Optimizing stability and performance is an aim for control system engineers. Engineers can modify a system's behavior to achieve certain performance goals while retaining stability by investigating alterations in the frequency domain, using feedback, and employing cascaded compensating mechanisms. In this project, frequency domain performance adjustment is investigated in practice. We demonstrate the benefits of these methods for improving the performance of stable systems across a variety of applications through case studies and simulations.

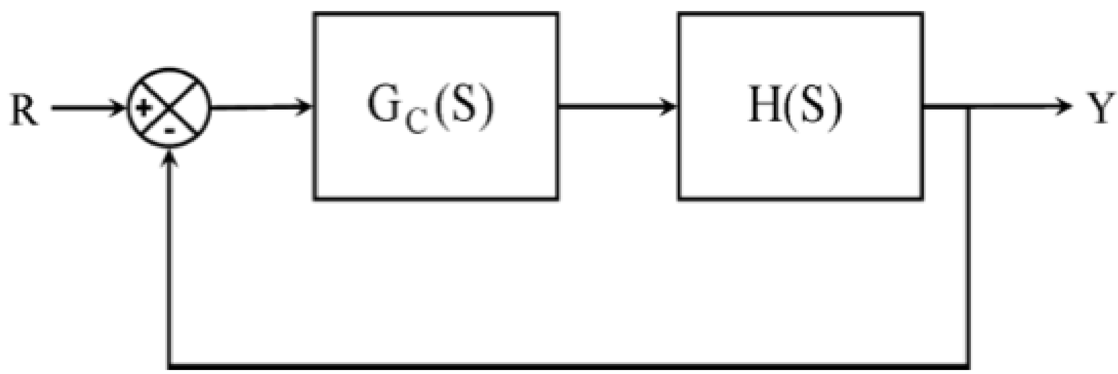


Figure (1). A feed-back system will be work on.

We can see our system and we need to find H(s) then find the rang of K which is Gc(s):

we need to select a stable system that is at least third order. Let's consider the following third-order system with transfer function:

We will choose H(s) as: $H(s) = \frac{1}{3S^3+16S^2+8S+14}$

Poles of open loop system H(s):

Using MATLAB: S= -4.9862 ,-0.1736 $\pm$ 0.9517i

Code:

```
P = pole(H);
```

Part A:

A compensating system is a type of control system designed to modify the response of a system in order to improve its performance. It typically involves using a feedback loop to monitor the output of the system and adjust the input accordingly.In the context of gain, a compensating system can be used to adjust the gain of a system to achieve a desired output.

Overall, a compensating system is a powerful tool for controlling the behavior of a system, and can be used to achieve a wide range of performance objectives.

Firstly, we will find the range of K using Routh-Hurwitz:

$$C.E: 1 + \frac{K}{3S^3 + 16S^2 + 8S + 14} = 0$$

$$C.E:\ 3S^3 + 16S^2 + 8S + 14 + \ K = 0$$

S^3	3	8
S^2	16	14+K
S^1	$\frac{16 \times 8 - (14+K)\times 3}{16}$	0
S^0	14+K	

$$An - 1 = \frac{16 \times 8 - (14+K)\times 3}{16}$$

$$An - 2 = \ 0$$

$$Bn - 1 = \ \ 14 + K$$

So , By the Routh-Hurwitz:

Third row: $K < 28.66667$

Forth row: $K > -14$

So, the range of K is: $-14 < K < 28.66667$

check:

Using MATLAB to plot root locus, the root locus enters the right-hand plane(making it unstable) when K > 28 (approximately).

Code:

```
syms s;
num1= [1];
den1= [3,16,8,14];
H= tf(num1,den1);
k=1;
sys1= feedback(k*H,1);
rlocus(sys1);
```

we will use MATLAB to find setting time (T_S) , maximum overshoot (δ)

and steady state error (ess) when K=1:

setting time (T_S) = 23.1 s

maximum overshoot (δ) = 57.4 %

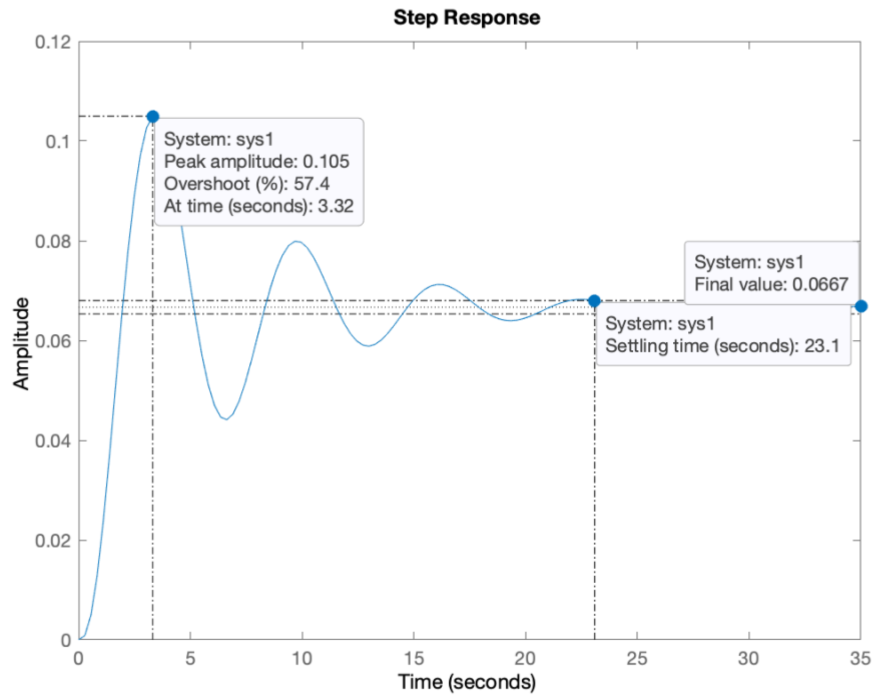


Figure (2). The step response of our system when K=1.

Code:

```
step(sys1);
grid on
stepinfo(sys1);
%% or
% x=stepinfo(sys1);
% display(x);
```

1)

Plot Ts vs K:

2)

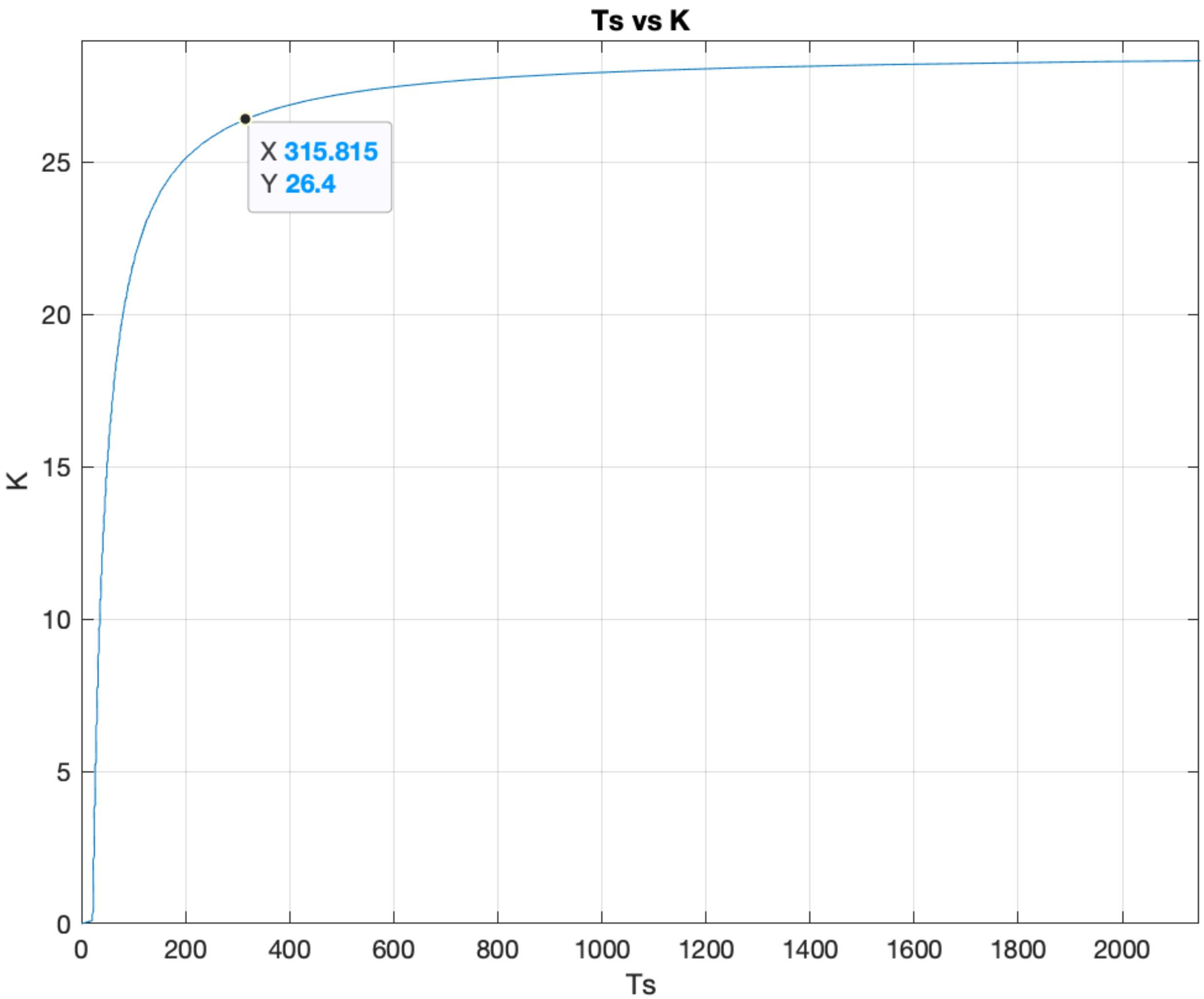


Figure (2). Ts versus K.

In figure 2, we can notice that while K swept from 0 to 28.66667 the settling time increasing as K increasing and it will reach to 316 s approximately (5.2min) when K= 26.4.

2)

Plot δ vs K:

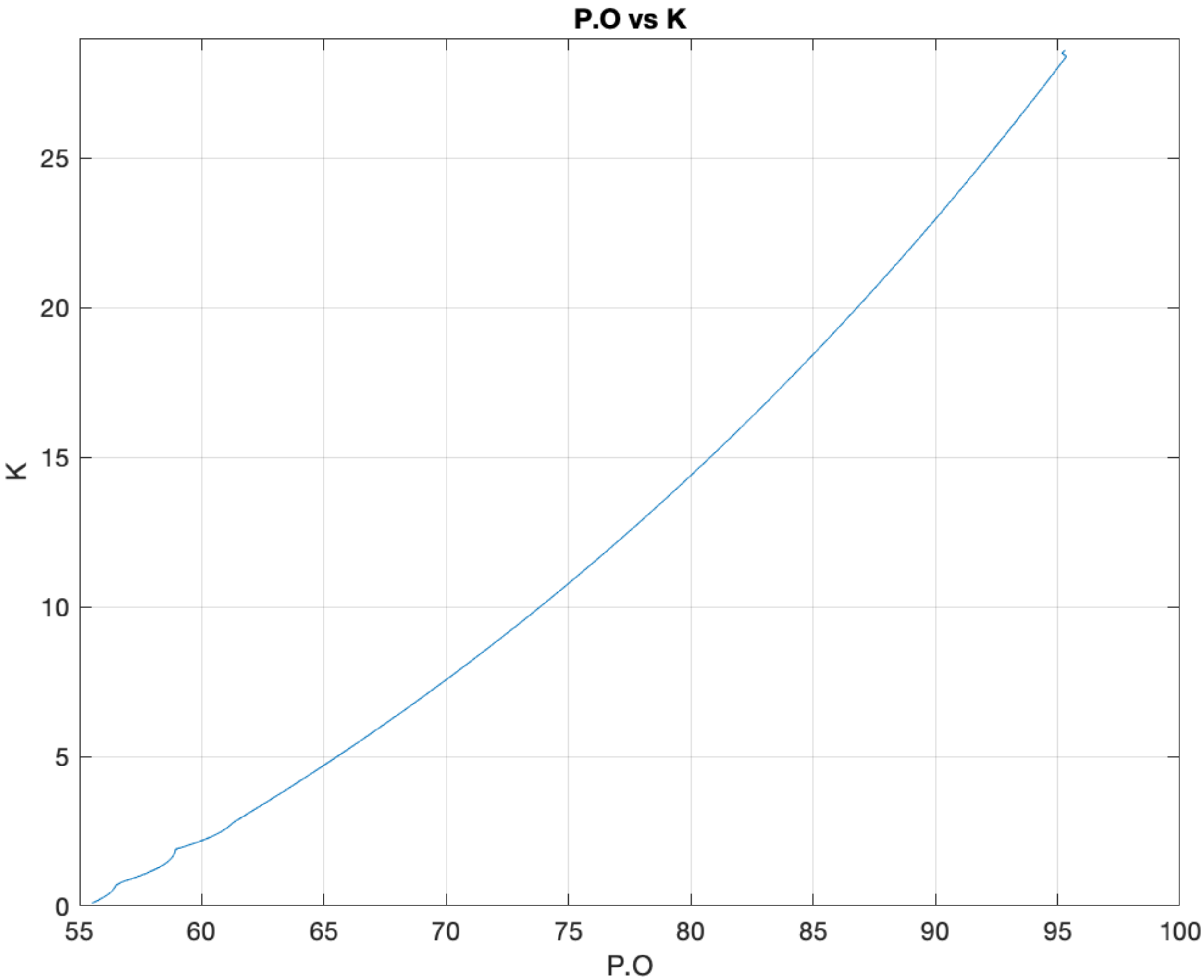


Figure (3). δ versus K.

In figure 3, we can see that while K swept from 0 to 28.66667 the maximum overshoot (δ) is increasing as well till it reach the value of 96 approximately.

3)

Plot ess vs K:

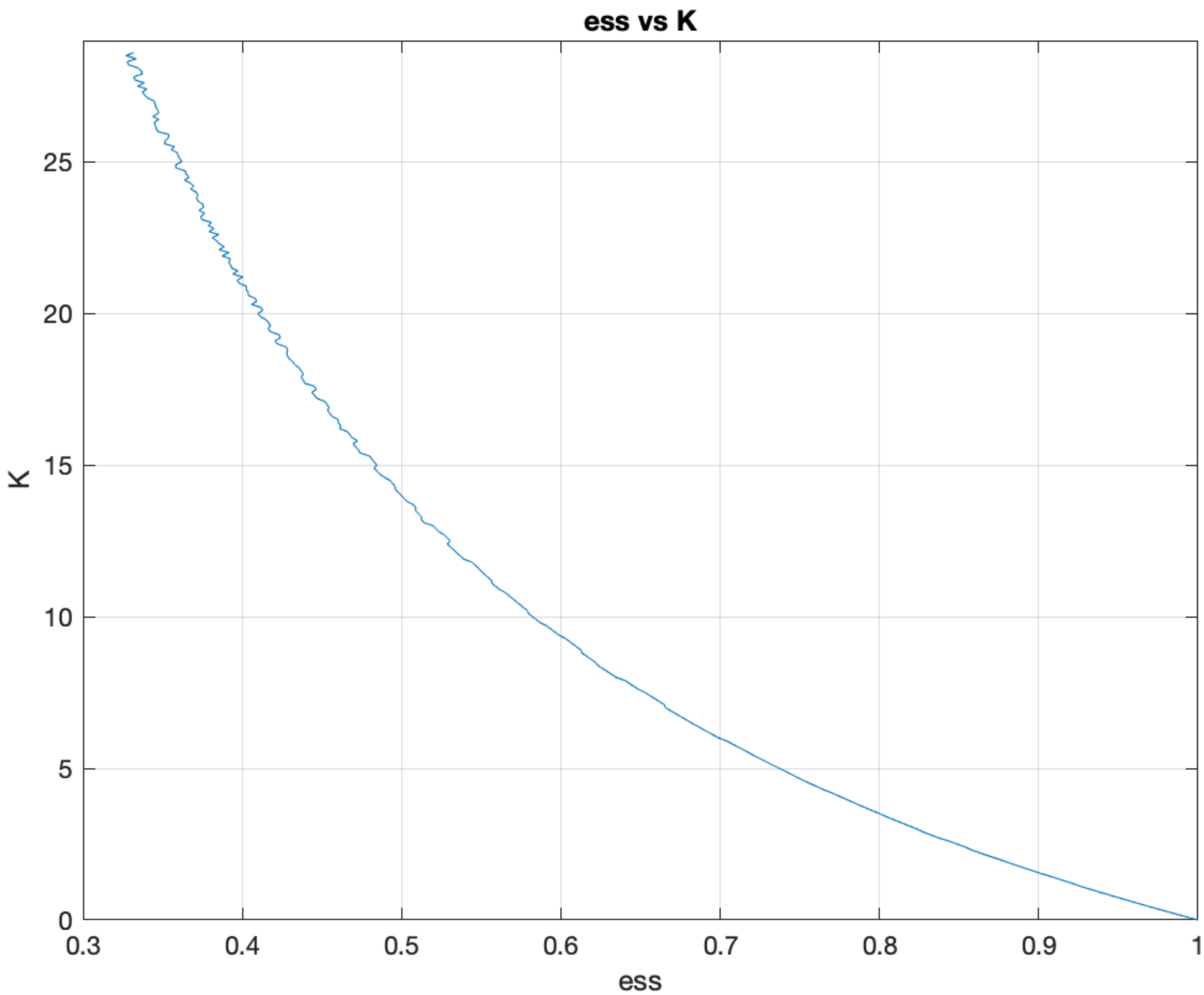
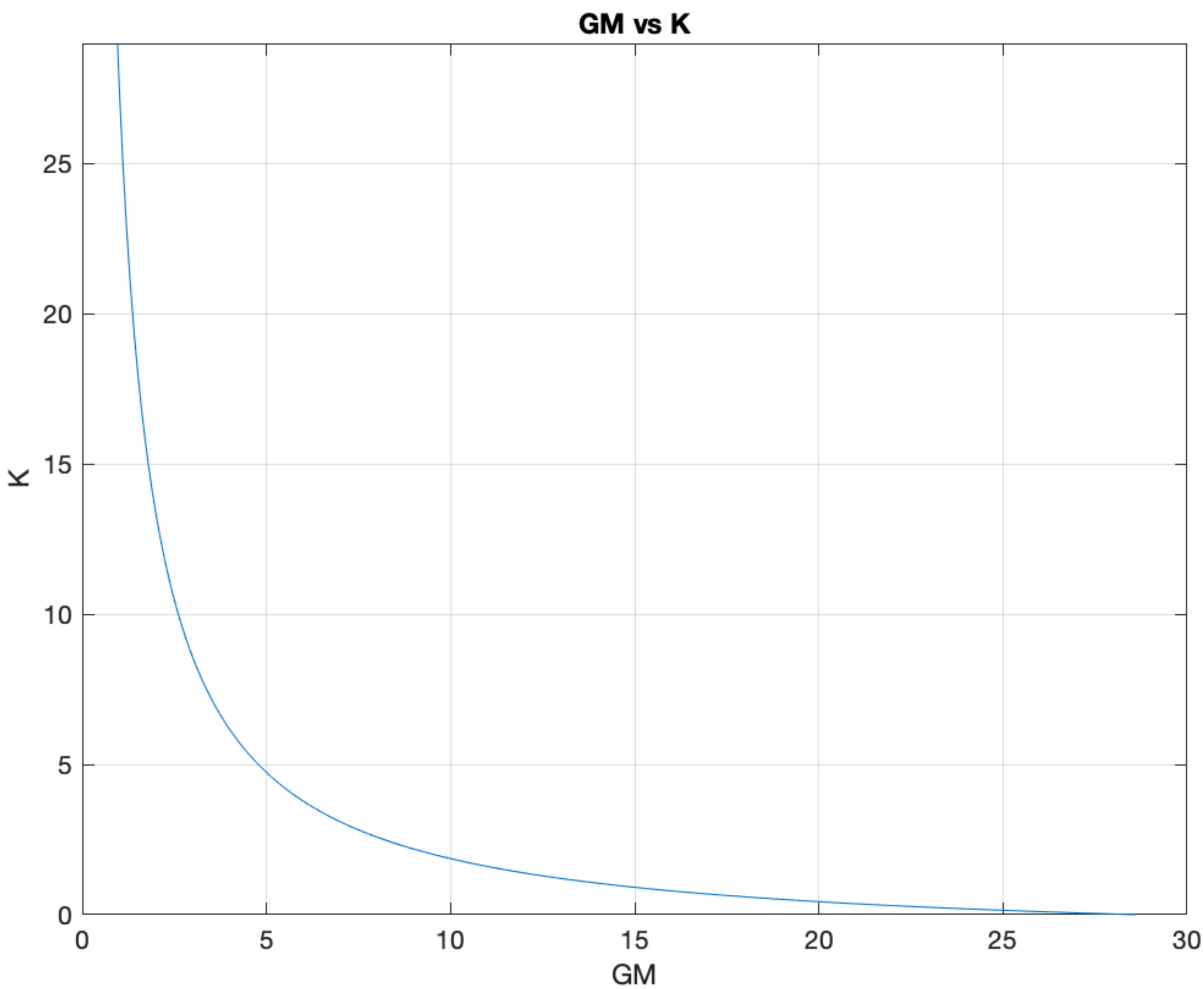


Figure (4). ess versus K.

In figure 4, when we have the maximum value of K that stabilized the system, the Ess is lowest which is approximately 33% while when K decreasing the steady state error is increasing.

4)

Plot GM vs K:

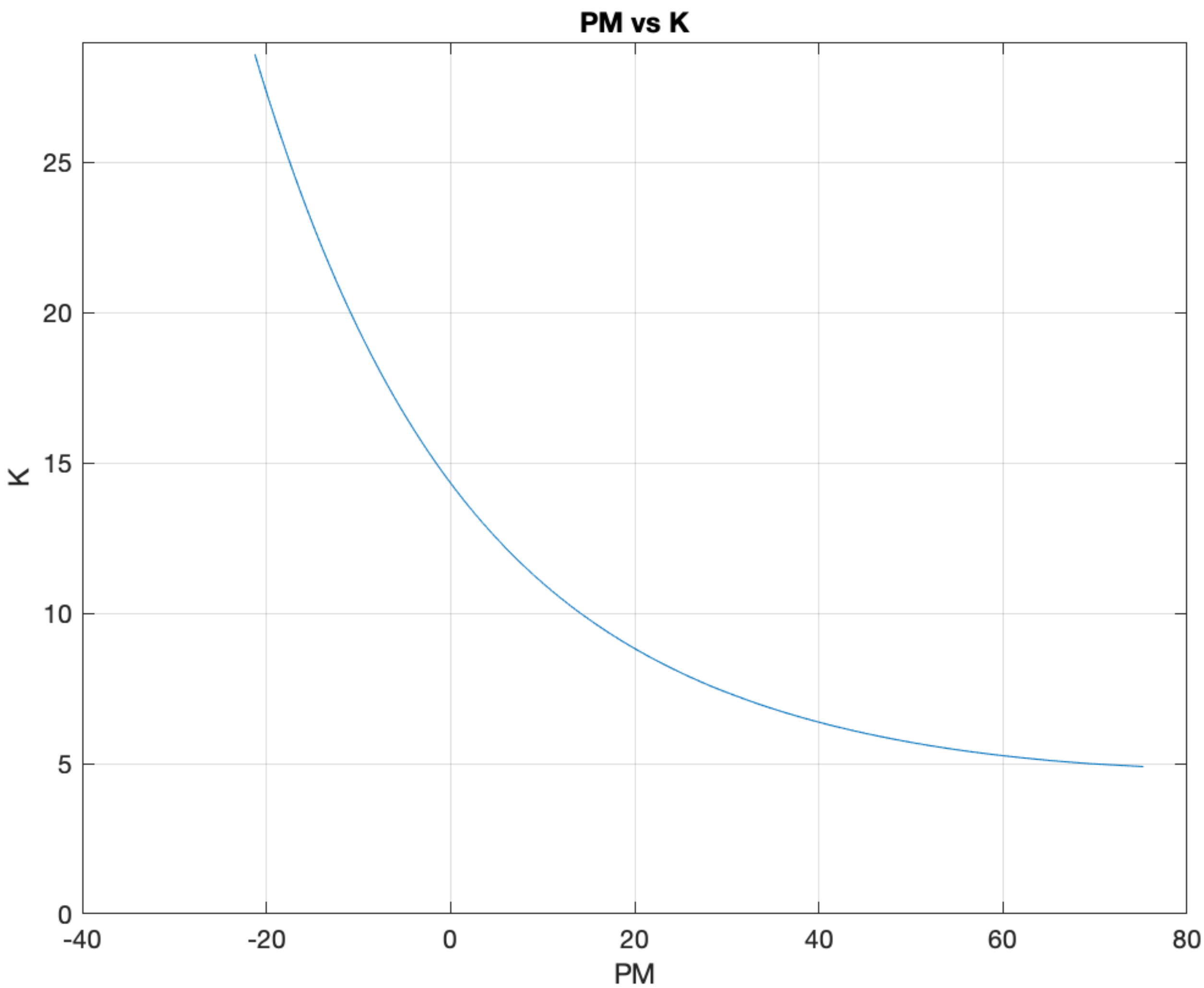


Figure(5). GM *versus K.*

In figure 5, at the low values of K the gain margin is high which is more than 28, but when K value is high the gain merging is increasing which is not proportional relation.

5)

Plot PM vs K:

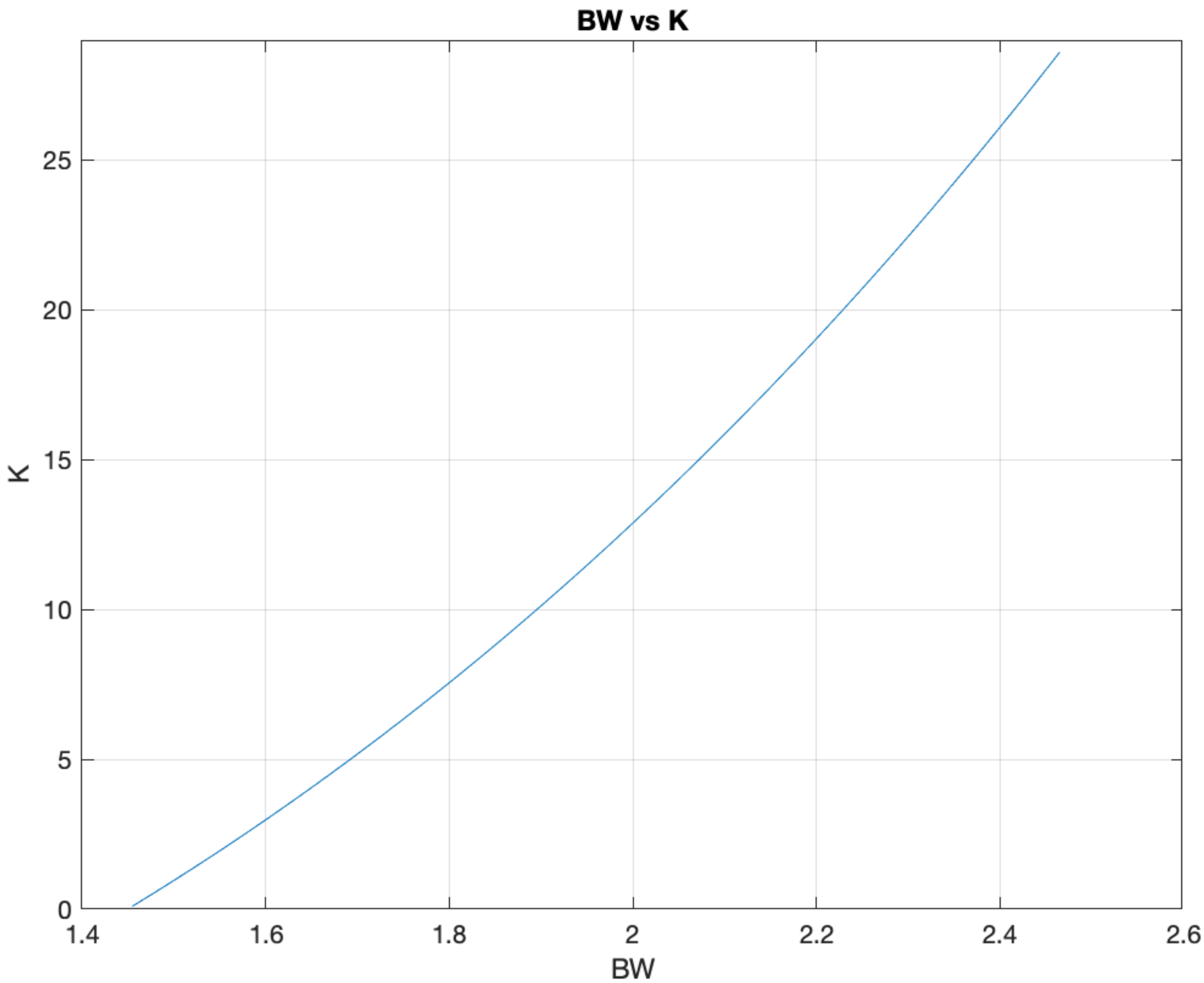


Figure(6). PM *versus K.*

In figure 6, for the phase margin we can see at is around -21 degree when we have the highest value of K, but it is start increasing while K decreasing until it reach roughly 75 degree.

6)

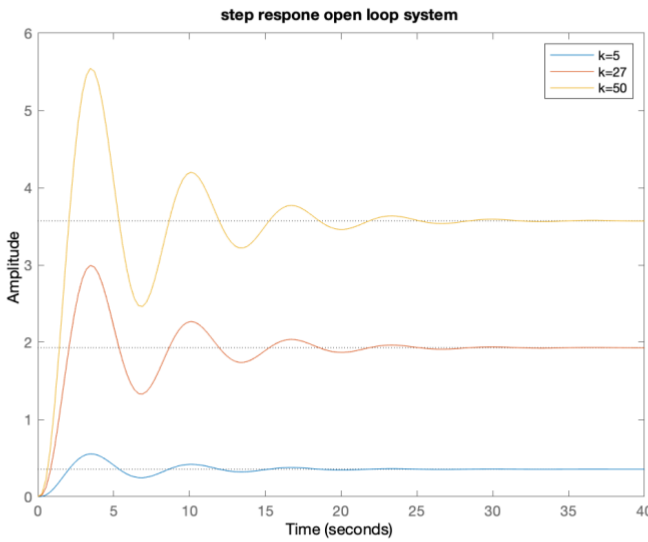
Plot BW vs K:



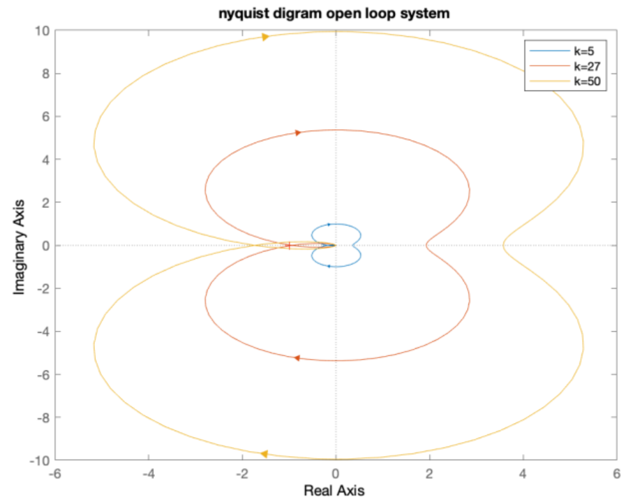
Figure(7). BW versus K.

For the 3dB bandwidth as can be seen in figure 7, it start around 1.4dB while K at very low then it will start increasing with K, and the value of the 3dB BW is 2.45dB when K equal to 28.67.

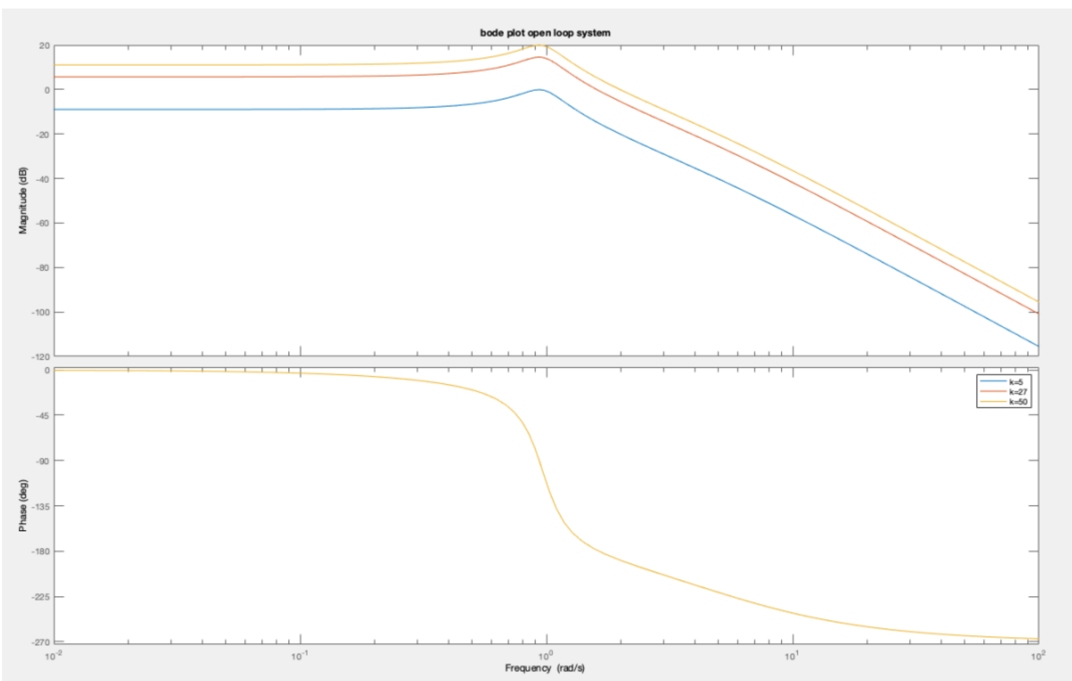
Open-loop system step response, Nyquist and Bode plot:



Figure(8). step response for open loop system K= 5,26,50.

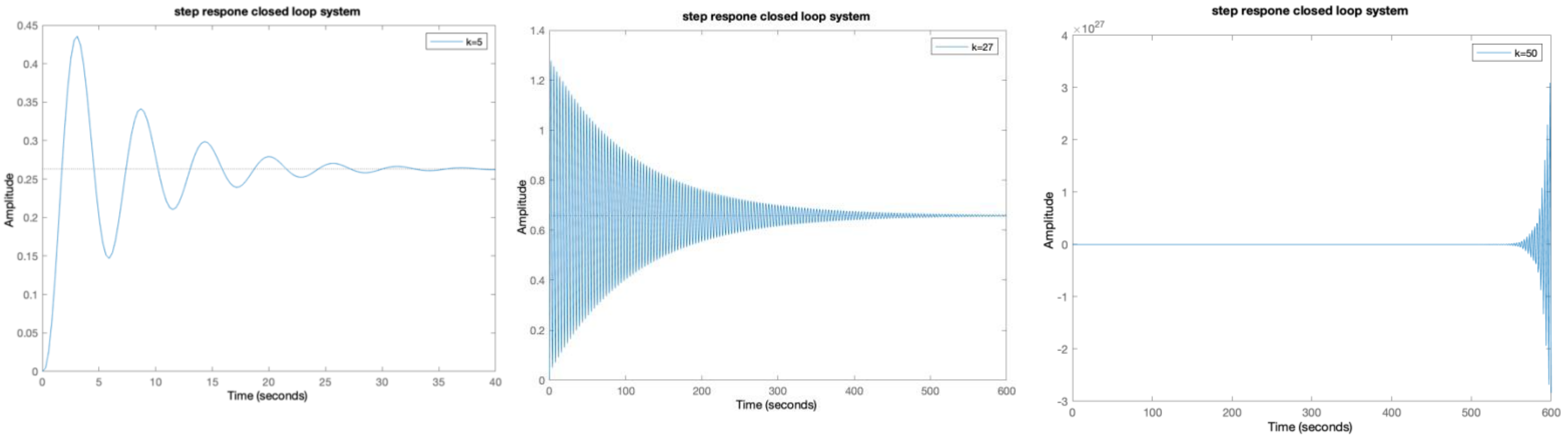


Figure(9). Nyquist diagrams for open loop system for K= 5,26,50.

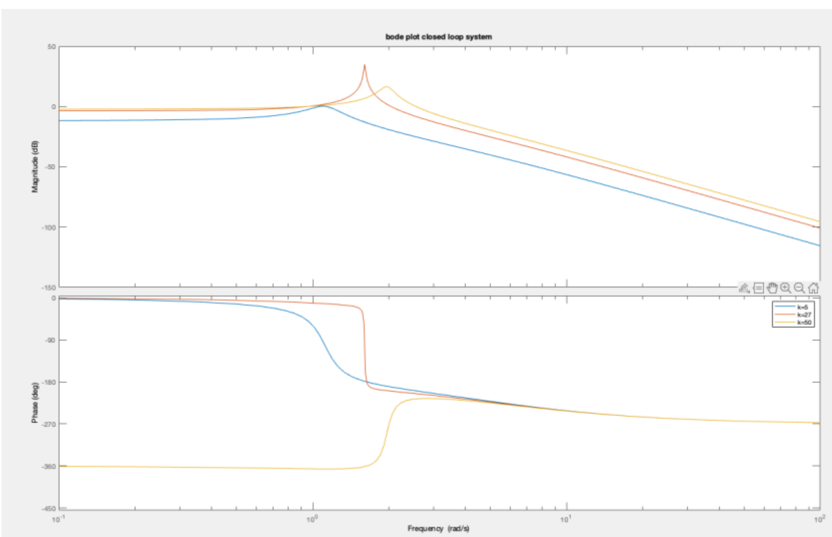


Figure(10). Bode plots for open loop system K= 5,26,50.

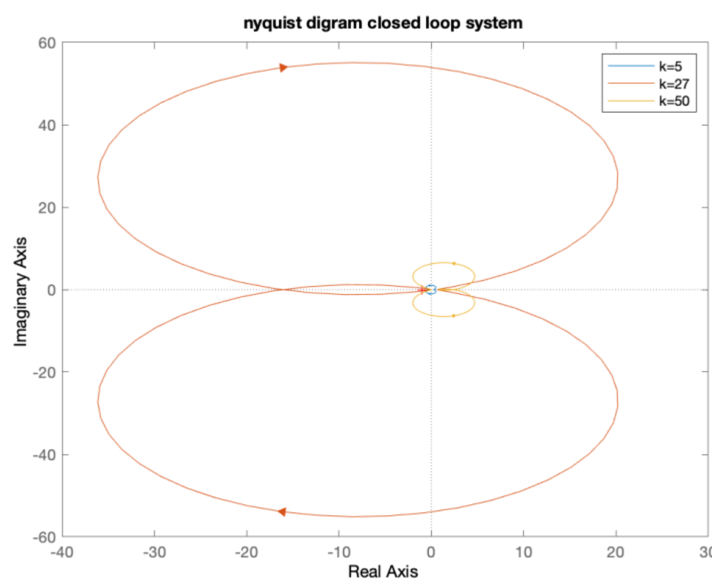
Closed-loop system step response, Nyquist and Bode plot:



Figure(11). step response for closed loop system K= 5,26,50.



figure(12). Bode plot for close loop system K= 5,26,50.



figure(13). Nyquist diagram for close loop system K= 5,26,50.

Conclusion:

As we can see from the results, as the value of Gc increases, the system becomes faster and more oscillatory. The settling time decreases, and the overshoot increases. Also, the value of Gc increases, the gain margin (Gm) decreases, and the phase margin (Pm) becomes more negative. The system becomes less stable as Gc increases, and it becomes more difficult to stabilize the system using feedback. Moreover, The bandwidth of the system increases as the value of Gc increases, indicating that the system becomes faster. The relationship between bandwidth and settling time is that a higher bandwidth results in a faster system, but it also leads to a larger overshoot and a longer settling time. There are some relationships between the gain margin (GM), phase margin (PM), and bandwidth (BW) performance metrics and other important performance metrics, such as settling time (Ts), percent overshoot (δ), and steady-state error (ess). A larger gain margin indicates greater stability, while a larger bandwidth indicates faster response, but increasing the gain margin will generally result in a decrease in bandwidth, and increasing the bandwidth will decrease the gain margin. The phase margin is also a measure of stability, but it relates to the system's phase response. A larger phase margin indicates greater stability, while a smaller phase margin may result in increased overshoot and longer settling time. Overall, these performance metrics are all interrelated, and an optimal balance between them needs to be achieved for a closed-loop control system to perform well.

Part A

Code:

```
close all;                                                  clc;
```

```
clear all;
syms s;
num1= [1];
den1= [3,16,8,14];
H= tf(num1,den1);
k=1;
sys1= feedback(k*H,1);
figure(1);
rlocus(sys1);
figure(2);
step(sys1);


%%%%%%%%%%%%%%%%%%%% Part A
%%%%%%%%%%%%%%%%%%%%%%%%
%%
Ts= [];
Po= [];
ess=[];
Gm=[];
Pm=[];
Bw=[];

i=0;
for K= 0:0.1:28.666667
   i=i+1;
   sys2= feedback(K*H,1);
   S1= stepinfo(sys2);
   ts = S1.SettlingTime;
   Ts(i)= S1.SettlingTime;
   Po(i)=S1.Overshoot;
   [y,t]=step(sys2);
   sserror=abs(1-y(end));
   ess(i)= sserror;
   [Gm(i),Pm(i)] = margin(sys2);
   Bw(i)=bandwidth(sys2,-3);


end
K= [0:0.1:28.666667];
figure(3);
plot(Ts,K);
grid on
xlabel("Ts")
ylabel("K")
title("Ts vs K")
ylim([0,29]);
figure(4);
plot(Po,K);
grid on
xlabel("P.O")
ylabel("K")
title("P.O vs K")
ylim([0,29]);
figure(5);
plot(ess,K);
grid on
xlabel("ess")
ylabel("K")
title("ess vs K")
ylim([0,29]);
figure(6);
plot(K,Gm);
grid on
xlabel("GM")
ylabel("K")
```

```
title("GM vs K")
ylim([0,29]);
figure(7);
plot(Pm,K);
grid on
xlabel("PM")
ylabel("K")
title("PM vs K")
ylim([0,29]);
figure(8);
plot(Bw,K);
grid on
xlabel("BW")
ylabel("K")
title("BW vs K")
ylim([0,29]);

k5=5;
k27=27;
k50=50;

sys5= k5*H;
sys27= k27*H;
sys50= k50*H;
figure(9);
hold on
nyquist(sys5);
nyquist(sys27);
nyquist(sys50);
title("nyquist digram open loop system");

legend('k=5','k=27','k=50');
hold off
figure(10);
hold on
bode(sys5);
bode(sys27);
bode(sys50);
title("bode plot open loop system");

legend('k=5','k=27','k=50');
hold off

figure(11);
hold on
step(sys5);
step(sys27);
step(sys50);
title("step respone open loop system");
legend('k=5','k=27','k=50');
hold off

%%%%%%%%%%

figure(12);
hold on
nyquist(feedback(sys5,1));
nyquist(feedback(sys27,1));
nyquist(feedback(sys50,1));
title("nyquist digram closed loop system");
legend('k=5','k=27','k=50');
hold off

figure(13);
hold on
bode(feedback(sys5,1));
```

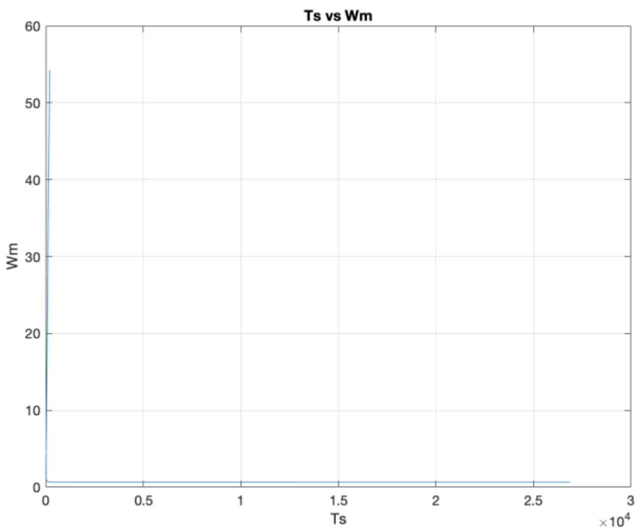
```
bode(feedback(sys27,1));
bode(feedback(sys50,1));
title("bode plot closed loop system");
legend('k=5','k=27','k=50');
hold off
figure(14);
step(feedback(sys5,1));
title("step respone closed loop system");
legend('k=5');
figure(15);
step(feedback(sys27,1));
title("step respone closed loop system");
legend('k=27');

figure(16);

step(feedback(sys50,1));
title("step respone closed loop system");
legend('k=50');
```

Part B:

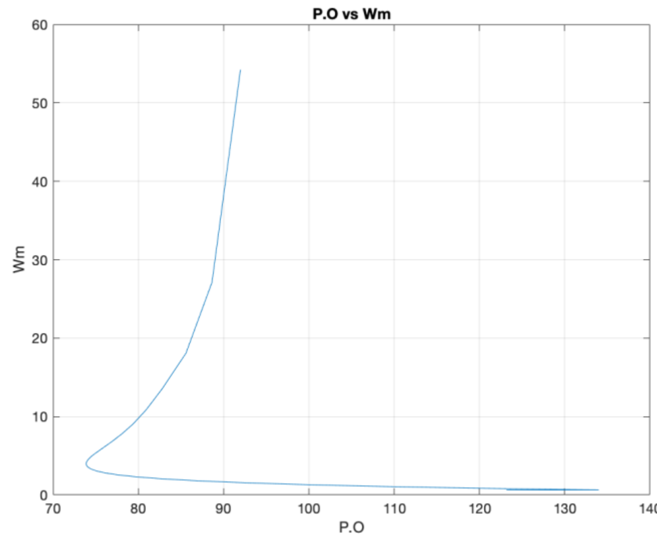
Lead Compensator to the System.

we will use the transfer function of the lead compensator given by:

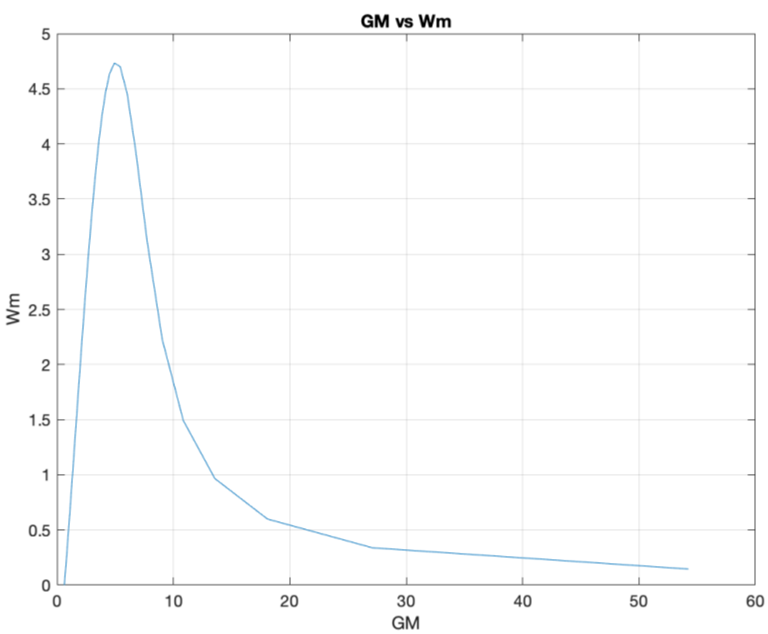
$$G_C(s) = K\,\frac{1 + \alpha\,\tau\,s}{1 + \tau\,s}$$

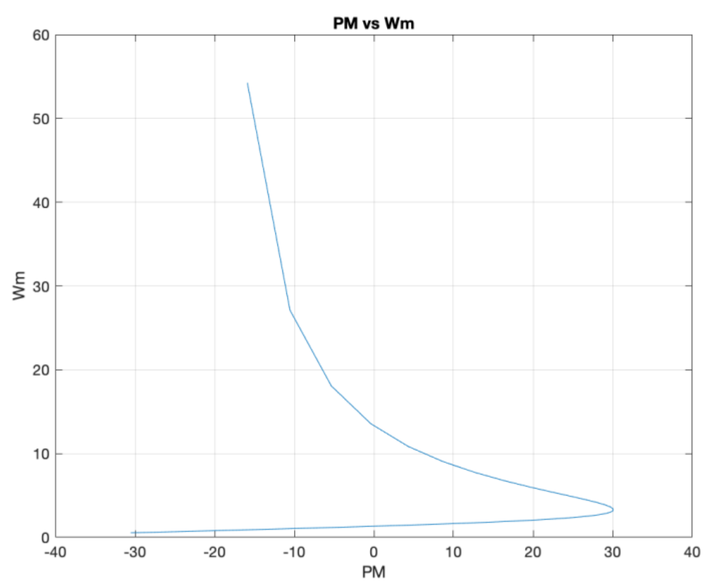


figure(14). Ts vs Wm.



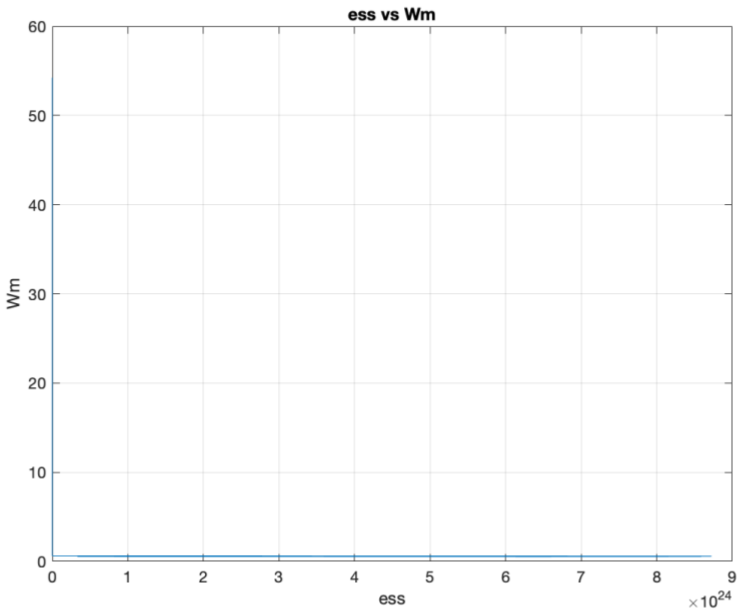
figure(15). P.O. vs Wm.



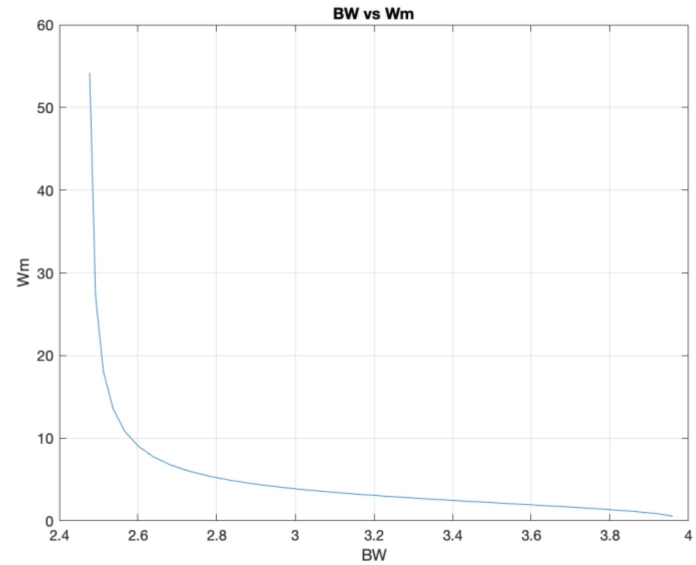


figure(17). PM vs Wm.

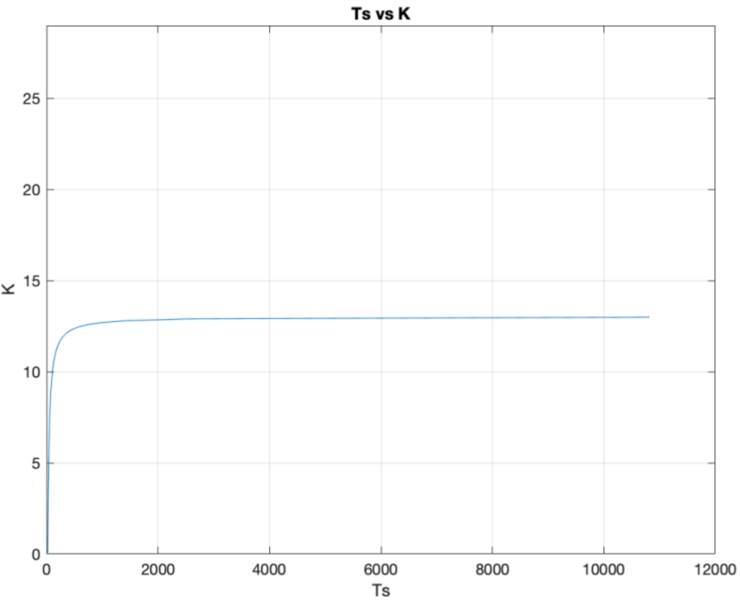
figure(16). GM vs Wm.



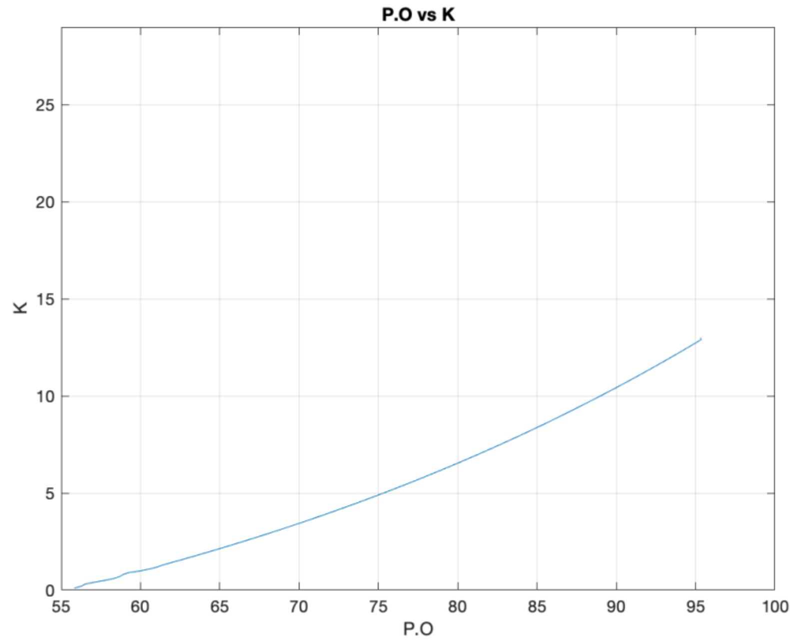
figure(18). ess vs Wm.



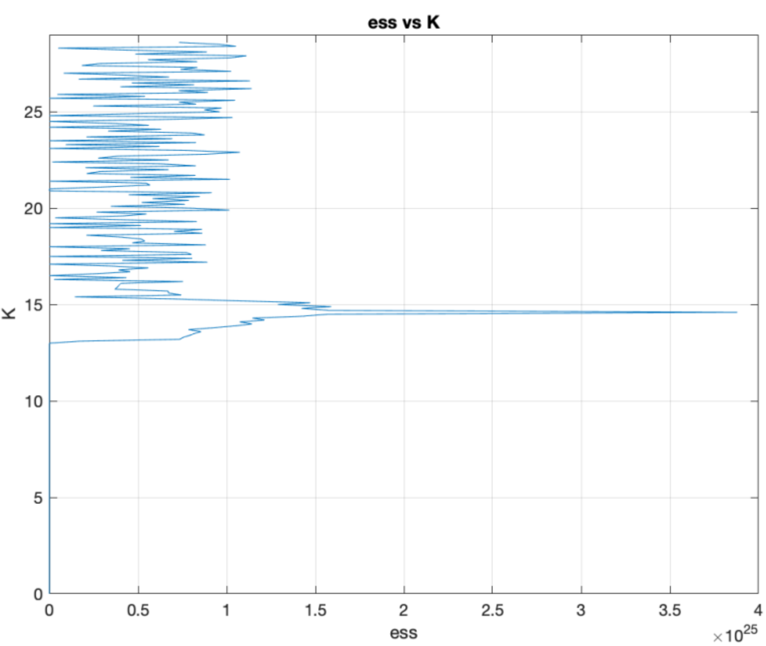
figure(19). BW vs Wm.

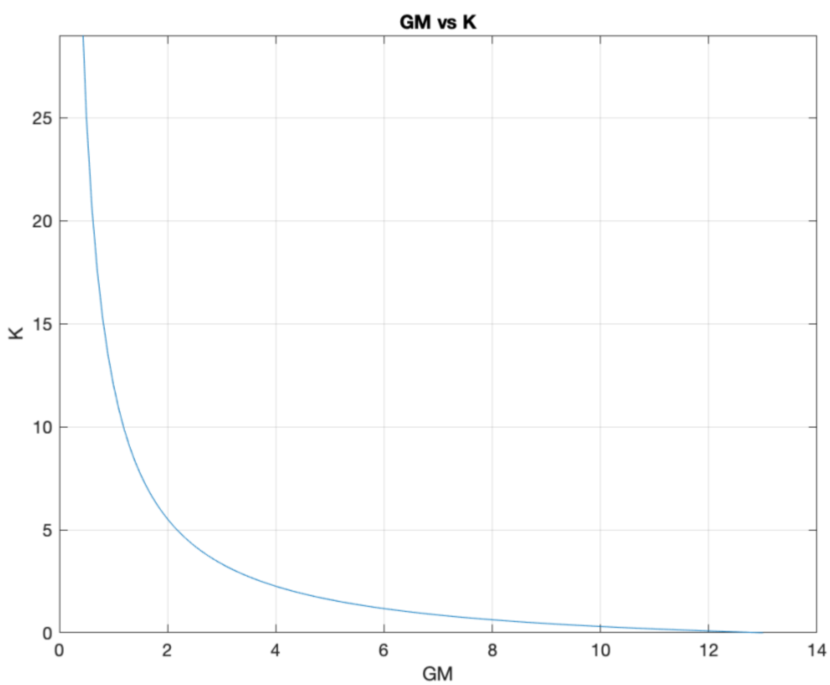


figure(20). Ts vs Wm.



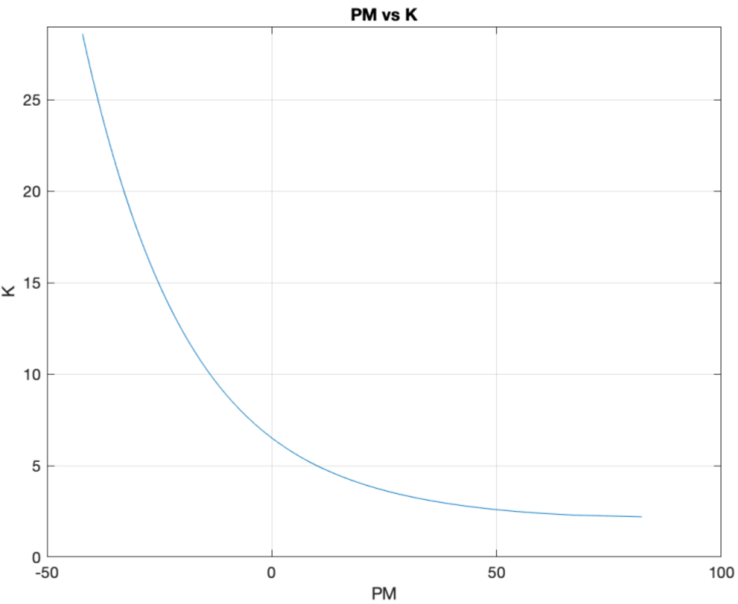
figure(21). P.O. vs Wm.



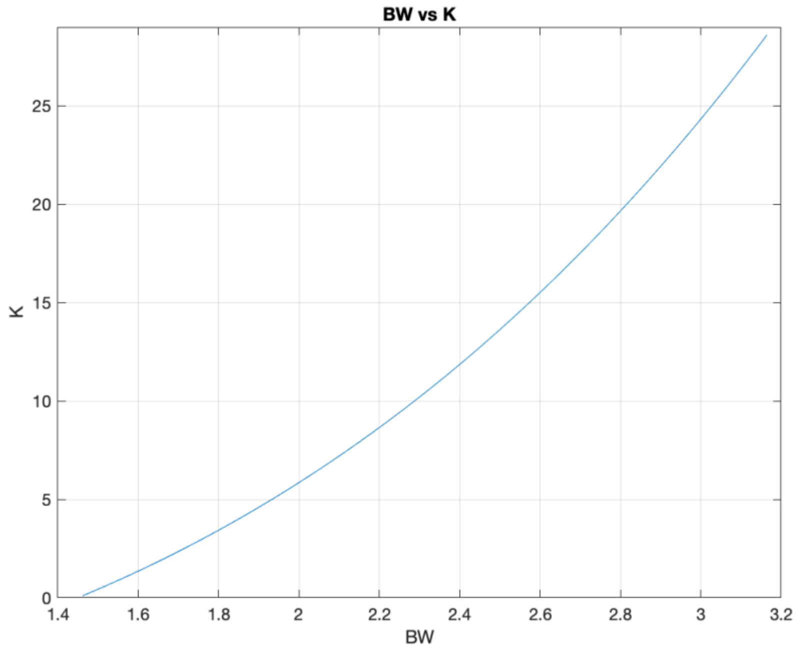


figure(22). GM vs Wm.

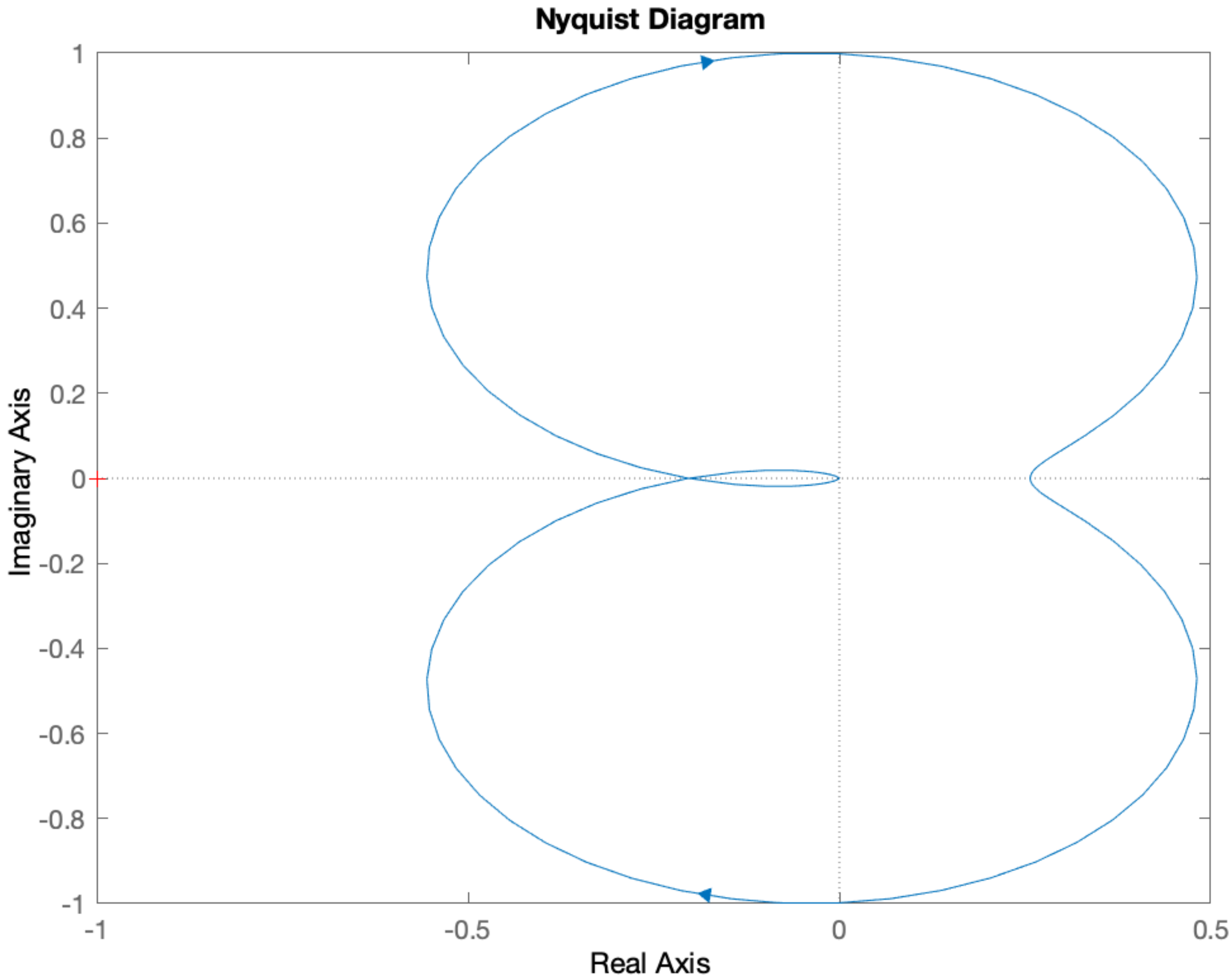
figure(23). PM vs Wm.



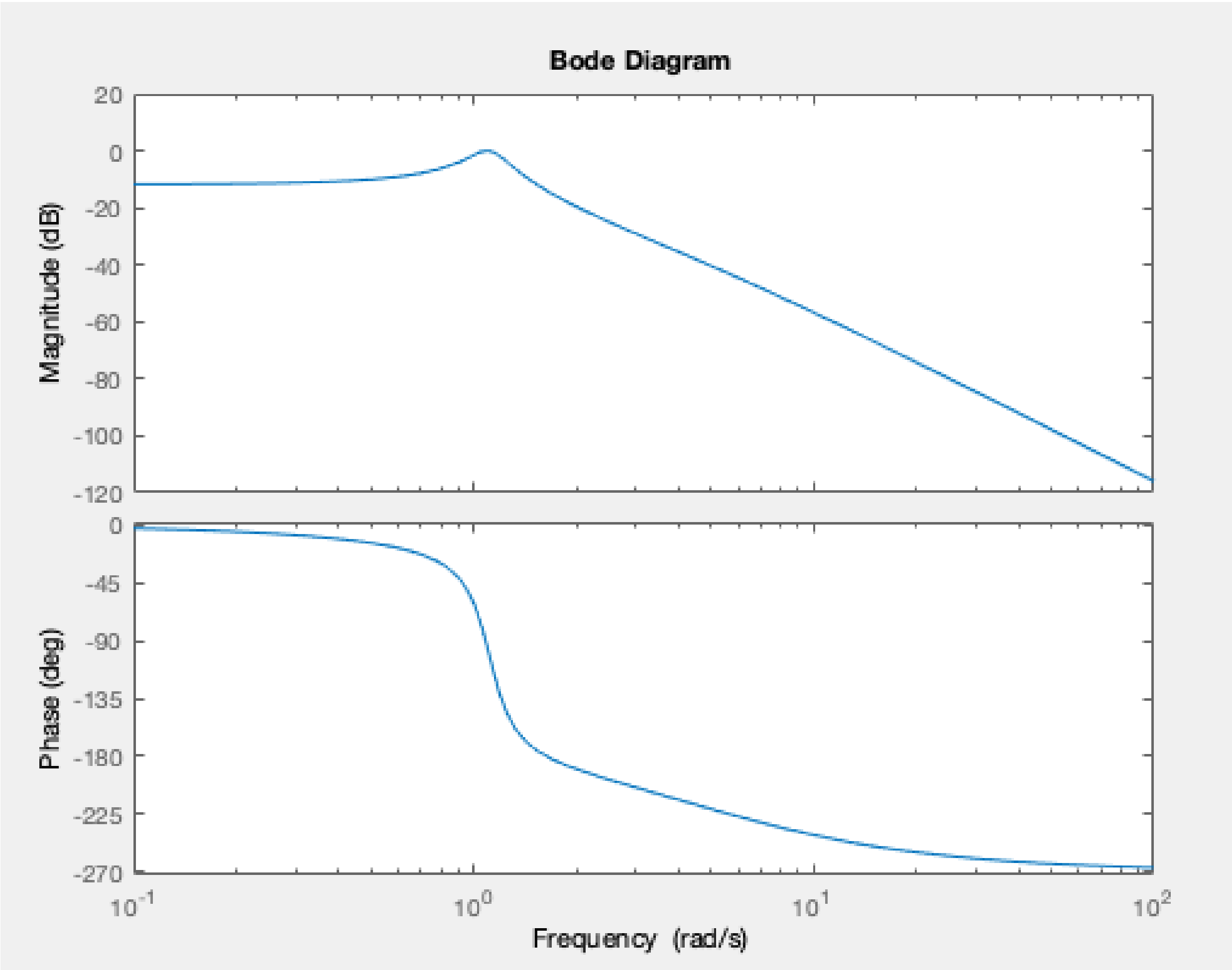
figure(25). BW vs Wm.



figure(24). PM vs Wm.



figure(25). Nyquist diagram

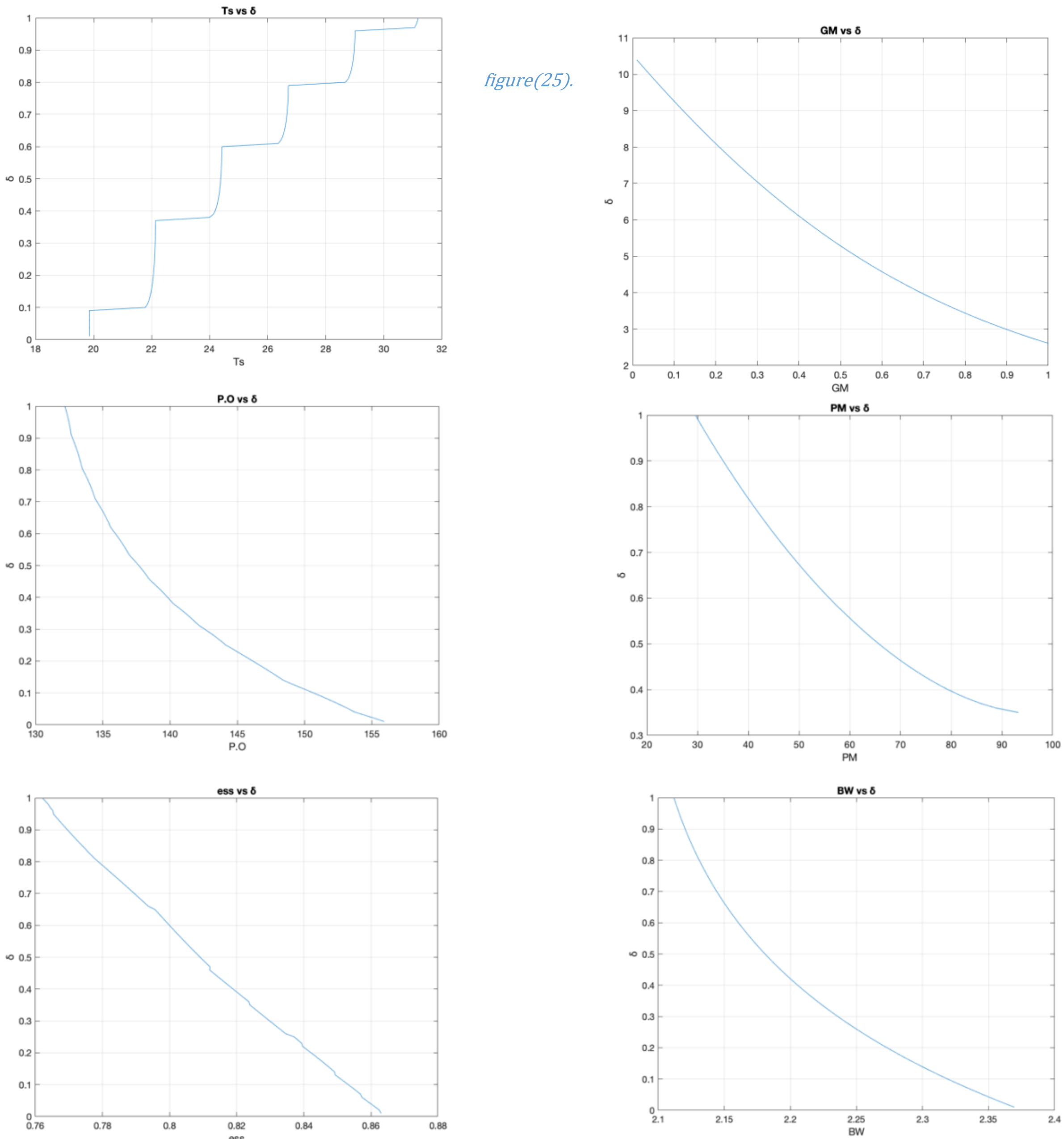


figure(26). Bode plot

Nyquist diagram and Bode plots is very close comparable when K=5 in part A.

Part C:

Case 1:



figure(25).

figure(27). Ts, P.O., ess, GM, PM and BW vs δ , with Plg= 1.0 , Zlg= 1.0+δ

Case 2:

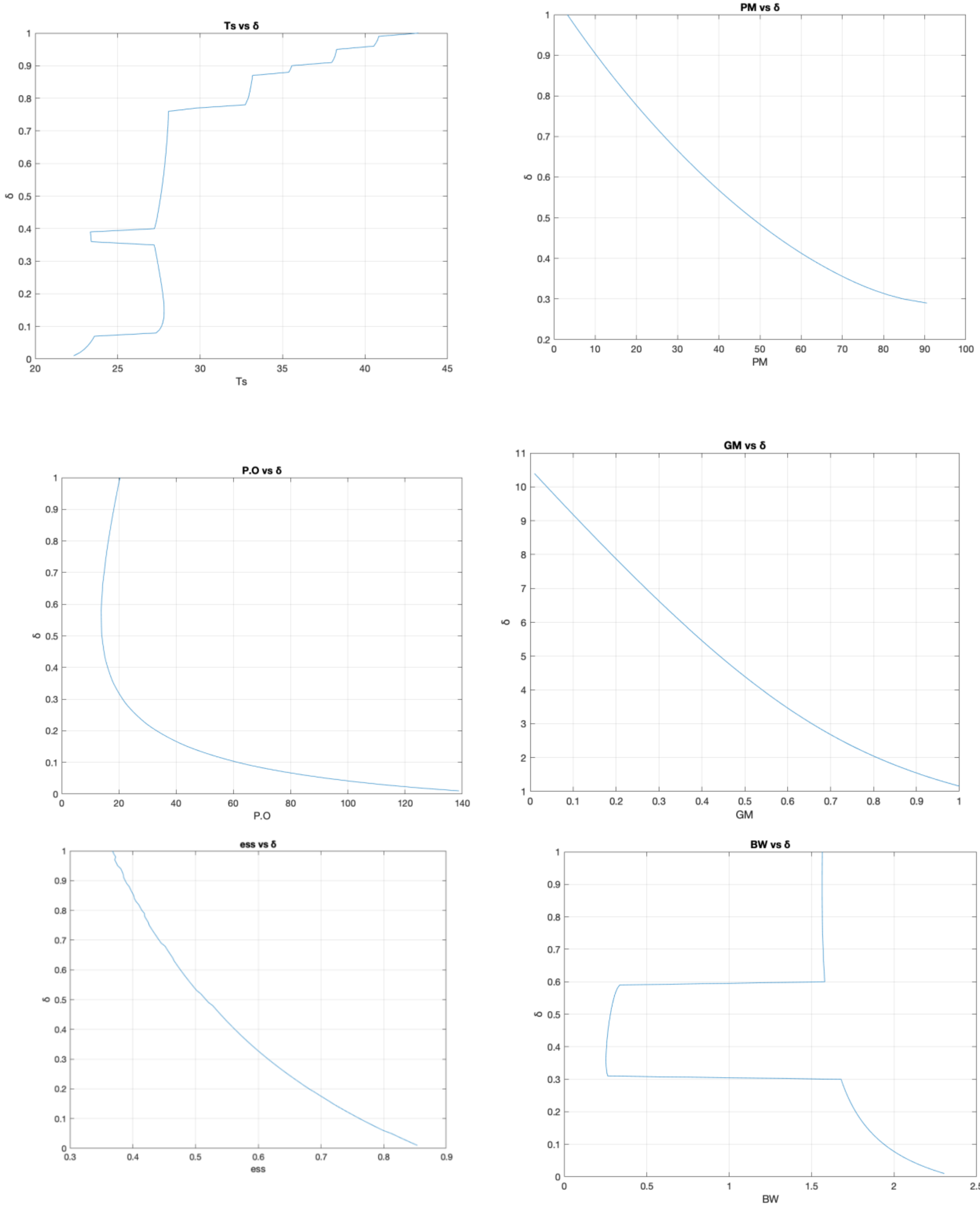


figure (28). Ts, P.O., ess, GM, PM and BW vs δ , Plg= 0.1 , Zlg= 0.1+δ

As can be seen from the two cases while we make the pole and the zero from the origin the error decreases and become like part B, so as we bring the pole and zero near from the origin the effect of the lag decreases rapidly.

Code:

Part c:

```
Wm=[];
Gc=[];
Ts= [];
Po= [];
ess=[];
Gm=[];
Pm=[];
Bw=[];
Plg1= 1.0;
i=0;
%%%%%%%% case 1
for x=[0.01:0.01:1]
   i=i+1;
   Zlg2= 1.0+ x;
   sys8= feedback(KmaxPm*
((1+taum*alpham*s)/(1+taum*s))*((s+Zlg2)/(s+Pl
g1))*H,1);
   S1= stepinfo(sys8);
   ts = S1.SettlingTime;
   Ts(i)= S1.SettlingTime;
   Po(i)=S1.Overshoot;
   [y,t]=step(sys8);
   sserror=abs(1-y(end));
   ess(i)= sserror;
   [Gm(i),Pm(i)] = margin(sys8);
   Bw(i)=bandwidth(sys8,-3);
end
x=[0.01:0.01:1];
figure(31);
plot(Ts,x);
grid on
xlabel("Ts")
ylabel("δ")
title("Ts vs δ")
figure(32);
plot(Po,x);
grid on
xlabel("P.O")
ylabel("δ")
title("P.O vs δ")
figure(33);
plot(ess,x);
grid on
xlabel("ess")
ylabel("δ")
title("ess vs δ")
figure(34);
plot(x,Gm);
grid on
xlabel("GM")
ylabel("δ")
title("GM vs δ")
```

```
figure(35);
plot(Pm,x);
grid on
xlabel("PM")
ylabel("δ")
title("PM vs δ")
figure(36);
plot(Bw,x);
grid on
xlabel("BW")
ylabel("δ")
title("BW vs δ")

%%%%%%%% case 2

Plg2= 0.1;
i=0;
for x=[0.01:0.01:1]
    i=i+1;
    Zlg2= 0.1+ x;
    sys8= feedback(KmaxPm*
((1+taum*alpham*s)/(1+taum*s))*((s+Zlg2)/(s+Pl
g2))*H,1);
    S1= stepinfo(sys8);
    ts = S1.SettlingTime;
    Ts(i)= S1.SettlingTime;
    Po(i)=S1.Overshoot;
    [y,t]=step(sys8);
    sserror=abs(1-y(end));
    ess(i)= sserror;
    [Gm(i),Pm(i)] = margin(sys8);
    Bw(i)=bandwidth(sys8,-3);
end
x=[0.01:0.01:1];

figure(37);
plot(Ts,x);
grid on
xlabel("Ts")
ylabel("δ")
title("Ts vs δ")
figure(38);
plot(Po,x);
grid on
xlabel("P.O")
ylabel("δ")
title("P.O vs δ")
figure(39);
plot(ess,x);
grid on
xlabel("ess")
ylabel("δ")
title("ess vs δ")
figure(40);
plot(x,Gm);
grid on
xlabel("GM")
ylabel("δ")
title("GM vs δ")
figure(41);
plot(Pm,x);
grid on
xlabel("PM")
ylabel("δ")
title("PM vs δ")
figure(42);
```

```
plot(Bw,x);
grid on
xlabel("BW")
ylabel("δ")
title("BW vs δ")
```