Control Systems Design

Lab 2

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Section : 8

A. Evaluate Closed Loop Transfer Function.

$$J\ddot{\theta} + B\dot{\theta} = K(\theta_r - \theta)$$

$\mathcal{L}$

$$Js^2\theta + Bs\theta = K\theta_r - K\theta$$

$$\theta\left[Js^2 + Bs + K\right] = K\theta_r$$

o/p i/p

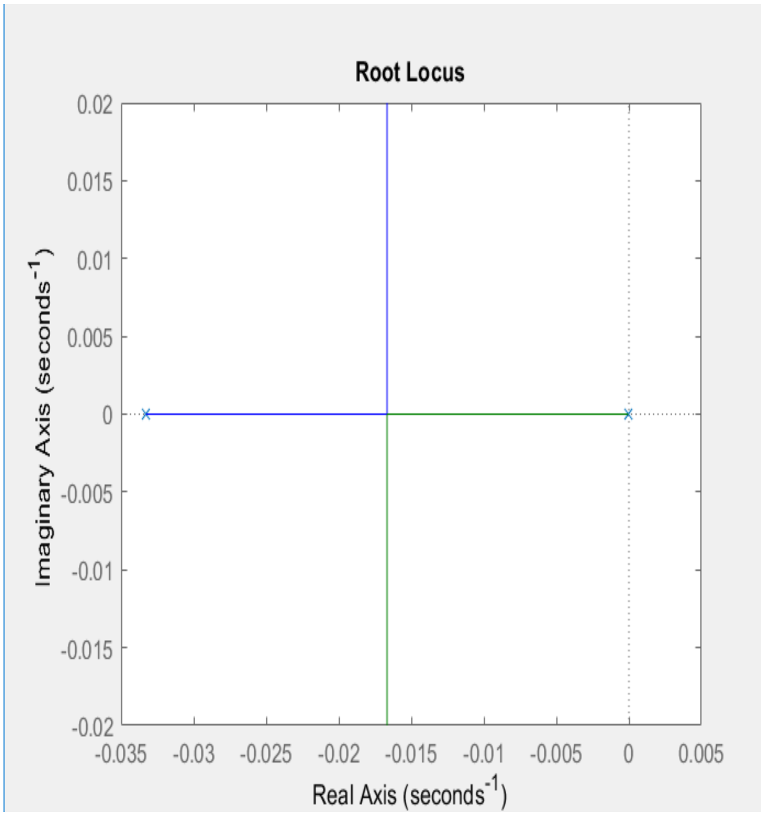
$$\boxed{T(s) = \frac{\theta}{\theta_r} = \frac{K}{Js^2 + Bs + K}}$$

B. Use Matlab to generate the state space.

- Code :

```
%% ****************** part a and b **************************
j = 600e3; B = 20e3; k = 1;
trans = tf(k, [j B k]);
rlocusplot(trans);
state = ss(trans);
info = stepinfo(ss(trans));
```

- Output of the matlab




```
state =

  A = 
                x1         x2
   x1   -0.03333  -0.001707
   x2  0.0009766          0

  B = 
              u1
   x1    0.03125
   x2          0

  C = 
              x1        x2
   y1          0   0.05461

  D = 
          u1
   y1      0

Continuous-time state-space model.
```

C. Maximum value of k that makes the Closed loop system stable :

- Using Routh Herwitz :

$\mathbf{Js^2 + Bs + k = 0}$

$\mathbf{s^2}$	$\mathbf{J}$	$\mathbf{k}$
$\mathbf{s^1}$	$\mathbf{B}$	$\mathbf{0}$
$\mathbf{s^0}$	$\mathbf{k > 0}$	$\mathbf{0}$

- So for any positive value of k the closed loop system will be positive.

D. Maximum value of k to have $M_P < 10\%$:

K = 477

```
%% ****************** part d ******************
j = 600e3; B = 20e3; k = 1;
trans = tf(k, [j B k]);
info = stepinfo(ss(trans));
while info.Overshoot < 10
    k = k + 1;
    trans = tf(k, [j B k]);
    info = stepinfo(ss(trans));
end
max_k_overshot = k;

```

B	20000
info	1x1 struct
j	600000
k	477
max_k_oversh...	477
state	1x1 ss
trans	1x1 tf

E. Max value of k to have risetime less than 80 msec :

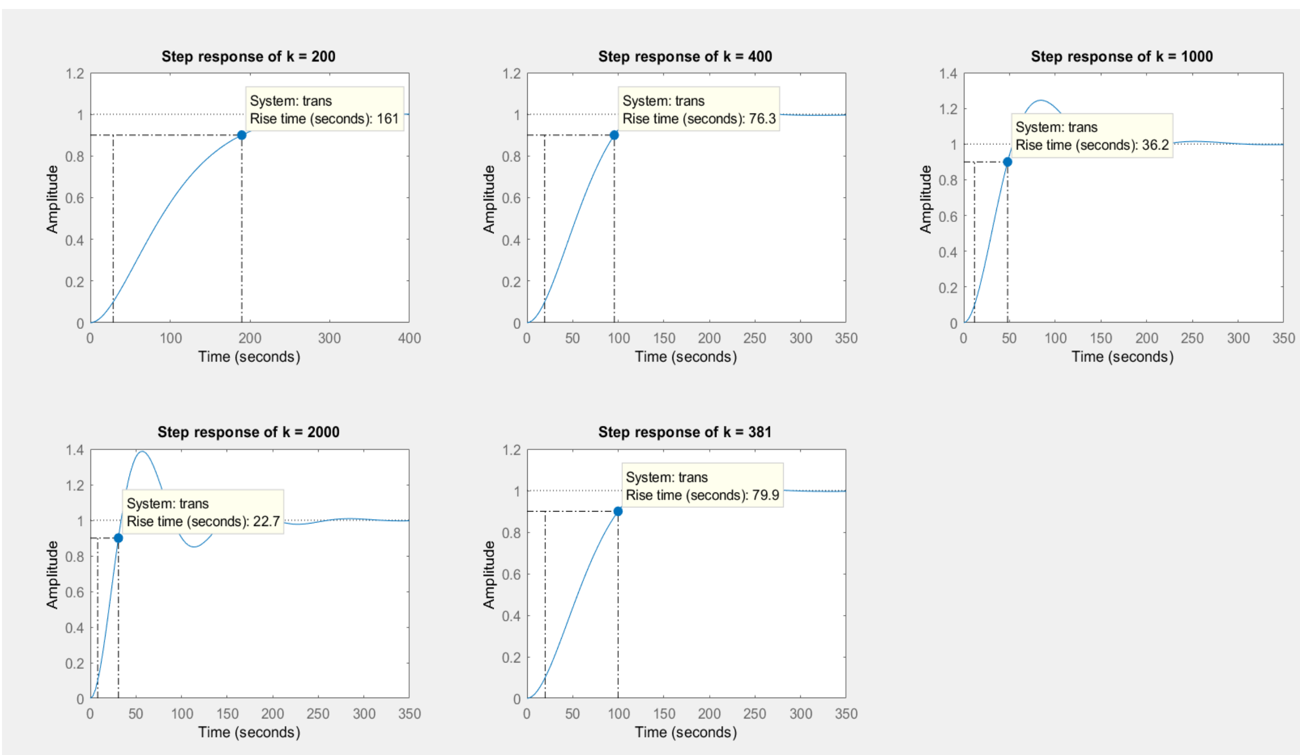
K = 381

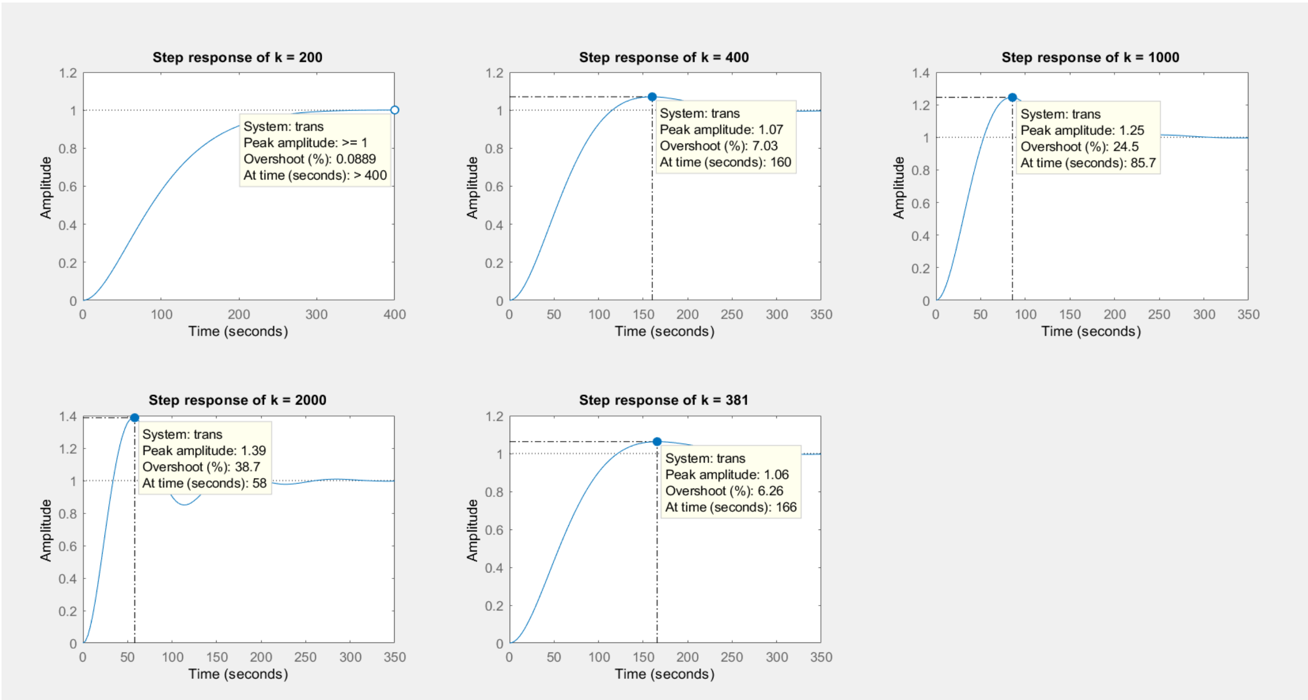
```
%% ****************** part e ******************
j = 600e3; B = 20e3; k = 1;
trans = tf(k, [j B k]);
info = stepinfo(ss(trans));
while info.RiseTime > 80
    k = k + 1;
    trans = tf(k, [j B k]);
    info = stepinfo(ss(trans));
end
max_k_risetime = k

```

Name	Value
B	20000
info	1x1 struct
j	600000
k	381
max_k_oversh...	477
max_k_risetime	381
state	1x1 ss
trans	1x1 tf

F. Step response of k = 200, 400, 1000, 2000, 381 rise time and over shot :

```
%% ***************** part f, g and h *************************
j = 600e3; B = 20e3; k = [200, 400, 1000, 2000, 381];
overshot = [];   risetime = []; ss_error = [];
for i=1:1:5
    trans = tf(k(i), [j B k(i)]);
    info = stepinfo(ss(trans));
    overshot(i) = info.Overshoot;
    risetime(i) = info.RiseTime;
    ss_error(i) = abs(1-(info.SettlingMax + info.SettlingMin)/2);
    figure(1);
    subplot(2,3,i);
    stepplot(trans); title(sprintf('Step response of k = %d',k(i)));
    figure(2);
    subplot(2,3,i);
    pzplot(trans); title(sprintf('Poles ans zeros of k = %d',k(i)));
end
```

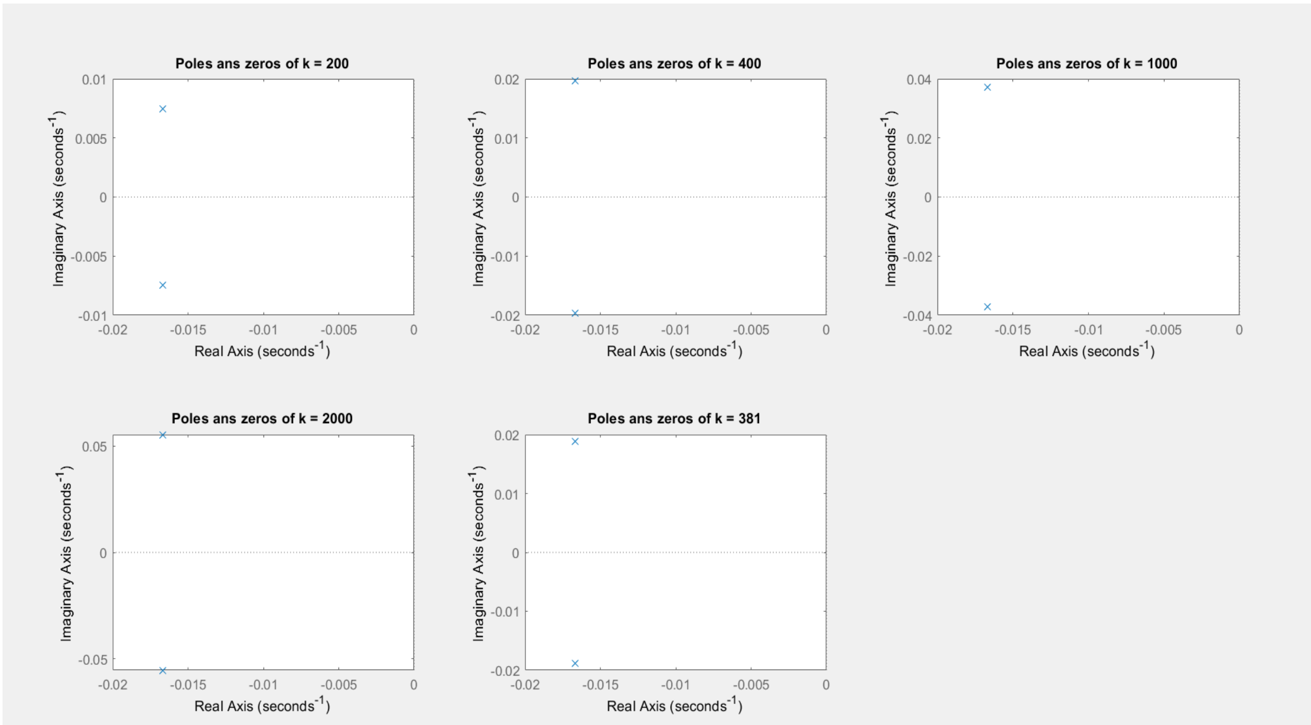





```
overshot =

    0.0889    7.0269   24.5005   38.6910    6.2638


risetime =

  161.1305   76.3235   36.2328   22.6671   79.9361


ss_error =

    0.0488    0.0115    0.0897    0.1183    0.0116
```

As shown in the photo above the rise time and overshoot output of the plots is the same as the code.

G. Poles and zeros



As show when the value of k increases the poles become farther. However ther is no zeros in the transfer fuction so the increasing of k won't affect zeros due to absence of s in the numerator.

Same code as part F

H. Steady state error

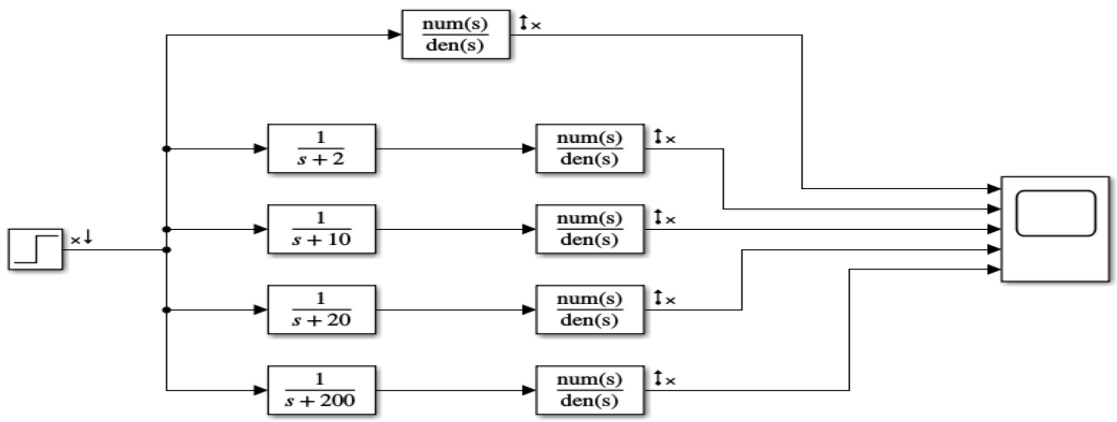
To get the steady-state error I used the following equation

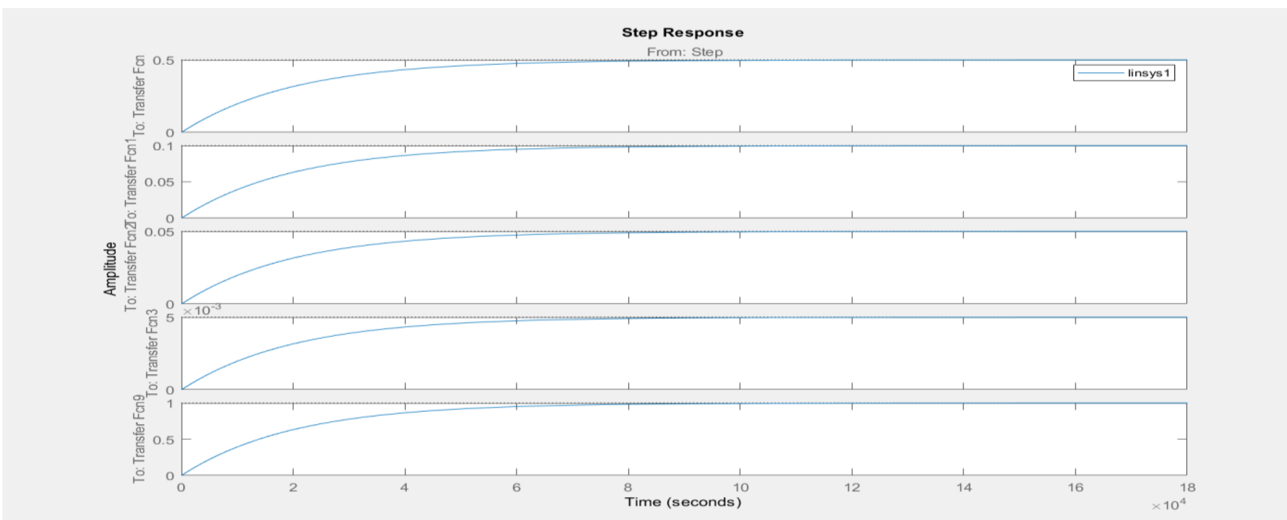
$$e_{ss} = \left|1 - \frac{SettlingTime_{Min} + SettlingTime_{Max}}{2}\right|$$

```
ss_error =

    0.0488    0.0115    0.0897    0.1183    0.0116
```

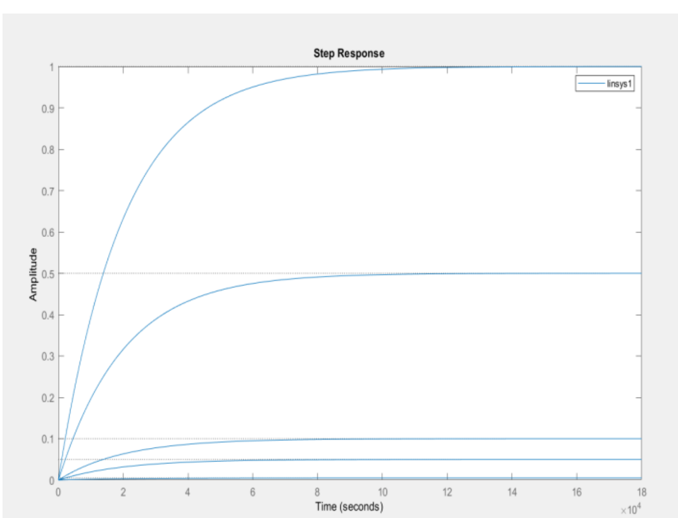
Same code as part F and G

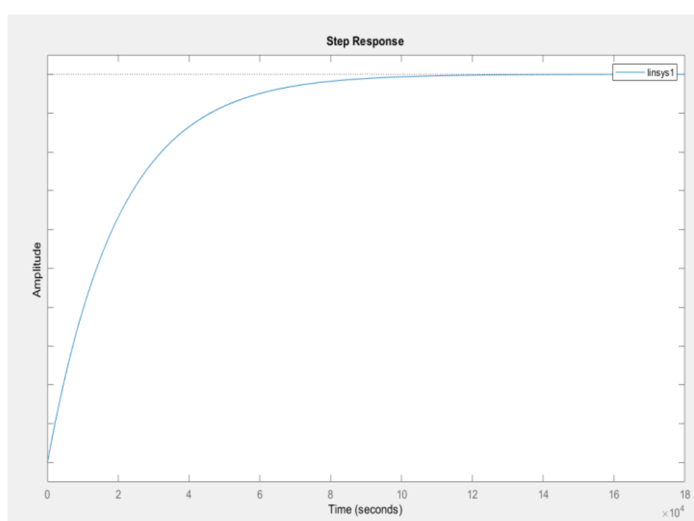
I. Poles at -2, -10, -20, -200 at k=1

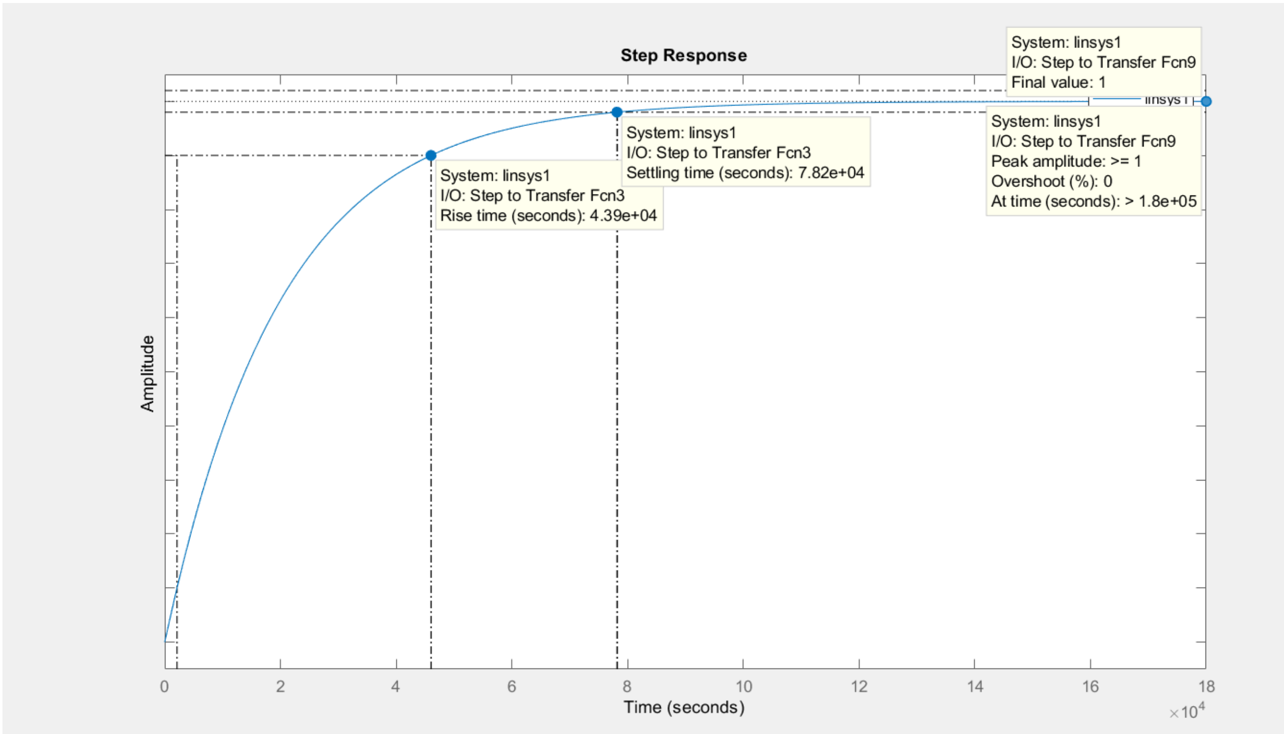




After groping all **normalized**







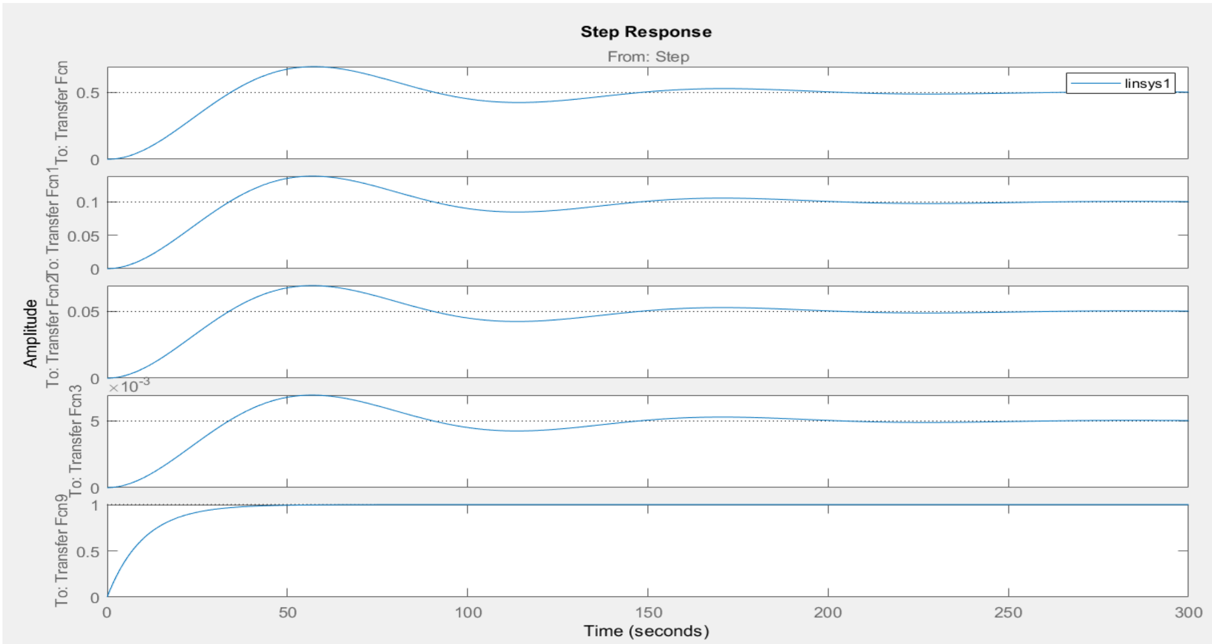
Rise time = 4.39 x 10^4 seconds

Settling time = 7.82 x 10^4 seconds

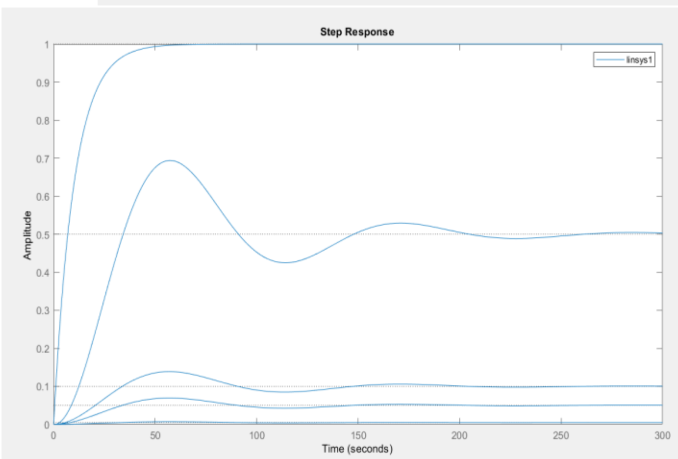
Peak time = 1.8 x 10^5 seconds

Max overshoot = 0%

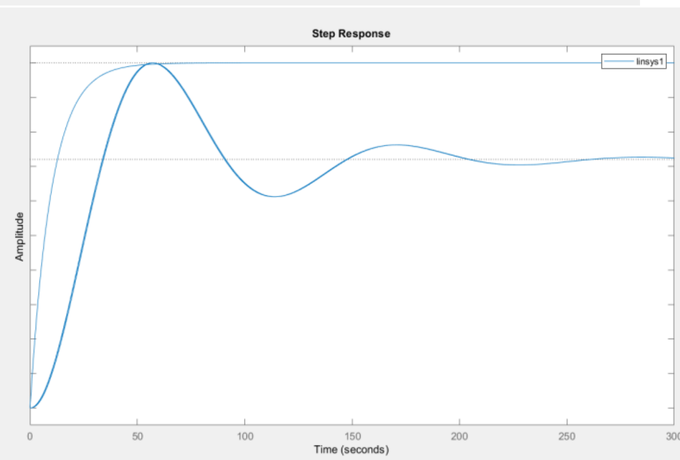
At k = 2000



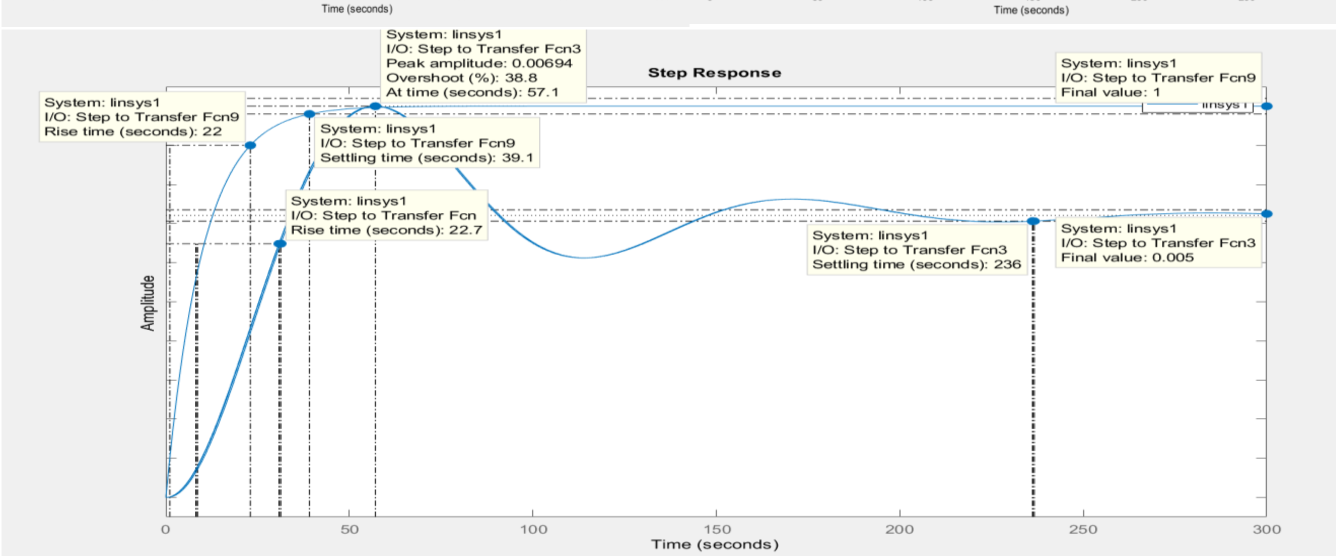
Step Response
From: Step
linsys1
To: Transfer Fcn
To: Transfer Fcn1
To: Transfer Fcn2
To: Transfer Fcn3
To: Transfer Fcn9
Amplitude
Time (seconds)



Step Response
linsys1
Amplitude
Time (seconds)



Step Response
linsys1
Amplitude
Time (seconds)



Step Response
System: linsys1
I/O: Step to Transfer Fcn3
Peak amplitude: 0.00694
Overshoot (%): 38.8
At time (seconds): 57.1
System: linsys1
I/O: Step to Transfer Fcn9
Final value: 1
System: linsys1
I/O: Step to Transfer Fcn9
Rise time (seconds): 22
System: linsys1
I/O: Step to Transfer Fcn9
Settling time (seconds): 39.1
System: linsys1
I/O: Step to Transfer Fcn
Rise time (seconds): 22.7
System: linsys1
I/O: Step to Transfer Fcn3
Settling time (seconds): 236
System: linsys1
I/O: Step to Transfer Fcn3
Final value: 0.005
Amplitude
Time (seconds)

Rise time = 22.7 seconds

Settling time = 236 seconds

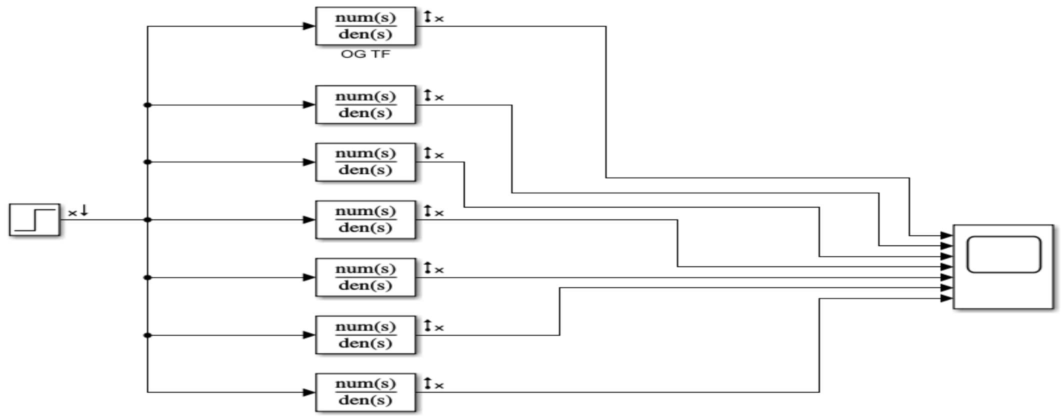
Peak time = 57.1 seconds

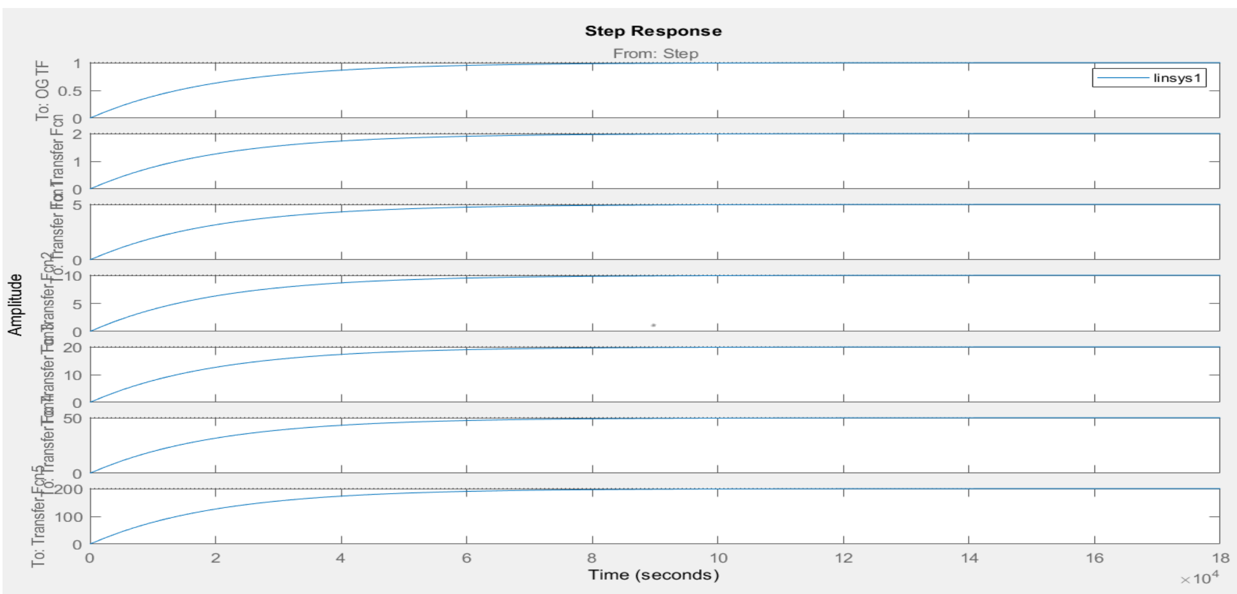
Max overshot = 38.8%

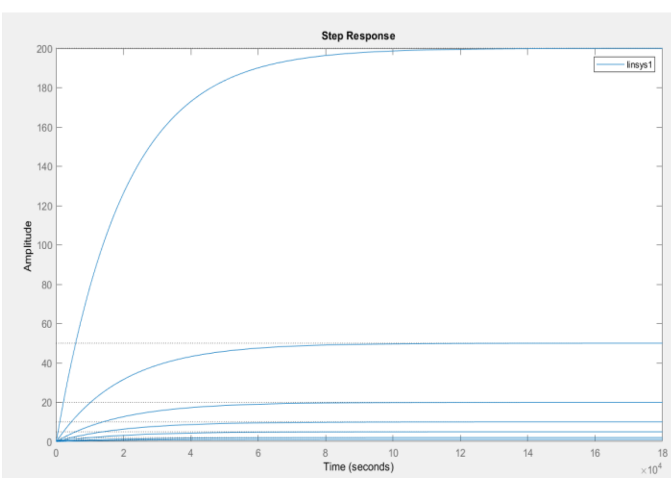
J.

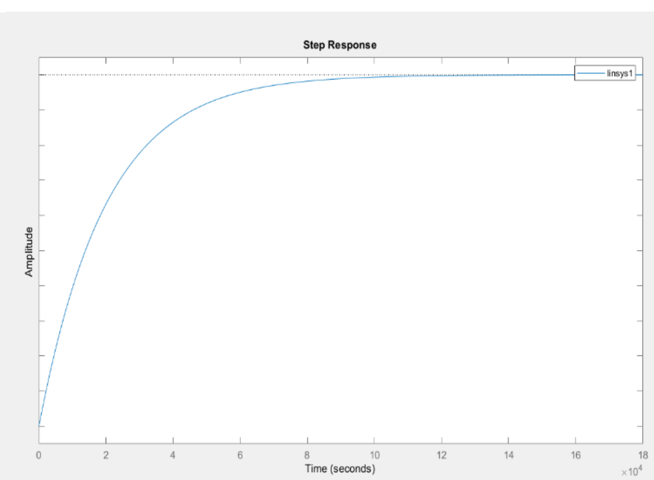
As the number of poles in a system increase, the transient response becomes slower. However, if they are quite far from the imaginary axis compared to the pole pair of the original second order system, the effect of slowing the transient response decreases, and as the new poles become nearer to the proximity of the pole pair, their effect increases and the pole pair dominance decreases.
As the pole value rises, the final value decreases, while everything else remains largely the same.

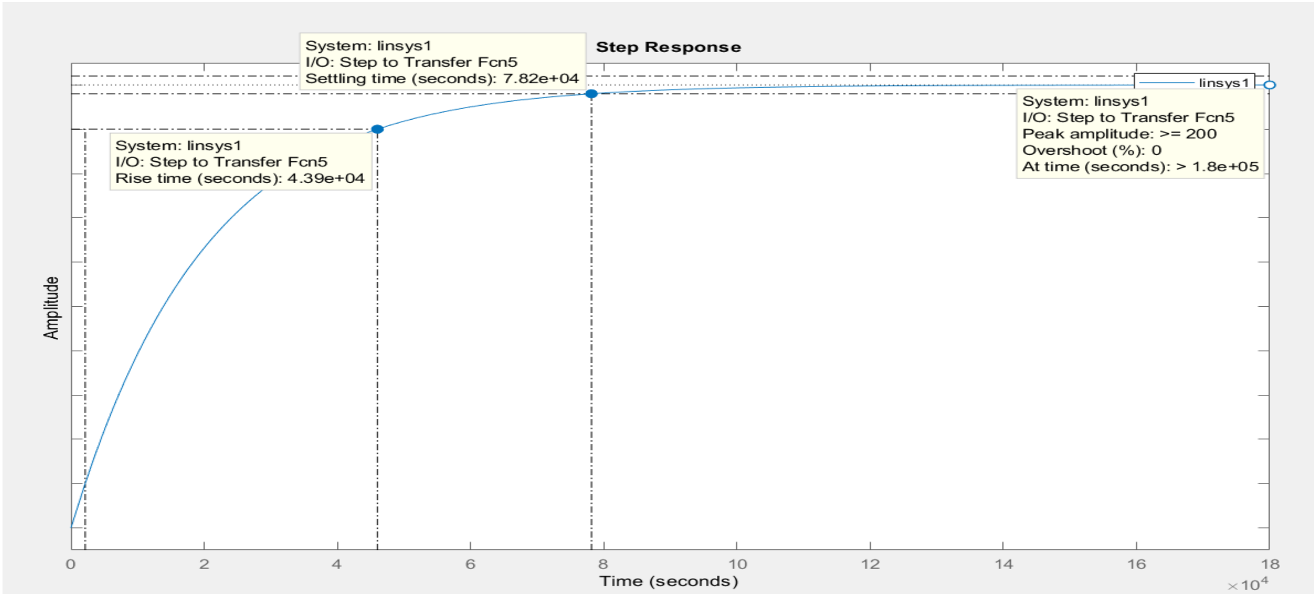
K. Zeros at -2, -5, -10, -20, -50, -200 at k=1











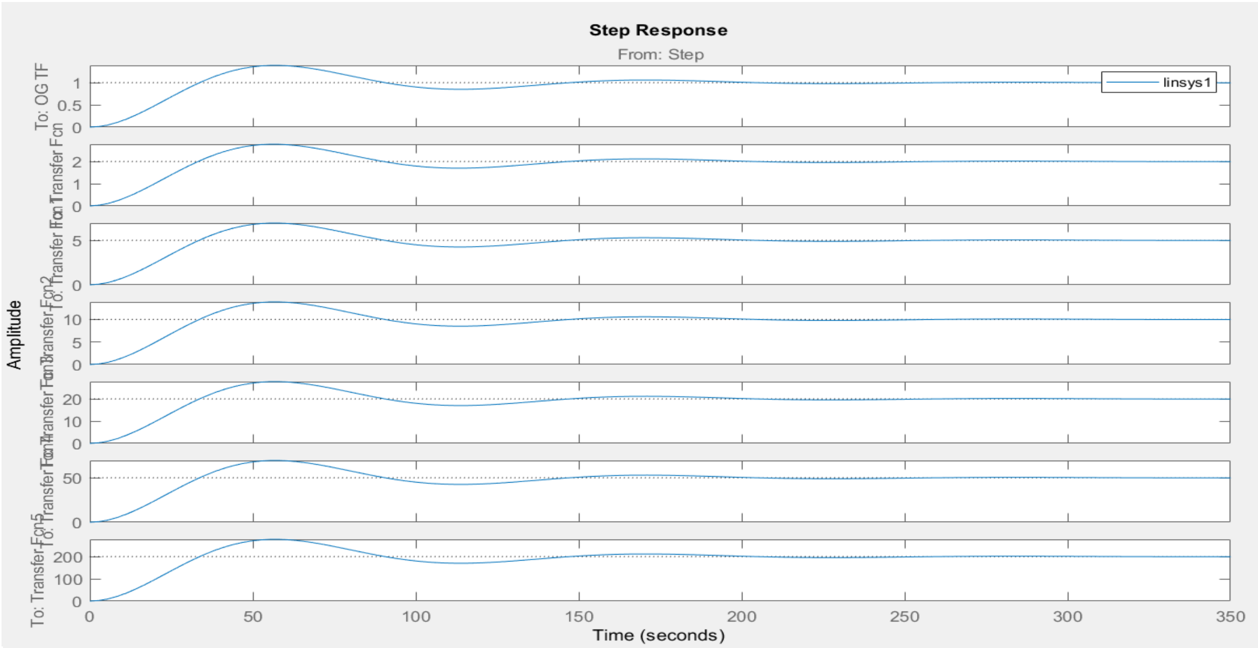
Rise time = 4.39 x 10^4 seconds

Settling time = 7.82 x 10^4 seconds

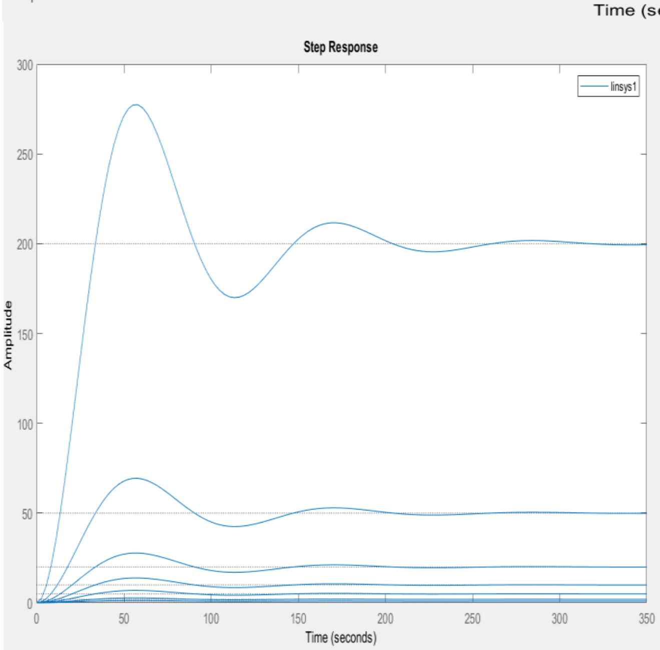
Peak time = 1.8 x 10^5 seconds

Max overshot = 0%

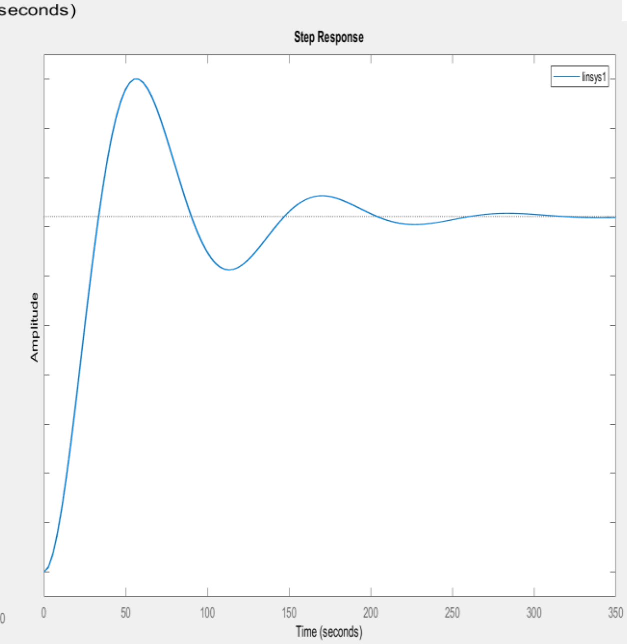
At k = 2000:



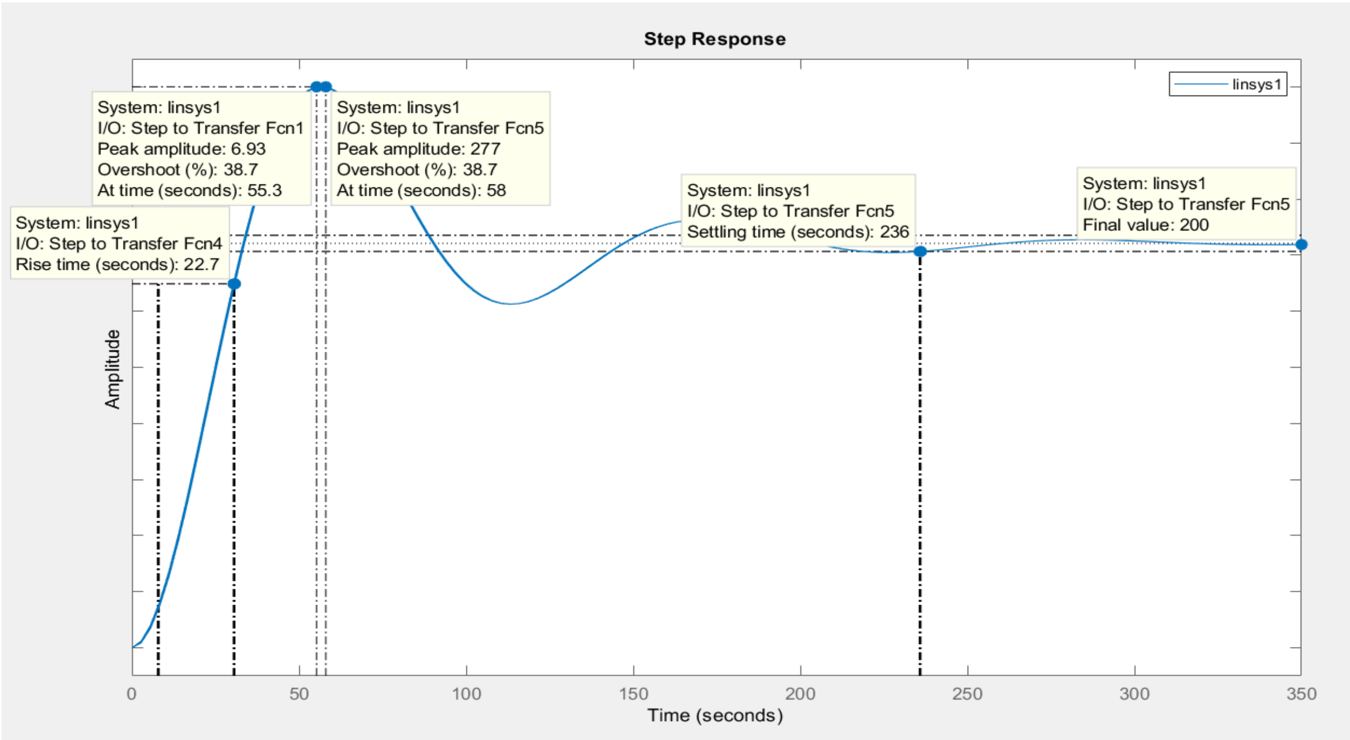
Step Response
From: Step
linsys1
To: OG TF
To: Transfer Fcn
To: Transfer Fcn2
Amplitude
To: Transfer Fcn5
Time (seconds)



Step Response
linsys1
Amplitude
Time (seconds)



Step Response
linsys1
Amplitude
Time (seconds)



Rise time = 22.7 seconds

Settling time = 236 seconds

Peak time = 58 seconds

Max overshoot = 38.7%

L.

The dominant pole pair is the pair closest to the imaginary axis of the S-plane plot, far closer than the rest of system roots, making the pole pair have a greater effect on the system, while the rest have little to none, and thus negligible.
As number of zeros increases, stability and overshoot increases, but rise time and peak time decrease. However, as they remain

farther from the imaginary axis on the S-plane plot, their effect decreases. As such, even for a higher-order system, the zero can be ignored if it is too far from the rest of the roots.
The dominant second-order pair exist when they are far closer to the imaginary axis than the rest of the poles and as a result let us assume the system to be of the second order since the rest of the roots are too far to affect the system.
As the zero value rises, the final value rises, while everything else remains the same.