# EE411 Lab 6

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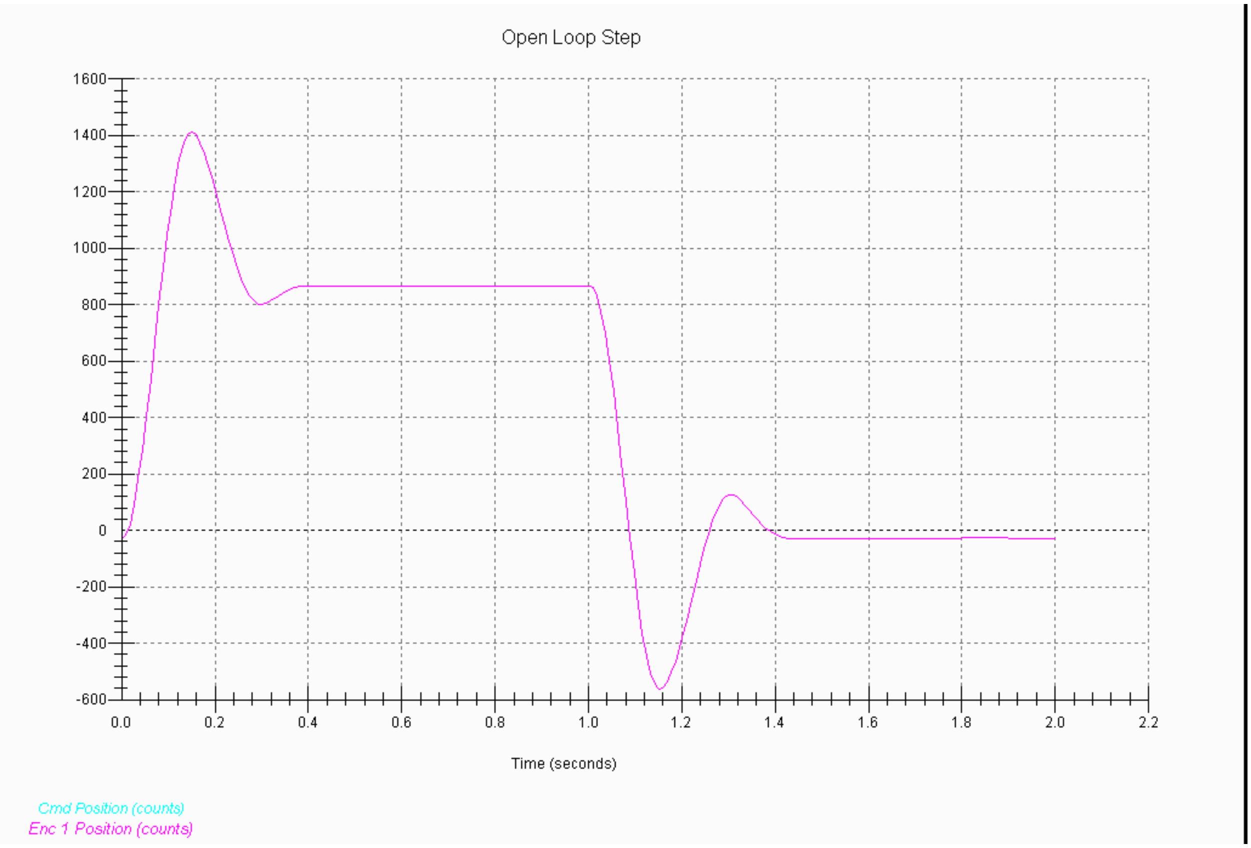
## Introduction

In this lab we will be testing a system to find the plant model. From this plant we will design a controller to give a better step response of the system. We chose to analyze Rectilinear Dynamic System (Mass Spring)/ Model and chose to use the PID controller to give us this better response.

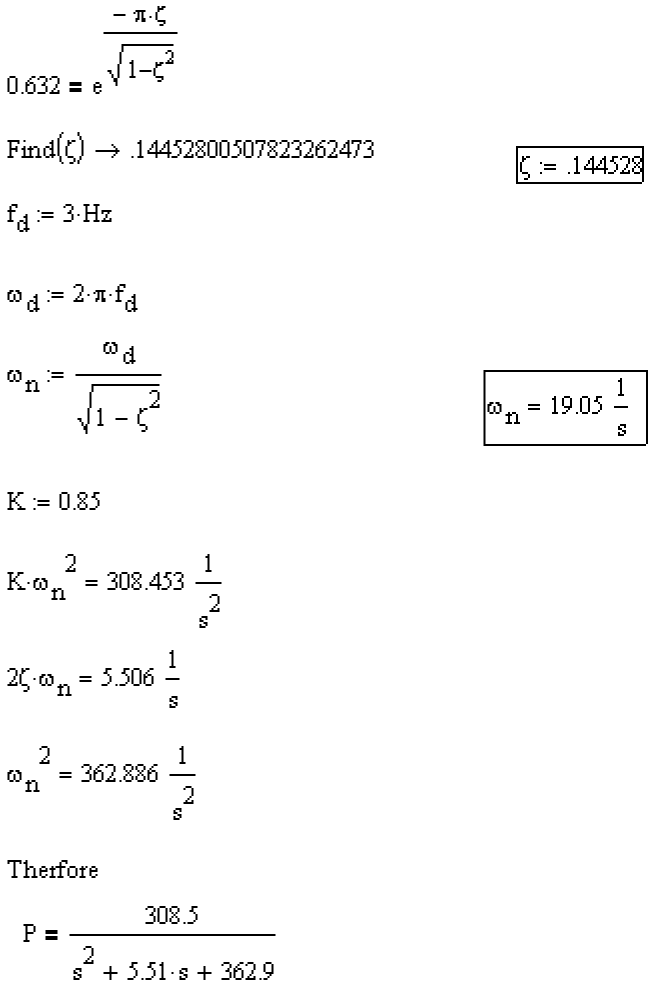
## Analysis and Identification of System Properties

The open loop step response of the mass spring system is shown below. From this response we found the system characteristics shown in the table below.



| | |
|---|---|
| Overshoot | 63.2% |
| Damped Frequency | 3 Hz |
| DC Gain | 0.85 |

From the numbers above we where able to find the transfer function of the system using Mathcad.



$$0.632 = e^{\frac{-\pi\cdot\zeta}{\sqrt{1-\zeta^2}}}$$

$$\text{Find}(\zeta) \rightarrow .14452800507823262473 \qquad \boxed{\zeta := .144528}$$

$$f_d := 3\cdot\text{Hz}$$

$$\omega_d := 2\cdot\pi\cdot f_d$$

$$\omega_n := \frac{\omega_d}{\sqrt{1-\zeta^2}} \qquad \boxed{\omega_n = 19.05\ \frac{1}{s}}$$

$$K := 0.85$$

$$K\cdot\omega_n^{\ 2} = 308.453\ \frac{1}{s^2}$$

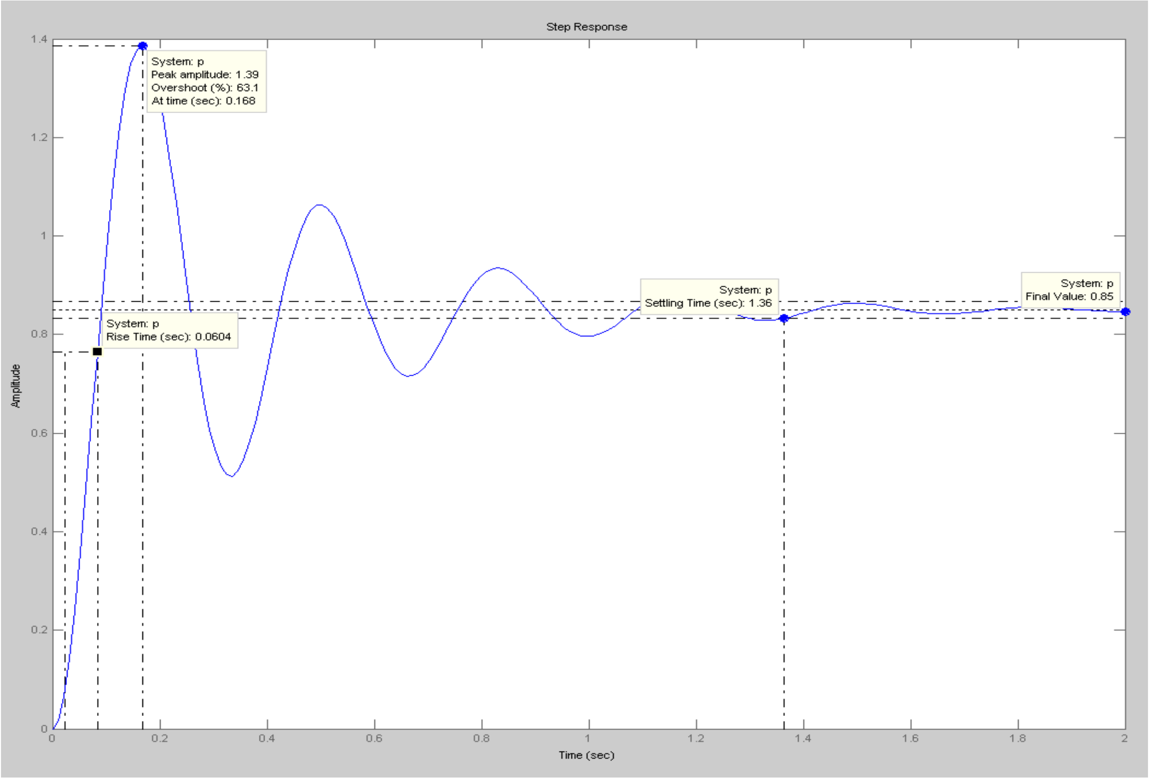
$$2\zeta\cdot\omega_n = 5.506\ \frac{1}{s}$$

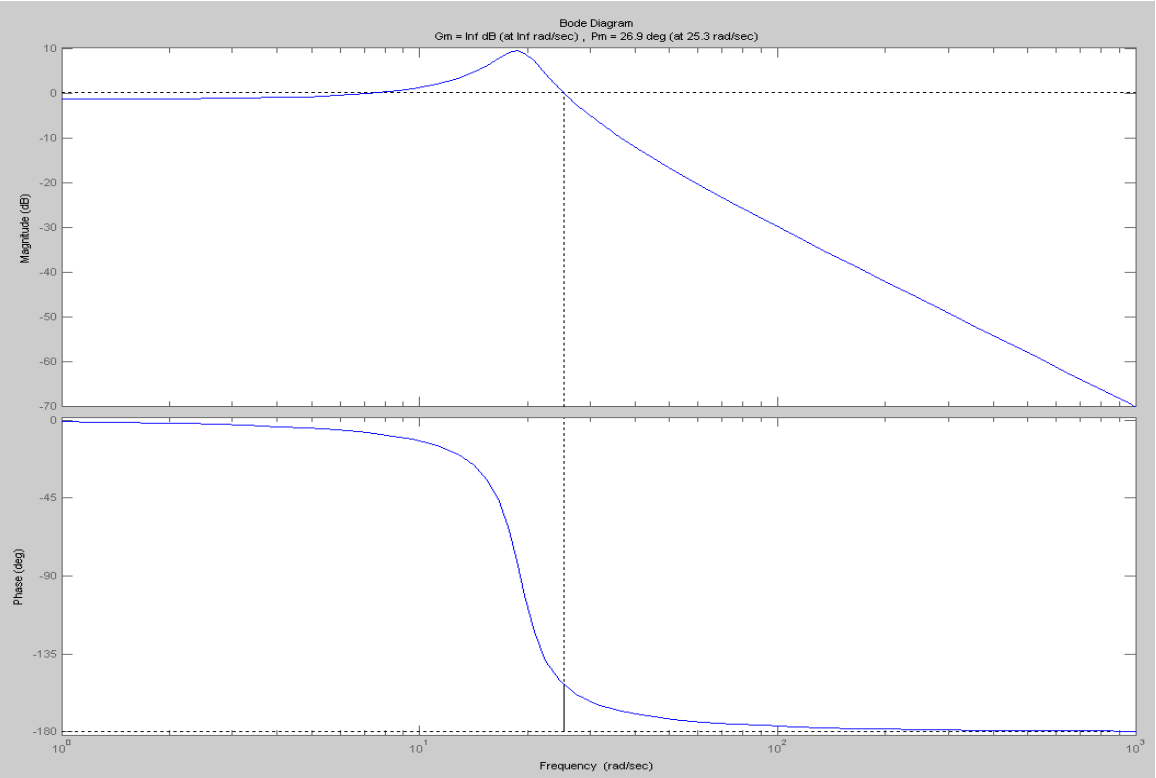
$$\omega_n^{\ 2} = 362.886\ \frac{1}{s^2}$$

Therfore

$$P = \frac{308.5}{s^2 + 5.51\cdot s + 362.9}$$

Below is our Matlab simulation of our open loop plant model and the Bode plot.





Below is a table summarizing the characteristics of our plant model.

| | |
|---|---|
| Overshoot | 63.1% |
| Damped Frequency | 3 Hz |
| DC gain | 0.85 |
| Gain Margin | Infinite |
| Phase Margin | 26.9 deg |
| Settle Time | 1.36 seconds |

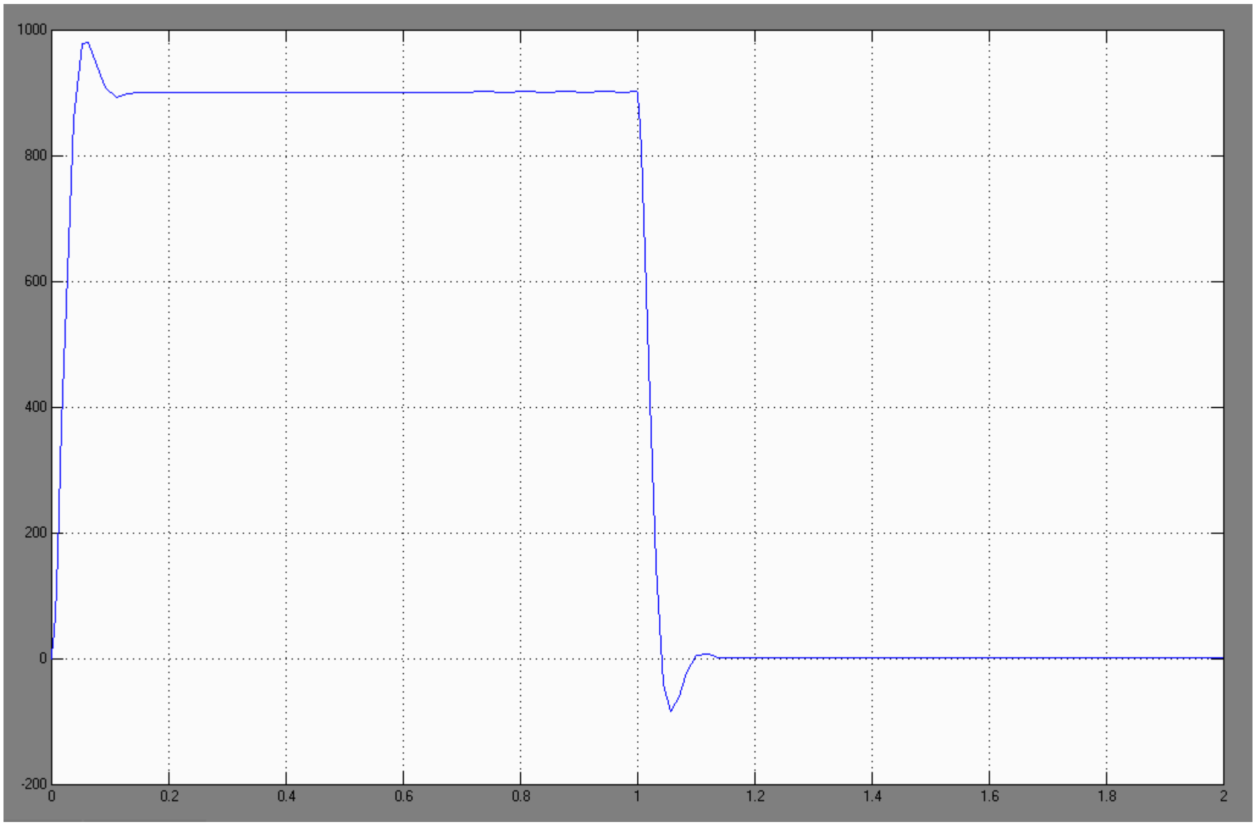
This is very close to our physical system characteristics.

## **Design of Controller**

We chose to design a controller to give us 20% overshoot and reduce the settle time to 0.1 seconds. Using the analytical PID design method we obtained the controller design shown below.

| Proportional Gain $K_P$ | Integral Gain $K_I$ | Derivative Gain $K_D$ |
|---|---|---|
| 10.6 | 0.1 | 0.19 |

Below is the Simulink model of our system with the PID controller.

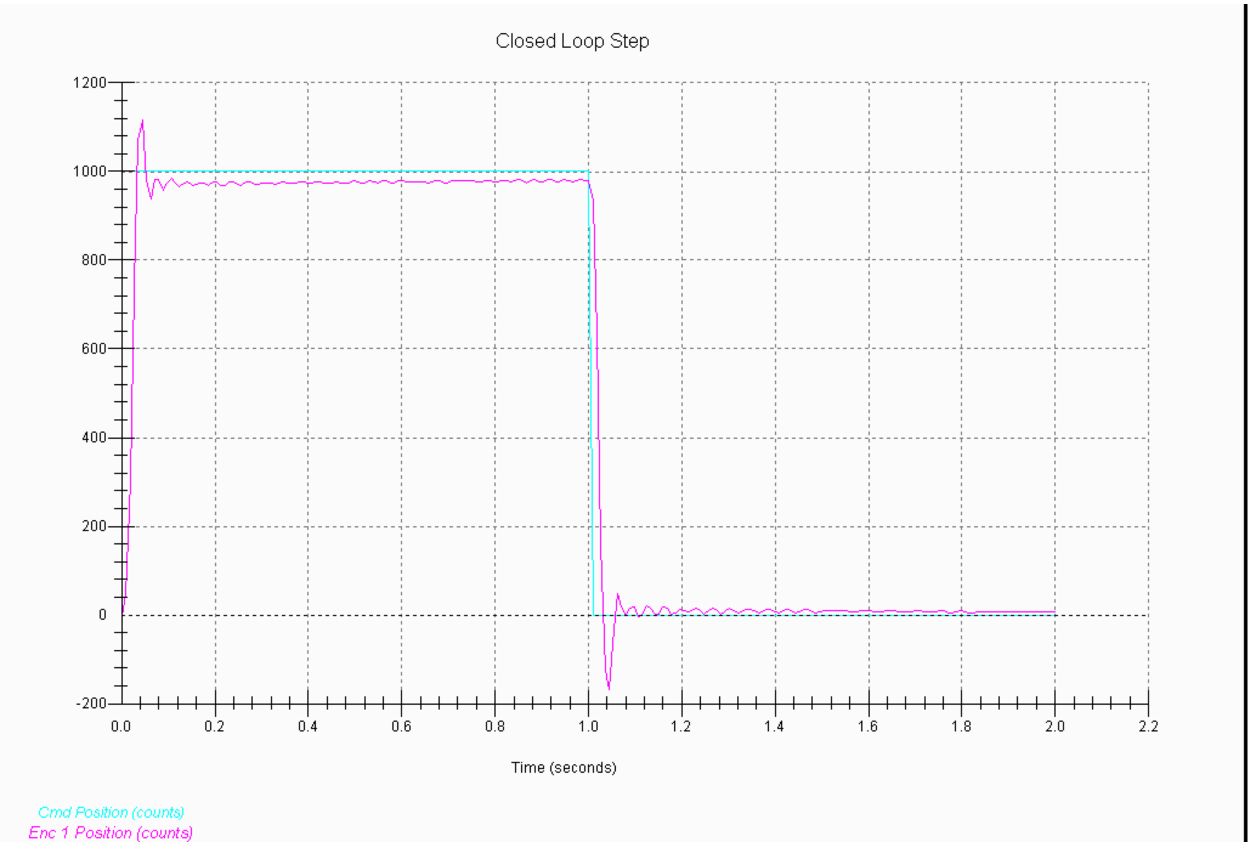


When we tried to implement this controller for the physical system, we found that these gains were far too high and the system would become unstable. We reduced the gain until we achieved stability in the system. When stability was attained, we adjusted the gain until the optimal step response within our design specifications was observed.

Below is the final numbers we obtained for the physical system controller.

| Proportional Gain $K_P$ | Integral Gain $K_I$ | Derivative Gain $K_D$ |
|---|---|---|
| 1.5 | 0.6 | 0.015 |

Below is the closed loop step response of our system with the included PID controller.

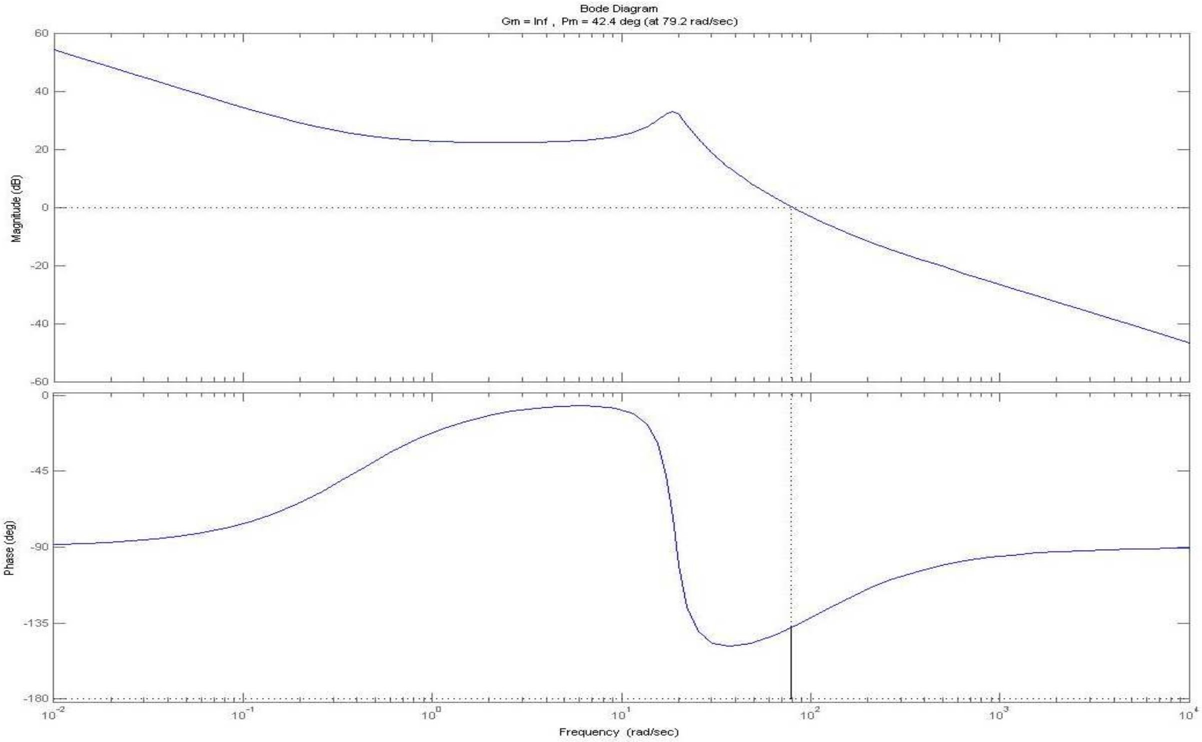


Below is a table of our system with the controller implemented.

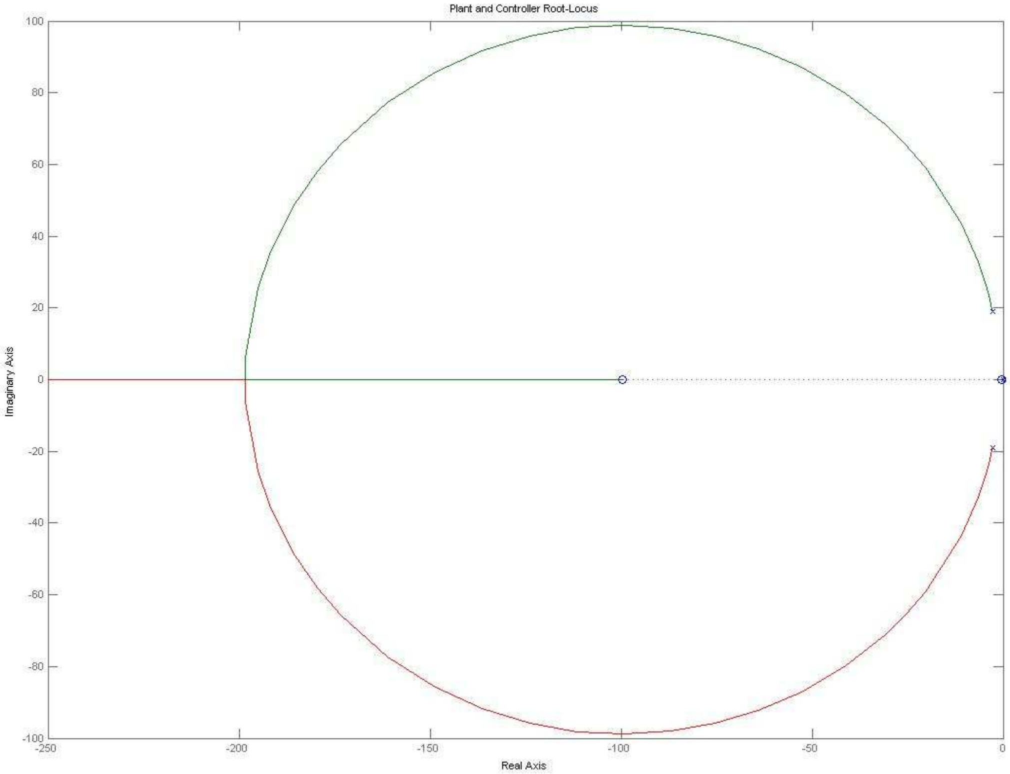
| | |
|---|---|
| Overshoot | 14.4% |
| Settle Time | 0.08 seconds |
| DC Gain | 0.975 |

We returned to Matlab with our iteratively determined numbers. We noticed that these numbers where a factor of ten different than those previously determined. Thus we multiplied our experimentally determined gains by ten in our model. This gave us the following graphs.

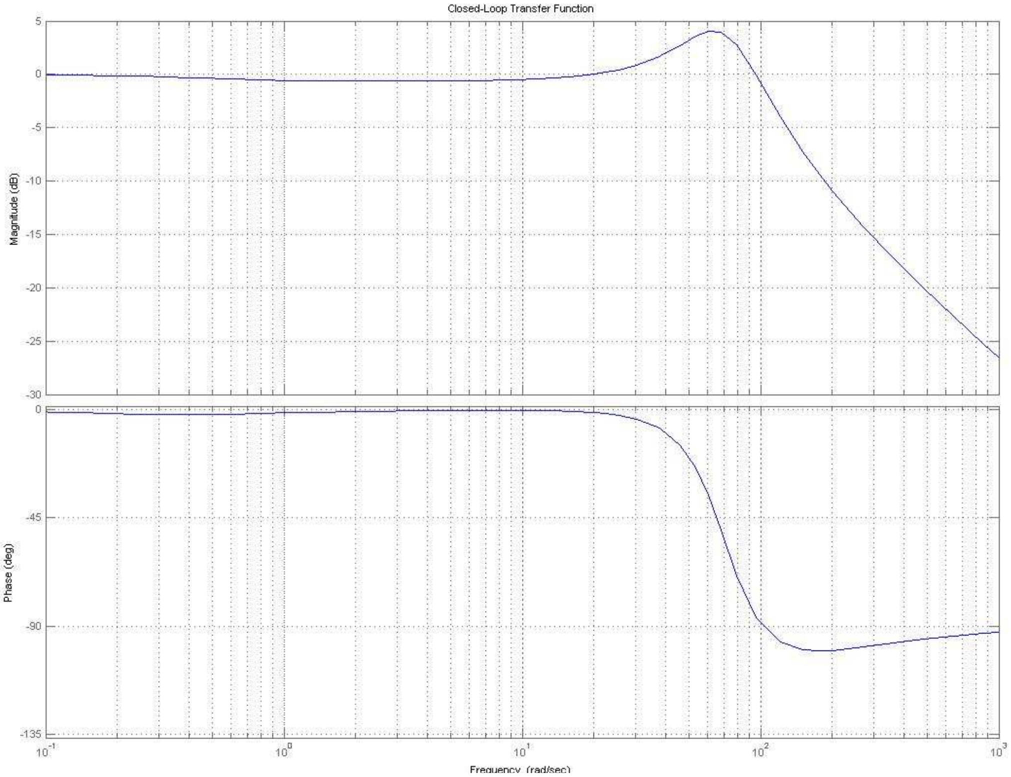
Step Response of the controlled system



Bode plot of the controlled system forward path



Root locus plot of the plant and controller



Closed loop frequency response

## Analysis of results

We noted that there seems to be a discrepancy of a factor of ten between our Matlab numbers and our physical system numbers. Possible reasons for this could be changes made to the system by other users (damper screw, etc.) or discrepancies in the controller software. When we simulated using the physical numbers multiplied by ten we observed very similar results.

We improved the overshoot from 63.1% to 14.4%, the settle time from 1.36 seconds to 0.08 seconds and the steady state error from 15% to 2.5%. In theory with the presence of an integrator we should have a 0% steady state error; however our step response period was not long enough to see our system reach 0% steady state error.

We achieved numbers better than our specifications for the overshoot and settle time. This is likely due to our iterative method of design. A drawback to this design is we cannot reproduce the results exactly in Matlab.

## Conclusion

For this laboratory, we analyzed the step response of the mass/spring system to obtain a plant model and then designed a PID controller to improve this response. Using the analytical PID design contained in our textbook, we calculated the necessary PID components to lower the percentage overshoot, as well as lower the settle time with the following parameters: P= 0.41, I= 0.1, D= 0.002. When we used this controller on the actual mass/spring system, the response was not as anticipated, as it became unstable when any input or noise was added to the system. The most likely factor causing the system to behave differently is the plant could have been altered since the previous time we used it. Although we made strides to recreate the original system, the damper was moved since we last had modeled the plant and it is possible that a different spring was inserted into the system. As a result, the plant was altered and our controller did not behave properly.

Once we saw the controller was not working for this “new” system, we found an effective PID controller by an iterative approach. We found a PID controller with the following parameters to be effective: P= 1.5, I= 0.6, D= 0.015. We used this controller in Simulink with our original plant model and it was in turn, not effective. Again, this was most likely caused by the plant being changed.

From this laboratory, we learned it is absolutely essential that the plant is not altered at all when a controller is being designed to control the plant. If the plant is altered, the controller that was designed will most likely be ineffective. Additionally, it is impossible to perfectly model any physical system. Any model that is generated for a physical system is an approximation. For this second order system, it is usually possible to make a fairly accurate model that can be simulated in Simulink. Our original model did closely model the original system, so our controller should have been effective had the original plant not changed. Overall, this lab provided us with good experience on real life controller design and some of the potential difficulties.