Stony Brook University

MEC 411 GROUP #26

Lab #2: PID Speed Control of a Turntable
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ABSTRACT

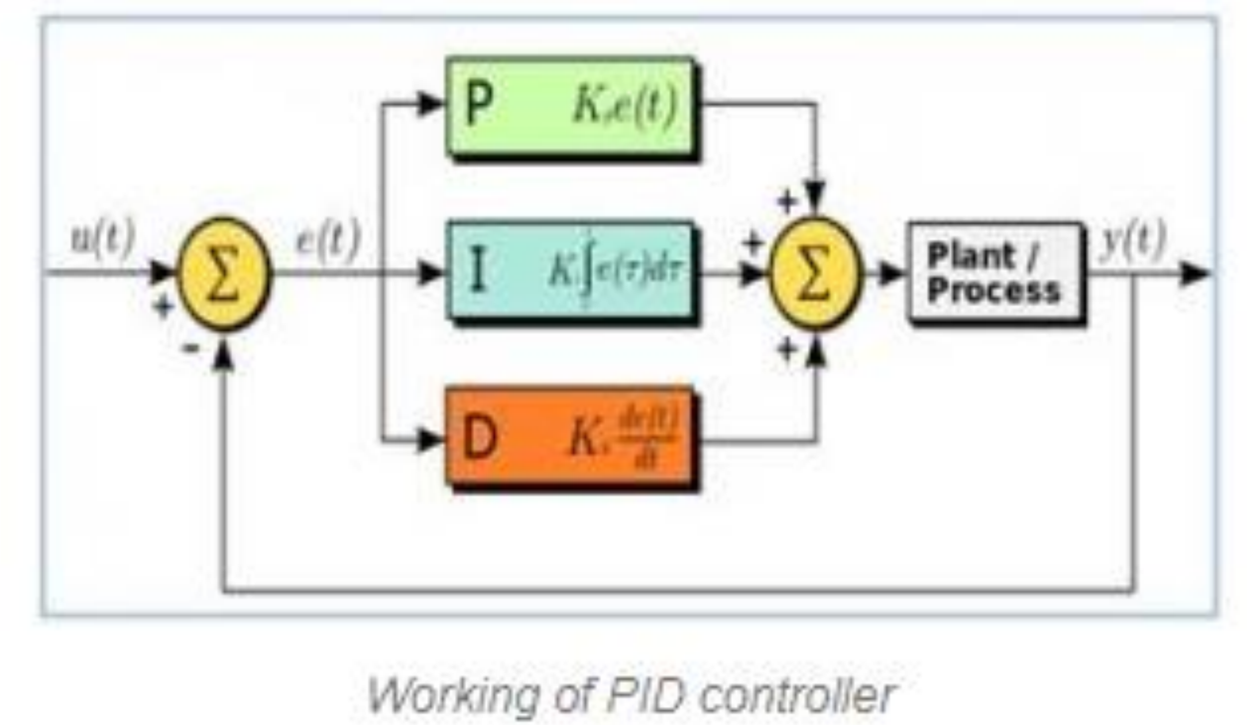
This experiment complies with the design as well as the execution of the PID turntable speed control system which is in accordance with defined performance specifications. An analog circuit is to be used to carry through the PID application along with the comparison of experimental data with the theoretical data obtained through MATLAB. The system output requires to satisfy the percentage overshoot to be within 10% whereas the settling time within 2% of the accepted value is to be less than 500 ms and rise time is required to be less than 200ms. K_c proportional, T_i integral, and T_d derivative were adjusted manually in the circuit with the help of potentiometer in order to achieve the tasks. 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 3.880kΩ, 3.980kΩ, and 0.853kΩ respectively. The experimental data was obtained by using Ultra Scope software to record the input and output waveforms from the circuit and put into an excel file. 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, settling time, and percent overshoot obtained for the PID controller are 0.012s, 0.018s, and 22.8%. The percent overshoot is the only design specification that was not met due to time constraint while the rise and settling time do meet the design specifications. Compared to the digital PID controller from lab 1 the analog PID controller only produced a better settling time.

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.

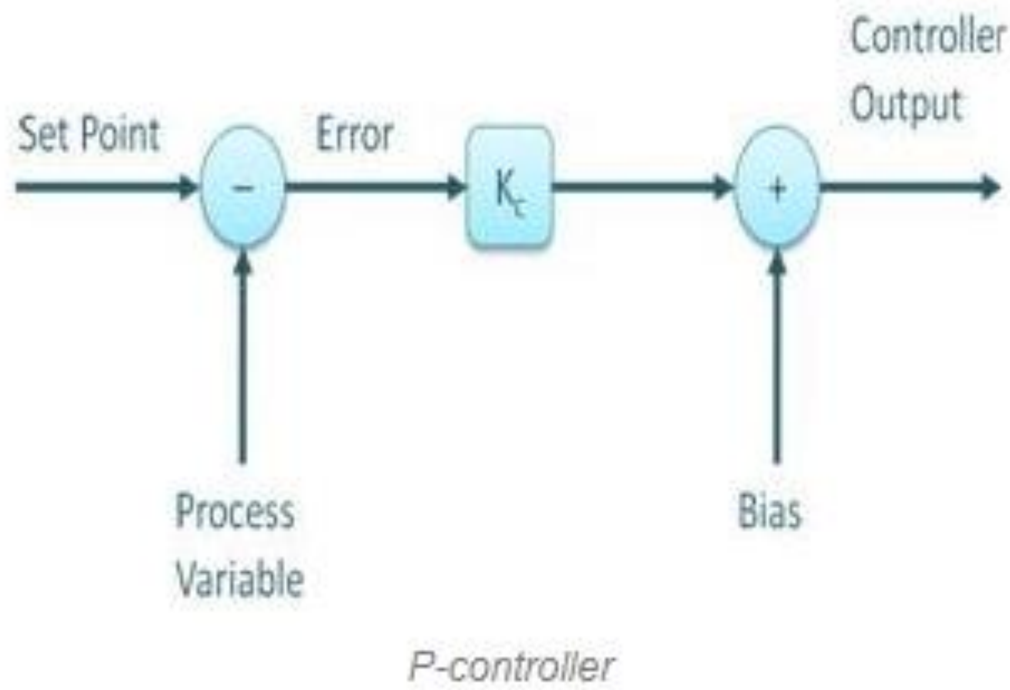


[3] **Fig.1.** PID controller block diagram

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

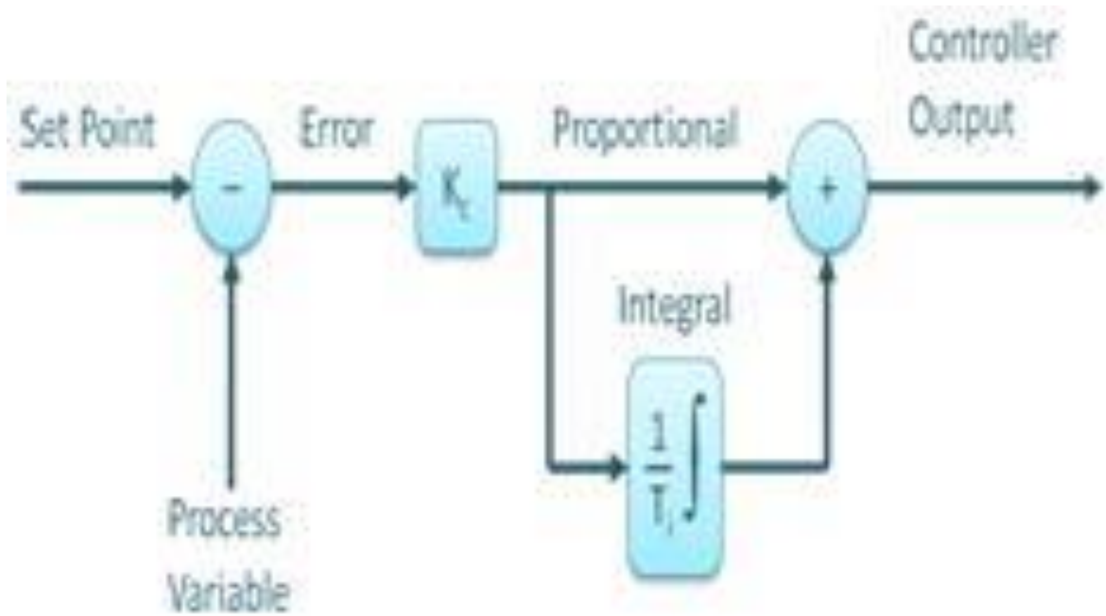
[3] Proportional or P- controller gives output which is proportional to the current error e (t). In the P controller, output values are compared with the original values and the resulting error is then multiplied with the proportional constant to provide the outcome. The system keeps the stability, but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



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

I-Controller

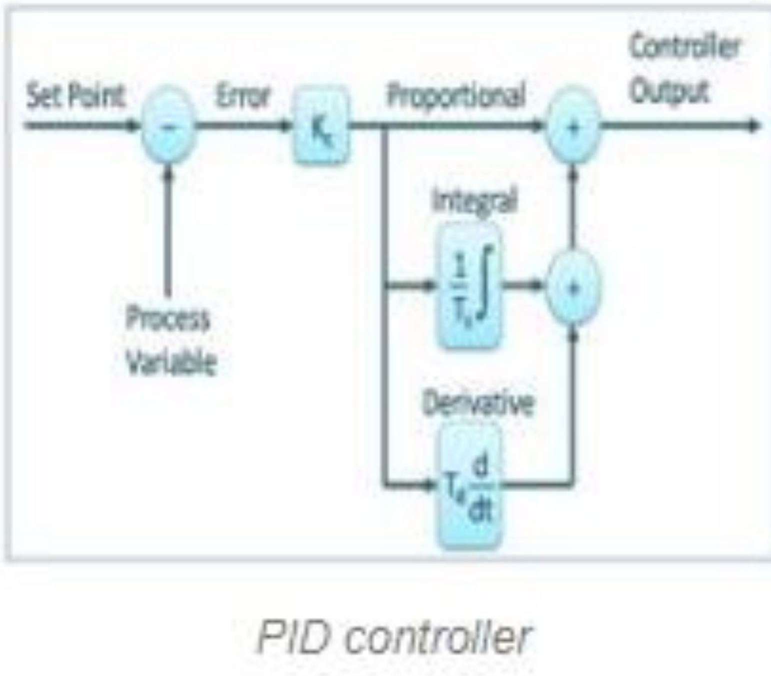
There comes a point where P-controller is restricted and then I-Controller plays its part there to get the work done.[3] It helps to narrow down the value of error to zero over a period while integrating it and helps to bring down the steady state error. Hence the error becomes zero due to I-controller 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.

$$u(t) = k_p \left(e(t) + \frac{1}{T_i} \int_0^t e(\tau) d\tau + T_d \frac{de(t)}{dt} \right),$$

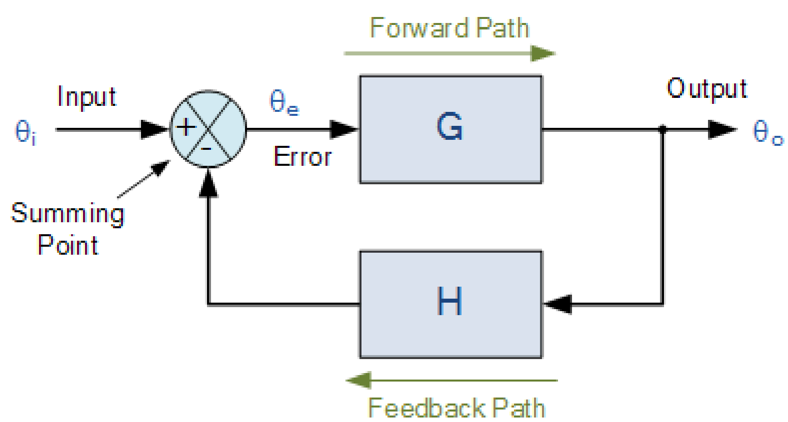
Eq 2

[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.

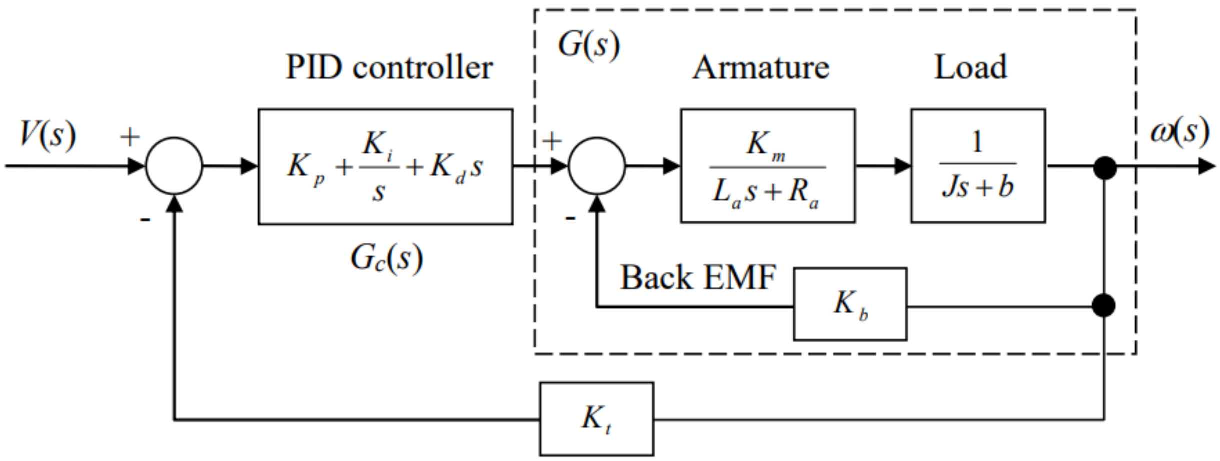
$$Y(s) = R(s) * G(s) \qquad \text{Eq 4}$$

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

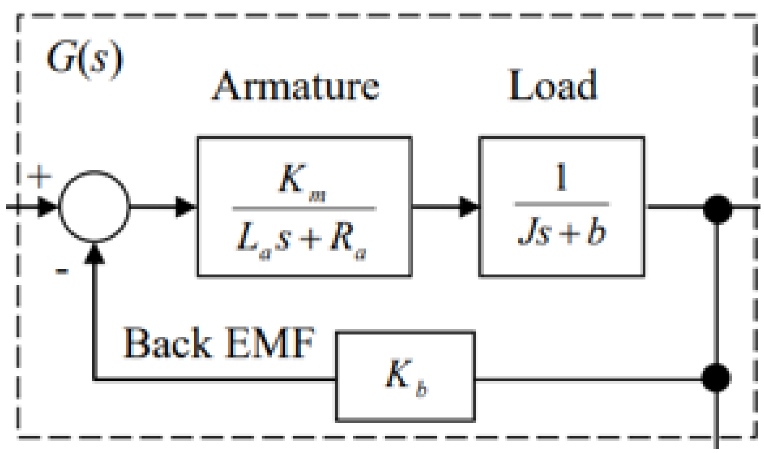
$$T(s) = \frac{Y(s)}{R(s)} = \frac{G(s)}{1+H(s)*G(s)} \qquad \text{Eq 6}$$

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

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

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

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

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

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

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

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

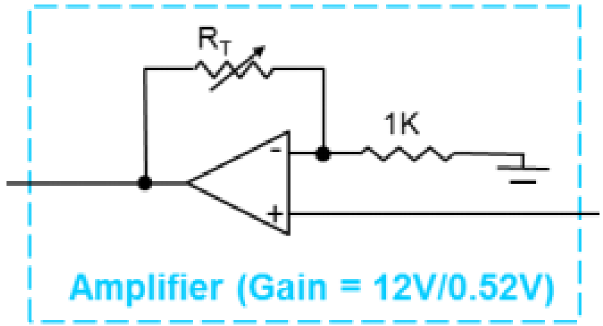
$$\frac{K_p K_m T_i T_d s^2 + K_p K_m T_i s + K_p K_m}{(T_i R_a J + K_m K_t K_p T_d T_i)s^2 + (K_m K_b T_i + K_m K_t K_p T_i)s + K_m K_t K_p}$$

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:

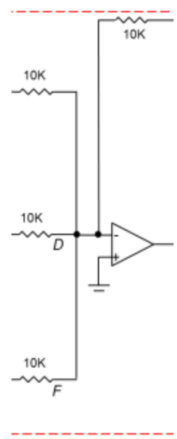
$$i = \frac{Vi}{1K} \qquad \text{Eq 10}$$

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

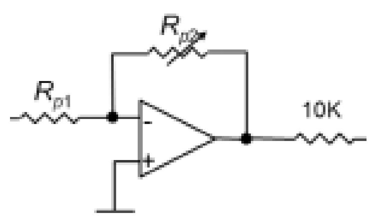
$$\frac{V_1}{R} + \frac{V_2}{R} + \frac{V_3}{R} + \frac{V_o}{R} = 0 \qquad \text{Eq 12}$$

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

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}:

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

Current equation for $R_{p2:}$

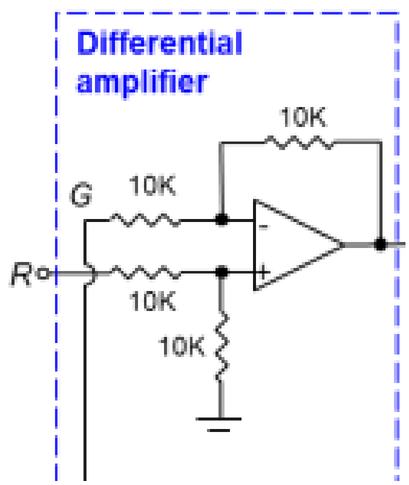
$$i = \frac{V_2 - V_o}{R_{p2}} \qquad \text{Eq 15}$$

Output voltage and Transfer function is given as below:

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

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

- **Differential Amplifier**



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

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

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

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

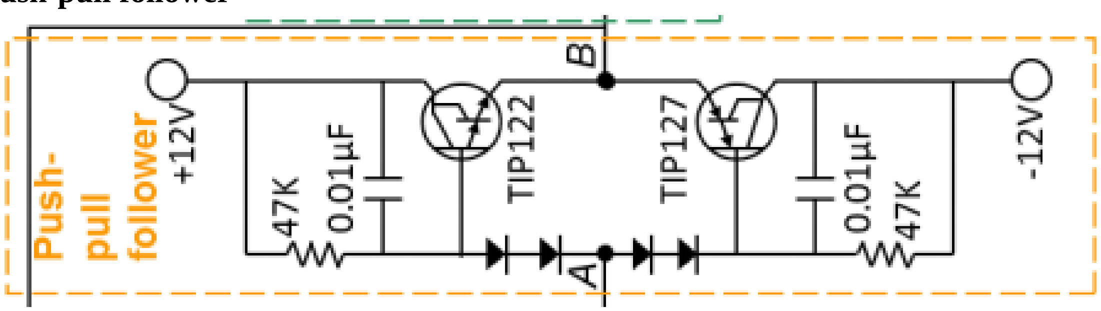
$$V_{o(b)} = V_2\left(\frac{R_4}{R_2+R_4}\right)\left(\frac{R_1+R_3}{R_1}\right) \quad \& \quad V_{o(a)} = -V_1\left(\frac{R_3}{R_1}\right) \qquad \text{Eq 22}$$

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:

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

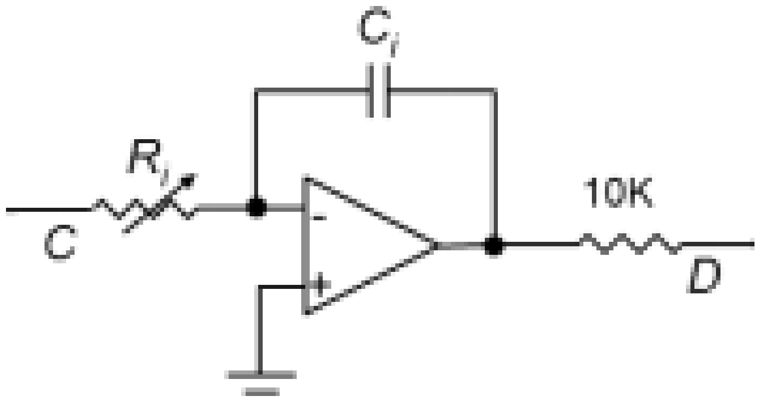
- **Push-pull follower**



[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

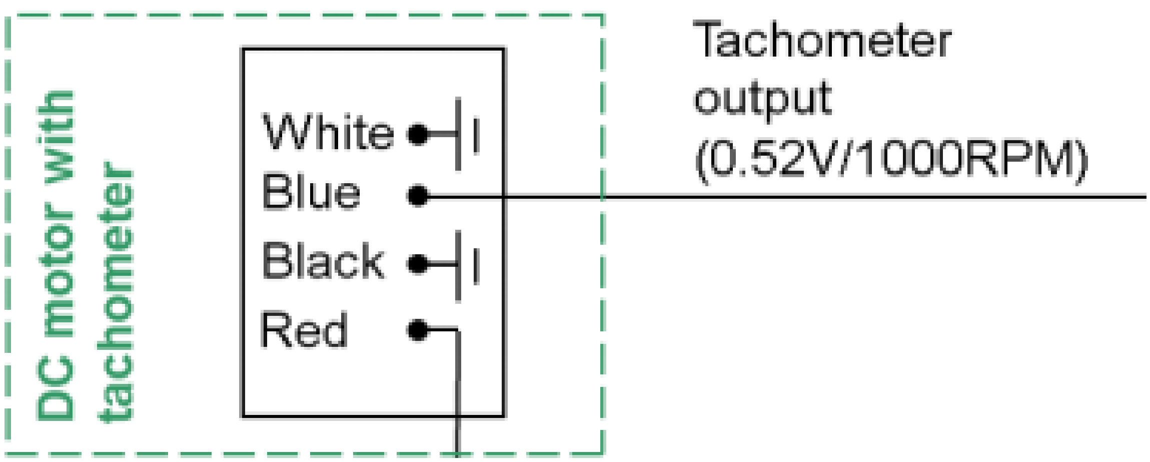
It is seen in figure 6 that Ri is in series with the capacitor which means same current flows through them and at both nodes.

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

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

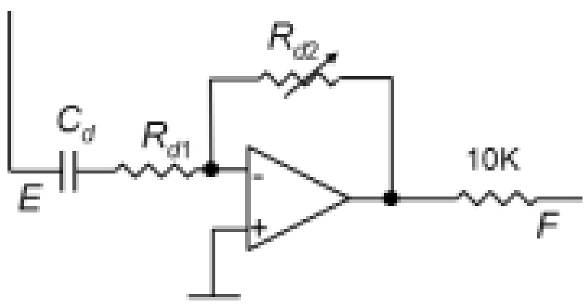
EMF: $$e = K_e \dot{\theta}$$ Eq 30

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

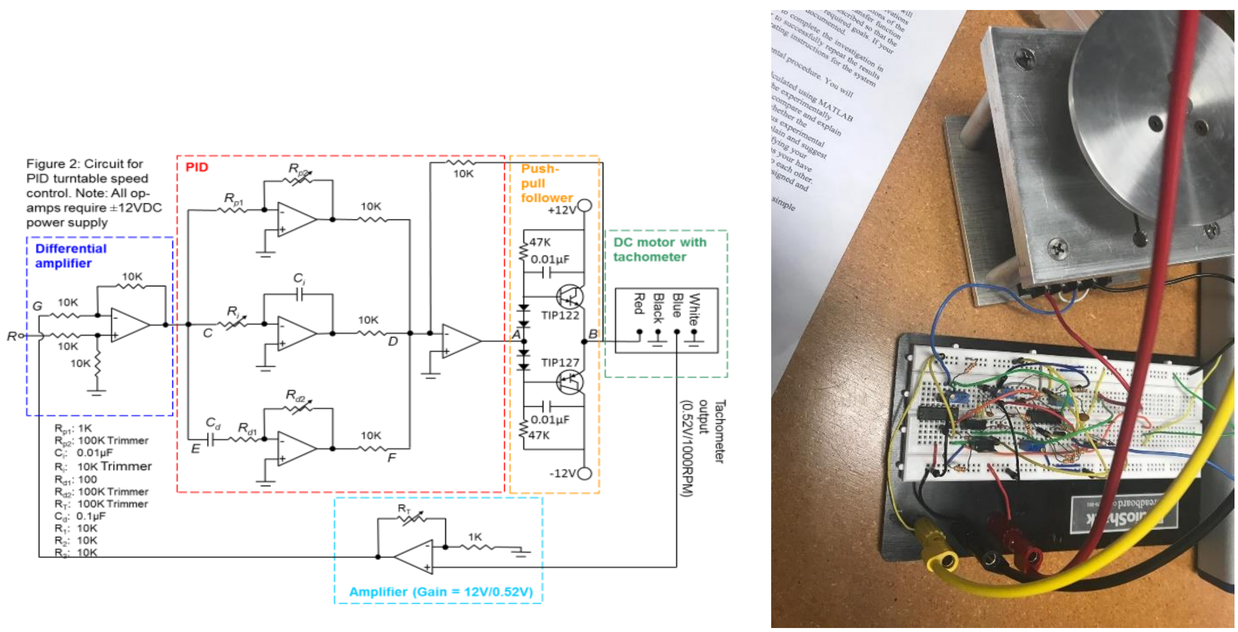
$$\frac{V_o}{V_i} = T(s) = -\frac{R_{d2}}{\frac{1}{sC_d}+R_{d1}}$$ Eq 35

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

II. LIST OF EQUIPMENT:

- National Instruments DAQ system
- 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.16.** Circuit schematics and actual circuit

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

- Put Channel 1 of the oscilloscope and connect it to input R and connect channel 2 to point G in order to get feedback voltage which will give the actual speed of the turntable measured by the tachometer.
- Make sure all the wires are set correctly and PID controllers works properly.
- Now turn on the power supply with 12V and the oscilloscope.
- Now the system is ready to take the data, as power supply gets turned on, DC motor starts spinning back and forth because of the feedback received from the PID controller.
- Adjust the oscilloscope as per desired resolution and the graph can be observed in the oscilloscope as well as the computer.
- One of the most important things to take notice is to take the potentiometers off the circuit to measure the system resistance.
- For the circuit, disconnect points at C, D, E and F which eventually becomes feedback control with proportional controller. Then adjust Rp2 where the turntable output speed is brought close enough to the input speed to keep the system stable.
- All the data with Rp2, input and output is recorded in MS Excel using the computer software.
- Now connect the circuit again at point C and point D hence, the circuit becomes Proportional Integral controller.
- Then adjust Rp2 and Ri to make sure that the turntable output speed reaches as close as possible to the input while the system stays stable.
- Record all the data at this point including Rp2, Ri, input and output waveforms.
- At this point, attach points E and F back to the circuit making it PID (Proportional Integral-Derivative) controller.

- All the three trimmers need to be adjusted to get the required results as per specifications.
- Then record the values for Rp2, Rd2, Ri along with input and output waveforms.

IV. RESULTS

The goal of this experiment is to create and tune the PID controller depicted in figure X to meet design specifications. 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 Ultra Scope software, the experimental data is plotted using MATLAB, and the theoretical data is simulated then plotted in MATLAB.

P Controller

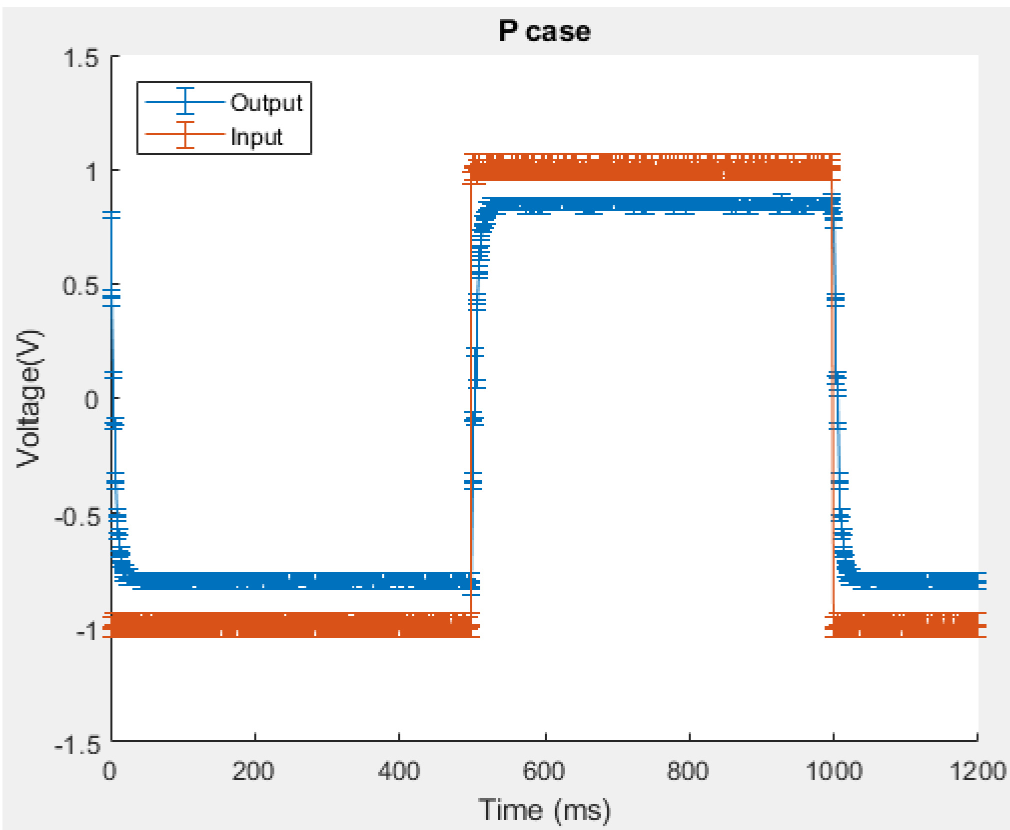


Fig. 17: experimental P case with error bars

For P case the I and D sections were disconnected from the circuit so only the proportional gain is measured. Figure A shows the output response of the P controller and the input voltage with error bars. The figure shows that for minimal noise, the output could not reach the desired input. The potentiometer, R_{p2}, was adjusted until the output got as close as possible to the input with the final value for R_{p2} being 15.027kΩ. The rise and settling time were calculated to be 0.021s and 0.031s respectively. Since the output does not cross the input there is no overshoot. The accepted value was 0.848V.

PI Controller

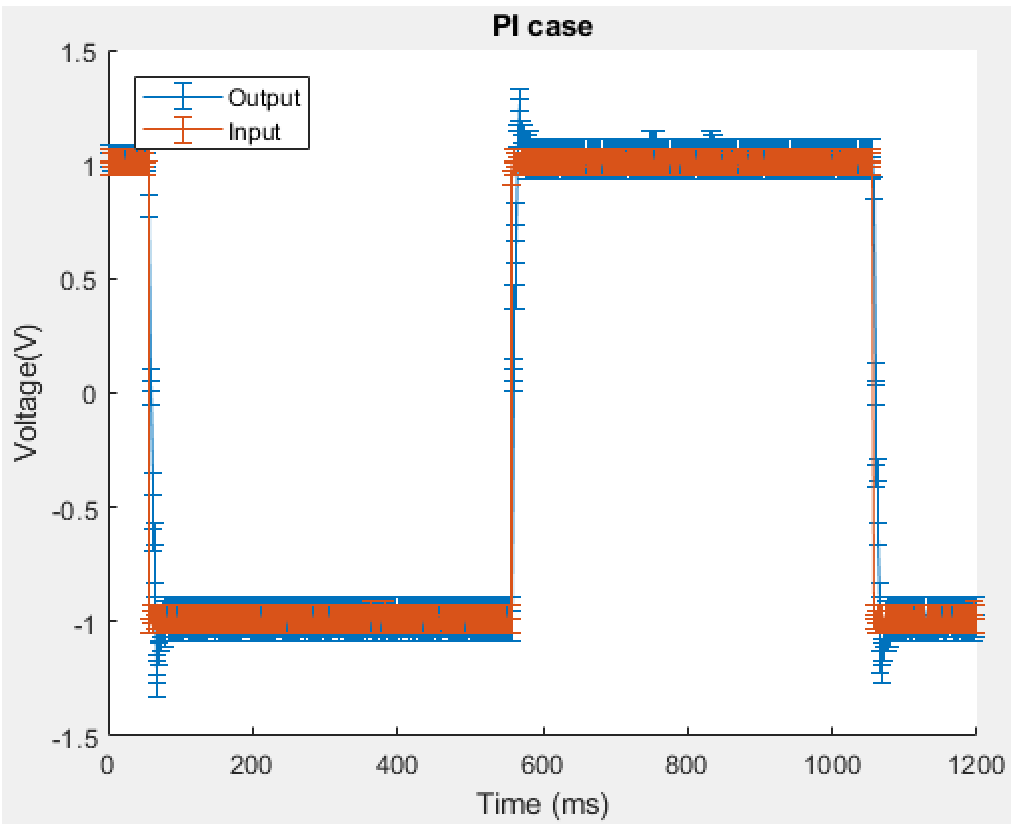


Fig. 18: Experimental PI case with error bars

For PI case the D section is disconnected so only proportional and integral gains are measured. Figure 17 shows the input and output for the PI case with error bars. For the PI case, it was possible to get the output to better match the input, however, the output has a significant overshoot and the output noise and error bars are greater than those of the input. The recorded potentiometer values are 22.034kΩ and 7.041kΩ for R_{p2} and R_i respectively. The rise and settling time were calculated to be 0.008s and 0.025s respectively. The peak value and accepted value are found to be 1.260V and 1.021V respectively. The percentage overshoot is calculated to be 23.4%. The PI case is significantly better than the P case, but still does not meet the design specs.

PID Controller

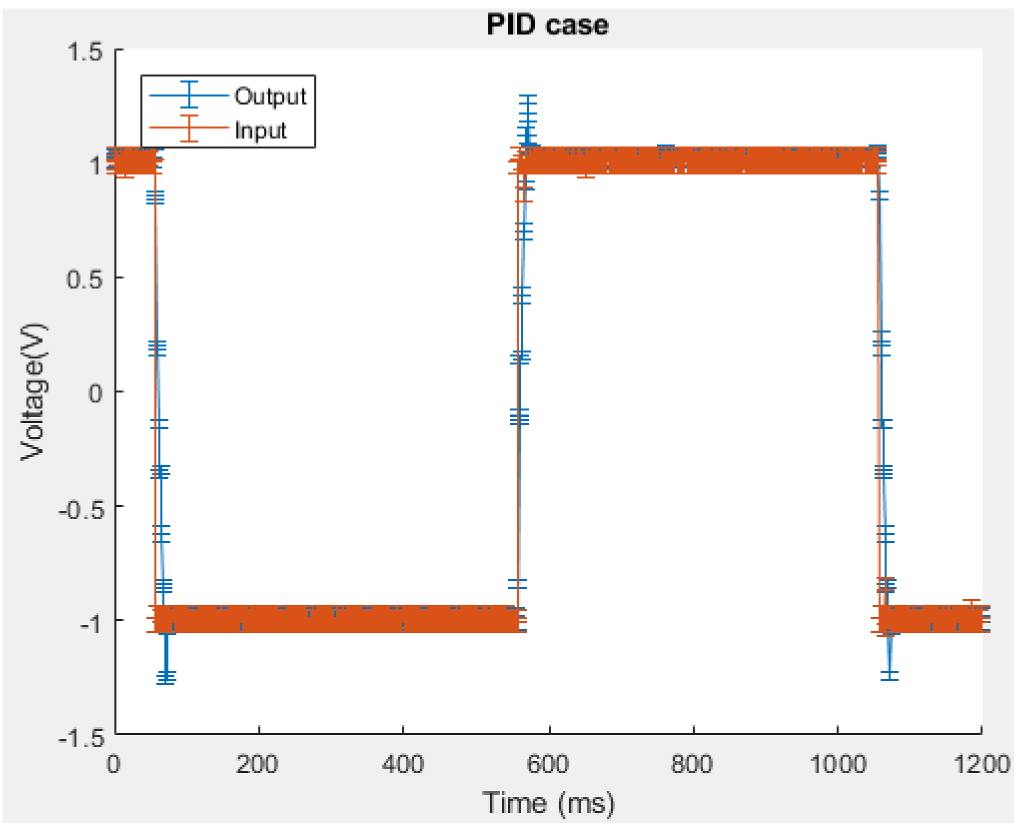


Fig. 19: Experimental PID case with error bars

For PID case proportional, integral, and derivative gains are connected and measured. Figure 18 shows the input and output for the PID case with error bars. For PID case it was possible to reduce the error bars and noise of the output to within a reasonable range, but do to time constraints the percent overshoot couldn't be lowered to meet the design specs. The recorded potentiometer values are 3.880kΩ,3.980kΩ, and 0.853kΩ for R_{p2}, R_i, and R_{d2} respectively. The rise and settling time were calculated to be 0.012s and 0.018s respectively. The peak value and accepted value are found to be 1.260V and 1.026V respectively. The percentage overshoot is calculated to be 22.8%. The PID case is better than the PI case because the noise is reduced, but still does not meet the design specs for the percent overshoot because the right potentiometer values were not obtained within the given timeframe of 3 lab sessions.

Table 1. Experimental Results obtained from MATLAB graphs

Experimental	P controller	PI controller	PID controller
Rise Time(s)	0.021	0.008	0.012
Settling Time(s)	0.031	0.025	0.018
Accepted Value(V)	0.848	1.021	1.026
Avg. Peak Value(V)	0.848	1.260	1.260
Percent Overshoot (%)	-	23.4%	22.8%

Table 2. Potentiometer values for each case

cases	R_{p2} (kΩ)	R_i (kΩ)	R_{d2} (kΩ)
P	15.027	-	-
PI	22.034	7.041	-
PID	3.880	3.980	0.853

Table 1 shows the specifications of each case for the PID controller and Table 2 shows the potentiometer values that best optimized the output for each controller case. Adding the integral gain allowed for the output to get closer to the input but had a high percent overshoot and a lot of noise. Adding the derivative gain reduced the noise to within accepted values but the percent overshoot only decreased by a small amount.

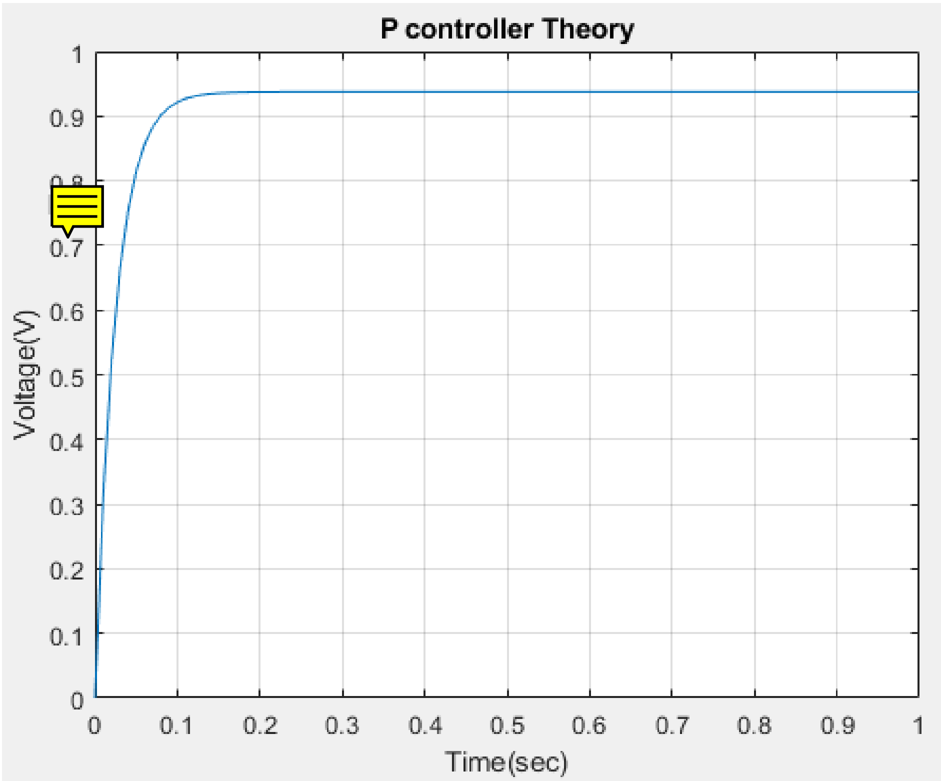


Figure 20: MATLAB P controller output based on recorded parameters

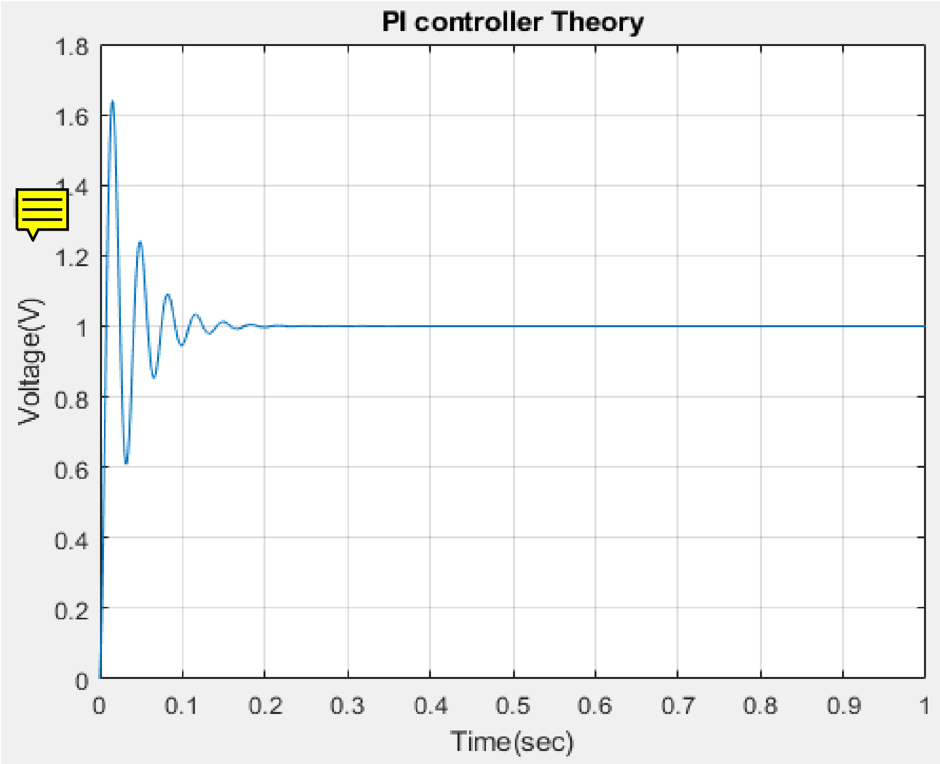


Figure 21: MATLAB PI controller output based on recorded parameters

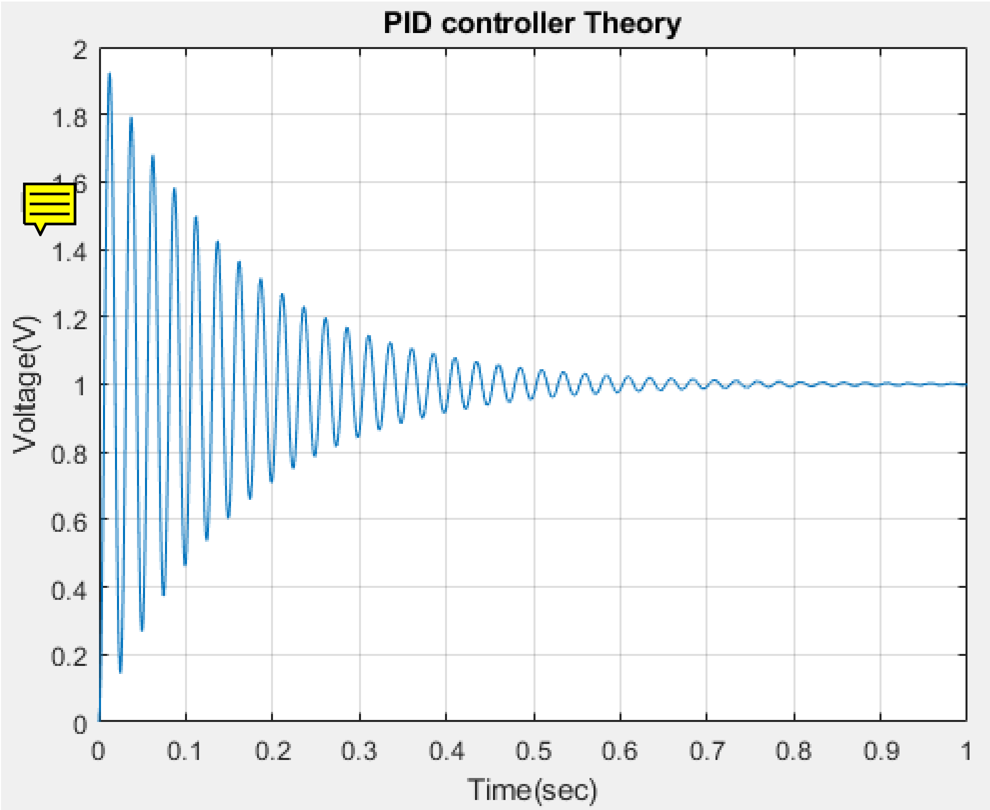


Figure 22: MATLAB PID controller output based on recorded parameters

Table 3. Theoretical Values obtained from MATLAB graphs

Theoretical	P controller	PI controller	PID controller
Rise Time(s)	0.054	0.006	0.004
Settling Time(s)	0.106	0.135	0.623
Accepted Value(V)	0.938	1	1
Peak Value(V)	0.938	1.640	1.924
Percent Overshoot (%)	0%	64.0%	92.5%

Table 3 shows the specs of the theoretical outputs obtained by simulation using the recorded potentiometer values in MATLAB. Figures D to F show the theoretical output of P, PI, PID controller based on the relevant potentiometer values shown in Table 2.

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

	PID experimental (lab 1)	PID theoretical (lab 1)	PID experimental (lab 2)	PID theoretical (lab 2)	Design Specs.
Rise Time(s)	0.006	0.015	0.012	0.004	≤0.2
Settling Time(s)	0.184	0.094	0.018	0.623	≤0.5
Accepted Value (V)	1.006	1.016	1.026	1.000	-
Peak Value (V)	1.048	1.016	1.260	1.924	-
Percent Overshoot (%)	4.2%	0%	22.8%	92.5%	≤10%

Table 5 gives a comparison between the experimental, theoretical, and design specs for both lab 1 and 2. The lab 1 values were taken from the previous report, where the RPM values were converted to voltage using the conversion of 12V/KRPM. The lab 2 values were determined by zooming in on the relevant plots and calculating the specs using the equations below.

$$T_{rise} = T_{90\%} - T_{10\%} \qquad \text{Eq 37}$$

$$T_{peak} = T_{peak_0} - T_0 \qquad \text{Eq 38}$$

$$bounds = accepted\ value \pm 2\% \qquad \text{Eq 39}$$

$$T_{set} = T_{set_0} - T_0 \qquad \text{Eq 40}$$

$$P.O. = \frac{peak\ value - accepted\ value}{accepted\ value} \times 100\% \qquad \text{Eq 41}$$

V. DISCUSSION

For this experiment, our purpose is to design an analog circuit which implements the PID system to satisfy certain performance specifications. We obtained three experimental results from MATLAB graphs, P, PI, and PID case. For the Rise time, the results of these three cases are around 0.01s. For the settling time, we found that it decreases as we go from P controller to PID controller. The settling time reduced from 0.031s to 0.018s. After that, we found the accepted value increased from P controller's 0.848V to the PID controller's 1.026V. For the peak value, it increased from 0.848V to 1.260V. Finally, we reduced the percent overshoot from 23.4% to 22.8%. The PID result is much better than PI. Table 4 is the comparison of experimental, theoretical and design specifications for labs 1 & 2. We got 0.012s rise time for PID experimental and 0.004 rise time for PID theoretical. There is only 0.008s difference between these two results and both rise times meet our design specification which must be less than 0.2s. For the settling time, our PID experimental successful meets the design specification with 0.018s settling time which is less than 0.5s. The PID theoretical settling time is 0.623s which is bigger than the design specification. After that, we find both accepted values are very close to each other. And, the PID theoretical peak value is larger than the experimental peak result. Unfortunately, we have both percent overshoots higher than the design specification’s 10% requirement. With the exception of the percent overshoot the experimental results are acceptable. The rise time and settling time meet the design specifications, and the percent overshoot is close to the design specification. Errors exist in every experiment. For the PID theoretical percent overshot, we believe it’s not reasonable. 92.5% overshot is too high. Now, we consider there are three reasons for the error. First, we 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 amplifier potentiometer was not the same for all cases. We couldn't fully tune PID before the deadline of 2 lab periods. In order to get better results, we’re going to improve our circuit for next lab.

VI. CONCLUSIONS

• After this lab, we learned how to use 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 and settling time meet the design specifications and the percent overshoot is higher than the design specifications.

• The rise time and settling time are acceptable. Although 22.8% overshot is higher than 10%, its still close to the design specification. So, the experimental percent overshoot is still acceptable.

• The experimental rise time, settling time and accepted value did agree with the experimental value. However, the experimental peak value and percent overshoot are much lower than the theoretical. Therefore, the experimental peak value and percent overshoot prove to be more reasonable than the theoretical value.

• 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
%P---------------------------------------------------------------------
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;
Cd=0;
```

```
Rp2=15027 ;
Ri=0;
Rd2=0;
kp=Rp2/Rp1;
ki=0;
kd=0;
t=0:0.01:1;
num=[kd*km kp*km ki*km];%numerator
den=[Ra*J+kt*km*kd kb*km+kt*km*kp kt*km*ki];%denominator
sys=tf(num,den);%system
y=kt*step(sys,t);
P_Contoller=stepinfo(y) %step specs
step(sys)
plot(t,y);%display graph of system
title('P controller Theory');
xlabel('Time(sec)');
ylabel('Voltage(V)');
grid on
%PI---------------------------------------------------------------------
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;
Rp2= 22034;
Ri=7041;
Rd2=0;
kp=Rp2/Rp1;
ki=1/(Ri*Ci);
kd=0;
t=0:0.001:1;
num=[kd*km kp*km ki*km];
den=[Ra*J+kt*km*kd kb*km+kt*km*kp kt*km*ki];
sys=tf(num,den);
y=kt*step(sys,t);
PI_Contoller=stepinfo(y)
figure
plot(t,y);
title('PI controller Theory');
```

```
xlabel('Time(sec)');
ylabel('Voltage(V)');
grid on
%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=3880;
Ri=3980;
Rd2=853;
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 3

1. parameters
2. You did not use this component in lab 2.

Page 4

3. of what?

Page 24

4. Need to plot the response for square wave.

Page 25

5. Plot the response of square waveform.
6. Plot the response of square waveform.

Page 27

7. Image of equations is not acceptable.

Page 28

8. Please explain the reason for the difference between theoretical and experimental results. You also need to compare the control systems in lab 1 and 2.

Page 29

9. Do not use bold in reference.

Page 30

10. You need to cite reference 8 in your text.