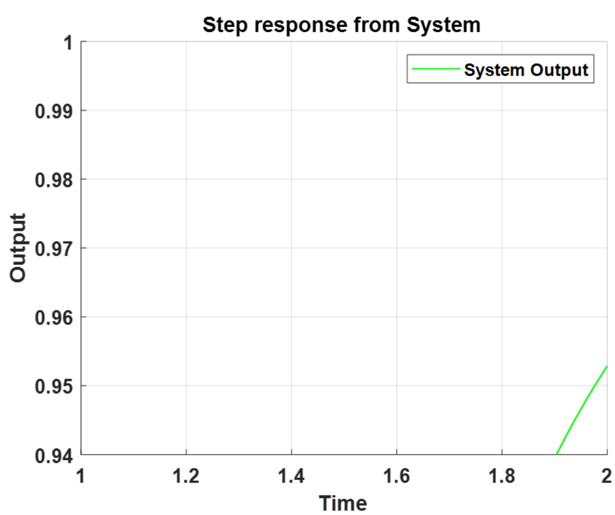


Figure provide the details for the step response output from the system. From the figure settling time for 5% settling observed to be 0.95sec against required of 1sec. Below are the zoomed response details showing system going above 0.95 of original value at around 1.95 sec against the step starting at 1 sec.



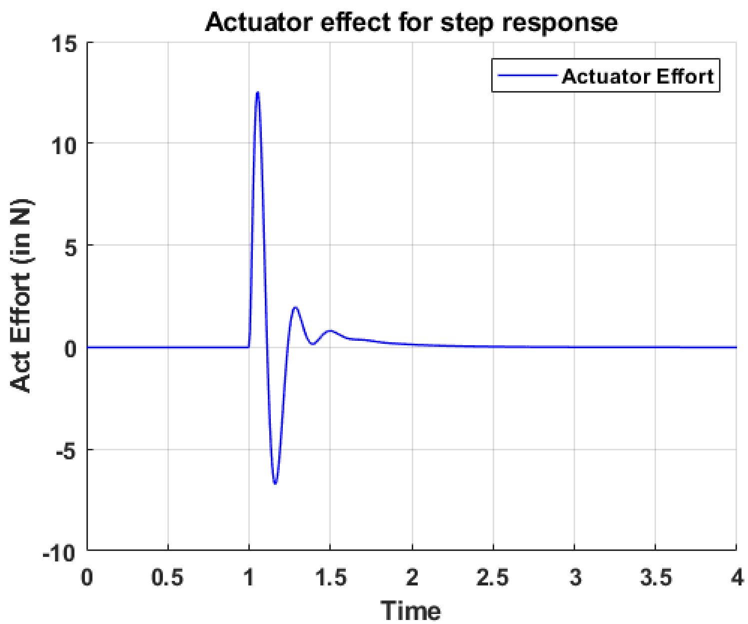
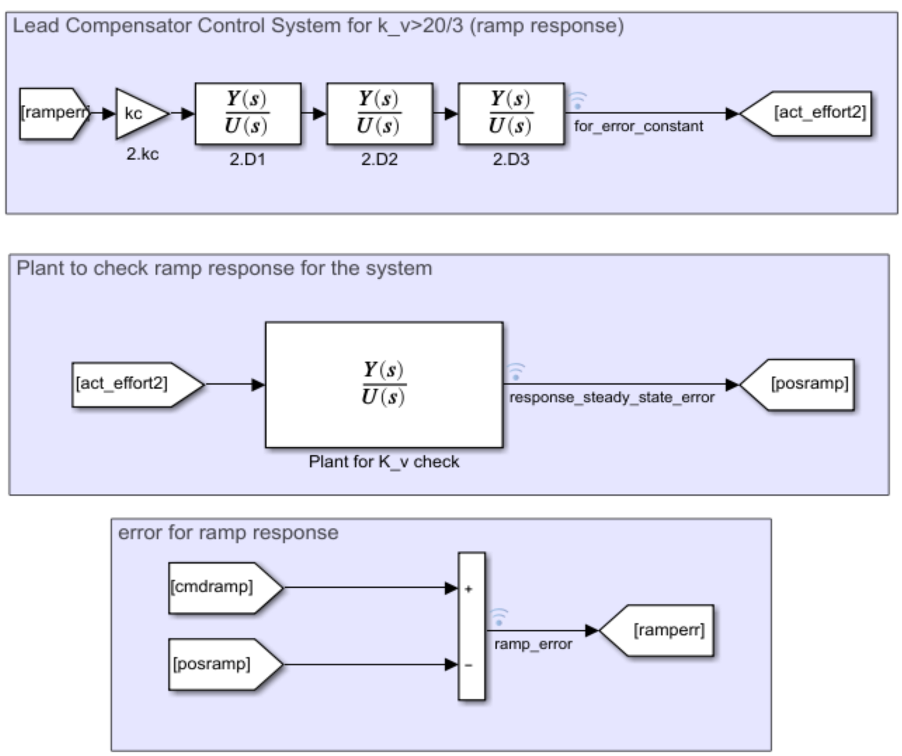


Figure above provide the details for the actuator effort, with filters in the system actuator effort observed to be less than $\pm 15N$. And at around 2 seconds actuator effort are going to zero as system is getting settled.

Below is the model used for ramp command response for verifying steady state error of the system-



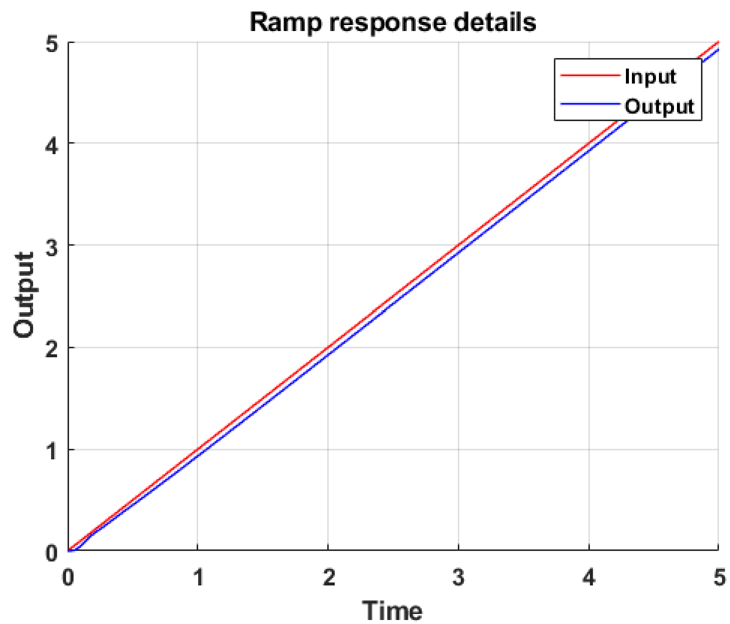
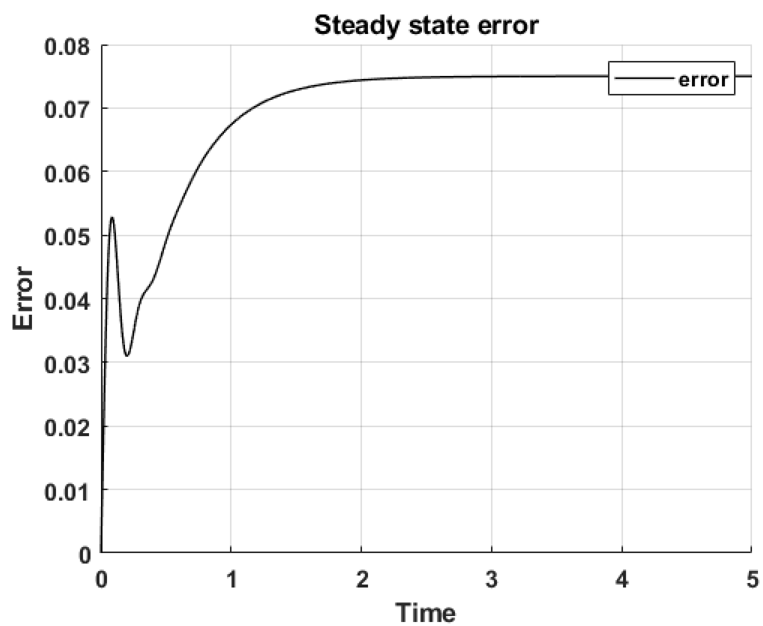


Figure above provide the details for the system response for the ramp input, verified for the steady state error less than $\frac{3}{20}$ or $K_v > \frac{20}{3}$



Above graph provide the details for the error observed in the system for the ramp input. Steady state error for the system observed to be 0.075.

We have, $ess = \frac{A}{K_v}$, where $A = 1$

Hence, we get, $K_v = 13.33 > \frac{20}{3}$

With the simulations system designed observed to be within design requirements for the system.

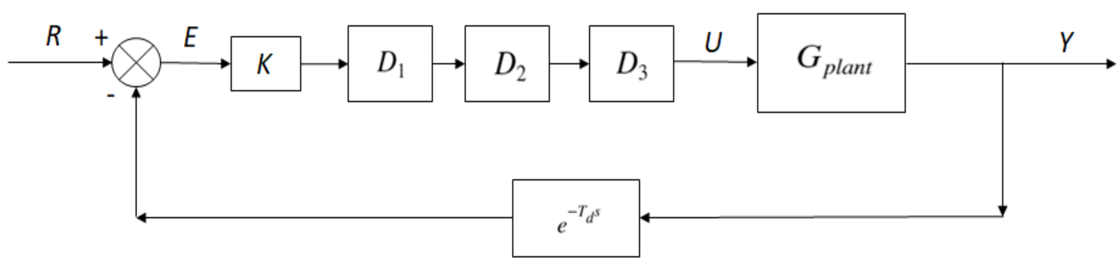
Effect of Time Delay T_d on System - Going away from the design

With time delay in feedback, system response starts to vary and even though closed loop system is stable, due to time delay it can go unstable.

Initial design for the system was done for $PM > 40$ and settling time for 5% settling less than 1 sec.

With the help of the system designed and using the MATLAB code provide below, time delay for system for $PM < 40$ observed to be 0.4ms and for closed loop system to have settling time below 1sec for 5% settling observed to be 25ms.

System with time delay in the system can be represented with below block diagram-



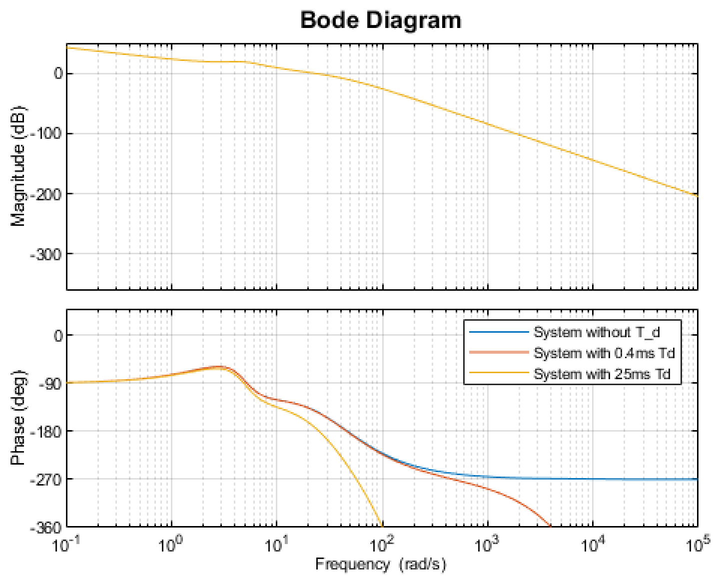
Plant equation to consider time delay in the system can be modified to as shown below-

For system having 5% settling time more than 1 sec equation can be written as-

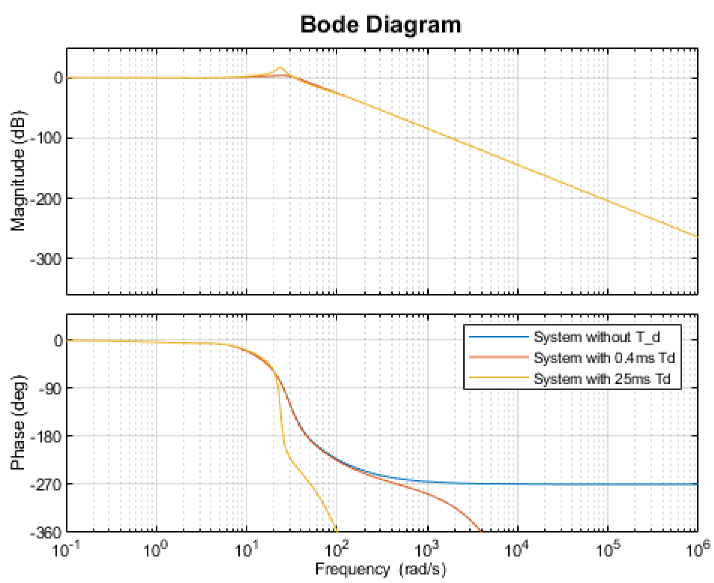
$$G_{plant} = e^{-0.025s}\frac{50(s+4)}{s(s+6)(s^2+4s+25)}$$

For system to have PM<40, plant equation with time delay can be written as,

$$G_{plant} = e^{-0.0004s}\frac{50(s+4)}{s(s+6)(s^2+4s+25)}$$

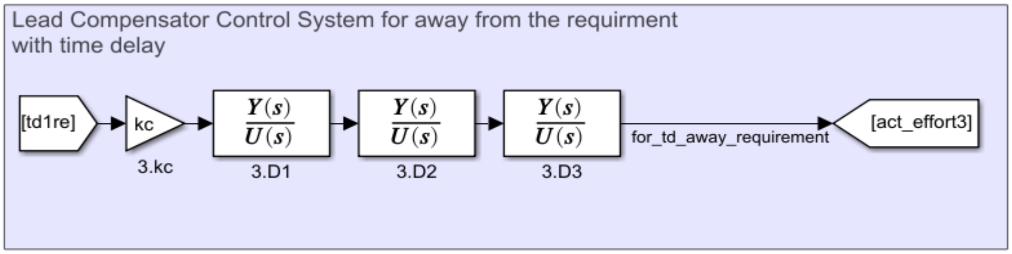


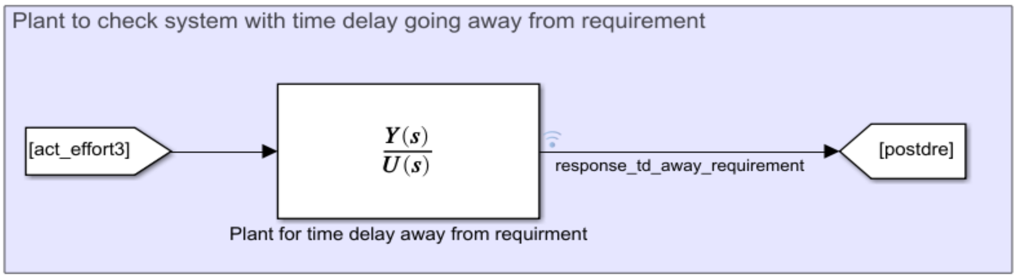
Above is the bode plot for the loop transfer function with time delay taken into consideration. As from the above graph for time delay of 0.4ms system observed to have phase margin of 39.8766deg against required of 40deg.

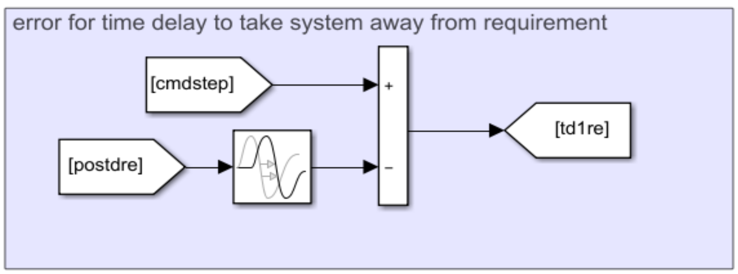


Above is the feedback from the system for with and without time delay, with addition of time delay there observed to be no change in the system for magnitude plot, but phase plot observed to have loss of phase with rise in the time delay. At time delay of 25ms, phase margin for the system observed to be of value around 9.5deg.

For checking settling time variation in the system time delay used was 25ms, and below simulation model used for the same.







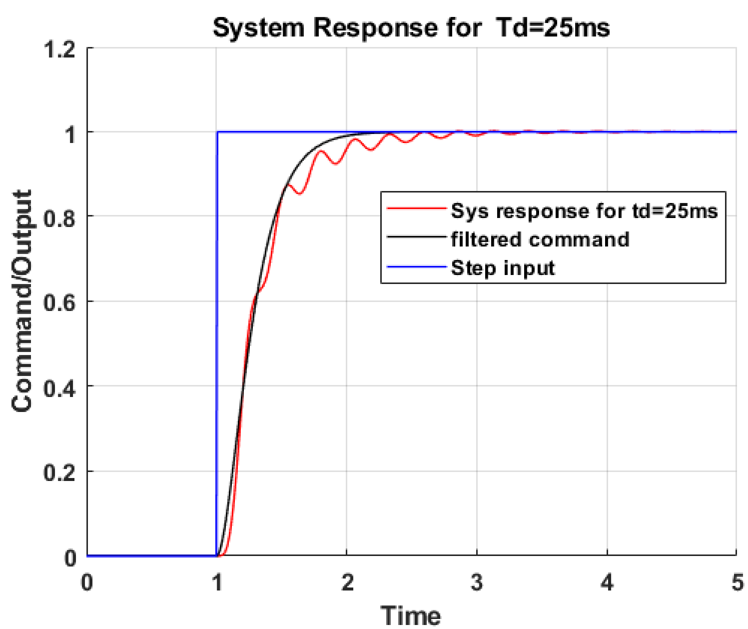
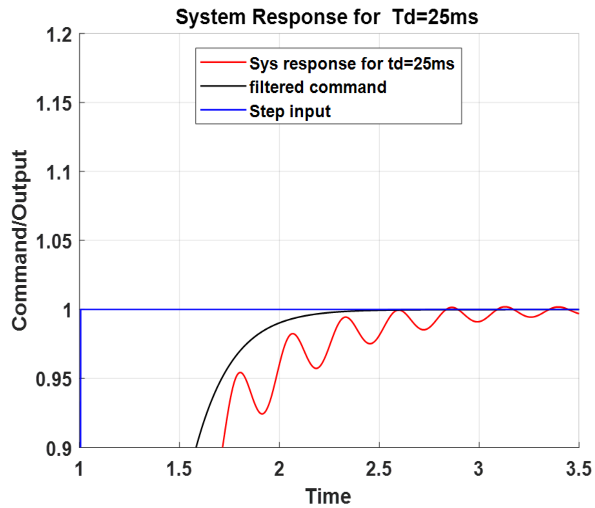


Figure above provide the details for the system with variation from required settling time for 5% settling going away from the required 1sec. Figure below provide the details of the variations observed with time delay of 25ms.



From the above graphs and discussion available, it can be concluded that for maintaining the $PM > 40$ fast sensor is required, as time delay allowed in this case is 0.4ms. For maintaining 5% settling less than 1sec, slightly slow sensor in comparison with the one required for $PM > 40$ can be utilized as system observed to cross that requirement at time delay of 25ms as compared to earlier one of 0.4ms.

Effect of Time Delay T_d - System going unstable

From the MATLAB code provided below, time delay for system to go unstable observed to be 32.4ms.

Plant equation with this time delay identified can be written as below-

$$G_{plant} = e^{-0.0324s} \frac{50(s+4)}{s(s+6)(s^2+4s+25)}$$

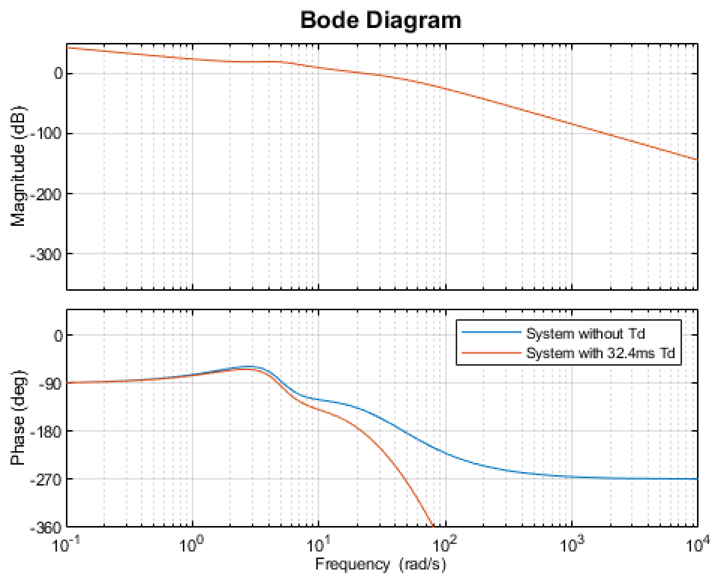


Figure above provide the details of the Bode plot comparison of the system for loop transfer function, as observed earlier in magnitude plot no change observed in the system. But in phase plot, system starts to lose phase with increase in time delay. At time delay of 32.4ms, system have phase margin of -0.81deg, and the system goes unstable.

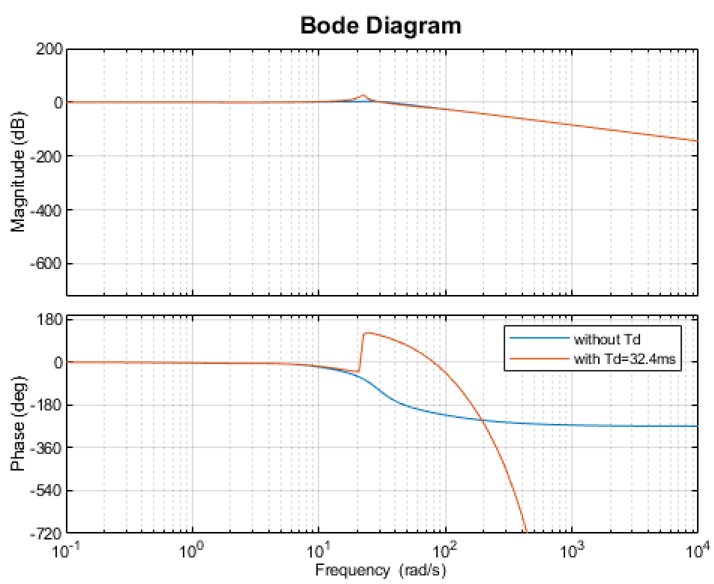
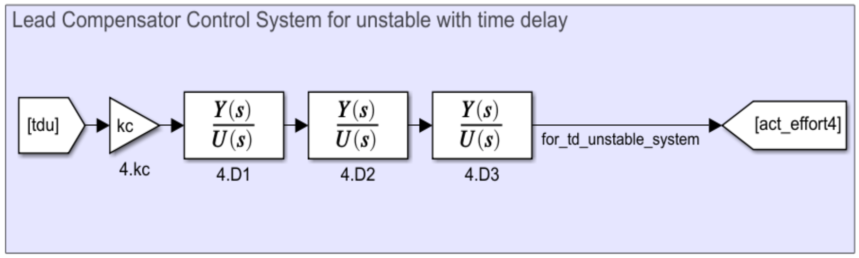
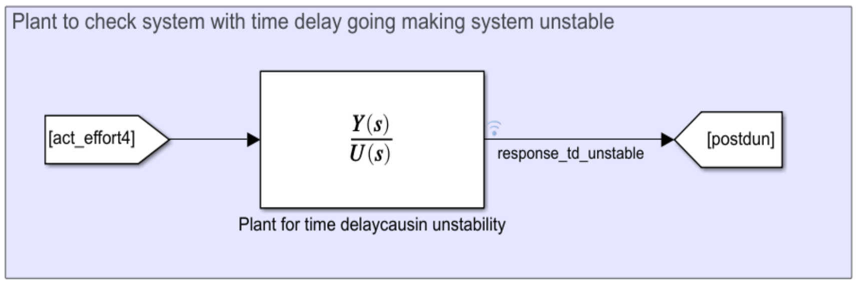
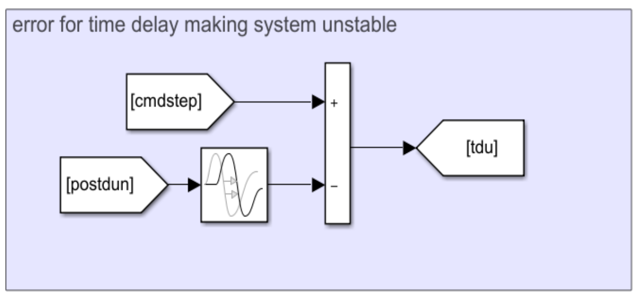


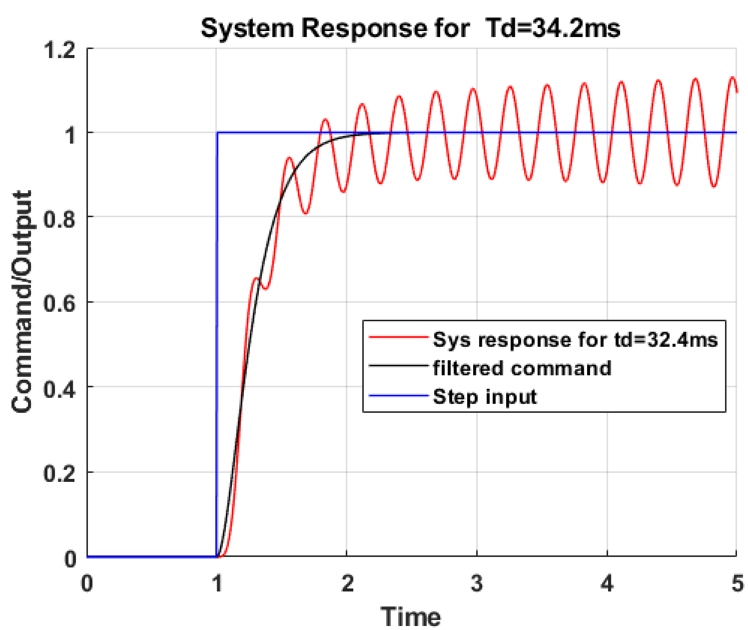
Figure above provide the details of the closed loop bode plot for the time delayed system. As seen from the graph above system observed to lose phase rapidly at time delay of 32.4ms and goes unstable.

Below is the Simulink model used for the simulation for the system going unstable with time delay-

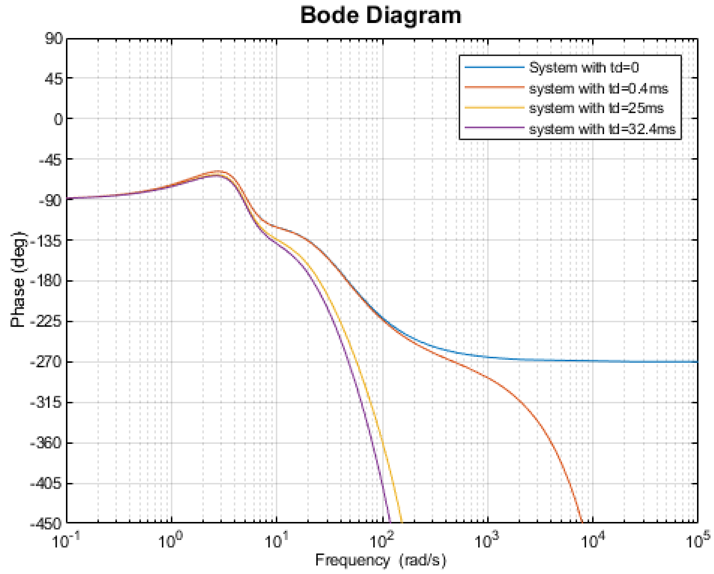








Above figure provide the details of the system response for the time delay of 32.4ms. At $T_d = 32.4ms$ system starts to go unstable. From the above graphs, if the feedback from the system requires more time than 32.4ms to flow back to compensator, though designed properly system will go unstable.



Above is the phase plot of the bode plot for the all the systems, discussed above. From the graph with rise in time delay, system starts to lose the phase and moves towards becoming unstable.

Summary

For provided system, gain required to satisfy the system's velocity error constant requirement observed to make system unstable and taking phase margin in -ve. To make the system stable with the gain finalized lead compensators were designed to obtain the $PM > 40$. While designing phase lead compensators design was done for the additional phase than required as with steep loss in phase in the unstable region, final phase margin obtained after adding the phase lead compensator is less than targeted.

Hence, to obtain the phase margin of 40degree 3 lead compensators were designed two of which are having phase of 49 deg and one having phase of 23deg, to obtain the total PM of 40.8, from the observed -42.5 with gain required for the system.

From the designed system, actuator requirement was not confirmed, hence simulations were required to check for meeting actuator requirement. With initial designed system and having gain in the system due to sudden rise in the command, large actuator force was required to satisfy the other design requirements, hence filters were introduced to smooth out the input command to reduce actuator effort. With addition of filters settling time for the system observed to be changed, whereas no effect of the same observed for steady state error and phase margin of the system. Hence to satisfy the requirement for settling time, system redesigned with higher gains and less settling time.

With introduction of time delay in system, system observed to lose phase rapidly with rise in time delay to the signal received. It was evident from the phase plot of the bode plot, whereas there observed nearly no change in magnitude plot.

It was observed that designed phase margin acts as a cushion to avoid system for going unstable or delay in response to the settling time designed. It was evident from the fact that time delay required to overcome the settling time requirement was 25ms as compared to the time delay required to overcome the PM requirement which was 0.4ms.

With time delay introduced in the system, it was observed that though designed system is stable with good phase margin, system went unstable with higher time delay of around 32.4sec.

Time delay factor evidently provide the implications of the sensors used, with the slow sensors time required to receive the feedback increases, thus increasing the time delay, due to which well-designed system can also go unstable.

Conclusion

System designed with numerical calculations, required to be verified with simulations to check for the actuator efforts which provide the idea for problems might be faced due to limitations of the actuator. It provided the way out to redesign the system, to avoid any new surprises at last minute.

Once designed, system should be verified for the time delay component. As with various system in use, there will always be some delay in receiving the feedback depending on the sensor it might be of few milliseconds to seconds. It also depends upon time constant of the sensor, Dc gain of the sensor, condition of the sensor, detoriation in sensor quality over the use period, environment in which sensor is to be used etc. Verifying system against the time delay component provide way to counteract some of the issues which might be faced in real world, it also provides means to select the sensors which can be used for the desired operation.

MATLAB Code Used

```
% Cleanup
clearvars
close ('all')


% Defining plant transfer function in MATLAB
g1 = 50*tf([1 4],conv([1 6 0],[1 4 25]));            % Initial System Transfer
function
% Obtaining frequency corresponding to gain
% wm = 1:0.01:20;              % defined range of frequency
% for ii = 1:length(wm)
%     dbc = 20*log10(abs(evalfr(kc*g1,wm(ii)*1i)));
%     if dB1>=dbc
%         rwm1 = wm(ii)              % frequency at which compensator to be added
%         break
%     end
% end
% Phase added with design
phase_value = angle(evalfr(kc*g1,rwm1*1i))*180/pi;
if phase_value >0 || phase_value == 180
    new_PM = -(180 - phase_value);
else
    new_PM = 180 + phase_value;
```

```
end
phase_lost = phkc - new_PM;                        % Extra Phase loss from original
phase loss
phase_obtained_designe1 = phi1 - phase_lost;    % phase obtained from the design
final_estimated_phase = phkc + phase_obtained_designe1; % Phase eastimation from
calculations done
T1 = 1/(rwm1*sqrt(alpha1));      % paramter for lead compensator
% First Lead phase compensator
D1 = tf([T1 1],[alpha1*T1 1]);   % 1st lead compensator
[mg3,ph3] = margin(D1*kc*g1);   % Phase received form the first lead compensator
ST = 0.05;
gcl = feedback(kc*D1*D2*D3*g1,1);
S = stepinfo(gcl,'SettlingTimeThreashhold',ST);
S.SettlingTime;
%% roots for the k=10 for the initial system
% [ri,ki] = rlocus(g1);
% for ii = 1:length(ki)
%     if ki(ii) >= 10
%         rti = ri(:,ii)
%         break
%     end
% end

%% Time step calculations for RK-4
%Getting Eigen values for integration step size for RK-4
cls01ei = roots(gcl.Denominator{1});
% Calculations to find time step for first simulations
lambda_max_sc = max(abs(cls01ei));      % Maximum eigen value to be used for
                                        % time step calculations
e_lambda = 0.01;                        % Maximum error of 1% in simulations


g = g1*D1*D2*D3*10;
r = 1.5;                        % Define radius for the pole at the origin
wMax = 50;                      % largest w value


%% s = rj -> wMax j
s1 = (r:.1:wMax)' * (1i);       % getting s value on imaginary axis to substitute
in transfer function for obtaining nyquit plot points
nyq1 = zeros(size(s1));
for k = 1:length(s1)
    nyq1(k) = evalfr(g,s1(k));  % Getting nyquist plot points
end


%% s = re^(j*phi), phi = -90 -> 90
phi = (-90:1:90)';              % getting phi for values at circle considered in
nyquist plot
```

```
s2 = ( r*cosd(phi) + (1i)*r*sind(phi) ); % value of comples number to substitute
in transfer function for getting nyquist plot values
nyq2 = zeros(size(s2));
for k = 1:length(s2)
    nyq2(k) = evalfr(g,s2(k));  % evaluation nyquist plot values
end


%% s = -rj -> -wMax j
s1a = (-r:-.01:-wMax)' * (1i);  % for -ve side of the imaginary axis
nyq1a = zeros(size(s1a));
for k = 1:length(s1a)
  nyq1a(k) = evalfr(g,s1a(k));  % evaluating points for the nyquist plot
end


%% Unit Circle- for phase margin
tht = 0:1:359;
x = cosd(tht);          % x points on the unit circle
y = sind(tht);          % y points on the unit circle


%% An M circle- for resonant frequncy, bandwidth
M = -3;
tht=0:1:359;
r = abs(M./(M.^2-1));   % radius for m circle
xc = M.^2./(1-M.^2);    % x related point on the M circle
for k=1:length(xc)
  mc(k).c = xc(k) + r(k)*(cosd(tht)+sind(tht)*(1i));    % points for the M circle
with respect to M value
end


%% PM- with help from unit circle cross point in the nyquist plot
idL = find(abs(nyq1)<1,1);      % find number of values on nyquist data less than
magnitude of 1 for complex number
idH = idL-1;                    % subtract 1 from the total number values
ww = [s1(idL) s1(idH)];         % new vector with two points having magnitude on
either side of magnitude 1
                                % abs(s1(idL))<1<abs(s1(idH))
mm = abs([nyq1(idL) nyq1(idH)]);% new vector with values of those magnitude
wGC = interp1(mm,ww,1);         % interpolation command to otain exact s value
which lies on unity circle
pPT = evalfr(g,wGC);            % determining the complex number lying on unity
circle and on nyquist plot
zAng = angle(pPT)*180/pi - 180; % phase margin for the point obtained
% to represent the phase margin with -180 to 180 window as displayed with margin
command
if zAng < -180
  pM = (zAng+360);
```

```
else
  pM = (zAng);
end


%% GM
idL = find(imag(nyq1)>0,1); % finding no of values in nyquist which are on +ve
side of imaginary axis(or I and II quadrant)
wPC = s1(idL);              % finding first number at which crossover happened
gM = -20*log10(abs(nyq1(idL))); % calulating dB value for the cross over point
gPT = nyq1(idL);                % storing point for further use in graph


%% Plotting of figure
id5 = id4+1;
h(id5).fig = figure(id5);
h(id5).axs = axes;
h(id5).ln(1) = line(real(nyq1),imag(nyq1),'Color','r','LineStyle','-
','Linewidth',LW);  % plot corresponding to points on imaginary axis after small
circle for the pole at origin
h(id5).ln(2) = line(real(nyq2),imag(nyq2),'Color','k','LineStyle','-
','Linewidth',LW);  % plot corresponding to small circle around point at origin
h(id5).ln(3) =
line(real(nyq1a),imag(nyq1a),'Color','r','LineStyle',':','Linewidth',LW);% plot
corresponding to - ve side points on the imaginary axis
h(id5).ln(4) = line(x,y,'Color','k','LineStyle','--','Linewidth',LW);
% unit circle plot
% blue dot for phase margin
h(id5).ln(5) =
line(real(pPT),imag(pPT),'Marker','o','MarkerSize',5,'LineStyle','none','Color','
b','MarkerFaceColor','b');
% blue dot for gain margin
h(id5).ln(6) =
line(real(gPT),imag(gPT),'Marker','o','MarkerSize',5,'LineStyle','none','Color','
k','MarkerFaceColor','k');
% plot for M circles
for k=1:length(mc)
    h(id5).ln(6+k) = line(real(mc(k).c),imag(mc(k).c),'Color','g','LineStyle','--
','Linewidth',LW);
end


axis equal
h(id5).tit = title('Finalised System K_{c}*D_{1}*D_{2}*D_{3}*G_{Plant} Nyquist
plot');
h(id5).xlb = xlabel('Re(G(s))');
h(id5).ylb = ylabel('Im(G(s))');
% h(id5).leg = legend('Points for +ve Imag axis s-value','Points corre. to max
frequency','Points for -ve Imag axis s-value','Unit Circle','PM','GM','3dB
circle');
```

```
h(id5).axs.FontSize   = FS;                     % axis font size for first plot
h(id5).axs.FontWeight = 'Bold';                 % Set axis type for first plot
grid on


% Considering RK-4 method for integration we have e_I = 1/120 and k = 4
e_I = 1/120;
k = 4;
Tstep2 = (e_lambda/e_I)^(1/k)/(lambda_max_sc);
% Time delay in system for detoriating from the requirement provided
% td = 0.0001:0.0001:1;
% for ii=1:length(td)
%     gtd = tf(50*[1 4],conv([1 6 0],[1 4 25]),'InputDelay',td(ii));
%     gcl = feedback(kc*D1*D2*D3*gtd,1);
%     S3 = stepinfo(tf_filt*tf_filt*gcl,'SettlingTimeThreashhold',ST);
%     if S3.SettlingTime>=1
%         tdrb1 = td(ii)
%         break
%     end
% end
% for ii=1:length(td)
%     gtd = tf(50*[1 4],conv([1 6 0],[1 4 25]),'InputDelay',td(ii));
%     [m34,p34] = margin(kc*D1*D2*D3*gtd);
%     if p34<40
%         tdrb2 = td(ii)
%         break
%     end
% end
```