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By filling out the names above, the group members acknowledge that a) they have jointly authored this submission, b) this work represents their original work, c) that they have not been provided with nor examined another person's assignment, either electronically or in hard copy, and d) that this work has not been previously submitted for academic credit.			

LAB 2. SECOND-ORDER SYSTEM IDENTIFICATION AND ANALYSIS

ASSIGNED DATA

For easily referencing it, the Assigned Data has been placed at the start of this document.

On your pre-lab and post-lab submissions, always include this page at the beginning of the document.

Select your lab session:		☐ morning lab; ☒ afternoon lab; ☒ Tue; ☐ Wed; ☐ Thu
CourseBook Group Number		45
Assigned plant number ($Plant ¿= CourseBook\ GroupNumber ¿$		45
Plant parameters:	a	2
	b	5
	T	100
	K_i	330

The green highlighting present in this document is meant to draw your attention to things that need to be done.

Section 4.1

Calculations for table 2:

Using the formula for overshoot

$$
\begin{aligned}
OS &= e^{\frac{-\zeta\pi}{\sqrt{1-\zeta^2}}} \\
0.48 &= e^{\frac{-\zeta\pi}{\sqrt{1-\zeta^2}}} \\
\ln 0.48 &= \frac{-\zeta\pi}{\sqrt{1-\zeta^2}} \\
\ln^2 0.48 &= \frac{\zeta^2\pi^2}{1-\zeta^2} \\
\ln^2 0.48 \times (1-\zeta^2) &= \zeta^2\pi^2 \\
\ln^2 0.48 &= \zeta^2 \times (\pi^2 + \ln^2 0.48) \\
\zeta &= \sqrt{\frac{\ln^2 0.48}{\pi^2 + \ln^2 0.48}} \\
\zeta &= 0.2275
\end{aligned}
$$

Using the formula for peak time

$$
\begin{aligned}
T_p &= \frac{\pi}{\omega_n\sqrt{1-\zeta^2}} \\
\omega_n &= \frac{\pi}{T_p\sqrt{1-\zeta^2}} \\
\omega_n &= \frac{\pi}{0.00822\sqrt{1-\zeta^2}} \\
\omega_n &= \frac{382.93}{\sqrt{1-\zeta^2}} \\
\omega_n &= \frac{382.93}{\sqrt{1-0.2275}} \\
\omega_n &= 435.68
\end{aligned}
$$

Discussing Table 2 Prelab values: zeta = 0.2462 omega = 406.20

Experimental values: zeta = 0.2275 omega = 435.68

The experimental values differed from the theoretical values calculated in the prelab by around 8%. Errors may have stemmed from inaccurate graph reading when recording experimental values, or by small rounding errors during mathematical calculations for experimental and theoretical values.

Section 4.2

Discussing Table 3 **Peak Value**: This increased with Kp. This fits control theory as the peak value is the highest oscillation above the steady state value, since the steady state value is increasing without ζ changing this value should rise as well.

Steady state: As Kp increases the steady state value increases to match the Kp value. This fits with control theory as the output for G(S) has a steady state value of 1, experimentally verified. For the open loop system the output should be equal to $G(S) \times K \times K_p$ (as they are all in series) and since K stayed at 1 for all experiments the output increase was proportional to Kp.

T_p(s)	c_{max} (V)	c_{ss}(V)	T_r(s)	T_s(s)
8.22E-003	1.48	1	3.01E-003	3.364E-002

Table 1: Response specifications - experimental values

Figure 1: Second order underdamped

Overshoot and Peak time: These values did not change much. This fits control theory as the equations for overshoot and peak time are proportional to ζ and ω_n which do not vary with with K or Kp in the open-loop system.

TODO: FIGURE OUT STEADY STATE ERROR FOR TABLE 3

Discussing Table 4 Peak Value and Steady State value: These values are increasing with Kp. Due to control theory our system output with the increase of Kp from 1 is:

$$Y(S) = \frac{K_p H(S)}{1 + K_p H(S)}$$

As Kp increases in the above equation the output will also increase is what causes the increase in the peak value and the steady state value.

Overshoot: The overshoot does not change much. This is due to the steady state and peak value increasing by the same ratio. We can also see that this value will not change because it is related to ζ which has not changed.

Peak Time: The peak time is decreasing as Kp increases TODO: FIGURE THIS OUT LATER

TODO: CHECK THAT THIS IS LEGAL CALCULATE ZETA AND OMEGA N FOR OPEN AND CLOSED LOOP

T_p(s)	c_{max} (V)	c_{ss}(V)	OS(%)	ζ	ω_n(rad/s)
8.22E-003	1.48	1	48	0.2275	435.68

Table 2: System identification data and results

Figure 2: Open-loop step response with K=1

AND COMPARE WITH THEORETICAL Using the formula for overshoot

$$\zeta = \sqrt{\frac{\ln^2 OS}{\pi^2 + \ln^2 OS}}$$

$$\zeta = \sqrt{\frac{\ln^2 0.64}{\pi^2 + \ln^2 0.64}}$$

$$\zeta = 0.14$$

Using the formula for peak time

$$\omega_n = \frac{\pi}{T_p\sqrt{1-\zeta^2}}$$

$$\omega_n = \frac{\pi}{0.0056\sqrt{1-0.14^2}}$$

$$\omega_n = 572.21$$

Open loop values Theoretical: zeta = 0.2462 omega = 406.20

Experimental values: zeta = 0.2275 omega = 435.68

K_p	T_p(s)	y_{max}(V)	y_{ss}(V)	OS(%)
1	8.2E-003	1.48	1	48
1.3	8.17E-003	1.98	1.33	49
1.66	8.27E-003	2.47	1.66	49
2	8.17E-003	2.93	2	47

Table 3: Open-loop step response values for Kp=variable

Figure 3: Closed-loop step response with K=1

Adjusted value is k=1.04

DISCUSS EFFECTS OF CLOSING THE LOOP ON FREQUENCY RESPONSE

WHY IS IT DESIRABLE TO CHANGE BANDWIDTH

Section 4.3

Comment qualitatively on which frequency ranges present better disturbance rejection

K_p	T_p(s)	y_{max}(V)	y_{ss}(V)	e_{ss}	OS(%)
1	5.6E-003	0.82	0.5		64
1.3	5.2E-003	0.93	0.57		63
1.66	4.92E-003	1.03	0.64		62
2	4.5E-003	1.12	0.68		65

Table 4: Closed-loop step response values for Kp=variable

	Low-freq gain (dB)	Experimental bw (rad/s)	Theor or sim bw (rad/s)	Error (%)
Open-loop	0.5	589		
Closed-loop	-5.8	850		

Table 5: Bandwidth (bw) measurement results

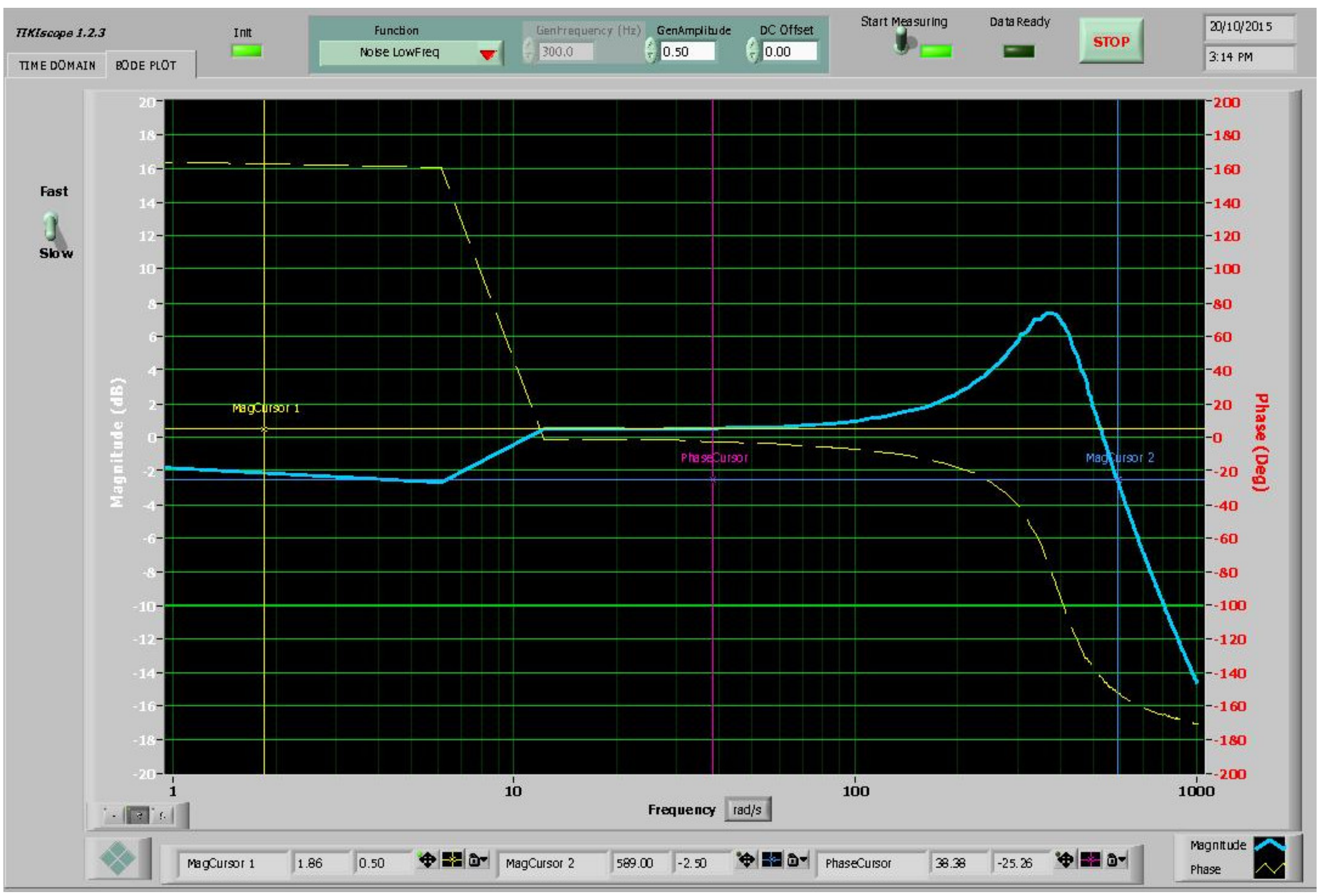

Figure 4: Open-loop frequency response

4_2c(open)_matlab.jpg

Figure 5: Matlab open-loop frequency response

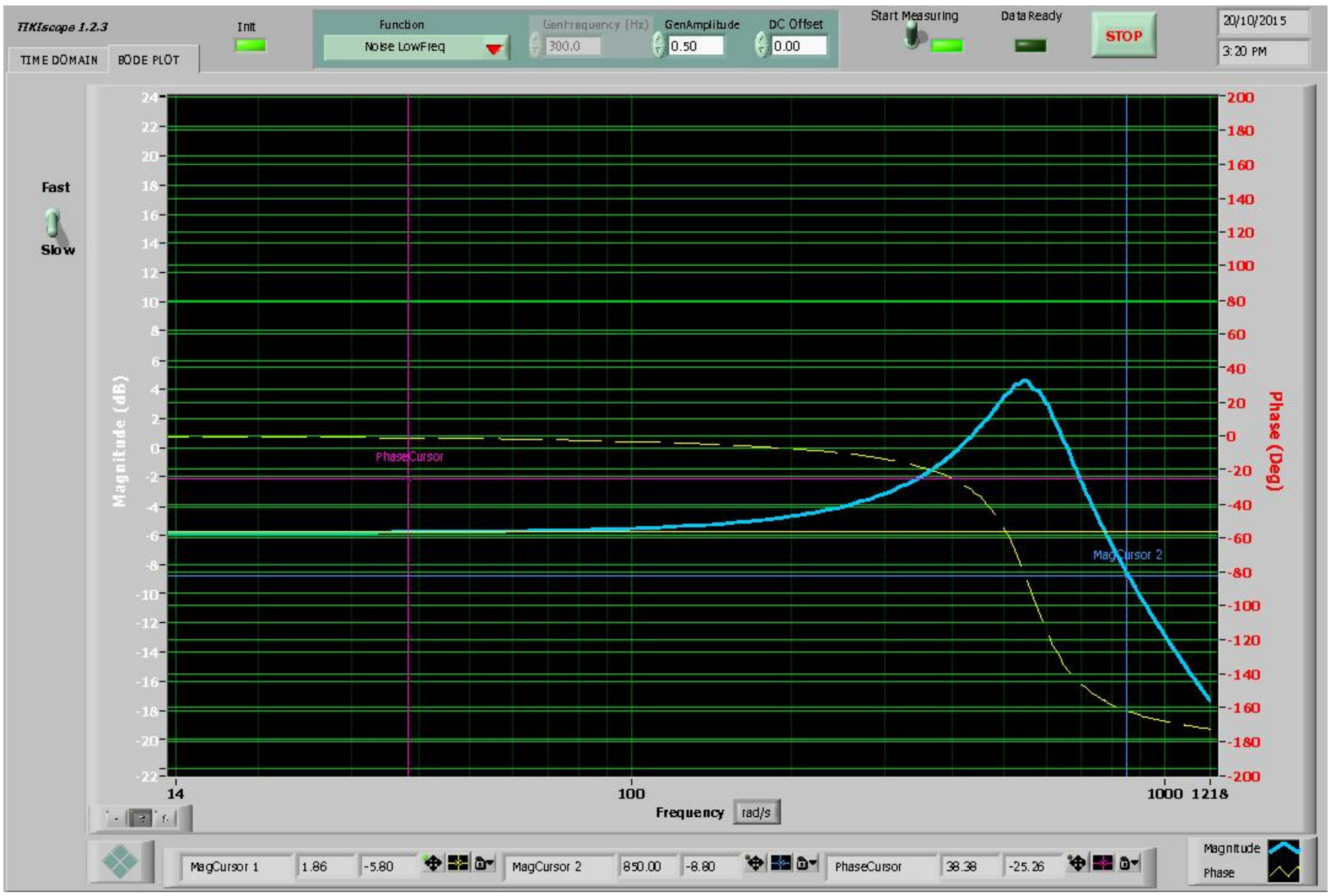

Figure 6: Closed-loop frequency response

4_2c(closed)_matlab.jpg

Figure 7: Matlab closed-loop frequency response

Figure 8: Frequency response response with disturbance

4_3_matlab.jpg

Figure 9: Frequency response response with disturbance in Matlab