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LabVIEW PD Controller Design and Implementation

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III. Objectives:

The objective of Experiment 9, is to utilize the model developed in the previous experiment to create a positional transfer function for the QUBE-Servo-2. Additionally, the experiment involves designing and implementing a controller that allows for the precise position control of the motor. This objective builds upon the foundations laid in prior experiments, advancing the understanding and application of control systems in the context of motor position control.

IV. Equipment Used:

- Labview
- Quarc Software
- Qube-2 Servo
- Computer

V. Background Theory:

The theory progresses to discuss the concepts of peak time and overshoot. It explains how to calculate the peak time, the moment when the response reaches its maximum, and the percent overshoot, which represents how much the peak exceeds the steady-state value. These calculations are crucial for understanding how the damping ratio affects the response's shape and how the natural frequency influences the speed of the response. Unity feedback is another critical component of the background theory. The experiment uses a unity-feedback control loop to manage the position of the QUBE-Servo 2. The voltage-to-position transfer function of the QUBE-Servo 2 is elaborated upon, detailing the relationship between the motor/disk position, the applied motor voltage, the steady-state gain, and the time constant. Further, the experiment addresses PD control, specifically focusing on the Proportional-Velocity (PV) control variant. This section explores the structure of PV control, including its implementation and the use of a low-pass filter to suppress measurement noise. The document outlines the closed-loop transfer function of the QUBE-Servo 2 under PV control, emphasizing its significance in the practical application of the theory.

VI. Preliminary Calculations:

6.1: Calculate natural frequency and damping ratio.

Given: K=21.9, τ = 0.15 sec

$$\frac{\omega n^2}{s^2 + 2\zeta\omega ns + \omega n^2} = \frac{\frac{K}{\tau}}{s^2 + \frac{s}{\tau} + \frac{K}{\tau}}$$

$$\omega n^2 = \frac{K}{\tau} \therefore \omega n = \sqrt{\frac{K}{\tau}} = \sqrt{\frac{21.9}{0.15}} = 12.083$$

$$2\zeta\omega n = \frac{1}{\tau} \therefore \zeta = \frac{1}{2\tau\omega n} = \frac{1}{2(0.15)(12.083)} = 0.276$$

6.2: Calculate peak time and percent overshoot based on calculated ωn and ζ.

$$Tp = \frac{\pi}{\omega n\sqrt{1-\zeta}} = \frac{\pi}{12.083\sqrt{1-0.276}}0.306sec$$

$$\%OS = 100e^{\frac{-\pi\zeta}{\sqrt{1-\zeta^2}}} = 100e^{\frac{-\pi(0.276)}{\sqrt{1-0.276^2}}} = 40.59\%$$

7.5: Calculate the proportional and derivative gains.

$$\frac{KKp}{\tau s^2 + (1 + KKd)s + KKp} = \frac{\frac{KKp}{\tau}}{s^2 + \left(\frac{1 + KKd}{\tau}\right)s + \frac{KKp}{\tau}} = \frac{\omega n^2}{s^2 + 2\zeta\omega ns + \omega n^2}$$

$$\omega n^2 = \frac{KKp}{\tau} \therefore Kp = \frac{\omega n^2\tau}{K}$$

$$2\zeta\omega n = \left(\frac{1 + KKd}{\tau}\right) \therefore Kd = \frac{2\zeta\omega n\tau - 1}{K}$$

7.6: Calculate the control gains needed to satisfy the given requirements.

$$\text{Given: } \omega n = 32.3, \zeta = 0.76, K = 21.9, \tau = 0.15$$

$$Kp = \frac{\omega n^2\tau}{K} = \frac{(32.3)^2(0.15)}{21.9} = 7.15$$

$$Kd = \frac{2\zeta\omega n\tau - 1}{K} = \frac{2(0.76)(32.3)(0.15) - 1}{21.9} = 0.29$$

VII. Procedure/Result/Analysis:

I. Part 6: Unity Feedback Control and System Response Analysis:

In Part 6 of Experiment 9, we concentrated on implementing Unity Feedback Position Control for the QUBE-Servo motor using LabVIEW and QUARC blocks. This process can be divided into several key activities:

Designing the Unity Feedback Position Control System: We created a block diagram for the Unity Feedback Position Control of the QUBE-Servo, as depicted in **Figure 1** below. This was a crucial step for setting up the control system to achieve precise position control of the motor.

Observing the System's Response: After setting up the control system, we ran it to observe its response. The main goal here was to evaluate the system's stability and the accuracy of its response. The observed response of the system, essential for our analysis, is shown in **Figure 2** below.

Measuring Key System Parameters: An important part of our experiment was to measure the peak time and percent overshoot of the system. These measurements are vital for understanding the dynamic behavior of the control system. We utilized cursors to accurately measure these parameters directly from the system's response graph. The peak time and percent overshoot were found to be slightly lower than our initial calculations, with a peak time of 263ms compared to the calculated 306ms, and a percent overshoot of 34.6% against a calculated 40.59%. These measurements are detailed in **Figure 3** below.

	Calculated	Measured
Peak Time	306ms	263ms
Percent Overshoot	40.59%	34.6%

Throughout Part 6, we effectively demonstrated the practical application of control system design, specifically focusing on position control using Unity Feedback. The difference between the calculated and actual measurements provided valuable insights into the real-world application of theoretical models in control systems.

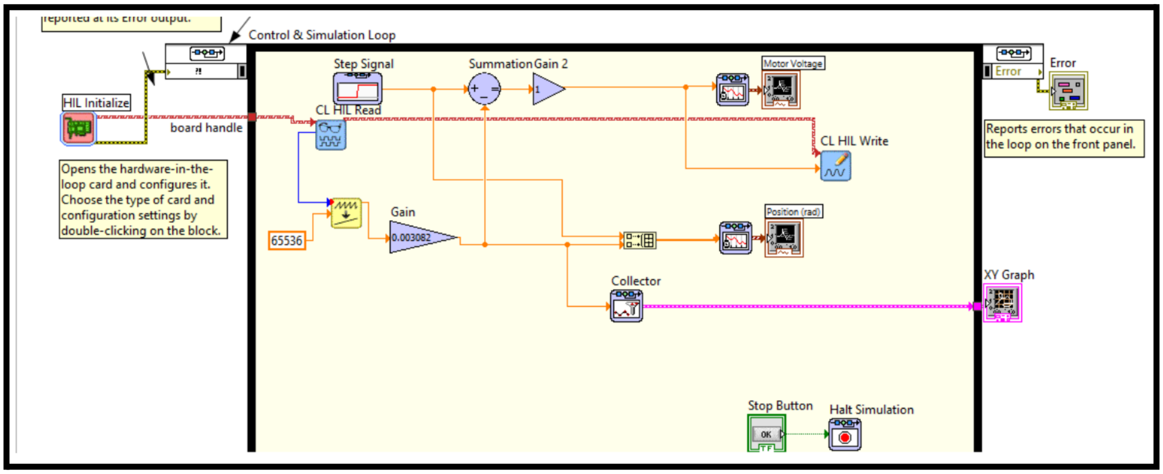

Figure 1: Unity Feedback Position Control of QUBE-Servo Block Diagram (6.3)

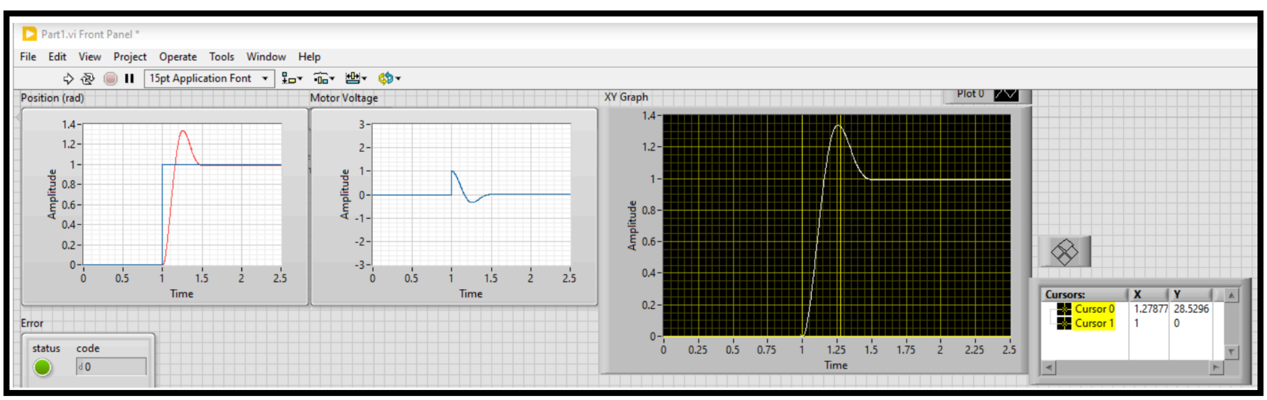

Figure 2: Unity Feedback Position Control Response (6.3)

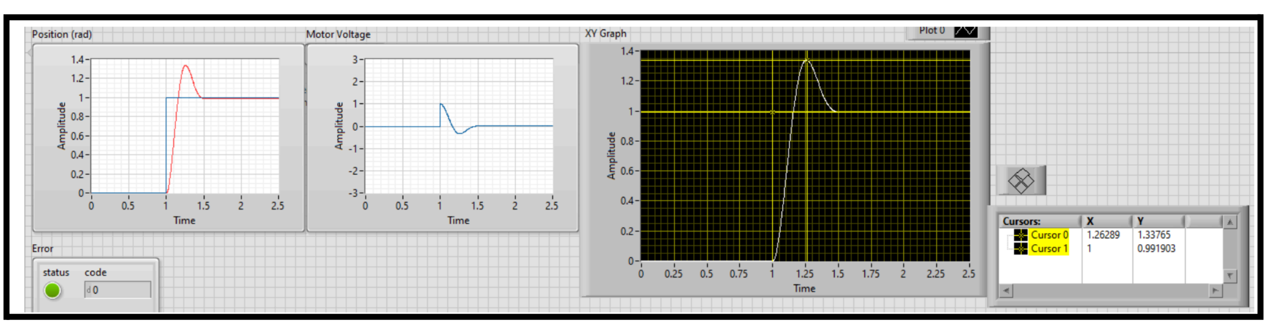

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Figure 3: Peak Time and Percent Overshoot of System (6.5)

II. Part 7: Proportional-Velocity (PV) Control Implementation and Optimization:

In Part 7 of Experiment 9, we engaged in a detailed exploration of Proportional-Velocity (PV) Control on the QUBE-Servo system, focusing on the effects of varying control gains on the system's response. This part of the experiment was divided into several phases, each emphasizing a different aspect of PV control:

Implementing PV Control on QUBE-Servo: We started by designing and setting up the PV control for the QUBE-Servo, as represented in **Figure 4** below. This initial step was crucial for establishing the framework within which we would conduct further explorations and measurements.

Analyzing the Effect of Proportional Gain (Kp): Our next step involved varying the proportional gain (Kp) while keeping the derivative gain (Kd) constant at zero. We systematically adjusted Kp to values of 1, 2, 3, and 4, observing the system's response at each setting. This allowed us to understand how changes in Kp affected the system's stability, overshoot, and peak time. The responses for Kp values of 1, 2, 3, and 4 are depicted in **Figures 5, 6, 7, and 8**, respectively. We noted that as Kp increased, the system exhibited greater overshoot and peak time, and it took longer for the system to stabilize.

Studying the Impact of Derivative Gain (Kd): Subsequently, we shifted our focus to the derivative gain. Keeping the proportional gain fixed at 2.5, we altered Kd through a range from 0.05 to 0.15. This phase aimed to observe how varying levels of Kd influenced the system's response, particularly in terms of overshoot and peak time. The responses for Kd values of 0.05, 0.1, and 0.15 are shown in **Figures 9, 10, and 11**, respectively. Our observations revealed that increasing Kd resulted in reduced overshoot and peak time.

Evaluating the System with Calculated Control Values: Finally, we tested the PV Control Response using the control gains calculated earlier in the experiment. This step was crucial for comparing the theoretical control gains with practical system behavior. The response obtained using these calculated values is illustrated in **Figure 12 & 13** below.

Throughout Part 7, our experiments provided deep insights into the dynamic behavior of the QUBE-Servo system under PV control. By methodically adjusting the control gains and analyzing the resulting system responses, we gained valuable understanding of the principles of control system design and optimization in a practical setting.

	Calculated	Actual	Adjusted
Kp	7.15 V/rad	7.15 V/rad	2.7 V/rad
Kd	0.29 V/(rad/s)	0.29 V/(rad/s)	0.1 V/(rad/s)
Tp	0.15 sec	0.183 sec	1.6 sec
%OS	2.5%	0%	2.4%

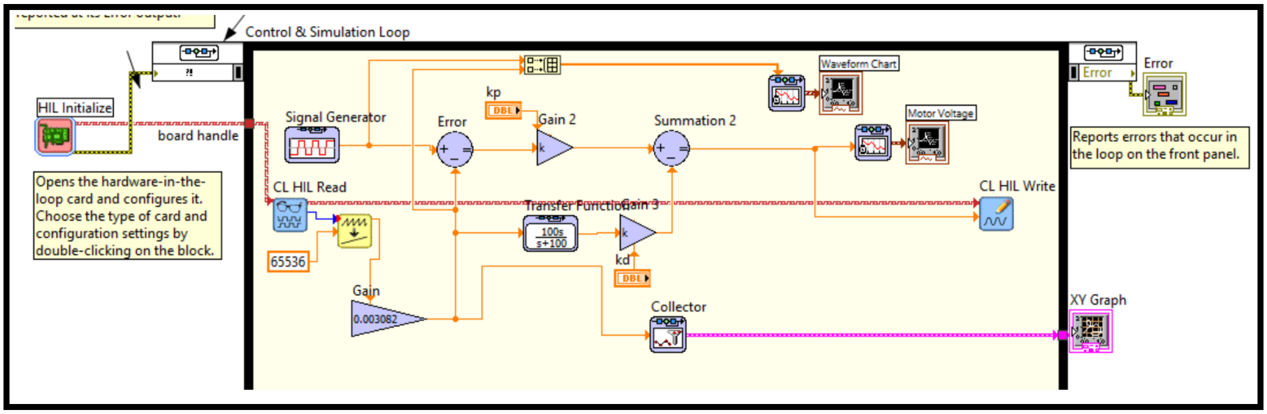

Figure 4: PV Control on QUBE-Servo (7.2).

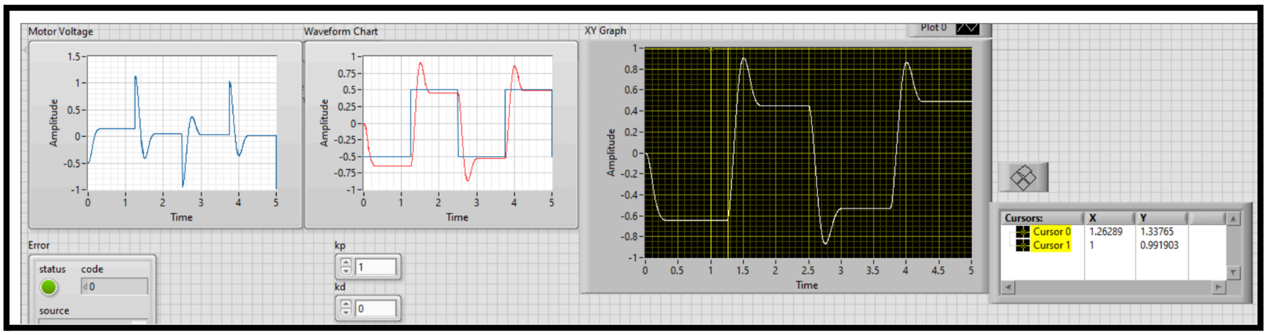

Figure 5: PV Control Response for Kp = 1 (7.2).

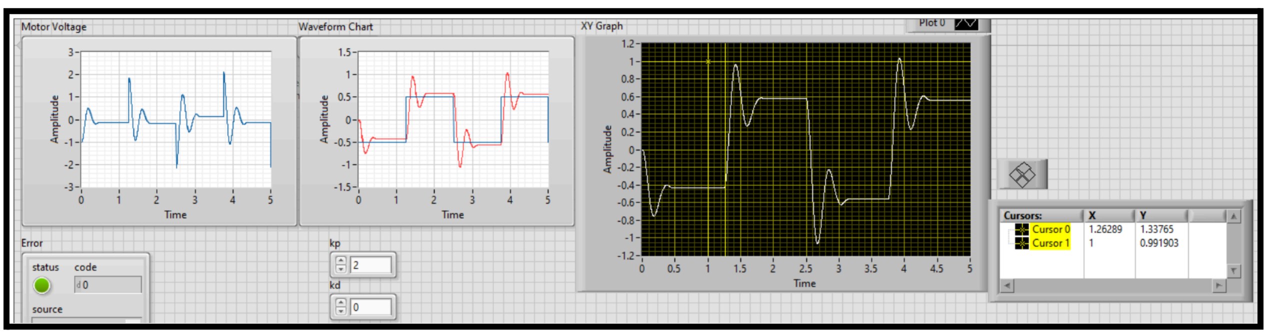

Figure 6: PV Control Response for Kp = 2 (7.2).

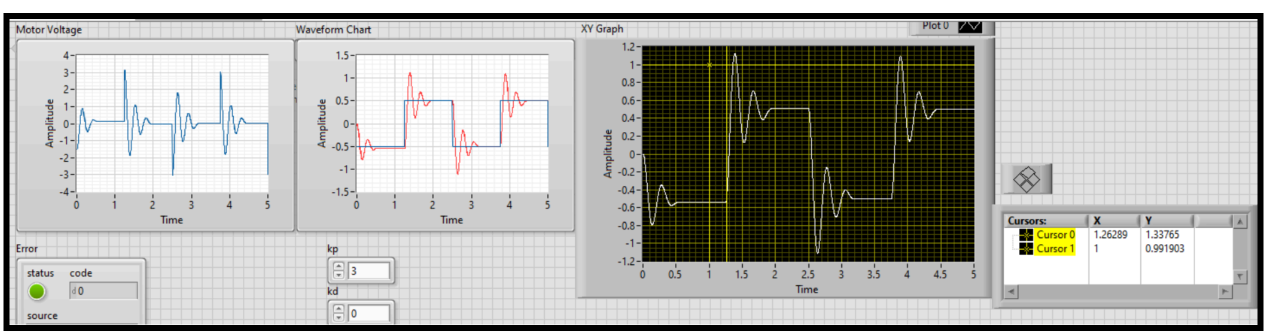

Figure 7: PV Control Response for Kp = 3 (7.2).

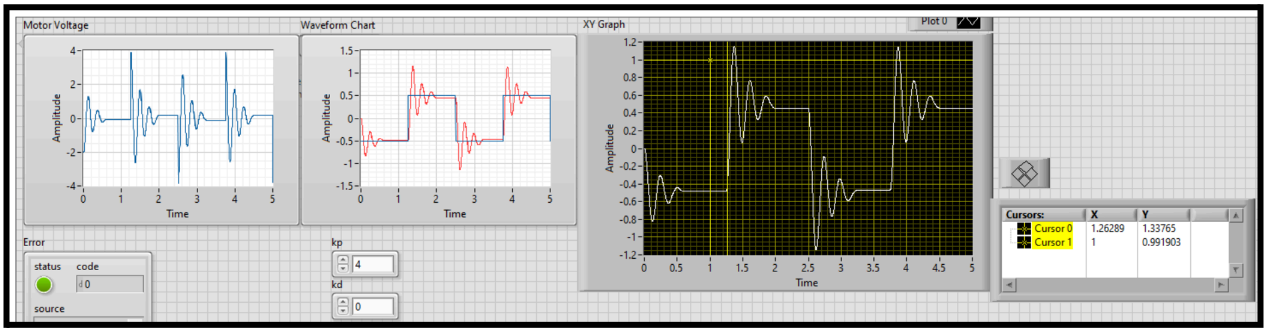

Figure 8: PV Control Response for Kp = 4 (7.2).

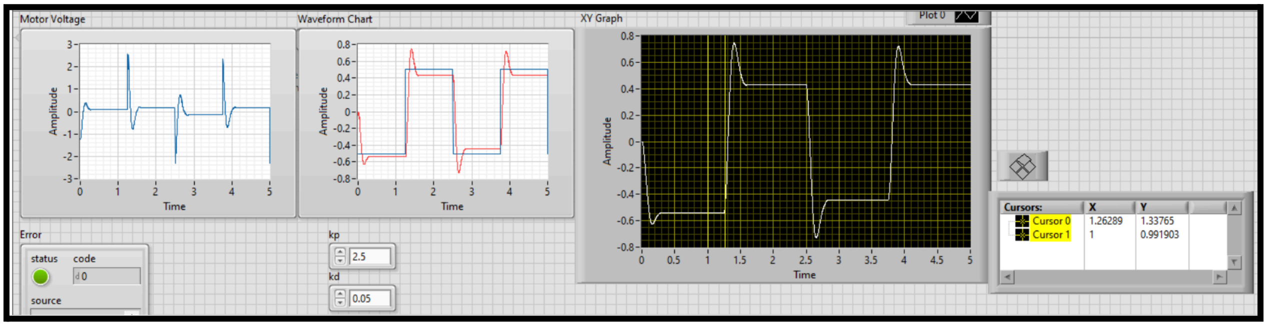

Figure 9: PV Control Response for Kd = 0.05 (7.3).

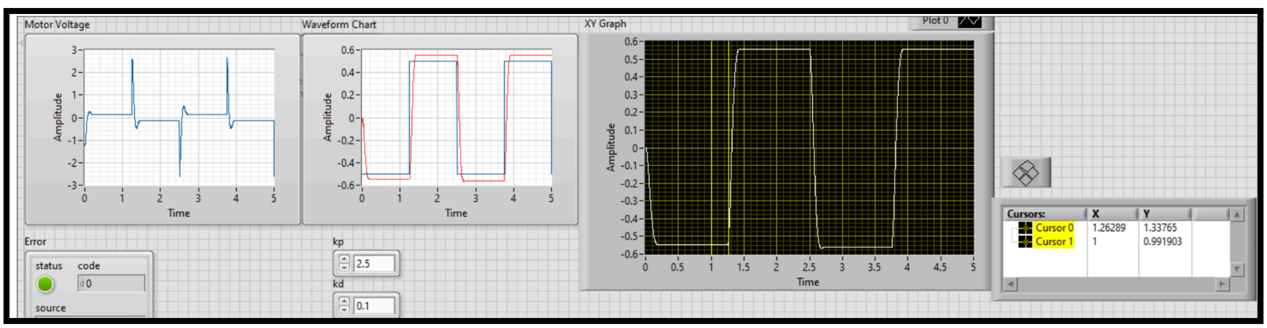

Figure 10: PV Control Response for Kd = 0.1 (7.3).

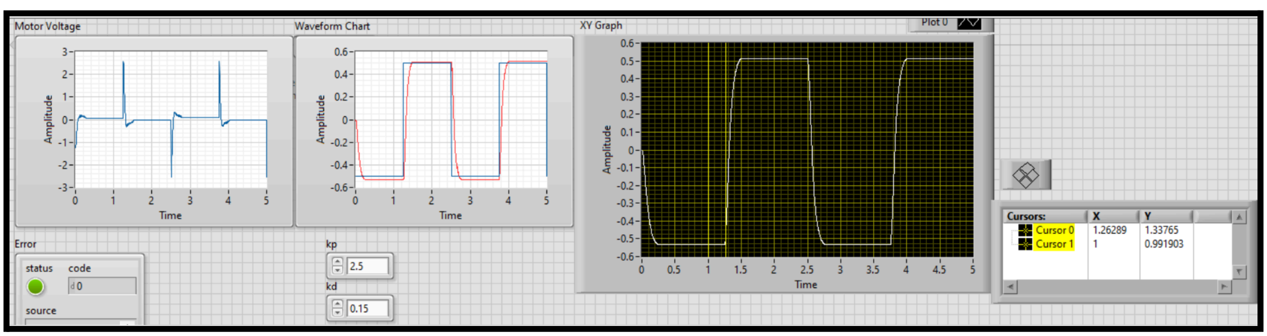

Figure 11: PV Control Response for Kd = 0.15 (7.3).

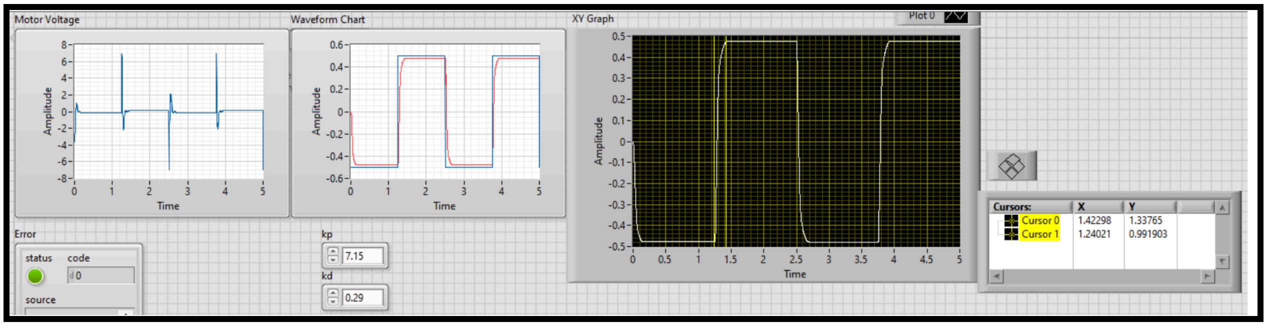

Figure 12: PV Control Response for Calculated Values (7.7).

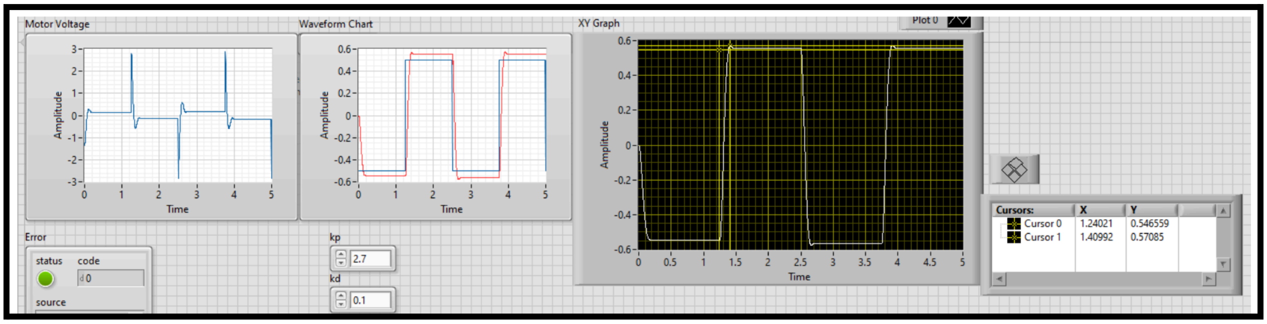

Figure 13: PV Control Response for Adjusted Values (7.9)

VIII. Conclusion:

In conclusion, Experiment 9 provided us with profound insights into the design and implementation of PD and PV control systems using the QUBE-Servo motor. Throughout the experiment, we meticulously applied theoretical concepts to practical scenarios, gaining a comprehensive understanding of control system dynamics. Proportional and derivative gain have a direct effect on the second-order step response. Varying the proportional gain changes the stability, percent overshoot, and peak time of the system. Varying the derivative gain changes the percent overshoot and peak time of the system. This lab also showed that we can use calculated values to predict the response of a system.