Stony Brook University

MEC 411 GROUP #26

Lab # 1: Digital PID Speed Control of a Turntable
Last Performed On 09/25/2019

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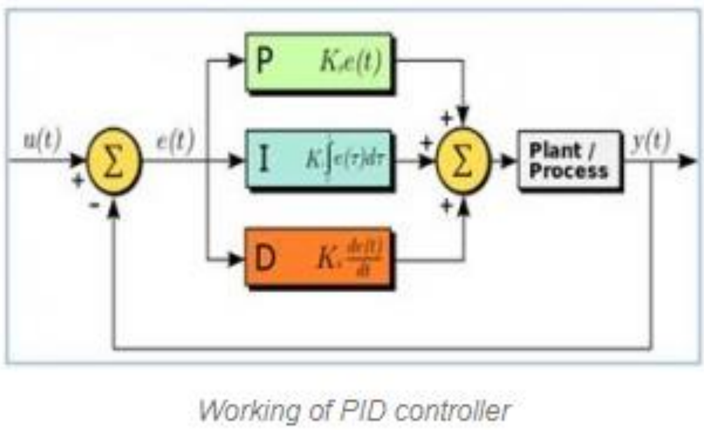
ABSTRACT

The experiment helps to understand the Digital PID Speed Control of a Turntable. In particular, the PID controller is connected to Data Acquisition (DAQ) interface in order to get several performance outcomes. The theoretical findings using Matlab software are then compared to the experimental data gathered during the experiment. [1] PID control circuit was designed and modified using software in order to get percentages overshoot less than 10 percent, settling time to be within 2 percent of the final value which was to be less than 500ms and finally rise time to be less than 200ms. During the first stage of the experiment, a complete circuit was built as per the requirements and a DC motor was attached to it along with the function generator and DAQ system. The next stage was to set the K_C , T_i, T_d, values in the computer to get the required results. The K_C , T_i, T_d, values were recorded as 11.2, 0.0002, and 1E-7 respectively. For each setting, data was recorded for about 10 seconds and converted into an excel file to get a graph. This data was used to do the comparison and data analysis with the theoretical data obtained using MATLAB. From the graphs the experimental rise time, settling time, and percent overshoot for the final PID controller are 0.006s, 0.184s, and 4.2% and are well within the design specifications, signifying the success of the experiment.

I. INTRODUCTION

PID controllers are known as proportional integral derivative controllers. They have the mechanism of control loop feedback and have an accurate outcome as a controller. [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.



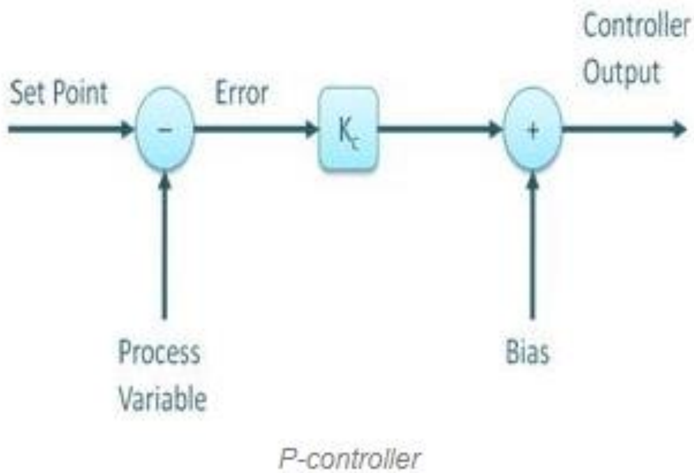
[3]**Fig.1.** PID controller block diagram

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

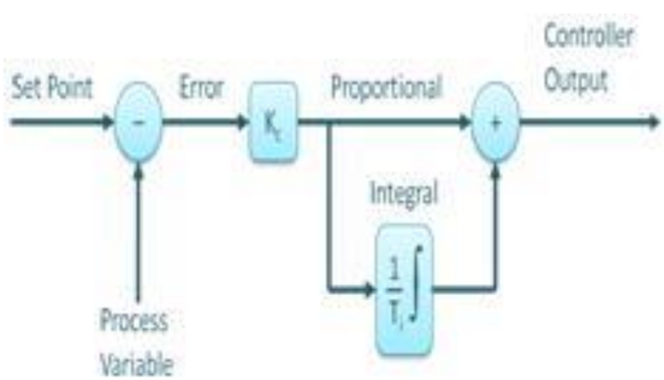
stability but it can never have the steady state circumstances. The output is maintained by adjusting the Kc value.



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

I-Controller

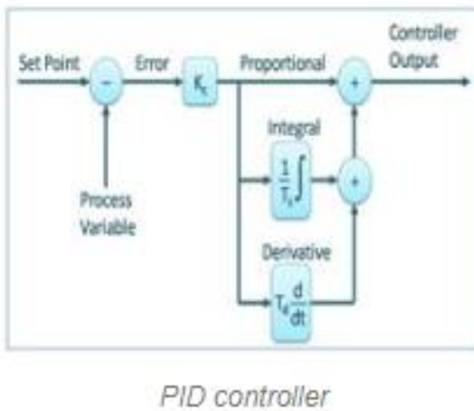
There comes a point where P-controller is restricted and then I-Controller plays its part there to get the work done.[3] It helps to narrow down the value of error to zero over a period of time while integrating it and helps to bring down the steady state error. Hence the error becomes zero due to I-controller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

$$u(t) = k_p e(t) + k_i \int_0^t e(\tau)\, d\tau + k_d \frac{de}{dt}, \qquad \text{Eq 1}$$

[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.

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

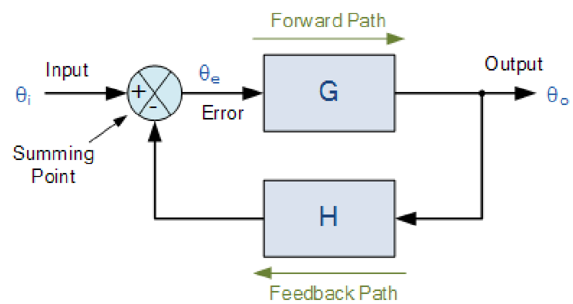
Eq 2

[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.

$$T(s) = \frac{Y(s)}{R(s)}$$ 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.

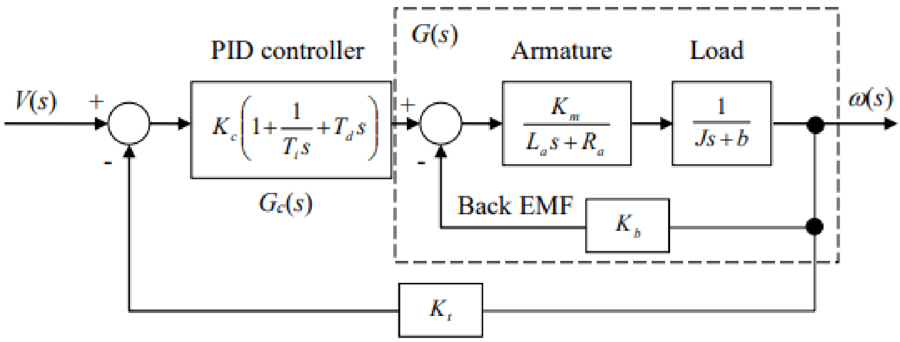
$$Y(s) = R(s) * G(s)$$ Eq 4

R(s) - Y(s) * H(s) Eq 5

$$T(s) = \frac{Y(s)}{R(s)} = \frac{G(s)}{1+H(s)*G(s)}$$ 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 its taken back as feedback to G(s) or to the K_T where it reaches back to the input as feedback.



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

$$T(s) = \frac{\omega(s)}{V(s)} = \frac{G_c(s)G(s)}{1+K_t G_c(s)G(s)}$$ Eq 7

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

$$G_c(s) = K_c\left(1+\frac{1}{T_i s}+T_d s\right)$$ Eq 9

IV. EXPERIMENTAL PROCEDURE

- Firstly, check all the components and materials to be needed along with their data sheet in order to successfully complete the experiment.

- Now using the proposed circuit diagram, build the circuit carefully to have a turntable speed PID control complete circuit as shown below in Fig. X
- After the circuit is ready, connect the DC motor to the circuit.
- Then connect the National Instrument Multifunction DAQ system to the circuit.
- Connect the function generator with a square wave and set the frequency to 1Hz and amplitude of 1V.
- Make sure to connect the power supply to the circuit with ±12V.
- Once everything is ready as shown in Fig. X, open the software and set the integration time described as T_i to zero whereas put the derivative time T_d to zero as well and use trial and error method to get results for the experiment.
- Now K_c can be adjusted to change the turntable output speed and the feedback control with P controller is given and here K_c is to keep the system maintained while bringing the output speed closer to the input. Then record the data for 10 seconds and save it as an excel file.
- In order to control the system using PI controller, K_c and T_i values can be adjusted while keeping the T_d at zero and repeat the same process to get the data for PI controller.
- To make the circuit controller PID, none of the values are to be set as zero. K_c, T_i and T_d are adjusted to get the required results as close as they could get while the system remains stable.

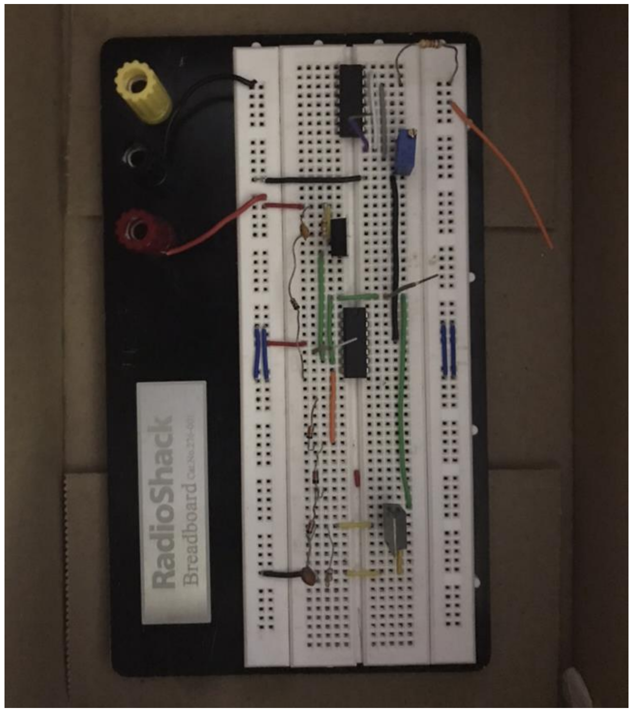


Fig.7. Proposed PID controller circuit

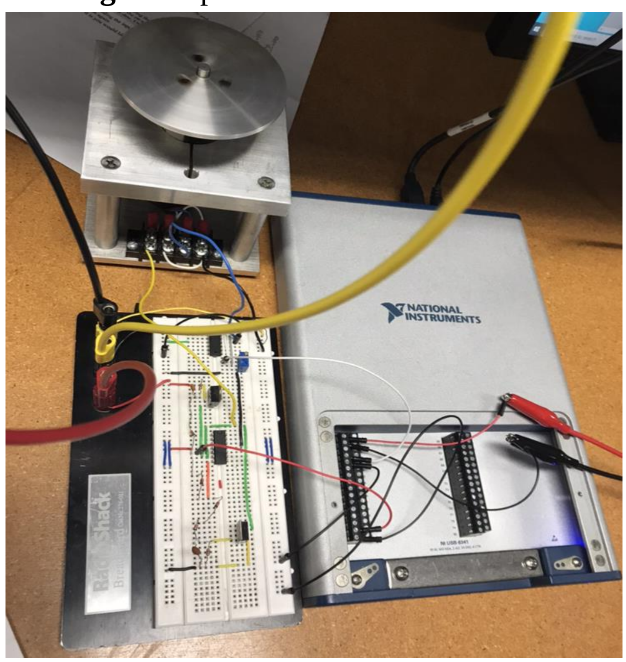


Fig.8. Proposed PID controller circuit connected to DC motor and DAQ system

IV. RESULTS

The experimental data for P, PI, and PID controller were recorded using LabView software once relative parameters K_c,T_i, and T_d were determined. The theoretical results were obtained using simulink in matlab to create the block diagram, seen in Figure 9, from the lab to simulate the theoretical output. A combination of the input, experimental output, and theoretical output can be seen in Figure's 10 to 12 for P, PI, and PID cases. Table 1 gives the recorded parameters for the PID controller.

Table 1. Recorded Parameters of PID controller

K_c	T_i	T_d
11.2	0.0002	1E-7

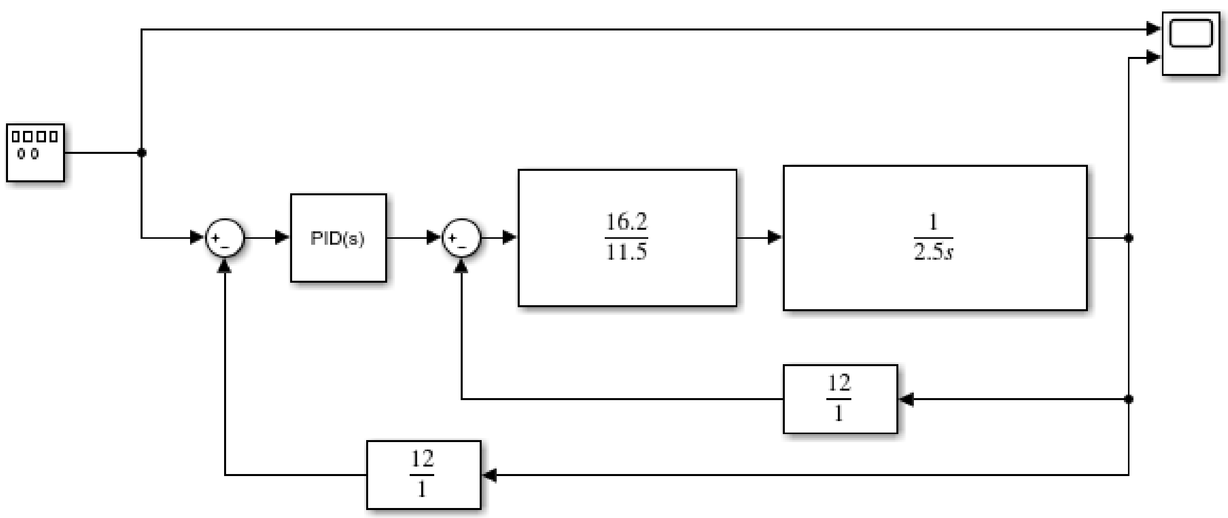


Fig. 9. Simulink Block Diagram

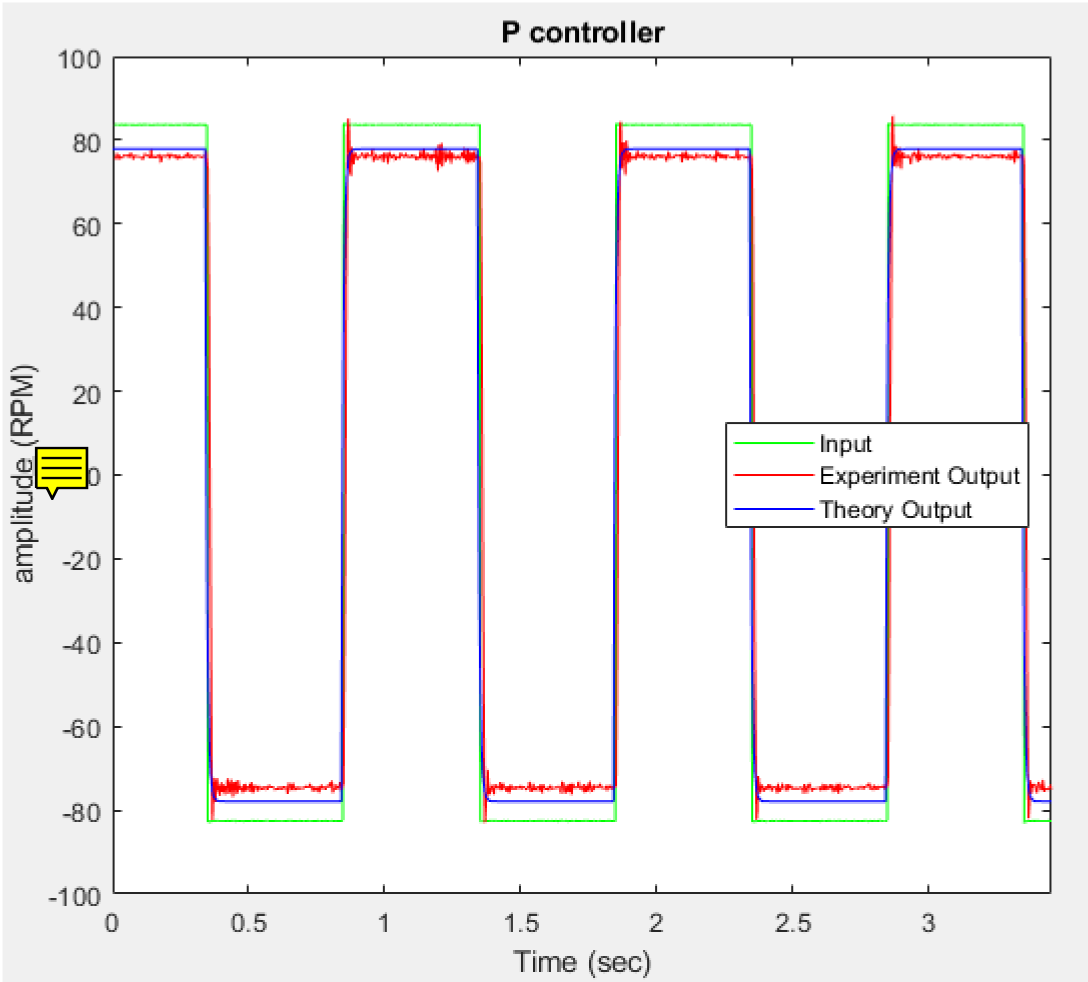


Fig. 10. P controller graph

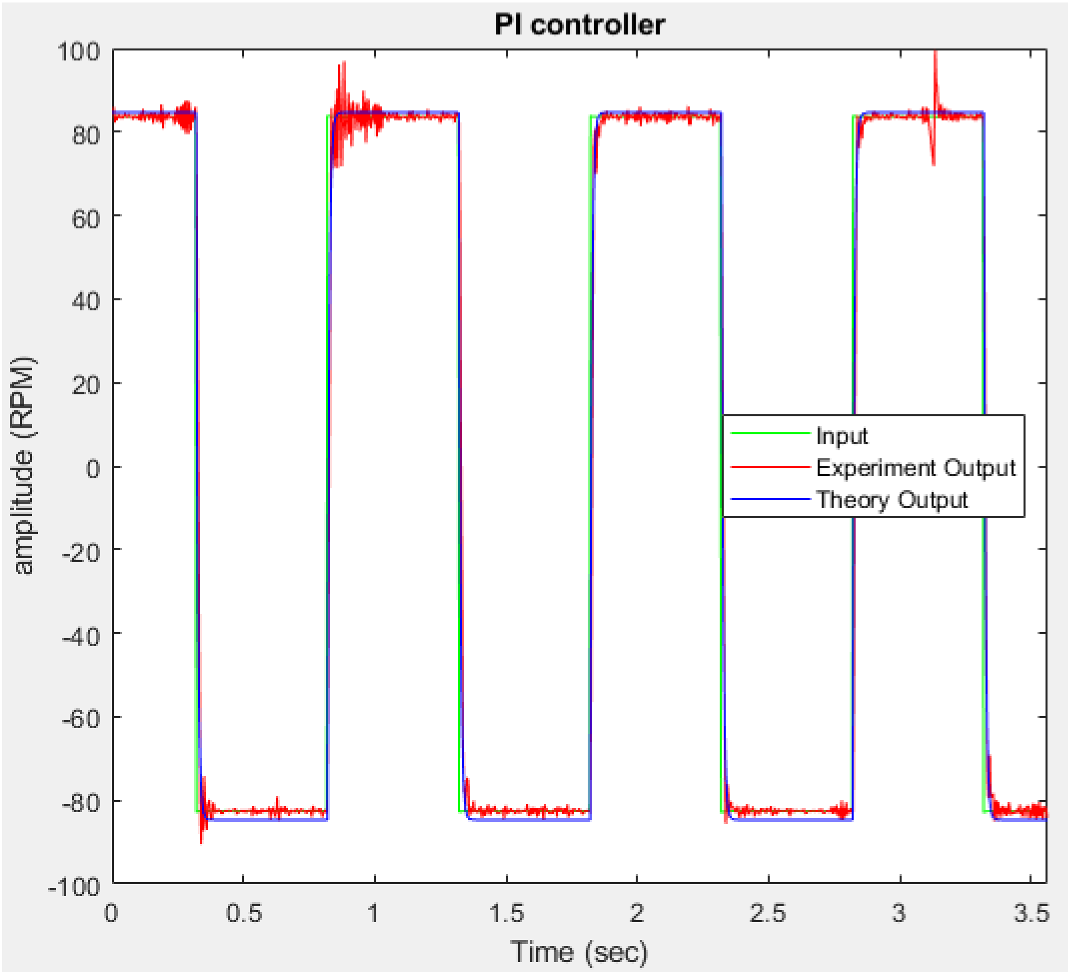


Fig. 11. PI controller graph

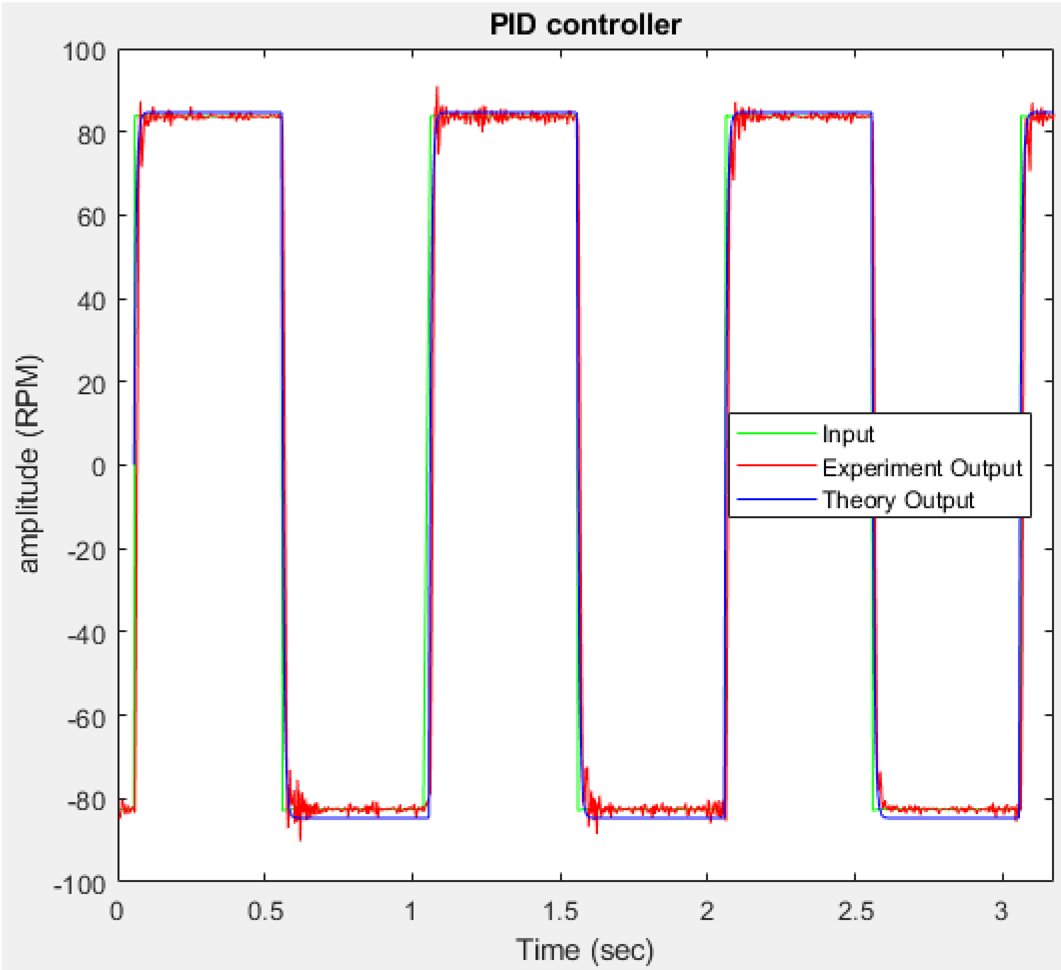


Fig. 12. PID controller graph

The first full step of the graphs are used to determine the results for P, PI, and PID case respectively. In matlab it is possible to zoom in on the graph and determine points to a certain decimal place, which is useful for determining the rise time, settling time, peak time, peak value, and accepted value. First, the final value is found from the graph. Next the rise time is found by calculating the 10-90% amplitudes and finding the times these occur at. The rise time is then calculated as the difference between these values. Now the peak and peak time are found at the highest point in the step. The settling time is determined by calculating the tolerance bounds based on the accepted value. When the output first enters this tolerance without leaving is the settling time. The percent overshoot is calculated using the percent error. Below is a summary of the equations used and Tables 2 to 4 show the results of experimental and theoretical data as well as a comparison for PID controller.

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

$$T_{peak} = T_{peak_0} - T_0 \qquad \text{Eq 11}$$

$$bounds = accepted\ value\ \pm 2\% \qquad \text{Eq 12}$$

$$T_{set} = T_{set_0} - T_0 \qquad \text{Eq 13}$$

$$P.O. = \frac{peak\ value - accepted\ value}{accepted\ value} \times 100\% \qquad \text{Eq 14}$$

Table 2. Experimental Results obtained from matlab graphs

Experimental	P controller	PI controller	PID controller
Rise Time(s)	0.005	0.006	0.006
Settling Time(s)	0.045	0.059	0.184
Accepted Value(RPM)	76.2	82.6	83.8
Peak Value(RPM)	85.1	90.5	87.3
Peak Time(s)	0.010	0.011	0.012
Percent Overshoot(%)	11.7%	9.56%	4.2%

Table 3. Theoretical Values obtained from matlab graphs

Theoretical	P controller	PI controller	PID controller
Rise Time(s)	0.014	0.015	0.015
Settling Time(s)	0.025	0.080	0.094
Accepted Value(RPM)	77.9	84.7	84.7
Peak Value(RPM)	77.9	84.7	84.7
Peak Time(s)	0.025	0.08	0.094
Percent Overshoot(%)	0%	0%	0%

Table 4. Comparison of experimental, theoretical, and design specifications

	PID experimental	PID theoretical	Design Specs.
Rise Time(s)	0.006	0.015	≤0.2
Settling Time(s)	0.184	0.094	≤0.5
Accepted Value(RPM)	83.8	84.7	-
Peak Value(RPM)	87.3	84.7	-
Peak Time(s)	0.012	0.094	-
Percent Overshoot(%)	4.2%	0%	≤10%

V. DISCUSSION

For this experiment, our purpose is making the PID turntable speed control system which satisfies certain performance specifications. Base on the design specifications, we see the percentage overshoot is to be less than 10%, the settling time is to be less than 500ms, and the rise time is to be less than 200ms. Comparing the theoretical results and the experimental results in Table 4, both values are very close. The final PID controller only has 0.009s difference in rising time compared with the theoretical result which is meaning the rise time is less than 200ms. Comparing with the settling times, we get 0.184s for experimental values and 0.094s for theoretical values. That means there is only 0.09s difference, and the difference in settling time is less than 500ms. After that, we find the accepted experimental rotational speed equals to 83.8 RPM, and the peak equals to 87.3 RPM. The calculated percent overshoot is 4.2% which is less than 10%. And, the values are very close to the theoretical value which is 84.7 RPM. Finally, we find the experimental peak time equals 0.012s, only 0.082s difference by comparing with the theoretical value. According to Figure 12, we can see our experiment output (Red) almost matches the theory output (Blue). Therefore, the experimental results agree with the theoretical model. And, this experimental results are successfully meeting all the design specifications. There may have been some errors during the lab experiment cause the experimental results can't perfectly match theoretical values. The lab equipment is old which causes unstable or imprecise power supply, or resistance amount. The circuit is not built perfectly and may have bad connections. For the improvement, we would like to check all the equipment before the experiment and double-check the circuit before data collecting.

VII. CONCLUSIONS

- Based on Table 4, it is easy to see the difference between the experimental values and theoretical val and both values were close to each other.
- The relevant values were found to be acceptable.
- The experimental results did agree with the theoretical results.
- The discrepancy is attributed to the equipment aging and the uncertainty of the equipment or circuit connection setup. We used reversed direction for the resistor and had a short circuit in our first circuit draft. After debugging, we fixed the issue and realized the Emitter to Collector connection must be E to E.
- In future investigations, the equipment should be double-checked and adjusted before the experiment.

IIX. REFERENCES

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2. **OMEGA Engineering. (n.d.). Retrieved October 1, 2019, from https://www.omega.co.uk/prodinfo/pid-controllers.html.**
3. **Shaheen, W., Agarwal, T., Shaheen, W., Agarwal, T., Prasanna, J., Agarwal, T., … Kali, H. (2018, November 10). How Does a PID Controller Work? - Structure & Tuning Methods. Retrieved October 1, 2019, from https://www.elprocus.com/the-working-of-a-pid-controller/.**
4. **Honeywell D. (2000). Chapter 10 PID Control. Retrieved October 1, 2019, from http://www.cds.caltech.edu/~murray/books/AM08/pdf/am06-pid_16Sep06.pdf**
5. **Closed-loop System and Closed-loop Control Systems. (2018, March 4). Retrieved October 1, 2019, from https://www.electronics-tutorials.ws/systems/closed-loop-system.html.**

IX. APPENDIX A

MATLAB code for graphs

```
close all;
clear;
clc;
%MEC411 code for graphs
filenameP='MEC_411_Group26_Lab1_P_Data';
filenamePI='MEC_411_Group26_Lab1_PI_Data';
filenamePID='MEC_411_Group26_Lab1_PID_Data';
%data starts at row 23
%columns:
% 1:time
% 2:input
% 3:experimental output
% 6:theoretical output
% 7:theoretical time
P=xlsread(filenameP);
PI=xlsread(filenamePI);
PID=xlsread(filenamePID);
%graphs
%P
   T=P(23:end,1);%time
   IN=P(23:end,2);%input
   EX=P(23:end,3);%exp. output
   Th=P(23:end,6);%the. output
   ThT=P(23:end,7);%the. time
figure
plot(T,IN,'g',T,EX,'r',ThT,Th,'b')
```

```
axis([0 10 -100 100])
title('P controller');
ylabel('amplitude (RPM)');
xlabel('Time (sec)');
legend('Input','Experiment Output','Theory Output','Location','east')
%PI
   T=PI(23:end,1);%time
   IN=PI(23:end,2);%input
   EX=PI(23:end,3);%exp. output
   Th=PI(23:end,6);%the. output
   ThT=PI(23:end,7);%the. time
figure
plot(T,IN,'g',T,EX,'r',ThT,Th,'b')
axis([0 10 -100 100])
title('PI controller');
ylabel('amplitude (RPM)');
xlabel('Time (sec)');
legend('Input','Experiment Output','Theory Output','Location','east')
%PID
   T=PID(23:end,1);%time
   IN=PID(23:end,2);%input
   EX=PID(23:end,3);%exp. output
   Th=PID(23:end,6);%the. output
   ThT=PID(23:end,7);%the. time
figure
plot(T,IN,'g',T,EX,'r',ThT,Th,'b')
axis([0 10 -100 100])
title('PID controller');
ylabel('amplitude (RPM)');
xlabel('Time (sec)');
legend('Input','Experiment Output','Theory Output','Location','east')
%----------------------------------------------------------------------%
```

Comment Summary

Page 6

1. Please use proper ratio for figures.

Page 8

2. Do not paste the figure for equations.
3. Please present the calculation for the potentiometer resistance.
4. You need to show the derivation of the system TF in expanded form.
5. You need to provide a list of equipments used.

Page 11

6. You are to show parameters for P and PI controller as well.

Page 12

7. Amplitude of what?

Page 17

8. What is the relevant value? Please be more specific.