Executive Summery

The objective of this lab is to investigate a real servo motor controller. Using different types of controllers the specifications outlined by the lab manual were to be attempted to satisfied. The specification for the PID controller are supposed to be:

- Settling time (+/-2%) <0.3s
- Rise time (10-90%) < 0.15
- Percent Overshoot <10%
- Zero steady state error

At fist a Proportional controller under specific gains with a square and ramp responses. Next a the effect of increasing and decreasing gain were investigated with the proportional controller. What was noticed was that as the gain increased the so did the percent overshoot.

Following the experiment with the P controller, the PID controller was investigated. The PID proved much better at giving values that satisfied the specifications however, it was still not perfect and posed problems with rise time. The PID+A controller was investigated next however it did not seem to give significantly different results when compared wit the PID. So the final "best" response was chosen to be a PID controller design.

The non-linear effect is then investigate by allowing the system to fully saturate with the P, PID, and PID+A controllers. What was found was the P controller was better when operating out of nominal range however, the PID and PID+A were able to settle faster that the P controller but with steady state error.

Introduction:

The purpose of this lab will be implementing a PID controller on a real-life control system, to complete such a task each group will use a Servo module in order to improve a system closed loop response. The group will observe and record how both step and ramp inputs affect specific systems. Through investigation of the characteristics of the system it was determined that the system is a Type 0 system. First the group was tasked with observing how a proportional controller acts upon a real world system, then move onto a PID controller. Once the basic values of the PID have been recorded the group will attempt to change the values of the PID controller to find the "best" results given specifications. In this lab the group used the "trail and error" method to achieve the "best" results. By examining the change in the integral, derivative time constants or gain through Mathlab the group was able to achieve the optimal results in the PID controller.

Part 1: Uncompensated Servo Module

1) The response of the uncompensated servo module with a square wave input:

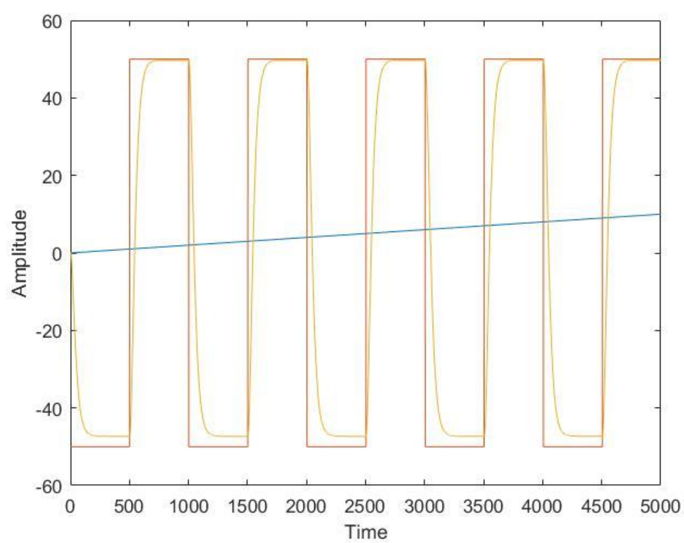


Figure 1.1: Uncompensated Servo Module Response for Square Wave Input

a) By observing the figure above one is able to clearly distinguish the nonlinearities present in the square wave response. These errors are due to the fact that only a P controller is being used instead of the other options available. It should be noted that even when using a PID controller, the main proportion of control is handled by the P controllers work.

b) Also by observation it is apparent that the nonlinearities are caused by the dead-zone effect. The effects of the system can be adjusted by manipulation the K_p value. Due to the characteristics of the P controller the gain is the only parameter that is adjustable. This limiting factor makes accounting for the nonlinearity to difficult to accomplish. The figure above represents the best possible linear response by adjusting the gain to a stable value.

2) Each group was tasked in finding the time-response value specified in the lab report. To do this a step response is inputted into a uncompensated servo module, and the results were recorded. Next the students were tasked with calculating and verifying if specific parameters have been met. These parameters include: the percent overshoot, the rise time (10%-90%), the settling time (+/- 2%), and lastly the steady state error for both inputs ramp and step. Below is a table comparing the results achieved from both Part 1 with an uncompensated mode, as well as the PID model from Part 2.

System Type	PO(%)	Settling Time (± 2%) (s)	Rise Time (10%-90%) (s)	Steady State Error (step) (%)	Steady State Error (ramp) (%)
Uncompensated P Control	0	0.093	0.136	4.86%	∞
PID Control (Compensated System)	1.99	1	0.009	4.9	∞

3) Lastly the group was tasked with observing and recording the results of a ramp response of the uncompensated system.

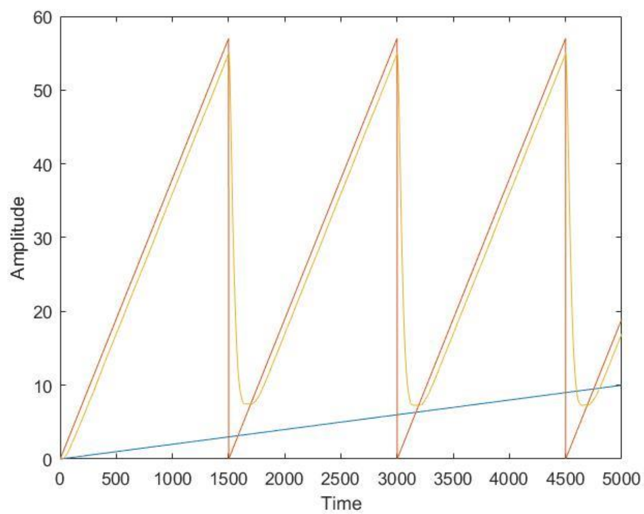


Figure 1.2: Proportional Control Response for Uncompensated Servo Module

Through observation of both the step and ramp response of the system the group has come to the unanimous decision that the system is a Type 0 system. The conclusions was made by viewing the steady state error of the system response. In a Type 0 system the steady state error of the positional gain is a constant value, this is denoted by the equation:

$$ess = \frac{1}{1 + Kp}$$

With other system types, the stead state positional error is 0. Another way the group concluded that the system was Type 0 was due to the fact that a Type 0 system has an infinite steady state error unlike Type 1 which has a constant ramp response error value.

Part 2: Compensated Servo Module Response

In the first section of this second part of the lab the proportional controller was investigated with increasing and decreasing the gain. Both the square wave and saw tooth wave inputs were tested for. The following images will show the results of the system tracking under different gain values:

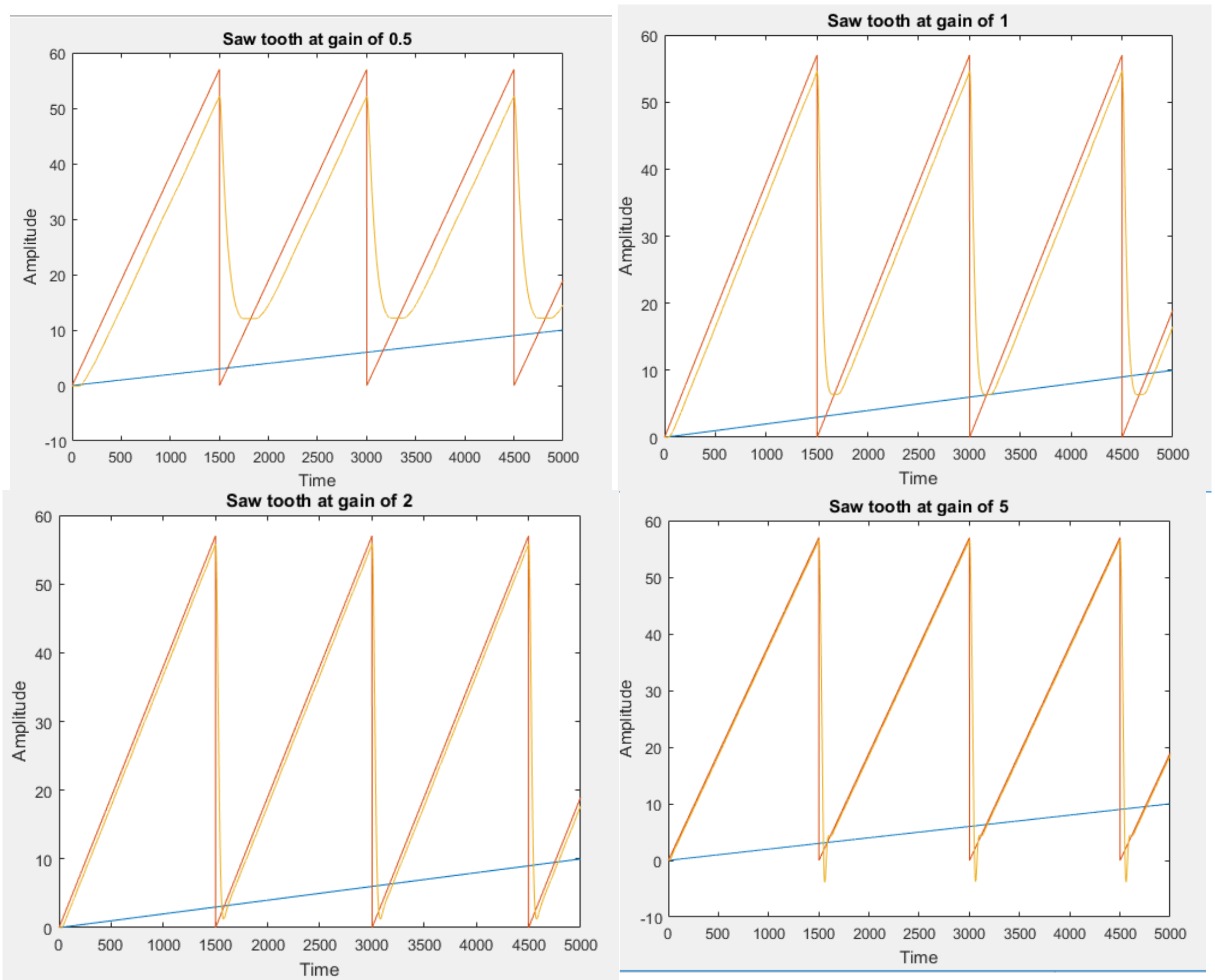


Figure 2.1 : Saw tooth at different gain values under proportional controller.

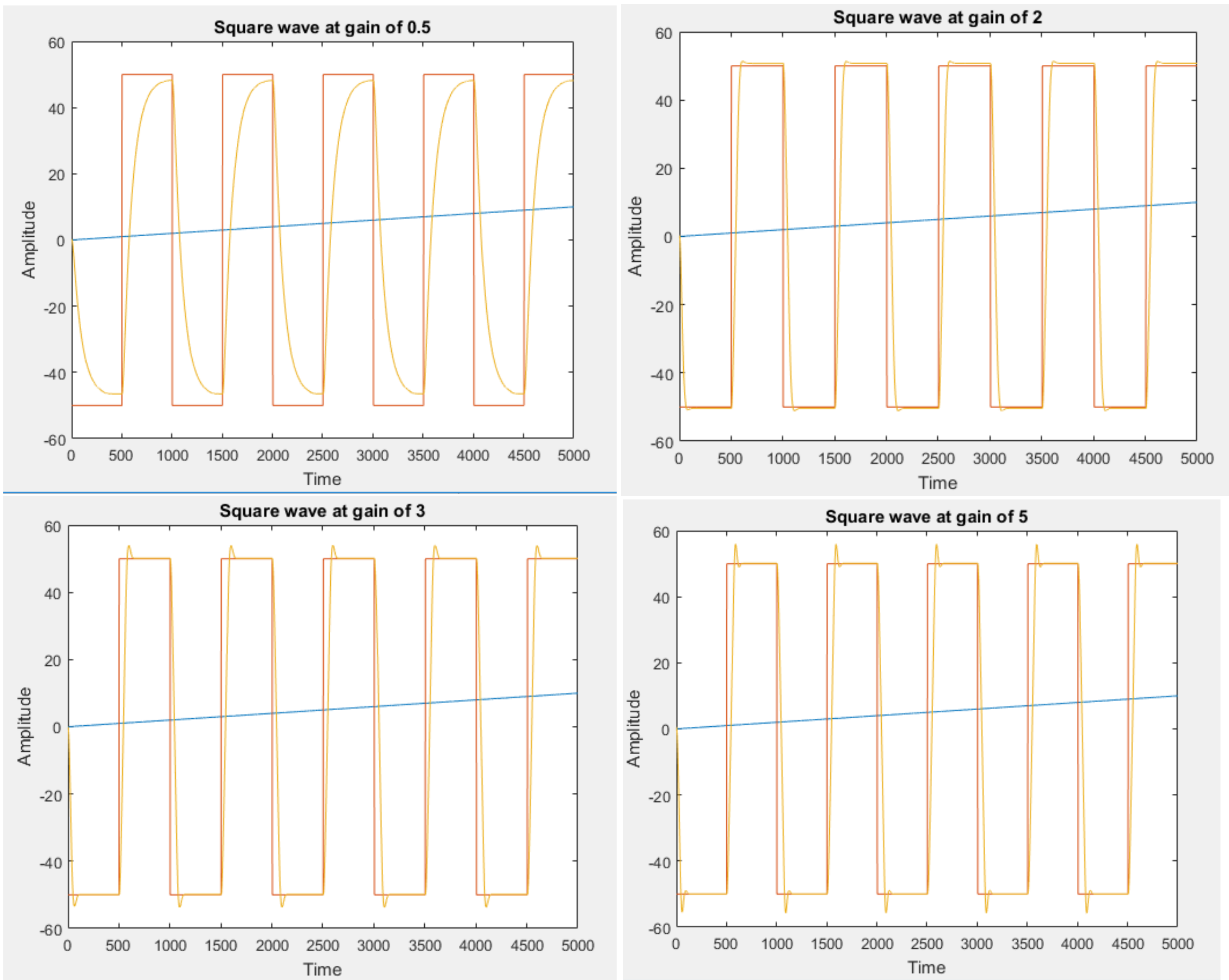


Figure 2.2 :Square wave at different values under proportional controller.

It seems that the steady state error decreases and rise time decreases as the gain increases, however as the gain increase so does the percenter overshoot. Any nonlinearities will start to be noticed when the gain of the system causes marginal stability. It is not possible for a proportional controller to meet all the proper specifications since it is a system of type 0. The best value for gain for a proportional controller seems to be when the gain is 2.

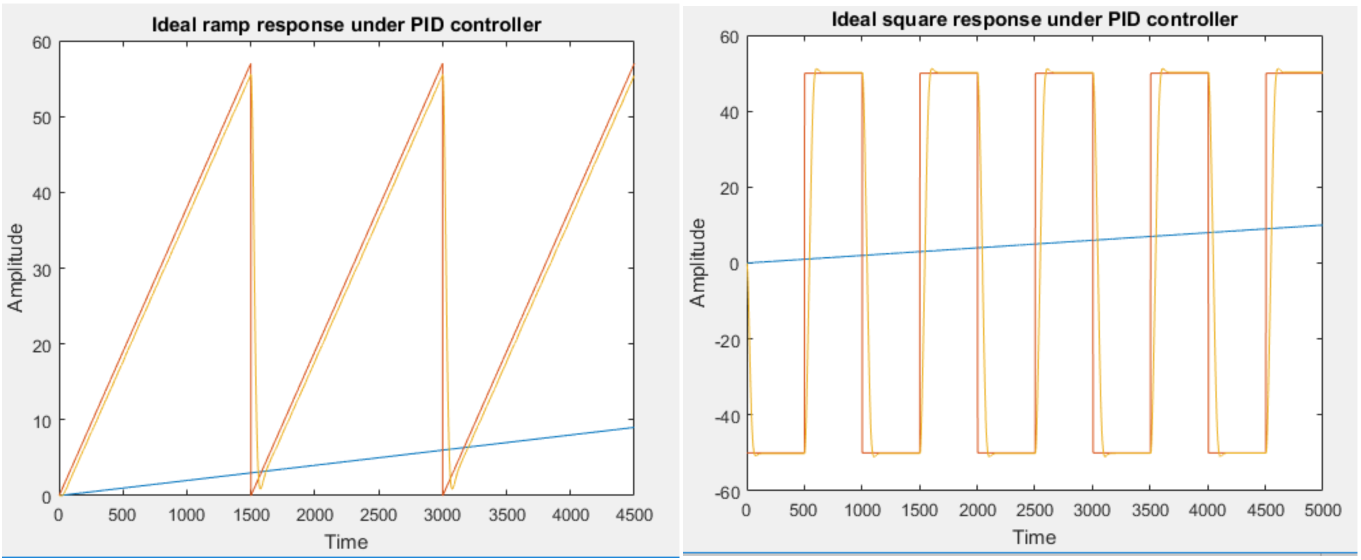


Figure 2.3: Ideal response under PID controller for both Ramp and Square Input

The ideal responses were acquired mainly through trial and error. After applying the PID+A controller there wasn't much difference noticed between the PID and PID+A. The integral time constant that was used was 0.0001 and the derivative time content was 2.

Discussion

1. The differences between the PID and P controller of this part of the experiment were significant. The PID could approaches the desired specification specified in the lab far better than the P controller could. The overshoot was less and the time to get to steady was also decreased in the PID controller. It is also important to note that when it came to the ramp input that the P controller would result diverge while with the PID it would be content, this is because PID controller is a type 1 system.
2. The PID controller setting were arrived at through knowledge acquired during lectures about how different types of controllers effect different specification in the response (i.e. settling time, percent over shoot etc.) however, some trial and error was used as well at times.
3. After experimenting with the Anti-windup the wasn't any big Signiant differences. It was slightly noticeable that the with the PID+A that the rise time slightly increased while the

percent overshoot decreased slightly, however it was very marginal. The T_a constant was arrived at through trial and error.

4. The final settings that resulted in the "best" response were with gain being 1, T_i = 0.0001, and T_D = 2.
5. Comparison between P and PID controllers are showmen in the following tables:

	PO	**Rise Time (10 – 90%)**	**Settling Time (2%)**	**Steady State Error (step %)**	**Steady State Error (ramp %)**
P controller	1.28%	1.002s	0.009s	4.9%	∞
PID Controller	1.99%	1s	0.009s	4.9%	∞

Table 2.1: Comparison between P and PID for square input

	PO	**Rise Time (10 – 90%)**	**Settling Time (2%)**	**Steady State Error (step %)**	**Steady State Error (ramp %)**
P controller	2.15%	0.99s	0.01	0	1.67
PID Controller	0.22%	2.99s	0.0088s	0	5.44

Table 2.2: Comparison between P and PID for ramp input

The percent overshoot for both controller types were always relatively under 2% . The rise times were significantly higher than the specification of 0.15s. The Settling times (2%) was very good at well below 0.3s. The steady state error (ramp,step) were bad for square input and ok for ramp input.

6. The main areas where the design could improve on is with the rise time. In general the PID is better that the P controller however it is still not perfect and could improvement in the areas of rise time and steady state error (step). The PID+A didn't really show any significant changes that the PID controller.

Part 3: PID Controller outside the Nominal range

To test how the controller fares when operating outside the nominal range, first a baseline was established in Part 1. Figure 3.1 shows again how a basic Proportional controller, with gain of 1 functioned within the Nominal range of +/- 50degrees. This can be contrasted with Figure 3.2 showing the same proportional controller well outside the Nominal range, tested with a unit step of +/- 300degrees. From the steady slope of 790degrees/second shown in Figure 3.2 it can be concluded that the system has reached the saturation point of the motor, moving as fast as it can to try and reach the set point. This will need to be confirmed by preforming the same comparison with a PID and PID-A controller.

Figure 3.1

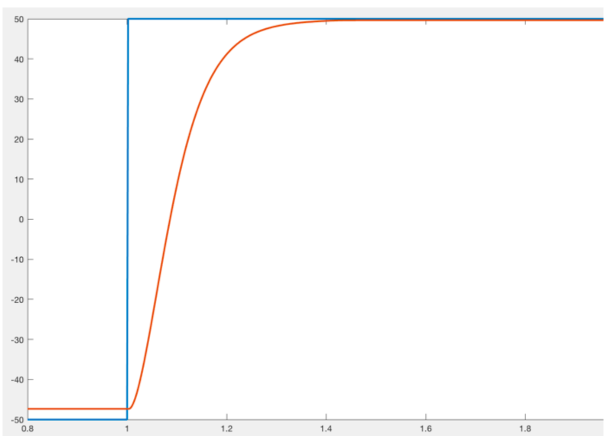
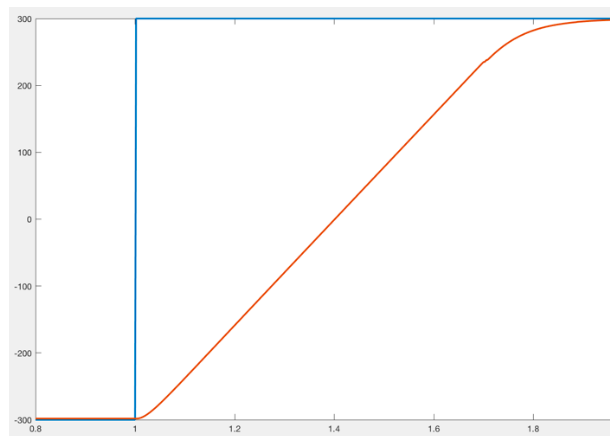


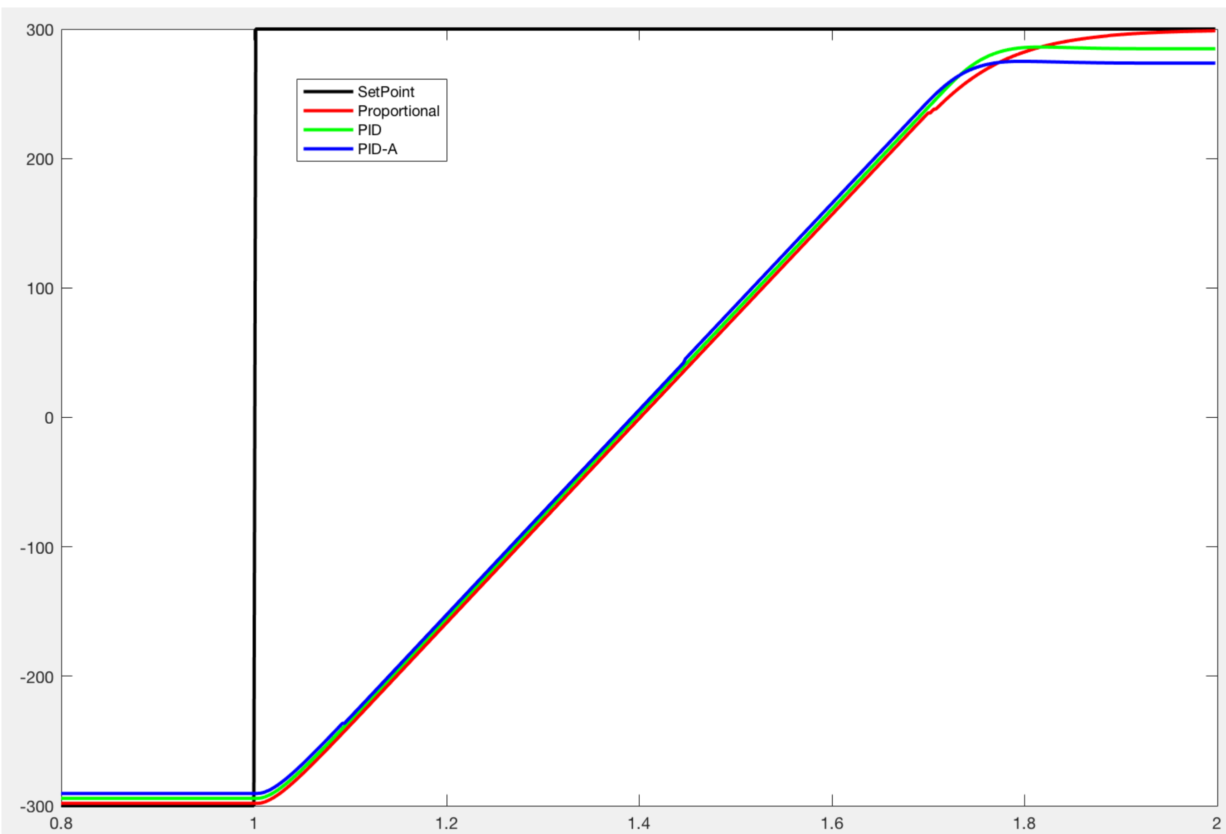
Figure 3.2



Although the graph in Figure 3.1 appears steeper, the maximum speed achieved is only 625degrees/second, proving that +/- 50degrees is well under the Saturation level of the system, and within the Nominal range. The same test is performed with the optimal PID controller found in Part 2, with Kp=0.1 Ti=0.00001 Td=200. Although this compensated controller showed a marked improvement from the basic Proportional Control in Part 2, the effects of saturation and integral error due to large set-point change result in a worse controller when operating outside the Nominal range. As shown in in Figure 3.3, both PID and PIDA controllers fare worse than the Proportional controller when operating outside of the system's Nominal range.

Note that all three controllers generate the same slope of 790degrees/second that was found when analyzing the Proportional controller at +/- 300degrees. This confirms the earlier theory that the controller is fully saturated at the motors maximum speed. Both the PID and PID-A controllers settle quicker than the Proportional Controller, but due to the large step size, they both incur large amounts of error from the Integral, resulting in worse steady state error when compared to the Proportional Controller.

Figure 3.3



Its clear that the ideal controller for a particular range, is not always transferable to other ranges, particularly when you exceed the Nominal range and saturate the system. Although the PID controller was able to drastically improve the step response of +/- 50degrees, there is little that it can do to improve upon Proportional control, when the system is so saturated. The PID control did have a shorter settling time, even relative to when it started to slow down, but had unreasonable error, rendering it a worse controller.

To test the lower end of the controller, a range of +/- 20degrees was used to try and demonstrate the effects of gear backlash, and static friction. Again the first test case can be used as a baseline to look for any changes in the systems reaction time. Figure 3.4 shows the same graph again, with a simple Proportional controller and Gain of 1 following a +/- 50degree step response. Figure 3.5 is the same controller following a +/- 20degree step response.

Figure 3.4

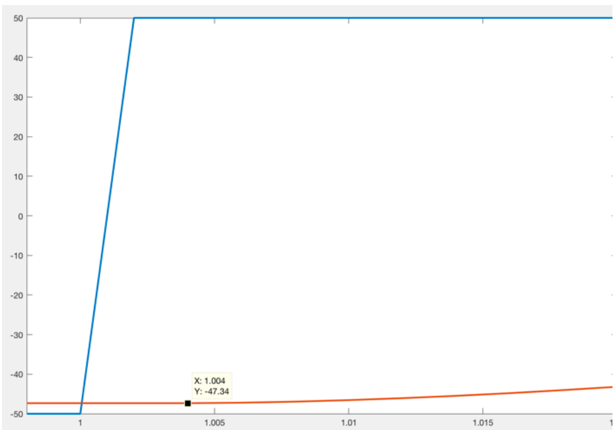
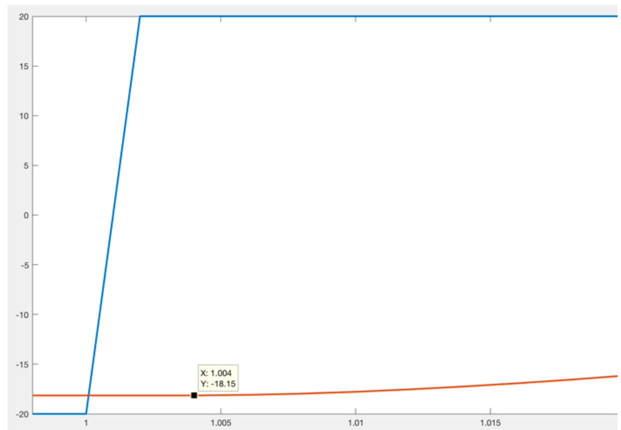


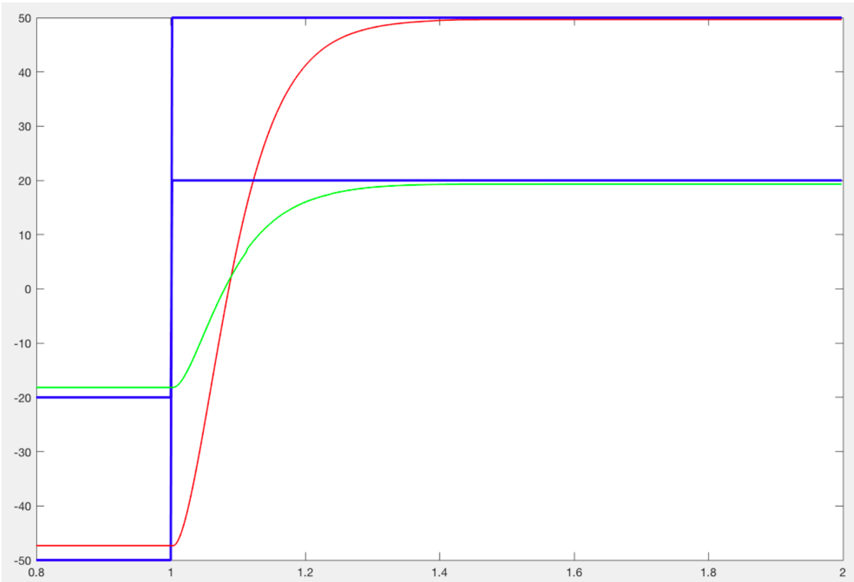
Figure 3.5



Both graphs indicate the position started to change 0.004 seconds after the change in set point. This could be that the step is not small enough to show a noticeable effect from static friction. It is hypothesized that the 0.004 second delay shown with both step responses is due to gear slippage since there was no change between +/- 50degrees and +/-20degrees.

One place where there was noticeable change was in the steady state error. With the +/- 50 degree step there was 0.7% error while the +/- 20 degree step had 3.3% error. This could be attributed to static friction taking effect earlier than it normally would in the Nominal range. Because the change in step is so small, the max speed of the motor is lower, and the time it takes to stop is shortened. Because of this friction could be a bigger factor in slowing down the motor prematurely resulting in a larger steady state error. This can be seen in figure 3.6 below with both step responses together.

Figure 3.6



Conclusion

The results that were acquired during this lab were not perfect. There were things that made sense and fell in line with common theory and things that did not. The PID controller seemed to meet specification to a higher degree than the P controller however, the PID didn't prove to produce significantly different results as the theory would hint at. It is impotent to note that PID+A didn't really show much difference when compared with the PID. Overall this experiment partially successful at demonstrating the effect of the PID and PID+A controller for the system.