Cairo University
Faculty of Engineering

Dereqment of Computer
Engineering

Control Engineering

Project

Submitted to

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Submitted by

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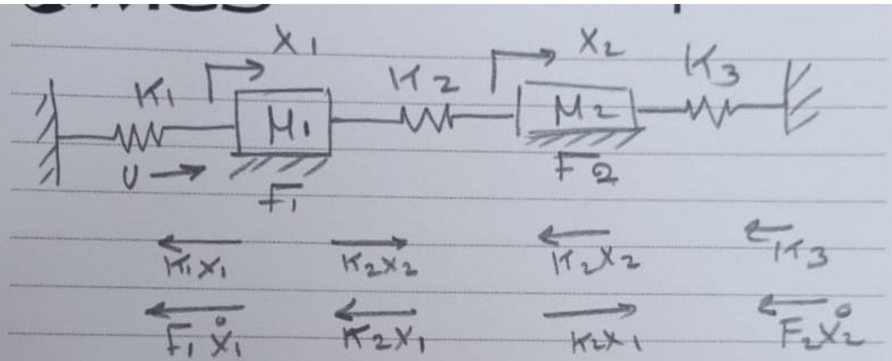
Req 1 :

dynamic equations:



$$M_1 \ddot{x}_1 = -K_1 x_1 + U - F_1 \dot{x}_1 - K_2 x_1 + K_2 x_2$$

$$M_2 \ddot{x}_2 = -K_2 x_2 - K_3 x_2 + K_2 x_1 - F \dot{x}_2$$

* by laplace:-

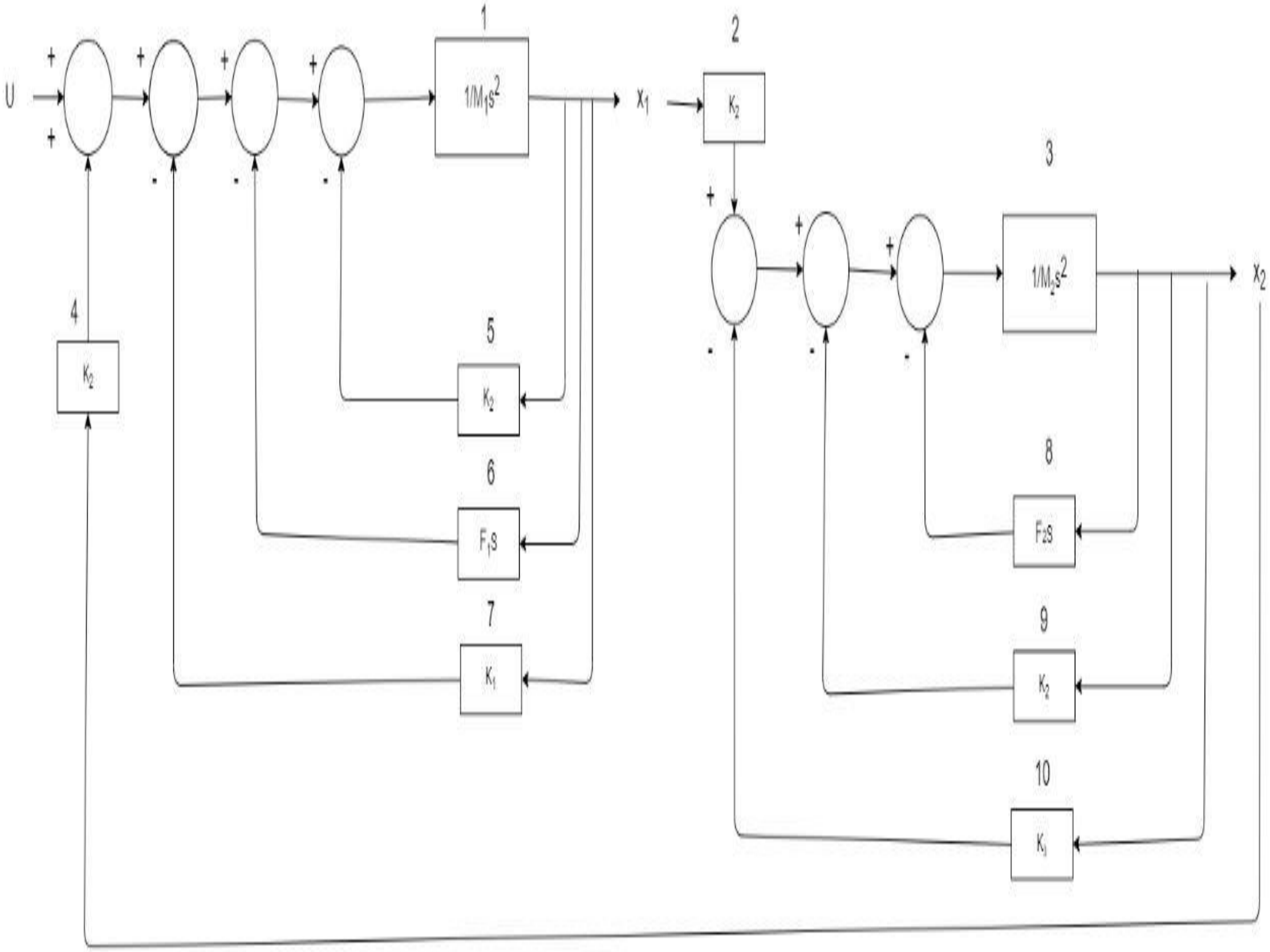
$$S^2 X_1 M_1 = -K_1 X_1 - f_1 S X_1 - K_2 X_1 + K_2 X_2 + U$$

$$S^2 X_2 M_2 = K_2 X_1 - K_3 X_2 - f_2 S X_2 - K_2 X_2$$

$\therefore$ this are the dynamic equations

#

BlockDiagram:



Req2:

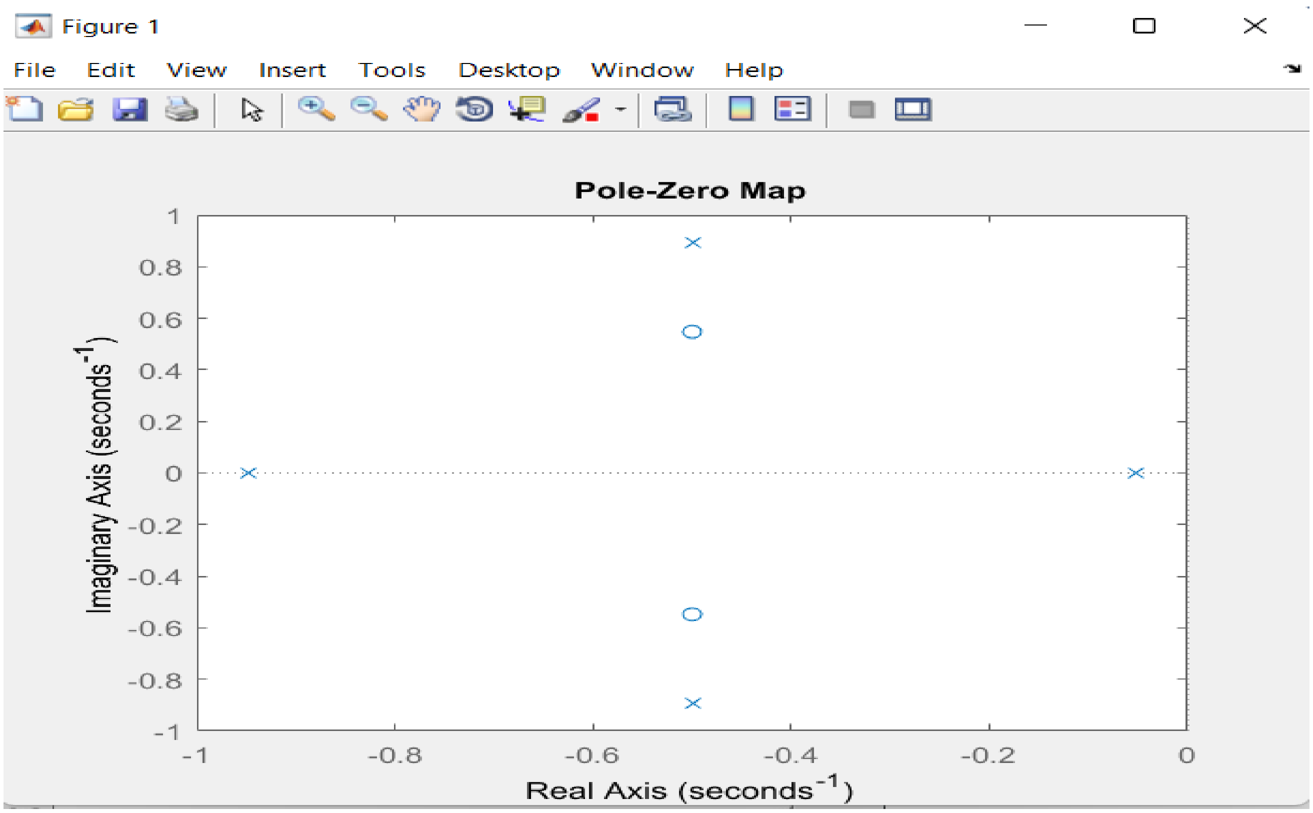
Transfer Functions:

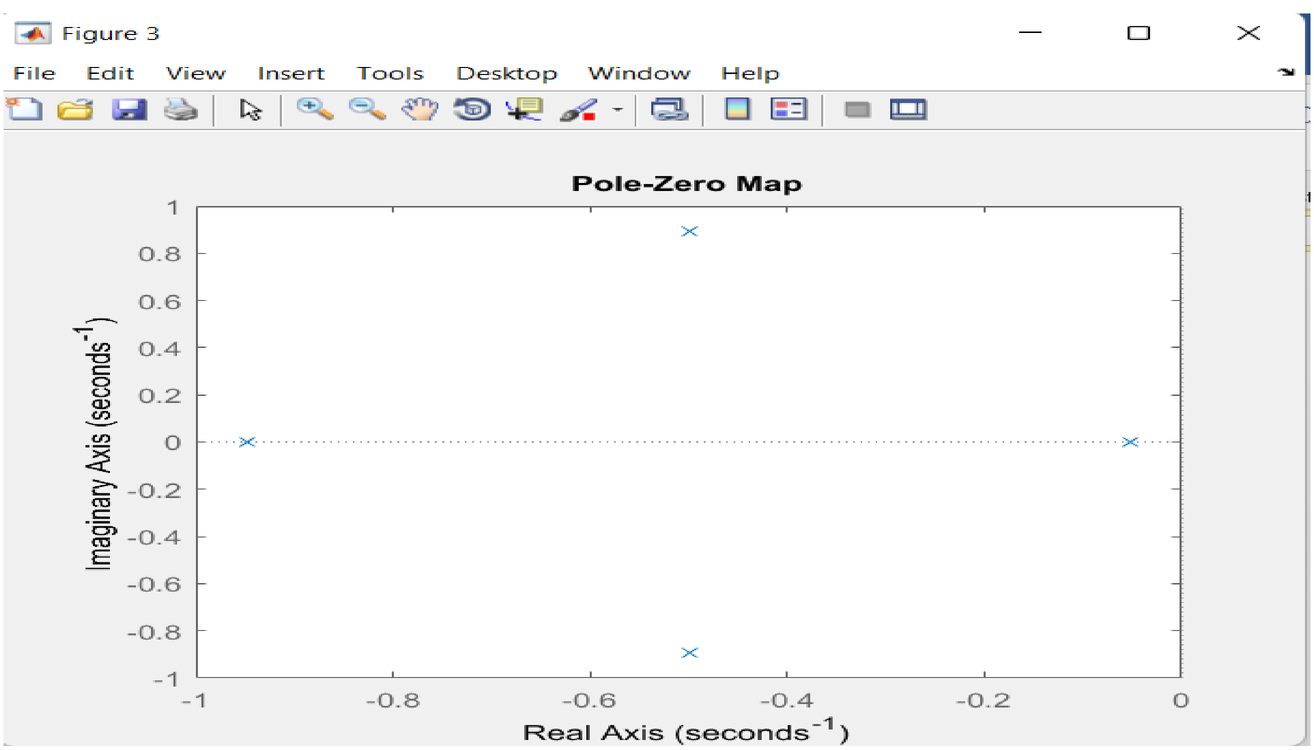
```
The value of X1/U transfer function is:
numerator: [0 0 0.01 0.01 0.0055]
denominator: [1 2 2.1 1.1 0.0525000000000001]
```

```
The value of X2/U transfer function is:
numerator: [0 0 0 0 0.00500000000000001]
denominator: [1 2 2.1 1.1 0.0525000000000001]
```

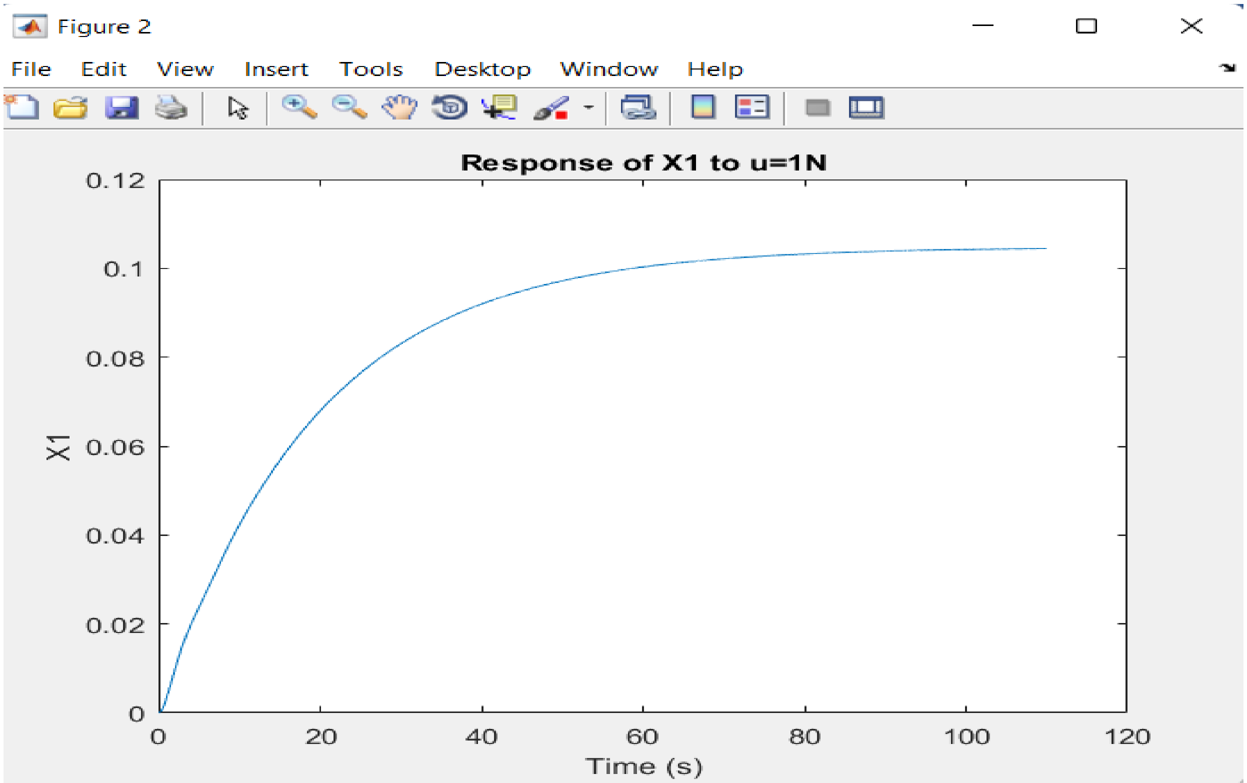
Req3:

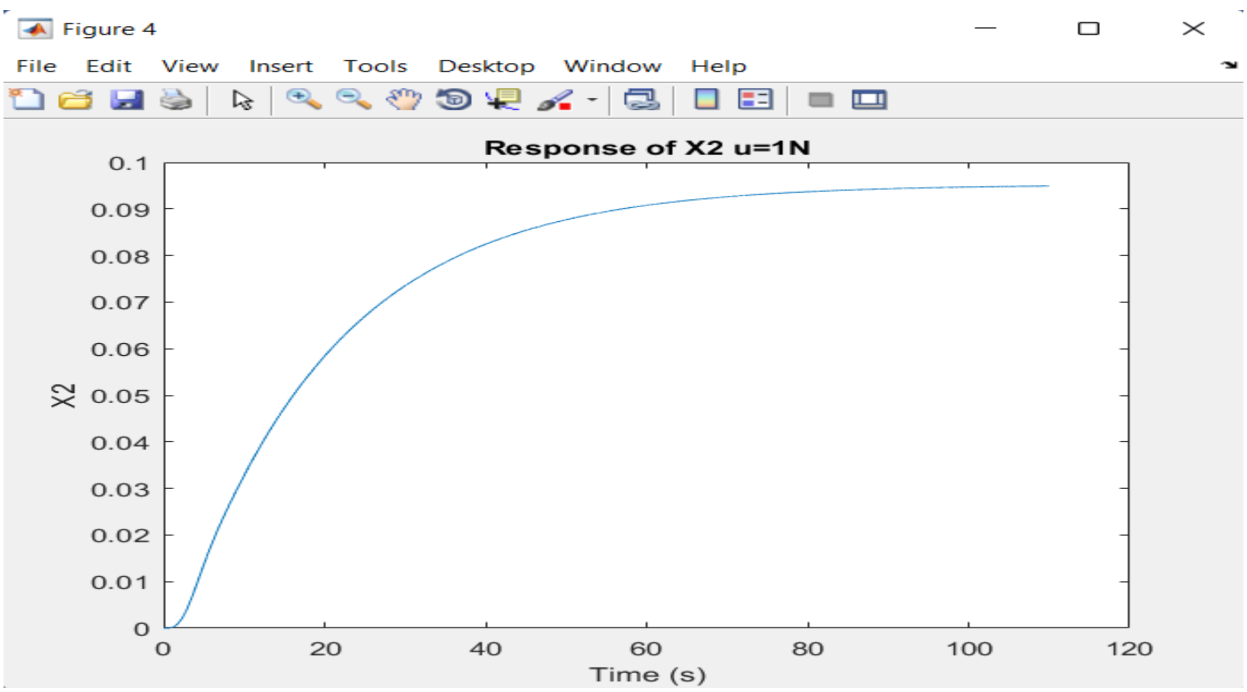
both systems are stable





Req 4 :





SteadyStateValues:

```
X1_steadystate is 0.104435 m
X2_steadystate is 0.094911 m
```

Req 5:

from the hint, here We used unity feedback H(S)=1

```
closedloop = feedback(system2, 1);
```

Req 6:

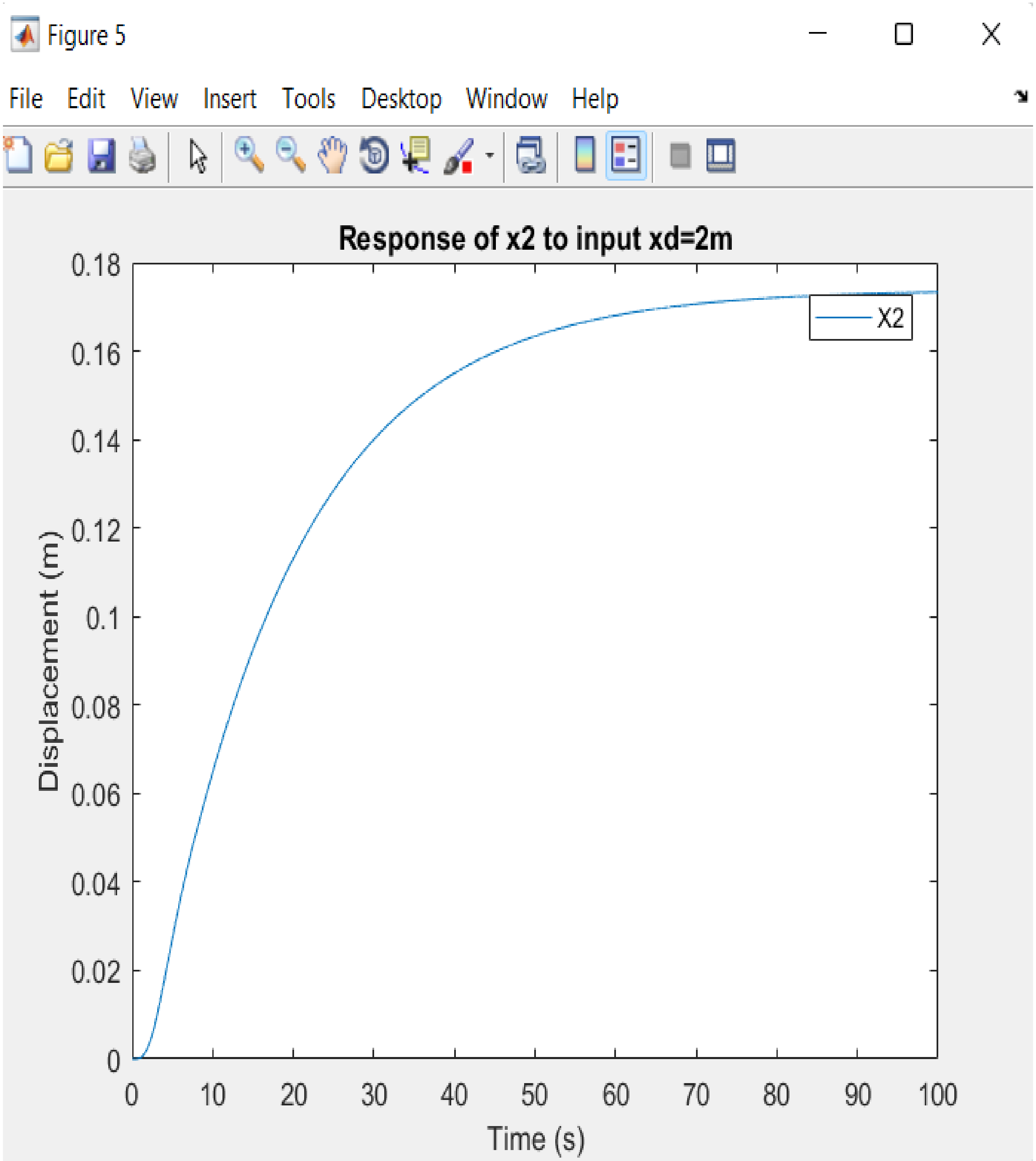


Figure 5
File Edit View Insert Tools Desktop Window Help
Response of x2 to input xd=2m
X2
Displacement (m)
Time (s)
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0
10
20
30
40
50
60
70
80
90
100

Req7:

```
before using proportional controller
Rise Time: 37.47 s
Peak Time: 125.29 s
Maximum Peak: 0.17
Settling Time: 68.97 s
Ess: 1.83
```

Req 8:

Kp=1

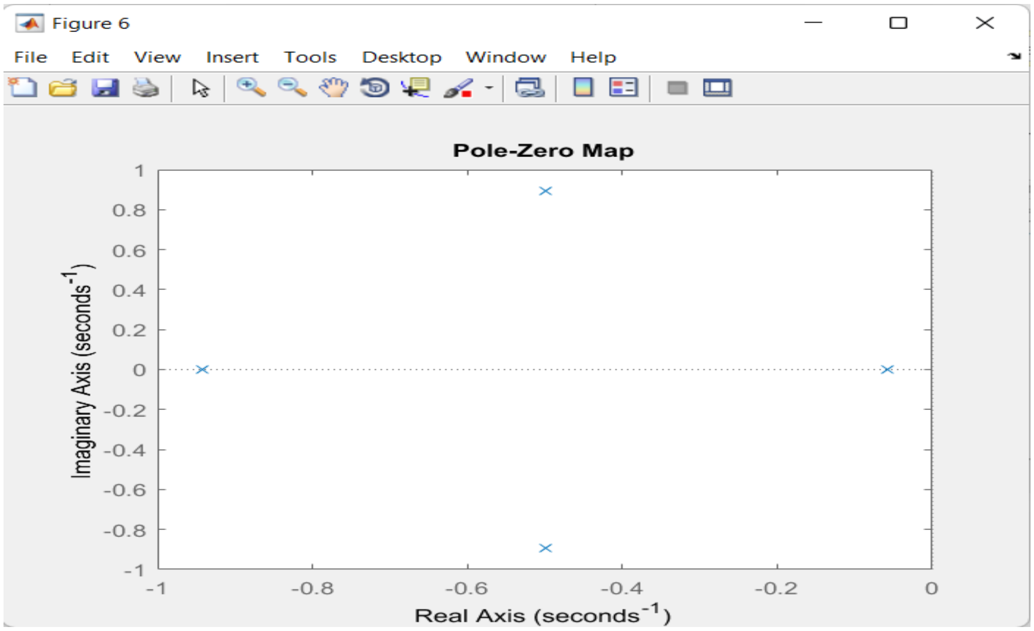


Figure 6
File Edit View Insert Tools Desktop Window Help
Pole-Zero Map
Imaginary Axis (seconds⁻¹)
Real Axis (seconds⁻¹)
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1
-0.8
-0.6
-0.4
-0.2
0

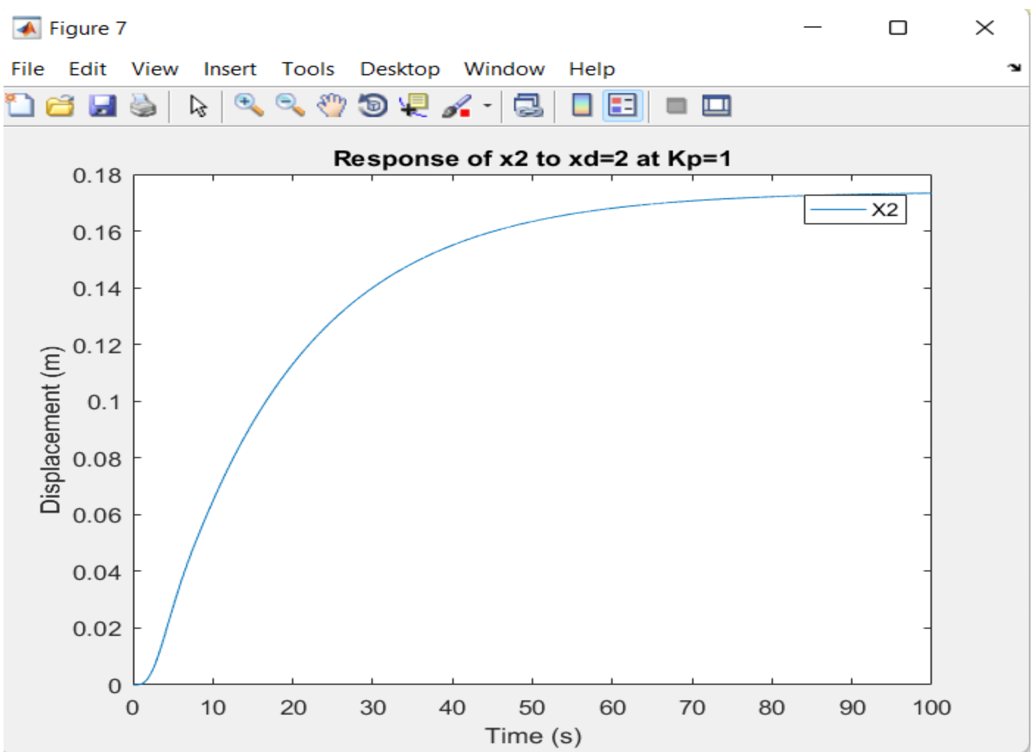


Figure 7
File Edit View Insert Tools Desktop Window Help
Response of x2 to xd=2 at Kp=1
X2
Displacement (m)
Time (s)
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0
10
20
30
40
50
60
70
80
90
100

Transient Response:

```
kp=1
Rise Time: 37.47 s
Peak Time: 125.29 s
Maximum Peak: 0.17
Settling Time: 68.97 s
Ess: 1.83
The system is (stable)
```

Kp=10

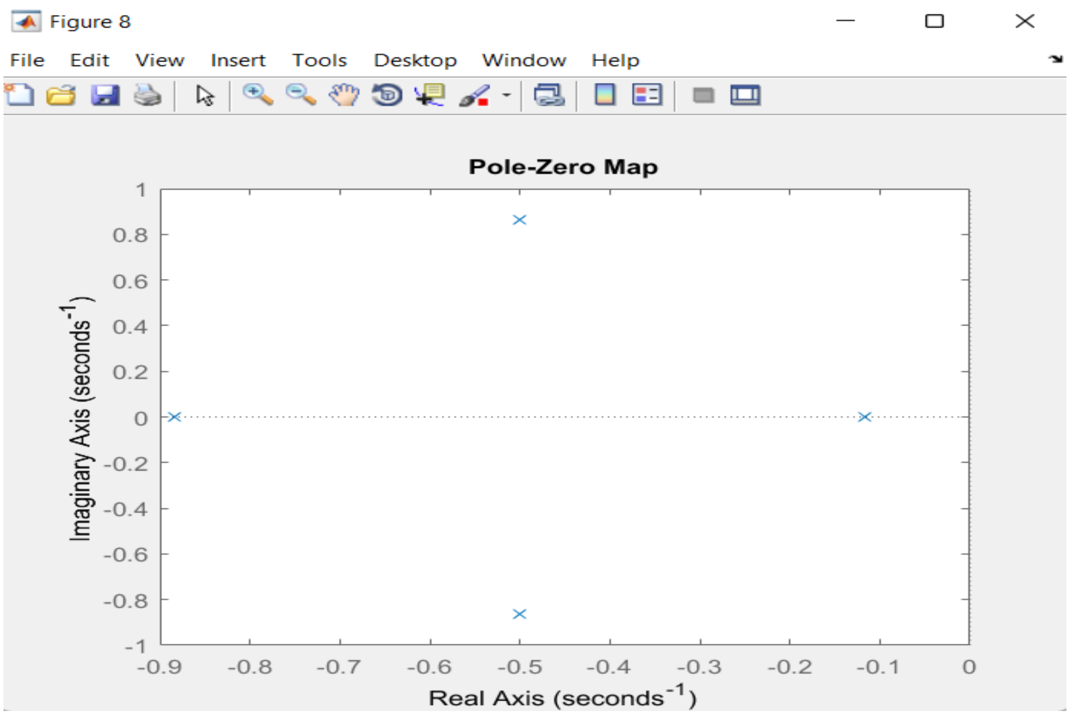


Figure 8
File Edit View Insert Tools Desktop Window Help
Pole-Zero Map
Imaginary Axis (seconds⁻¹)
Real Axis (seconds⁻¹)
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-0.9 -0.8 -0.7 -0.6 -0.5 -0.4 -0.3 -0.2 -0.1 0

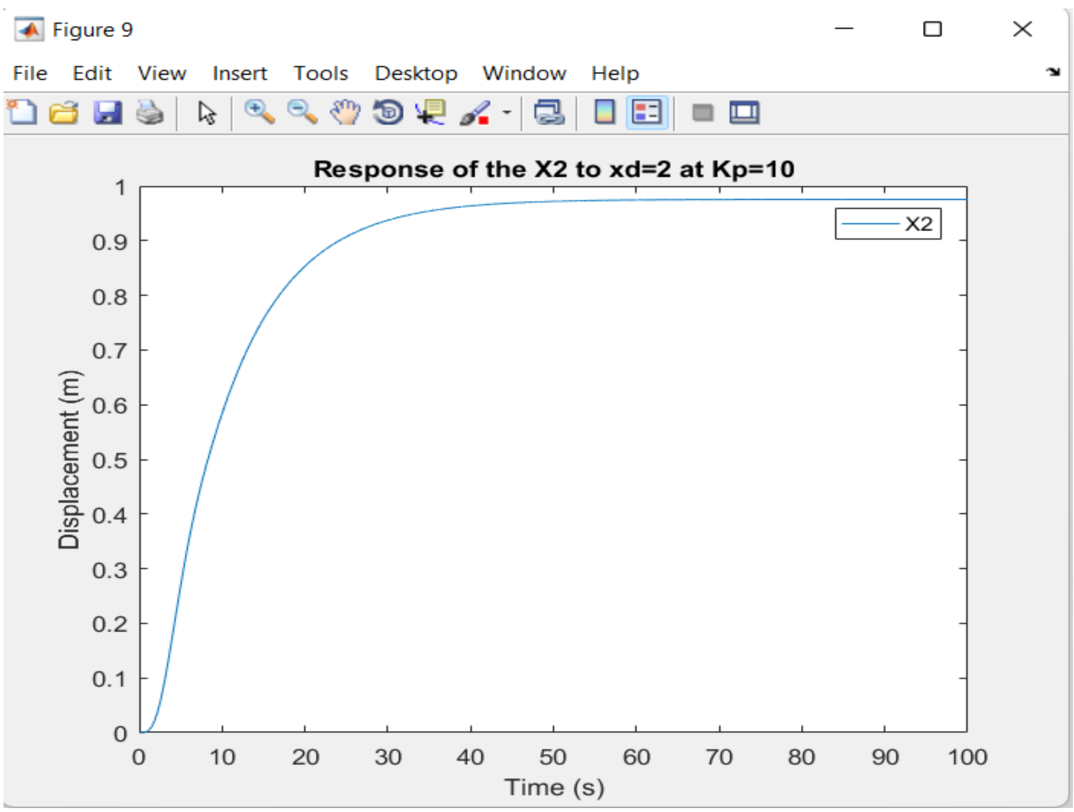


Figure 9
File Edit View Insert Tools Desktop Window Help
Response of the X2 to xd=2 at Kp=10
X2
Displacement (m)
Time (s)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 10 20 30 40 50 60 70 80 90 100

Transient Response:

```
at kp=10)
Rise Time: 18.85 s
Peak Time: 61.39 s
Maximum Peak: 0.97
Settling Time: 35.78 s
Ess: 1.02
The system is (stable)
```

Kp=100

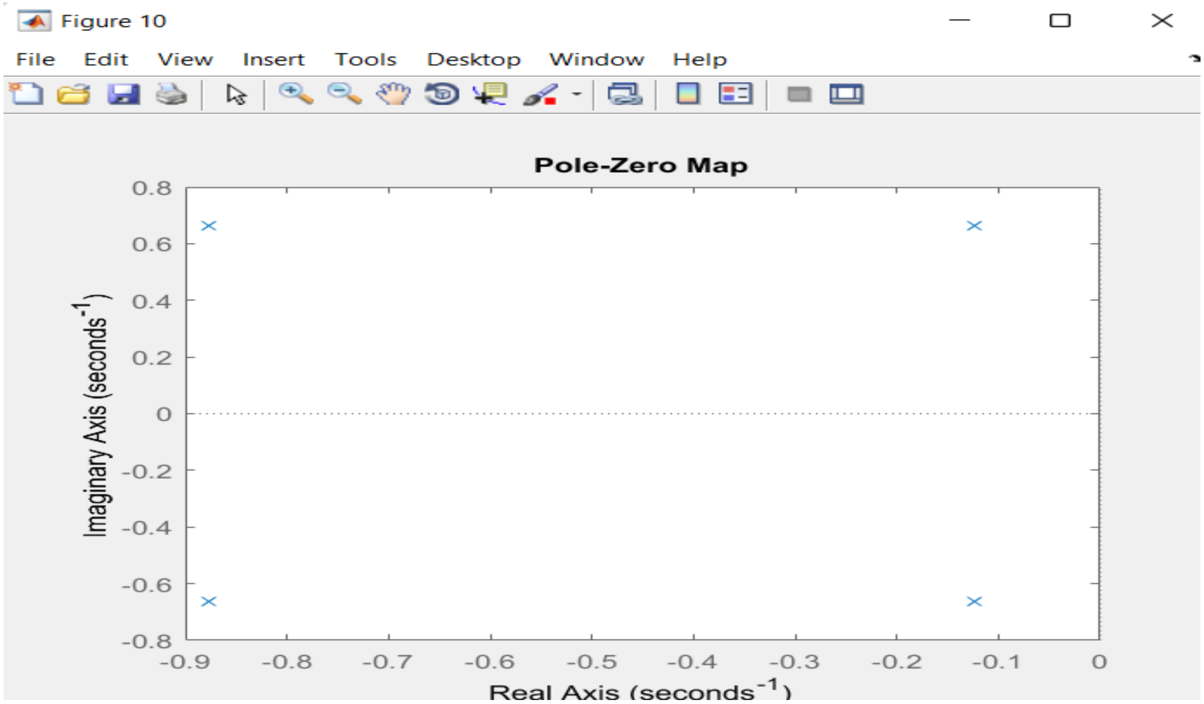


Figure 10
File Edit View Insert Tools Desktop Window Help
Pole-Zero Map
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
Imaginary Axis (seconds^-1)
-0.9 -0.8 -0.7 -0.6 -0.5 -0.4 -0.3 -0.2 -0.1 0
Real Axis (seconds^-1)

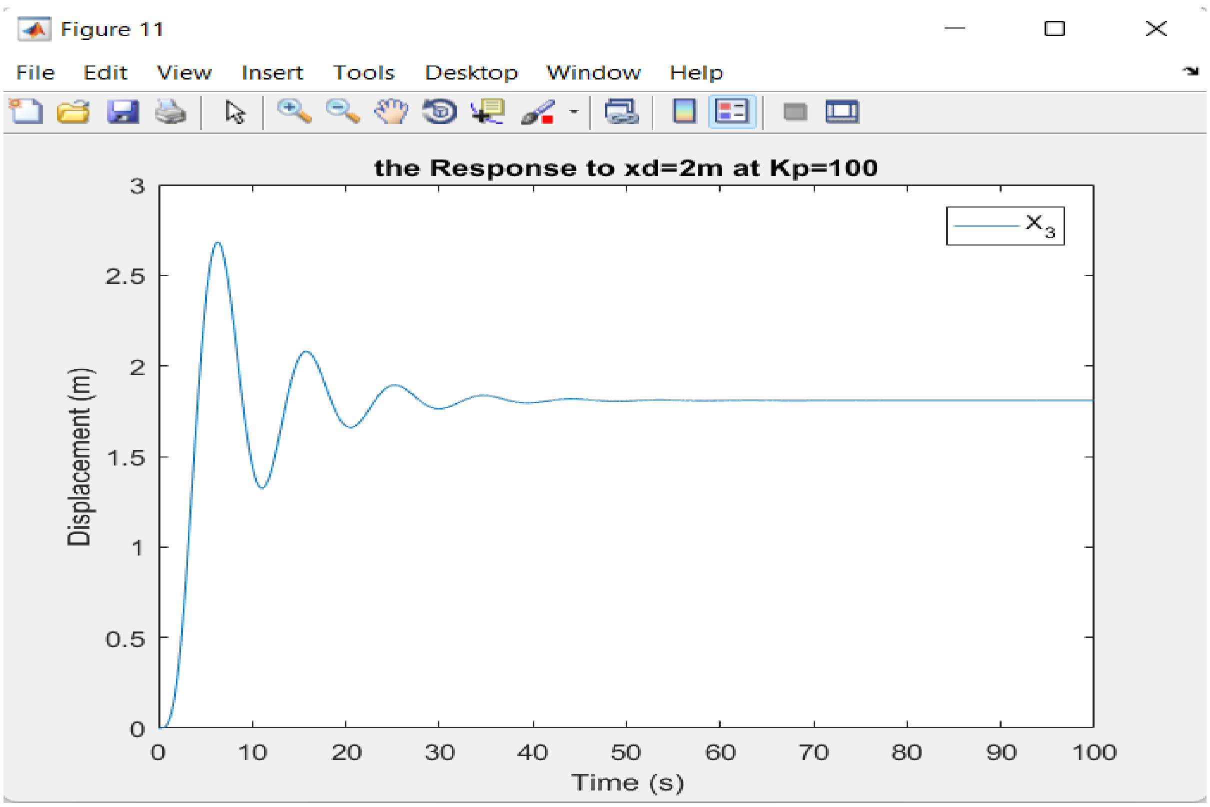


Figure 11
File Edit View Insert Tools Desktop Window Help
the Response to xd=2m at Kp=100
X3
3
2.5
2
1.5
1
0.5
0
Displacement (m)
0 10 20 30 40 50 60 70 80 90 100
Time (s)

Transient Response:

```
at kp=100
Rise Time: 2.22 s
Peak Time: 6.31 s
Maximum Peak: 2.68
Settling Time: 31.01 s
Ess: 1.02
The system is (stable)
```

Kp=1000

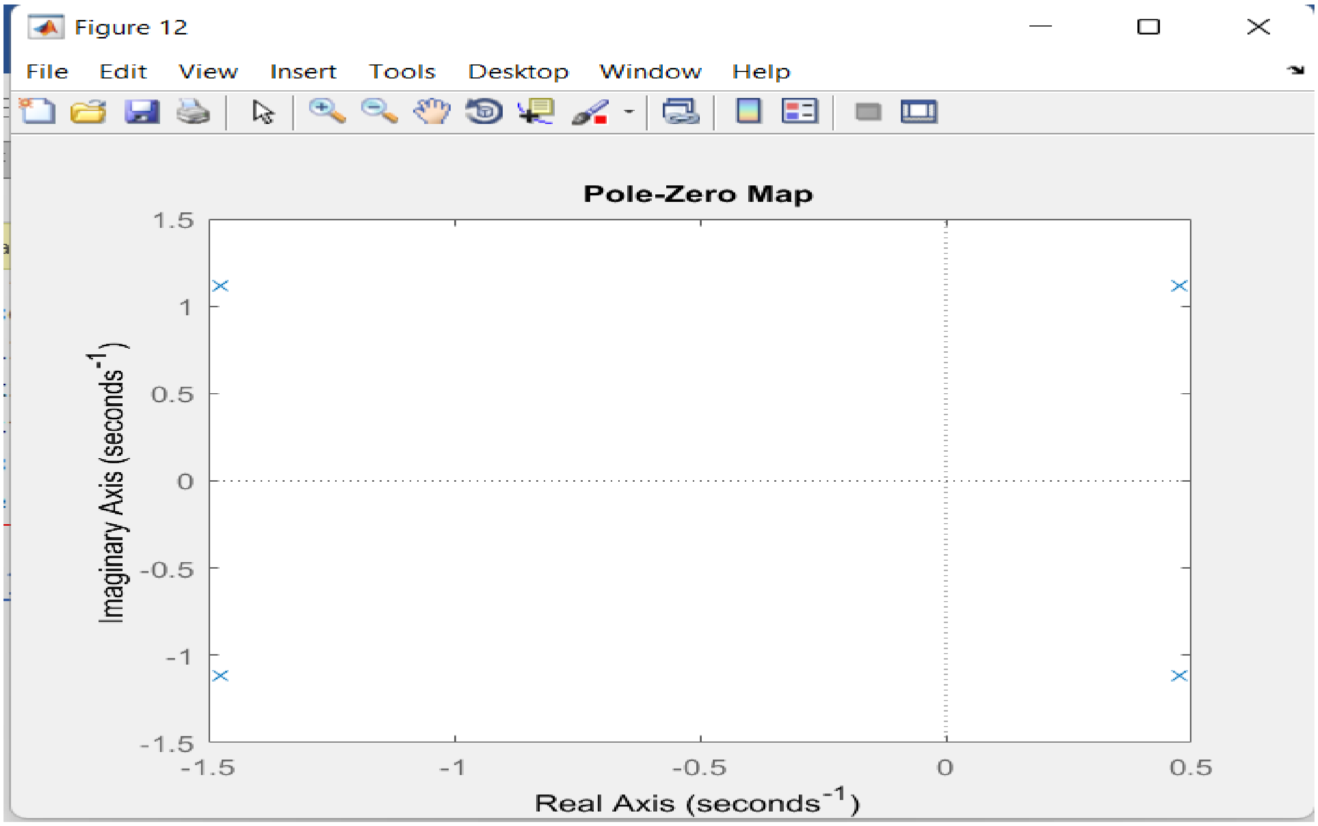
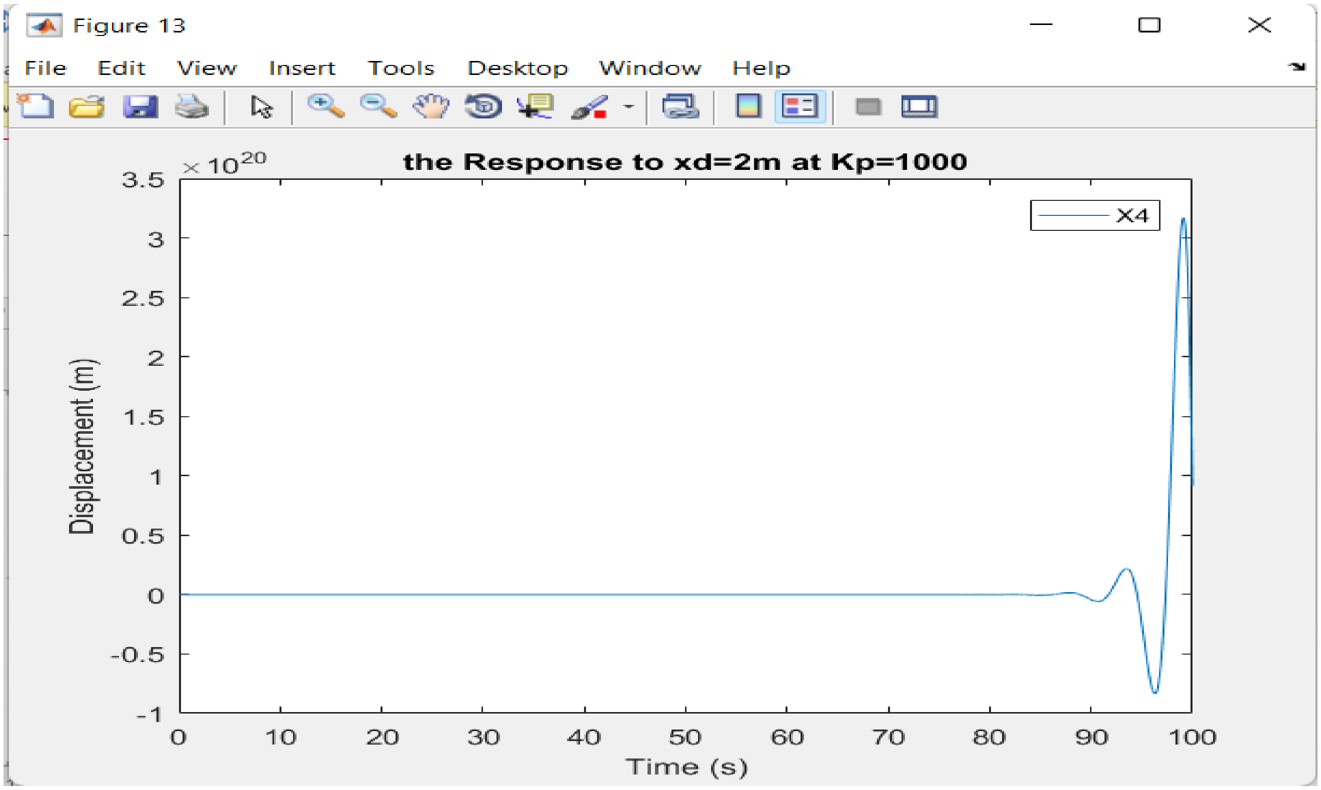


Figure 12
File Edit View Insert Tools Desktop Window Help
Pole-Zero Map
1.5
1
0.5
0
-0.5
-1
-1.5
Imaginary Axis (seconds^{-1})
-1.5
-1
-0.5
0
0.5
Real Axis (seconds^{-1})



Transient Response:

```
at kp=1000
Rise Time: NaN s
Peak Time: Inf s
Maximum Peak: Inf
Settling Time: NaN s
Ess: 1.02
The system is (unstable)
```

conclusion about req8:

As the value of Kp increases:

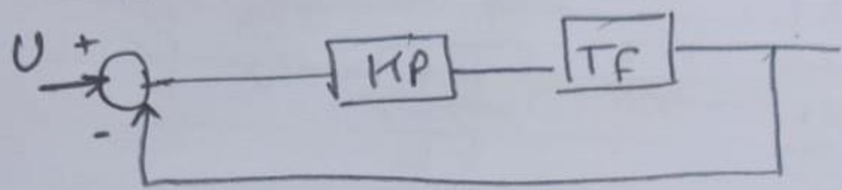
- The steady-state error (es.s) decreases. This means that the system's output approaches and maintains its desired value more closely.

- The rise time decreases. Rise time refers to the time it takes for the system's output to reach and settle within a small range around the steady-state value for the first time.
- The settling time decreases. Settling time is the time required for the system's output to reach and remain within a specific tolerance band around the desired value.
- The peak time decreases. Peak time is the time taken for the system's output to reach the first peak or overshoot after the step input.
- The magnitude of the maximum peak increases. This refers to the maximum overshoot of the system's output beyond the desired value.

However, it's important to note that increasing Kp beyond a critical value can lead to instability and unpredictability in the system. At this critical value, the system can become highly sensitive to changes and may exhibit oscillations or divergent behavior.

Req 9:

req 9:



$\because e_{s.s} = \frac{1}{1+K_p}$, input is unit step of value 4 m

$\therefore r(t) = 4t$

$\therefore e_{s.s} = \frac{4}{1+K_p}$

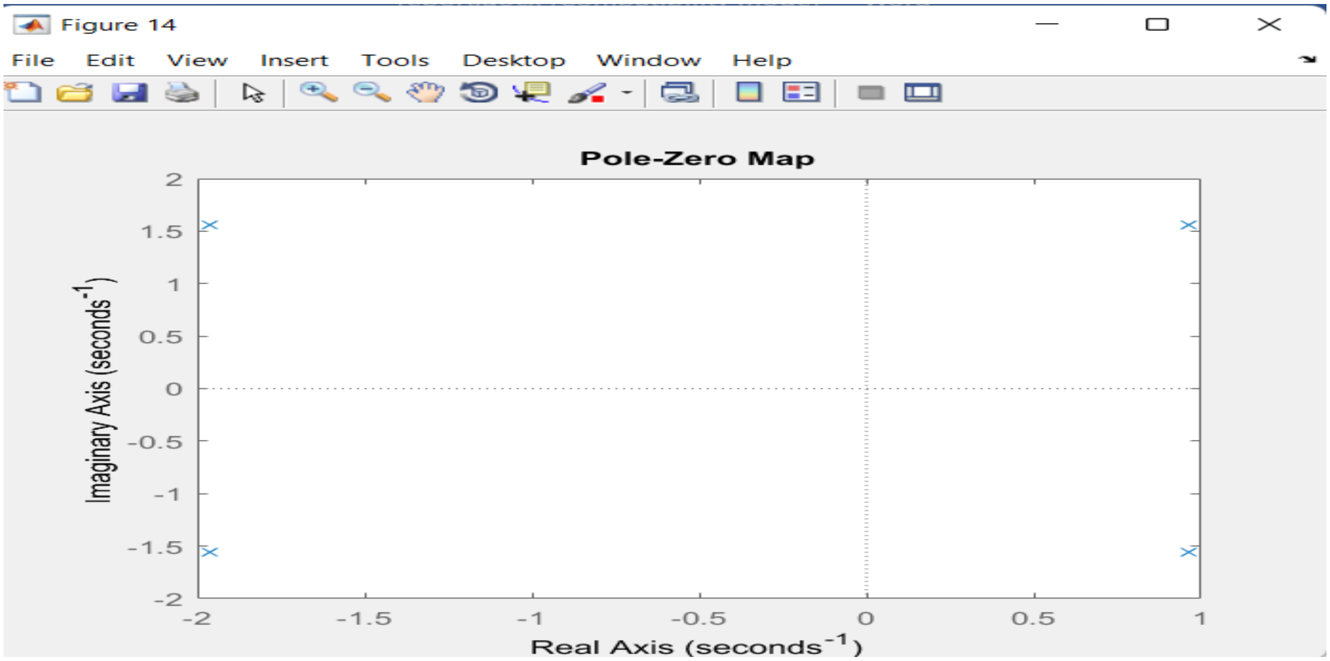
$$K_p = \lim_{s\to\infty} G(s) = \lim_{s\to 0} \frac{K_p(0.005)}{s^4+2s^3+2.1s^2+1.1s+0.525}$$

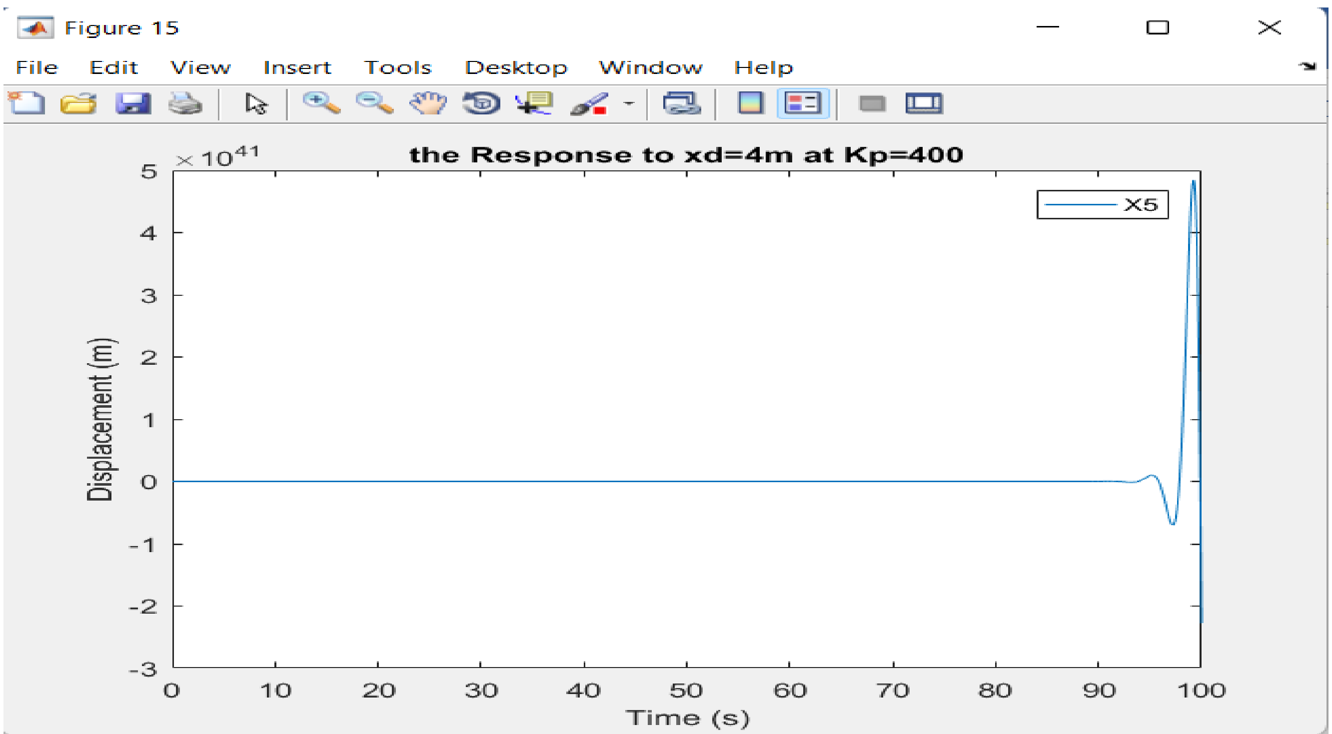
$$= \frac{K_p(0.005)}{0.0525} = \frac{2}{21}K_p$$

$$\therefore \frac{4}{1+\frac{2}{21}K_p} < 0.01$$

$$\therefore 4 < 0.01\left(1+\frac{2}{21}K_p\right)$$

$$\therefore \boxed{K_p > 4189.5} \quad \#$$





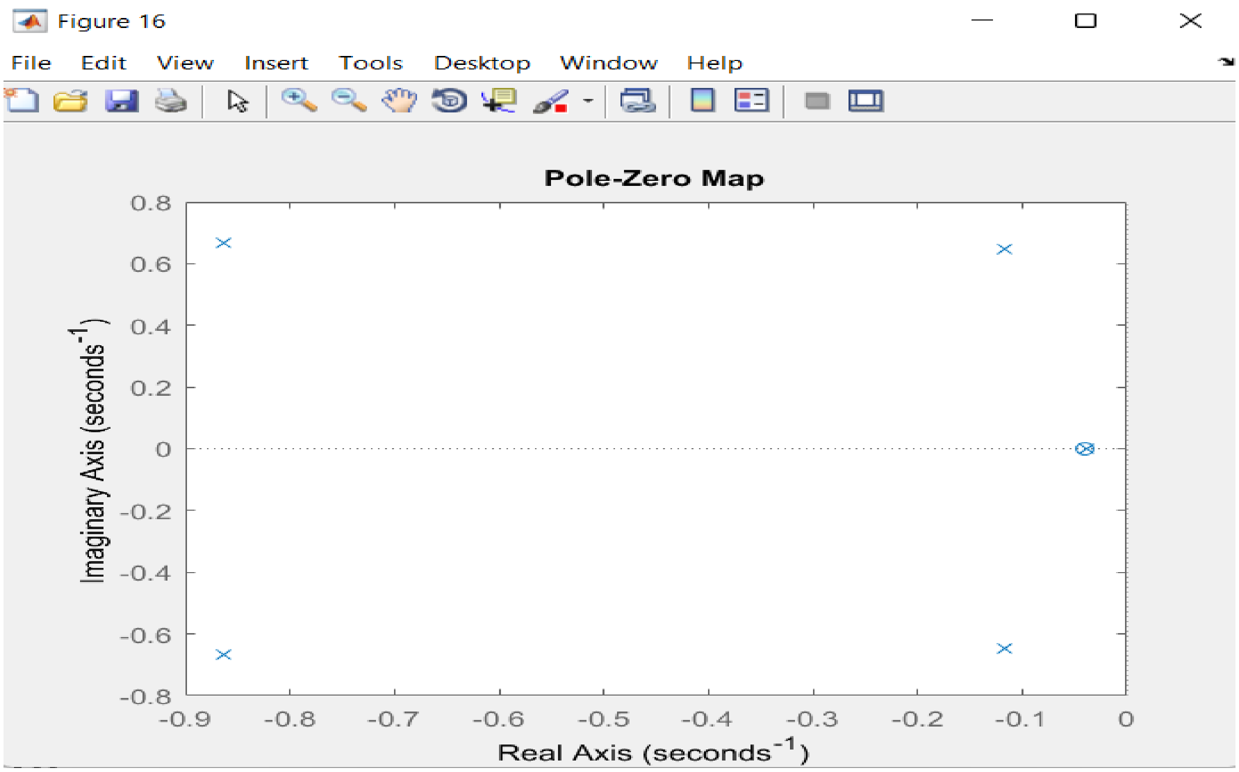
Note:

after solving the problem, we conclude that we need Kp to be greater than 4189.6 to make the es.s less than 0.01 , but this value of Kp make the system unstable.

Req 10:

To improve the steady-state error (ess) in the system, we decided to use a PI controller, which includes an integrator component. After experimenting with different values, we found that setting the integral gain (KI) to 4 and the proportional gain (Kp) to 100 resulted in a stable system.

To enhance the system's steady-state error performance, a PI controller was implemented by adding an integrator. After conducting several trials, it was determined that assigning a value of KI = 4 and Kp = 100 to the integral and proportional gains, respectively, achieved stability while satisfying the desired steady-state error requirements.



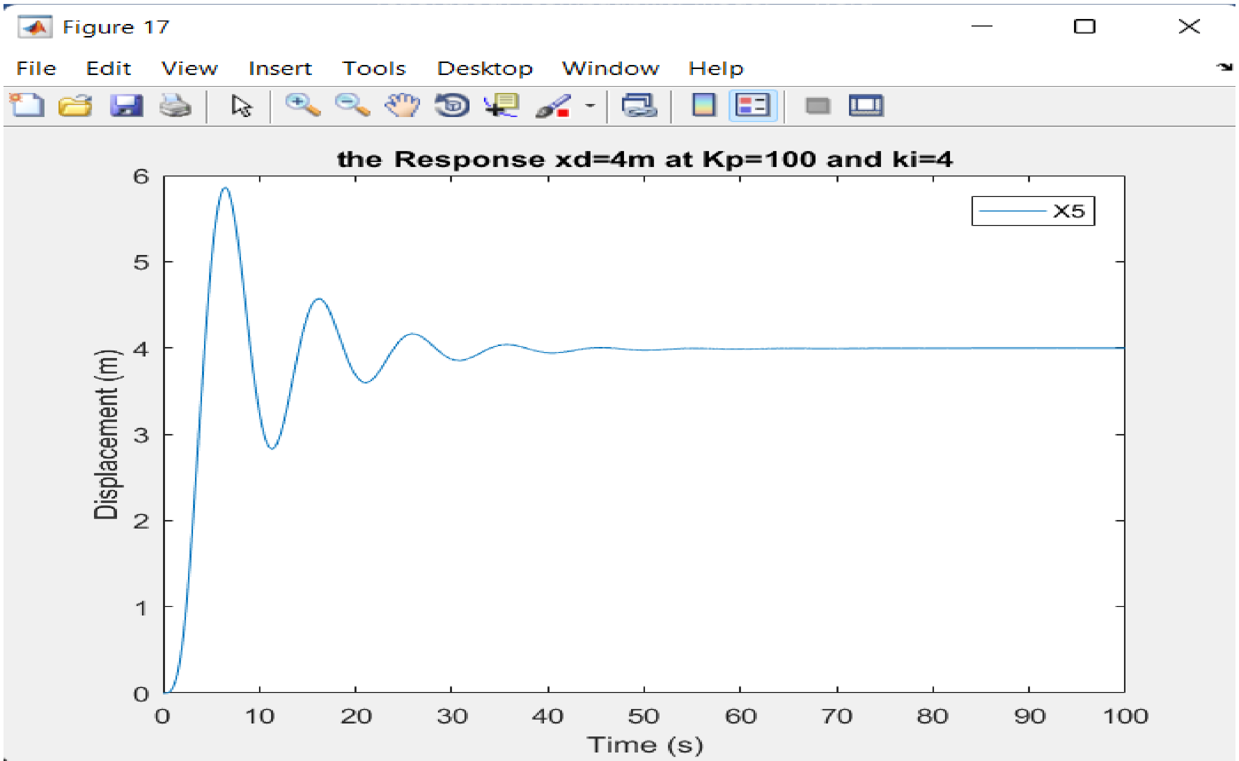


Figure 17
File Edit View Insert Tools Desktop Window Help
the Response xd=4m at Kp=100 and ki=4
X5
Displacement (m)
Time (s)
0
1
2
3
4
5
6
0
10
20
30
40
50
60
70
80
90
100