UNIVERSITY OF GUELPH
SCHOOL OF ENGINEERING ENGG*3410

Instructor:
Dr. Biglarbegian

Lab 4: Investigating PID Controllers
By Julie Vale and Mike Stachowsky

Bilal Ayyache- 0988616
Suyash Singhal- 0987450

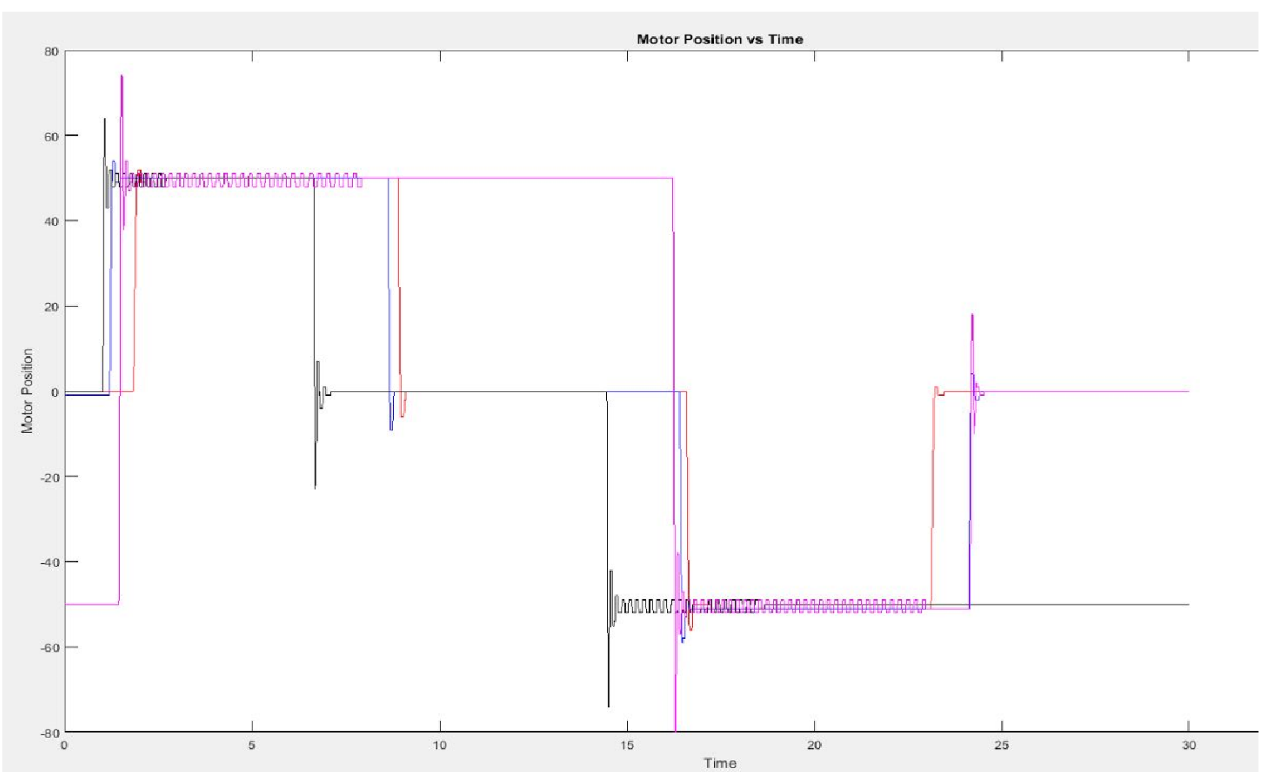
Contents

1.0 Introduction

The main objective of lab 4 is to understand how steady state error is minimized by adjusting the respective proportional values, integrator value, and derivative gain values in a transfer function. The transfer function calculated in lab 3 was used in the experiments conducted. To analyze how the system reacts to specific changes in these parameters, every aspect was tested individually as these aspects affect the DC motor system.

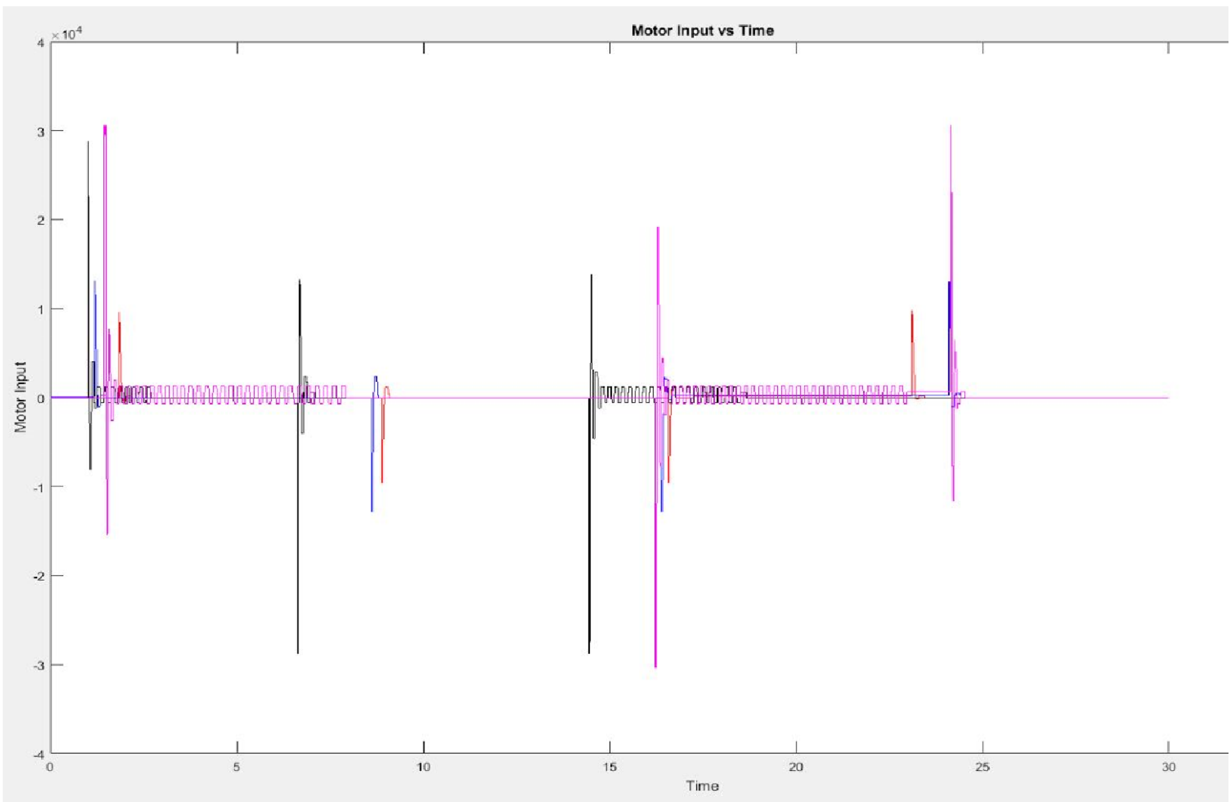
2.0 Experimental Results

A P gain of 3, 4, 8 and 9 was plotted in the figure below. The graph below describes the relationship between motor position vs time. By analyzing the graph below, the settling time and overshoot increases as the P gain of the system increases. This analysis is noticeable as the P gain increases from 3 to 9. The overshoot and the settling time of a P gain value of 9 is higher and longer. The P gain of 9 has an overshoot of 40% and compared to a p gain of 3 overshoot which was calculated to be 16%. A more detailed graph can be found in the appendix section. The peak overshoot increases as the P gain increase. The P gain of 9 has more oscillations around the 0 bound compared to the P Gain of 3 results. This makes sense as the settling time is longer compared to the P gain of three. The settling time for the P gain of 9 is roughly 0.75 seconds whereas the P gain of 3 is about 0.3 seconds.



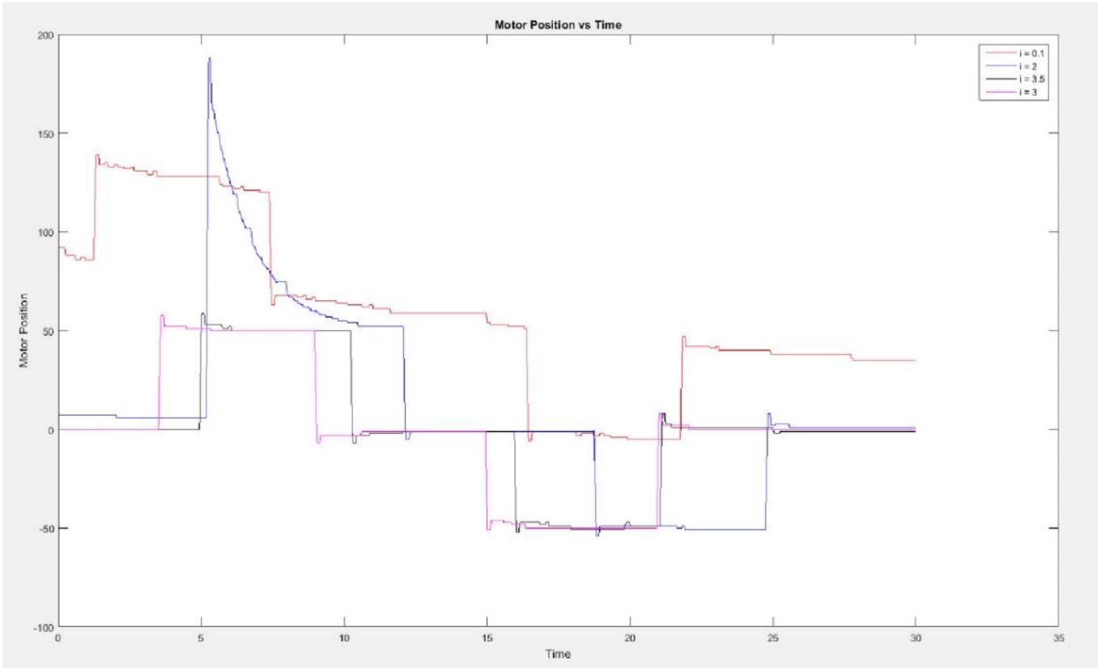
(Figure 1- Orange line => Kp = 3, Blue line => Kp = 4, green line => Kp = 8 , Purple Line => Kp = 9)

The figure below shows the motor input vs time for the same P gains mentioned above. By analysing the graph below, the effect of changing The P gain causes an increase in the motor input for all the Kp value cases. From the graph below, the P gain of 9 (purple) had an overshoot of 2.9 and the P gain of 3 had a peak overshoot of 1. From this experiment, it is analyzed that as the P gain increases the settling time gets faster. The difference between the two graphs is that the motor input is bounded at 0. As the motor input is disabled the signal is 0. The motor position graph is bounded by + or – 50 as it helps the analyzer read the current position of the motor.



(Figure 2- Orange line => Kp = 3, Blue line => Kp = 4, green line => Kp = 8 , Purple Line => Kp = 9)

Figure 3 below shows the relationship between motor position and time for the differing integrator values of 0.1, 2, 3 and 3.5. The integrator when increased has the effect of increasing overshoot and settling time for the PID controller. In Figure 3 it can be seen that the integrator changes the location of the zero bound of the system (initial motor position). For the lowest integrator of 0.1 the motor position at zero time was roughly 80. As the integrator increased to values trended closer to zero which should ideally seen, eliminating the error. In the cases where the integrator was at 3 and 3.5, they both started at a motor position of zero. One outlier in the graph did show up on the plot. The integrator of 2 in blue had a disproportionate rise for the first increase in setpoint. This disproportionality carries over to the next plot of motor input vs time.



(Figure 3-Orange line => Kp = 0.1, Blue line => Kp = 2, green line => Kp = 2.5, Purple Line => Kp = 3)

The relationship for the motor input vs time is displayed in the graph below. This graph clearly depicts the effects of the increased settling time, the increased overshoot and the elimination of steady state error as the integrator value increases. The integrator of 2 is an outlier in the data set, however the relationship can be seen in the first rise in setpoint.

Looking at the first rise in setpoint, the integrator of 0.1 has an overshoot of 0.98 and the integrator of 3.5 had an overshoot of around 1.10, showing that it increases overshoot. The settling time increasing can be seen as the integrator of 1 does not have a chance to fully settle in any of the cases of changes in setpoint whereas the integrator of 3.5 settles quite quickly in about 1.3 seconds. The elimination of steady state error can be seen in both plots. The integrator of 0.1 and 2 have oscillations around the bound in Figure 4, however the integrators of 3 and 3.5 have a straight line relationship which is seen because of the increased selling time.

The I gain can be useful if you want the PID controller to make the closed loop system stable. Due to the effect of the elimination of steady state error as the I gain increases stability is made possible. This is the case since the integral sums up error over time. With a big increase in error, the response from the integral is greater. The disadvantage of the I gain is that it causes a slow rise time as seen in the linear rise relationship in Figure 4.

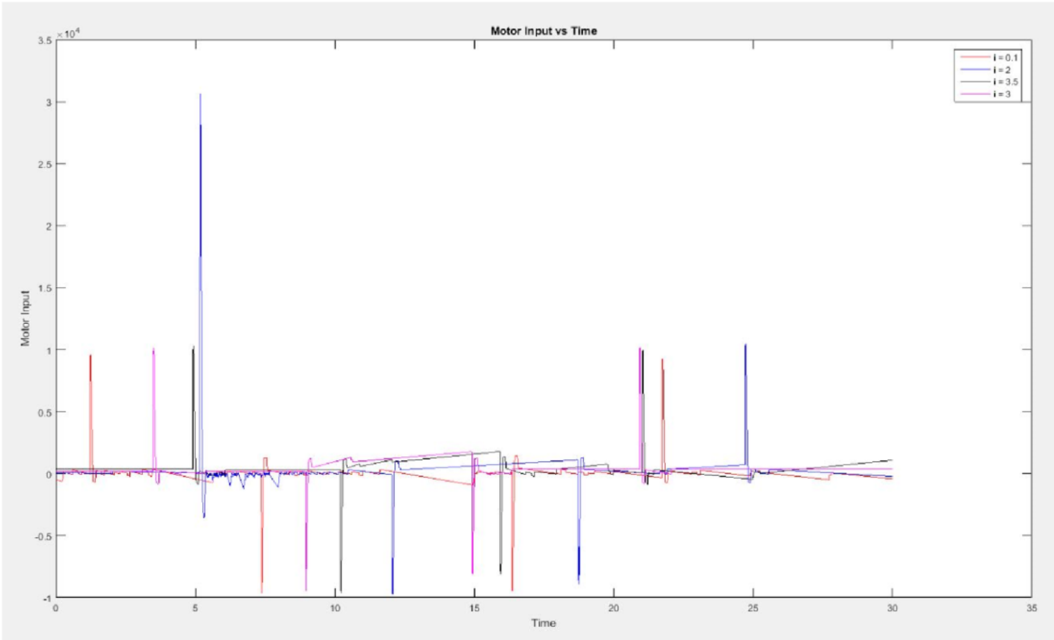


Figure 4

The graph in Figure 5 depicts the motor position vs time and the graph in Figure 6 plots motor input vs time, with varying values of the derivative. The derivative controller acts to decrease the overshoot in the system as well as having a decreased settling time as a result. In the experiment the D gains used were 0, 2, 5, and 8. In Figure 5 the decrease in overshoot can be seen as the derivative of 0 had overshoot in all three changes in setpoint whereas the derivatives of 2,5, and 8 did not have any overshoot. The decrease in settling time can be seen as the derivative of 2 had a settling time of 11 second and the derivative of 10 had a settling time of roughly 13 seconds.

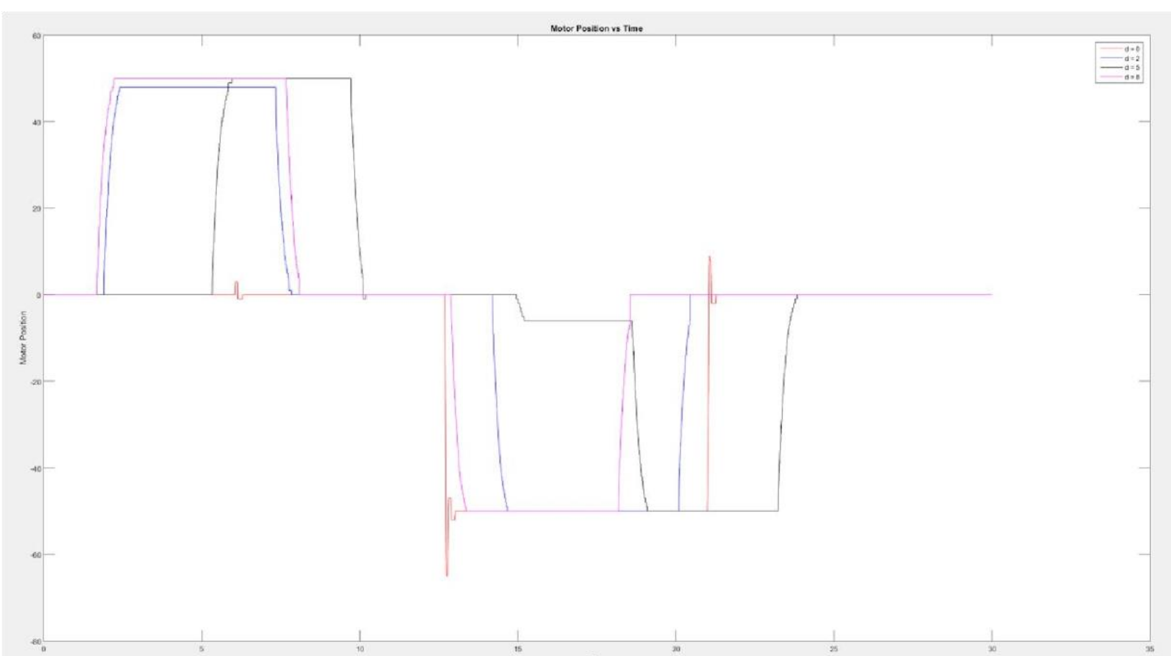


Figure 5

As stated in the lab manual, derivative gains amplify high frequency signals. This is clear in the above Bode plots. Figure 8 shows the Bode plot for the transfer function with no control. It shows a steady decline in magnitude as the frequency increases. Figure 7 shows the Bode plot in closed loop feedback with a derivative gain of 5, and a proportional gain of 1. As the plot shows, this gain amplifies the decrease in magnitude, showing a larger ratio of decrease in the ratio of magnitude decrease/frequency increase. As a result, this shows that the derivative gain does amplify signals at higher frequencies.

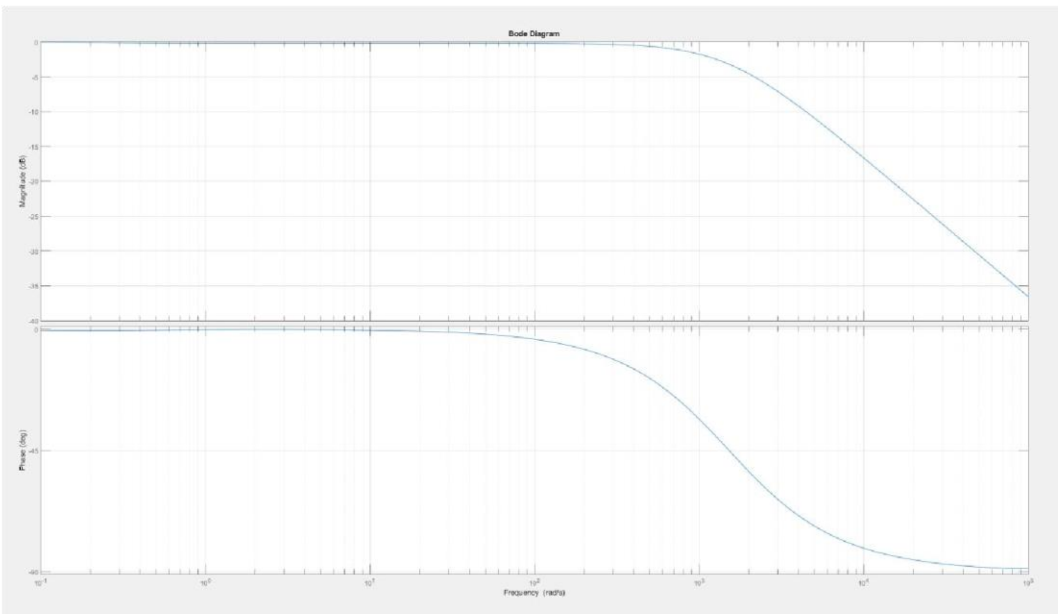


Figure 6

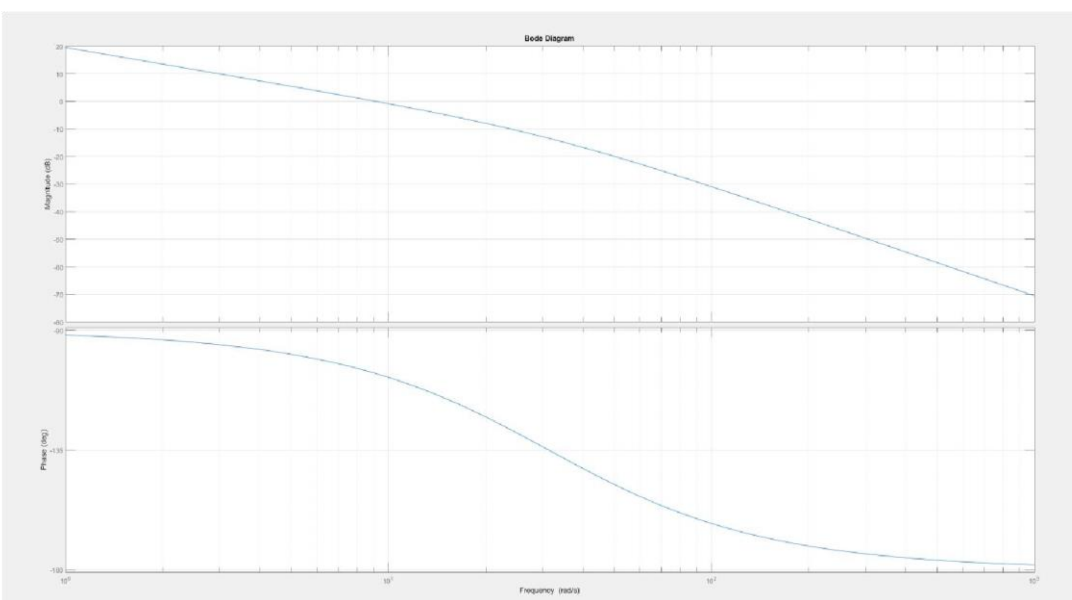


Figure 7

In a perfect tracking control system, the output Y must follow an input I, resulting in a transfer function of Y/R = 1. In this case, the transfer function for a closed loop PD control feedback is as follows:

$$\frac{Y}{R} = \frac{HC}{1+HC} = 1$$

$$H(s) = \frac{9.5}{s(0.032s + 1)}$$

$$C(s) = K_d s + K_p$$

This results in a transfer function of:

$$T = \frac{9.5Kds + 9.5Kp}{0.032s^2 + (1 + 9.5Kd)s + Kp}$$

As the limit of K_p approaches zero, the value of the transfer function T will remained largely unchanged. This means that to the fact that theoretically, the system will have good tracking regardless of how small the K_p value is.

This disagrees with the results from the lab experiment. The main reason for this discrepancy between the actual and theoretical models is due to the fact that the theoretical model assumes linearity, while the actual model is non-linear. Many reasons for non-linearity exist within the motor. These include friction within the motor, resistance to the input signal, and possible wear from prior use. Due to these factors, the assumed linear model is incorrect, and will result in incorrect assumptions when using the mathematical model to determine the impact of various factors, such as lowering the K_p value. Although in theory an extremely low value of proportional gain is irrelevant to the tracking, in reality it causes a non-zero steady state error, and inaccurate tracking.

In control, P gain has an effect on the steady state error. As P gain increases, the steady state error decreases. When this is desired, the highest P gain value possible is ideal. However, in these systems, too high of a P gain value may cause saturation. In this case, the saturation will occur when the input is required to exceed 5V. In this case, the required voltage is directly impacted by the error and the P gain value. For this model, the maximum error is the difference between the 2 set points. Since they are 0 and 1 (unit step), the maximum steady state error is 1. The maximum proportional gain can be determined by using the following equation:

$$Input = K_p \times error$$

$$5 = K_p \times 1 \; K_p$$

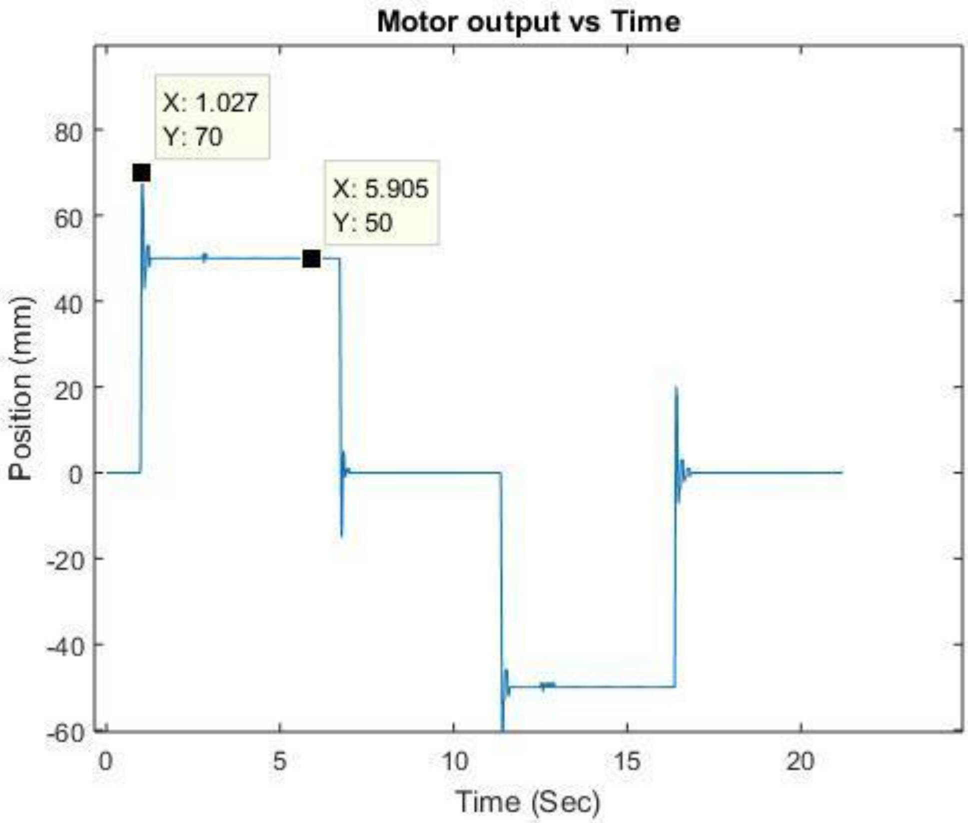
$$= 5$$

Therefore, the maximum K_p value without causing saturation of the motor in this model is a gain of 5.

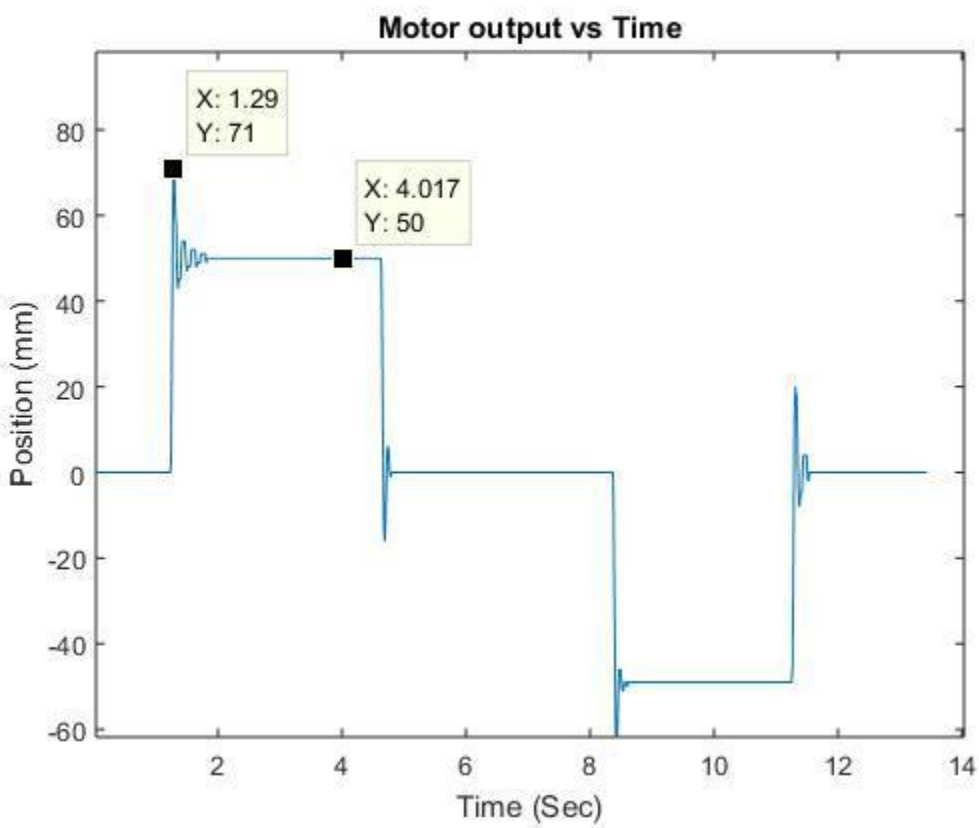
3.0 Conclusions

Through this lab, the methods of analyzing a transfer function was explored and how the Kp value of the transfer function affects specific characteristics of the system was analyzed. By understand these characteristics and how Kp affects the system helps a control engineer to understand the behaviors of the system. Understanding the behavior helps in the design process of controllers as these controllers are currently used in most engineering plants. To conclude the results, as the Kp increase, the overshoot and the settling time of the system increase. This makes the system less efficient as having a high Kp value causes a decrease in performance.

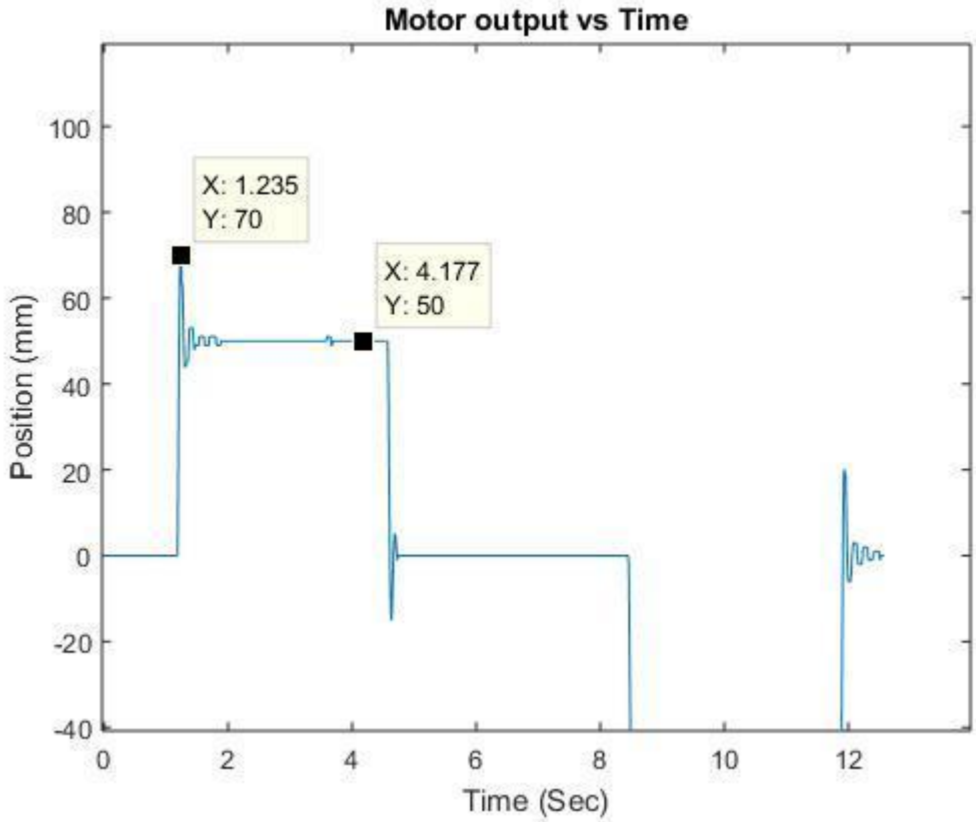
Appendices



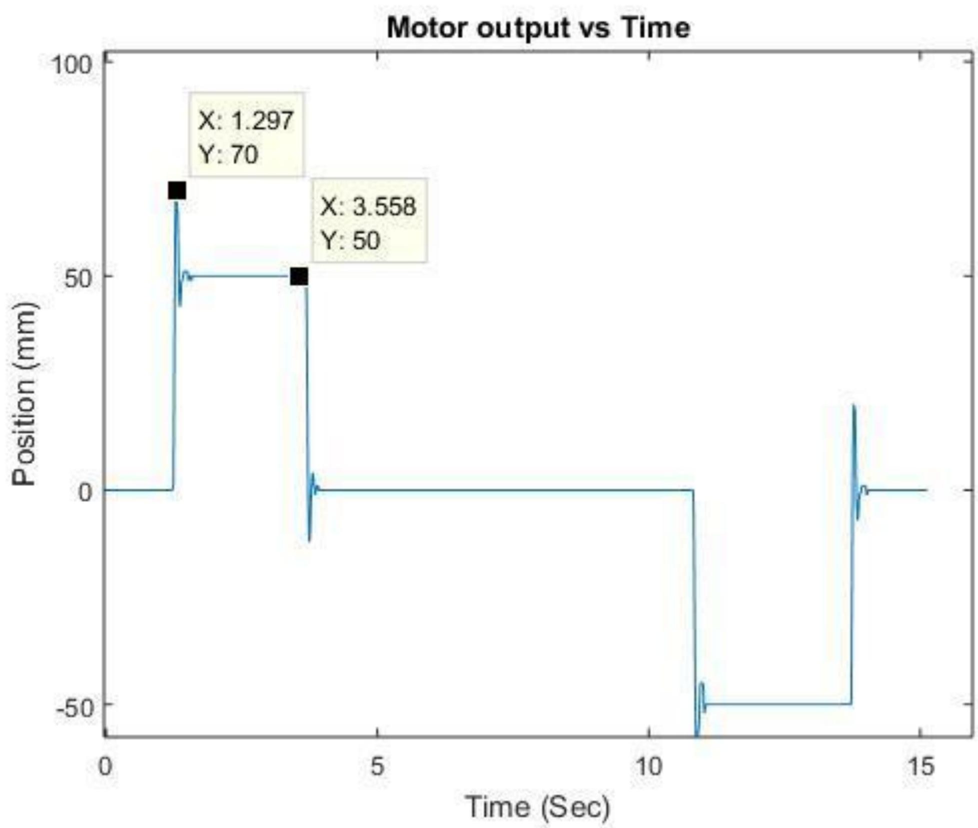
P Gain of 9 and a setpoint of 50



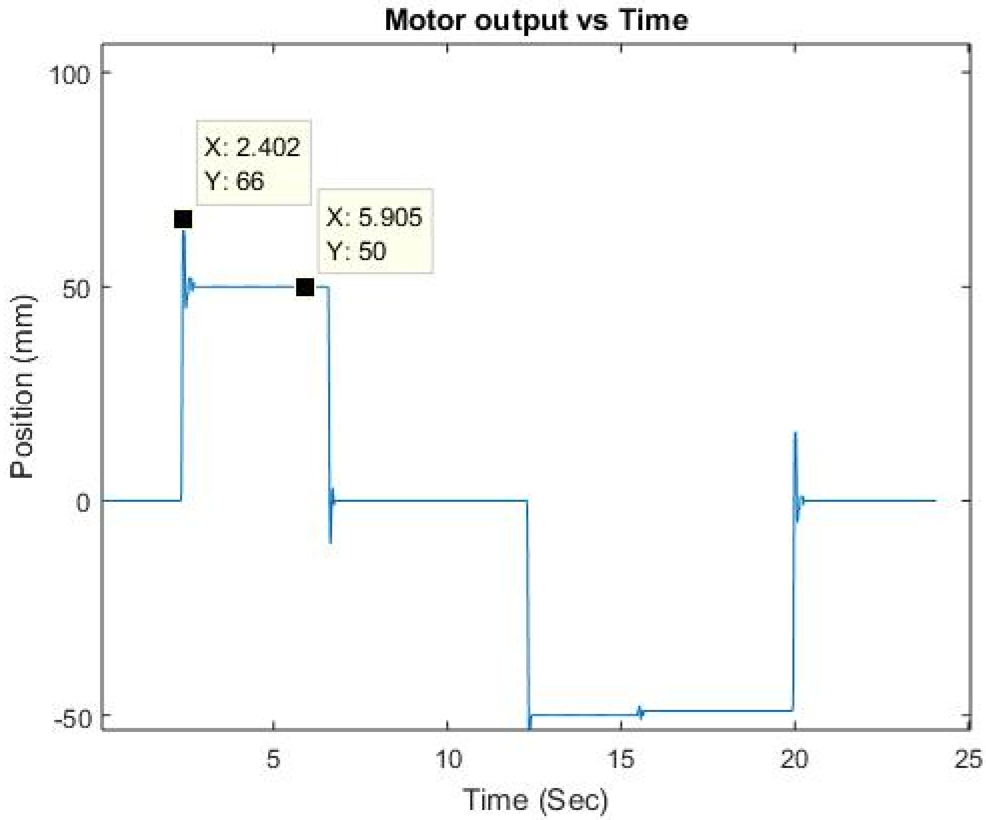
P Gain of 9.5 and a setpoint of 50



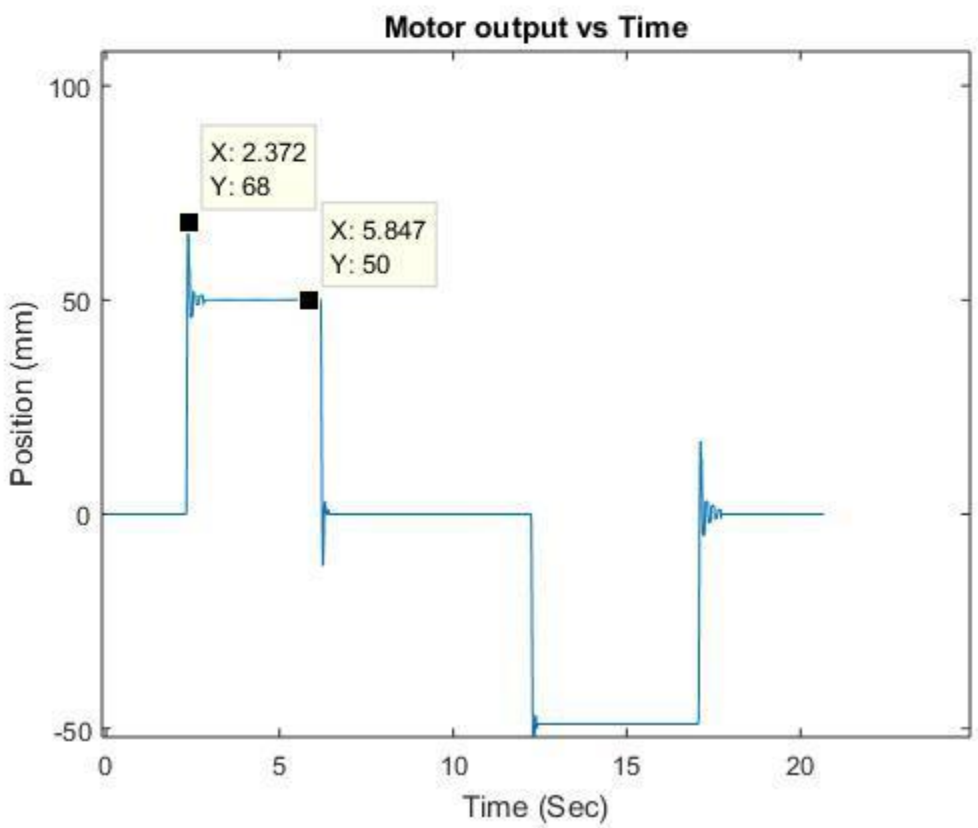
P Gain of 8 and a setpoint of 50



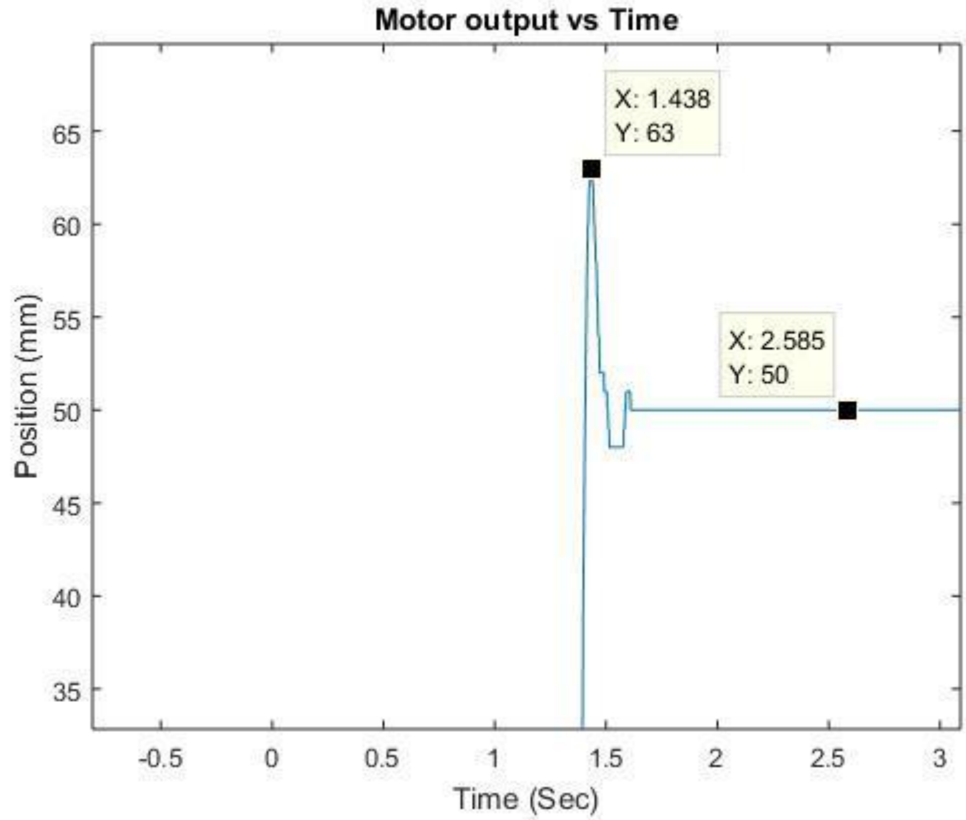
P Gain of 8.5 and a setpoint of 50



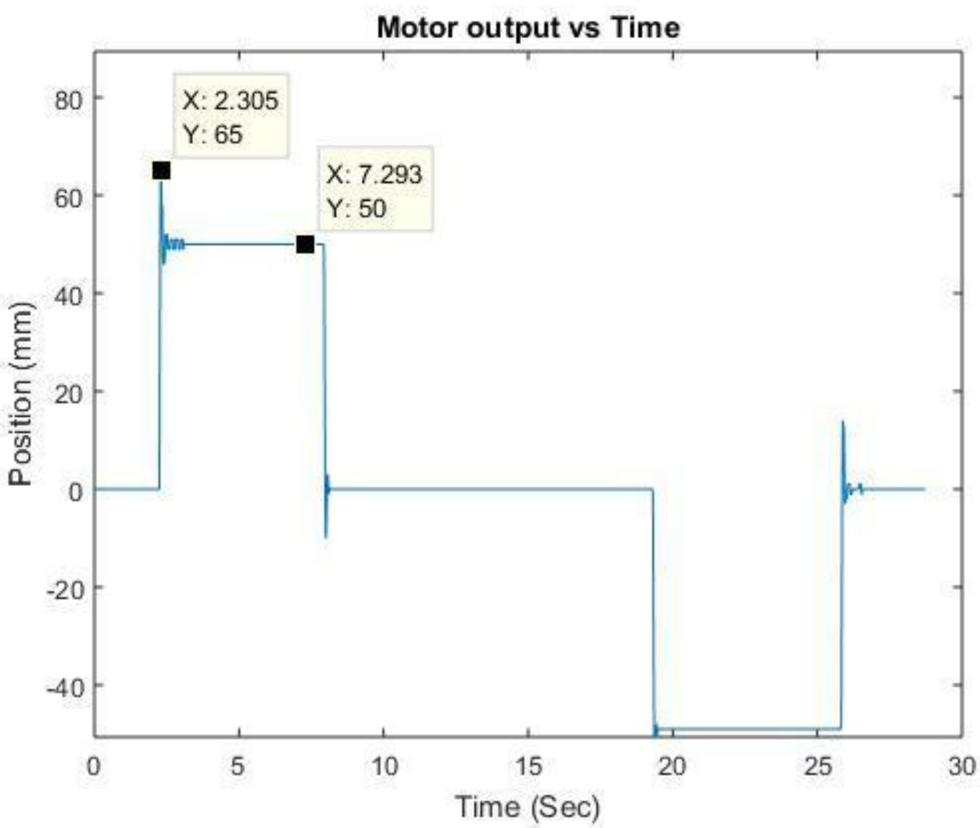
P Gain of 7 and a setpoint of 50



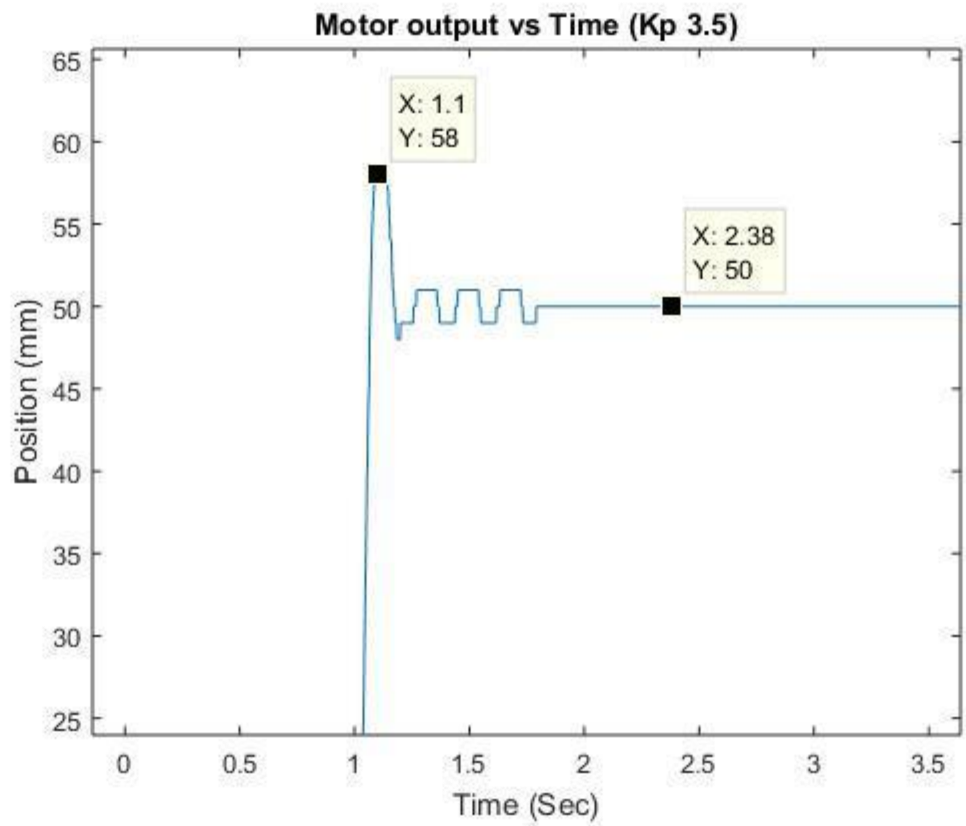
P Gain of 7.5 and a setpoint of 50



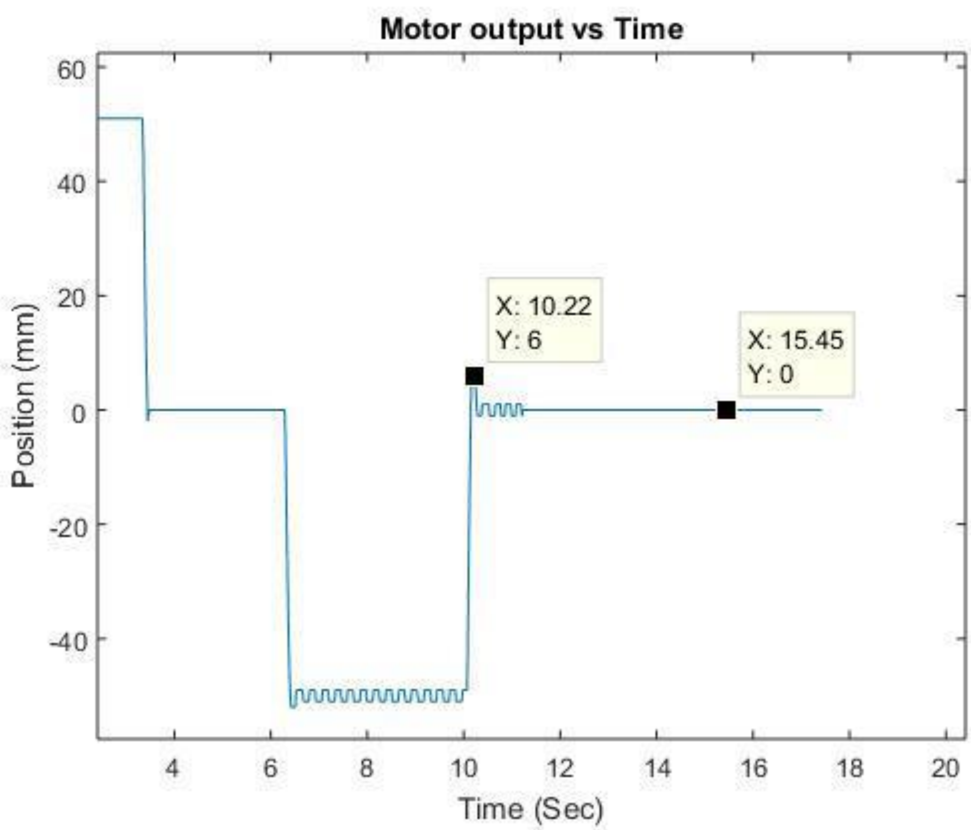
P Gain of 6 and a setpoint of 50



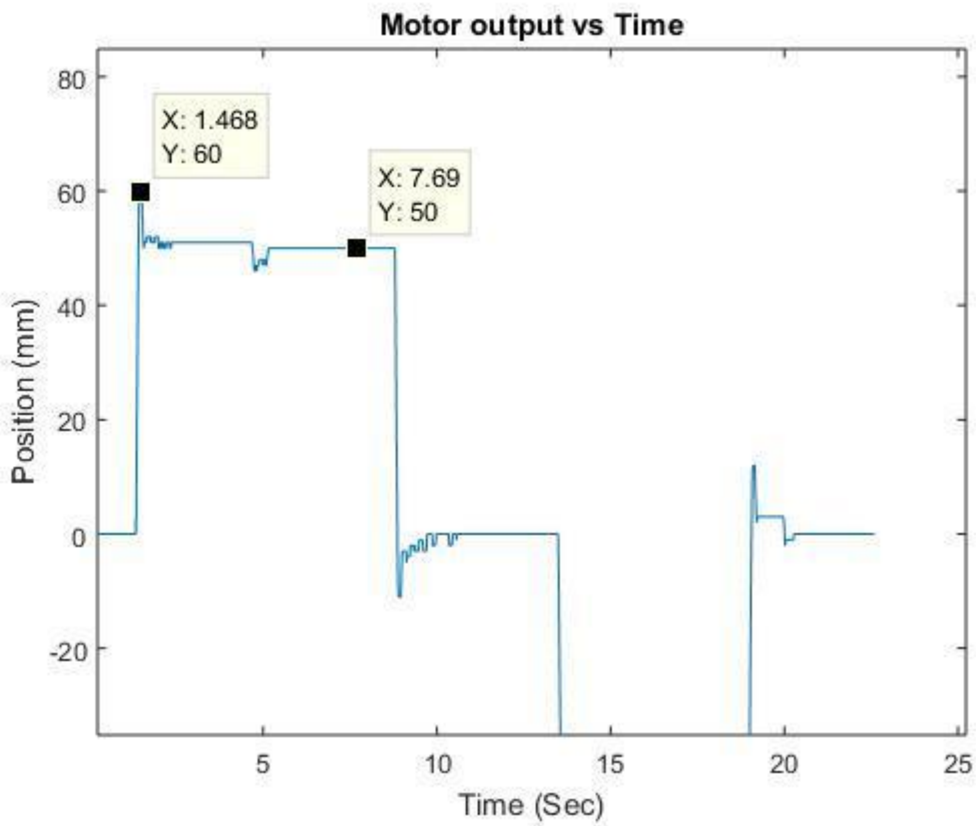
P Gain of 6.5 and a setpoint of 50



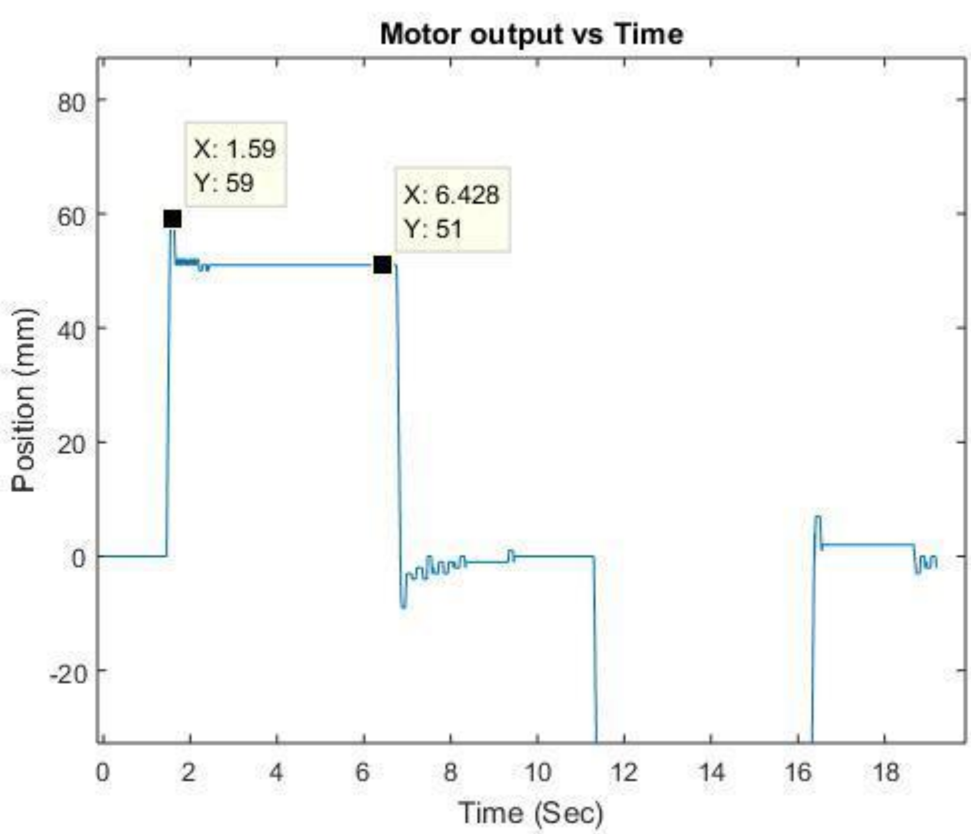
P Gain of 3.5 and a setpoint of 50



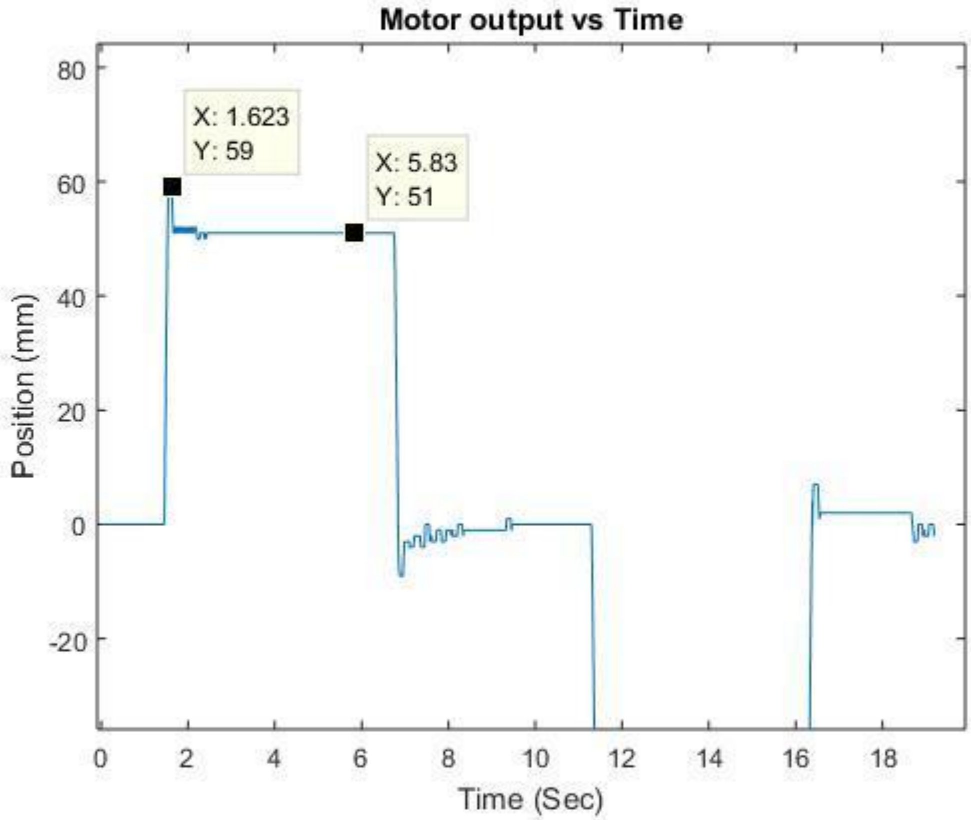
P Gain of 0.1 and a setpoint of 50



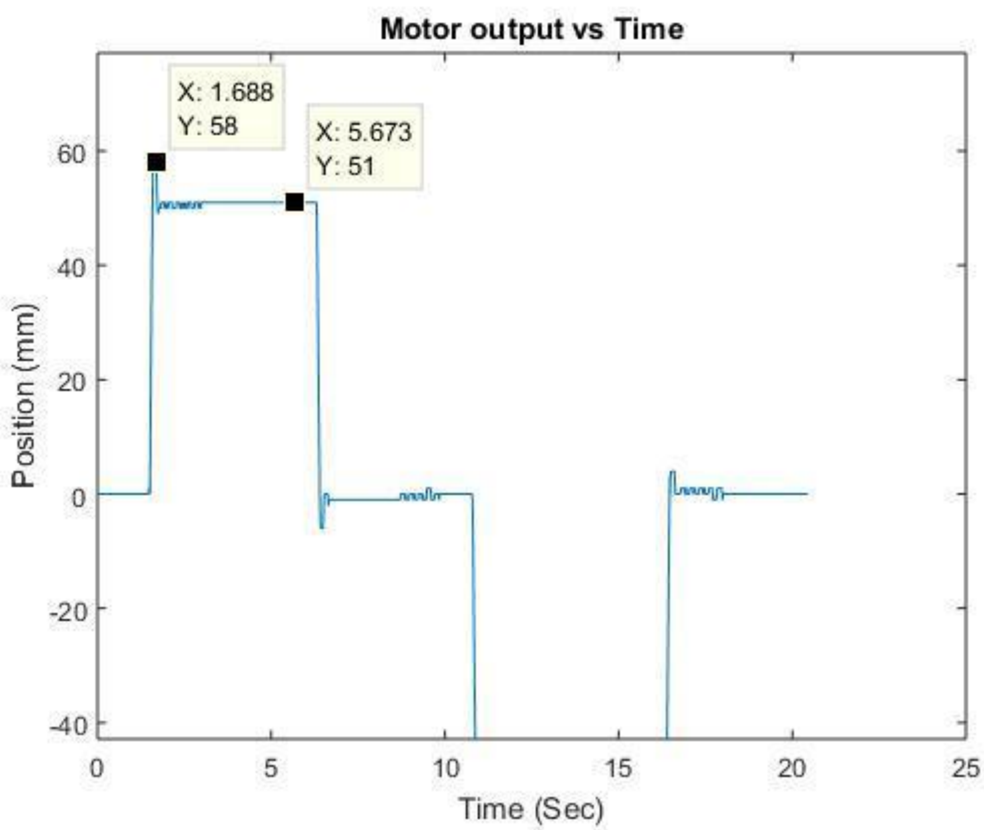
P Gain of 4 and a setpoint of 50



P Gain of 3 and a setpoint of 50



P Gain of 2 and a setpoint of 50



P Gain of 1 and a setpoint of 50