信号、系统与控制课程报告

2020 至 2021 学年第二学期

项目名称：Project II

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CQU-UC Joint Co-op Institute (JCI)
Student Project Report

Project I of System & Signal Control

Institution CQU-UC Joint Co-op Institute (JCI)

Grade 2018 **Major** Mechanical Engineering **Class** 01

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MECH 4081 (15FS)

In Part I, the open loop transfer function for the electro-hydraulic system was found. Refer to the Part I solution (posted on Blackboard after Nov. 30) and, in case of disagreement, use the pole and zero locations given for this transfer function $G_p(s)$ as the plant transfer function:

$$\frac{Y(s)}{U(s)} = \frac{X_3(s)}{U(s)} = \frac{(\ )s + (\ )}{(\ )s^6 + (\ )s^5 + (\ )s^4 + (\ )s^3 + (\ )s^2 + (\ )s + (\ )} = G_p(s)$$

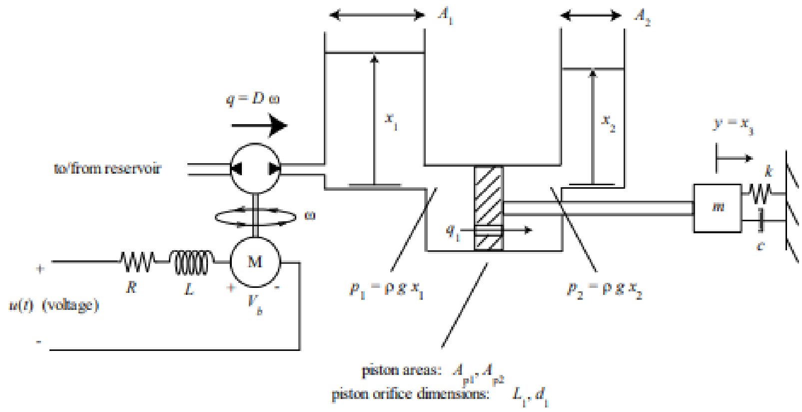

Figure 1: Open loop system (plant).

This system will be evaluated for its step response in a feedback configuration, as shown in Figure 2. The use of feedback presumes that we have a position sensor (to measure x_3) and the necessary amplifiers. The allowable filter transfer functions $G_c(s)$, or $G_{c1}(s)$ and $G_{c2}(s)$, will be described shortly.

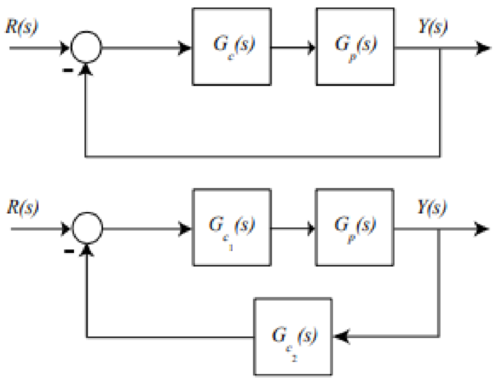

Figure 2: Above system shows feedback configuration with forward path filter transfer function $G_c(s)$ and plant transfer function $G_p(s)$. In some cases, if $G_c(s)$ contains multiple lead and/or lag filters, it may be advantageous to locate some terms in the feedback path (shown below).

Design Criteria:

You need to design a number of filter transfer functions $G_c(s)$ (or $G_{c1}(s)$ and $G_{c2}(s)$), within the limitations described below, which yield a closed loop system having the following design targets:

- Overshoot/oscillation (for a step input) of the closed loop system should (if possible) be reduced to a level equivalent to a damping ratio of 0.6 or greater.
- The *rise time* or effective *time constant* of the closed loop system should be equivalent to or faster (i.e., shorter) than that of the open loop system.
- Steady-state error or final value of the system response may be ignored in this study.

Complete the following steps:

1. Using proportional control, $G_c(s) = k_0$
    - Plot the root locus in Matlab.
    - Select a value of gain k_0 which yields a stable closed loop system.
    - Form the closed loop transfer function, and plot the closed loop step response.
    - Discuss.

2. Using a fourth-order filter, $\alpha = 20,\ G_c(s) = \dfrac{k_0(s+z_1)(s+z_2)(s+z_3)(s+z_4)}{(s+20z_1)(s+20z_2)(s+20z_3)(s+20z_4)}$
    - Select z_1, z_2, and z_3 to approximately cancel the three real plant poles closest to the imaginary axis.
    - Plot the root locus in MATLAB for the compensated system $G_c(s)G_p(s)$ for various values of z_4, and tune the value of z_4 to attempt to meet the damping ratio specification. Then,
        - Using the data cursor in the root locus window, find the value of gain k_0 corresponding to the required damping ratio along the dominant branch(es) of the locus.
        - Form the closed loop transfer function using this k_0, and plot the step response.
        - Some trial and error may be required. Use a high precision root locus plot, as described in Hint #6.
    - Discuss.

Catalog

Problem 1

Introduction

Among this part, a close system was formed according to the below schematic diagram based on the primary system mentioned and calculated in the previous main question.

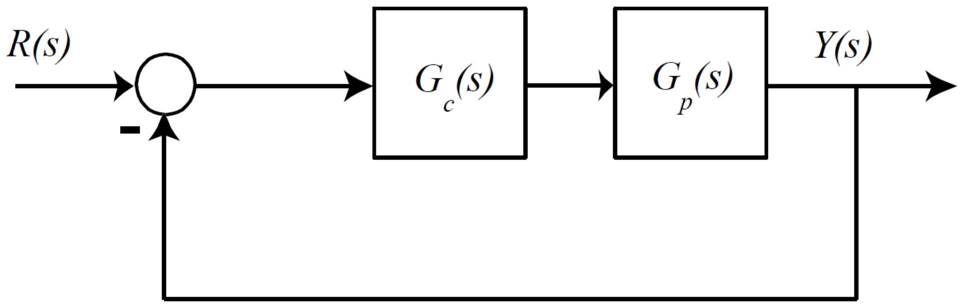

Figure 1: The schematic diagram of this close system

Assume the open loop transfer function in Part 4 can be regarded as following:

$$G_{open} = \frac{N(s)}{D(s)}$$

As a result, the closed loop transfer function can be calculated as following:

$$G_{open} = \frac{G_{open}}{1 + G_{open}} = \frac{\frac{k_0 N(s)}{D(s)}}{1 + \frac{k_0 N(s)}{D(s)}} = \frac{k_0 N(s)}{D(s) + k_0 N(s)}$$

In code aspect, the new system can be regarded as the original system was series connected with a proportional shifter and then feedback with feedback coefficient equal to 1. This is the key point of coding this part.

Root Locus Plot

It is known that the Root Locus Plot rely on the open loop transfer function, so in the fourth part of our code, rlocus(sys1) was applied to generate the root locus diagram as below:

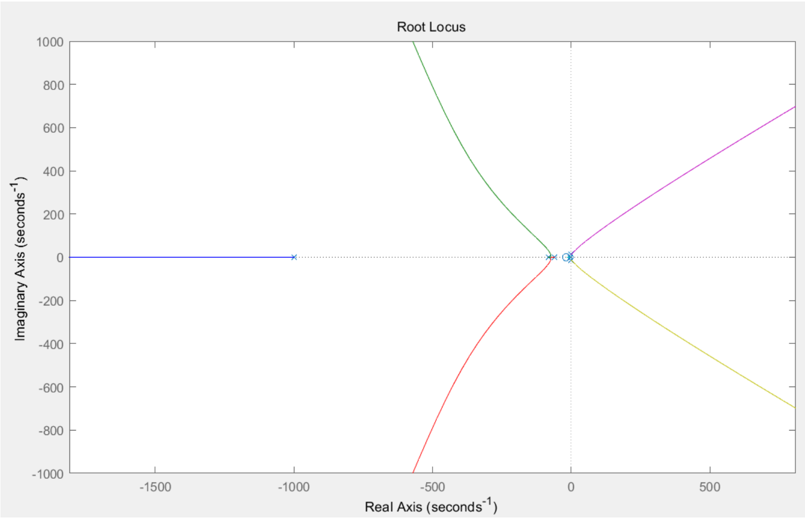

Figure 2: The root locus diagram of this close system

After modifying the axis region to equal, the left side single pole was discarded, as a result, a dense distribution of poles and zero points near the imaginary axis is revealed:

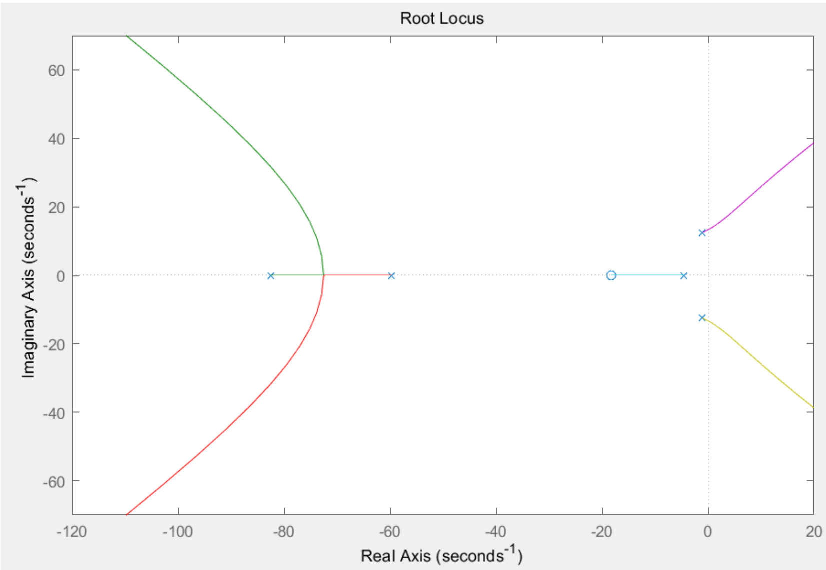

Figure 3: The root locus diagram of this close system after axis region modifying

Select appropriate k_0

To determine whether a value of $k0$ will leads to a stable system or an open system, we are supposed to check the trend of $k0$ on the right-hand side of the Ima-axis:

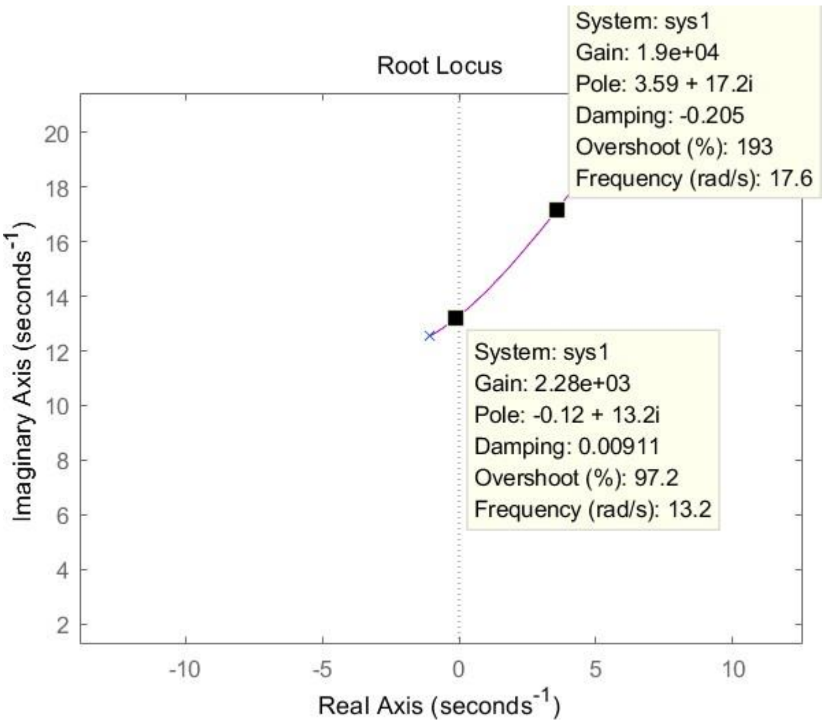

Figure 4: The trend of $k0$ on the right-hand side of Img-axis of root locus diagram

It can be seen that the critical value of $k0$ is about 2280, and it has the increasing tendency while getting far away from the Img-axis. So, the condition of $k0$ to yield a stable close loop system is:

$$0 < k0 < 2280$$

For security, we make this region smaller on the right-hand side:

$$0 < k0 < 2000$$

After acquiring the region of close-loop-system $k0$ value, we can randomly select a value within the region. For convenience, we select $k0 = 100$.

Under this circumstance, the transfer function is:

$$G_{close} = \frac{4.12 \times 10^6 s + 7.524 \times 10^7}{s^6 + 1149s^5 + 1.549 \times 10^5 s^4 + 6.1 \times 10^6 s^3 + 5.833 \times 10^7 s^2 + 9.367 \times 10^8 s + 3.586 \times 10^9}$$

Moreover, the step response of this stable close loop system is shown as following:

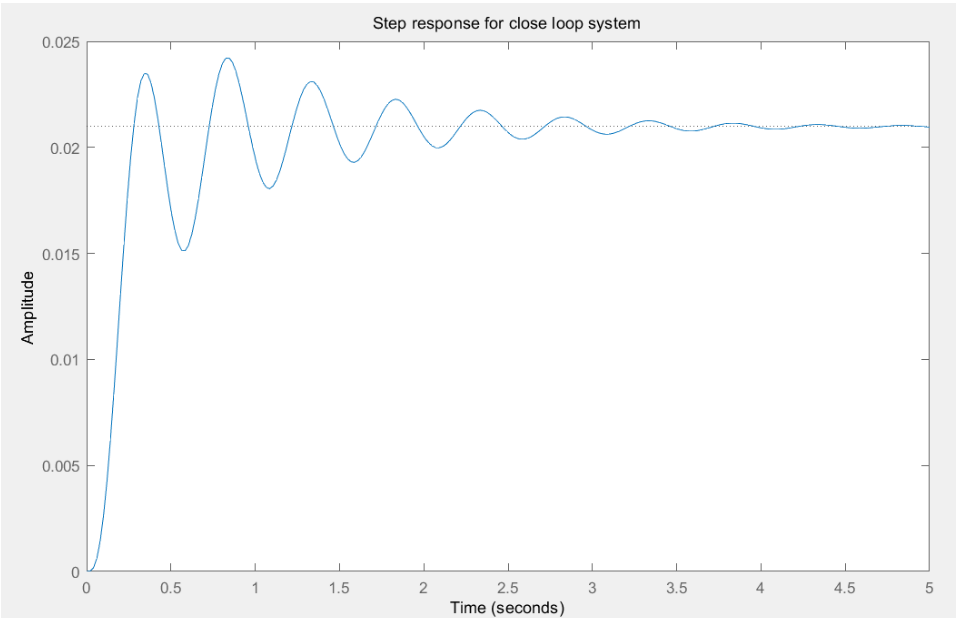

Figure 5: The step response of this stable close loop system with $k0$ equals to 100

Discussion

In the additional problem, due to many undesirable properties of the open-loop system, we need to design it as a stable closed-loop system, so the trunk proportional parameters and feedback proportional coefficient of the closed-loop system need to be determined.

Fortunately, the feedback scaling factor is known to be one, so the only objective is to determine the trunk scaling parameter.

In order to achieve this goal, we determine the range of trunk proportional parameters by image method again. Since it is chosen as a random value, our group takes 100 as the value of $k0$. From the image of step response, it can be also seen that the system converges, making a double insurance for our value.

Problem 2

Select appropriate z1, z2, z3

From part 1, we know that:

$$G_p(s) = \frac{(4.1202\times10^4)s + (7.5239\times10^5)}{s^6 + (1.1488\times10^3)s^5 + (1.5498\times10^5)s^4 + (6.1557\times10^6)s^3 + (6.2045\times10^7)s^2 + (8.394\times10^8)s + (3.5111\times10^9)}$$

Meanwhile, roots and zeros are shown as following:

Poles	Zeros
-999.900097674933	-18.2609209567312
-82.5247594166687	
-59.7138897620699	
-1.07746927972736+12.5345683779693i	
-1.07746927972736-12.5345683779693i	
-4.50210380482392	

For Gc,

$$G_c(s) = \frac{k_0(s+z_1)(s+z_2)(s+z_3)(s+z_4)}{(s+20z_1)(s+20z_2)(s+20z_3)(s+20z_4)}$$

We set

z1 = 4.50210380482392;

z2 = 59.7138897620699;

z3 = 82.5247594166687;

Plot the root locus

For z_4, we first plug several guesses. For instance, we guessed 1, 5, 10, 50, 100, 500 We found that when z_4=5, the time consuming of step response to reach steady state is the smallest. Hence, we choose z_4=5.

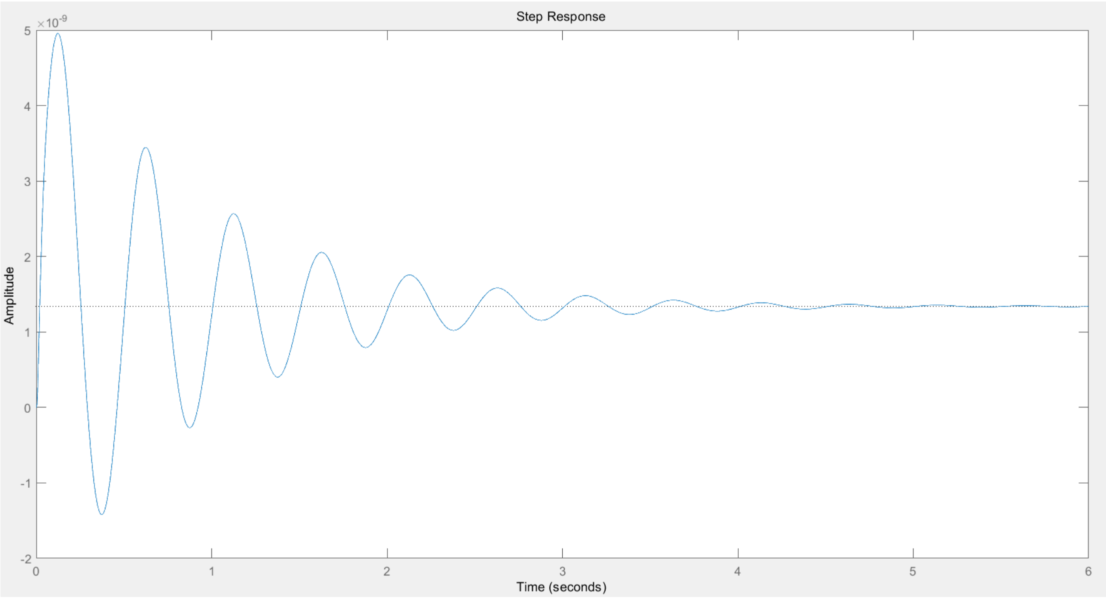

Figure 6: The step response when z_4=5

After choosing z_4=5, we plot the root locus as following:

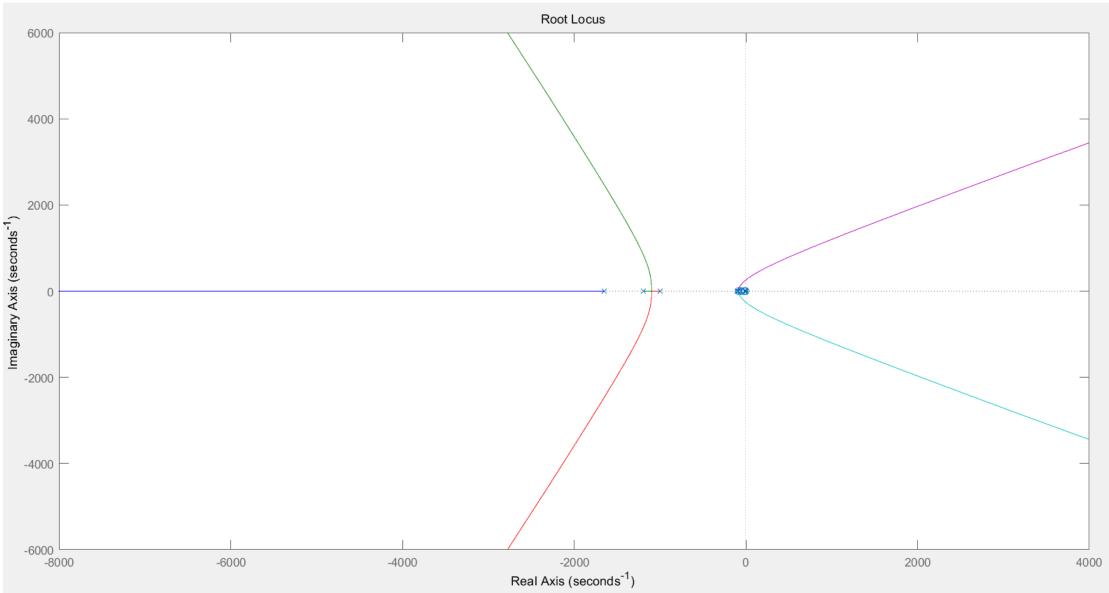

Figure 7: The root locus when z_4=5

After zooming on, we can read the gain k_0, which is 3.87×10^9

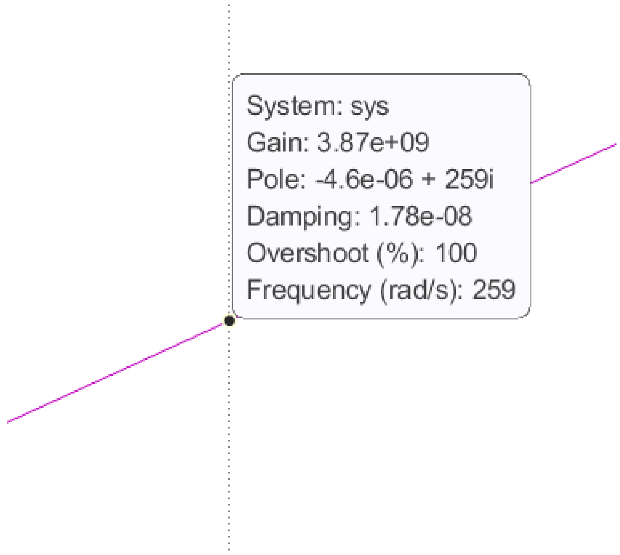

Figure 8: The gain k_0 read from root locus plot

Then we plug the new gain k_0 into the expression and plot the new step response as following shown:

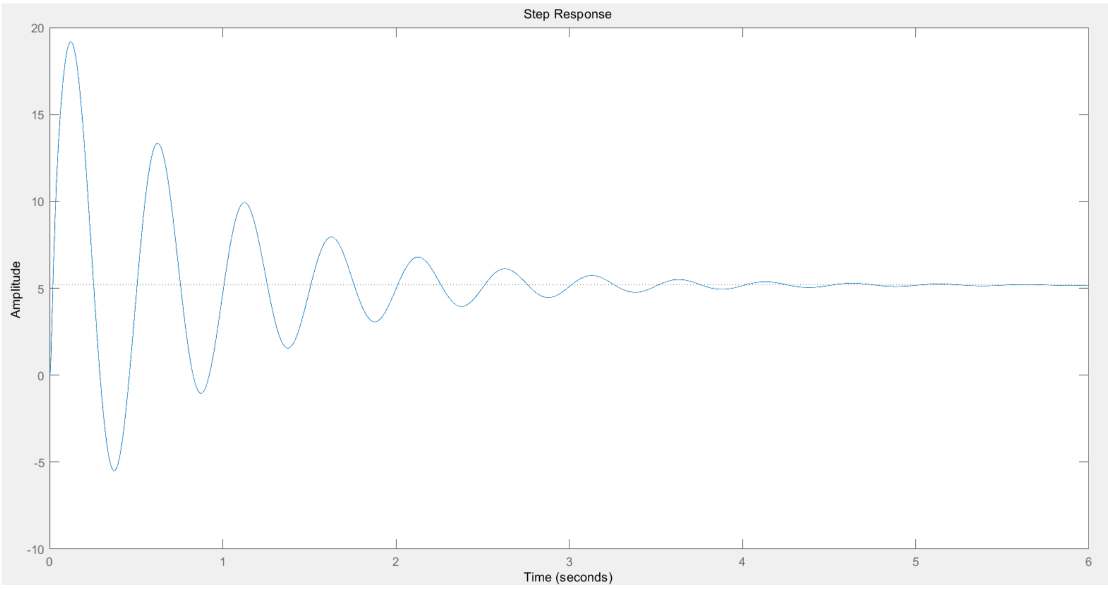

Figure 9: The step response after set k_0

We see that the time consuming of step response to reach steady state is smaller than that before we set k_0. Meanwhile, the amplitude became more readable.

Discuss

First, we adjusted the parameters of the fourth-order filter, using the poles of G_p as the numerator of the filter equation, and eliminated the denominator of G_p in this way.

Then we select the most appropriate z_4 by comparing the stable speed of the step response in the case of multiple z_4.

Moreover, after selecting z_4, we found k_0 corresponding to the stable critical state.

When we finish the whole process, we can see that after we add a fourth-order filter, by observing the response speed of the step response, we can find that the entire system is more likely to stabilize.

Problem 3

We set G_{c1} as following:

$$G_{c1} = \frac{k_0(s+z_3)}{s+20z_3}$$

and we set G_{c2} as following:

$$G_{c2} = \frac{(s+z_1)(s+z_2)(s+z_4)}{(s+20z_1)(s+20z_2)(s+20z_4)}$$

Hence, the new system response can be expressed by:

$$H(s) = \frac{G_{c1} \times G_p}{1 + G_{c1} \times G_p \times G_{c2}}$$

The new system response is plotted as shown, the time consuming of step response to reach steady state is just about 3.5 second.

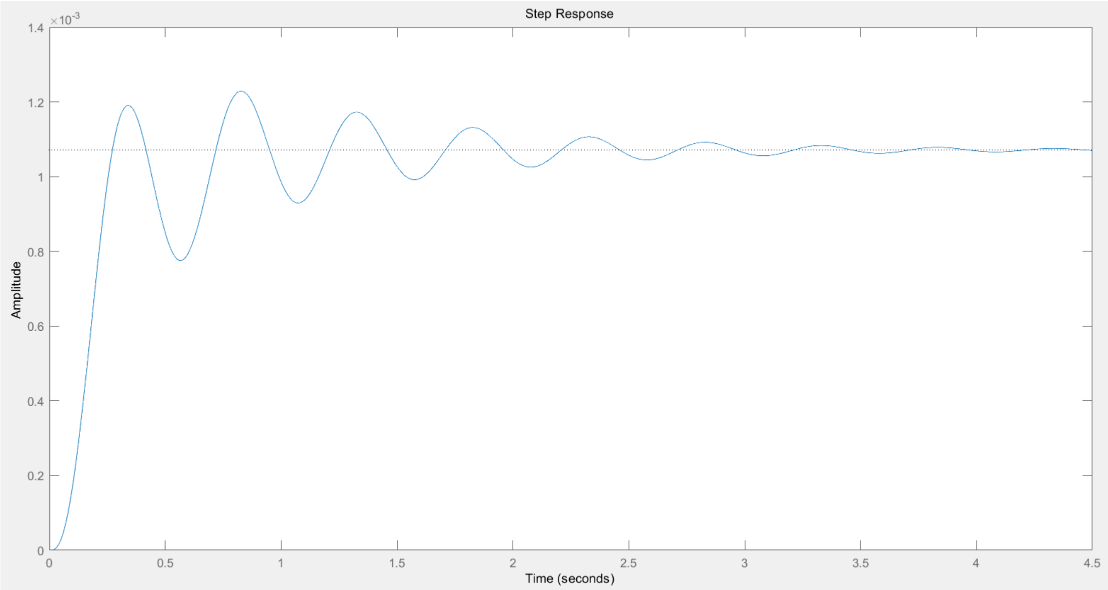

Figure 9: The step response when α=20

Before we separate the Gc1 and Gc2, the time consuming of step response to reach steady state is about 4.5 second.

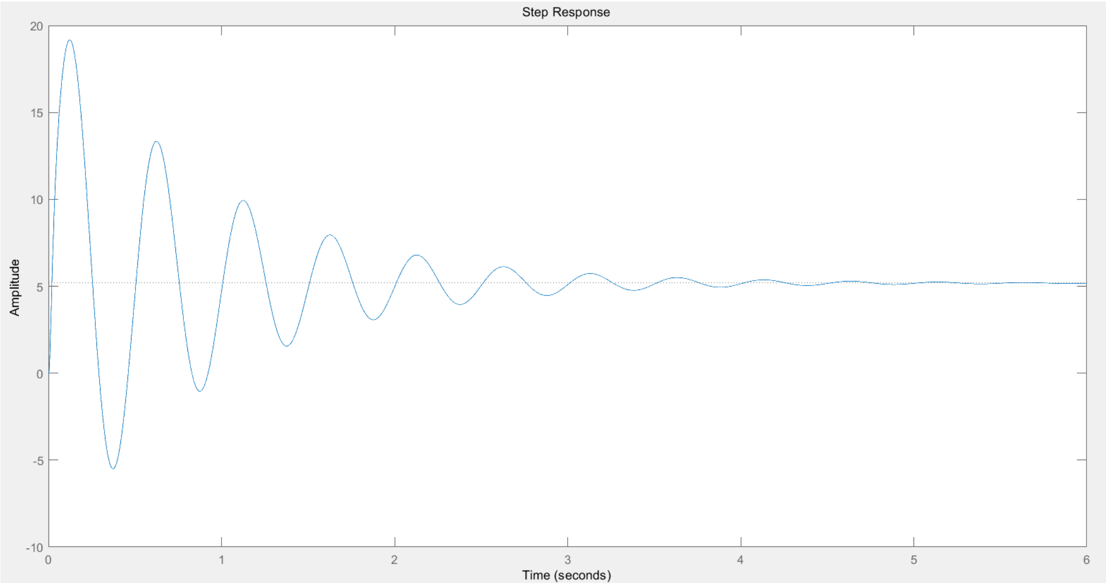

Figure 10: The step response without separate Gc1 and Gc2

Overall, the step response time consuming of the new system is greatly reduced, which can show that the stability of the system has been greatly improved after Gc1 and Gc2 are split. Moreover, we believe that this system has a better performance, and it is a more efficient and economical system.

Problem 4

When we choose the previous design ($\alpha = 20$), the time consuming of step response to reach steady state is about 4.5 second.

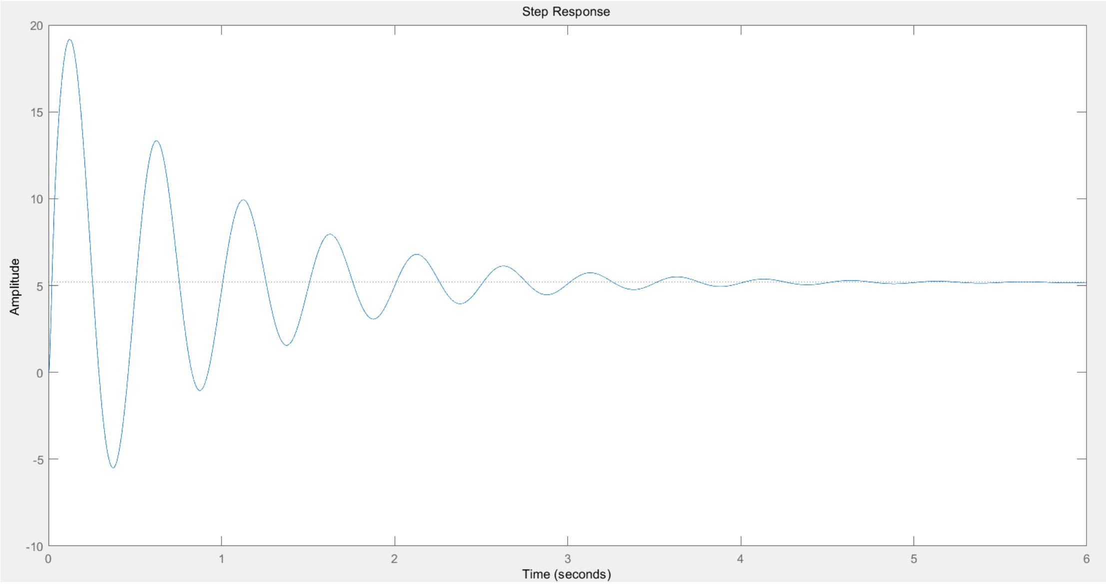

Figure 10: The step response when α=20

When we choose $\alpha = 1000$, the time consuming of step response to reach steady state is about 5 second.

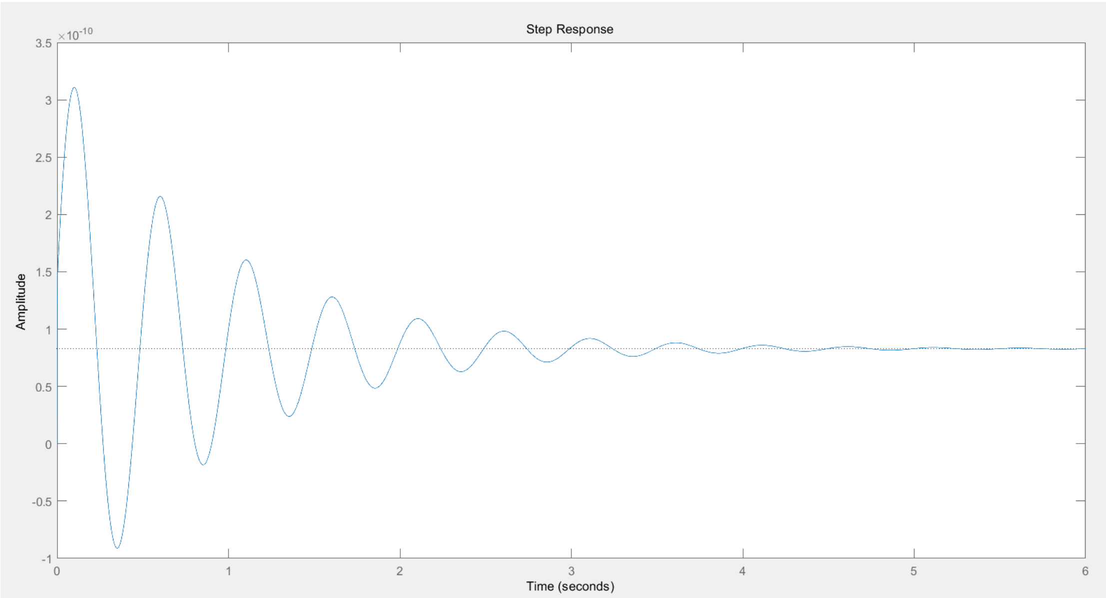

Figure 9: The step response when α=1000

When we choose $\alpha = 1$, the time consuming of step response to reach steady state is about 4 second.

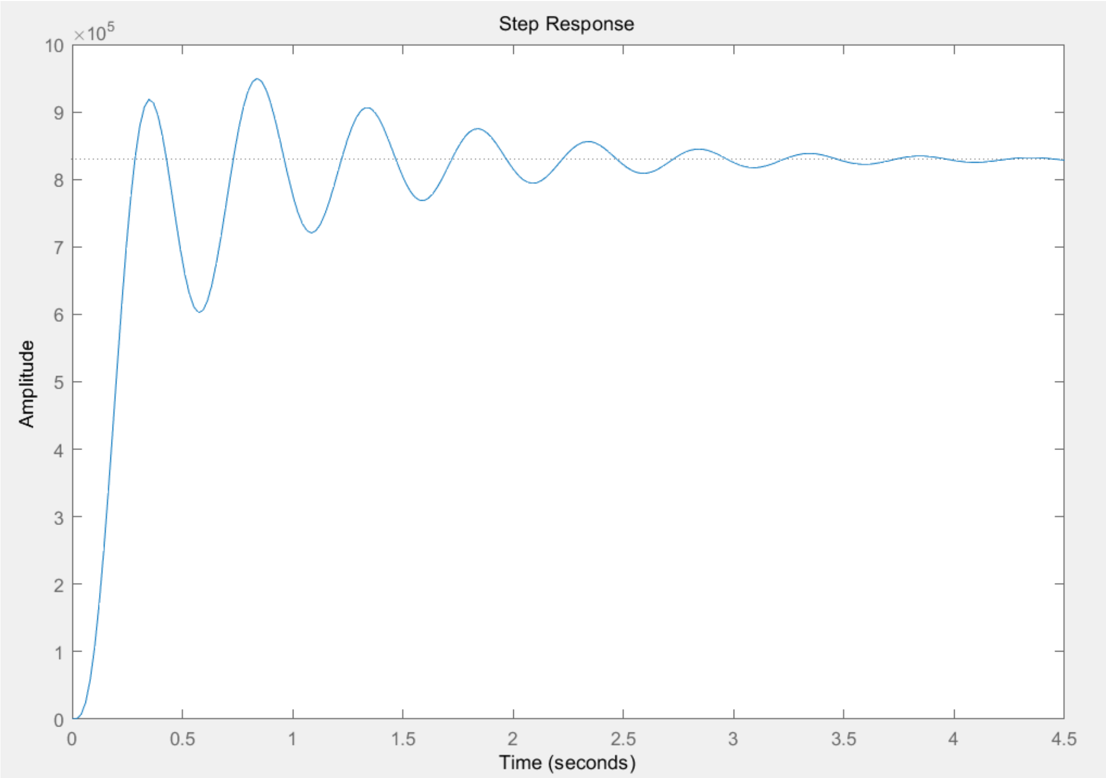

Figure 9: The step response when α=1

Comparing these two cases, it is easily for us to find that smaller α can lead to less time to reach steady state. Namely, it means that the system is more economical.

Appendix

```
%% Project
% Group Member: Xiangyu Han 20186102
%                        Hongrui Yi    20186103
%                        Yan Zhuang    20186105
% Initialize
clear;clc;close all; format long e
%% Constant parameters
R=2;
L=0.002;
J=0.005;
b=0.5;
kb=0.03;
kt=0.03;
D=0.0035;
m=2.5;
k=300;
c=0.25;
A1=0.025;
A2=0.015;
Ap1=0.025;
```

```
Ap2=0.010;

density=1000;

viscosity=0.00089;

d1=0.015;

L1=0.03;

g=9.81;

R1=128*viscosity*L1/pi/d1^4;


%% first-order (state variable) form

A = [-R/L, -kb/L, 0, 0, 0, 0;

kt/J, -b/J,-D*density*g/J, 0, 0, 0;

0, D/A1,-density*g/A1/R1, density*g/A1/R1, 0, - Ap1/A1;

0, 0, density*g/A2/R1, -density*g/A2/R1, 0, - Ap2/A2;

0, 0, 0, 0, 0, 1;

0, 0, Ap1*density*g/m, -Ap2*density*g/m, -k/m, - c/m;];


%% Find the open loop system transfer function

%denote y(t) = x3

% so y(t) = [0 0 0 0 1 0]*[Unknowns]';

b = [1/L; 0; 0; 0; 0; 0];

c = [0, 0, 0, 0, 1, 0];

sys1 = ss(A,b,c,0);
```

```
[num,den] = tfdata(sys1,'v'); root_zeros = roots(num); root_poles =
roots(den); tf_func = tf(num,den)

%% Plots
figure(1)
pzmap(sys1);
axis equal
figure(2)
step(sys1);
title('Step response for open loop system')
figure(3)
rlocus(sys1);
axis([-1500 500 -1000 1000])
axis equal
zoom on
figure(4)
rlocus(sys1);
axis([-120 20 -70 70])
axis equal zoom on

%% Part II prob1
% Select k0 making gain = 1.5e04;
```

```
value_num = polyval(num,-77.4);

value_den = polyval(den,-77.4); k0 = 100;

sys2 = k0;

sys3 = series(sys2,sys1);

sys4 = feedback(sys3,1);

figure(5)

step(sys4);

title('Step response for close loop system')


%% Part II prob2

% set z1 to z4

z1 = 4.50210380482392;

z2 = 59.7138897620699;

z3 = 82.5247594166687;

z4 = 5;

alpha = 1;% set alpha

s = tf('s');

sys = 3.87e+9 * ((s+z1)*(s+z2)*(s+z3)*(s+z4)) /

((s+alpha*z1)*(s+alpha*z2)*(s+alpha*z3)*(s+alpha*z4))

*       ((4.12*10^4*s+7.524*10^5) /

(s^6+1149*s^5+1.549e+5*s^4+6.1e+6*s^3+5.833e+7*s^2+9.

325e+8*s+3.511e+9));
```

```
% plot the step response and root locus
figure(6)
step(sys)
figure(7)
rlocus(sys)

%% Part II prob3
% set z1 to z4
z1 = 4.50210380482392;
z2 = 59.7138897620699;
z3 = 82.5247594166687;
z4 = 5;
% seperate Gc1 and Gc2
s = tf('s');
Gc1=k0*(s+z3)/((s+20*z3));
Gc2=(s+z1)*(s+z4)*(s+z2)/((s+20*z1)*(s+20*z4)*(s+20*z2))
;
sys = Gc1*sys1/(1+Gc1*sys1*Gc2);
% plot the step response and root locus
figure(8)
step(sys)
figure(9)
```

```
rlocus(sys)
```