EE208 EXPERIMENT 5

CONTROLLER DESIGN ON MATLAB PLATFORM BY DISCRETE FREQUENCY RESPONSE

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Objective

The given digital OLTF is closed through negative feedback of different gains, examining the consequences on gain and phase margins.

Sensitivity to the choice of sampling time is additionally examined for the design procedure.

System

The digital OLTF of a furnace model, inclusive of a first order actuator, is given by:

$$G_{ol}(z) = 10^{-5}\frac{4.711z + 4.644}{z^3 - 2.875z^2 + 2.753z - 0.8781}$$

Tasks

- The furnace output can be fed back to the actuator input with different positive integer gains in the feedback loop.
- Study in detail the variation of gain and phase margin as the control is implemented as above.
- *The nominal sampling time for the system is 0.01s.*
- Record and discuss the proximity to instability as the furnace is operated with different feedback gain settings.
- For different feedback gain values that you consider, how are the margins (hence stability) affected by the choice of sampling time.

MATLAB Functions Used

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zeros, log10, margin, bode, tf, pzmap, step
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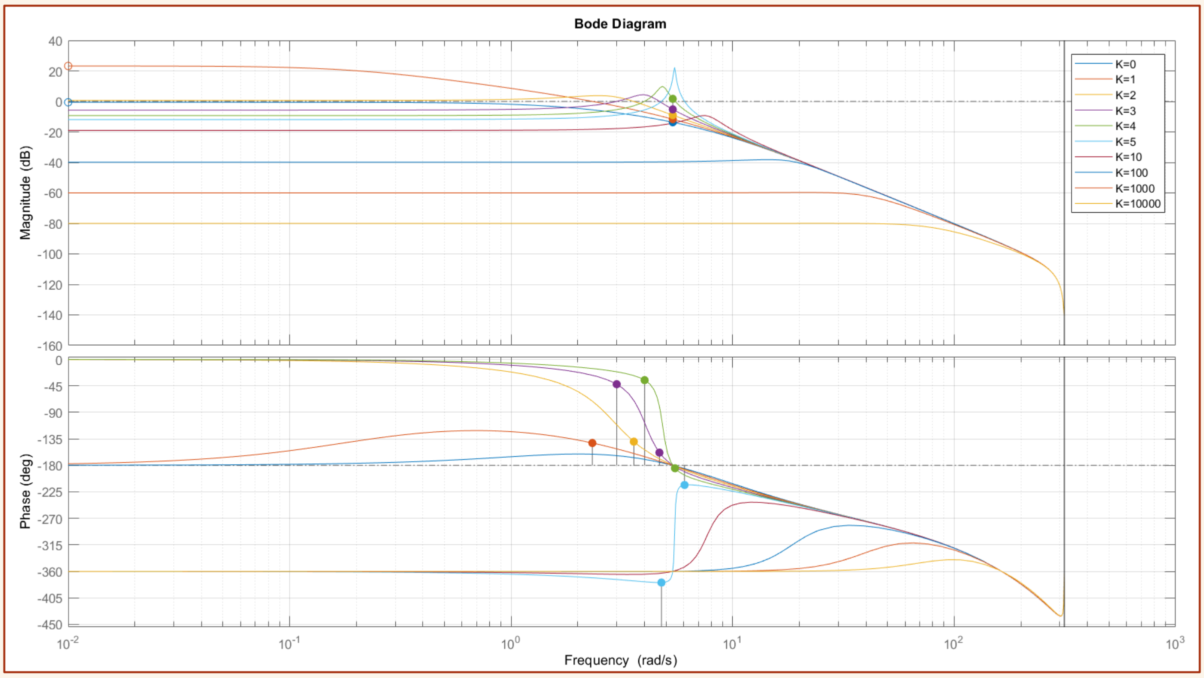
Observations

Varying feedback gain

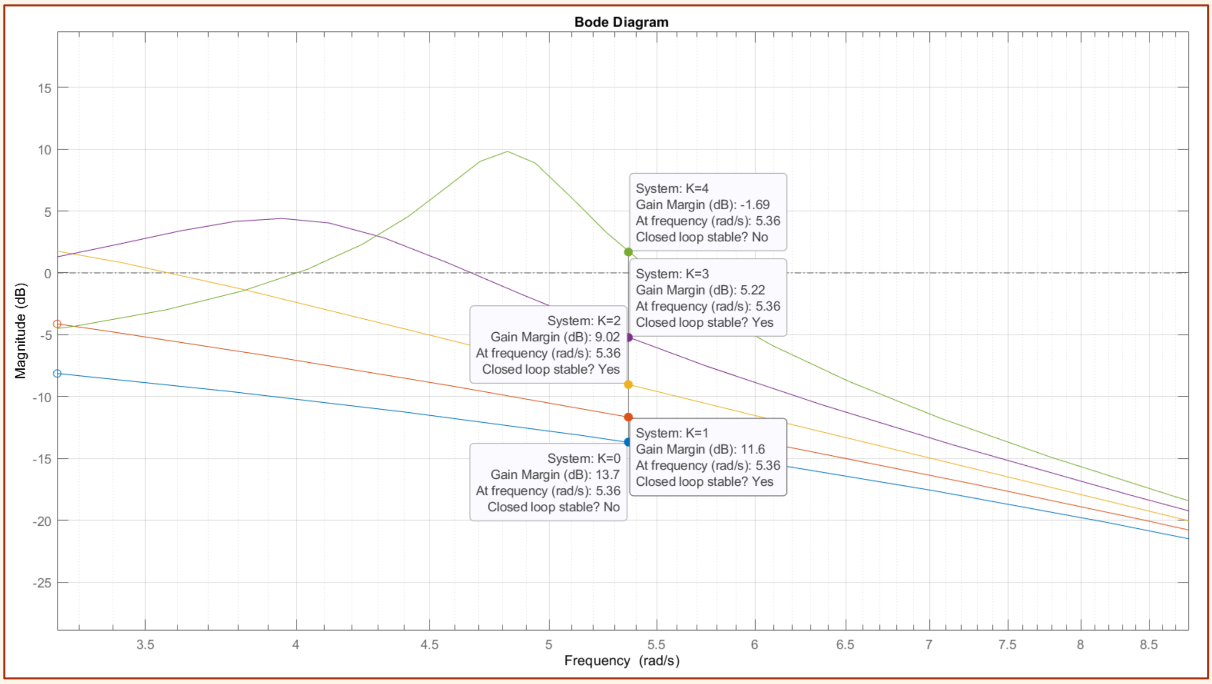
Bode plots



Gain Margin is infinite beyond K =4: thus, none of these systems are stable.

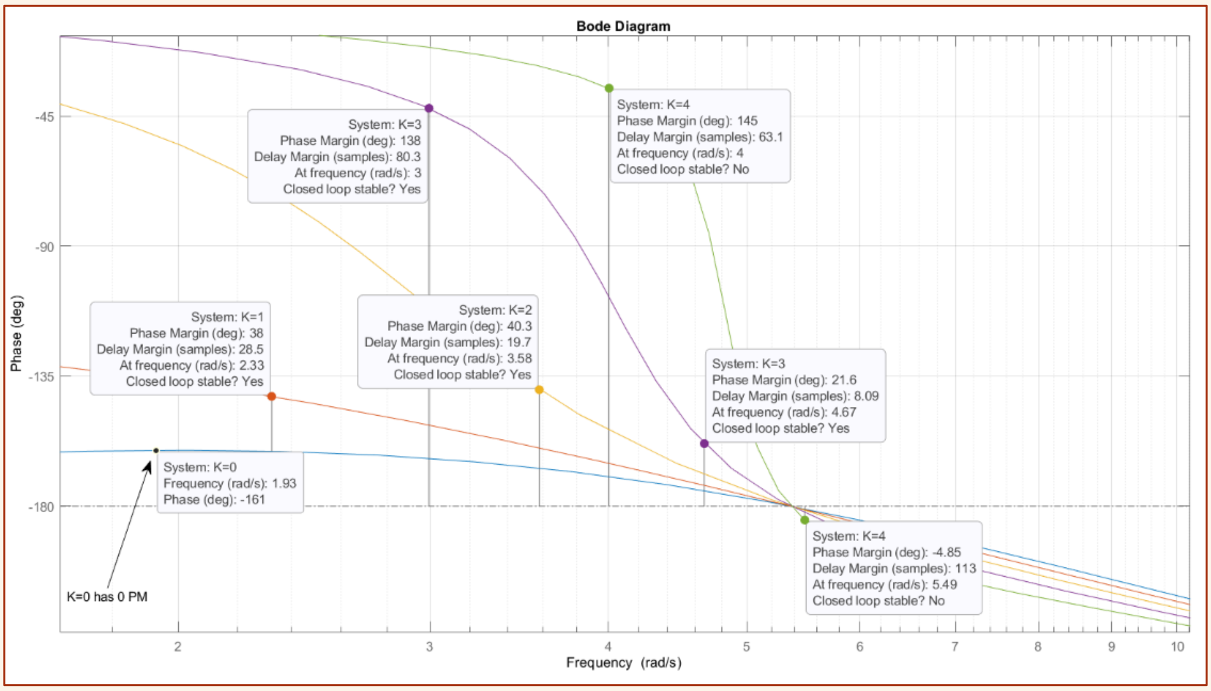
Let us focus in on K=0 to K=4.

Gain Plot –



The PCO Frequency is constant for all values of K (b/w 0 and 4).

Phase Plot –



Minimum PM decreases beyond K=1.

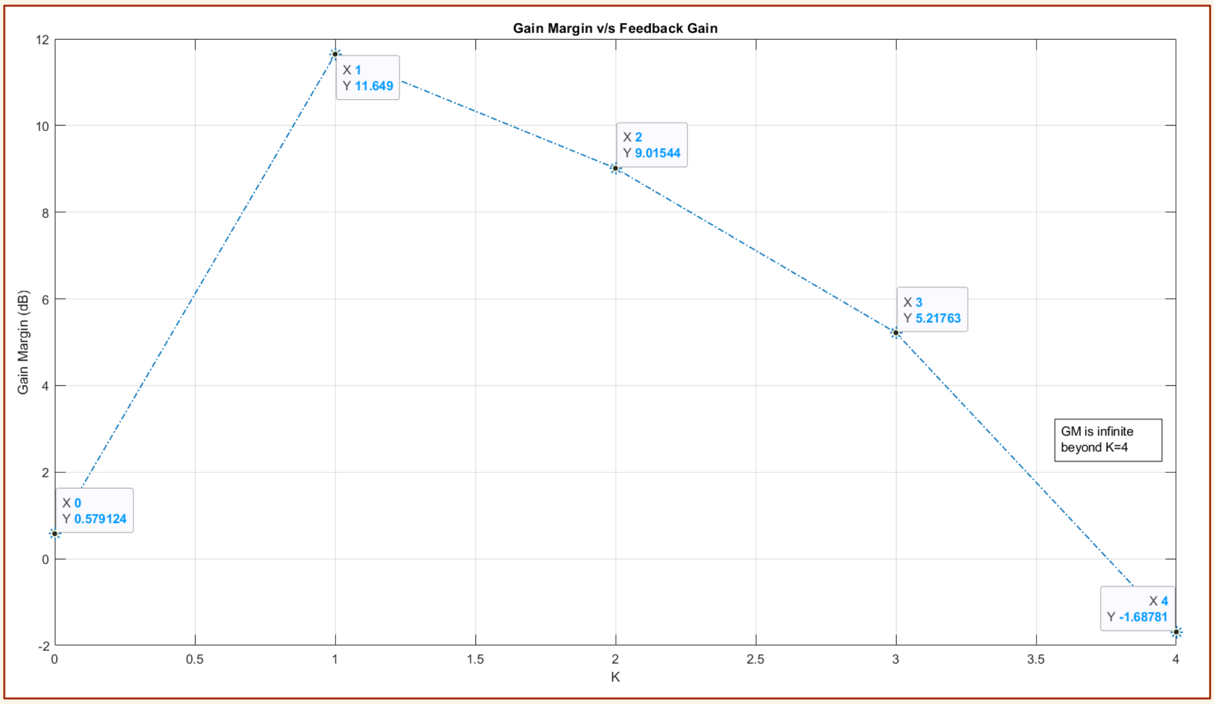
Gain and Phase Margins

Let us tabulate the Stability Margin data. We are recording the minimum stability margins in case of multiple crossovers.

K	Gain Margin (dB)	PCO Freq. (rad/s)	Phase Margin (deg)	GCO Freq. (rad/s)
0	0.5791	0	inf	nan
1	11.649	5.3635	37.9894	2.3252
2	9.0154	5.3635	40.3154	3.5788
3	5.2176	5.3635	21.6315	4.6683
4	-1.6778	5.3635	-4.845	5.4888
5	inf	nan	-33.29112	6.0636
6	inf	nan	-65.9897	6.4286
7	inf	nan	inf	nan
8	inf	nan	inf	nan
9	inf	nan	inf	nan
10	inf	nan	inf	nan
100	inf	nan	inf	nan
1000	inf	nan	inf	nan
10000	inf	nan	inf	nan

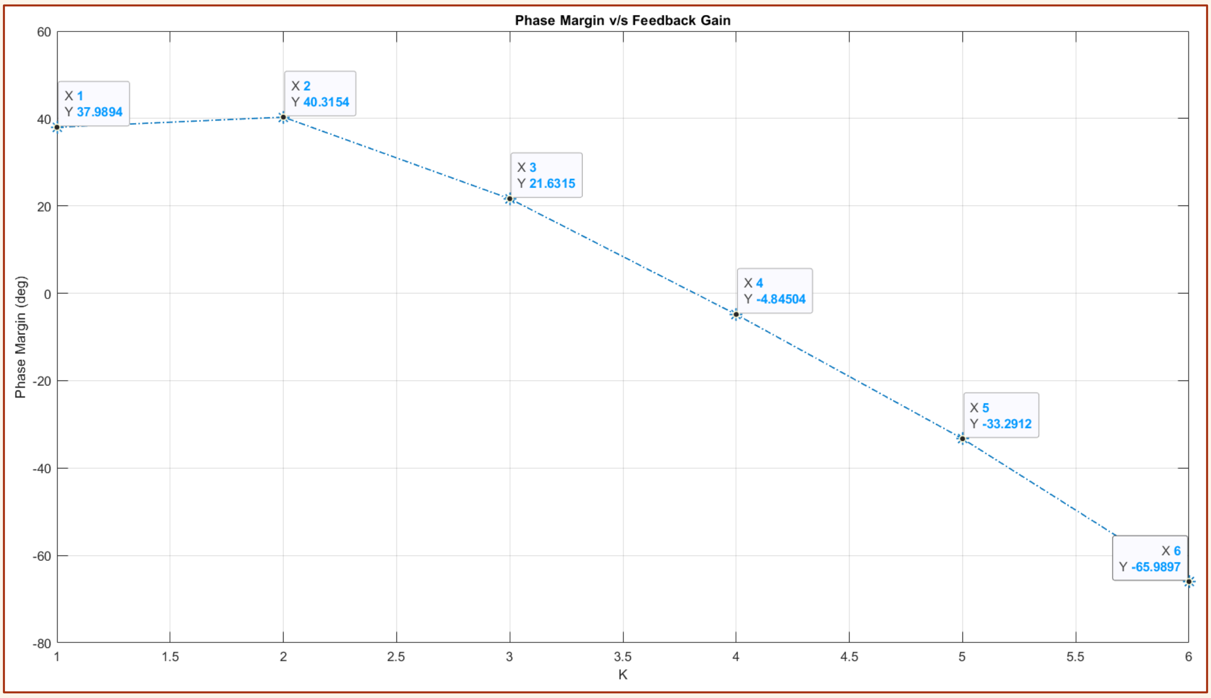
We can also plot this data –

Gain Margin v/s K



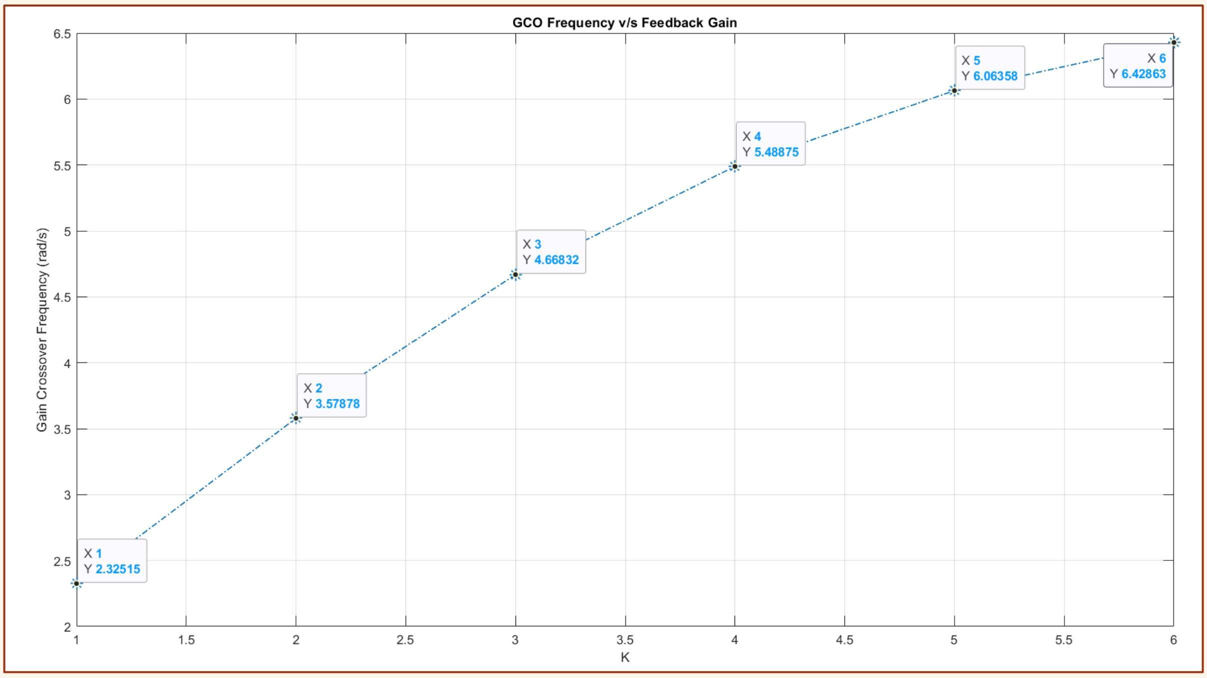
- Maximum gain margin of 11.648 dB is observed for unity gain feedback, and it decreases thereafter.
- Gain Margin is negative for $K = 4$, and becomes infinite for larger values of K.

Phase Margin v/s K



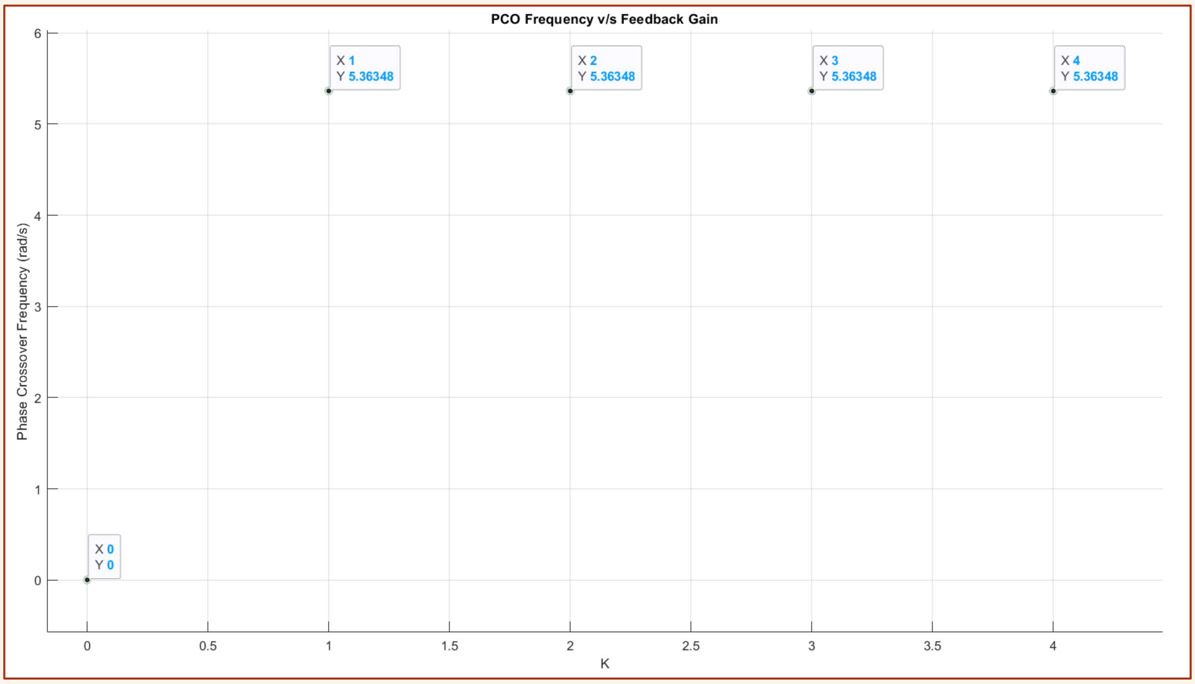
- PM rises from K=1 to K=2, then decreases till K=6.
- PM is infinite beyond K=6.

GCO Frequency v/s K



- GCO Frequency increases as K increases.

PCO Frequency v/s K

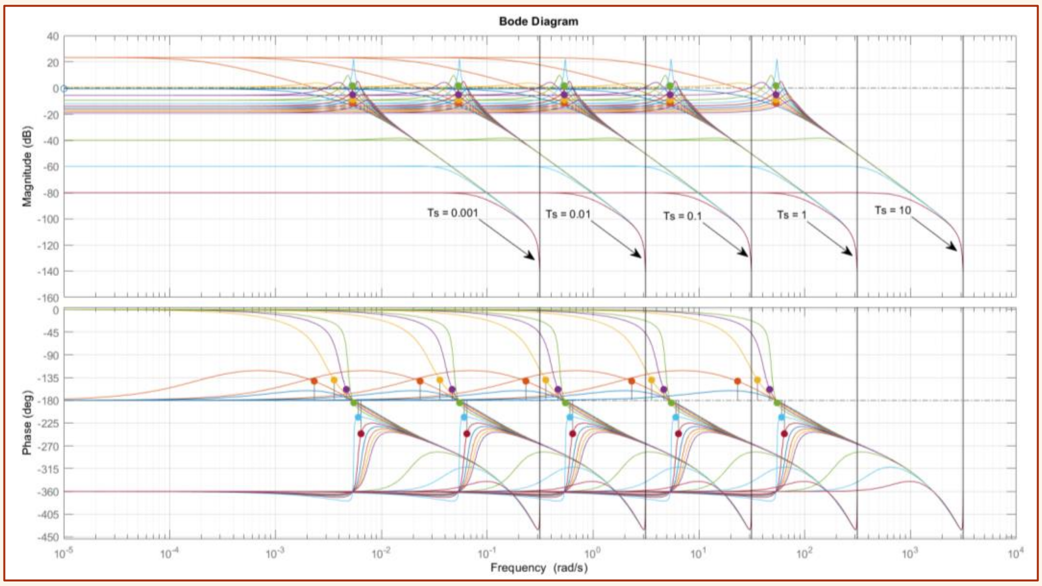


- PCO Frequency does not vary with K.

Changing Sampling Time

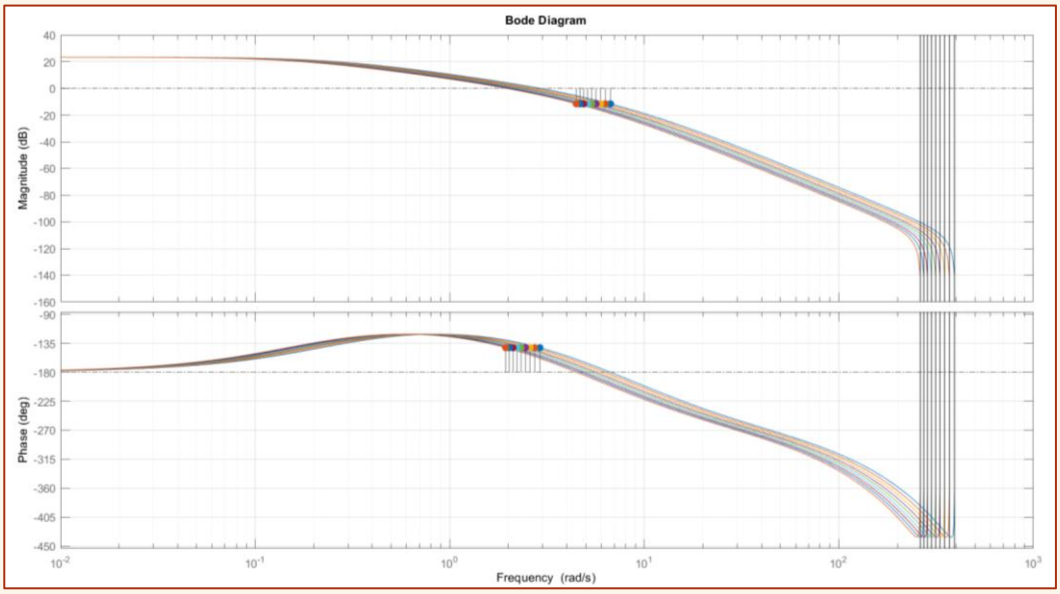
$T_s = [0.001\ \ 0.01\ \ 0.1\ \ 1\ \ 10]$

Let us view the bode plots for various T_s –



- The plots are similar in shape, but appear scaled in frequency.
- The values of GM and PM are the same.
- GCO and PCO frequencies are scaled by relevant amounts (i.e., if Ts is made 10 times, GCO frequency scales by 10 times).

20% variation around $T_s = 0.01$ for Unity Gain



We have taken Ts between 0.008 and 0.012.

- We can observe that, as before, GM and PM are not changed.
- The GCO and PCO Frequencies are scaled accordingly.

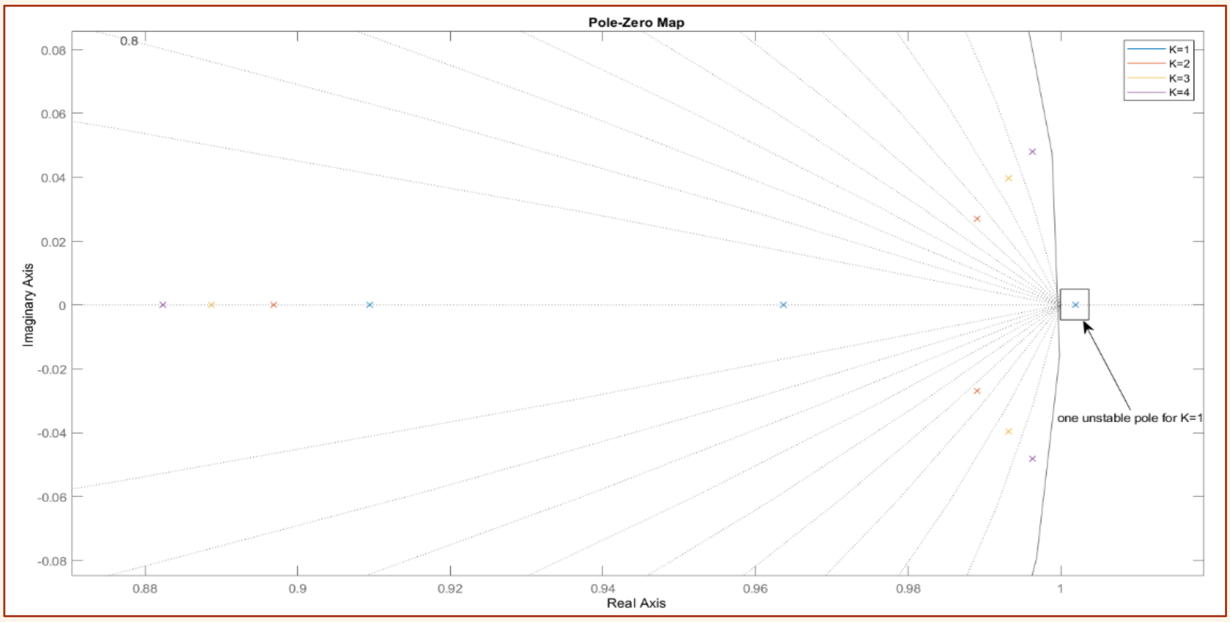
Discussions

Effect of K

- We saw the effect of changing feedback gain in the previous section.
- We discovered that gain margin is infinite for $K > 4$, hence the closed-loop system is unstable for gains larger than 4.
- It is also unstable in open-loop (K=0).
- The CLTF system is closed-loop stable (i.e., a second loop) for K = 1, 2, 3.
- However, this does not imply stability for the CLTF itself.
- To make a judgement for the CLTF stability we shall observe the pole-zero maps for various K values.

Pole-zero map

Let us draw the pole-zero maps for K=1, 2 ,3, 4.

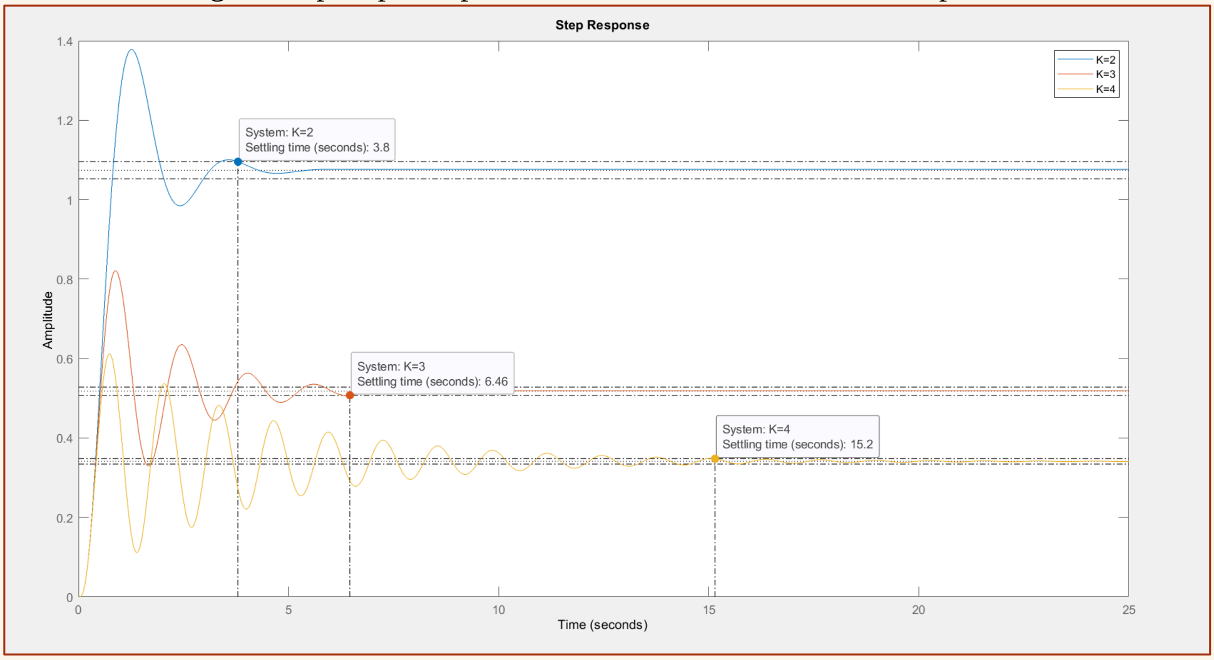


We see that even though CLTF(K=1) is Closed-Loop stable, the CLTF itself is not stable because of having a pole at $z = 1$.

Thus, we can surmise that:

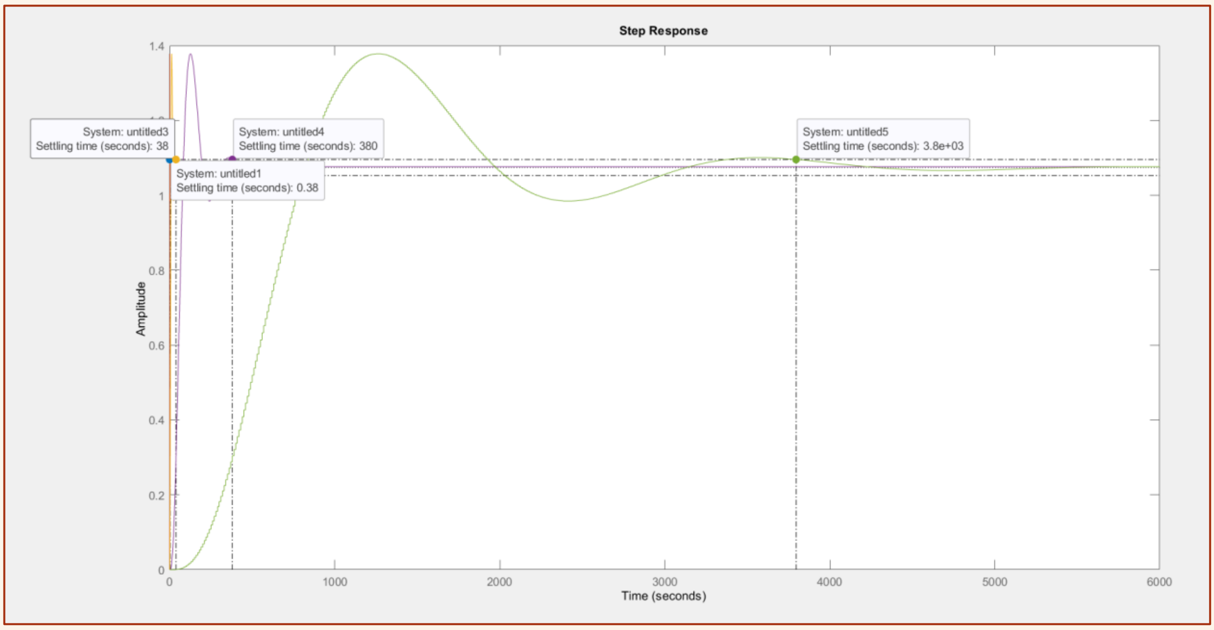
1. The CLTFs are stable for K = 2, 3, 4.
2. In case the design requires a second loop parallel to the constant gain block, the CLTFs are stable for K=1, 2, 3.
3. The Furnace system is unstable in open-loop and unity-gain closed-loop, and is also unstable in closed loop for feedback gains greater than 4.
4. We can thus choose between K = 2, 3, 4 for a stable closed-loop system depending on the specifications.

We are including the step response plots at Ts = 0.01 for the sake of completeness.



Effect of Sampling Time

- Changing sampling time does not affect GM or PM.
- GCO and PCO frequencies are scaled accordingly based on choice of sampling time.
- The effect of sampling time is felt in the time domain – we can see this with the step response plots.



(K=2)

We can see that the settling times are simply scaled as per the sampling time that is chosen.

Changing Ts has no effect on the stability of the system itself.

Conclusions

In this experiment we worked with the digital transfer function of a furnace model. We studied the variation of feedback gains and the effect on system stability and frequency domain stability margins. We also studied the effect of changing sampling time. Our findings are summarized as follows:

1. Feedback gains of K = 2, 3, 4 provide a stable closed-loop system. The corresponding stability margins have been tabulated earlier in the report.
2. Changing sampling time does not affect the gain and phase margins, and does not show any effect on the stability of the system.

MATLAB Script (2022a)

https://drive.google.com/file/d/1b0gbi2Km6Y-DSF6y9gDn9j9YyizoDfrk/view?usp=sharing