Lab #5 Report
PD Control—Analog Computer and Windows Target

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Total: ___ /90

1 Comparison of Responses ___ /44

1.1 Theoretical Performance Criteria ___ /8

Table 1: Theoretical Values according to Figure 5.1 (Lab Manual)

parameters	Gains Set 1	Gains Set 2	Gains Set 3	Gains Set 4
	$P_1 = 0.15$, $P_2 = 0$	$P_1 = 0.25$, $P_2 = 0.35$	$P_1 = 0.1$, $P_2 = 0.5$	$P_1 = 0.888$, $P_2 = 0.807$
ζ [s]	0.109	0.471	1.006	0.517
ω_n [$\mathrm{rad\,s^{-1}}$]	22.77	29.39	18.59	55.4
M_p [%]	70.7	18.69	0	14.98
t_r [s]	0.052	0.053	0.182	0.03
t_s [s]	1.201	0.226	0.271	0.11

1.2 Experimental Performance Criteria ___ /12

Note: M_p, t_r, t_s are calculated with respect to the steady state responses, not the reference signals.

Table 2: Section I—Analog Computer

parameters	Gains Set 1	Gains Set 2	Gains Set 3	Gains Set 4
	$P_1 = 0.15$, $P_2 = 0$	$P_1 = 0.25$, $P_2 = 0.35$	$P_1 = 0.1$, $P_2 = 0.5$	$P_1 = 0.888$, $P_2 = 0.807$
M_p [%]	40.01	0	0	2.8
t_r [s]	0.059	0.081	Over-Damped	0.041
t_s [s]	0.888	0.211	≈ 1	0.158

1.3 Comparison of Sections I and II ___ /8

(Note any differences and characteristic similarities. Should they be the same? If they are different, why do they differ?)

Table 3: Section II—Windows Target

parameters	Gains Set 1	Gains Set 2	Gains Set 3	Gains Set 4
	$P_1 = 0.15,\ P_2 = 0$	$P_1 = 0.25,\ P_2 = 0.35$	$P_1 = 0.1,\ P_2 = 0.5$	$P_1 = 0.888,\ P_2 = 0.807$
M_p [%]	45.4	2.9	0	6.3
t_r [s]	0.054	0.06	Over-Damped	0.034
t_s [s]	0.708	0.482	≈ 1	0.474

Table 4: Section III—Windows Target with Friction Compensation

parameters	Gains Set 1	Gains Set 2	Gains Set 3	Gains Set 4
	$P_1 = 0.15,\ P_2 = 0$	$P_1 = 0.25,\ P_2 = 0.35$	$P_1 = 0.1,\ P_2 = 0.5$	$P_1 = 0.888,\ P_2 = 0.807$
M_p [%]	69	8.54	0	4.15
t_r [s]	0.042	0.054	0.276	0.034
t_s [s]	0.918	0.134	0.4	0.048

The Windows Target controller should theoretically be the same as the one implemented using the analog computer since both are implementing the same controller diagram. However, due to physical factors present in the implementation of the analog computer which are not present in the code generated by SIMULINK, there may be behavior that is present in the first trial that is not present in the second.

We can see that this is the case because the results of the two trials, while similar, are not quite the same. The M_p values of the second trial are slightly higher, which makes sense since physical factors and imperfect transitions within the controller logic would likely cause the first response to be slower to shift. Thus, we can see that the response in the second case is faster and as such overshoots past the first trial. This also leads to a t_r that is marginally faster, because the response shifts faster than in the first trial. Finally, because the system is functionally 'less dampened' by these factors, we can see that the t_s values we obtained are generally higher than those in the first test. This makes sense since the faster response will oscillate more before converging upon the steady-state value.

1.4 Comparison of Sections II and III ___/16

(Note any differences and characteristic similarities. Should they be the same? If they are different, why do they differ? Also, what are the effects of friction on the response of the system? How does it affect M_p, t_r, and t_s?)

Based on the info shown in the tables, there are a few conclusions that we can discern based on the responses that are achieved when using the controllers with and without friction compensation.

For example, in general we can see that the responses with the friction compensation have higher overshoot values that are likely caused by the fact that the friction compensation in the system causes it to rise faster and thus slip much further past the steady-state value before settling. As such, the rise times are all slightly faster than their un-compensated counterparts. However, in the case of poorly chosen gains, this compensation will also result in a large degree of oscillation in the output and thus the the time to steady state will be increased. But, if the gains are chosen correctly then the response will quickly fall to oscillations within the 5% degree band that defines the steady state time, reducing the t_s measured.

2 Performance ___/18

2.1 Compare the Performance of Your Design to the Specifications ___/10

(Did your design meet the specifications given in the prelab ($M_p < 15\%$ and $t_r < 30$ms)? If not, can you give some suggestions to improve the performance? For example, which gain could be improved and better?)

In the case of our final controller, we found that the system's response was quite good, especially when compared with some of the earlier responses, however it does not quite satisfy the $t_s < 30ms$ requirement. This could be resolved by modifying the controller design slightly, specifically by increasing the value of P_2 since that value corresponds to the derivative gain in the system. By increasing it, we will cause the response to shift faster and move towards the steady state more quickly. We performed a few tests to see if this would fix the slight issues with the response generated and found that increasing the derivative gain (to ≈ 0.98) did actually push the system to achieve a faster and more responsive output.

2.2 Unmodeled Plant Dynamics ___/8

(Explain how unmodeled plant might cause problems. Give an example of dynamics that were unmodeled or ignored in the prelab. What problems could these dynamics cause?)

While we did take into account a large number of important factors while designing this controller, there are some that were not included in its consideration that may cause there to be some unexpected results in the output of the system. For example, the inertia of the rotating disk and other components was not a factor in determining the gains, meaning that they may cause some unexpected overshoot. Additionally, there could be inconsistencies in the motor and other physical components that may cause specific issues in the output that would not be the result of the controller but rather the system introducing variables that were unaccounted for. In a physical sense this is manifested as slight deviations from the expected result of the system, such as small overshoots or jerkiness in the motor's travel from one position to another.

3 Steady State Error ___/16

3.1 Theoretical and Measured e_{ss} ___/8

Table 5: Steady State Error in Each Trial

Trials	Gains Set 1	Gains Set 2	Gains Set 3	Gains Set 4
	$P_1 = 0.15$, $P_2 = 0$	$P_1 = 0.25$, $P_2 = 0.35$	$P_1 = 0.1$, $P_2 = 0.5$	$P_1 = 0.888$, $P_2 = 0.807$
Theoretical [%]	0.19	0.12	0.29	3.25E-2
Section I [%]	8.7	4.7	22.5	2.5
Section II [%]	0.25	0.05	25	1.4E-3
Section III [%]	0.52	0.22	0.26	0.11

3.2 Gain Adjustments to Decrease e_{ss} ___/8

(What gain adjustments helped decrease steady state error? Can you give a general rule for which gain values give the lowest steady state error?)

In finding gain values that would reduce error and improve the performance of the controller, we employed a great degree of trial and error which made the effects of modifying each of the gain values very clear. For example, we found that increasing both of the gain values generally had a positive effect on reducing the error and causing the system to track the steady state more quickly. This is likely because the controller will respond with a larger output even when the position is very close to the reference. In this case, increasing the derivative gain is very useful as it prevents the proportional gain from taking over and causing the response to oscillate. Thus, we found values of both gains that were higher ($P_1 = 0.91, P_2 = 0.98$) to be much more effective at stabilizing the system.

4 Friction Compensation ___ /12

4.1 Friction Values ___ /6

Table 6: Friction Values

	Lab4	Lab 5 Section III Full Values	Lab 5 Section III Reduced Values
c^+ [N m]	2.54E-5	8E-4	6.1E-4
c^- [N m]	0.0075	0.015	0.01
b^+ [N m s rad^{-1}]	2.76E-5	8E-4	6.1E-4
b^- [N m s rad^{-1}]	-0.0074	-0.015	-0.01

4.2 Discussion ___ /6

(How much did you have to reduce the friction values (in order to get "stable" step responses)? How do both results from Lab 5 compare with Lab 4?)

We needed to reduce the friction values by roughly a third each to make the responses stable enough while still getting a response that resembled 'friction-less' motion. This makes sense because overcompensating for this effect will cause the response to spin out of control as the input from this module accumulates and continues to spin the motor faster and faster. As a result, we reduced the values of the friction compensation and found that we were able to make the system stable and still account for the friction present in the system.

The values that we ended with were slightly higher than the ones measured in lab 4, likely because there are other sources of friction in the system that were not considered in our calculations as well as the fact that inconsistencies in the apparatus may also have been at play. As such, we were slightly overcompensating for the friction that we measured but it was necessary in order to make the system behave as expected. Without the correct values introduced into the compensation mechanism, we found that the results were essentially the same as without that part connected. This shows that while many calculations can be made in order to guess the values of the gains and other experimental values necessary to control the system, there will be a reasonable degree of trial and error involved in tuning the system to behave in the smoothest possible way.