Stony Brook University

MEC 411 GROUP #26

Lab #3: Design Project: Turntable Speed Control System Design
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ABSTRACT

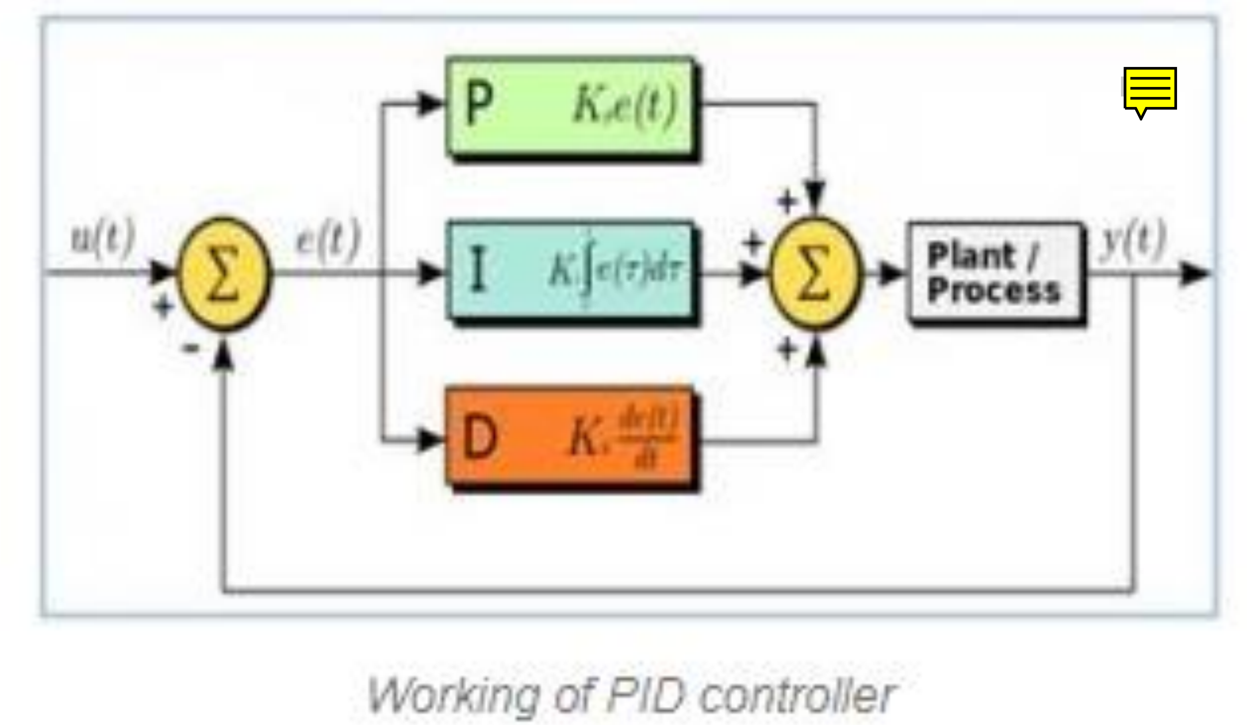
This experiment complies with the custom LabView program design as well as the execution of the PID turntable speed control system which is in accordance with the given design specifications. An analog circuit is to be used to carry through the PID application along with the custom made LabView program in order to achieve the tasks and the comparison is to be done for the experimental data through LabView with the theoretical data obtained through MATLAB. In real time, the system must display the input and output waveforms along with controls for any tunable parameters and must indicate passing or failing results for overshoot value. Some of the other requirements include that the system can record the input and output waveforms and a way to stop the entire system from running if unattended. KC proportional, Ti integral, and Td derivative were adjusted manually in the circuit with the help of potentiometers in order to tune the PID controller. The circuit was connected to the waveform generator, National Instruments DAQ and DC motor with tachometer. The final potentiometer values obtained for P, I, and D were 20.946kΩ, 6.336kΩ, and 0.845kΩ respectively. The experimental data was obtained by using the custom LabView program created to record the input and output waveforms from the circuit. MATLAB is used to plot the experimental data as well as produce the theoretical data based on the recorded potentiometer values. The experimental rise time and percent overshoot obtained for the PID controller are 0.013s and 4.41%. The settling time could not be obtained because the PID controller could not be fully tuned due to the time constraint but can easily be corrected by retuning the controller. The safety feature and settling time are the only design specification that were not met due to time constraint while the rest of the design features meet the design specifications.

I. INTRODUCTION

PID controller is a combination of Proportional, Integral and Derivative to work with control applications. It is highly popular industrial instrument that helps with pressure, temperature and a lot more processes.[6] PID controller are termed as very stable and accurate controllers that use control loop feedback mechanism to control process variables

[2] The first PID controller came into existence in 1911 by Elmer Sperry and by mid 1950s automatic PID controllers were major part of industries. Their simplicity makes them very easy to use and are very economical. [2] Due to their simple nature, they are an integral part of industries where it's a digital control system or temperature control

The PID controllers are assembled in a way that they produce a signal to control a task. In order to control the output as needed, it could be set as a feedback controller. [3] Nowadays the PID controller are processed by microprocessors and are traditionally used in process control applications. It takes the stability to the maximum level by analyzing the data and providing feedback. A simple controller gives fully on and fully off features whereas PID brings the oscillating conditions to have more leverage. The closed loop operations are used in the PID controller to stabilize between the process variable and the desired output.

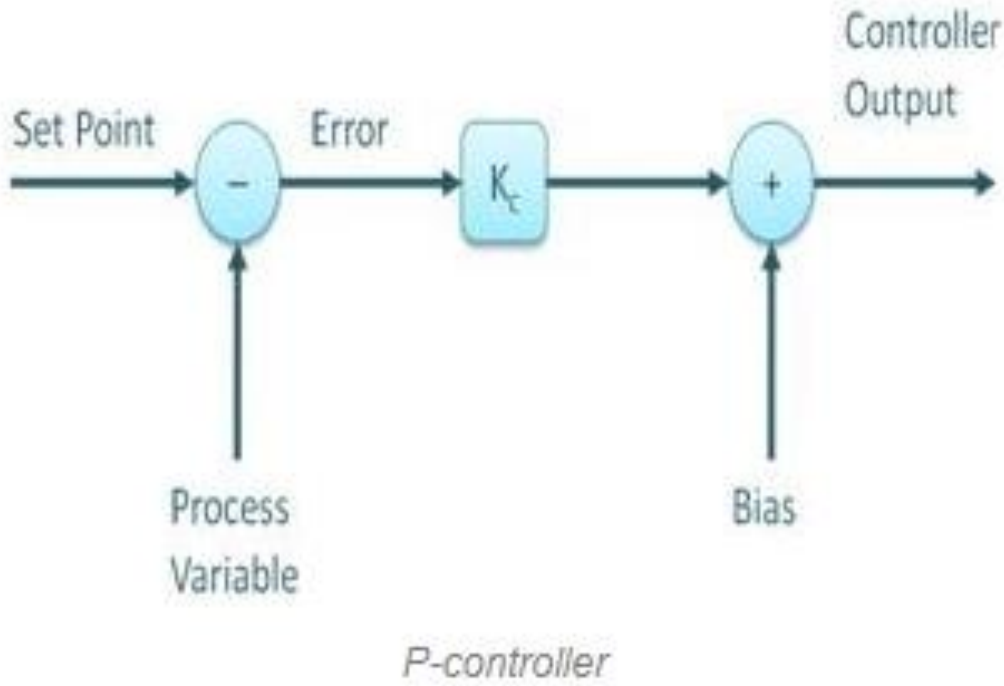


[3] **Fig.1.** PID controller block diagram

In the diagram above the plant I is to be controlled and it gives output y(t) which follows with the set point value of u(t). To control the system, the value of e(t) is adjusted to get desired results.

P controller

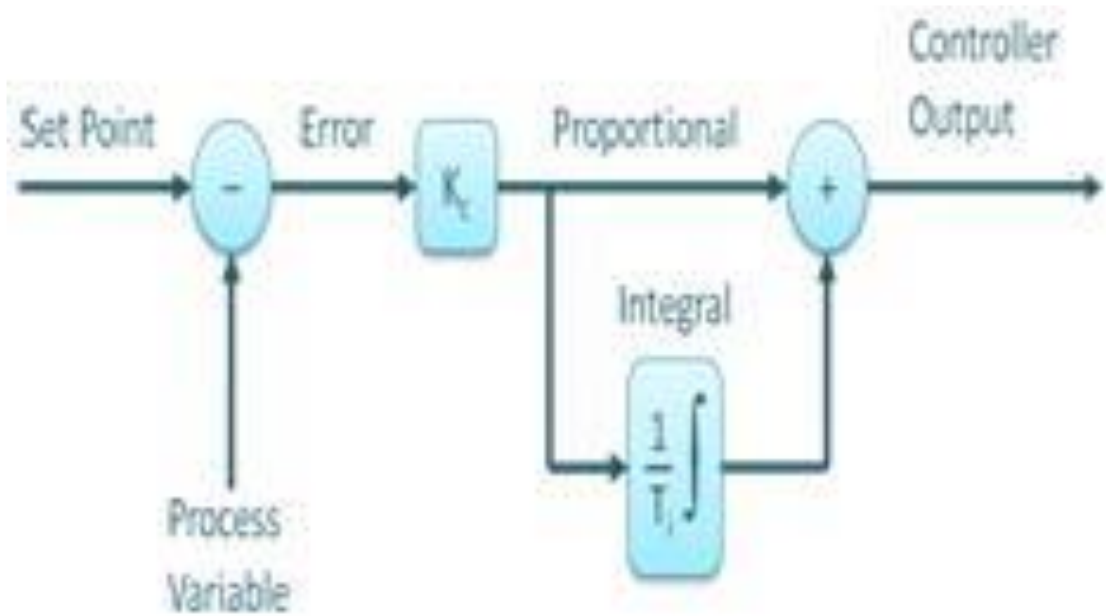
[3] Proportional or P- controller gives output which is proportional to the current error e (t). In the P controller, output values are compared with the original values and the resulting error is then multiplied with the proportional constant to provide the outcome. The system keeps the stability, but it can never have the steady state circumstances. The output is maintained by adjusting the Kc value.



[3] **Fig.2.** P controller

I-Controller

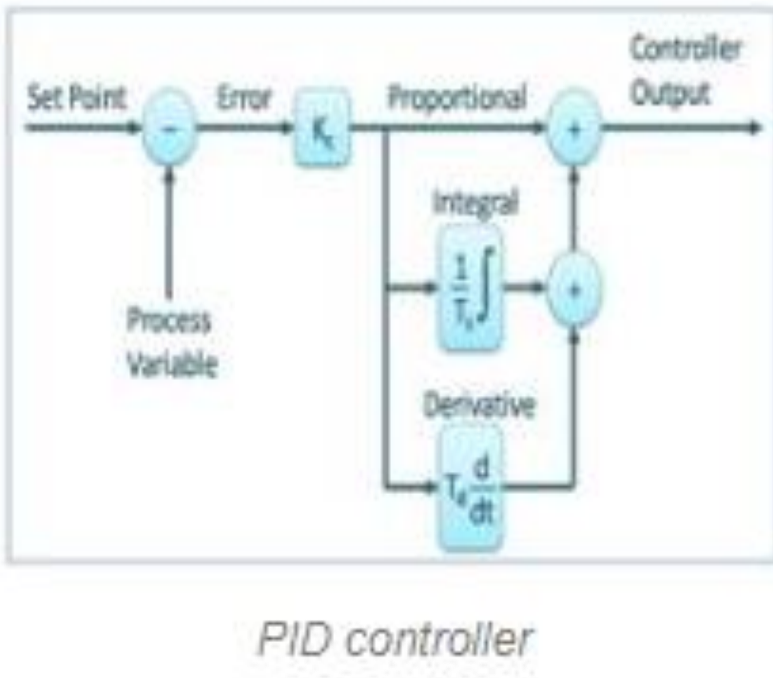
There comes a point where P-controller is restricted and then I-Controller plays its part there to get the work done.[3] It helps to narrow down the value of error to zero over a period while integrating it and helps to bring down the steady state error. Hence the error becomes zero due to I-controller and brings up the stability of the process. In that situation, the output increased by decreasing the Ki.



[3] **Fig.3.** P controller

D-Controller

After the P-controller and I-controller comes the D-controller which over smarts both by predicting the error behavior. [3] Its output depends on the rate of change of error with respect to time, multiplied by derivative constant. It brings up the output of the system by increasing the system response and therefore make the stability of the system better with the increase in the derivative gain.



[3] **Fig.4.** P controller

PID controller equations

$$u(t) = k_p e(t) + k_i \int_0^t e(\tau)\, d\tau + k_d \frac{de}{dt},$$

Eq 1

[4] Where u is the control signal e is the control error. The control signal is a sum of three terms a proportional term that is proportional to the error, an integral term that is proportional to the integral of the error, and a derivative term that is proportional to the derivative of the error. The controller parameters are proportional gain kp, integral gain ki.

$$u(t) = k_p \left(e(t) + \frac{1}{T_i} \int\limits_0^t e(\tau) d\tau + T_d \frac{de(t)}{dt} \right),$$

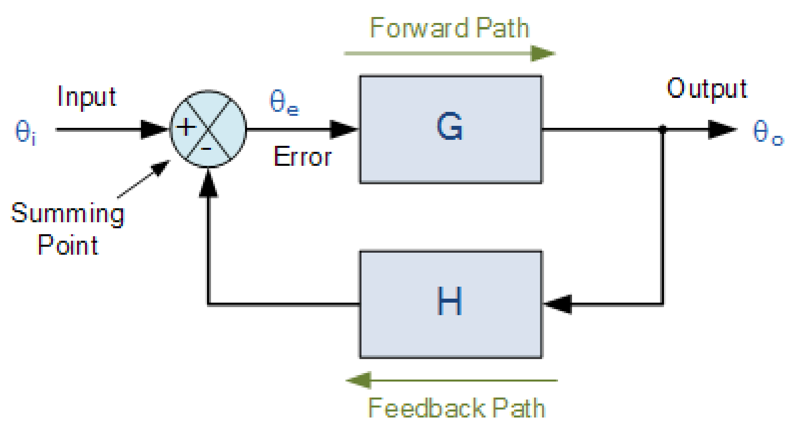
Eq 2

[4] where Ti is the integral time constant and Td is the derivative time constant.

Closed loop transfer function

[5]It is the mathematical relationship between the system input and the output. Therefore, it best defines the behavior of the system. It is denoted as T*(s)* and it is equal to the ratio of the Y(s) output function to the R(s) input function.

$$T(s) = \frac{Y(s)}{R(s)} \qquad \text{Eq 3}$$



[5] **Fig.5.** P controller

In the picture above, the input signal goes through the summing point and then reaches to G to give an output signal which is given as Eq. 4. Then it goes through the Feedback path and reaches the summing point again and produces H(s) as Eq.5. Thus, giving us the transfer function as Eq. 6.

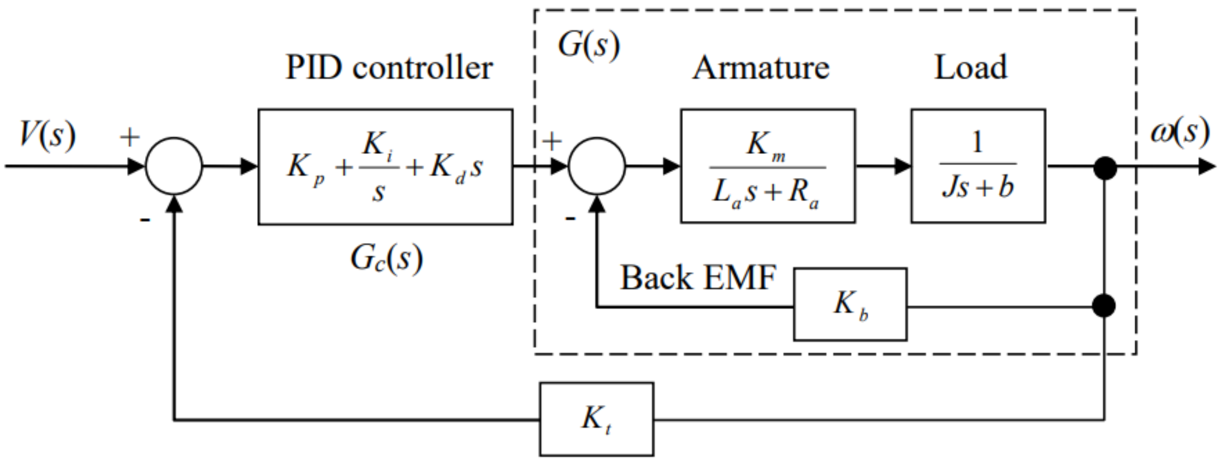
$$Y(s) = R(s) * G(s) \qquad \text{Eq 4}$$

$$R(s) - Y(s) * H(s) \qquad \text{Eq 5}$$

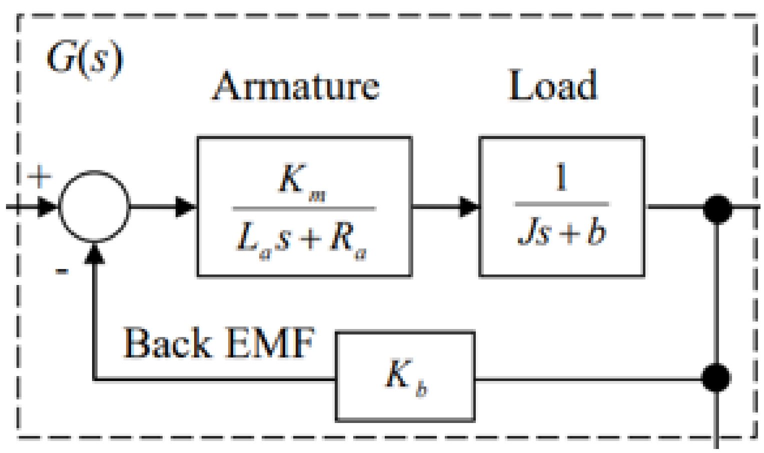
$$T(s) = \frac{Y(s)}{R(s)} = \frac{G(s)}{1+H(s)*G(s)} \qquad \text{Eq 6}$$

PID turntable speed control system

The block diagram is given below along with the governing equations for the PID turntable speed control system. The signal fromV(s) passes through the PID controller $G_e(s)$ where it could be adjusted as per the error circumstances and then to G(s) where it leads to Armature and then load section until it reaches the output. Now from the output it's taken back as feedback to G(s) or to the K_T where it reaches back to the input as feedback.



[7] **Fig.6.** Block diagram of a PID turntable speed control system



[7] **Fig.7.** Block diagram

$$\frac{K_m}{L_a s + R_a} \times \frac{1}{Js+b} = \frac{K_m}{(L_a s + R_a)(Js+b)} \quad \text{Eq 7}$$

$$G(s) = \frac{\frac{K_m}{(L_a s+R_a)(Js+b)}}{1+\frac{K_m K_b}{(L_a s+R_a)(Js+b)}} = \frac{K_m}{(L_a s+R_a)(Js+b)+K_b K_m} \qquad \text{Eq 8}$$

$$T(s) = \frac{\omega(s)}{V(s)} \qquad \text{Eq 9}$$

$$T(s) = \frac{\omega(s)}{V(s)} = \frac{G_c(s)G(s)}{1 + K_t G_c(s)G(s)}$$

$$= \left(\frac{K_p K_m(1 + \frac{1}{T_i s} + T_d s)}{R_a Js + K_b K_m}\right)$$

$$\frac{\frac{K_p K_m(1 + \frac{1}{T_i s} + T_d s)}{R_a Js + K_b K_m}}{\frac{R_a Js + K_b K_m + K_m K_t K_p(1 + \frac{1}{T_i s} + T_d s)}{R_a Js + K_b K_m}}$$

$$\frac{K_p K_m + K_p K_m \frac{1}{T_i s} + K_p K_m T_d s}{R_a Js + K_b K_m + K_m K_t K_p + K_m K_t K_p \frac{1}{T_i s} + K_m K_t K_p T_d s}$$

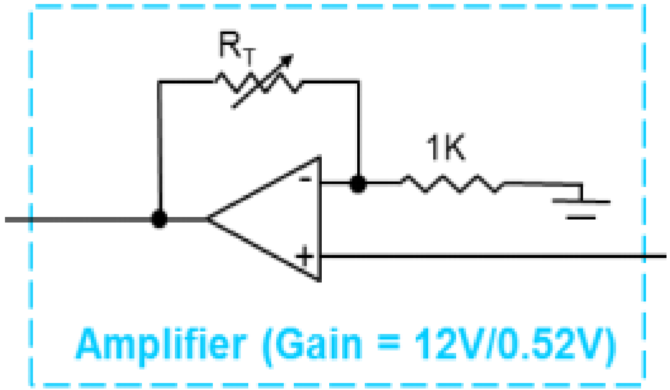
$$\frac{K_p K_m T_i T_d s^2 + K_p K_m T_i s + K_p K_m}{(T_i R_a J + K_m K_t K_p T_d T_i)s^2 + (K_m K_b T_i + K_m K_t K_p T_i)s + K_m K_t K_p}$$

The block diagram is solved by dividing it into smaller steps and then the transfer function is given along with the derivations in Eq 7-9

Circuit components of the PID turntable speed control

In this section all the components of the PID turntable speed control are given where ideal op-amp are considered as the pre-set condition to have voltages at two nodes to be zero and derivations are given along with the figures:

- **Amplifier**



[7] **Fig.8.** Amplifier Gain

Here Fig. 6 represents amplifier gain of the system which has 12V/0.52V. The input is considered as Vi and Vo represents the output then the impression of current is as follows:

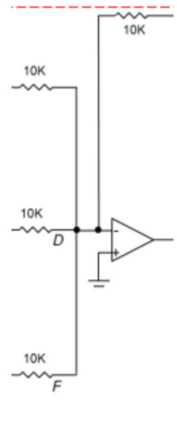
$$i = \frac{Vi}{1K} \qquad \text{Eq 10}$$

Here resistor is 1K and the trimmer R_T= 100K. Then using Kirchhoff's Current Law, we can determine that the sum of current should be zero at the nodes:

$$\text{Sum of current} = \frac{Vi}{1K} + \frac{Vo-Vi}{R1} = 0 \qquad \text{Eq 11}$$

With gain as 12V/0.52V, output V_o comes out to be same as gain 23xV_i and the resistance for the potentiometer comes out as 22 kΩ

- **Summing Amplifier**



[7] **Fig.9.** Summing Amplifier

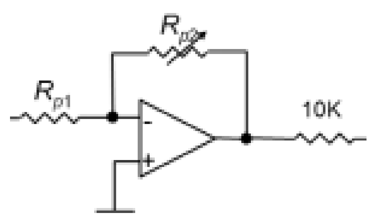
$$\frac{V_1}{R} + \frac{V_2}{R} + \frac{V_3}{R} + \frac{V_o}{R} = 0 \qquad \text{Eq 12}$$

$$V_o = -(V_1 + V_2 + V_3) \qquad \text{Eq 13}$$

The equation 12 is basically the sum of currents at node 1 near point D in the figure above.

The equation 13 above represent the sum of all the three voltages with a negative sign as the output voltage.

- **Proportional Amplifier**



[7] **Fig.10.** Proportional Amplifier

Here voltage at both nodes is zero whereas the current equation for R_{p1}:

$$i = \frac{V_i - V_2}{R_{p1}} = \frac{V_i}{R_{p1}} \quad \text{Eq 14}$$

Current equation for R_{p2}:

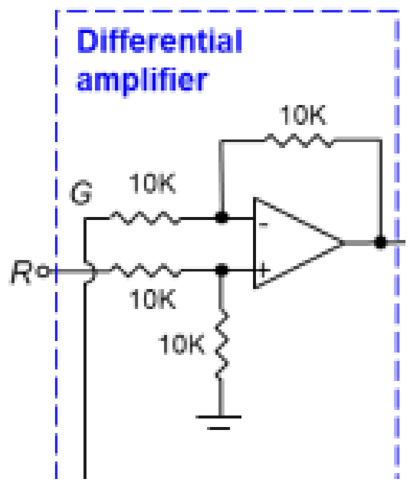
$$i = \frac{V_2 - V_o}{R_{p2}} \quad \text{Eq 15}$$

Output voltage and Transfer function is given as below:

$$V_o = -\frac{R_{p2}}{R_{p1}} V_i \quad \text{Eq 16}$$

$$\mathrm{T(s)} = -\frac{R_{p2}}{1K} \quad \text{Eq 17}$$

- **Differential Amplifier**



[7] **Fig.11.** Differential Amplifier

Here we see that the two nodes after 10K resistors have the same voltage. $V_a = V_b$

$$V_b = V_2 \left(\frac{R_4}{R_2 + R_4}\right) \quad \text{Eq 18}$$

Since Resistance is 10K for all so, $R_1 = R_2 = R_3 = R_4$

For current 1 and 2:

$$I_1 = \frac{V_1 - V_a}{R_1} \quad \& \quad I_2 = \frac{V_2 - V_a}{R_2} \qquad \text{Eq 19 \& 20}$$

Final current:

$$I_f = \frac{V_a - (-V_o)}{R_3} \qquad \text{Eq 21}$$

Now when V_a=0 and $V_b=0$

$$V_{o(b)} = V_2\left(\frac{R_4}{R_2+R_4}\right)\left(\frac{R_1+R_3}{R_1}\right) \quad \& \quad V_{o(a)} = -V_1\left(\frac{R_3}{R_1}\right) \qquad \text{Eq 22}$$

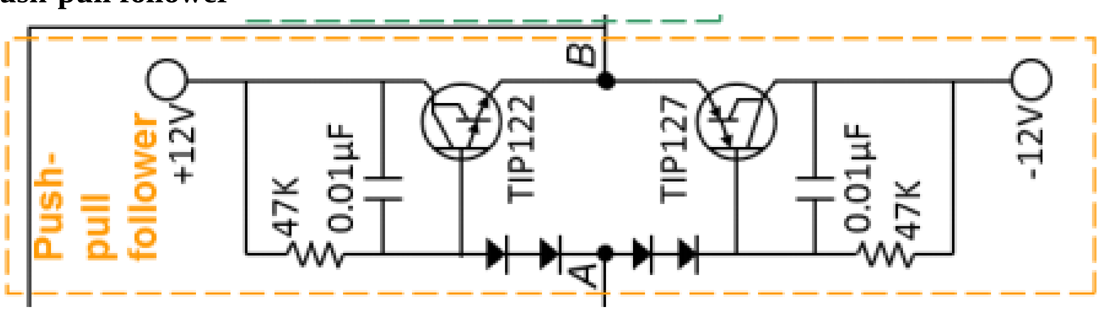
Hence,

$$V_o = -V_1\left(\frac{R_3}{R_1}\right) + V_2\left(\frac{R_4}{R_2+R_4}\right)\left(\frac{R_1+R_3}{R_1}\right) \qquad \text{Eq 23}$$

Where we know all the resistance is same and output voltage becomes:

$$V_o = V_2 - V_1 \qquad \text{Eq 24}$$

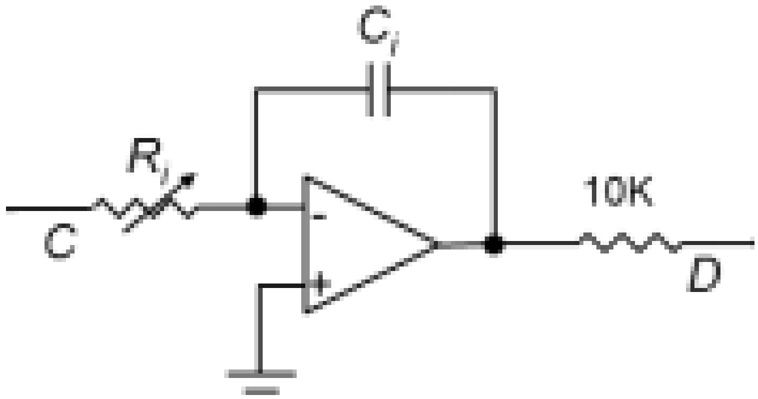
- **Push-pull follower**



[7] **Fig.12.** Push-pull follower

Push-pull follower has its own pros and cons. In Figure 6, it is evident that it is given +12V and -12V. It has a pair of transmitters, resistor as well as capacitor. There is also a central point A and B where it connects to analog PID and DC motor respectively. [7] It helps to amplify the current but at the same time could bring some crossover distortion as well.

- **Integral Amplifier**



[7] **Fig.13.** Integral Amplifier

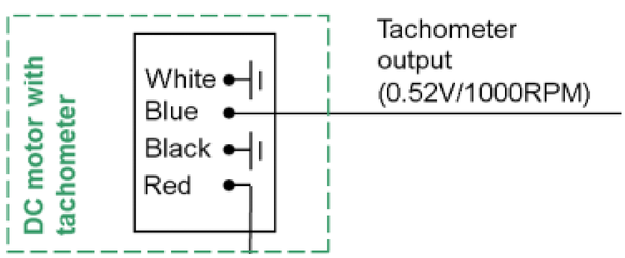
It is seen in figure 6 that Ri is in series with the capacitor which means same current flows through them and at both nodes.

$$i = \frac{V_i - V_1}{R_i} = \frac{V_i}{R_i} \quad \& \quad V_1 - V_o = \frac{1}{C_i}\int i\,dt = \frac{1}{R_i C_i}\int V_i dt = -V_o \qquad \text{Eq 25 \& 26}$$

Transfer function is given as: $$\frac{V_o}{V_i} = T(s) = -\frac{1}{R_i C_i}\frac{1}{s} \qquad \text{Eq 27}$$

$$K_i = \frac{1}{R_i C_i} \qquad \text{Eq 28}$$

- **DC motor with tachometer**



[7] **Fig.14.** Integral Amplifier

The DC motor is integral part of the system where the white and black wire goes to ground whereas blue goes to the amplifier gain and red connects to the central point B of the Push-pull follower. Following derivations are for DC motor:

Torque: $$T = K_t I$$ Eq 29

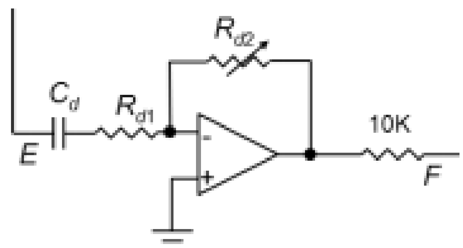
EMF: $$e = K_e \dot{\theta}$$ Eq 30

$$(Ls + R)I(s) = V - K\Theta(s)$$ Eq 31

Rotational speed and voltage are given as Transfer function:

$$\frac{\theta}{V} = \frac{K}{(Js+b)(Ls+R)+K^2}$$ Eq 32

- **Derivative Amplifier**



[7] **Fig.15.** Derivative Amplifier

Voltage difference is as follows:

$$V_i - V_1 = V_i = \frac{1}{C_d}\int idt + R_{d1}i$$ Eq 33

$$V_1 - V_o = -V_o = R_{d2}i$$ Eq 34

Now the transfer function is:

$$\frac{V_o}{V_i} = T(s) = -\frac{R_{d2}}{\frac{1}{sC_d}+R_{d1}}$$ Eq 35

$$K_d = R_{d2}C_d$$ Eq 36

For Lab 3, we have designed an analog PID using Lab 2 that goes parallel with the LabView system we have designed to achieve the performance and feature specifications. First percentage overshoot needs to be less than 10 5 for a unit step input whereas settling time has to stay within 2% of the final value which is to be less than 500ms for again a unit step input. Moreover, for rise time, it must be less than 200 ms for a unit step input. For the entire system, graph display must be possible for the input and output waveforms which in real time should be overlaid on the same scale to compare easily. Furthermore, the system must have real time controls for any tunable parameters. For the percent overshoot value, the system should be able to indicate the user in real time with the help of a light to decide whether the system is passing or failing specification 1. For safety reasons, the system must have a safety feature that knows if the user is present or absent and both cases keep the system on or off respectively. The system has to be capable of recording both input waveform as well as the output turntable speed to keep synchronicity with respect to time.

Most importantly, the entire system needs to be built out of the lab kits and system provided including custom LabView program and DAQ equipment. Any other stuff which is not part of the lab kit or system is not allowed to be used.

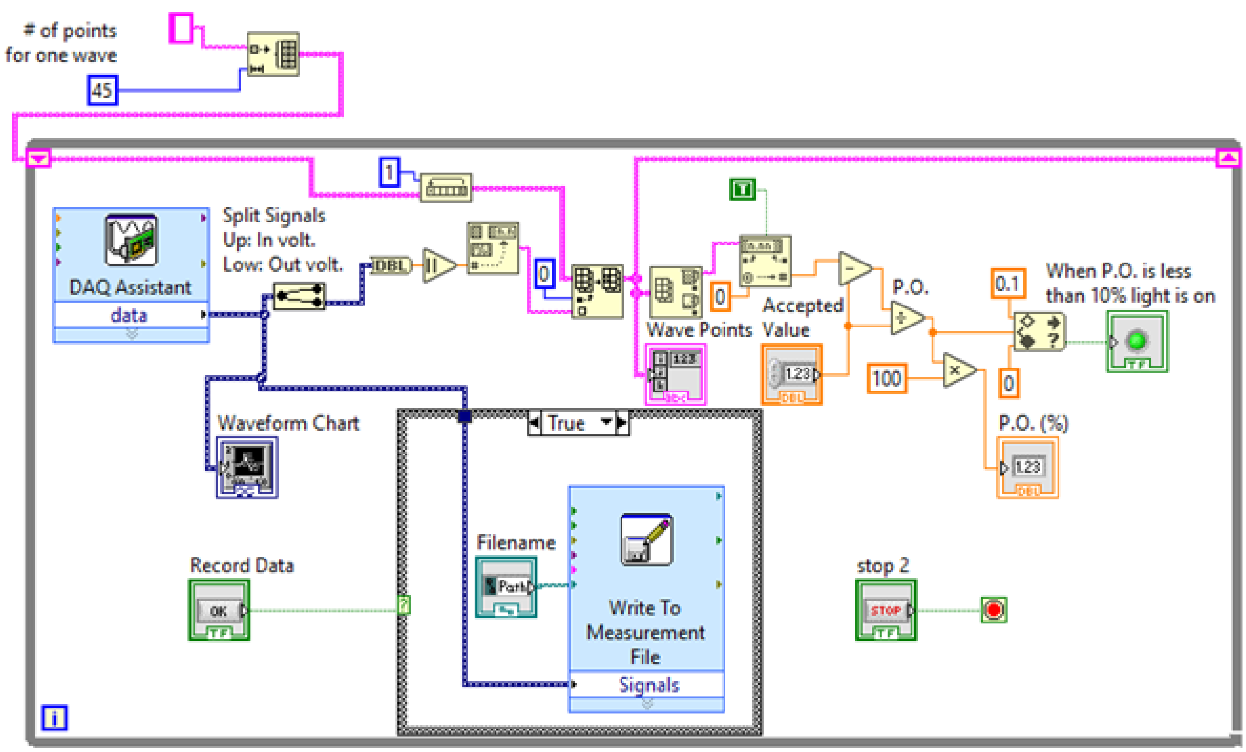
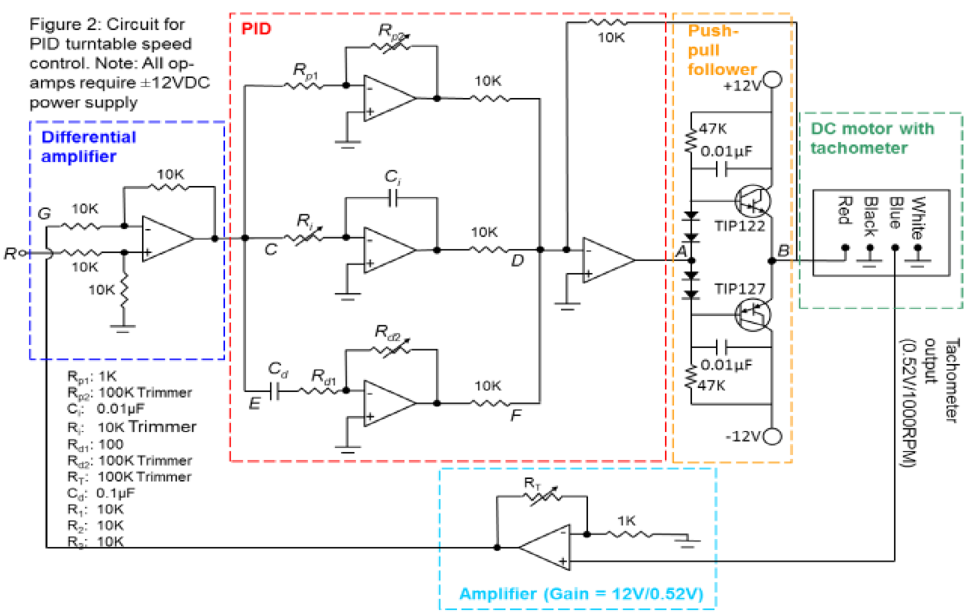


Fig.16. LabView Program

II. LIST OF EQUIPMENT:

- National Instruments DAQ system
- LabView program
- DC electric motor with tachometer
- Waveform generator
- Oscilloscope
- LM324/D Operational Amplifier
- Tip 125 and 127 Transistors
- Potentiometer
- Resistors 1K, 10K, 100K
- Capacitors 0.01uF, 0.1uF

IV. EXPERIMENTAL PROCEDURE



[7] **Fig.17.** Circuit schematics and actual circuit

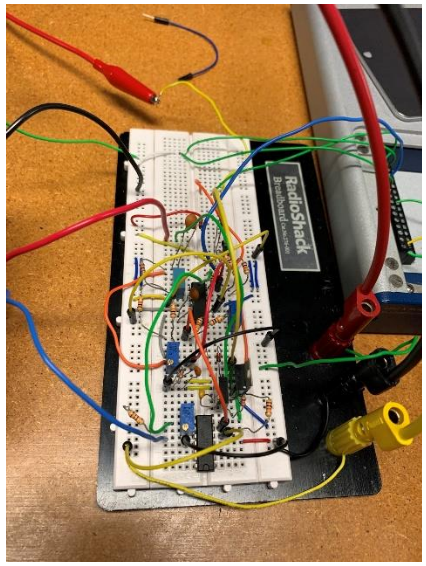


Fig.18. Analog PID controller

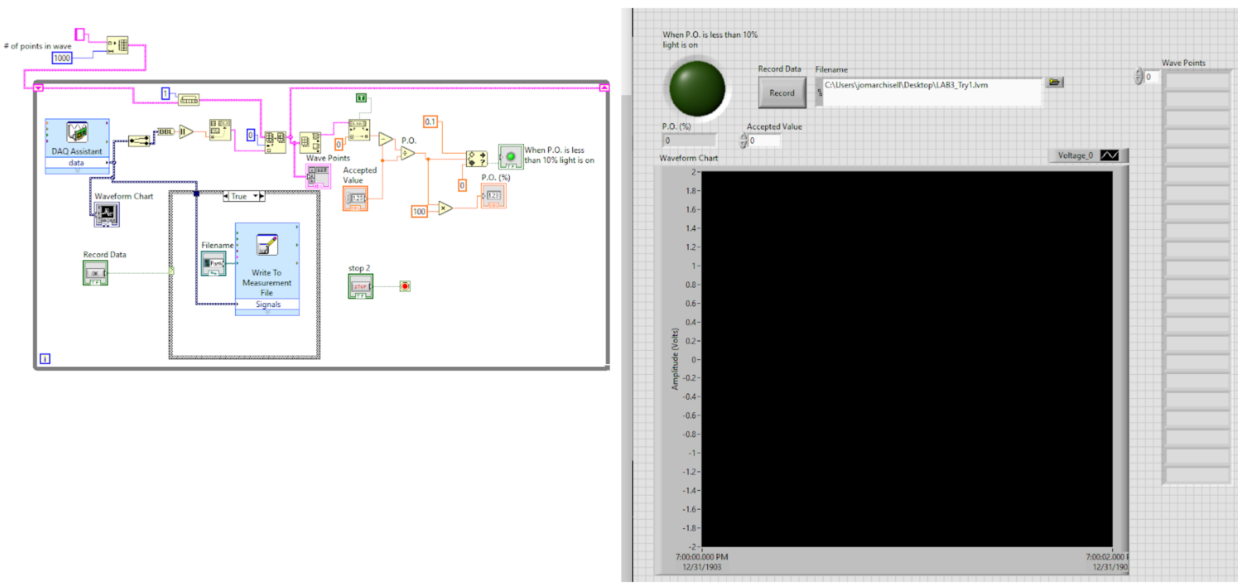


Fig.19. LabView program along with waveform graph and percent overshoot LED

Lab 3 will use the same circuit as built in lab 2[7].

- Complete the analog PID circuit for turntable speed control as per circuit schematics (Fig.17).
- Attach function generator to point R with a square wave and adjust the settings to frequency of 1Hz and 1V of amplitude.

- Connect channel A1 of the DAQ to input point R and connect channel A2 to output point G in order to get input and output waveforms.
- Make sure all the wires are set correctly and PID controller works properly.
- Now turn on the power supply with 12V.
- Now the system is ready, and the DC motor starts spinning back and forth because of the feedback received from the PID controller.
- Start up the custom-made LabVIEW program (Fig. 17 & 19) and input the following: filename, number of points for one cycle of the waveform (45 points for our case), and the accepted value.
- All three potentiometers need to be adjusted to tune the controller and produce results within the design specifications.
- The waveform chart in the LabVIEW program shows how the output relates to the input and the green light indicates when the percent overshoot is within 10%.
- Once satisfactory results are produced click the record but to start recording data and click again to stop recording data.
- With obtained data use MATLAB to plot experimental data and generate theoretical data for comparison.

IV. RESULTS

The goal of this experiment is to create and tune the pid controller depicted in figure X to meet design specifications as well as implement the design features. The specifications are a percentage overshoot less than 10%, settling time to within 2% of final value is to be less than 0.5s, and a rise time less than 0.2s. The data was recorded using the LabVIEW program created, the experimental data is plotted using MATLAB, and the theoretical data is simulated then plotted in MATLAB.

PID Controller

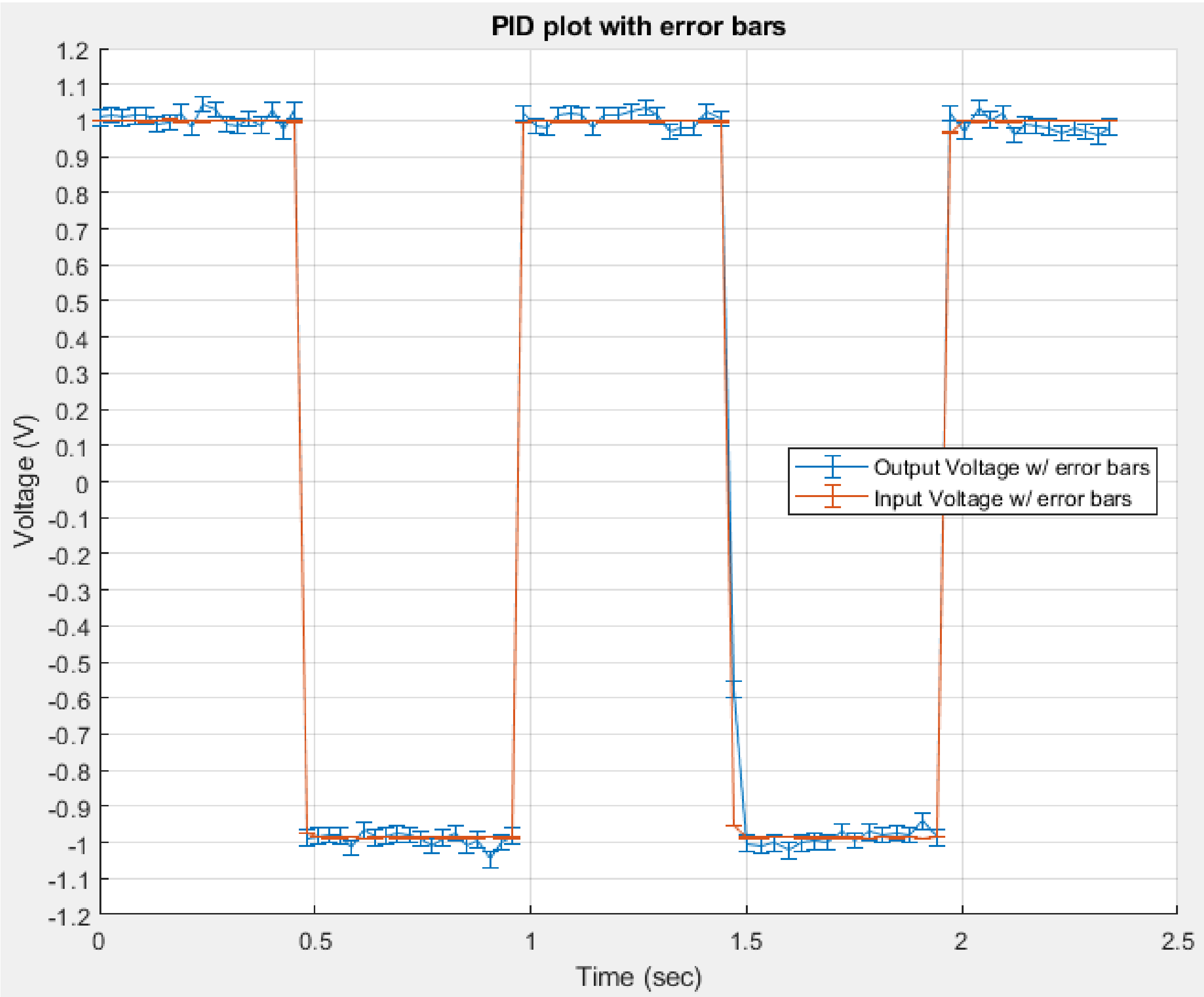


Fig.20. Experimental PID controller with error bars

For the PID controller, the circuit was set up similarly to the 2nd lab schematic [7] where the LabVIEW program reads the input and output voltages at point R and G respectively. Once the circuit was tuned to the best quality possible for the given time frame the waveforms were recorded using the LabVIEW program and the potentiometer values were recorded. Figure 20 shows the input and output voltages for the PID controller with error bars. The recorded potentiometer values are 20.946kΩ, 6.336kΩ, and 0.845kΩ for R_{p2}, R_i, and R_{d2} respectively. The rise time was calculated to be 0.013s. The average peak value and accepted value are found to be 1.042V and 0.998V respectively. The percentage overshoot is calculated to be 4.41%. The PID controller doesn't settle to within 2% of the final value where the upper and lower limits are 1.018V and 0.978V respectively. For the most part the noise stays within these limits but there are a few points that are outside this range. This is caused by not finishing tuning the circuit within the allotted time and can easily be fixed by retuning the circuit to meet the settling time specification. The PID controller meets the rise time and percent overshoot specifications but the settling time specification was not met within the three lab sessions but can easily be corrected.

Table 1. Experimental Results obtained from MATLAB graphs compared to design specs

Experimental	PID controller	Design Specs
Rise Time(s)	0.013	≤ 0.2
Settling Time(s)	Does Not Settle	≤ 0.5
Accepted Value(V)	0.998	-
Avg. Peak Value(V)	1.042	-
Percent Overshoot (%)	4.41%	≤ 10%

Table 2. Potentiometer values for each case

case	R_{p2} (kΩ)	R_i (kΩ)	R_{d2} (kΩ)
PID	20.946	6.336	0.845

Table 1 shows the specifications of the PID controller compared to the design specs and Table 2 shows the potentiometer values that best optimized the output for the PID controller for the allotted time frame. With the exception of the settling time all performance design specs were met.

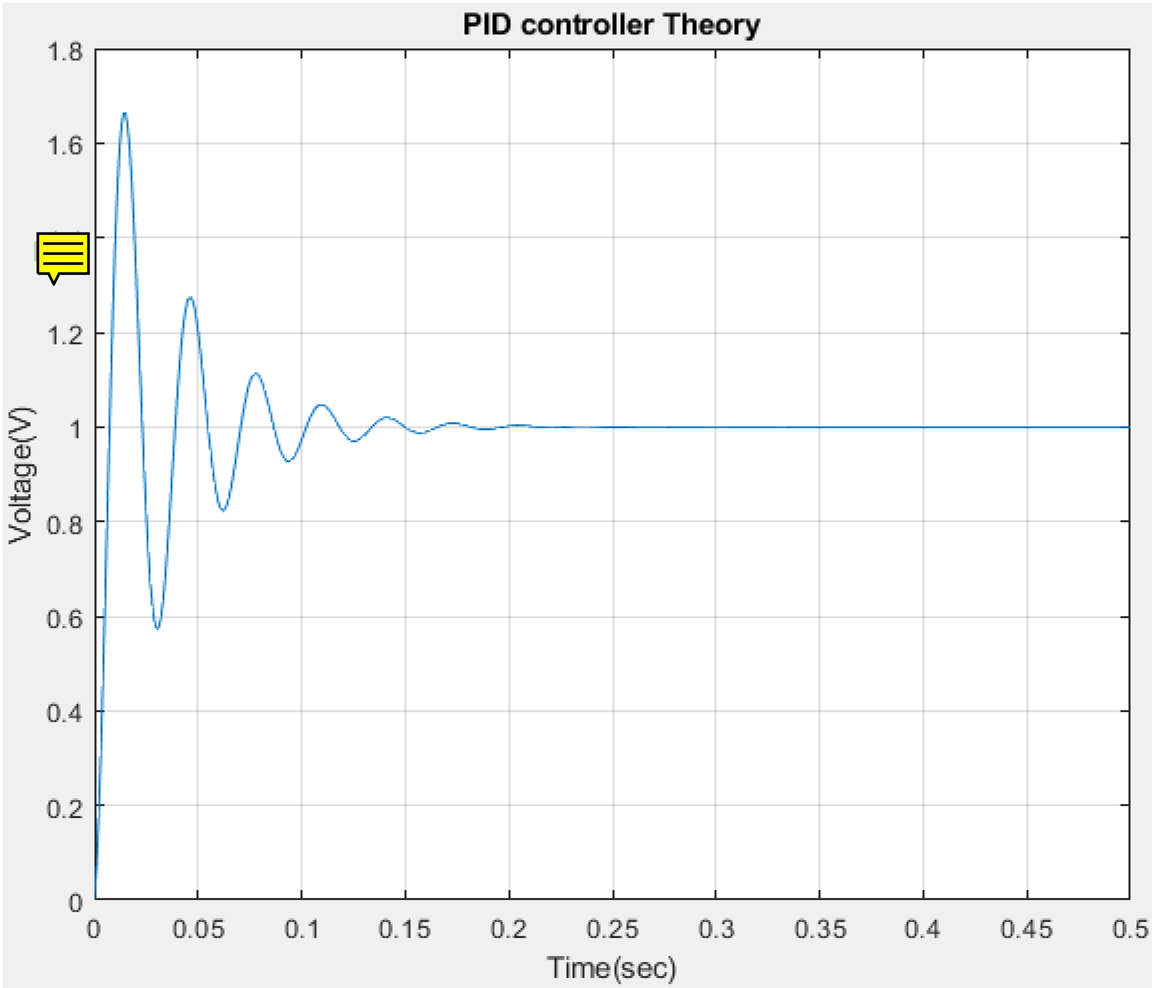


Fig.21. MATLAB PID controller output based on recorded parameters

Table 3. Theoretical Values obtained from MATLAB graphs

Theoretical	PID controller
Rise Time(s)	0.005
Settling Time(s)	0.131
Accepted Value(V)	1
Peak Value(V)	1.663
Percent Overshoot (%)	66.3%

Table 3 shows the specs of the theoretical outputs obtained by simulation using the recorded potentiometer values in MATLAB. Figure F shows the theoretical output of the PID controller based on the relevant potentiometer values shown in Table 2.

Table 4. Comparison of experimental, theoretical, and design specifications for labs 1, 2, and 3

Design Parameters	PID exp. (lab 1)	PID theory (lab 1)	PID exp. (lab 2)	PID theory (lab 2)	PID exp. (lab 3)	PID theory (lab 3)	Design Specs.
Rise Time (s)	0.006	0.015	0.012	0.004	0.013	0.005	≤ 0.2
Settling Time (s)	0.184	0.094	0.018	0.623	Does Not Settle	0.131	≤ 0.5
Accepted Value (V)	1.006	1.016	1.026	1.000	0.998	1	-
Peak Value (V)	1.048	1.016	1.260	1.924	1.042	1.663	-
Percent Overshoot (%)	4.2%	0%	22.8%	92.5%	4.41%	66.3%	≤ 10%

Table 4 gives a comparison between the experimental, theoretical, and design specs for labs 1 through 3. The lab 1 values were taken from the first report, where the RPM values were converted to voltage using the conversion of 12V/KRPM. The lab 2 values were taken from the second report. The lab 3 values were obtained by zooming in on the PID controller plot and using the below equations to calculate the specs.

$$T_{rise}=T_{90\%}-T_{10\%} \quad \text{Eq 37}$$
$$T_{peak}=T_{peak0}-T_0 \quad \text{Eq 38}$$
$$\text{bounds}=\text{accepted value} \pm 2\% \quad \text{Eq 39}$$
$$T_{set}=T_{set0}-T_0 \quad \text{Eq 40}$$

$$P.O=\frac{Peak\ value-Accepted\ value}{Accepted\ value}x100\% \quad \text{Eq 41}$$

V. DISCUSSION

For this experiment, our purpose is to design a PID system which fully implemented by a combination of self-authored software with a Data Acquisition interface and analog circuits. The experimental results should satisfy certain performance specifications. We obtained the PID controller experimental results and theoretical results from MATLAB graphs which are showing in Table 1 and Table 3. We found the rise time of the experimental was 0.013s and theoretical rise time was 0.005s. There was a 0.008s difference between these two values and both were met our design specification which required the rise time must be lower than 0.2s. We also found the settling time of theory was 0.131s and no settling time available for the experimental result because the top parts of the output waveform do not settle to within 2% of the final value. Therefore, both values met our design specifications. For the accepted value, we found the experimental value was 1V and the theoretical value was 0.998V. Both values were very close. After that, we found the peak value of the experimental result was 1.042V and the theoretical value was 1.663V. There was only 0.621V difference. The values were close enough. Finally, we got the percent overshoot for both experimental and theoretical results to compare our design specifications which required the percent overshoot must be lower than 10%. There were 4.41% overshoot for experimental results and 66.3% overshoot of theoretical results. All our experimental results met the design specifications. However, our theoretical percent overshoot was too high.

For Lab 1, we used software with a Data Acquisition interface to implement the PID controller. For Lab2, we used an analog circuit to implement the PID controller. For Lab3, we used the combination of self-authored software with the Data Acquisition interface and analog circuits to implement the PID controller. Table 4 is the comparison of experimental, theoretical and design specifications which is including all the experimental and theoretical results for Lab2, Lab2 and Lab 3.

For the experimental and theoretical rise time, we found the rise time of experimental values were increased from Lab1's 0.006s to Lab3's 0.013s. The rise time of theoretical rise time decreased from 0.015s to 0.005s. However, all the values were around 0.01s and met the design specifications, lower than 0.2s. For the experimental and theoretical settling time, we found the experimental settling time decreased from Lab1's 0.184s to Lab3's "Does Not Settle". For the settling time of theoretical values, we found Lab1 and Lab3 had very close values, 0.094s for Lab1 and 0.131s for Lab3 0.623s. Both theoretical settling times met our design specification, lower than 0.5s. Lab 2 had very high settling time of 0.623s which is higher than our design specification. For the experimental accepted values, the results always stay around 1V. I got 1.006V for Lab1, 1.026V for Lab2 and 0.998V for Lab3.

The theoretical accepted values were similar to the experimental values which kept around 1V. For the peak values, we found the experimental peak values kept around 1.1V. The Lab1 theoretical peak value is similar to the experimental value at 1.016V. However, the peak value of Lab2 and Lab3 were much higher than the experimental value. We got 1.924V for Lab2 theory and 1.663V for Lab3 theory. For the experimental percent overshoot, Lab1, and Lab3 got similar values, 4.2% for Lab 1 and 4.41% for Lab3. Both percent overshoots met our design specifications, lower than 10%. Our Lab2 result had a 22.8% overshoot which was higher than the design specifications. For Lab1, we have very similar percent overshoot for both experimental and theoretical values. For Lab2 and Lab3, our theoretical overshoots were much higher than our experimental overshoots. Both theoretical overshoots were higher than the design specifications. All in all, we believe that the experimental and theoretical results are reasonable and acceptable in

Lab1 because all the values met our design specifications. For Lab2, the experimental results are reasonable and acceptable, both rise time and settling time met our design specifications, the overshoot was higher than it but still close. The theoretical settling time and percent overshoot were higher than the design specifications in Lab2. The settling time was still acceptable because the value was close to the design specification. However, 92.5% overshoot was too high compared with the 10% requirement.

Lab3 experimental results perfectly met the design specification. The theoretical overshoot was 66.3% which was much higher than 10%. Base on above, we can see the experimental results agree with the theoretical model and did better. So, we can see the performance of these three different solutions, DAQ with analog circuits (Lab3) > DAQ(Lab1) > analog circuits (Lab2). Although Lab3 had best performance, it also had most cost in training, installation, and maintenance. and Lab 2 had the lowest cost at training and maintenance. Lab1 had the lowest time cost at installation. Now, we consider there are three reasons for the error. First, we may have a poor setup because we used a lot of wires to build the circuit. The wires had different resistance or other issues depend on their age. The adjusted amplifier potentiometer was not the same for all cases. In order to get better results, we would like to improve our circuit.

VI. CONCLUSIONS

• After this lab, we learned how to use a combination of self-authored software with an analog circuit to implement a PID turntable speed control system that meets the design specifications.

• Based on Table 4, the experimental results showed the rise time, settling time, and percent overshoot met the design specifications. The rise time was lower than 0.2s, settling time was lower than 0.5s, and 4.41% overshot was smaller than 10%.

• The control system used for Lab3 was found to be better performance. The control system used for Lab1 was found to be easy installation. The control system used for Lab2 was found to be lowest cost at training and maintenance.

• The rise time was 0.013s which lower than 0.2s. The settling time was “Does Not Settle” which means lower than 0.5s. And, the 4.41% overshoot was smaller than 10%. All the relevant values were found to be corresponding to the design specifications.

• For the rise time and settling time, our experimental results did agree with the theoretical results. However, our 4.41% experimental overshoot didn’t agree with 66.3% theoretical overshoot. Our experimental overshoot was better than the theoretical overshoot.

• Our Lab3 results did agree with our Lab1 results. However, the Lab3 results didn’t agree with our Lab2 results. Both Lab1 and Lab3 had better performance than Lab 2 results. Lab2 had the highest percent overshoot which was 22.8%.

• The discrepancy is attributed to the poor setup because we used a lot of wires to build the circuit. The wires had different resistance or other issues depend on their age. The adjusted amplifier potentiometer was not the same for all cases.

• In future investigations, we’re going to improve our circuit and adjust the equipment before recording the data.

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APPENDICES

MATLAB code

```
clc
clear
close all
%PID----------------------------------------------------------------------
km=16.2*0.02835*9.81*0.0254;
Ra=11.5;
J=2.5*0.02835*9.81*0.0254^2;
b=0;
kb=12/(1000*2*3.14/60);
kt=12/(1000*2*3.14/60);
Rp1=1000;
Rd1=100;
Ci=0.01*10^(-6);
Cd=0.01*10^(-6);
Rp2=20946;
Ri=6336;
Rd2=845;
kp=Rp2/Rp1;
ki=1/(Ri*Ci);
kd=Rd2*Cd;
t=0:0.001:1;
num=[kd*km kp*km ki*km];
den=[Ra*J+kt*km*kd Ra*b+kb*km+kt*km*kp kt*km*ki];
sys=tf(num,den);
y=kt*step(sys,t);
PID_Contoller=stepinfo(y)
figure
plot(t,y);
title('PID controller Theory');
xlabel('Time(sec)');
ylabel('Voltage(V)');
grid on
```

Comment Summary

Page 5

1. Poor image resolution.

Page 24

2. Show the response of full square wave.

Page 28

3. The explanation is not sufficient. And please compare and explain the difference in three systems.

Page 30

4. Please cite all references in your text with proper format.