Control Systems - Report

LTTS
GLOBAL ENGINEERING ACADEMY

L&T Technology Services

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Module: Control Systems

Document History

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1.0	14/04/2021	Pushkar Antony	Shiva Kumar	Dr.Prithvi Sekhar	Individual report- Control Systems

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1(a) First Order Equation with open loop and without controller

Plant Description

The Mass-damper first order system is taken as Plant. Equation: f= Bv + M v' f = force; B= coefficient of friction; M = mass ; v= velocity. Values: B1= 0.4, M1=1000; B2= 0.5, M2= 500; B3= 1.7, M3= 340;

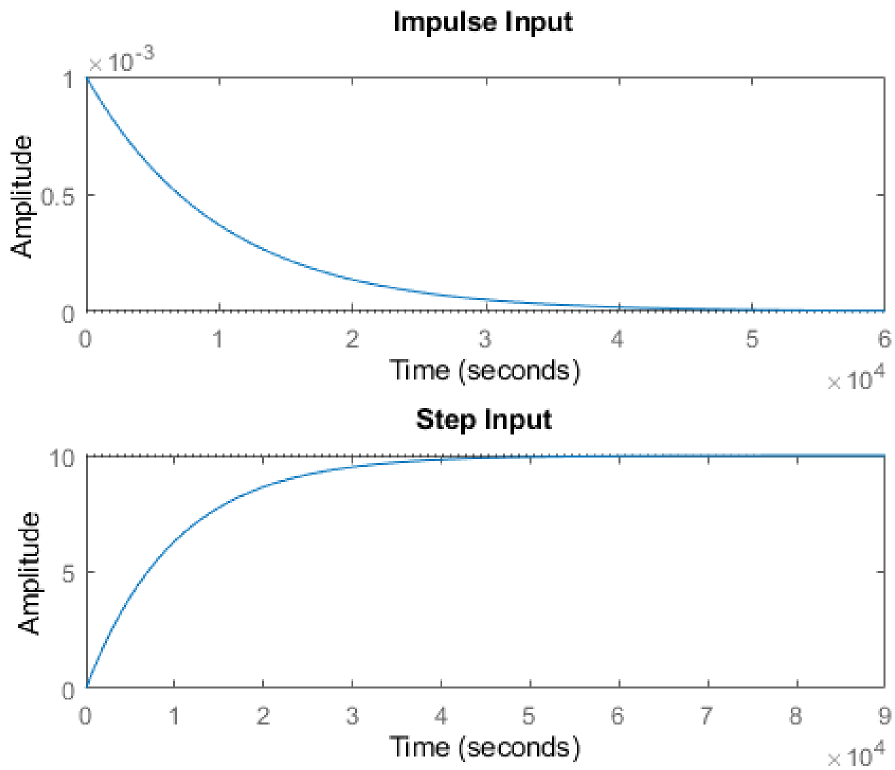
Code

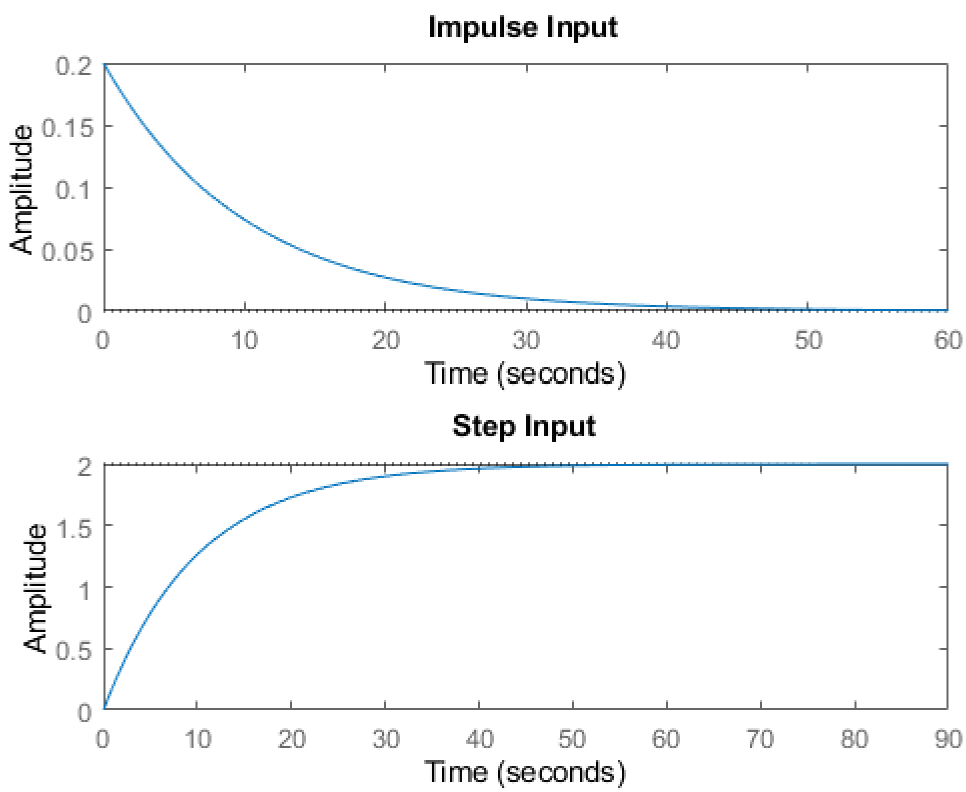
```
clc;
B1= ([0.1 0.5 1.7]);
M1=([1000 5 340]);
for i=1:3
    sys = tf([1/M1(i)],[1,B1(i)/M1(i)])
    figure(i);
    subplot(2,1,1);
    impulse(sys);
    title('Impulse Input');
    subplot(2,1,2);
    step(sys);
    title('Step Input');
    [z,p,k]= tf2zp([1/M1(i)],[1,B1(i)/M1(i)])
    figure(4);
    zplane(z,p);
    xlim([-4*1e5 2*1e5]);
    ylim([-4*1e5 2*1e5]);
    hold on;
    S = stepinfo(sys)
end
```

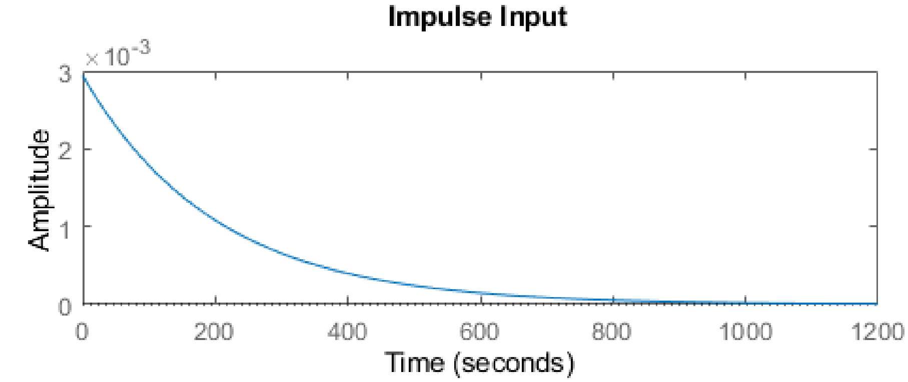
```
sys =

    0.001
  ----------
  s + 0.0001

Continuous-time transfer function.


z =

  0×1 empty double column vector


p =

  -1.0000e-04


k =
```

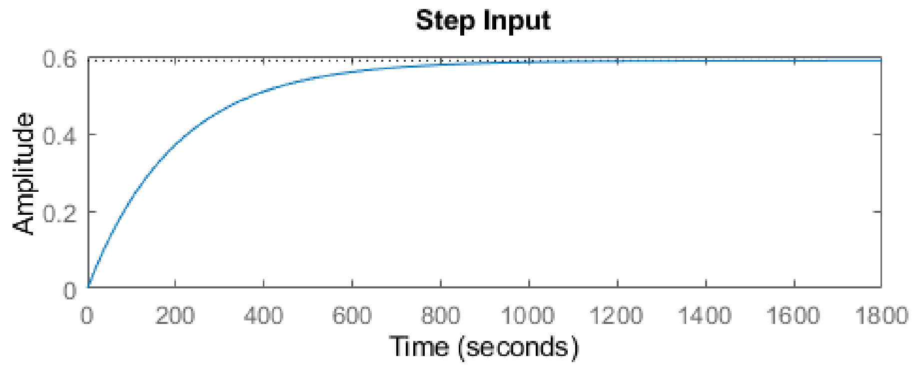
```
   1.0000e-03


S =

  struct with fields:

        RiseTime: 2.1970e+04
    SettlingTime: 3.9121e+04
     SettlingMin: 9.0450
     SettlingMax: 9.9997
       Overshoot: 0
      Undershoot: 0
            Peak: 9.9997
        PeakTime: 1.0546e+05


sys =

    0.2
  -------
  s + 0.1

Continuous-time transfer function.


z =

  0×1 empty double column vector


p =

   -0.1000


k =

    0.2000


S =

  struct with fields:

        RiseTime: 21.9701
    SettlingTime: 39.1207
     SettlingMin: 1.8090
     SettlingMax: 1.9999
       Overshoot: 0
```

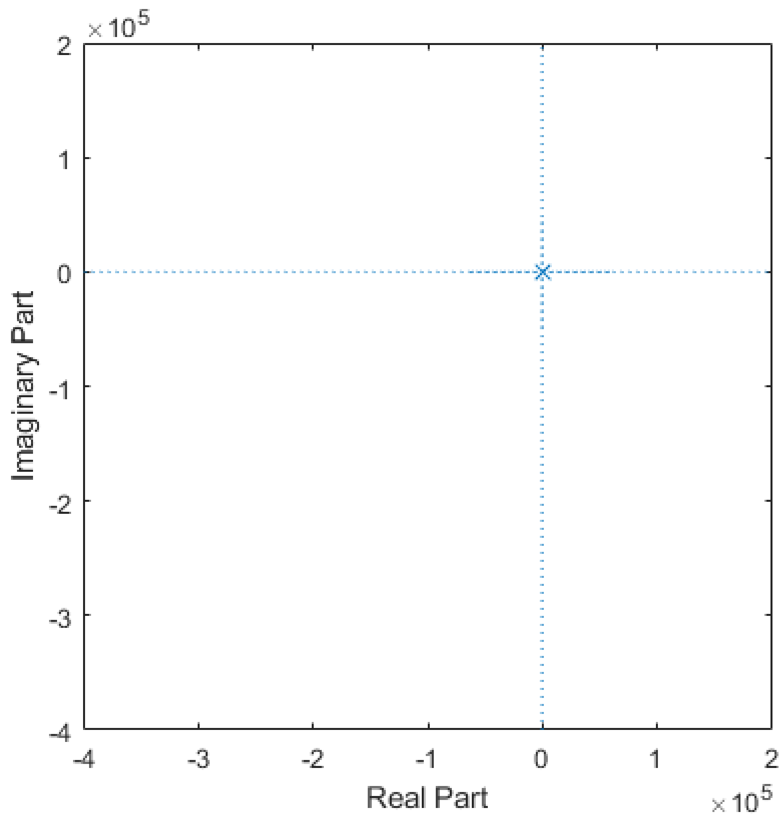
```
      Undershoot: 0
            Peak: 1.9999
        PeakTime: 105.4584


sys =

  0.002941
  ---------
  s + 0.005

Continuous-time transfer function.


z =

  0×1 empty double column vector


p =

   -0.0050


k =

    0.0029


S =

  struct with fields:

        RiseTime: 439.4013
    SettlingTime: 782.4149
     SettlingMin: 0.5321
     SettlingMax: 0.5882
       Overshoot: 0
      Undershoot: 0
            Peak: 0.5882
        PeakTime: 2.1092e+03
```


Impulse Input
× 10-3
1
0.5
0
Amplitude
0
1
2
3
4
5
6
Time (seconds)
× 104
Step Input
10
5
0
Amplitude
0
1
2
3
4
5
6
7
8
9
Time (seconds)
× 104


Impulse Input
0.2
0.15
0.1
0.05
0
Amplitude
0
10
20
30
40
50
60
Time (seconds)
Step Input
2
1.5
1
0.5
0
Amplitude
0
10
20
30
40
50
60
70
80
90
Time (seconds)


Impulse Input
$\times 10^{-3}$
Amplitude
Time (seconds)


Step Input
Amplitude
Time (seconds)


$\times 10^{5}$
Imaginary Part
Real Part
$\times 10^{5}$

Math Analysis

Independent: Time(t) Dependent: Velocity(v) and Force(f) Constant: Mass(M) and Frictional Coefficient(B)

```
% Roots:(-B)/M

% IVT:
% 1. For step input: 0
% 2. For impulse input: 1/M

% FVT:
% 1. For step input: 1/B
% 2. For impulse input: 0

% Time Response Results:
% Rise Time :4tau = (4M)/B; where tau = M/B
```

Comparison Analysis:(Speed, Accuracy and stability):

1) s=0.001/(0.0001s+1)- a stable system as the poles are in the 2nd

```
%and 3rd quadrant.
% 2) There is no overshoot since it’s a first order system.
% 3) The rise time of 2nd system is least and hence it is the fastest
%system.
% 4) The settling time of 2nd system is least and hence making it more
%accurate than the rest of them.
% 5) The poles are moving farther away, the more the system becomes stable,
%as we can see in 2nd system.
```

1(b) First Order Equation with open loop and controller

Plant Description

The Mass-damper first order system is taken as Plant. Equation: f= Bv + M v' f = force; B= coefficient of friction; M = mass ; v= velocity. Values: B1= 0.4, M1=1000; B2= 0.5, M2= 500; B3= 1.7, M3= 340;

Code

```
clc;
B1= 0.5;
M1= 5;
P = 2;

sys = tf([P/M1],[1,B1/M1])
subplot(3,4,1);
impulse(sys);
title('Impulse Input for k');
subplot(3,4,2);
```

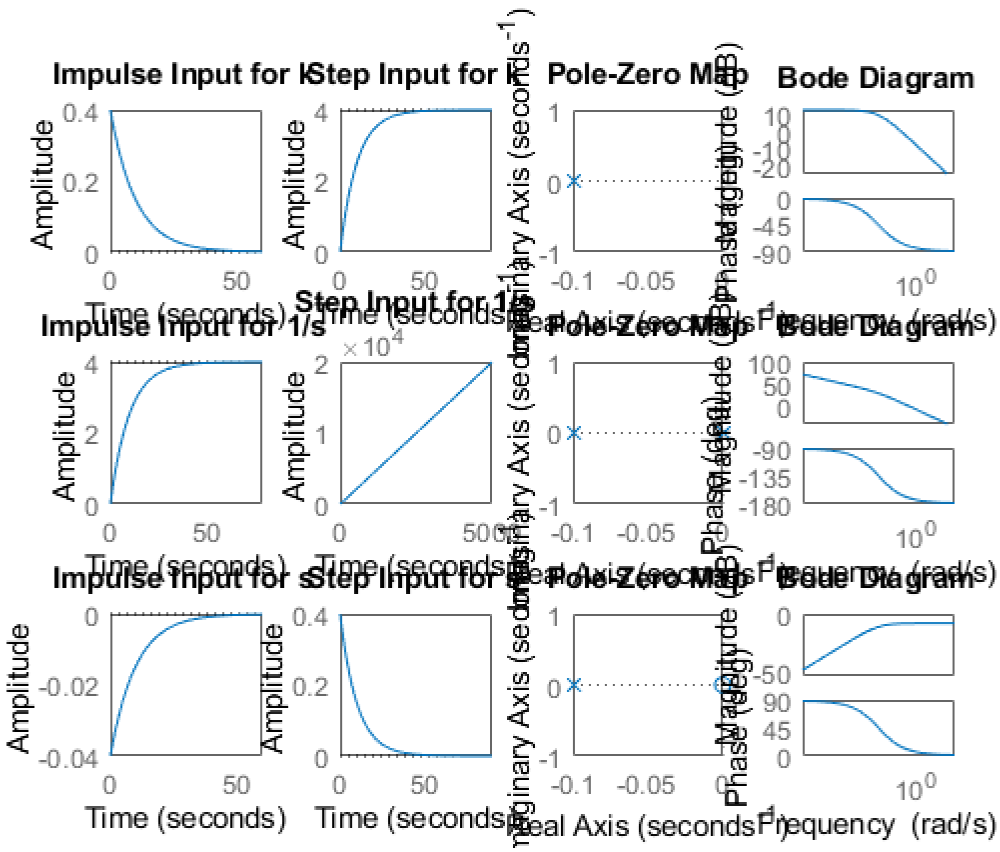
```
step(sys);
title('Step Input for k');
subplot(3,4,3);
[z,p,k]= tf2zp([P/M1],[1,B1/M1])
pzmap(sys)
subplot(3,4,4);
bode(sys)
hold on;
S = stepinfo(sys)

sys = tf([P/M1],[1,B1/M1,0])
subplot(3,4,5);
impulse(sys);
title('Impulse Input for 1/s');
subplot(3,4,6);
step(sys);
title('Step Input for 1/s');
subplot(3,4,7);
[z,p,k]= tf2zp([P/M1],[1,B1/M1,0])
pzmap(sys)
subplot(3,4,8);
bode(sys)
hold on;
S = stepinfo(sys)

sys = tf([P/M1,0],[1,B1/M1])
subplot(3,4,9);
impulse(sys);
title('Impulse Input for s');
subplot(3,4,10);
step(sys);
title('Step Input for s');
subplot(3,4,11);
[z,p,k]= tf2zp([P/M1,0],[1,B1/M1])
pzmap(sys)
subplot(3,4,12);
bode(sys)
hold on;
S = stepinfo(sys)
```

```
sys =

    0.4
  -------
  s + 0.1

Continuous-time transfer function.


z =
```

```
  0×1 empty double column vector


p =

   -0.1000


k =

    0.4000


S =

  struct with fields:

        RiseTime: 21.9701
    SettlingTime: 39.1207
     SettlingMin: 3.6180
     SettlingMax: 3.9999
       Overshoot: 0
      Undershoot: 0
            Peak: 3.9999
        PeakTime: 105.4584


sys =

      0.4
  -----------
  s^2 + 0.1 s

Continuous-time transfer function.


z =

  0×1 empty double column vector


p =

         0
   -0.1000


k =

    0.4000
```

```
S =

  struct with fields:

        RiseTime: NaN
    SettlingTime: NaN
     SettlingMin: NaN
     SettlingMax: NaN
       Overshoot: NaN
      Undershoot: NaN
            Peak: Inf
        PeakTime: Inf


sys =

   0.4 s
  -------
  s + 0.1

Continuous-time transfer function.


z =

     0


p =

   -0.1000


k =

    0.4000


S =

  struct with fields:

        RiseTime: 21.9701
    SettlingTime: 39.1207
     SettlingMin: 1.0521e-05
     SettlingMax: 0.0382
       Overshoot: 0
      Undershoot: 7.2058e+17
            Peak: 0.4000
```

```
PeakTime: 0
```



Math Analysis

Independent: Time(t) Dependent: Velocity(v) and Force(f) Constant: Mass(M) and Frictional Coefficient(B)

```
% Roots:(-B)/M

% IVT:
% 1. For step input: 0
% 2. For impulse input: 1/M

% FVT:
% 1. For step input: 1/B
% 2. For impulse input: 0

% Time Response Results:
% Rise Time :4tau = (4M)/B; where tau = M/B
```

Comparison Analysis:(Speed, Accuracy and stability):

1) when a Proportionality controller is introduced, only the amplitude

```
%is getting incremented and all other parameters like rise time, settling
%time remain same as first order without controller.
% 2) when an integrator controller is introduced, a pole gets added at the
%origin and makes the system marginally stable.
% 3) When a differentiator controller is introduced, a zero gets added to
%the origin making any unstable system also stable.
% 4) PID controllers control the whole system making them unstable to
%stable, more stable, add poles, add zeros.
```

1(c) First Order Equation

Plant Description

The Mass-damper first order system is taken as Plant. Equation: f= Bv + M v' f = force; B= coefficient of friction; M = mass ; v= velocity. Values: B1= 0.4, M1=1000; B2= 0.5, M2= 500; B3= 1.7, M3= 340;

Code

```
%Negative Feedback using gain input
clc;
B1= 0.5;
M1= 5;
P = 2;
sys = tf([P],[M1,B1+1])
figure(1);
subplot(2,2,1);
impulse(sys);
title('Impulse Input for k');
subplot(2,2,2);
step(sys);
title('Step Input for k');
subplot(2,2,3);
[z,p,k]= tf2zp([P],[M1,B1+1])
pzmap(sys)
subplot(2,2,4)
bode(sys)
margin(sys)
[Gm,Pm,Wcg,Wcp] = margin(sys)
hold on;
S = stepinfo(sys)

B2= 0.5;
M2= 5;
P2 = 2;
sys = tf([P2],[M2,B2+1,0])
figure(2)
subplot(2,2,1);
impulse(sys);
```

```
title('Impulse Input for Integrator controller');
subplot(2,2,2);
step(sys);
title('Step Input for Integrator controller ');
subplot(2,2,3);
[z,p,k]= tf2zp([P2],[M2,B2+1,0])
pzmap(sys)
subplot(2,2,4)
bode(sys)
margin(sys)
[Gm,Pm,Wcg,Wcp] = margin(sys)
hold on;
S = stepinfo(sys)

%Positive Feedback using integral input
B3= 0.8;
M3= 5;
sys = tf([1],[M3,B3-1,0])
figure(3);
subplot(2,2,1);
impulse(sys);
title('Step Input for Positive feedback');
subplot(2,2,2);
step(sys);
title('Step Input for Positive feedback');
subplot(2,2,3);
[z,p,k]= tf2zp([1],[M3,B3-1,0])
pzmap(sys)
subplot(2,2,4)
bode(sys)
margin(sys)
[Gm,Pm,Wcg,Wcp] = margin(sys)
hold on;
S = stepinfo(sys)

%Positive Feedback using differentiator input
B4= 0.8;
M4= 5;
sys = tf([1,0],[M4,B4-1])
figure(4)
subplot(2,2,1);
impulse(sys);
title('Step Input for Positive feedback');
subplot(2,2,2);
step(sys);
title('Step Input for Positive feedback');
subplot(2,2,3);
[z,p,k]= tf2zp([1,0],[M4,B4-1])
pzmap(sys)
subplot(2,2,4)
bode(sys)
```

```
margin(sys)
[Gm,Pm,Wcg,Wcp] = margin(sys)
hold on;
S = stepinfo(sys)
```

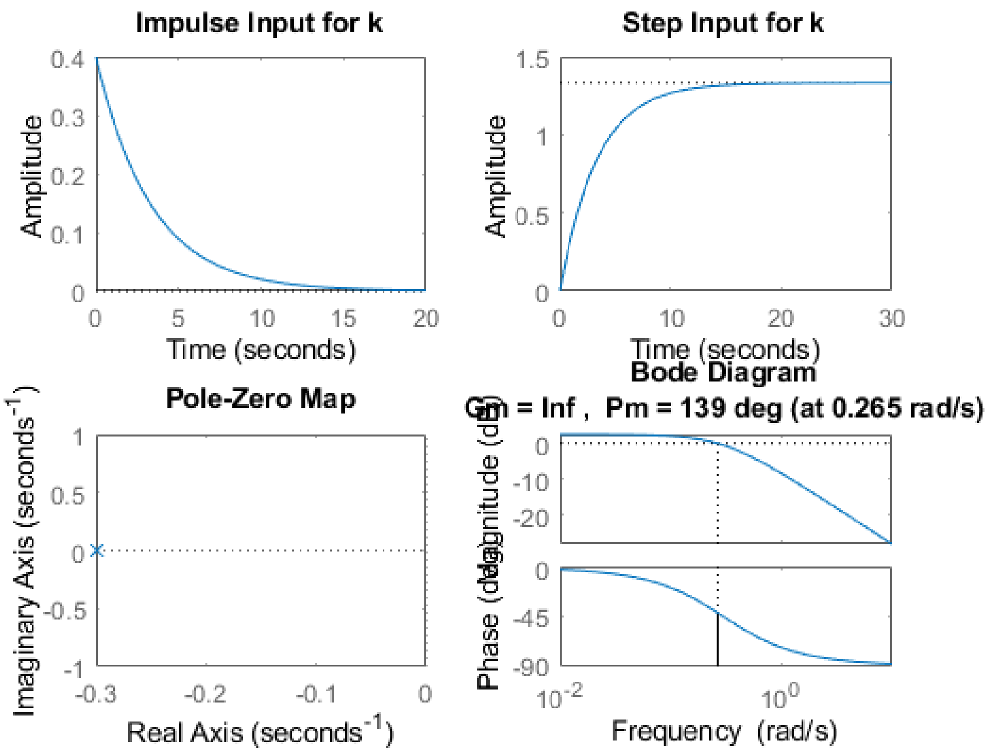
```
sys =

      2
  ---------
  5 s + 1.5

Continuous-time transfer function.


z =

  0×1 empty double column vector


p =

   -0.3000


k =

    0.4000


Gm =

   Inf


Pm =

  138.5925


Wcg =

   NaN


Wcp =

    0.2646


S =
```

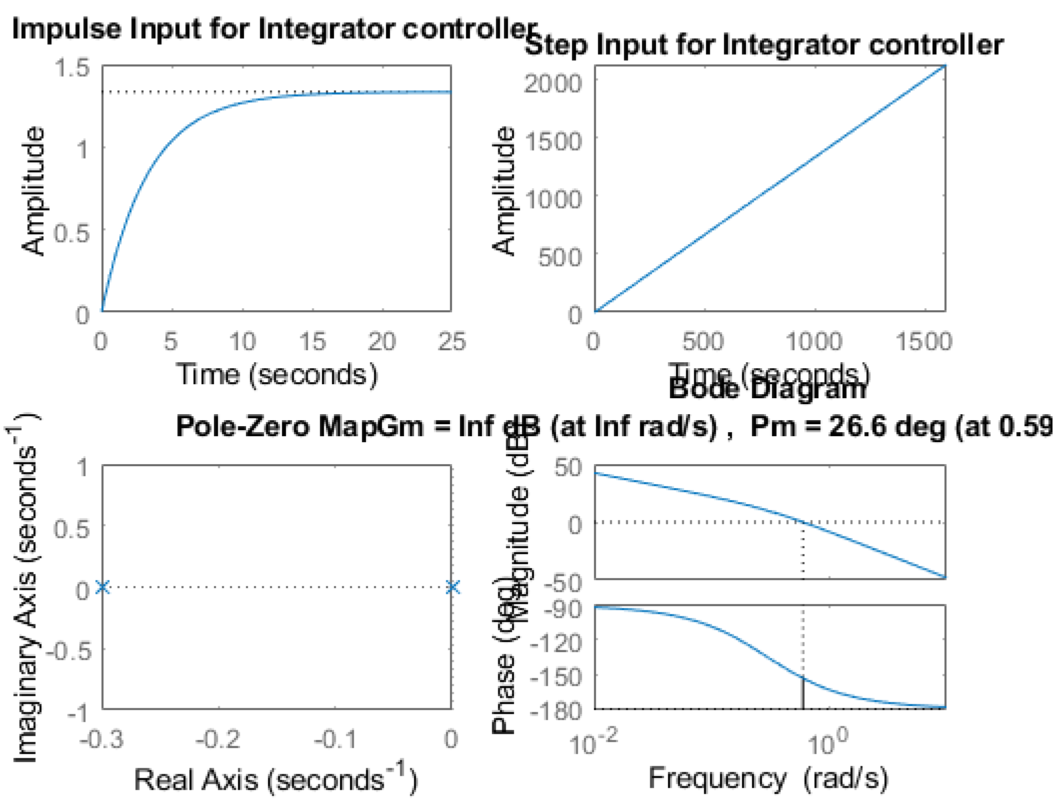
```
  struct with fields:

        RiseTime: 7.3234
    SettlingTime: 13.0402
     SettlingMin: 1.2060
     SettlingMax: 1.3333
       Overshoot: 0
      Undershoot: 0
            Peak: 1.3333
        PeakTime: 35.1528


sys =

        2
  -------------
  5 s^2 + 1.5 s

Continuous-time transfer function.


z =

  0×1 empty double column vector


p =

         0
   -0.3000


k =

    0.4000


Gm =

   Inf


Pm =

   26.6470


Wcg =

   Inf
```

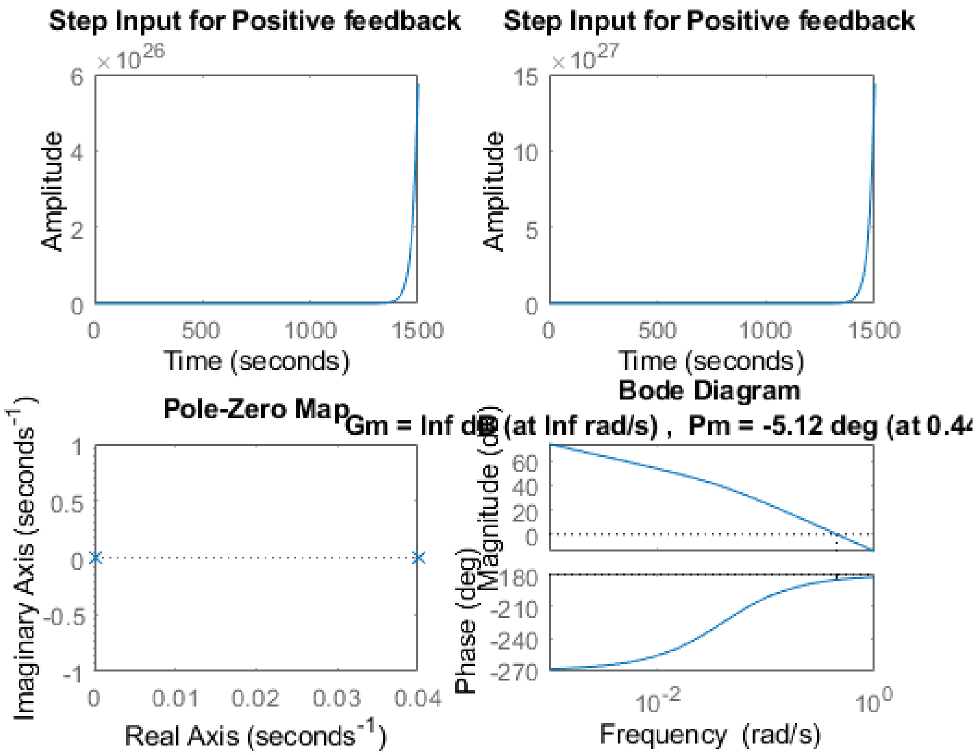
```
Wcp =

    0.5979


S =

  struct with fields:

        RiseTime: NaN
    SettlingTime: NaN
     SettlingMin: NaN
     SettlingMax: NaN
       Overshoot: NaN
      Undershoot: NaN
            Peak: Inf
        PeakTime: Inf


sys =

        1
  -------------
  5 s^2 - 0.2 s

Continuous-time transfer function.


z =

  0×1 empty double column vector


p =

         0
    0.0400


k =

    0.2000

Warning: The closed-loop system is unstable.

Gm =

   Inf
```

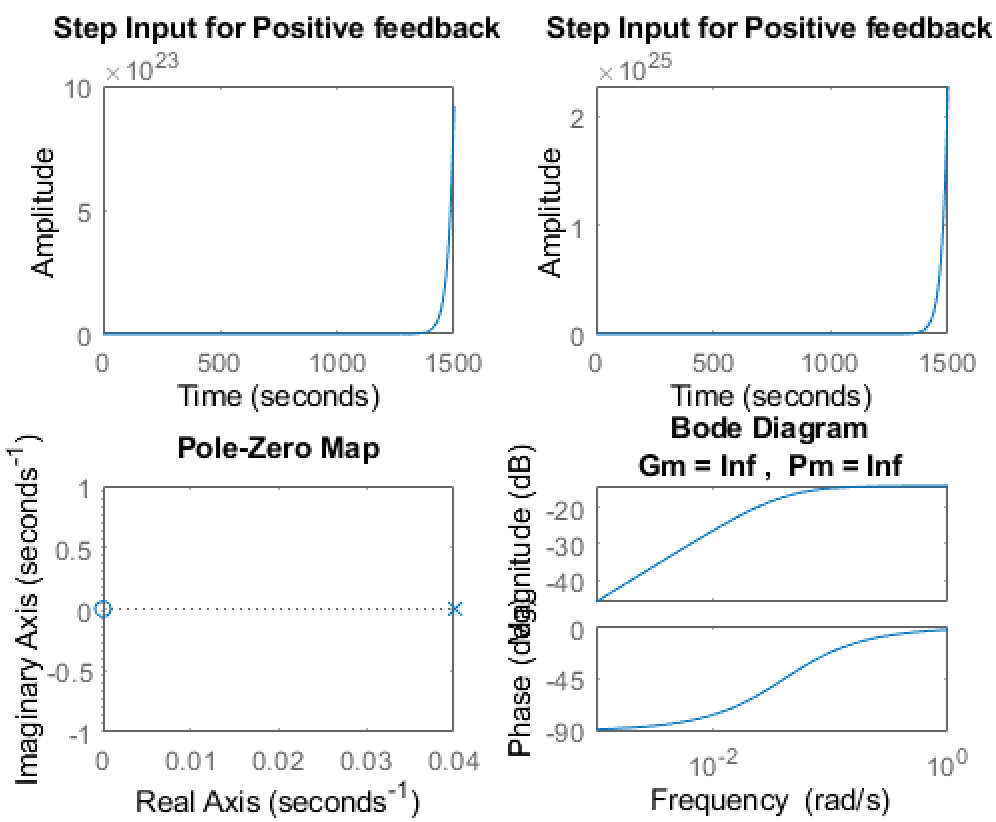
```
Pm =

  -5.1214


Wcg =

   Inf


Wcp =

    0.4463


S =

  struct with fields:

        RiseTime: NaN
    SettlingTime: NaN
     SettlingMin: NaN
     SettlingMax: NaN
       Overshoot: NaN
      Undershoot: NaN
            Peak: Inf
        PeakTime: Inf


sys =

      s
  ---------
  5 s - 0.2

Continuous-time transfer function.


z =

     0


p =

    0.0400


k =
```

```
    0.2000

Warning: The closed-loop system is unstable.

Gm =

   Inf


Pm =

   Inf


Wcg =

   NaN


Wcp =

   NaN


S =

  struct with fields:

        RiseTime: NaN
    SettlingTime: NaN
     SettlingMin: NaN
     SettlingMax: NaN
       Overshoot: NaN
      Undershoot: NaN
            Peak: Inf
        PeakTime: Inf
```


Impulse Input for k
Amplitude
Time (seconds)
Step Input for k
Amplitude
Time (seconds)
Pole-Zero Map
Imaginary Axis (seconds^-1)
Real Axis (seconds^-1)
Bode Diagram
Gm = Inf , Pm = 139 deg (at 0.265 rad/s)
Magnitude (dB)
Phase (deg)
Frequency (rad/s)


Impulse Input for Integrator controller
Amplitude
Time (seconds)
Step Input for Integrator controller
Amplitude
Time (seconds)
Pole-Zero Map
Imaginary Axis (seconds^-1)
Real Axis (seconds^-1)
Bode Diagram
Gm = Inf dB (at Inf rad/s) , Pm = 26.6 deg (at 0.59
Magnitude (dB)
Phase (deg)
Frequency (rad/s)


Step Input for Positive feedback
Step Input for Positive feedback
Amplitude
Time (seconds)
Pole-Zero Map
Imaginary Axis (seconds-1)
Real Axis (seconds-1)
Bode Diagram
Gm = Inf dB (at Inf rad/s) , Pm = -5.12 deg (at 0.4
Magnitude (dB)
Phase (deg)
Frequency (rad/s)


Step Input for Positive feedback
Step Input for Positive feedback
Amplitude
Time (seconds)
Pole-Zero Map
Imaginary Axis (seconds-1)
Real Axis (seconds-1)
Bode Diagram
Gm = Inf , Pm = Inf
Magnitude (dB)
Phase (deg)
Frequency (rad/s)

Math Analysis

Independent: Time(t) Dependent: Velocity(v) and Force(f) Constant: Mass(M) and Frictional Coefficient(B)

```
% Roots:(-B)/M

% IVT:
% 1. For step input: 0
% 2. For impulse input: 1/M

% FVT:
% 1. For step input: 1/B
% 2. For impulse input: 0

% Time Response Results:
% Rise Time :4tau = (4M)/B; where tau = M/B
```

Comparison Analysis:(Speed, Accuracy and stability):

1) When a P controller is introduced in a negative feedback system, the

```
%rise time and settling time decrease making the system more stable and
%more faster.
% 2) The P controller increases the amplitude of the entire system as well.
% 3) The gain margin is infinity and phase margin is 139 deg indicating
%that the loop never goes below 180 degree. The loop gain tf is a stable
%low pass of first order.
% 4) For positive feedback with controllers, the system becomes unstable.
```

2(a) Second Order MSD Equation

Plant Description

The Mass-damper Spring Second order system is taken as Plant. It is used in as suspension. Equation: Mx''(t)+ Bx'(t) + Kx(t)= Kf(t). f = force; B= coefficient of friction; M = mass ; v= velocity; k=spring

```
%constant.
% Values: K1= 0.9 B1= 0.4 M1=1000 Wn=0.03 ; K2= 1 B2= 0.5 M2= 500 Wn=0.44;
%K3= 3 B3= 1.7 M3= 340 Wn=0.09;
```

Code

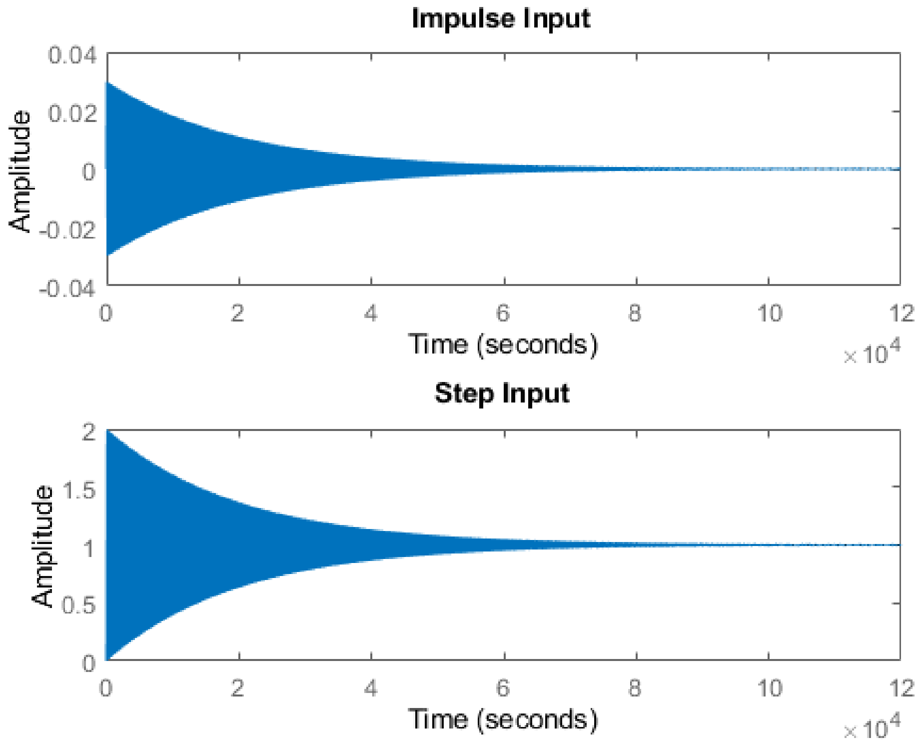
```
clc;
B1= ([0.1 0.5 1.7]);
M1=([1000 5 340]);
K1 = ([0.9 1 3]);
for i=1:3
    sys = tf([K1(i)/M1(i)],[1,B1(i)/M1(i),K1(i)/M1(i)])
```

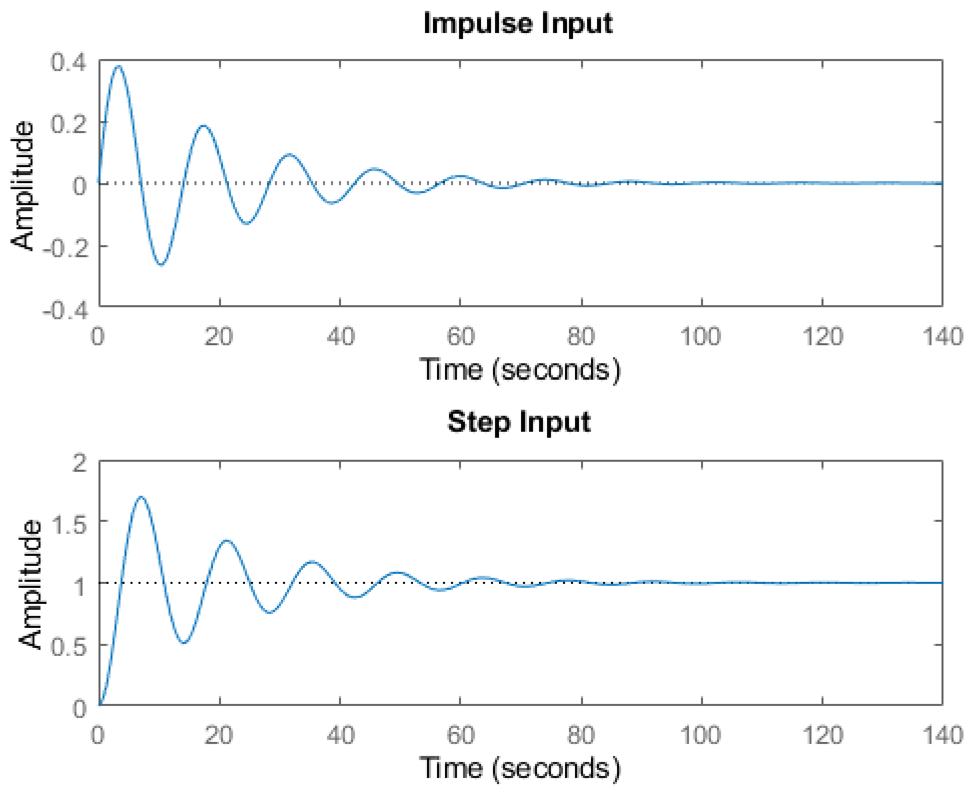
```
    figure(i);
    subplot(2,1,1);
    impulse(sys);
    title('Impulse Input');
    subplot(2,1,2);
    step(sys);
    title('Step Input');
    [z,p,k]= tf2zp([K1(i)/M1(i)],[1,B1(i)/M1(i),K1(i)/M1(i)])
    figure(4);
    zplane(z,p);
    xlim([-5*1e5 3*1e5]);
    ylim([-5*1e5 3*1e5]);
    hold on;
    S = stepinfo(sys)
end
```

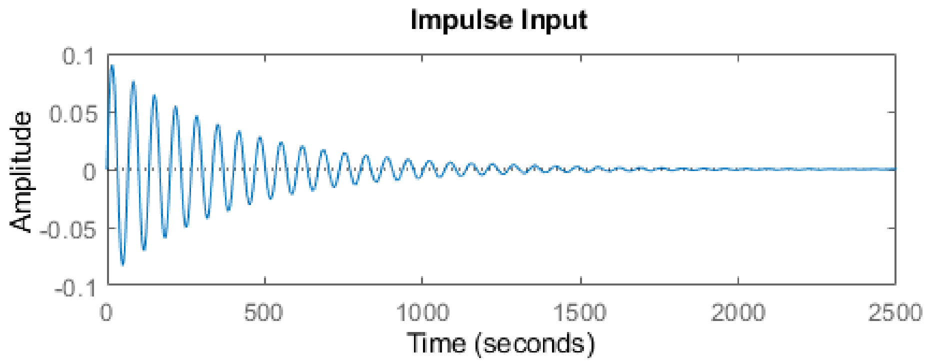
```
sys =

          0.0009
  -----------------------
  s^2 + 0.0001 s + 0.0009

Continuous-time transfer function.


z =

  0×1 empty double column vector


p =

  -0.0001 + 0.0300i
  -0.0001 - 0.0300i


k =

   9.0000e-04


S =

  struct with fields:

        RiseTime: 34.7791
    SettlingTime: 7.8226e+04
     SettlingMin: 0.0104
     SettlingMax: 1.9948
       Overshoot: 99.4778
```

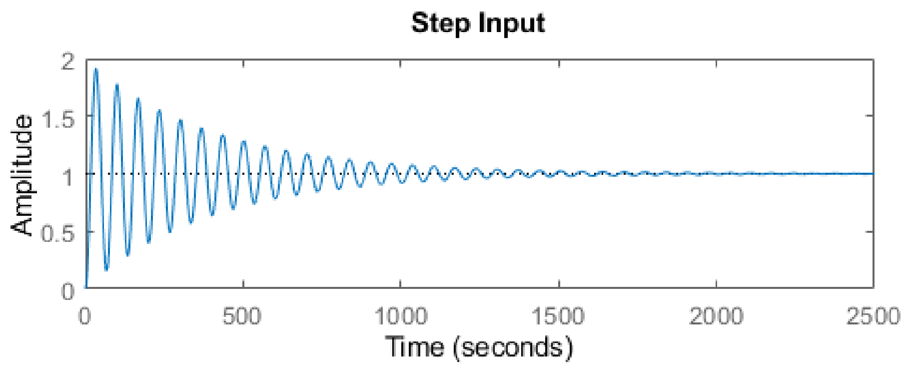
```
      Undershoot: 0
            Peak: 1.9948
        PeakTime: 104.7198


sys =

         0.2
  -----------------
  s^2 + 0.1 s + 0.2

Continuous-time transfer function.


z =

  0×1 empty double column vector


p =

  -0.0500 + 0.4444i
  -0.0500 - 0.4444i


k =

    0.2000


S =

  struct with fields:

        RiseTime: 2.5448
    SettlingTime: 78.1524
     SettlingMin: 0.5072
     SettlingMax: 1.7021
       Overshoot: 70.2118
      Undershoot: 0
            Peak: 1.7021
        PeakTime: 7.0248


sys =

          0.008824
  ------------------------
  s^2 + 0.005 s + 0.008824

Continuous-time transfer function.
```

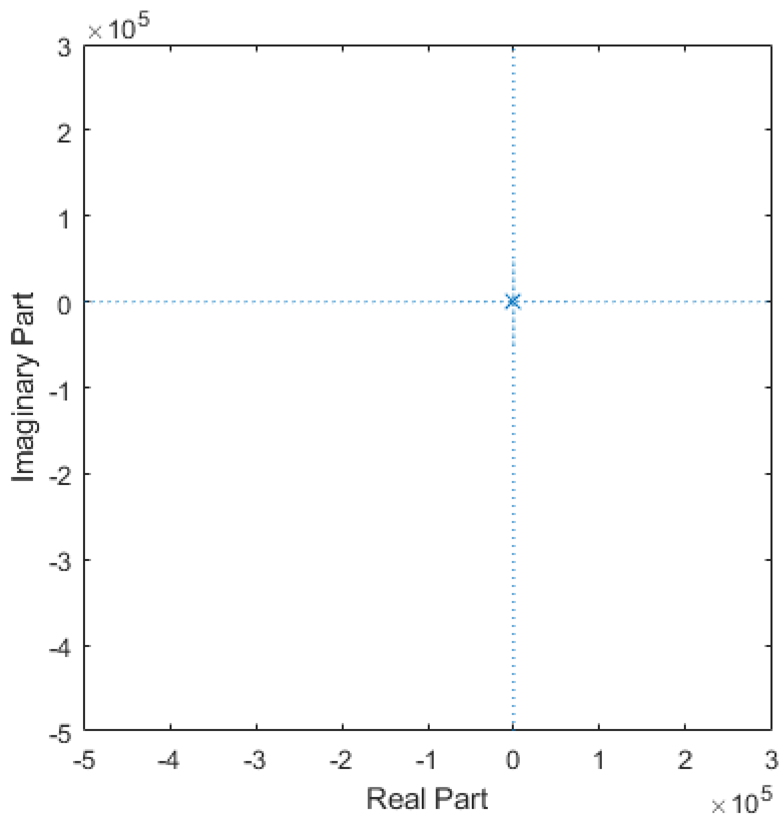
```
z =

  0×1 empty double column vector


p =

  -0.0025 + 0.0939i
  -0.0025 - 0.0939i


k =

    0.0088


S =

  struct with fields:

        RiseTime: 11.3230
    SettlingTime: 1.5426e+03
     SettlingMin: 0.1540
     SettlingMax: 1.9198
       Overshoot: 91.9760
      Undershoot: 0
            Peak: 1.9198
        PeakTime: 33.4448
```


Impulse Input
Amplitude
0.04
0.02
0
-0.02
-0.04
0
2
4
6
8
10
12
Time (seconds)
× 10^4
Step Input
Amplitude
2
1.5
1
0.5
0
0
2
4
6
8
10
12
Time (seconds)
× 10^4


Impulse Input
Amplitude
0.4
0.2
0
-0.2
-0.4
0
20
40
60
80
100
120
140
Time (seconds)
Step Input
Amplitude
2
1.5
1
0.5
0
0
20
40
60
80
100
120
140
Time (seconds)


Impulse Input
Amplitude
0.1
0.05
0
-0.05
-0.1
0
500
1000
1500
2000
2500
Time (seconds)


Step Input
Amplitude
2
1.5
1
0.5
0
0
500
1000
1500
2000
2500
Time (seconds)


× 10^5
3
2
1
0
-1
-2
-3
-4
-5
Imaginary Part
-5
-4
-3
-2
-1
0
1
2
3
Real Part
× 10^5

Math Analysis:

Independent: Time(t) Dependent: Velocity(v) and Force(f) Constant: Mass(M), Frictional Coefficient(B), Spring constant(K) Roots:((-B/M)+-sqrt(sq(B/M)-4K/M))/2

```
% IVT:
% 1. For step input: 0
% 2. For impulse input: 0

% FVT:
% 1. For step input: 1
% 2. For impulse input: K/M

% Time Response Results:
%        RiseTime: 34.7791
%    SettlingTime: 7.8226e+04
%     SettlingMin: 0.0104
%     SettlingMax: 1.9948
%       Overshoot: 99.4778
%      Undershoot: 0
%            Peak: 1.9948
%        PeakTime: 104.7198

%K2= 1 B2= 0.5 M2= 500
%        RiseTime: 2.5448
%    SettlingTime: 78.1524
%     SettlingMin: 0.5072
%     SettlingMax: 1.7021
%       Overshoot: 70.2118
%      Undershoot: 0
%            Peak: 1.7021
%        PeakTime: 7.0248

%K3= 3 B3= 1.7 M3= 340
%        RiseTime: 11.3230
%    SettlingTime: 1.5426e+03
%     SettlingMin: 0.1540
%     SettlingMax: 1.9198
%       Overshoot: 91.9760
%      Undershoot: 0
%            Peak: 1.9198
%        PeakTime: 33.4448
```

Comparison Analysis:(Speed, Accuracy and stability):

1) For sys 1 poles are on the LHS and they are complex conjugates which

```
%makes the system stable.
% 2) For sys 2 poles are on LHS and they are complex conjugates which makes
%the system stable.
% 3) For sys 3 poles are on LHS and they are complex conjugates which makes
```

```
%the system stable.
% 4) Sys 2 has the least rising time and settling time making the system
%fastest and most stable.
```

2(b) Second Order MSD Equation

Plant Description

The Mass-damper Spring Second order system is taken as Plant. It is used in as suspension.

```
% Equation: Mx''(t)+ Bx'(t) + Kx(t)= Kf(t).
% f = force; B= coefficient of friction; M = mass ; v= velocity; k=spring
%constant.
% Values: K1= 0.9 B1= 0.4 M1=1000 Wn=0.03 ; K2= 1 B2= 0.5 M2= 500 Wn=0.44;
%K3= 3 B3= 1.7 M3= 340 Wn=0.09;
```

Code

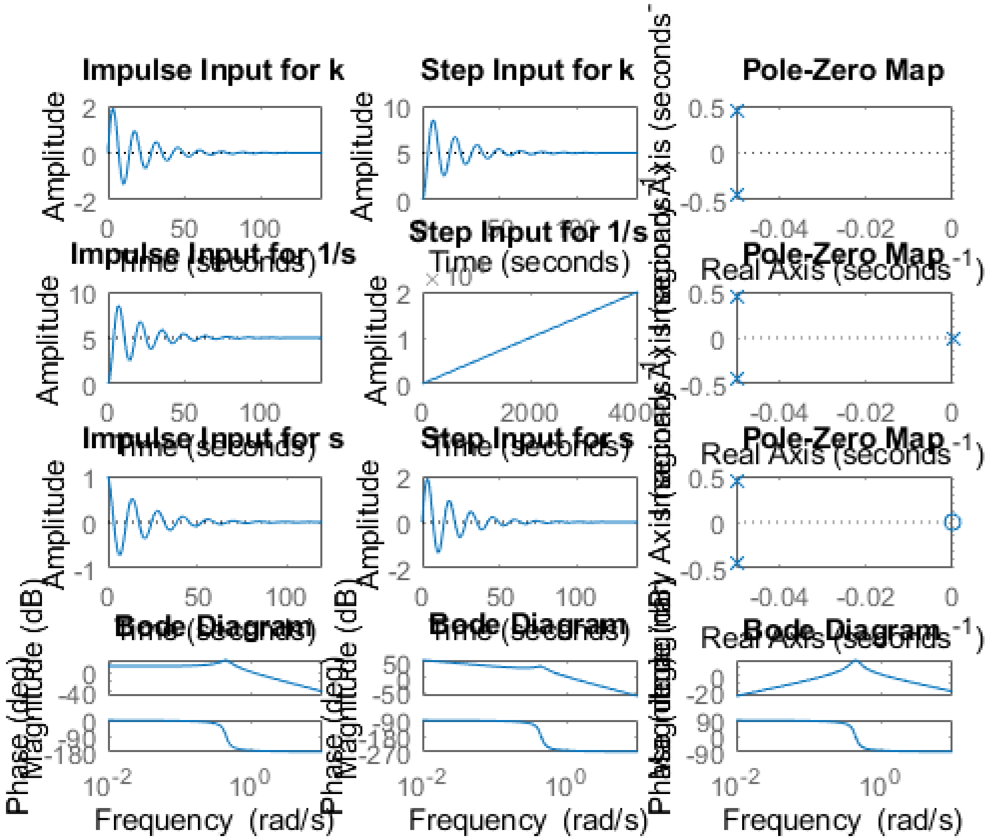
```
clc;
B1= 0.5
M1= 5;
K1 =1;
P=5;
sys = tf([P*K1/M1],[1,B1/M1,K1/M1])
subplot(4,3,1);
impulse(sys);
title('Impulse Input for k');
subplot(4,3,2);
step(sys);
title('Step Input for k');
subplot(4,3,3);
[z,p,k]= tf2zp([P*K1/M1],[1,B1/M1,K1/M1])
pzmap(sys)
subplot(4,3,10);
bode(sys)
hold on;
S = stepinfo(sys)

sys = tf([P*K1/M1],[1,B1/M1,K1/M1,0])
subplot(4,3,4);
impulse(sys);
title('Impulse Input for 1/s');
subplot(4,3,5);
step(sys);
title('Step Input for 1/s');
subplot(4,3,6);
[z,p,k]= tf2zp([P*K1/M1],[1,B1/M1,K1/M1,0])
pzmap(sys)
```

```
subplot(4,3,11);
bode(sys)
hold on;
S = stepinfo(sys)

sys = tf([P*K1/M1,0],[1,B1/M1,K1/M1])
subplot(4,3,7);
impulse(sys);
title('Impulse Input for s');
subplot(4,3,8);
step(sys);
title('Step Input for s');
subplot(4,3,9);
[z,p,k]= tf2zp([P*K1/M1,0],[1,B1/M1,K1/M1])
pzmap(sys)
subplot(4,3,12);
bode(sys)
hold on;
S = stepinfo(sys)
```

```
B1 =

    0.5000


sys =

          1
  -----------------
  s^2 + 0.1 s + 0.2

Continuous-time transfer function.


z =

  0×1 empty double column vector


p =

  -0.0500 + 0.4444i
  -0.0500 - 0.4444i


k =

     1
```

```
S =

  struct with fields:

        RiseTime: 2.5448
    SettlingTime: 78.1524
     SettlingMin: 2.5361
     SettlingMax: 8.5106
       Overshoot: 70.2118
      Undershoot: 0
            Peak: 8.5106
        PeakTime: 7.0248


sys =

            1
  ---------------------
  s^3 + 0.1 s^2 + 0.2 s

Continuous-time transfer function.


z =

  0×1 empty double column vector


p =

   0.0000 + 0.0000i
  -0.0500 + 0.4444i
  -0.0500 - 0.4444i


k =

     1


S =

  struct with fields:

        RiseTime: NaN
    SettlingTime: NaN
     SettlingMin: NaN
     SettlingMax: NaN
       Overshoot: NaN
      Undershoot: NaN
            Peak: Inf
```

```
        PeakTime: Inf


sys =

          s
  -----------------
  s^2 + 0.1 s + 0.2

Continuous-time transfer function.


z =

     0


p =

  -0.0500 + 0.4444i
  -0.0500 - 0.4444i


k =

     1


S =

  struct with fields:

        RiseTime: 0
    SettlingTime: 81.5509
     SettlingMin: -1.3280
     SettlingMax: 1.8877
       Overshoot: Inf
      Undershoot: Inf
            Peak: 1.8877
        PeakTime: 3.5124
```



Math Analysis:

Independent: Time(t) Dependent: Velocity(v) and Force(f) Constant: Mass(M), Frictional Coefficient(B), Spring constant(K)

```
% Roots:((-B/M)+-sqrt(sq(B/M)-4K/M))/2

% IVT:
% 1. For step input: 0
% 2. For impulse input: 0

% FVT:
% 1. For step input: 1
% 2. For impulse input: K/M

% Time Response Results:
% K1= 0.9 B1= 0.4 M1=1000
%        RiseTime: 2.5448
%    SettlingTime: 78.1524
%     SettlingMin: 2.5361
%     SettlingMax: 8.5106
%       Overshoot: 70.2118
%      Undershoot: 0
%            Peak: 8.5106
```

```
%        PeakTime: 7.0248


%K2= 1 B2= 0.5 M2= 500
%        RiseTime: NaN
%    SettlingTime: NaN
%     SettlingMin: NaN
%     SettlingMax: NaN
%       Overshoot: NaN
%      Undershoot: NaN
%            Peak: Inf
%        PeakTime: Inf

%K3= 3 B3= 1.7 M3= 340
%        RiseTime: 0
%    SettlingTime: 81.5509
%     SettlingMin: -1.3280
%     SettlingMax: 1.8877
%       Overshoot: Inf
%      Undershoot: Inf
%            Peak: 1.8877
%        PeakTime: 3.5124
```

Comparison Analysis:(Speed, Accuracy and stability):

1) with proportionality controller, only the amplitude changes and all

```
%other stats are same as in 2nd order system without controller.
% 2) On adding an integrator controller, a pole is getting added at the
%origin and makes the system marginally stable.
% 3) On adding a differentiator controller, a zero is added to the origin
%making an unstable system stable.
% 4) On adding a differentiator controller, the overshoot increases and
%also the response time increase.
```

2(c) Second Order MSD Equation

Plant Description

The Mass-damper Spring Second order system is taken as Plant. It is used in as suspension.

```
% Equation: Mx''(t)+ Bx'(t) + Kx(t)= Kf(t).
% f = force; B= coefficient of friction; M = mass ; v= velocity; k=spring
%constant.
% Values: K1= 0.9 B1= 0.4 M1=1000 Wn=0.03 ; K2= 1 B2= 0.5 M2= 500 Wn=0.44;
%K3= 3 B3= 1.7 M3= 340 Wn=0.09; B4= 9 M4= 5 K4=1;
```

Code

```
%For negative feedback
clc;
B1= 0.5
M1= 5;
K1 =1;
P=5;

sys = tf([P*K1],[M1,B1,2*K1])
subplot(4,4,1);
impulse(sys);
title('Impulse Input for k');
subplot(4,4,2);
step(sys);
title('Step Input for k');
subplot(4,4,3);
[z,p,k]= tf2zp([P*K1],[M1,B1,2*K1])
pzmap(sys)
subplot(4,4,4)
bode(sys)
margin(sys)
[Gm,Pm,Wcg,Wcp] = margin(sys)
hold on;
S = stepinfo(sys)

B2= -9
M2= 5;
K2=1;
P2=5;

sys = tf([P2*K2],[M2,B2,2*K2])
subplot(4,4,5);
impulse(sys);
title('Impulse Input for k- Unstable');
subplot(4,4,6);
step(sys);
title('Step Input for k- Unstable');
subplot(4,4,7);
[z,p,k]= tf2zp([P2*K2],[M2,B2,2*K2])
pzmap(sys)
subplot(4,4,8)
bode(sys)
margin(sys)
[Gm,Pm,Wcg,Wcp] = margin(sys)
hold on;
S = stepinfo(sys)

% For Positive feedback using I & D
```

```
B3= 9
M3= 5;
K3=1;
sys = tf([K3],[M3,B3,0,0])
subplot(4,4,9);
impulse(sys);
title('Impulse Input for Positive feedback 1/s ');
subplot(4,4,10);
step(sys);
title('Step Input for Positive feedback 1/s');
subplot(4,4,11);
[z,p,k]= tf2zp([K3],[M3,B3,0,0])
pzmap(sys)
subplot(4,4,12)
bode(sys)
margin(sys)
[Gm,Pm,Wcg,Wcp] = margin(sys)
hold on;
S = stepinfo(sys)


B4= 9
M4= 5;
K4=1;
sys = tf([K4,0],[M4,B4,0])
subplot(4,4,13);
impulse(sys);
title('Impulse Input for Positive feedback s ');
subplot(4,4,14);
step(sys);
title('Step Input for Positive feedback s');
subplot(4,4,15);
[z,p,k]= tf2zp([K4,0],[M4,B4,0])
pzmap(sys)
subplot(4,4,16)
bode(sys)
margin(sys)
[Gm,Pm,Wcg,Wcp] = margin(sys)
hold on;
S = stepinfo(sys)
```

```
B1 =

    0.5000


sys =

          5
  -----------------
```

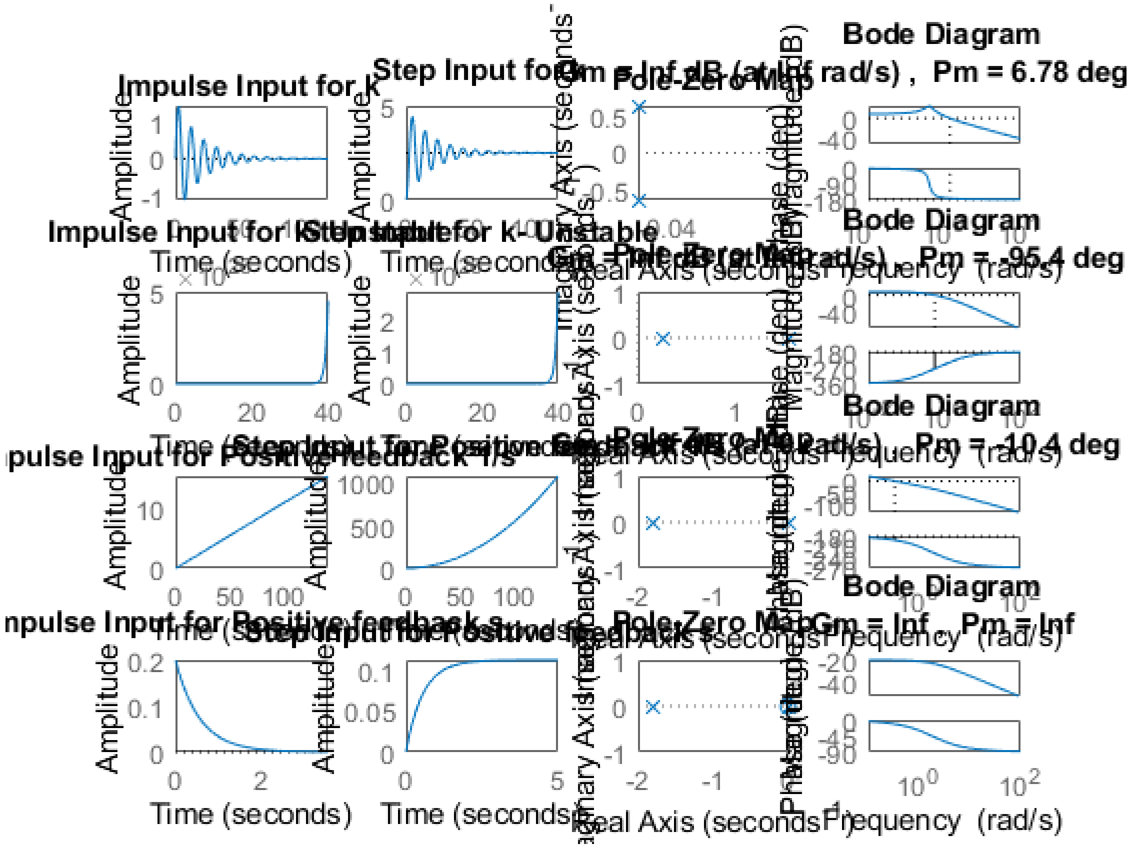
```
  5 s^2 + 0.5 s + 2

Continuous-time transfer function.


z =

  0×1 empty double column vector


p =

  -0.0500 + 0.6305i
  -0.0500 - 0.6305i


k =

     1


Gm =

   Inf


Pm =

    6.7782


Wcg =

   Inf


Wcp =

    1.1803


S =

  struct with fields:

        RiseTime: 1.7526
    SettlingTime: 75.6433
     SettlingMin: 0.9814
     SettlingMax: 4.4486
       Overshoot: 77.9429
      Undershoot: 0
```

```
          Peak: 4.4486
      PeakTime: 4.9673


B2 =

    -9


sys =

         5
  ---------------
  5 s^2 - 9 s + 2

Continuous-time transfer function.


z =

  0×1 empty double column vector


p =

    1.5403
    0.2597


k =

     1

Warning: The closed-loop system is unstable.

Gm =

   Inf


Pm =

  -95.4008


Wcg =

   Inf


Wcp =
```

```
    0.5531


S =

  struct with fields:

        RiseTime: NaN
    SettlingTime: NaN
     SettlingMin: NaN
     SettlingMax: NaN
       Overshoot: NaN
      Undershoot: NaN
            Peak: Inf
        PeakTime: Inf


B3 =

     9


sys =

        1
  -------------
  5 s^3 + 9 s^2

Continuous-time transfer function.


z =

  0×1 empty double column vector


p =

         0
         0
   -1.8000


k =

    0.2000

Warning: The closed-loop system is unstable.

Gm =
```

```
     0


Pm =

  -10.4065


Wcg =

     0


Wcp =

    0.3306


S =

  struct with fields:

        RiseTime: NaN
    SettlingTime: NaN
     SettlingMin: NaN
     SettlingMax: NaN
       Overshoot: NaN
      Undershoot: NaN
            Peak: Inf
        PeakTime: Inf


B4 =

     9


sys =

       s
  -----------
  5 s^2 + 9 s

Continuous-time transfer function.


z =

     0
```

```
p =

         0
   -1.8000


k =

    0.2000

Warning: The closed-loop system is unstable.

Gm =

   Inf


Pm =

   Inf


Wcg =

   NaN


Wcp =

   NaN


S =

  struct with fields:

        RiseTime: 1.2206
    SettlingTime: 2.1734
     SettlingMin: 0.1005
     SettlingMax: 0.1111
       Overshoot: 0
      Undershoot: 0
            Peak: 0.1111
        PeakTime: 5.8588
```



Math Analysis:

Independent: Time(t) Dependent: Velocity(v) and Force(f) Constant: Mass(M), Frictional Coefficient(B), Spring constant(K)

```
% Roots:((-B/M)+-sqrt(sq(B/M)-4K/M))/2

% IVT:
% 1. For step input: 0
% 2. For impulse input: 0

% FVT:
% 1. For step input: 1
% 2. For impulse input: K/M

% Time Response Results:
% K1= 0.9 B1= 0.4 M1=1000
%        RiseTime: 1.7526
%    SettlingTime: 75.6433
%     SettlingMin: 0.9814
%     SettlingMax: 4.4486
%       Overshoot: 77.9429
%      Undershoot: 0
%            Peak: 4.4486
```

```
%        PeakTime: 4.9673

%K2= 1 B2= 0.5 M2= 500
%        RiseTime: NaN
%    SettlingTime: NaN
%     SettlingMin: NaN
%     SettlingMax: NaN
%       Overshoot: NaN
%      Undershoot: NaN
%            Peak: Inf
%        PeakTime: Inf

%K3= 3 B3= 1.7 M3= 340
%        RiseTime: NaN
%    SettlingTime: NaN
%     SettlingMin: NaN
%     SettlingMax: NaN
%       Overshoot: NaN
%      Undershoot: NaN
%            Peak: Inf
%        PeakTime: Inf

%K4= 1 B4= 9 M4= 5;
%        RiseTime: 1.2206
%    SettlingTime: 2.1734
%     SettlingMin: 0.1005
%     SettlingMax: 0.1111
%       Overshoot: 0
%      Undershoot: 0
%            Peak: 0.1111
%        PeakTime: 5.8588
```

Comparison Analysis:(Speed, Accuracy and stability):

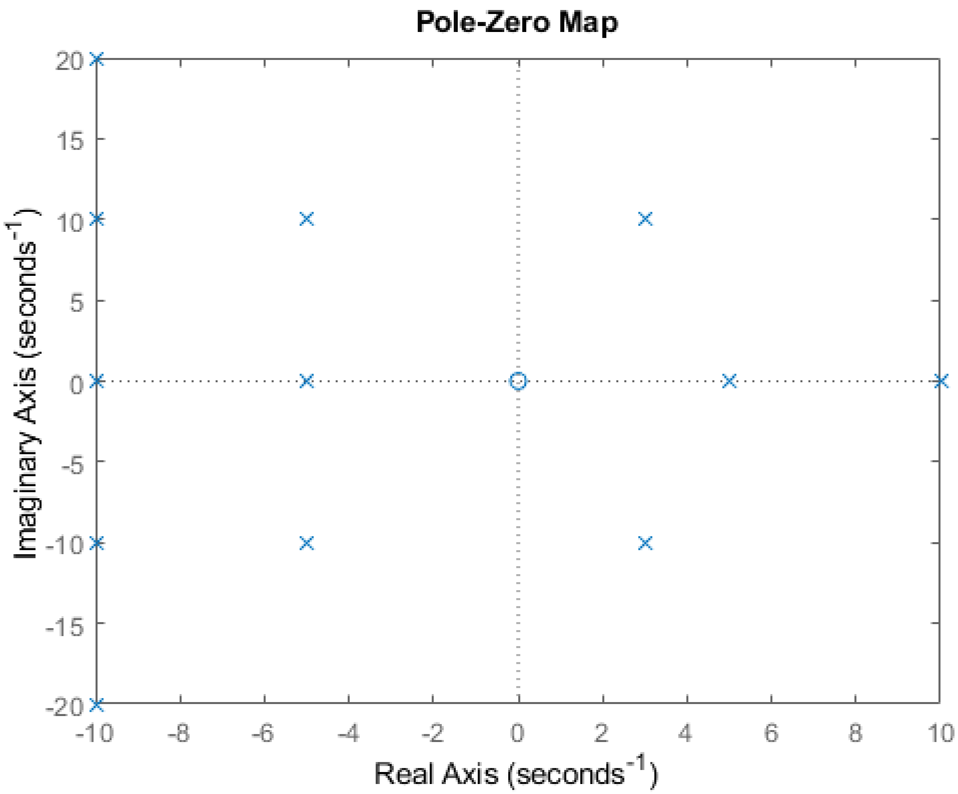
```
%-ve feedback
% 1) On adding a -ve feedback, the stability of the system reaches at a
%faster speed.
% 2) The gain margin is infinity and the phase margin is +ve value making
%the system stable.
% 3) When the gain margin is infinity and the phase margin is -ve value the
%system becomes unstable.
%+ve feedback
% 1)  When the gain margin is 0 and the phase margin is -ve value the
%system becomes unstable.
% 2) When both gain margin and phase margin are infinity, the errors get
%accumulated and makes the system unstable.
```

2(d) Movement of Poles.

Description: Movement of poles is shown along the real and imaginary axis

```
clc;
poles = [-10+20i -10-20i -5+10i -5-10i -10+10i -10-10i  3+10i 3-10i -5+0i +5+0i -10+0i +10-0i ];
zeros = [0 0];
gain = 0.9;
s=zpk(zeros,poles,gain);
pzplot(s)
[wn,zeta] = damp(s)
```

```
wn =

    5.0000
    5.0000
   10.0000
   10.0000
   10.4403
   10.4403
   11.1803
   11.1803
   14.1421
   14.1421
   22.3607
   22.3607


zeta =

    1.0000
   -1.0000
    1.0000
   -1.0000
   -0.2873
   -0.2873
    0.4472
    0.4472
    0.7071
    0.7071
    0.4472
    0.4472
```



Analysis

If we move along the roots along the wn, the frequency of the system increases. Overshoot remains same. If we move along the jw axis, overshoot of system increases. frequency of system increases. If we move along zeta wn axis or sigma, Overshoot increases, frequency decreases on right side movement. Overshoot decreases, frequency increases on left side movement.

2(e) Roots of the Standard Equation

Code

```
clc;
zeta=1;
TF=tf([1],[1,(2*zeta),1])
sys = tf([1],[1,(2*zeta),1])
figure
subplot(2,3,1)
S = stepinfo(sys)
[z,p,k]= tf2zp([1],[1,(2*zeta),1])
zplane(z,p)

zeta=0.7 ;
```

```
TF=tf([1],[1,(2*zeta),1])
sys = tf([1],[1,(2*zeta),1])
subplot(2,3,2)
S = stepinfo(sys)
[z,p,k]= tf2zp([1],[1,(2*zeta),1])
zplane(z,p)

zeta=2;
TF=tf([1],[1,(2*zeta),1])
sys = tf([1],[1,(2*zeta),1])
subplot(2,3,3)
S = stepinfo(sys)
[z,p,k]= tf2zp([1],[1,(2*zeta),1])
zplane(z,p)

zeta=-1.85;
TF=tf([1],[1,(2*zeta),1])
sys = tf([1],[1,(2*zeta),1])
subplot(2,3,4)
S = stepinfo(sys)
[z,p,k]= tf2zp([1],[1,(2*zeta),1])
zplane(z,p)

zeta=-0.4;
TF=tf([1],[1,(2*zeta),1])
sys = tf([1],[1,(2*zeta),1])
subplot(2,3,5)
S = stepinfo(sys)
[z,p,k]= tf2zp([1],[1,(2*zeta),1])
zplane(z,p)

zeta=-2.45;
TF=tf([1],[1,(2*zeta),1])
sys = tf([1],[1,(2*zeta),1])
subplot(2,3,6)
S = stepinfo(sys)
[z,p,k]= tf2zp([1],[1,(2*zeta),1])
zplane(z,p)
```

```
TF =

        1
  -------------
  s^2 + 2 s + 1

Continuous-time transfer function.


sys =
```

```
        1
  -------------
  s^2 + 2 s + 1

Continuous-time transfer function.


S = 

  struct with fields:

        RiseTime: 3.3579
    SettlingTime: 5.8339
     SettlingMin: 0.9000
     SettlingMax: 0.9994
       Overshoot: 0
      Undershoot: 0
            Peak: 0.9994
        PeakTime: 9.7900


z =

  0×1 empty double column vector


p =

    -1
    -1


k =

     1


TF =

         1
  ---------------
  s^2 + 1.4 s + 1

Continuous-time transfer function.


sys =

         1
  ---------------
  s^2 + 1.4 s + 1
```

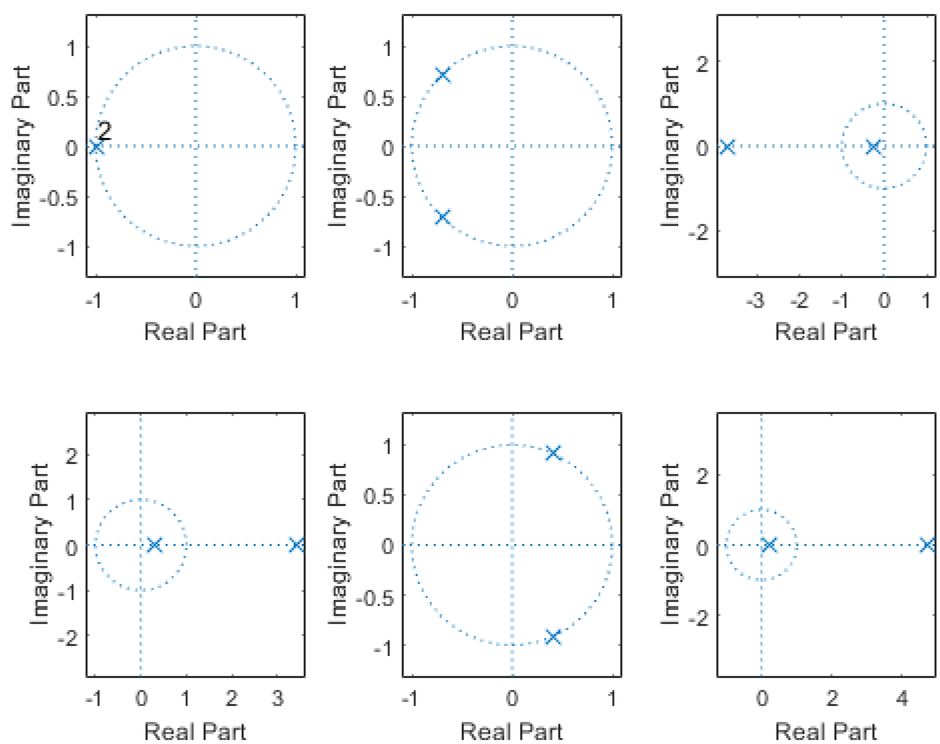
```
Continuous-time transfer function.


S =

  struct with fields:

        RiseTime: 2.1268
    SettlingTime: 5.9789
     SettlingMin: 0.9001
     SettlingMax: 1.0460
       Overshoot: 4.5986
      Undershoot: 0
            Peak: 1.0460
        PeakTime: 4.4078


z =

  0×1 empty double column vector


p =

  -0.7000 + 0.7141i
  -0.7000 - 0.7141i


k =

     1


TF =

        1
  -------------
  s^2 + 4 s + 1

Continuous-time transfer function.


sys =

        1
  -------------
  s^2 + 4 s + 1

Continuous-time transfer function.
```

```
S =

  struct with fields:

        RiseTime: 8.2308
    SettlingTime: 14.8789
     SettlingMin: 0.9017
     SettlingMax: 0.9993
       Overshoot: 0
      Undershoot: 0
            Peak: 0.9993
        PeakTime: 27.3269


z =

  0×1 empty double column vector


p =

   -3.7321
   -0.2679


k =

     1


TF =

         1
  ---------------
  s^2 - 3.7 s + 1

Continuous-time transfer function.


sys =

         1
  ---------------
  s^2 - 3.7 s + 1

Continuous-time transfer function.


S =
```

```
  struct with fields:

        RiseTime: NaN
    SettlingTime: NaN
     SettlingMin: NaN
     SettlingMax: NaN
       Overshoot: NaN
      Undershoot: NaN
            Peak: Inf
        PeakTime: Inf


z =

  0×1 empty double column vector


p =

    3.4064
    0.2936


k =

     1


TF =

         1
  ---------------
  s^2 - 0.8 s + 1

Continuous-time transfer function.


sys =

         1
  ---------------
  s^2 - 0.8 s + 1

Continuous-time transfer function.


S =

  struct with fields:

        RiseTime: NaN
```

```
    SettlingTime: NaN
     SettlingMin: NaN
     SettlingMax: NaN
       Overshoot: NaN
      Undershoot: NaN
            Peak: Inf
        PeakTime: Inf


z =

  0×1 empty double column vector


p =

   0.4000 + 0.9165i
   0.4000 - 0.9165i


k =

     1


TF =

         1
  ---------------
  s^2 - 4.9 s + 1

Continuous-time transfer function.


sys =

         1
  ---------------
  s^2 - 4.9 s + 1

Continuous-time transfer function.


S =

  struct with fields:

        RiseTime: NaN
    SettlingTime: NaN
     SettlingMin: NaN
     SettlingMax: NaN
```

```
       Overshoot: NaN
      Undershoot: NaN
            Peak: Inf
        PeakTime: Inf


z =

  0×1 empty double column vector


p =

    4.6866
    0.2134


k =

     1
```



Comparison Analysis:

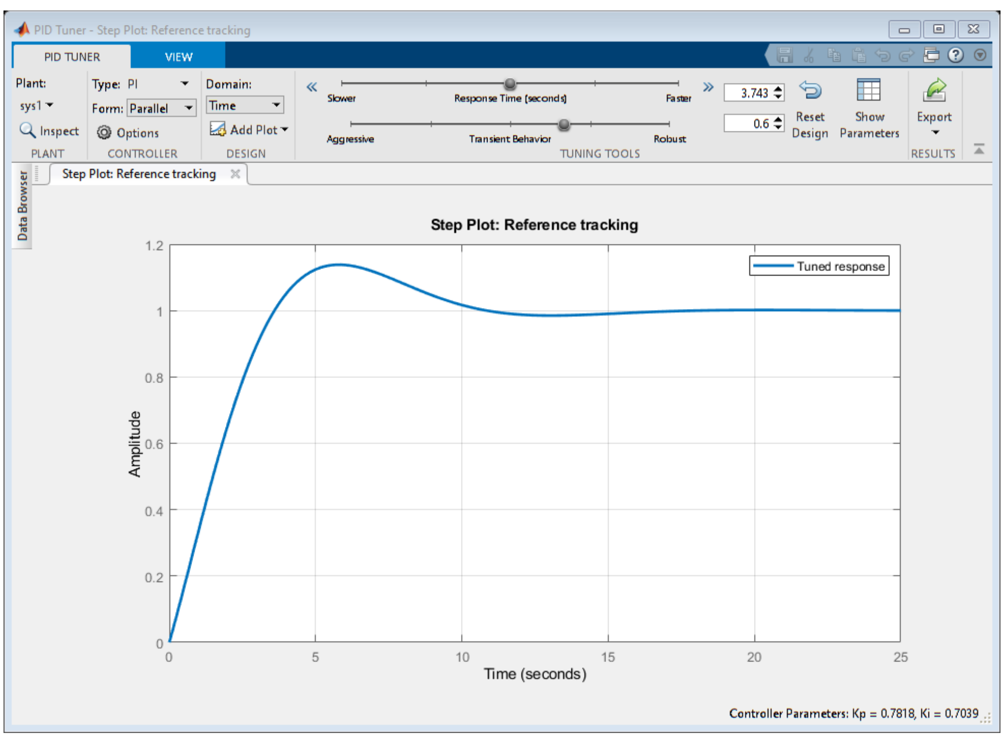
1st value lise on negative x axis means: Critically-damped case & stable 2nd value lise in 2nd & 3rd quadrant means: Under-damp case & stable 3rd value lise on negative x axis means: Overdamped case & stable 4th value lise on positive x axis means: unstable 5th value lise on 1st & 4th quadrant means: unstable 6th value lise on positive x axis means: unstable

2(f) PID Analysis

First Order System PID Analysis

```
clc;
B1= 0.5;
M1= 5;
P1 = 2;
sys1 = tf([P1],[M1,B1+1])
pidTuner(sys1)
```

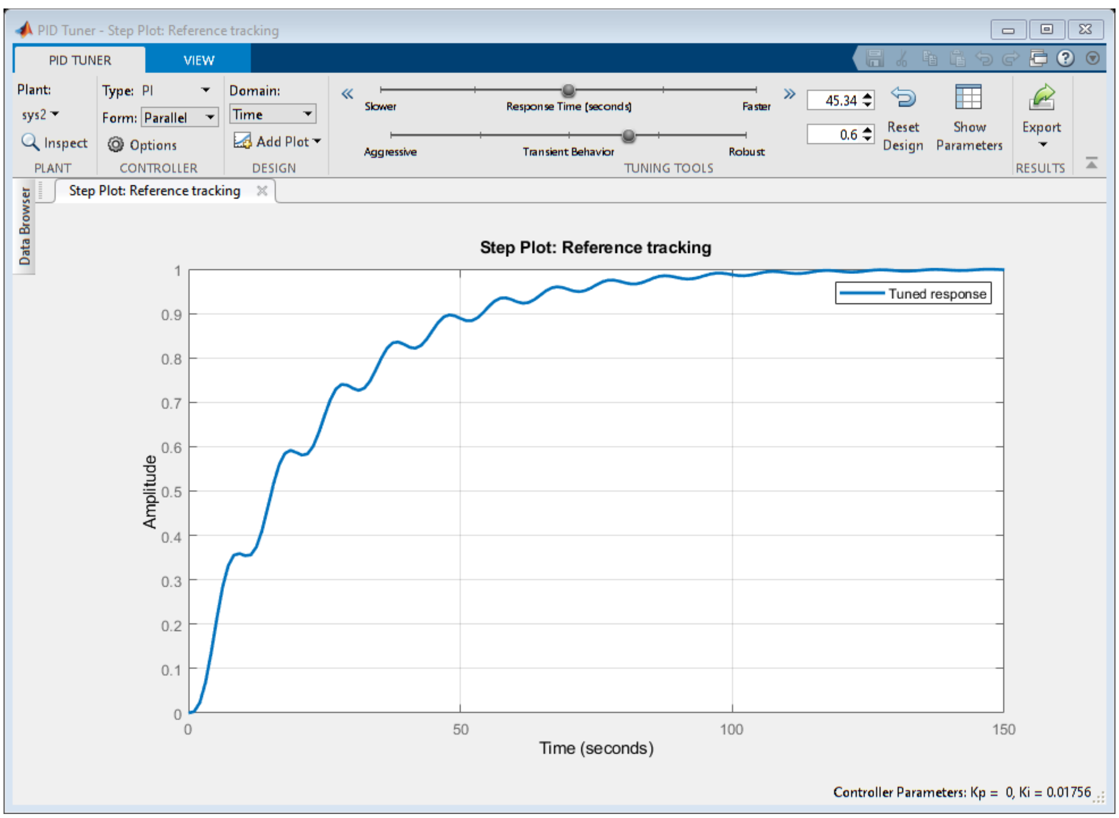
```
sys1 =

      2
  ---------
  5 s + 1.5

Continuous-time transfer function.
```



Second Order System PID Analysis

```
B2= 0.5
M2= 5;
K2 =1;
P2=5;
sys2 = tf([P2*K2],[M2,B2,2*K2])
pidTuner(sys2)
```

```
B2 =

    0.5000


sys2 =

          5
  -----------------
  5 s^2 + 0.5 s + 2

Continuous-time transfer function.
```



Comparison Analysis:

First Order sys: PI: Ideal system: Kp= 0.78 (Un-Tuned) Ki= 0.7 Tr= 2.7 Ts= 9.87 Overshoot= 13.8%

```
        Best system:  Kp= 1.25
    (After Tuning) Ki= 0.46
                   Tr= 3.59
                   Ts= 5.39
                   Overshoot= 1.33%
   PD: Ideal system: Kp= 53.18
     (Un-Tuned)    Kd= 0
                   Tr= 0.102
                   Ts= 0.181
                   Overshoot= 0
        Best system:  Kp= 53.18
    (After Tuning) Kd= 0
                   Tr= 0.102
                   Ts= 0.181
                   Overshoot= 0
   PID: Ideal system: Kp= 1.07
      (Un-Tuned)    Ki= 0.53
                   Kd= 0
                   Tr= 3.04
                   Ts= 10.6
                   Overshoot= 6.08%
        Best system:  Kp= 1.07
    (After Tuning) Ki= 0.53
                   Kd= 0
                   Tr= 3.04
                   Ts= 10.6
                   Overshoot= 6.08%
```

```
% Second Order sys:
%   PI: Ideal system: Tr= 51.1
%        (Un-Tuned)    Ts= 94.3
%                      Overshoot= 0%
%
%       Best system:  Tr= 50.4
%      (After Tuning) Ts= 93.4
%                      Overshoot= 0.00235%
%
%   PD: Ideal system: Kp= 2697.9
%        (Un-Tuned)    Kd= 63.48
%                      Tr= 0.0179
%                      Ts= 0.13
%                      Overshoot= 24.3%
%
%       Best system:  Kp= 27.35
%      (After Tuning) Kd= 6.251
%                      Tr= 0.175
%                      Ts= 1.35
%                      Overshoot= 24.71%
%
%  PID: Ideal system: Kp= 3.053
%        (Un-Tuned)    Ki= 0.68
%                      Kd= 2.66
```

```
%                      Tr= 0.495
%                      Ts= 9.3
%                      Overshoot= 12.4%
%
%        Best system:  Kp= 3.053
%       (After Tuning) Ki= 0.68
%                      Kd= 2.66
%                      Tr= 0.495
%                      Ts= 9.3
%                      Overshoot= 12.4%
```

3(a) Second Order Exponential Decay system

Plant Description

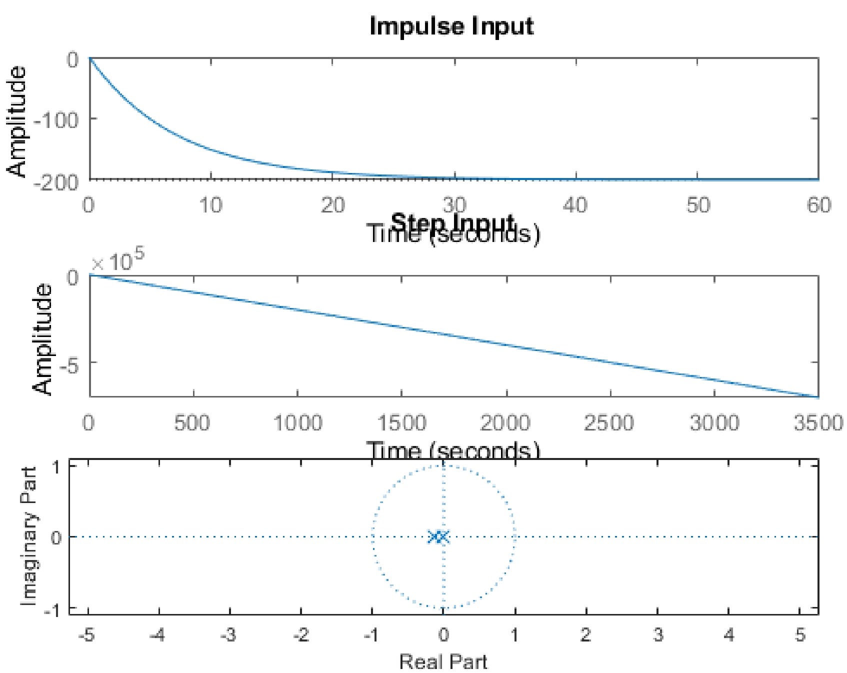
It is a exponential decay system of a radioactive material Equation- dM/dt=-kA(e^-kt) M=mass, k=constant, A= non zero constant, t=time Values- k=0.14, A=200

Without Controller

```
clc;
k= 0.14;
A= 200;
sys = tf([-k*A],[1,k,0])
figure(1);
subplot(3,1,1);
impulse(sys);
title('Impulse Input');
subplot(3,1,2);
step(sys);
title('Step Input');
[z,p,k] = tf2zp([-k*A],[1,k,0])
subplot(3,1,3);
zplane(z,p);
S = stepinfo(sys)
```

```
sys =

      -28
  ------------
  s^2 + 0.14 s

Continuous-time transfer function.


z =
```

```
  0×1 empty double column vector


p =

         0
   -0.1400


k =

  -28.0000


S =

  struct with fields:

        RiseTime: NaN
    SettlingTime: NaN
     SettlingMin: NaN
     SettlingMax: NaN
       Overshoot: NaN
      Undershoot: NaN
            Peak: Inf
        PeakTime: Inf
```

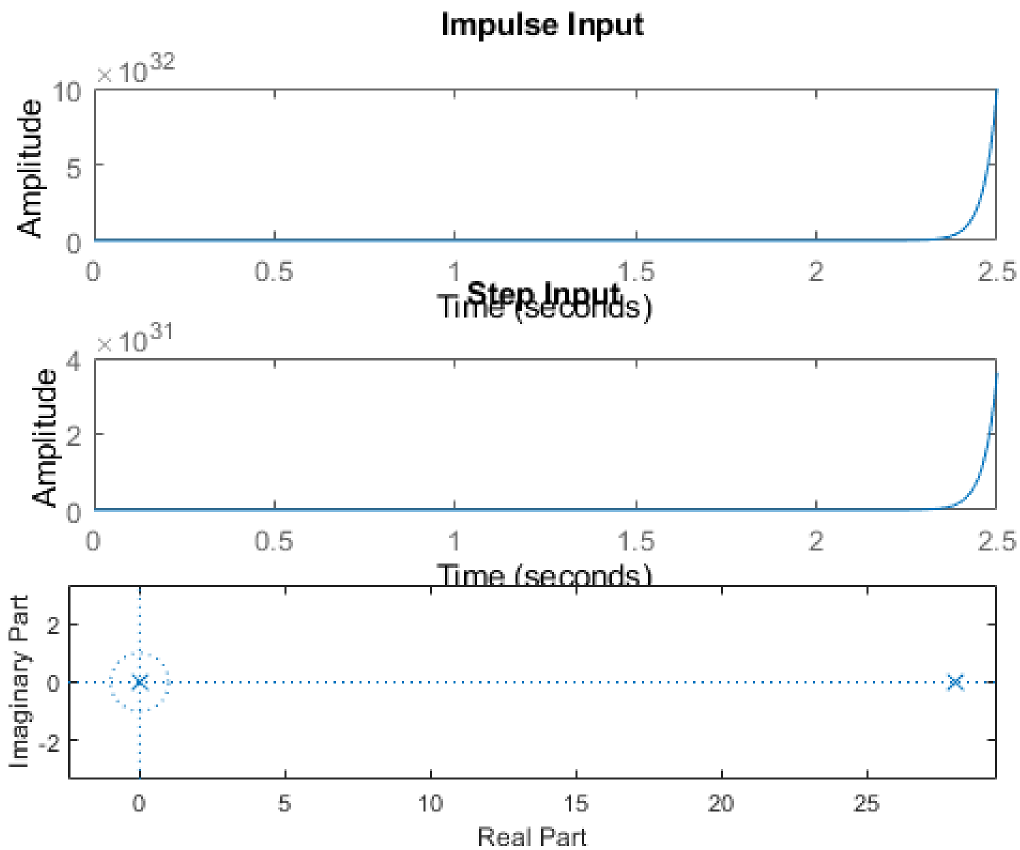


Open Loop with Controller (P)

```
P= 2;
sys = tf([P*(-k)*A],[1,k,0])
figure(2);
subplot(3,1,1);
impulse(sys);
title('Impulse Input');
subplot(3,1,2);
step(sys);
title('Step Input');
[z,p,k] = tf2zp([P*(-k)*A],[1,k,0])
subplot(3,1,3);
zplane(z,p);
S = stepinfo(sys)
```

```
sys =

   1.12e04
  ----------
  s^2 - 28 s

Continuous-time transfer function.


z =

  0×1 empty double column vector


p =

         0
   28.0000


k =

   1.1200e+04


S =

  struct with fields:

        RiseTime: NaN
    SettlingTime: NaN
     SettlingMin: NaN
     SettlingMax: NaN
```

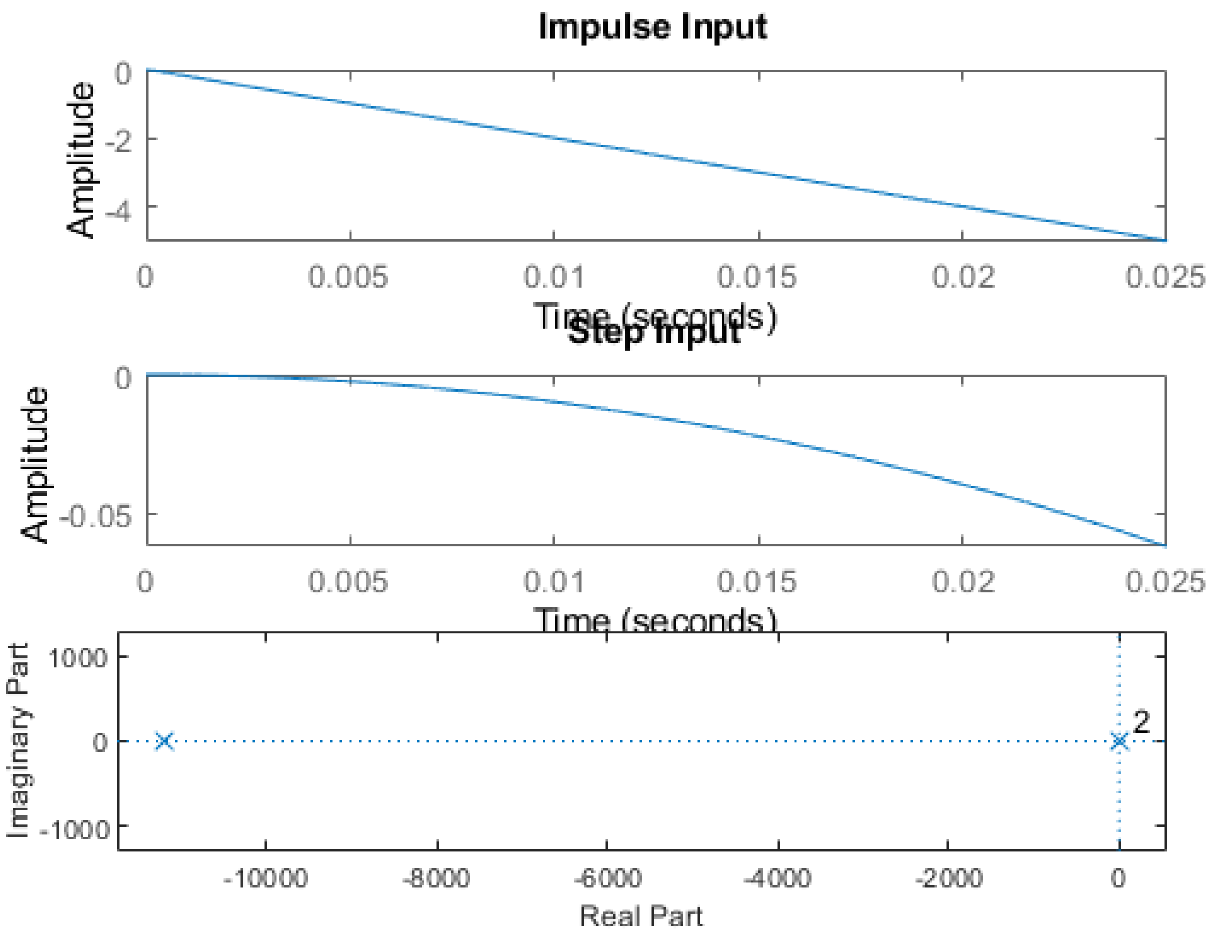
```
    Overshoot: NaN
   Undershoot: NaN
         Peak: Inf
     PeakTime: Inf
```



Open Loop with Controller (I)

```
sys = tf([(-k)*A],[1,k,0,0])
figure(3);
subplot(3,1,1);
impulse(sys);
title('Impulse Input');
subplot(3,1,2);
step(sys);
title('Step Input');
[z,p,k] = tf2zp([-k*A],[1,k,0,0])
subplot(3,1,3);
zplane(z,p);
S = stepinfo(sys)
```

```
sys =

      -2.24e06
  -----------------
  s^3 + 1.12e04 s^2

Continuous-time transfer function.


z =

  0×1 empty double column vector


p =

   1.0e+04 *

         0
         0
   -1.1200


k =

  -2.2400e+06


S =

  struct with fields:

        RiseTime: NaN
    SettlingTime: NaN
     SettlingMin: NaN
     SettlingMax: NaN
       Overshoot: NaN
      Undershoot: NaN
            Peak: Inf
        PeakTime: Inf
```

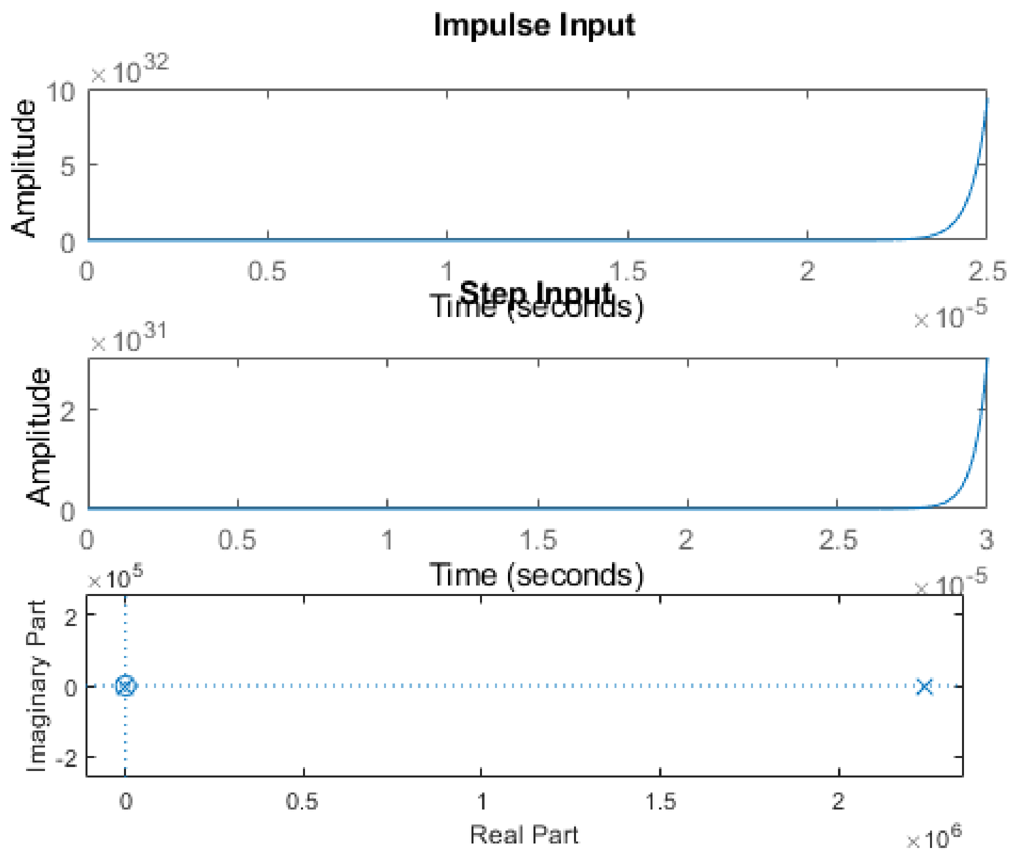


Closed Loop- Negative feedback with Controller (D)

```
sys = tf([(-k)*A,0],[1,k,(-k)*A])
figure(4);
subplot(3,1,1);
impulse(sys);
title('Impulse Input');
subplot(3,1,2);
step(sys);
title('Step Input');
[z,p,k] = tf2zp([-k*A,0],[1,k,(-k)*A])
subplot(3,1,3);
zplane(z,p);
S = stepinfo(sys)
```

```
sys =
```

```
         4.48e08 s
  -------------------------
  s^2 - 2.24e06 s + 4.48e08

Continuous-time transfer function.


z =

     0


p =

   1.0e+06 *

    2.2398
    0.0002


k =

   4.4800e+08


S =

  struct with fields:

        RiseTime: NaN
    SettlingTime: NaN
     SettlingMin: NaN
     SettlingMax: NaN
       Overshoot: NaN
      Undershoot: NaN
            Peak: Inf
        PeakTime: Inf
```

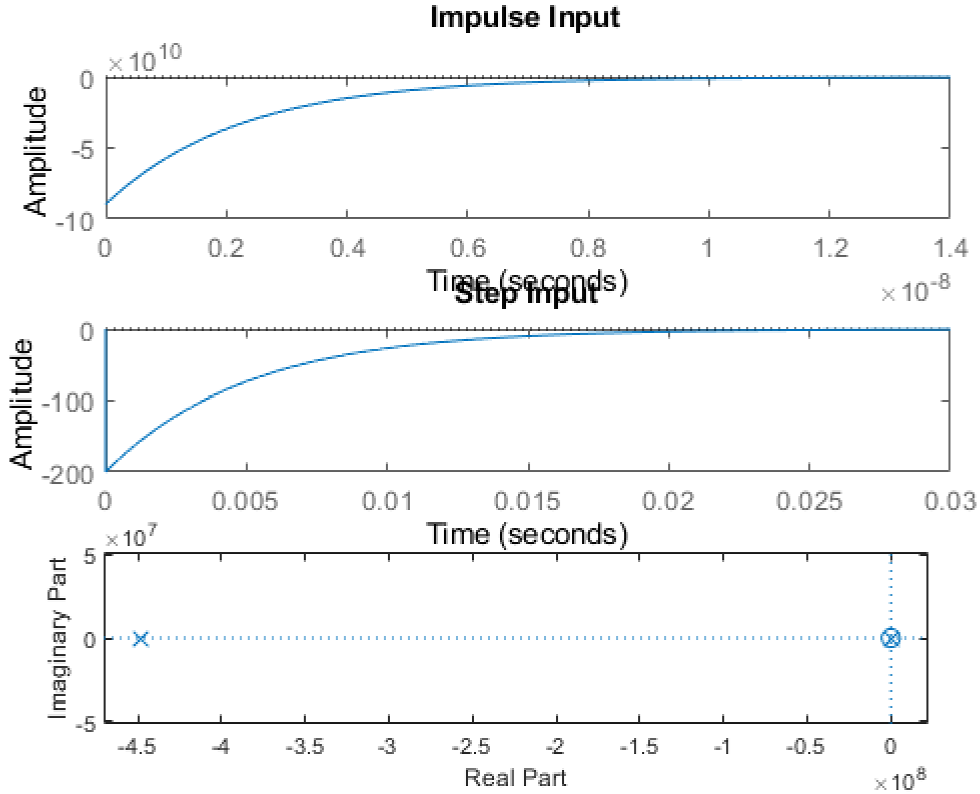


Closed Loop- Positive feedback with Controller (D)

```
sys = tf([(-k)*A,0],[1,k,k*A])
figure(5);
subplot(3,1,1);
impulse(sys);
title('Impulse Input');
subplot(3,1,2);
step(sys);
title('Step Input');
[z,p,k] = tf2zp([-k*A,0],[1,k,k*A])
subplot(3,1,3);
zplane(z,p);
S = stepinfo(sys)
```

```
sys =

         -8.96e10 s
  -------------------------
  s^2 + 4.48e08 s + 8.96e10
```

```
Continuous-time transfer function.


z =

     0


p =

   1.0e+08 *

   -4.4800
   -0.0000


k =

  -8.9600e+10


S =

  struct with fields:

        RiseTime: 0
    SettlingTime: 0.0196
     SettlingMin: -199.9633
     SettlingMax: -0.2598
       Overshoot: Inf
      Undershoot: Inf
            Peak: 199.9633
        PeakTime: 9.2103e-07
```



Math Analysis

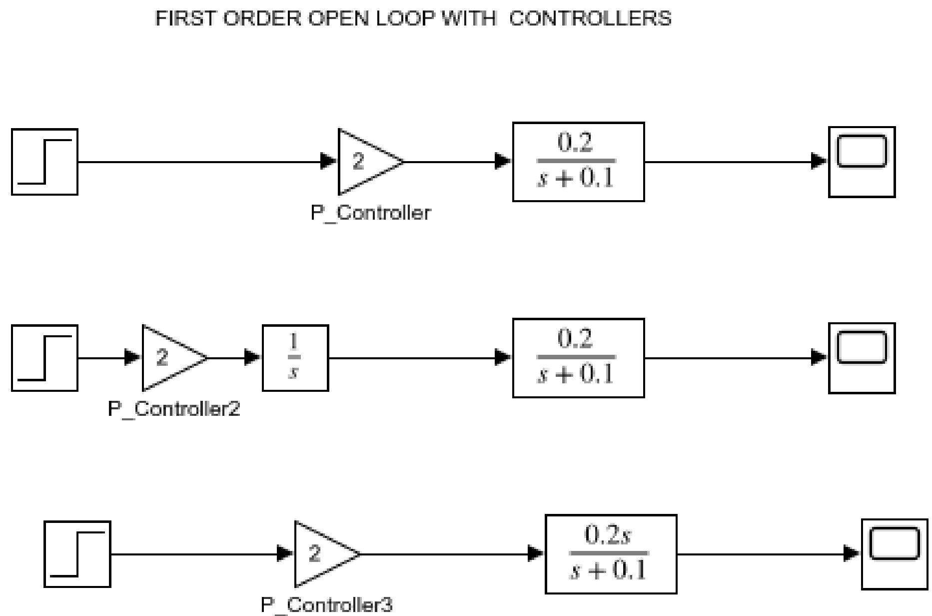
Independent: Time(t) Dependent: Mass(M) Constant: Non-zero constant(A), Constant(A)

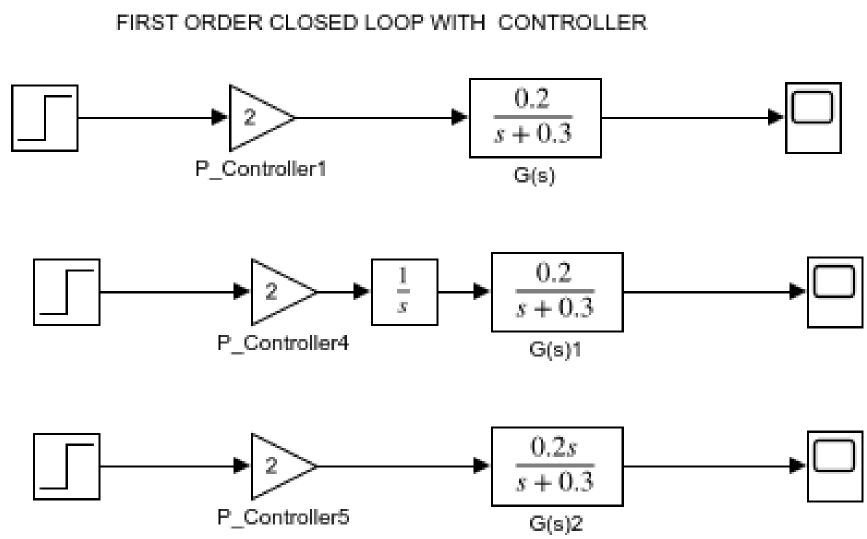
Comparison Analysis

1) System without controller behaves exactly like an exponential decay with the system decaying exponentially.
2) On adding a proportionality controller to system, the system becomes unstable.
3) On adding a Integrator controller to system, the response times have decreased hugely, making the system reach stability faster than a P controller.
4) Integrator controller adds a pole to zero also.
5) On addition of a differentiator controller in negative feedback the system becomes unstable.
6) A zero gets added at origin due to the differentiator.
7) On addition of a differentiator controller in positive feedback the system becomes stable.

4(a) 1st Order Differential Equation Model

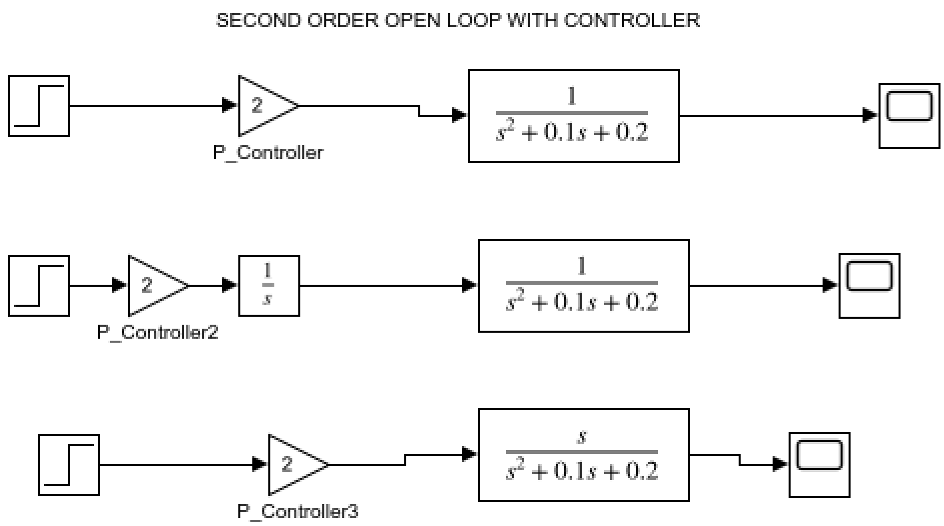
This was done in Simulink of MATLAB R2020b.

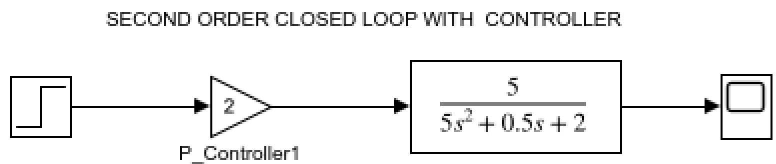




4(b) 2^{nd} Order Differential Equation Model

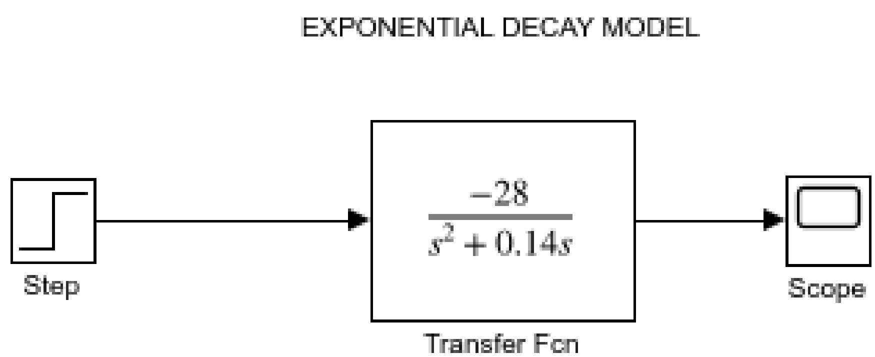
This was done in Simulink of MATLAB R2020b.





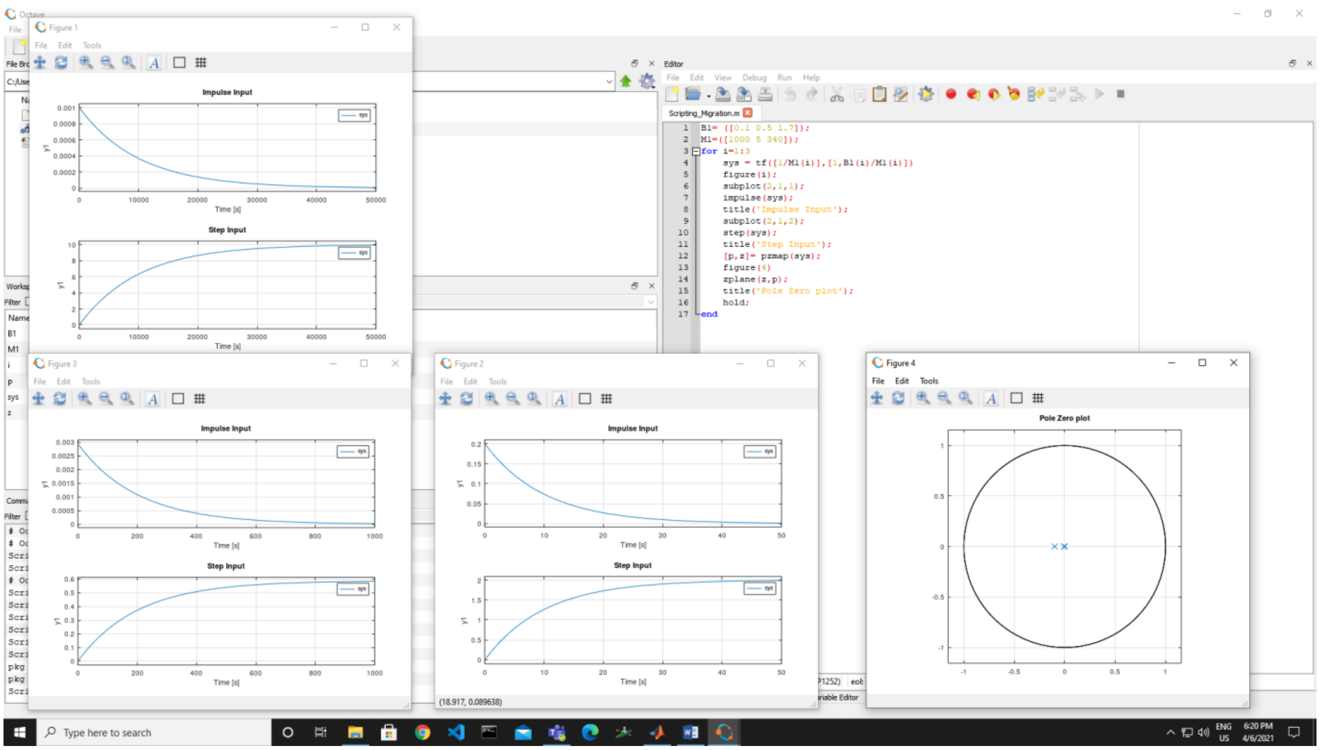
4(c) Exponential Decay- Radioactive Material Model

This was done in Simulink of MATLAB R2020b.



5(a) Migration of Scripts to GNU Octave

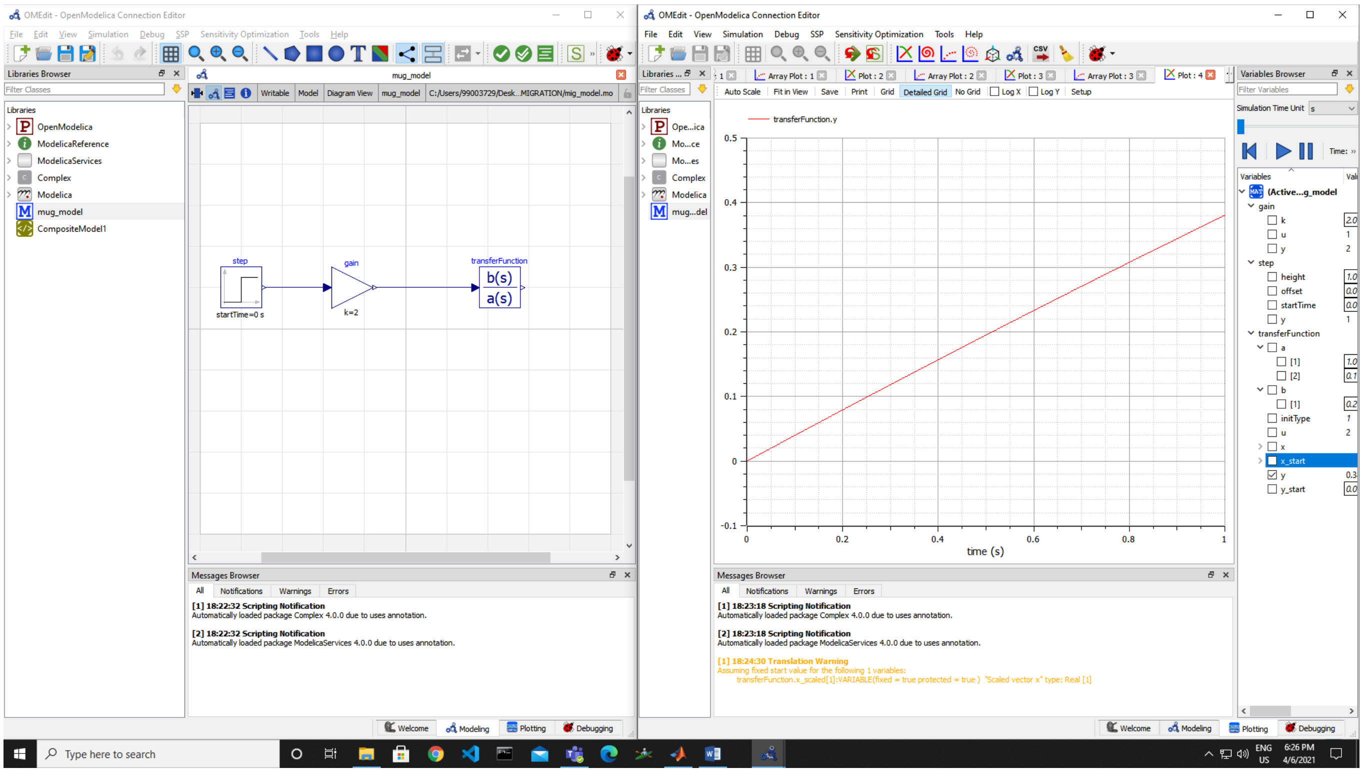
The results matched with the scripts executed in the MATLAB R2020b



GNU Octave is software featuring a high-level programming language, primarily intended for numerical computations. Octave helps in solving linear and nonlinear problems numerically, and for performing other numerical experiments using a language that is mostly compatible with MATLAB.

5(b) Migration of Model to OpenModelica

The results matched with the models executed in Simulink of MATLAB R2020b.



OpenModelica is a free and open source environment based on the Modelica modeling language for modeling, simulating, optimizing and analyzing complex dynamic systems. This software is actively developed by Open Source Modelica Consortium, a non-profit, non-governmental organization.