PES University, Bangalore
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UE20EC251- Control System

Control System Project

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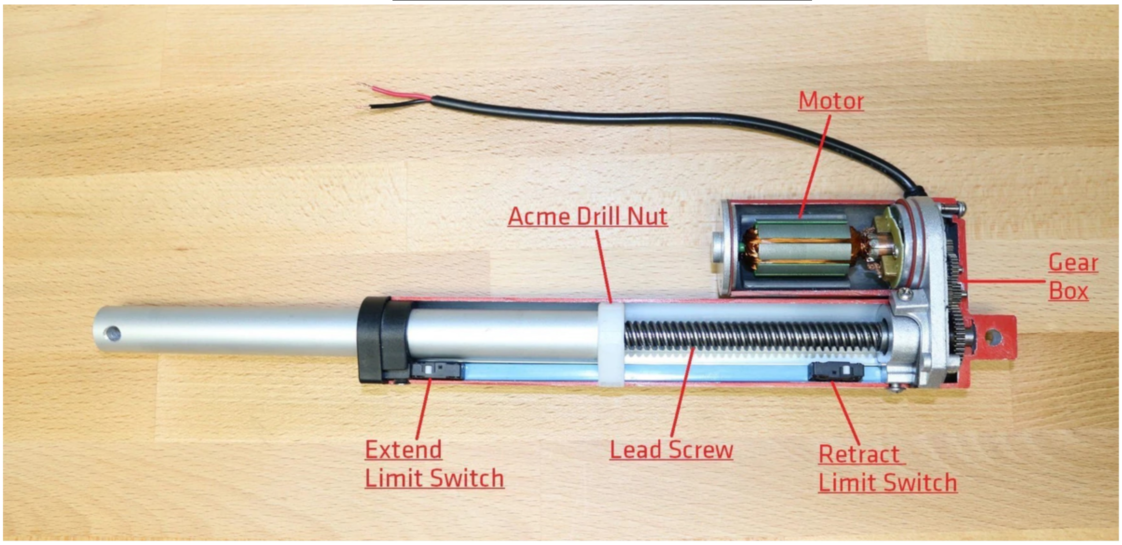
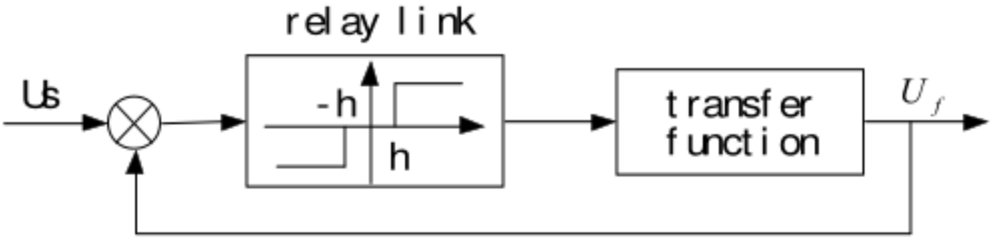
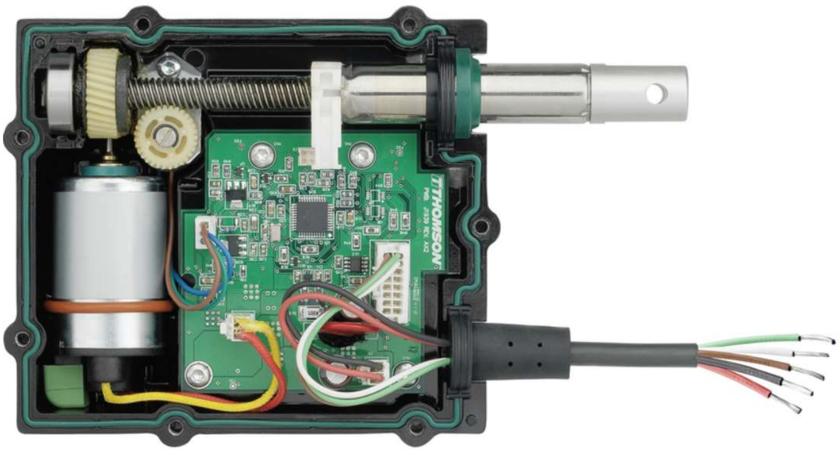
Report:

Electric Actuator







- An Electric Actuator is a device that can create movement of a load, or an action requiring a force such as clamping, using an electric motor to create the necessary force. Well-known examples include electric cars, manufacturing machinery, and

robotics equipment.
- Input : Voltage signal, Us
- Output : Voltage signal, Uf
- Us and Uf, two signals are through a relay - type nonlinear link to control the motor running and the motor drives the retarding mechanism to produce the corresponding displacement.

Electric Actuator: BACKGROUND

The basic structure of the actuator

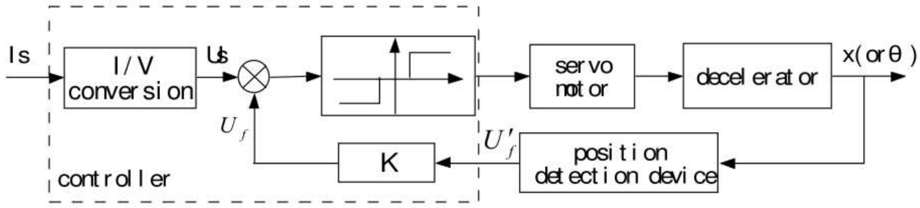


Fig1 Principle of the electric actuator

“The electric actuator can be simplified as a closed loop control system, which is composed of two parts, the relay link and the transfer function”.
“The input of the closed-loop control system is the voltage signal Us (the signal thought I/V conversion) and the output is the position feedback signal Uf.”

Selected Transfer Function:

```
G =

    100
----------
s^2 + 10 s

Continuous-time transfer function.
```

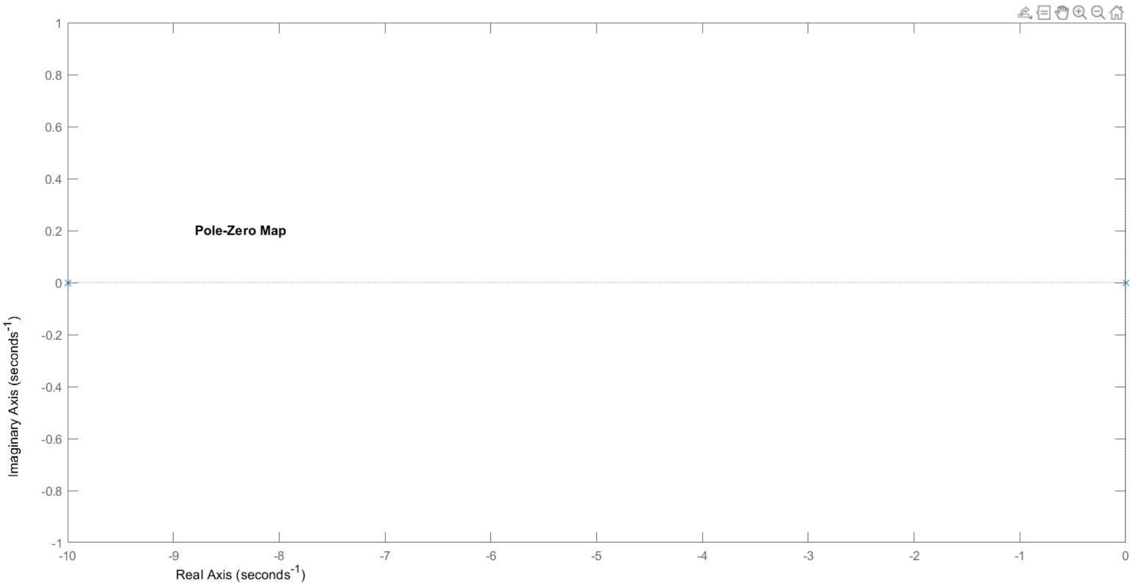
K = 100 and a = 10

Question 1 Solution:

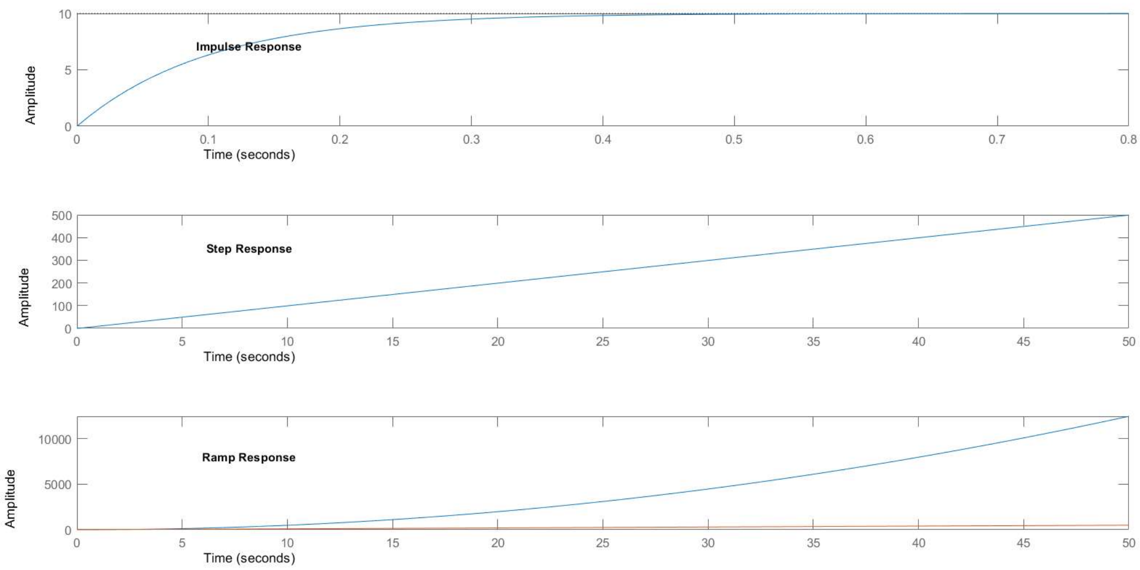
```
G =

    100
  ----------
  s^2 + 10 s

Continuous-time transfer function.
```

```
fb =

        100
  ----------------
  s^2 + 10 s + 100

Continuous-time transfer function.
```

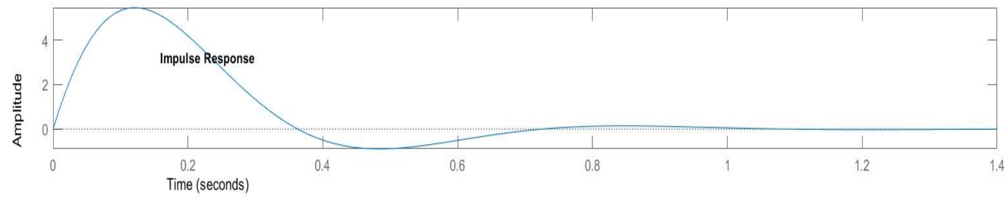
Pole – Zero Map:

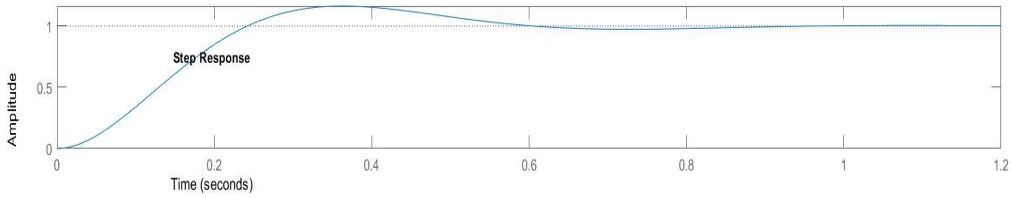


Responses of Open loop system:



Responses of closed loop system:



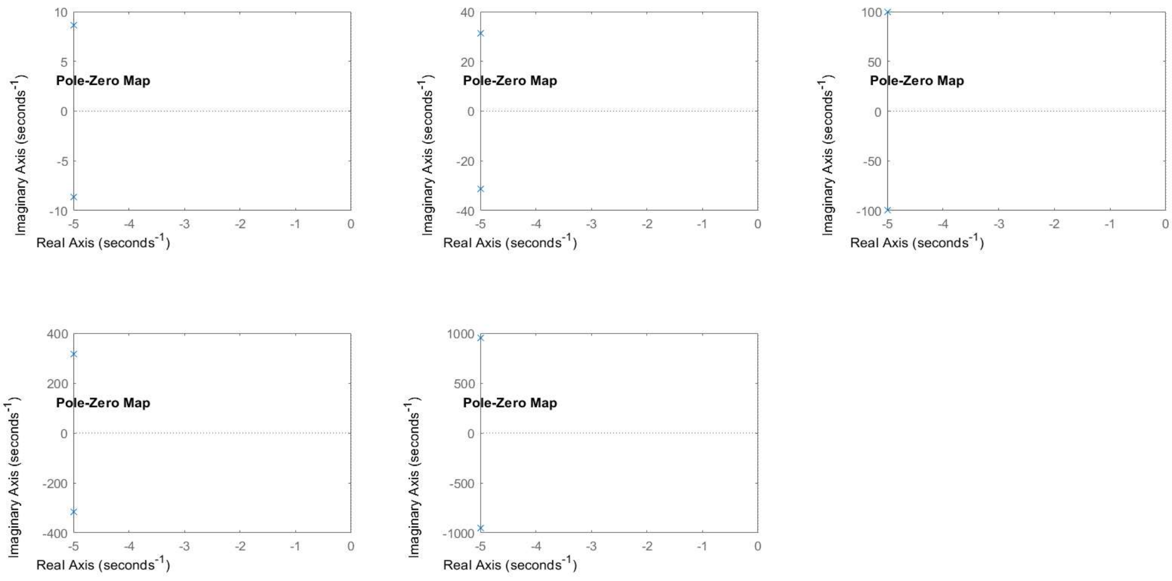


Conclusion for question 1:

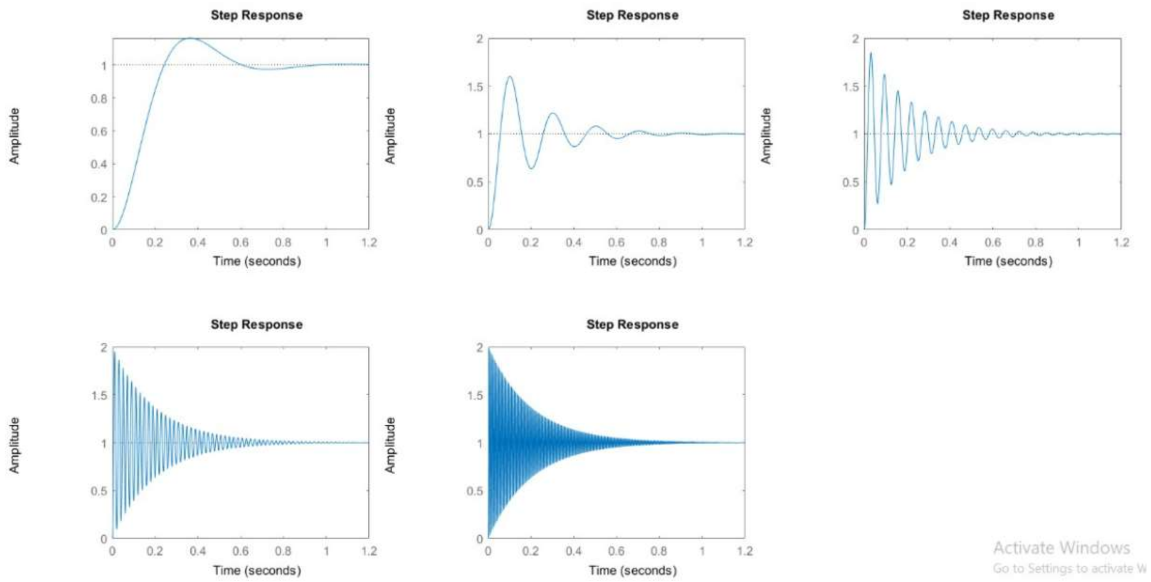
- There are 2 open loop poles and no open loop zeros , both poles are on left half s-plane.
- From the pole zero plot, we can see that there is 1 pole at origin so the system is marginally stable, it behaves differently for different inputs.
- This is a Type 1 system.
- The poles are at: -10, 0.
- Impulse response – Stable
- Step response – Unstable
- Ramp response – Unstable
- Closed loop system is a second order system with zeta = 0.5 and natural frequency = 10.
- Closed loop poles are -5+5sqrt(3)i and -5-5sqrt(3)i.
- The Closed loop system follows the inputs and steady state error is Zero for the above inputs

Question 2 and 3 Solution:

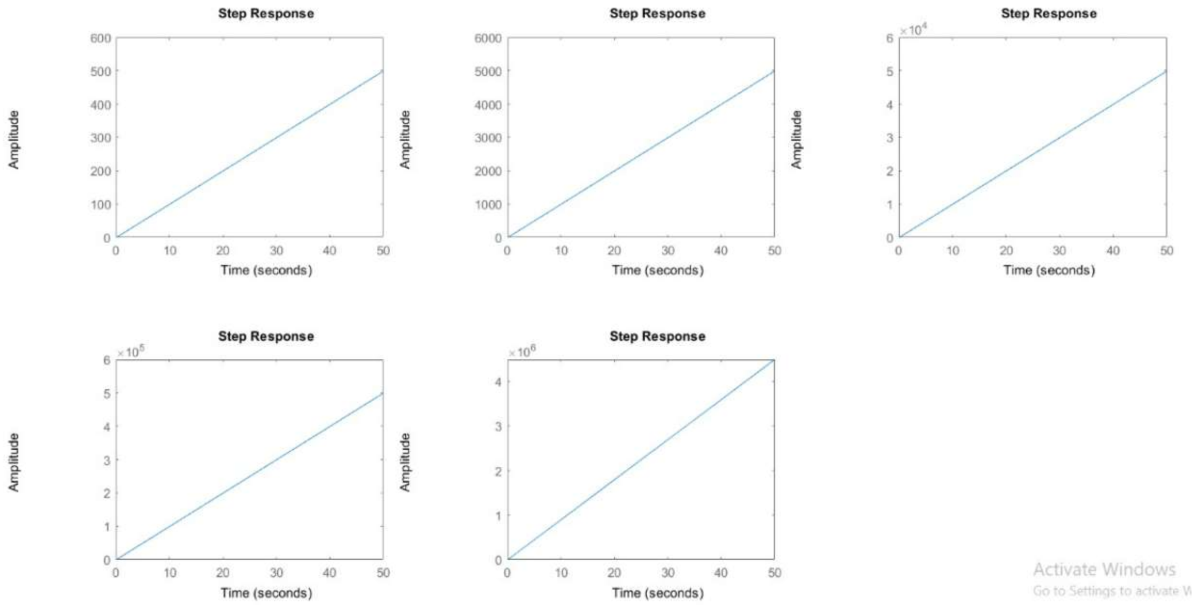
Pole-zero map of kG(s) for closed loop:



closed loop Step response of kg(S):



open loop Step response of kg(S):



Conclusion for Question 2:

From the RH table we found that k can take any value from zero to infinity and closed loop system is stable.
Hence, we took k = 1, 10, 100, 1000, 9001.
Yes, we Can increase K indefinitely
ITS STABLE EVEN OVER 9000.

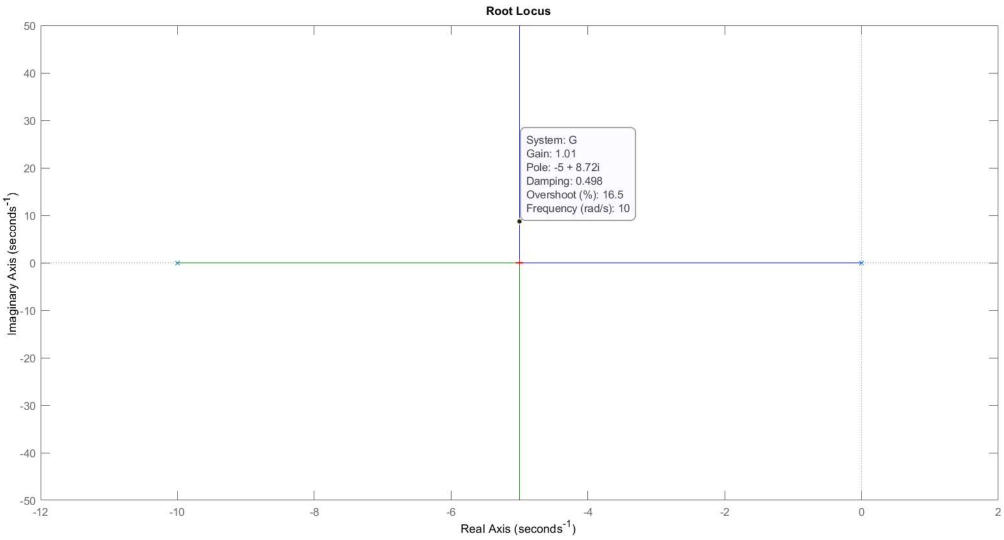
step response characteristics for question 3a:

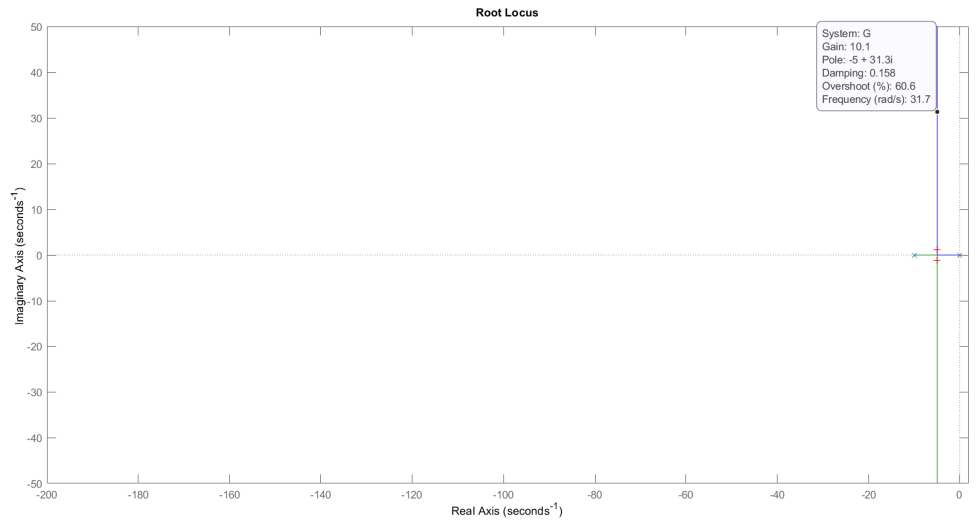
Step Reponse Characteristics

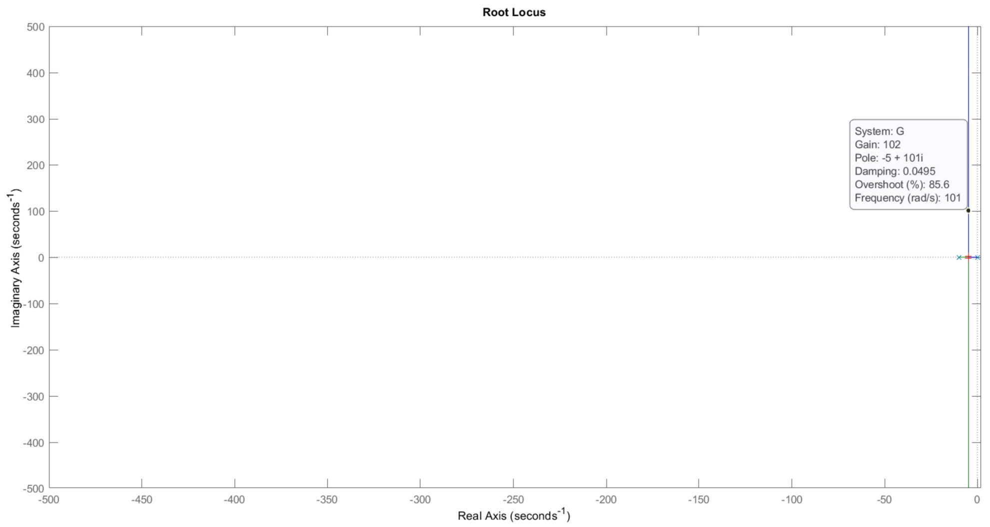
```
S1 = struct with fields:
        RiseTime: 0.1639
    SettlingTime: 0.8076
     SettlingMin: 0.9315
     SettlingMax: 1.1629
       Overshoot: 16.2929
      Undershoot: 0
            Peak: 1.1629
        PeakTime: 0.3592

         Pole              Damping       Frequency      Time Constant
                                       (rad/seconds)      (seconds)

  -5.00e+00 + 8.66e+00i     5.00e-01       1.00e+01         2.00e-01
  -5.00e+00 - 8.66e+00i     5.00e-01       1.00e+01         2.00e-01
S2 = struct with fields:
        RiseTime: 0.0374
    SettlingTime: 0.7315
     SettlingMin: 0.6347
     SettlingMax: 1.6045
       Overshoot: 60.4530
      Undershoot: 0
            Peak: 1.6045
        PeakTime: 0.1013

         Pole              Damping       Frequency      Time Constant
                                       (rad/seconds)      (seconds)

  -5.00e+00 + 3.12e+01i     1.58e-01       3.16e+01         2.00e-01

  -5.00e+00 - 3.12e+01i     1.58e-01       3.16e+01         2.00e-01
S3 = struct with fields:
        RiseTime: 0.0108
    SettlingTime: 0.7600
     SettlingMin: 0.2699
     SettlingMax: 1.8545
       Overshoot: 85.4461
      Undershoot: 0
            Peak: 1.8545
        PeakTime: 0.0314

         Pole              Damping       Frequency      Time Constant
                                       (rad/seconds)      (seconds)

  -5.00e+00 + 9.99e+01i     5.00e-02       1.00e+02         2.00e-01
  -5.00e+00 - 9.99e+01i     5.00e-02       1.00e+02         2.00e-01
```

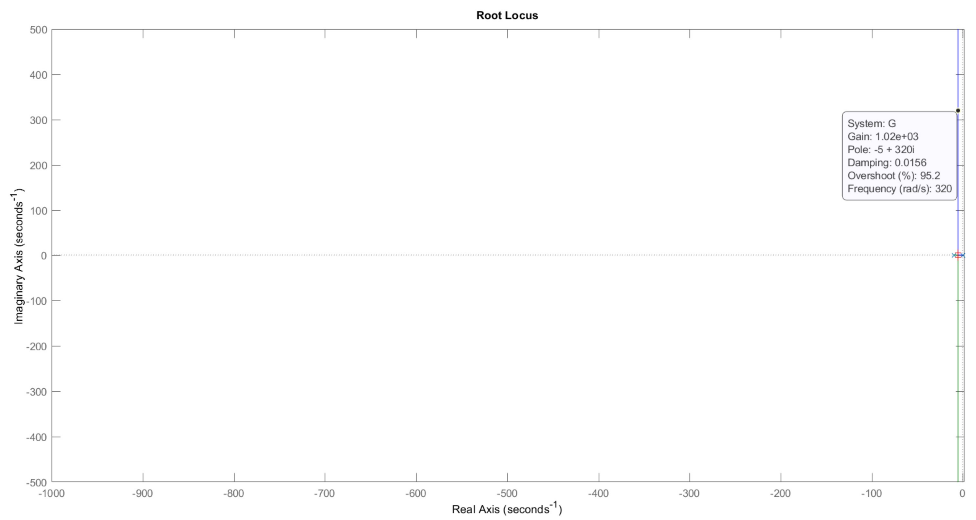
```
S4 = struct with fields:
        RiseTime: 0.0033
    SettlingTime: 0.7758
     SettlingMin: 0.0946
     SettlingMax: 1.9515
       Overshoot: 95.1535
      Undershoot: 0
            Peak: 1.9515
        PeakTime: 0.0099

         Pole              Damping       Frequency      Time Constant
                                       (rad/seconds)      (seconds)

 -5.00e+00 + 3.16e+02i     1.58e-02      3.16e+02         2.00e-01
 -5.00e+00 - 3.16e+02i     1.58e-02      3.16e+02         2.00e-01

S5 = struct with fields:
        RiseTime: 0.0011
    SettlingTime: 0.7815
     SettlingMin: 0.0326
     SettlingMax: 1.9836
       Overshoot: 98.3579
      Undershoot: 0
            Peak: 1.9836
        PeakTime: 0.0033

         Pole              Damping       Frequency      Time Constant
                                       (rad/seconds)      (seconds)

 -5.00e+00 + 9.49e+02i     5.27e-03      9.49e+02         2.00e-01
 -5.00e+00 - 9.49e+02i     5.27e-03      9.49e+02         2.00e-01
```

Root locus for 3b:









Conclusion for Question 2 and 3a:

- *Yes, we Can increase K indefinitely*
- *As K increases Rise Time Decreases, response is faster*
- *Overshoot increases since Zeta Decreases*
- *Settling time also decreases.*

- *Also, Frequency of oscillations is increasing as Wn is increases when K is increased and zeta also decreases*
- *Damping Decreases when K is increased.*
- *No oscillations in OL.*
- *OL responses are unstable.*
- *As K increases the OL step response gets faster.*

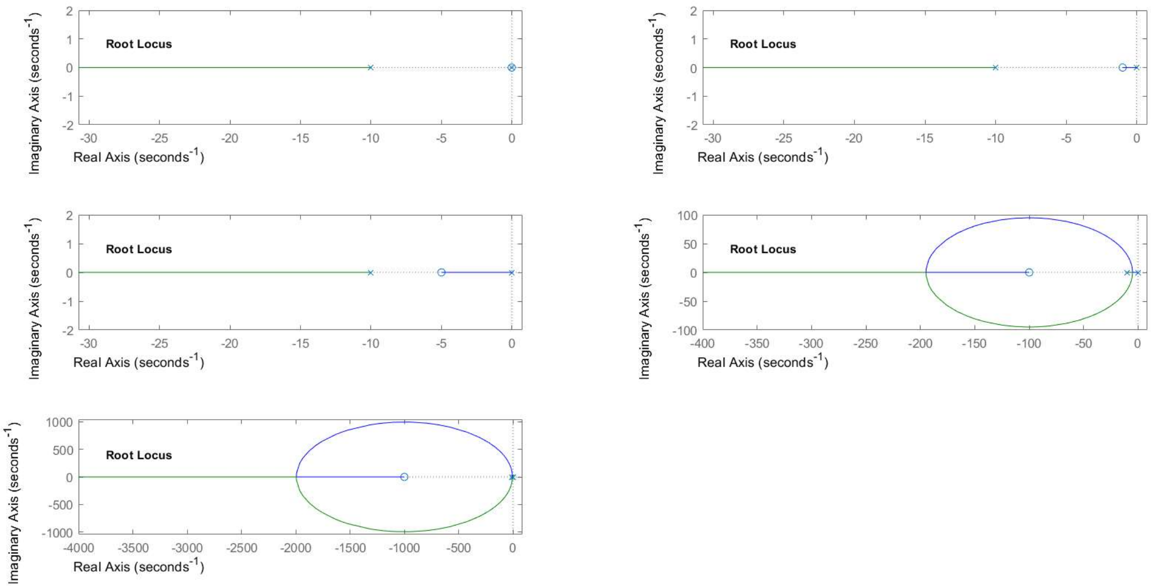
Conclusion for Question 3B:

As we marked the points on root locus, we can see that:

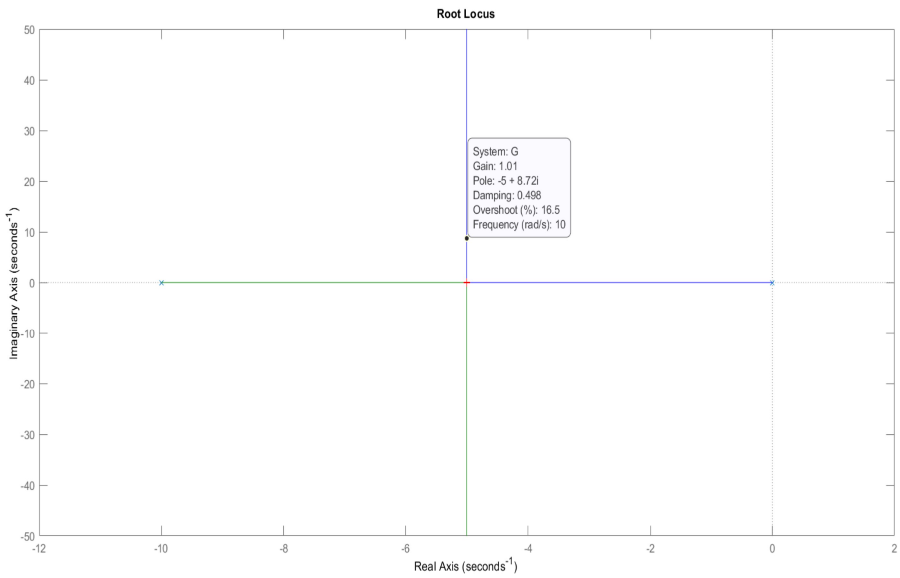
- *Damping coefficient decreases*
- *Frequency increases*
- *Overshoot increases*

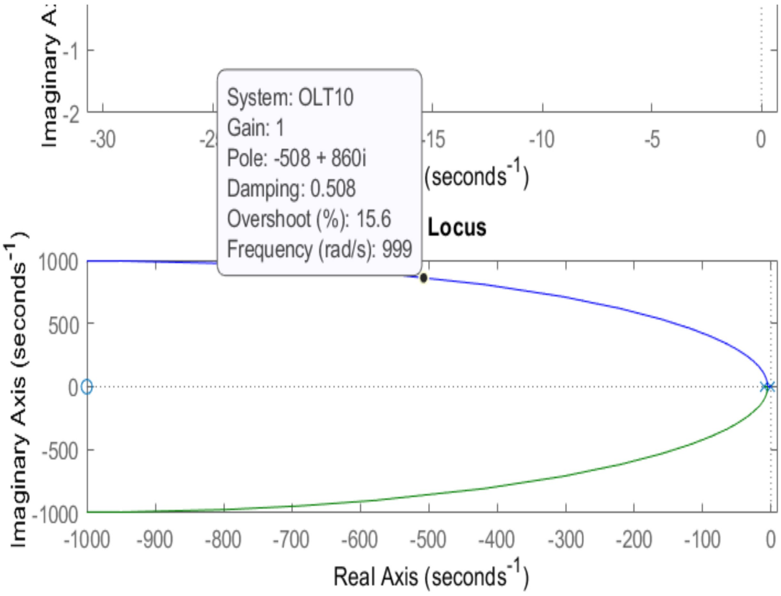
Question 4 Solution:

Root locus for K(s+Z) G(s), z=0.01,1,5,100,1000:



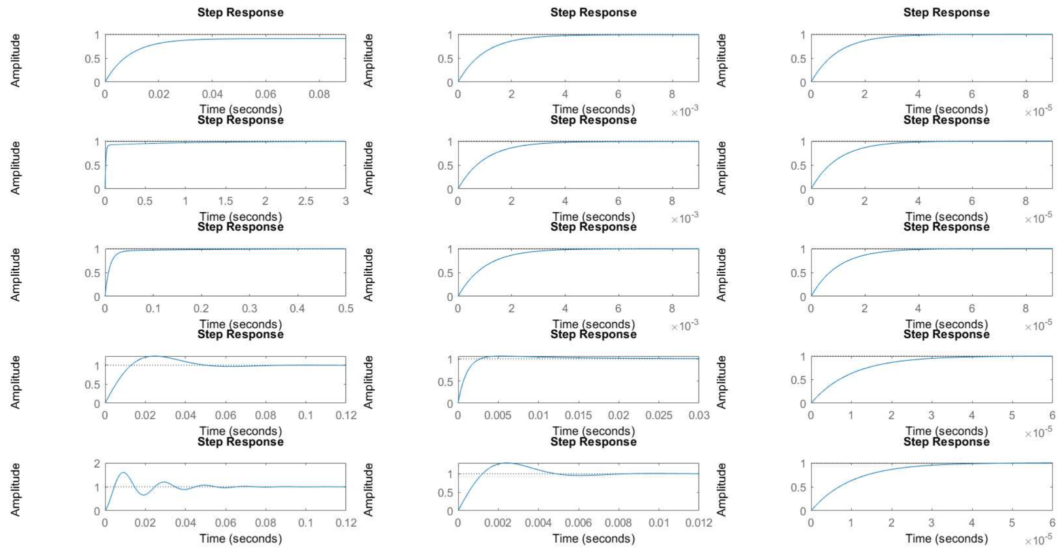
Comparison of root loci of p versus pd:





We note that, for the same gain damping is increasing, frequency is increasing and overshoot is decreasing.
Also, the root locus is moving further into the left.

<u>closed loop step response for Pd controller*g(s), from left to right K increases (1,10,10000) and top to bottom z increases (0.01,1,5,100,1000):</u>

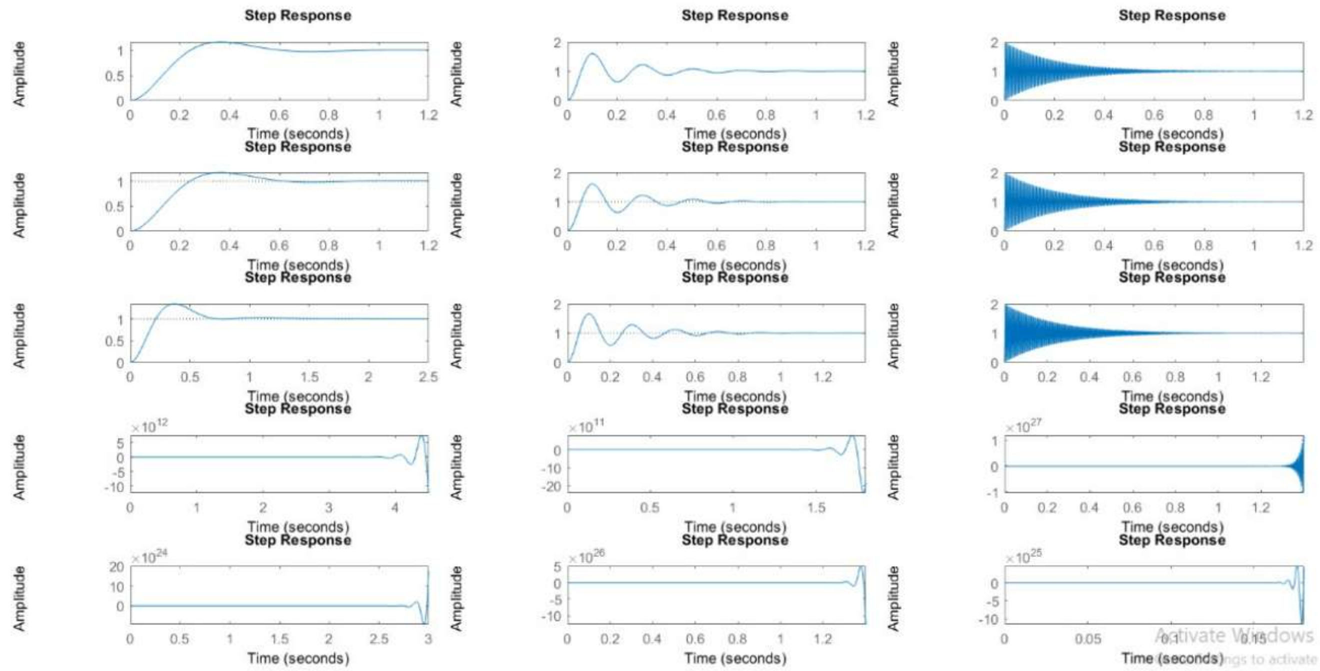


Conclusion for Question 4:

- *Z increases as we go below and K increases as we go left*
- *For a fixed Z. increasing K speeds up the response and decreases overshoot*
- *For a Fixed K, increasing Z towards = -inf speeds up the response and increases overshoot*
- *Also Compared to only P controller we can hence say that overall PD allows you to make the response faster while also decreasing the overshoot whereas with P you could make the response faster but Overshoot also increases.*
- *As the magnitude of zero increases, the root locus shifts further into the left half S-plane.*
- *The effect of adding a zero to the forward path is that is makes the system response faster. If the system is sluggish, we can add a zero to the forward path.*
- *Addition of zeros to open loop transfer function has the effect of shifting the root locus to the left side in S-plane i.e., increasing the relative stability and speeding up the settling of the response (decrease of settling time).*

Question 5 Solution:

Step with pole for k = 1,10,10000 and z = 0,0.1,1.5,100,1000:



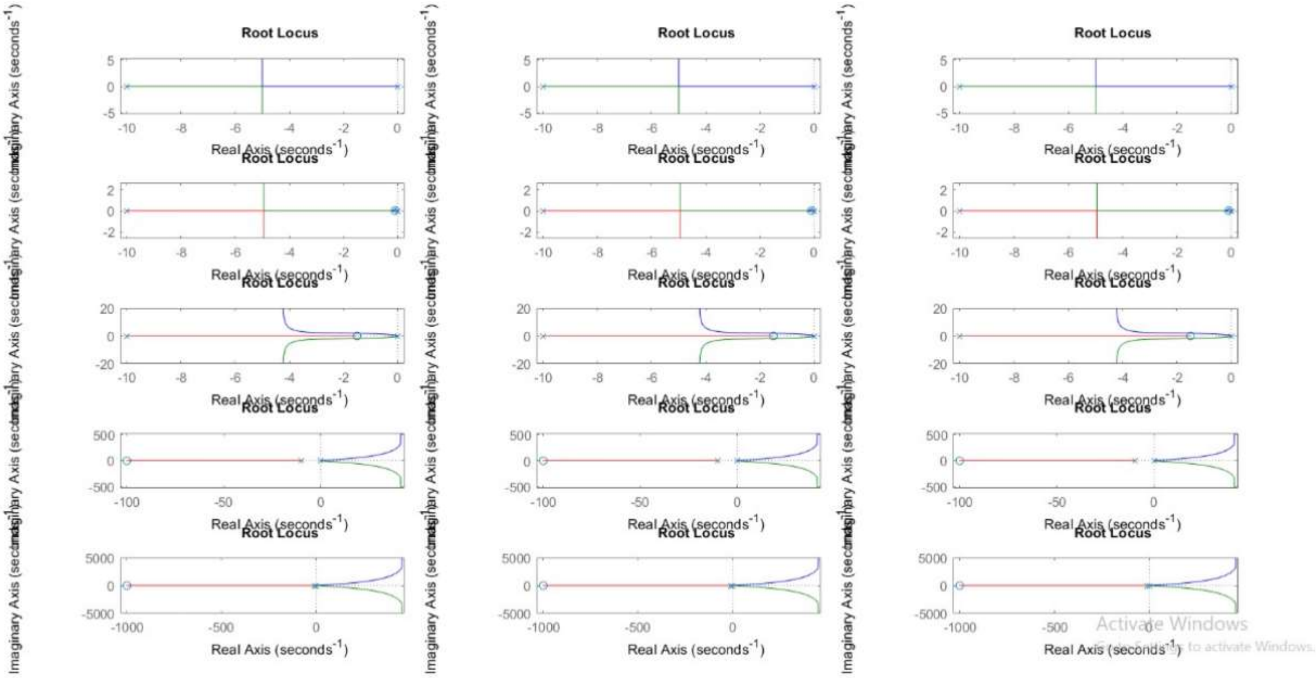
Step Response Characteristics:

```
Tk =

         100 s
  -------------------
  s^3 + 10 s^2 + 100 s

Continuous-time transfer function.
ans = struct with fields:
         RiseTime: 0.1639
    TransientTime: 0.8076
     SettlingTime: 0.8076
      SettlingMin: 0.9315
      SettlingMax: 1.1629
        Overshoot: 16.2929
       Undershoot: 0
             Peak: 1.1629
         PeakTime: 0.3592
y = 2
Tk =

         1000 s
  --------------------
  s^3 + 10 s^2 + 1000 s

Continuous-time transfer function.
ans = struct with fields:
         RiseTime: 0.0374
    TransientTime: 0.7315
     SettlingTime: 0.7315
      SettlingMin: 0.6347


      SettlingMax: 1.6045
        Overshoot: 60.4530
       Undershoot: 0
             Peak: 1.6045
         PeakTime: 0.1013
y = 3
Tk =

         1e06 s
  ---------------------
  s^3 + 10 s^2 + 1e06 s
```

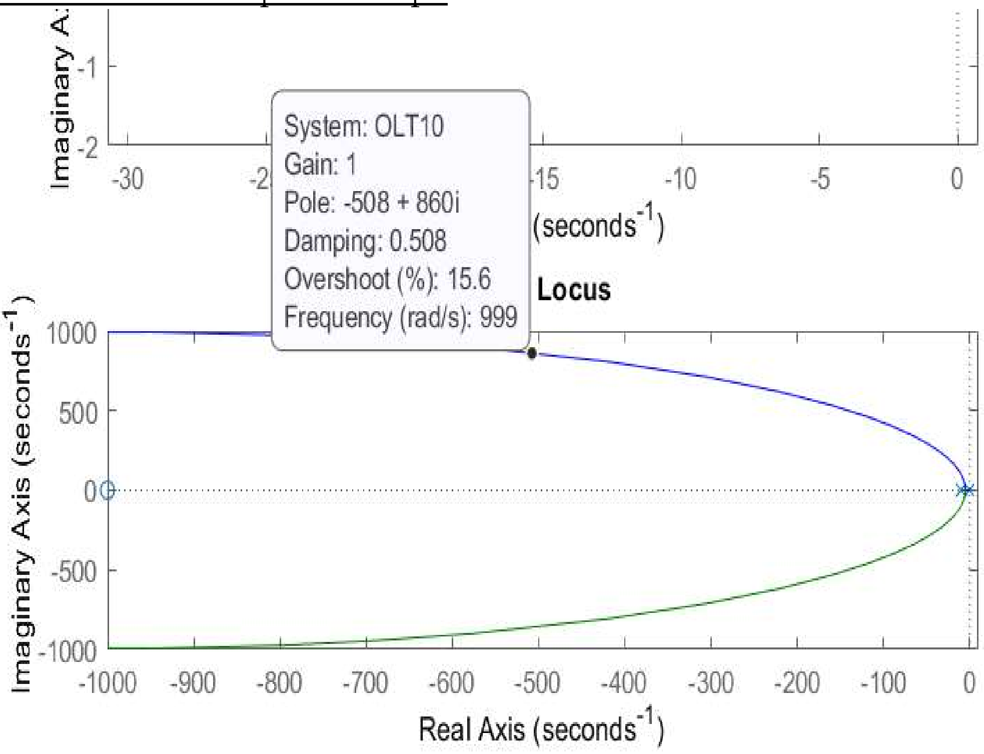
```
          Undershoot: 0
                Peak: 1.6045
            PeakTime: 0.1013
y = 3
Tk =

          1e06 s
  --------------------
  s^3 + 10 s^2 + 1e06 s

Continuous-time transfer function.
ans = struct with fields:
            RiseTime: 0.0010
       TransientTime: 0.7823
        SettlingTime: 0.7823
         SettlingMin: 0.0309
         SettlingMax: 1.9844
           Overshoot: 98.4415
          Undershoot: 0
                Peak: 1.9844
            PeakTime: 0.0031
y = 4
Tk =

          100 s + 10
  ------------------------
  s^3 + 10 s^2 + 100 s + 10

Continuous-time transfer function.
ans = struct with fields:
            RiseTime: 0.1622
       TransientTime: 0.5873
        SettlingTime: 0.5873
         SettlingMin: 0.9124
         SettlingMax: 1.1766
           Overshoot: 17.6566
          Undershoot: 0
                Peak: 1.1766
            PeakTime: 0.3629
y = 5
Tk =

          1000 s + 100
  --------------------------
  s^3 + 10 s^2 + 1000 s + 100

Continuous-time transfer function.
ans = struct with fields:
            RiseTime: 0.0373
       TransientTime: 0.7343
        SettlingTime: 0.7343
         SettlingMin: 0.6335
         SettlingMax: 1.6084
           Overshoot: 60.8367
          Undershoot: 0
                Peak: 1.6084
            PeakTime: 0.1023
```

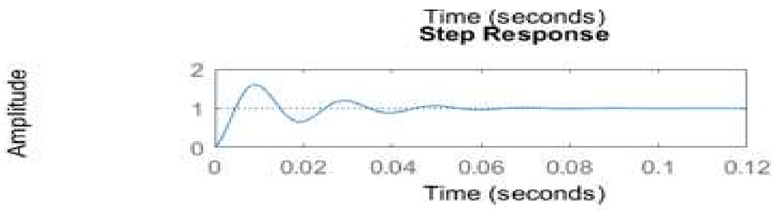
```
  s^3 + 10 s^2 + 1e06 s + 100000

Continuous-time transfer function.
ans = struct with fields:
            RiseTime: 0.0010
       TransientTime: 0.7886
        SettlingTime: 0.7886
         SettlingMin: 0.0306
         SettlingMax: 1.9846
           Overshoot: 98.4571
          Undershoot: 0
                Peak: 1.9846
            PeakTime: 0.0031
y = 7
Tk =

          100 s + 150
  -------------------------
  s^3 + 10 s^2 + 100 s + 150

Continuous-time transfer function.
ans = struct with fields:
            RiseTime: 0.1448
       TransientTime: 1.3443
        SettlingTime: 1.3443
         SettlingMin: 0.9451
         SettlingMax: 1.3504
           Overshoot: 35.0351
          Undershoot: 0
                Peak: 1.3504
            PeakTime: 0.3574
y = 8
Tk =

          1000 s + 1500
  ----------------------------
  s^3 + 10 s^2 + 1000 s + 1500

Continuous-time transfer function.
ans = struct with fields:
            RiseTime: 0.0366
       TransientTime: 0.9304
        SettlingTime: 0.9304
         SettlingMin: 0.5799
         SettlingMax: 1.6715
           Overshoot: 67.1547
          Undershoot: 0
                Peak: 1.6715
            PeakTime: 0.1000
y = 9
Tk =

          1e06 s + 1.5e06
  ------------------------------
  s^3 + 10 s^2 + 1e06 s + 1.5e06

Continuous-time transfer function.
```

Root locus for PI controller*G(s):

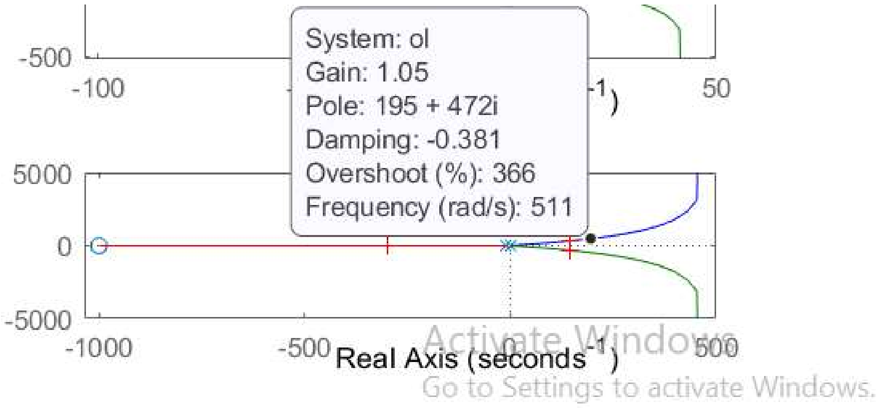


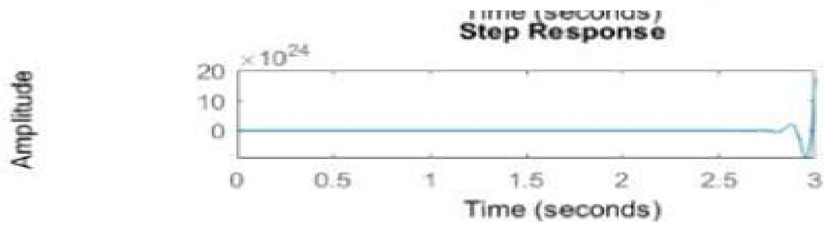
Comparison of root loci pd versus pi:





Versus



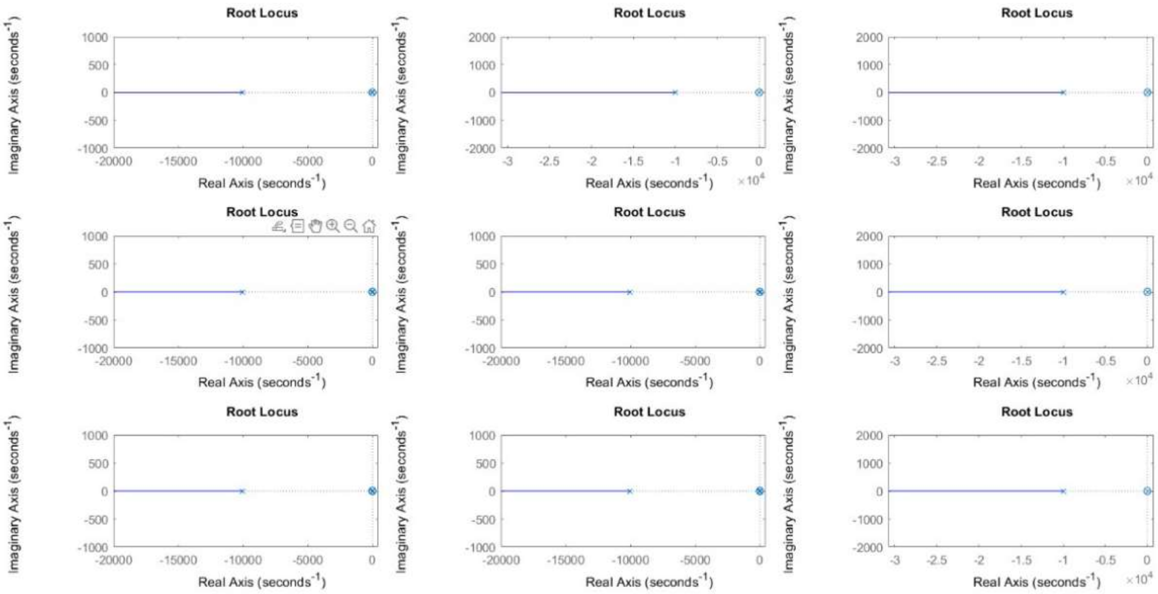


For same value of gain and z(=1000) adding a pole to the origin shifted the root locus entirely into the right half.
Hence the step response became very unstable.

PID Controller:

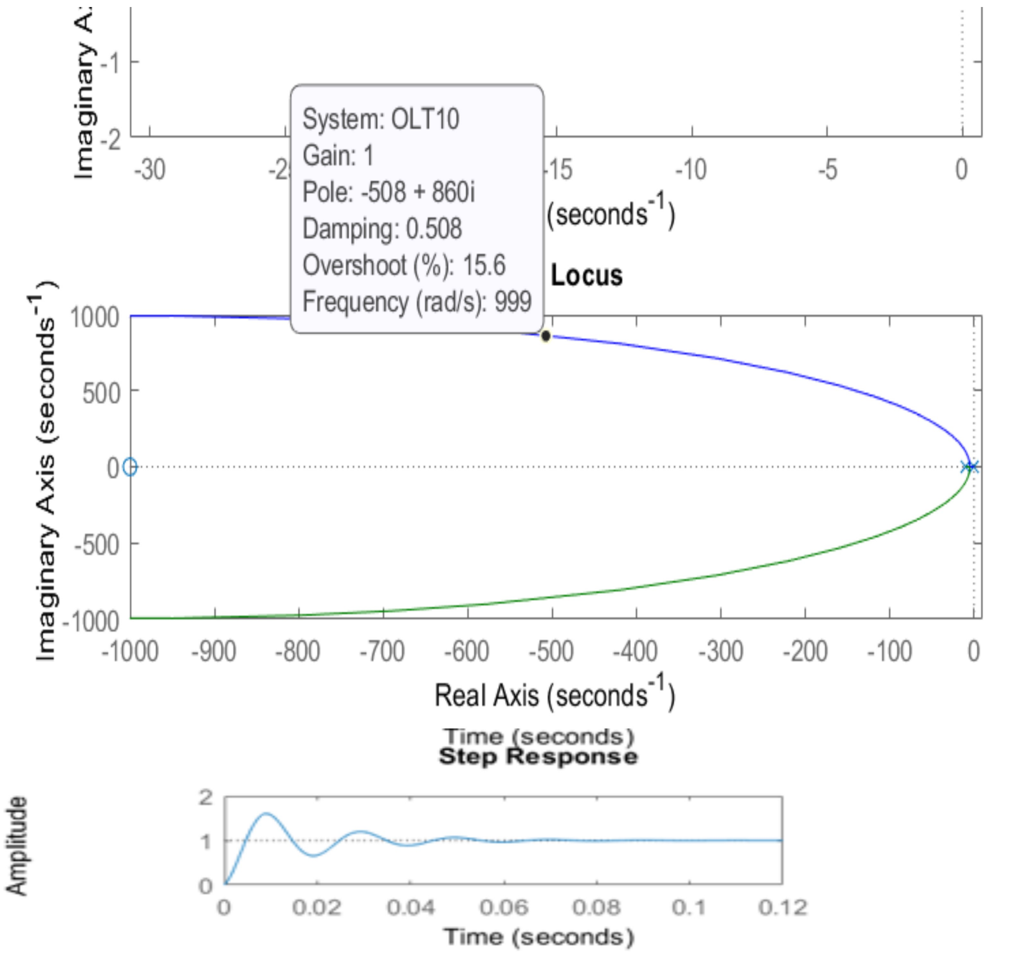
K3 =100 and K2 = 1,100, 1000 and K1= 1,100,1000.

<u>Root locus for pid*g(s):</u>

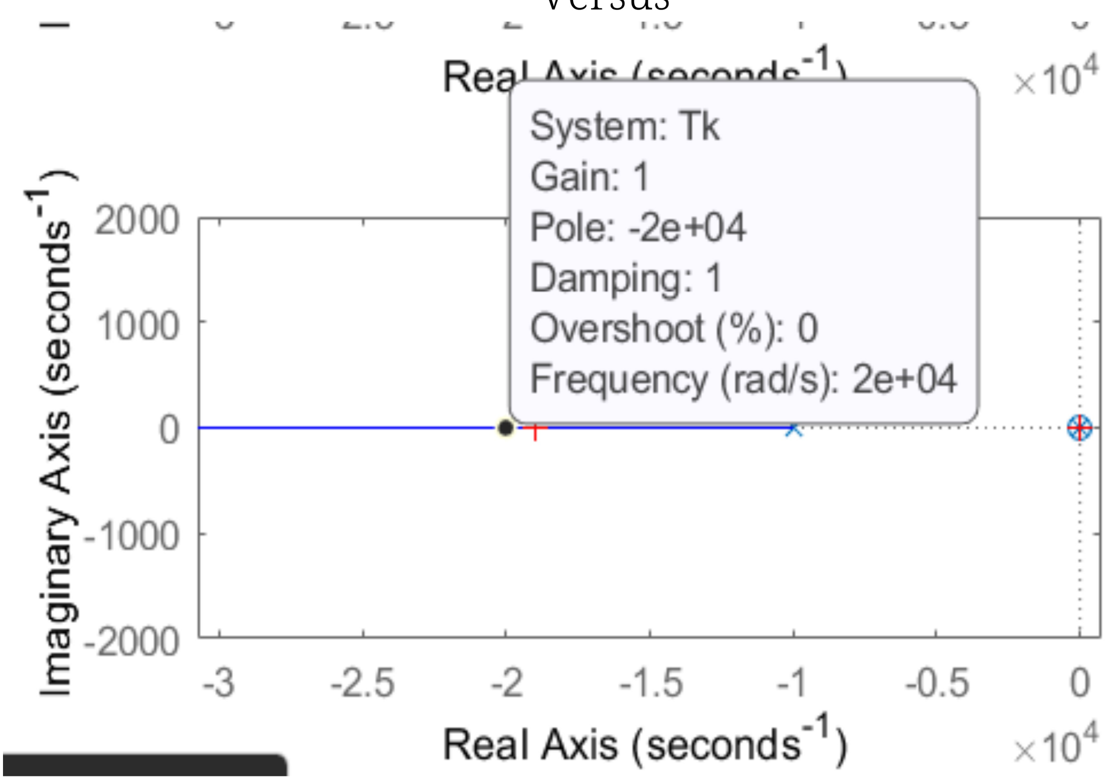


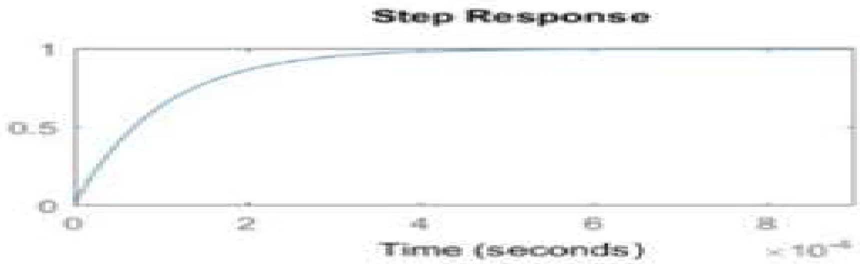
It's stable for all gain values.

<u>Root loci comparison for pd versus pid:</u>


System: OLT10
Gain: 1
Pole: -508 + 860i
Damping: 0.508
Overshoot (%): 15.6
Frequency (rad/s): 999
Locus
Imaginary Axis (seconds^{-1})
Real Axis (seconds^{-1})
Time (seconds)
Step Response
Amplitude
Time (seconds)

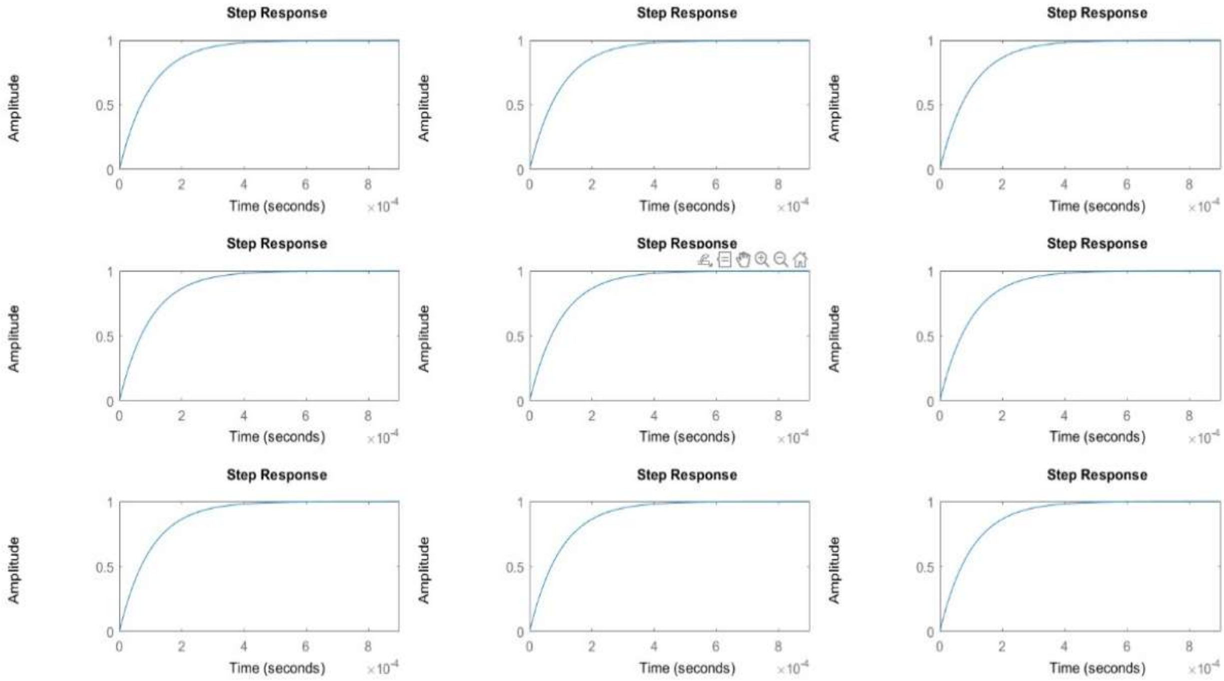
Versus


System: Tk
Gain: 1
Pole: -2e+04
Damping: 1
Overshoot (%): 0
Frequency (rad/s): 2e+04
Imaginary Axis (seconds^{-1})
Real Axis (seconds^{-1})
$\times 10^4$



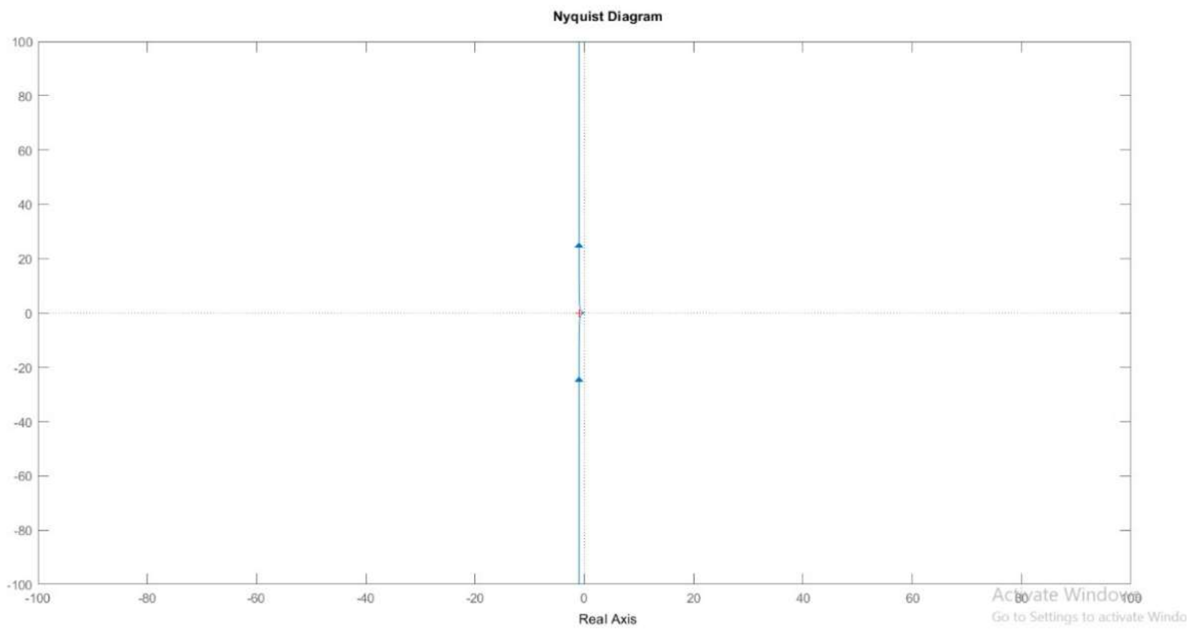
PID is faster as the frequency is higher. The damping is 1, thus it is critically damped.

PID controller:

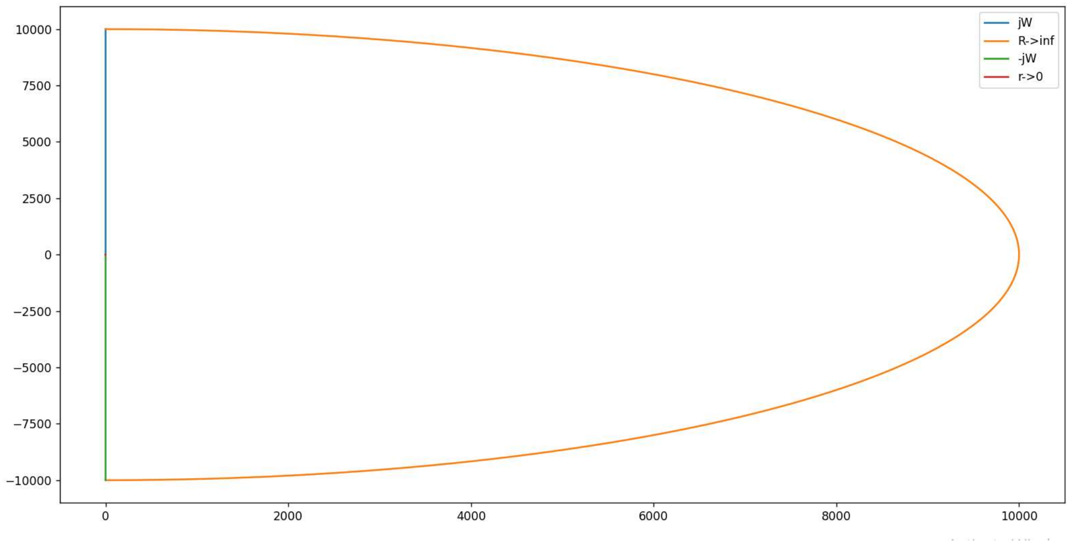


As K1 increases settling time decreases.

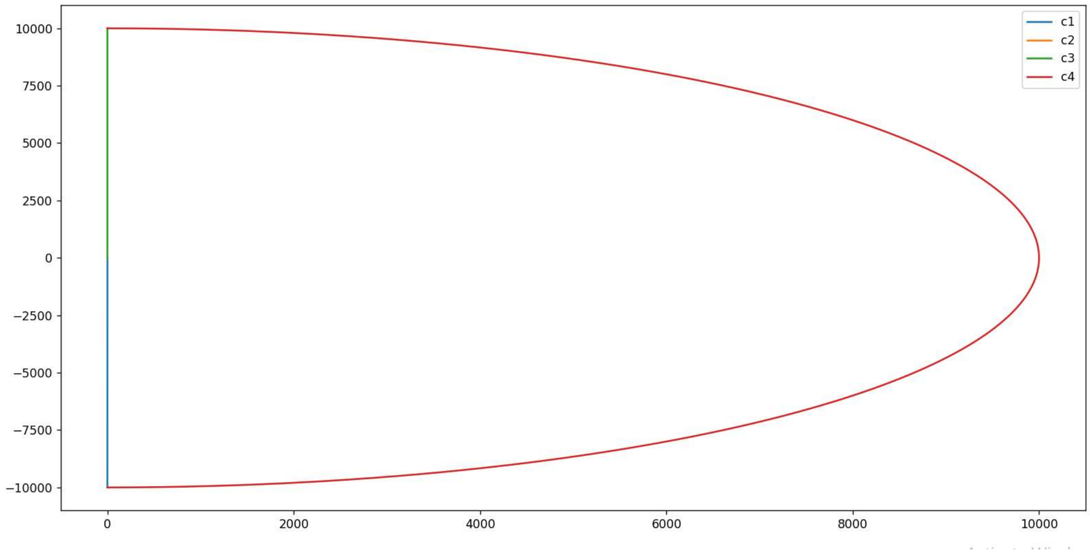
Nyquist:



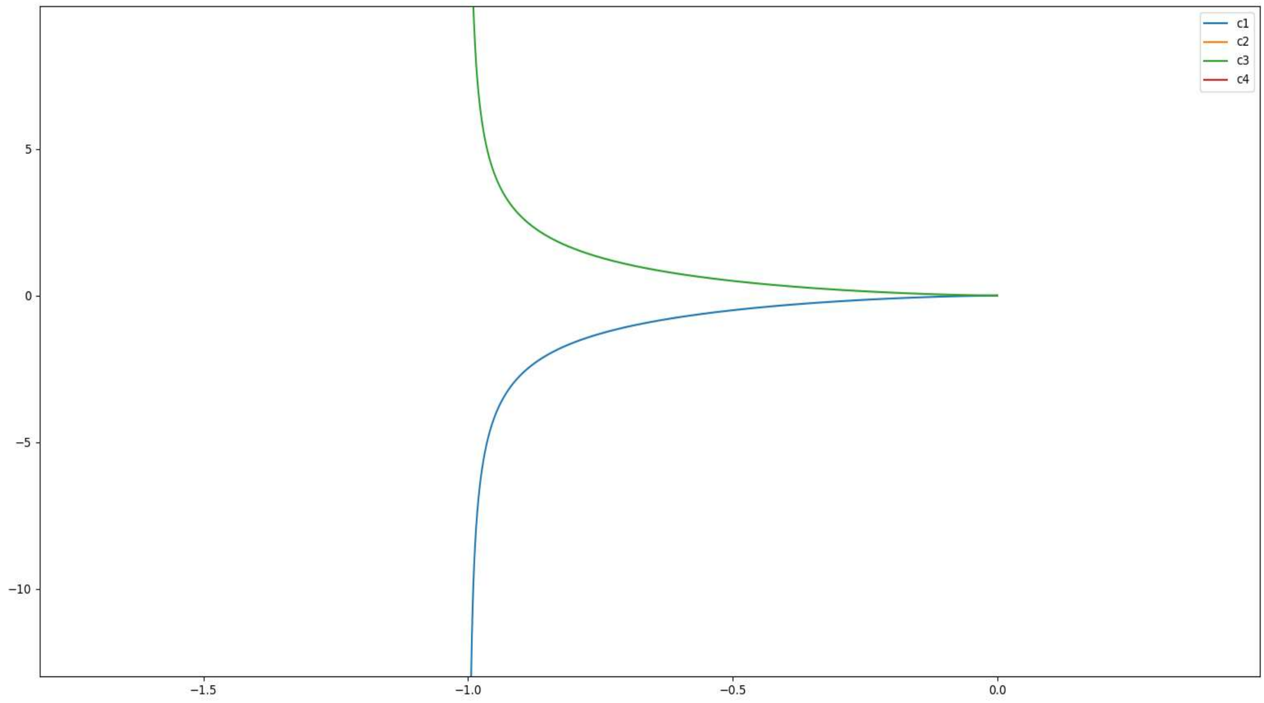
Contour:



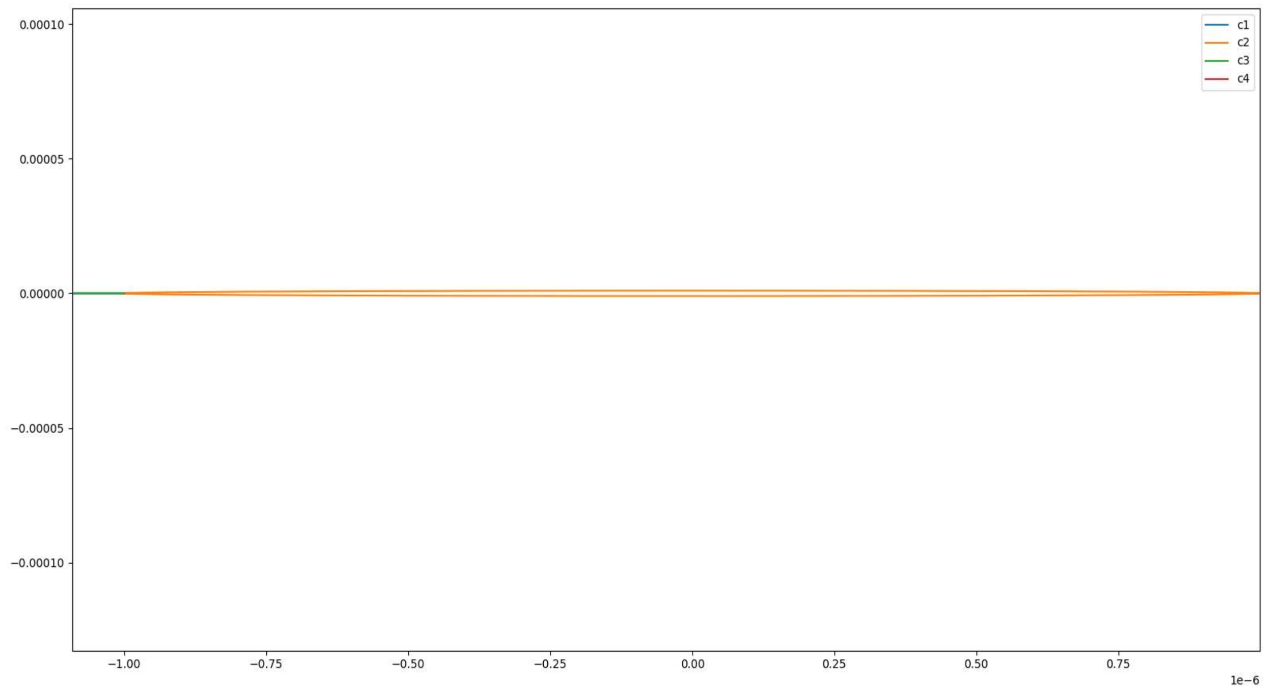
Nyquist Mapping:



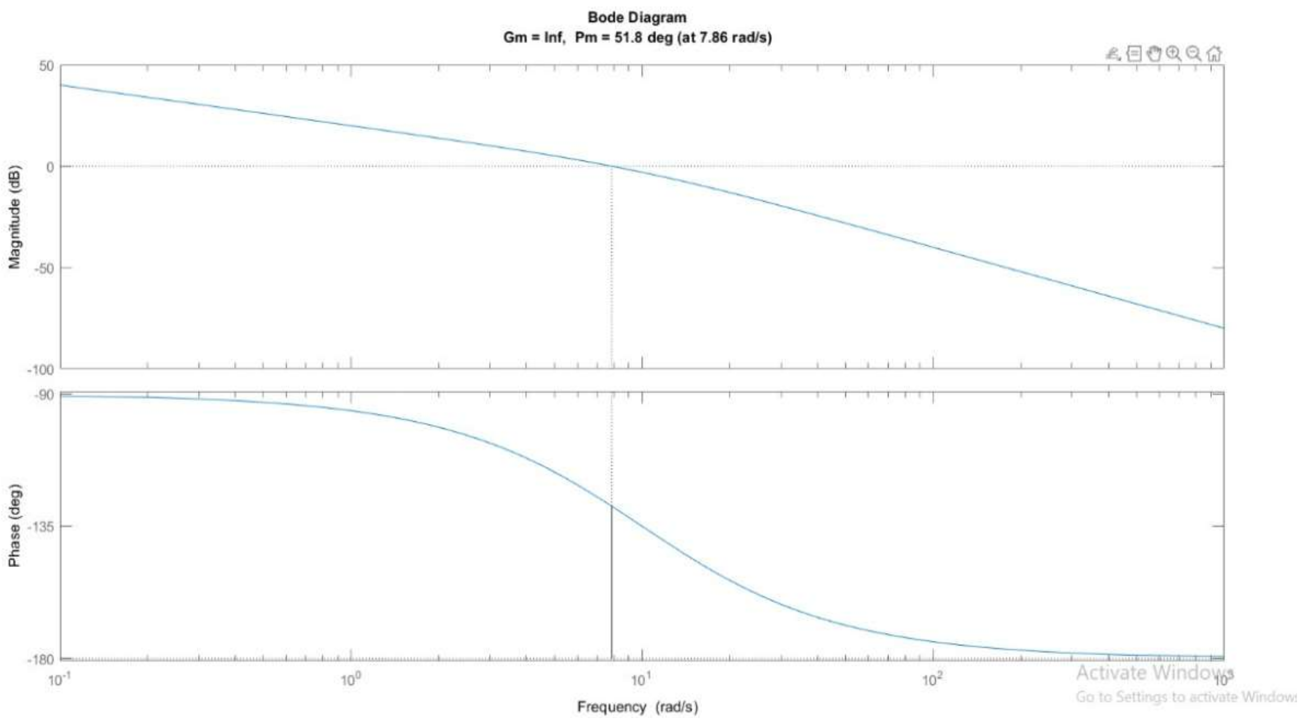
Let’s Take a Closer Look:



As we Can see it goes to the right half and avoids -1:



System Bode Plot:



Conclusion for Question 5:

5.i) PI

- *Increasing K and z to very high values make the system unstable due to addition of pole*
- *As K increases number of oscillations increases.*

- *As z increases the settling time decreases and the rise time decreases*
- *Overshoot increases as z increases*
- *Addition of pole makes the system sluggish and less stable*

5.ii) PID

- *As K1 increases transients improves ie becomes faster*
- *Steady State Error is Zero unlike P controller*
- *No overshoot even for very large values of K1, K2 and K3.*

5.b) FREQUENCY ANALYSIS:

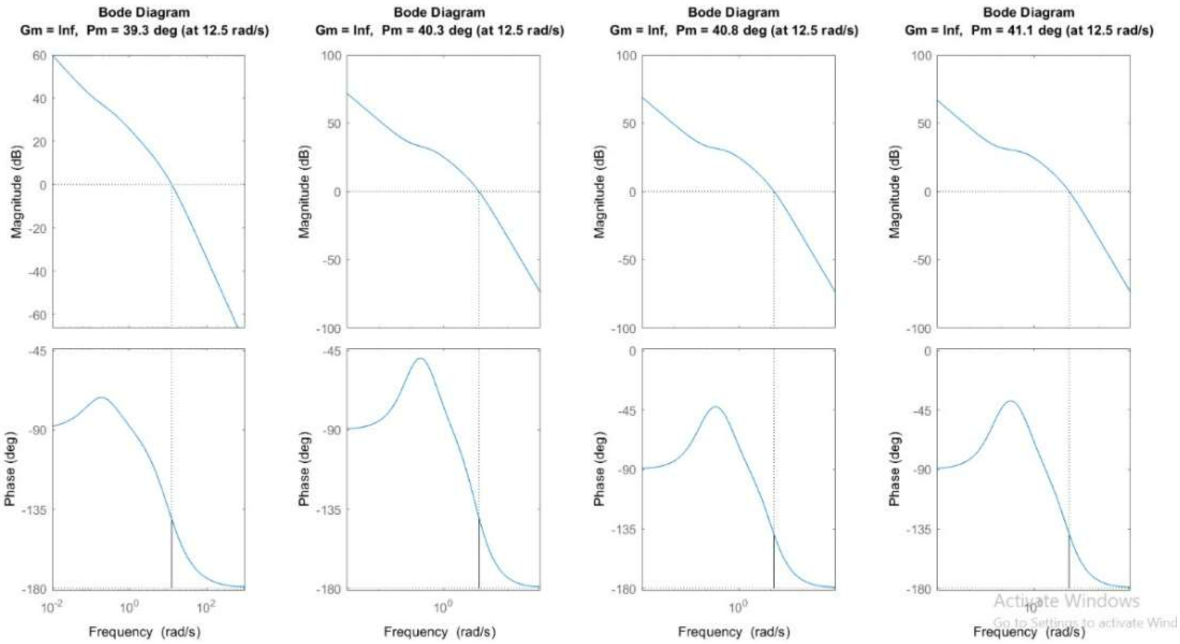
Nyquist Plot: There is no encirclement of -1 hence system has no right half poles hence CL is stable.

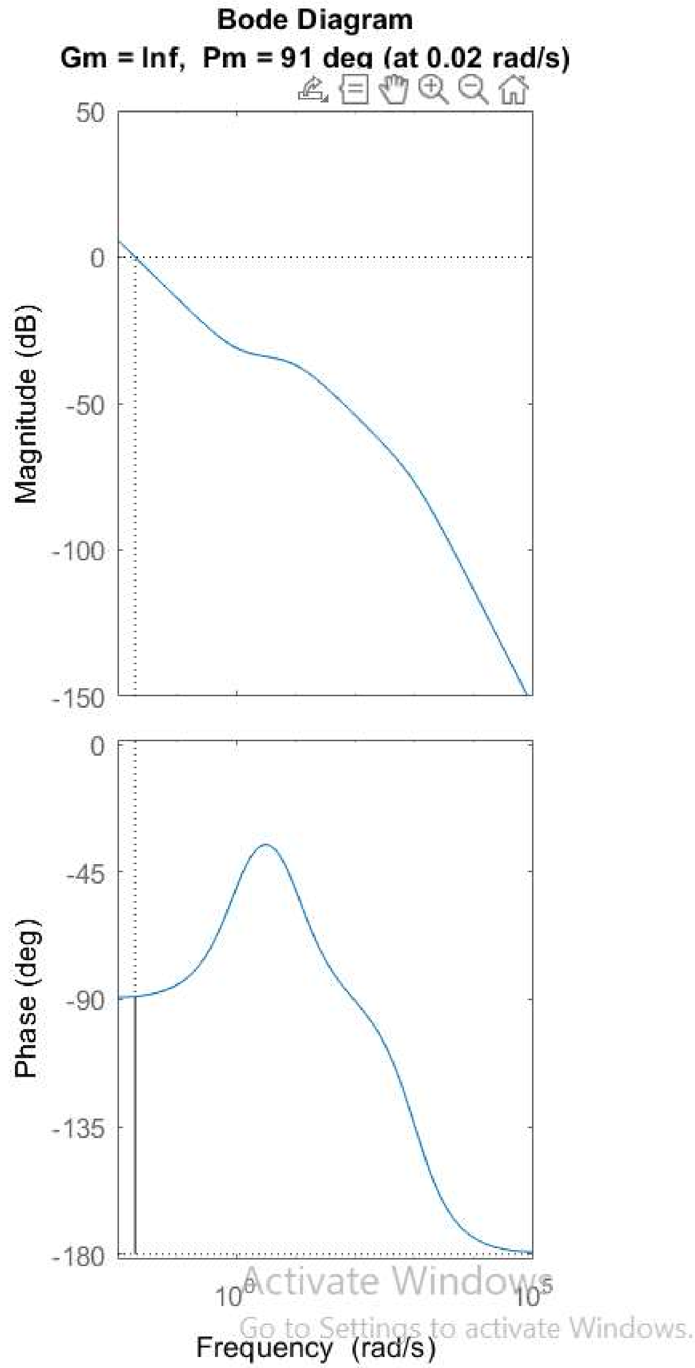
- *Gain margin is infinity hence we can increase K indefinitely and this was confirmed in question 2.*

Gain and phase margins are positive. Hence the closed loop system is stable.

Question 6 Solution:

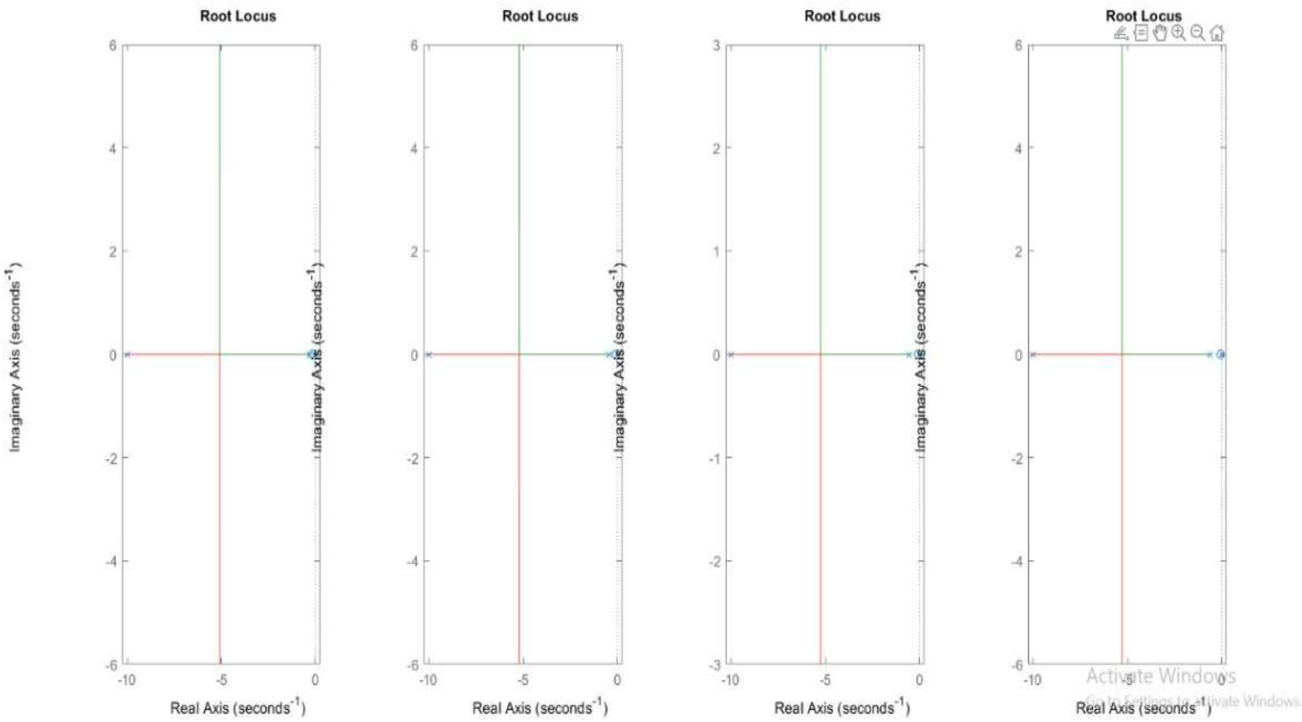
Bode plot for Phase Lead:



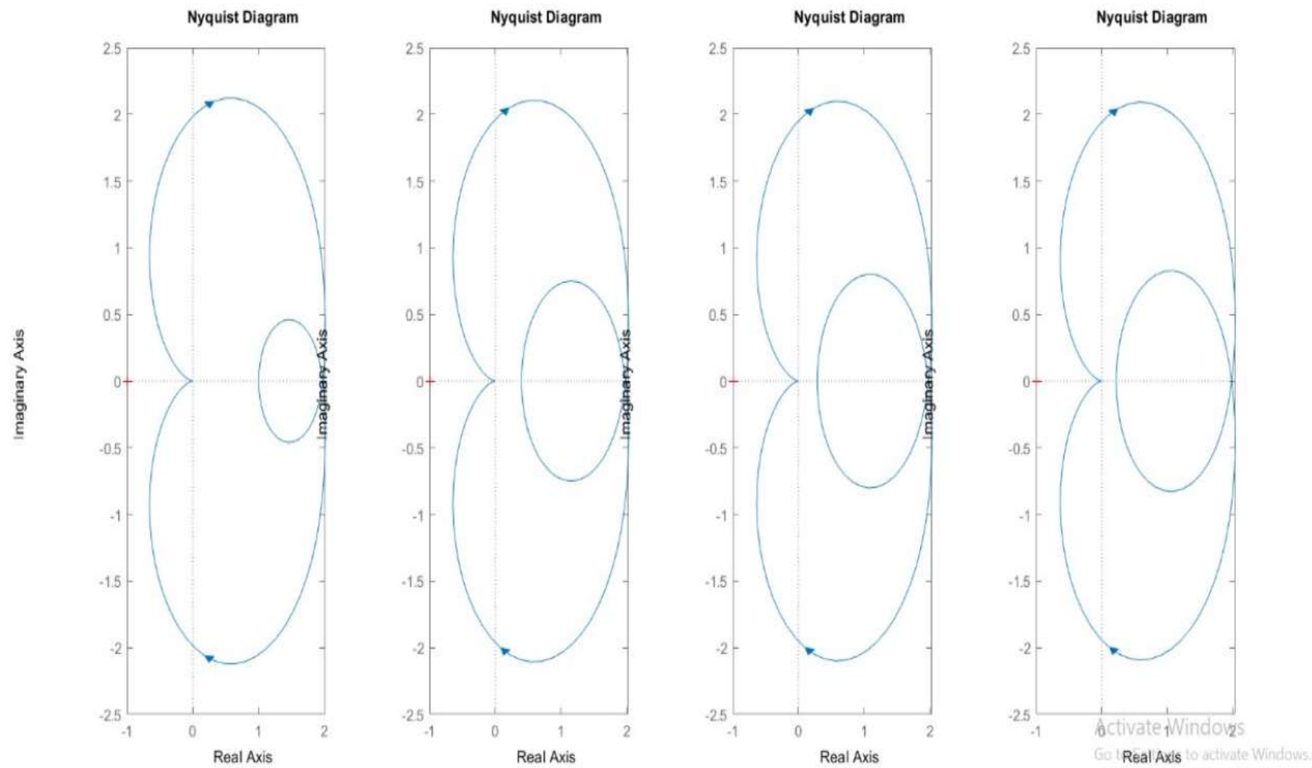


If we take tau as 0.001 and
Alpha as 1000 we can see that
We have successfully increased the phase margin to approximately 90.

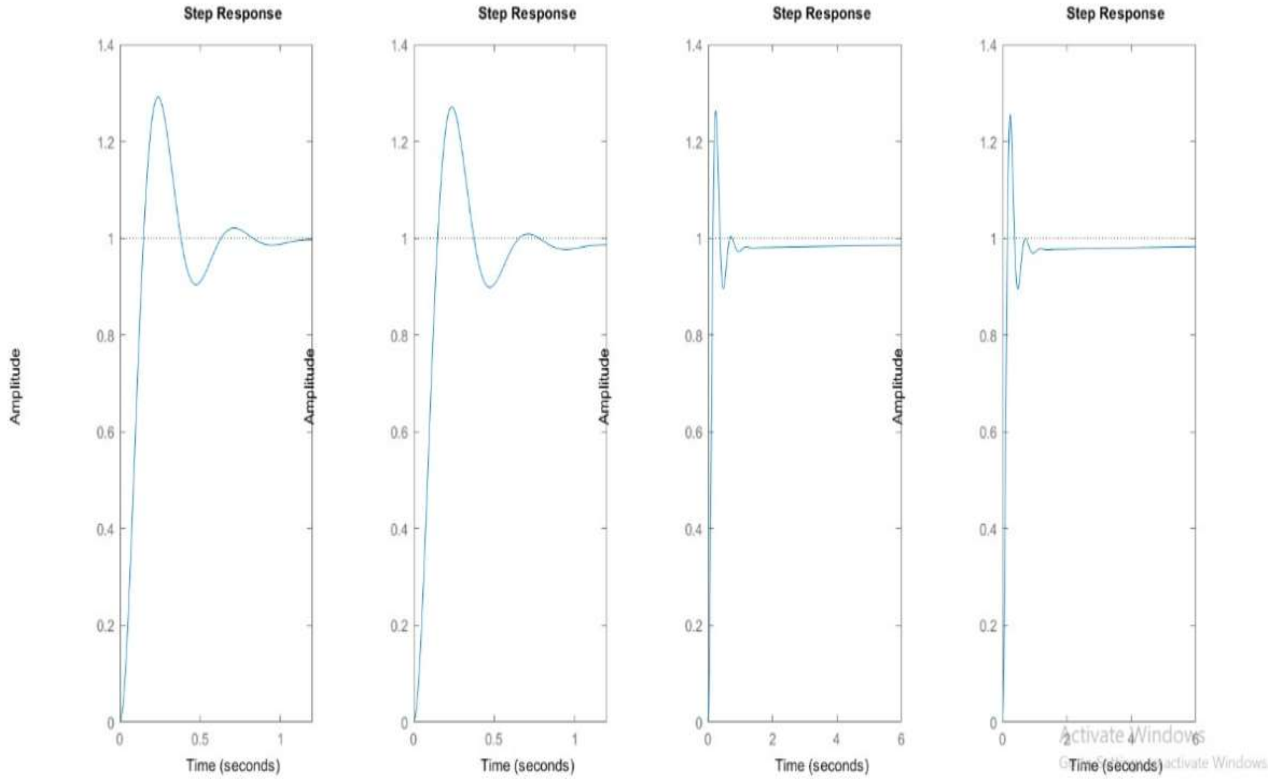
Root Locus for Phase lead:



Nyquist diagram for Phase lead:



Step response characteristics for phase lead:



1) Alpha = 2 and tau = 3.53
2) Alpha = 5 and tau = 2.23
3) Alpha = 7 and tau = 1.88
4) Alpha = 9 and tau = 1.66

Lead Compensator Root locus analysis:

We fixed K =2

K=2;

We varied the value of z and p (added pole and zero) such that the distance between them was fixed.

We took the following set of values

(MAGNITUDE ONLY WITHOUT SIGN)

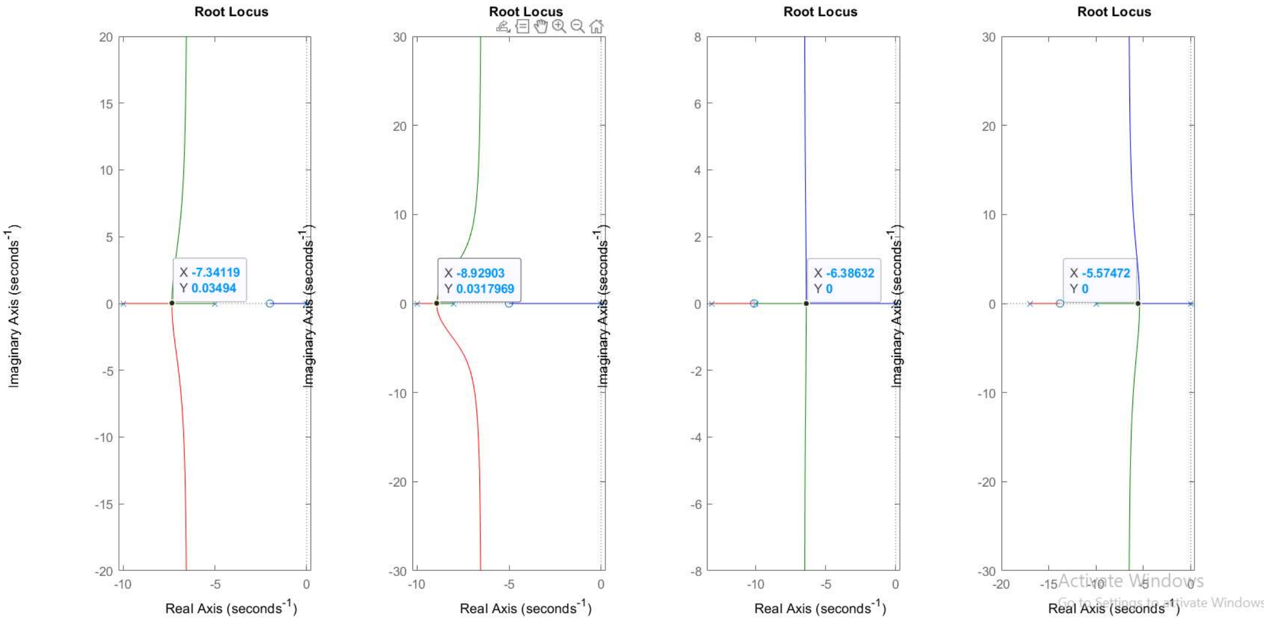
(z,p) = [(2,5),(5,8),(10,13),(14,17)]

Hence these are the variations in alpha and Tau

alpha1= [2.5 1.6 1.3 1.231];

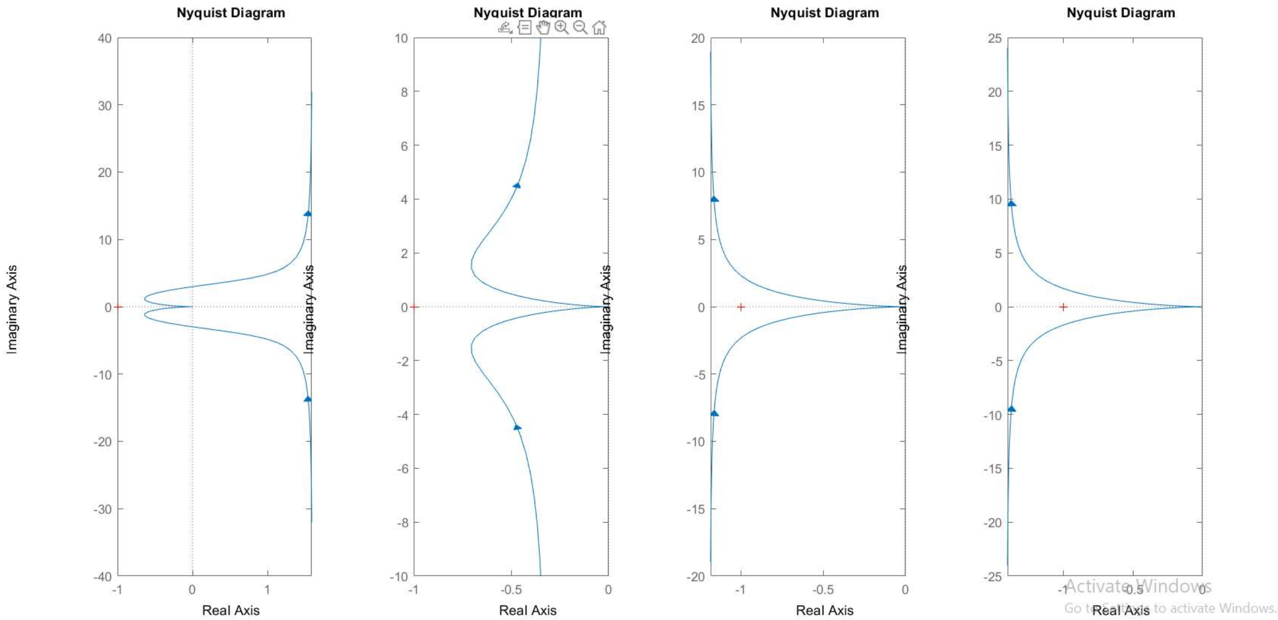
tou = [0.2 0.125 0.076 0.0588];

Root Locus:



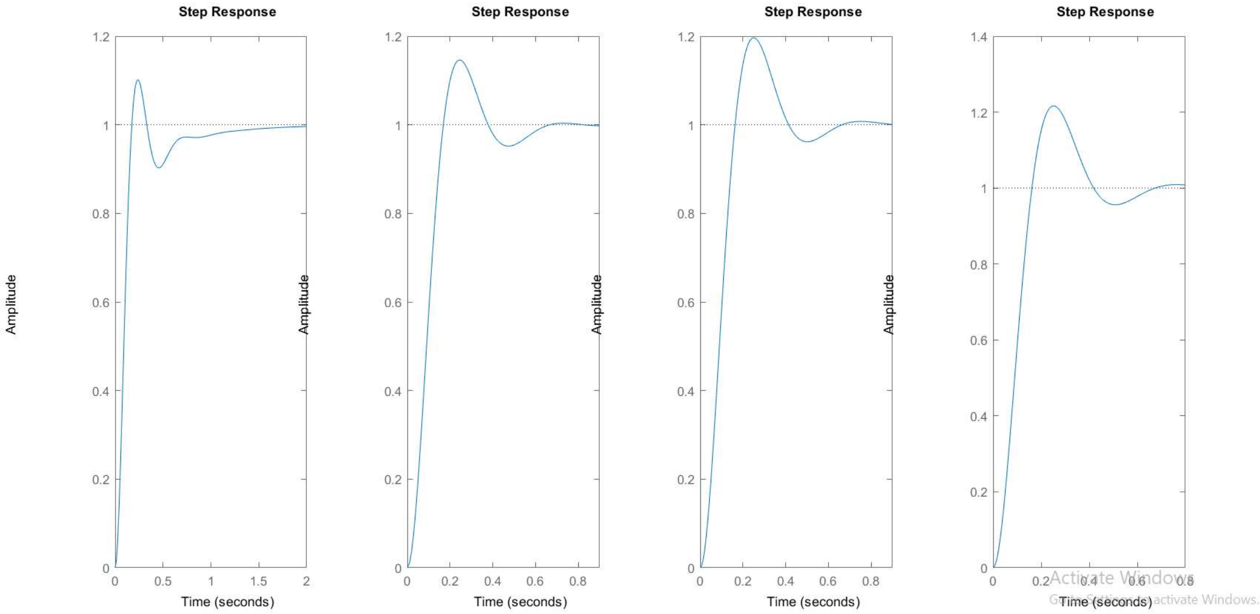
We can see the breakaway point starts shifting towards -infinity but when the added zero crosses the -10 Open Loop Pole the breakaway point shifts towards positive side .

Nyquist Plot for above:



Nyquist doesn’t encircle (-1,0) so its stable.

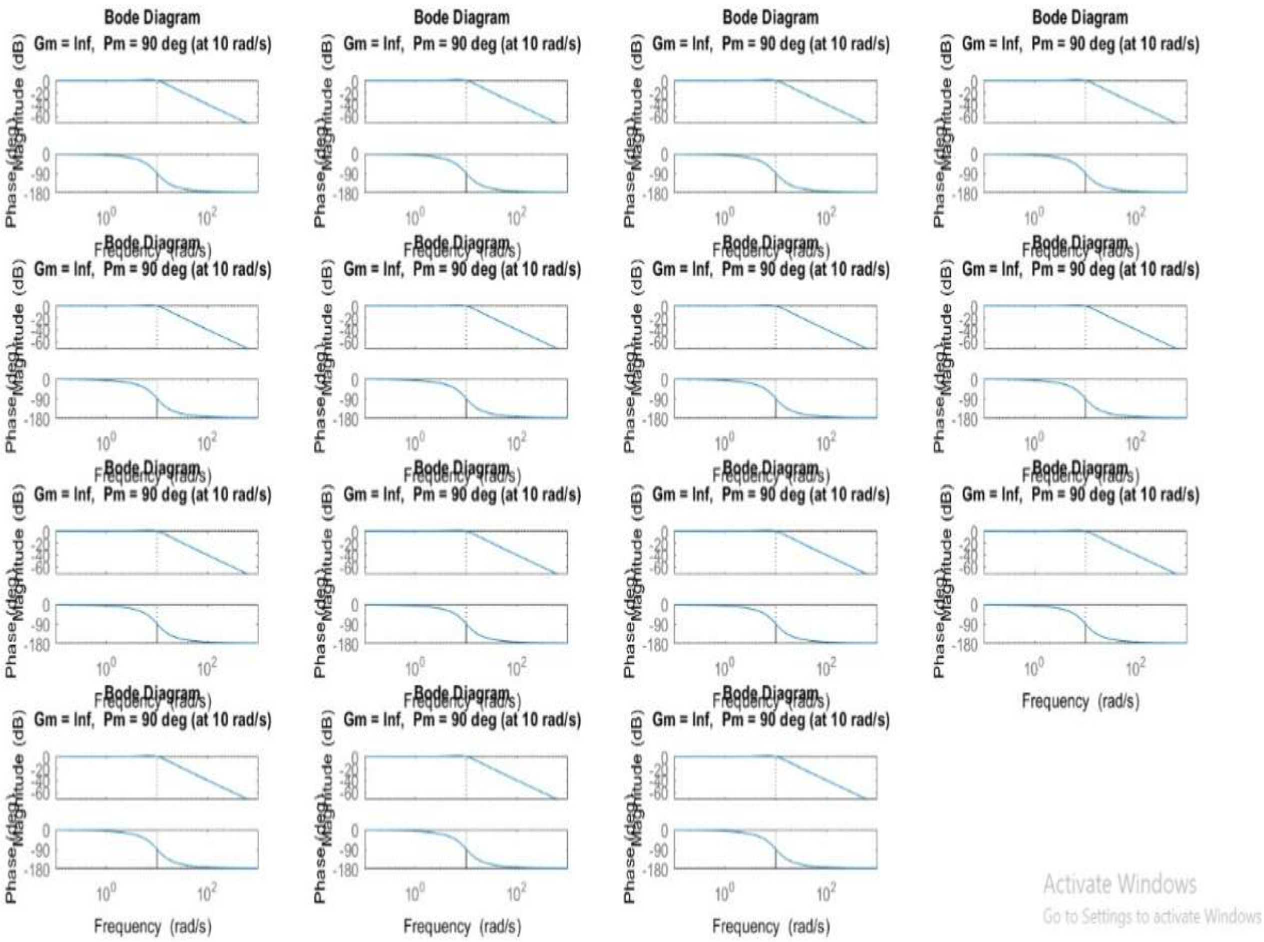
Step Response:



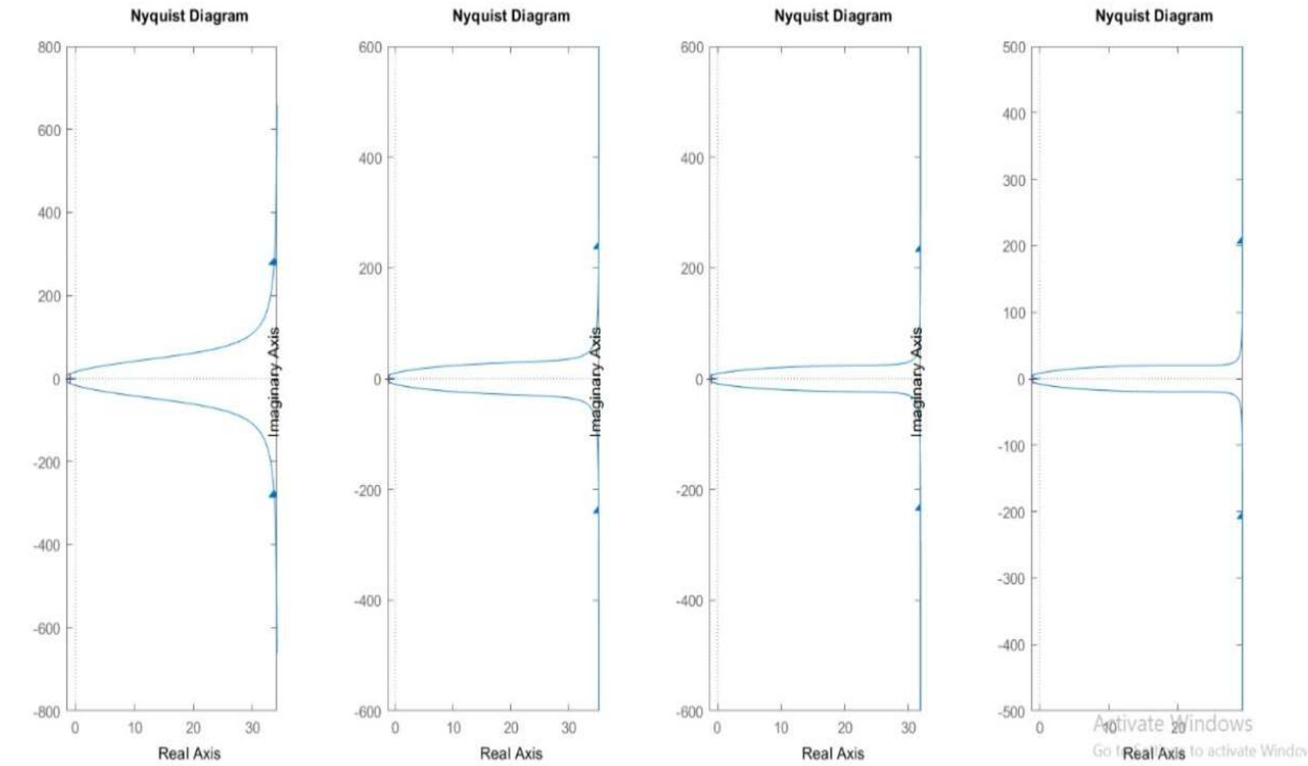
Overshoot is increasing in the step response.

Lag Compensator:

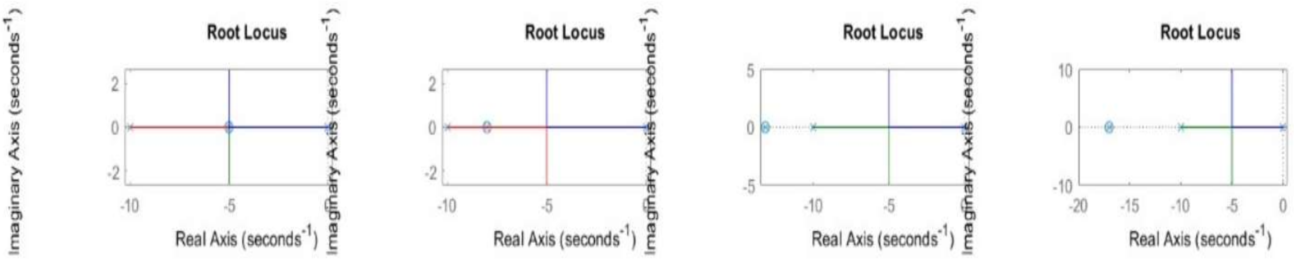
Bode plot:



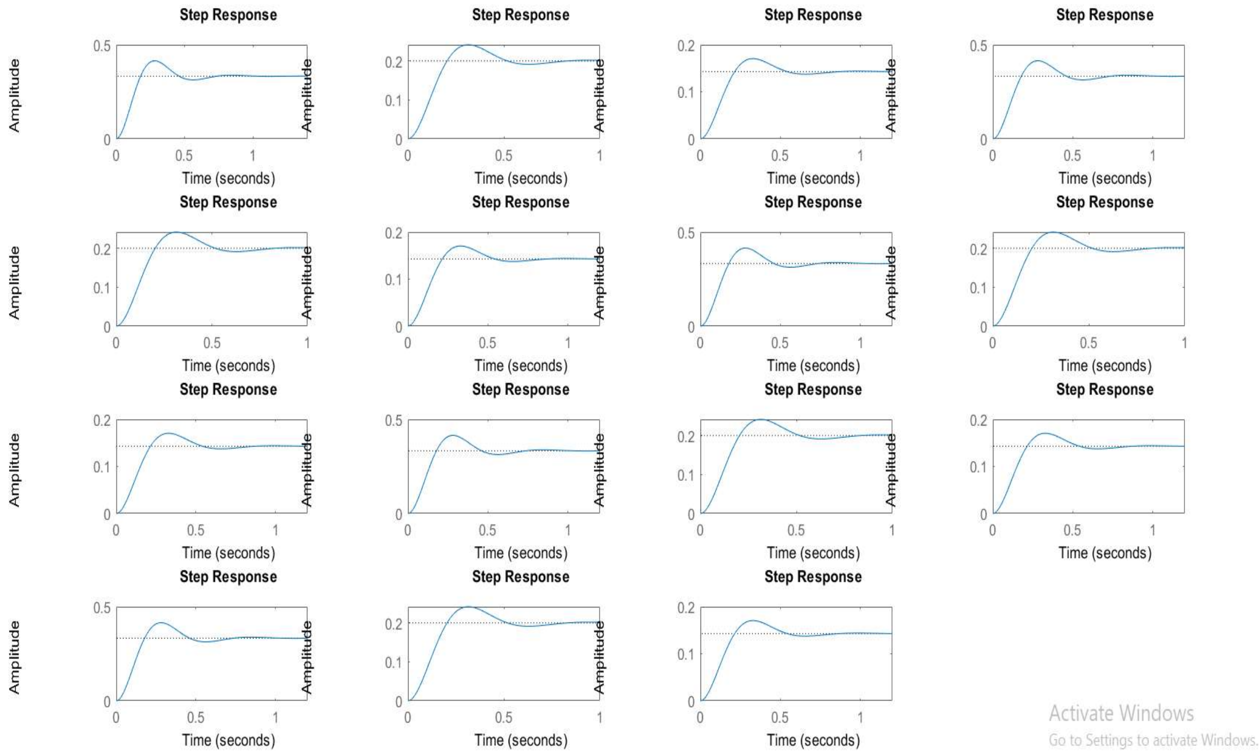
Nyquist plot for lag compensator:



Root locus for lag compensator:



Step response for lag compensator:

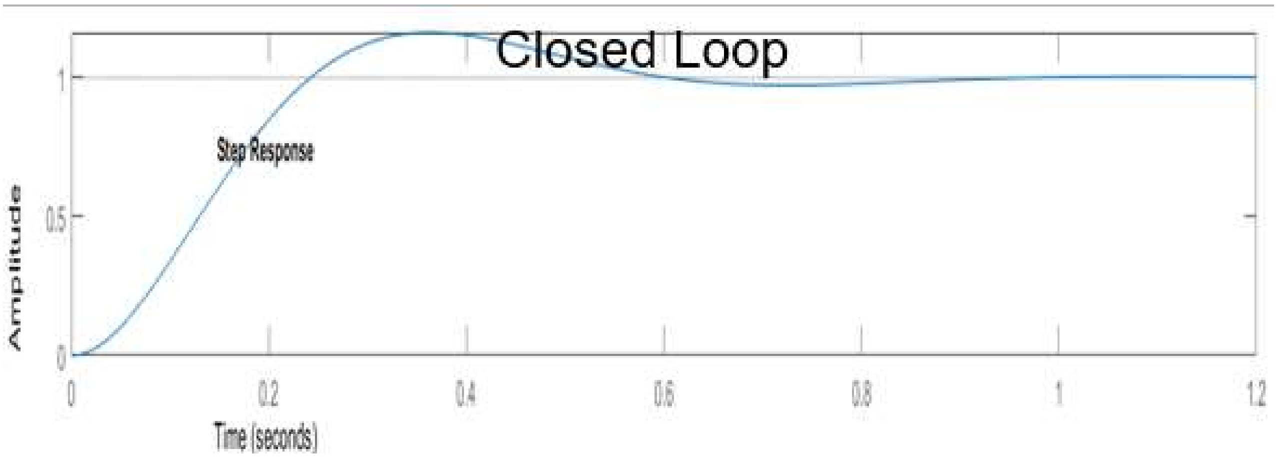


Conclusion for Question 6:

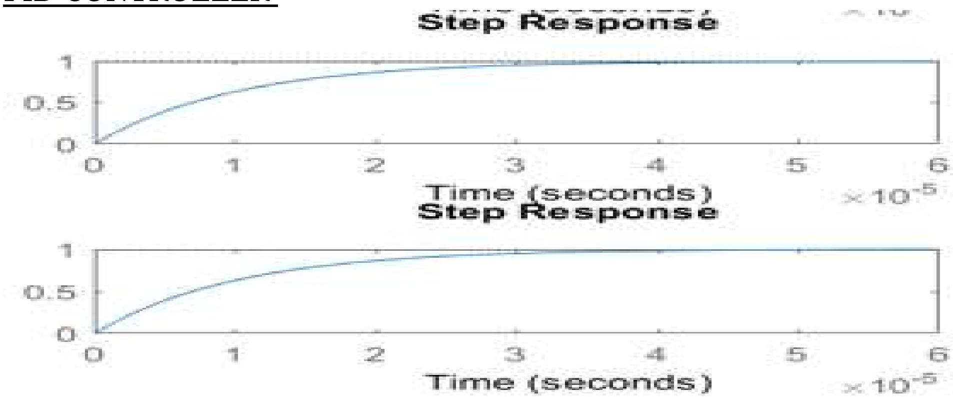
- *Phase margin increases as alpha increases and tau decreases for phase lead compensator.*
- *The transience improves for the same.*
- *Steady state error is increasing.*
- *PHASE LAG:*

1. *Phase margins and gain margins do not change as we vary alpha and tau.*
2. *<u>All phase margins and gain margins are positive and system is stable.</u>*

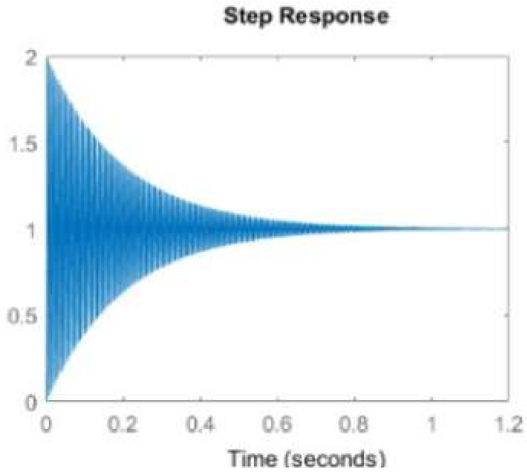
ALL Controllers STEP RESPONSE COMP: PID and PD Both give good transient response, P and Pi were not so good:



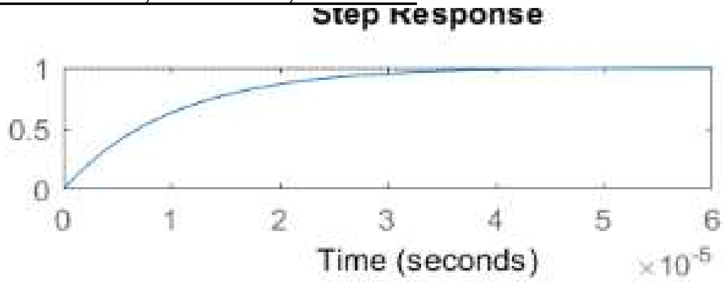
PID CONTROLLER



P Controller, K = 1000:



PD Controller, K = 1000, z=1000:



PI Controller: