California State Polytechnic University | Pomona

Electrical and Computer Engineering Department

Control System Laboratory

ECE 3709L

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DC Motor Control | Final Report

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Date:
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1.0 Objective

The objective of this lab was to acquire an understanding of control systems engineering through experience with design, testing, and model implementation.

2.0 Procedure

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2. Wiring schematic and circuit assembly. (Appendix B)
3. Software Setup. (Appendix C)
4. Performance of TE Tuning Method. (Appendix D)
5. Development of a mathematical model of the system. (Appendix E)
6. Frequency Response Analysis (SISO). (Appendix F)
7. Automation of Matlab analysis (script). (Appendix G)
8. PID Tuner Design using Matlab. (Appendix H).
9. Load execution. (Appendix I)
10. Analysis performance with load with consideration and application of previous procedures. (Appendix J)

3.0 Summary & Conclusion

The controller performed adequately, sustaining most of the load in both direction with the original K_I and K_P parameters that were supplied to the LabView module. However, the response for the downward direction was inadvertently to fast given that gravity is a much bigger factor in this direction adding to the speed at which the elevator would travel. Therefore, to compensate we applied a higher integral gain allowing the aggressive nature of the response downward to formulate into a recognizable smooth curve within the given timing constraints. This obstacle and the fact that weight of the quarters was not evenly distributed throughout the platform are both major factors affecting the ultimate result of the whole elevator. In this regard, the first tuning method proved to be the most practical as it allowed for a seamless transition into more suitable parameters for the load system. Some of the tools that we learned in the earlier weeks, specifically the application of Matlab in analysis of the final product, were applied seamlessly now that we had knowledge of what to search for as well as how to manipulate the built-in PID tuner.

Appendix A: Block Diagram

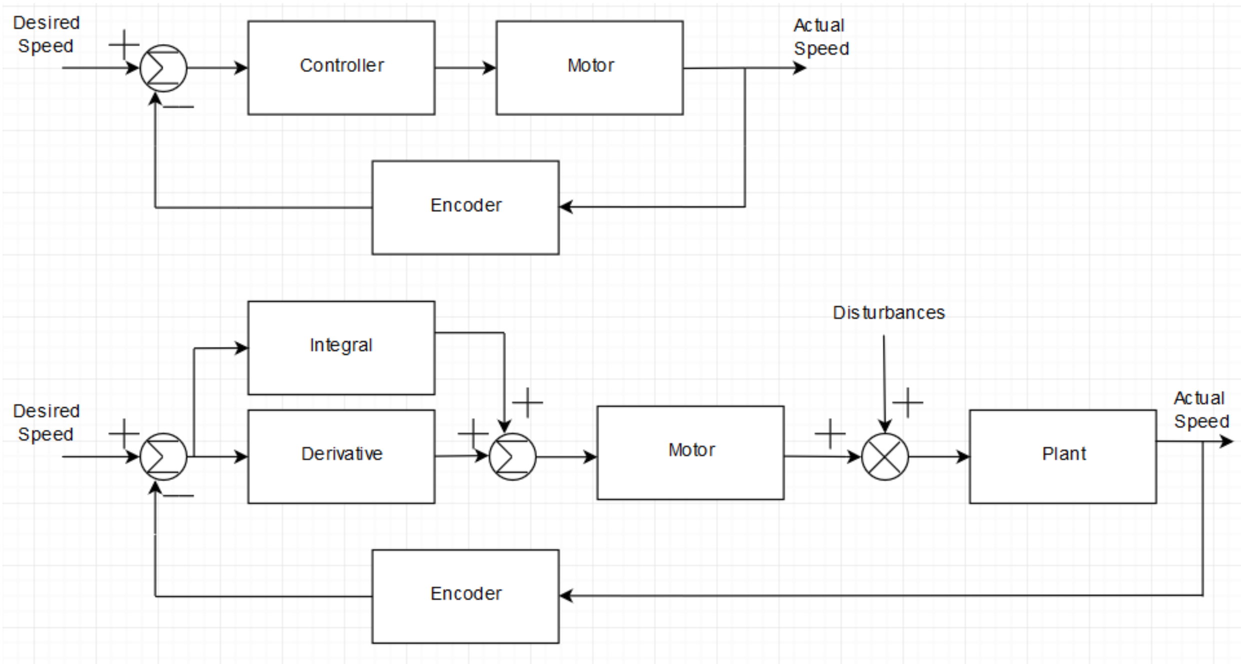

Figure A1

Appendix B: Wiring Schematic and Circuit Assembly

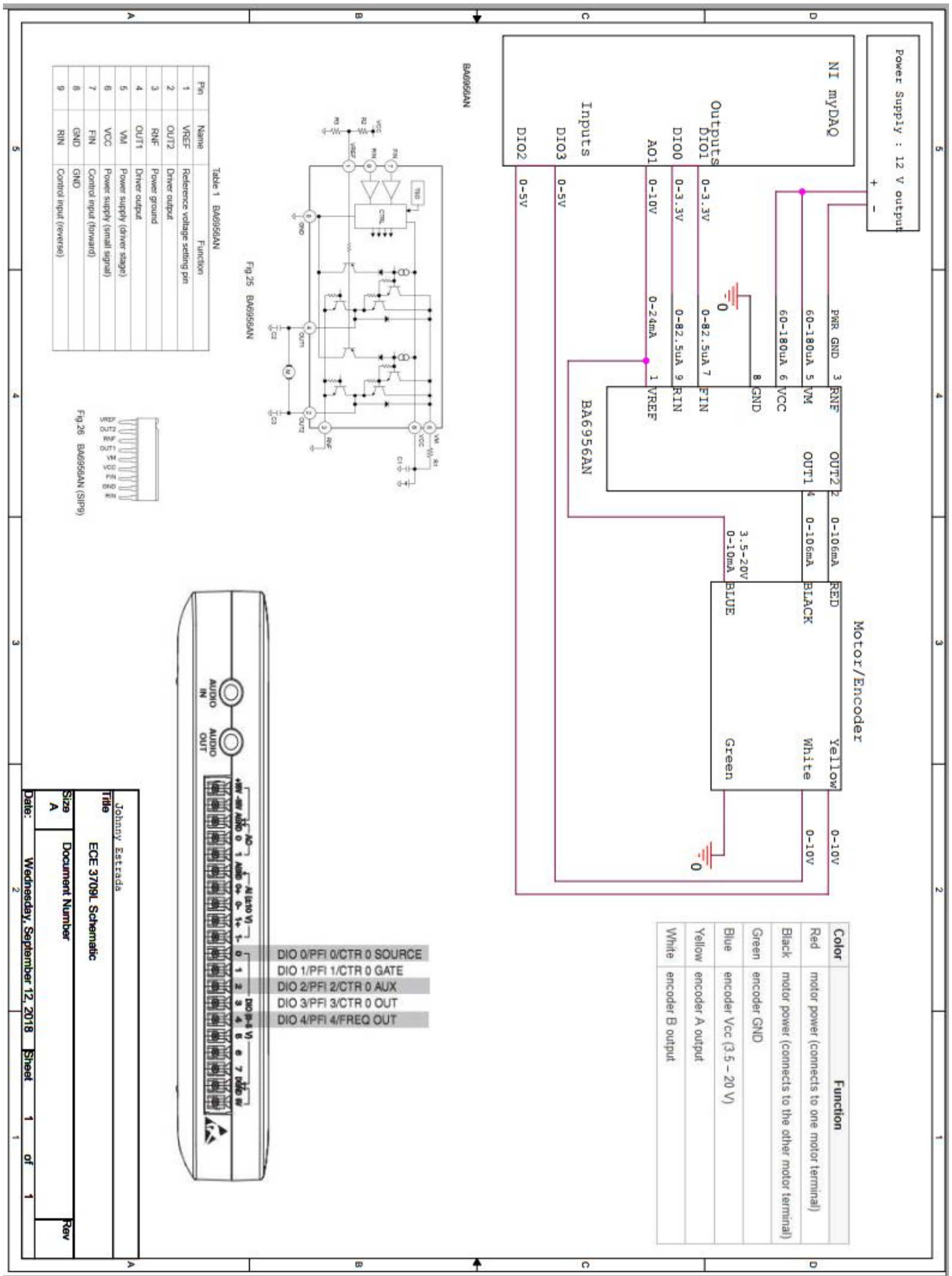

Figure B1

Appendix B Continued

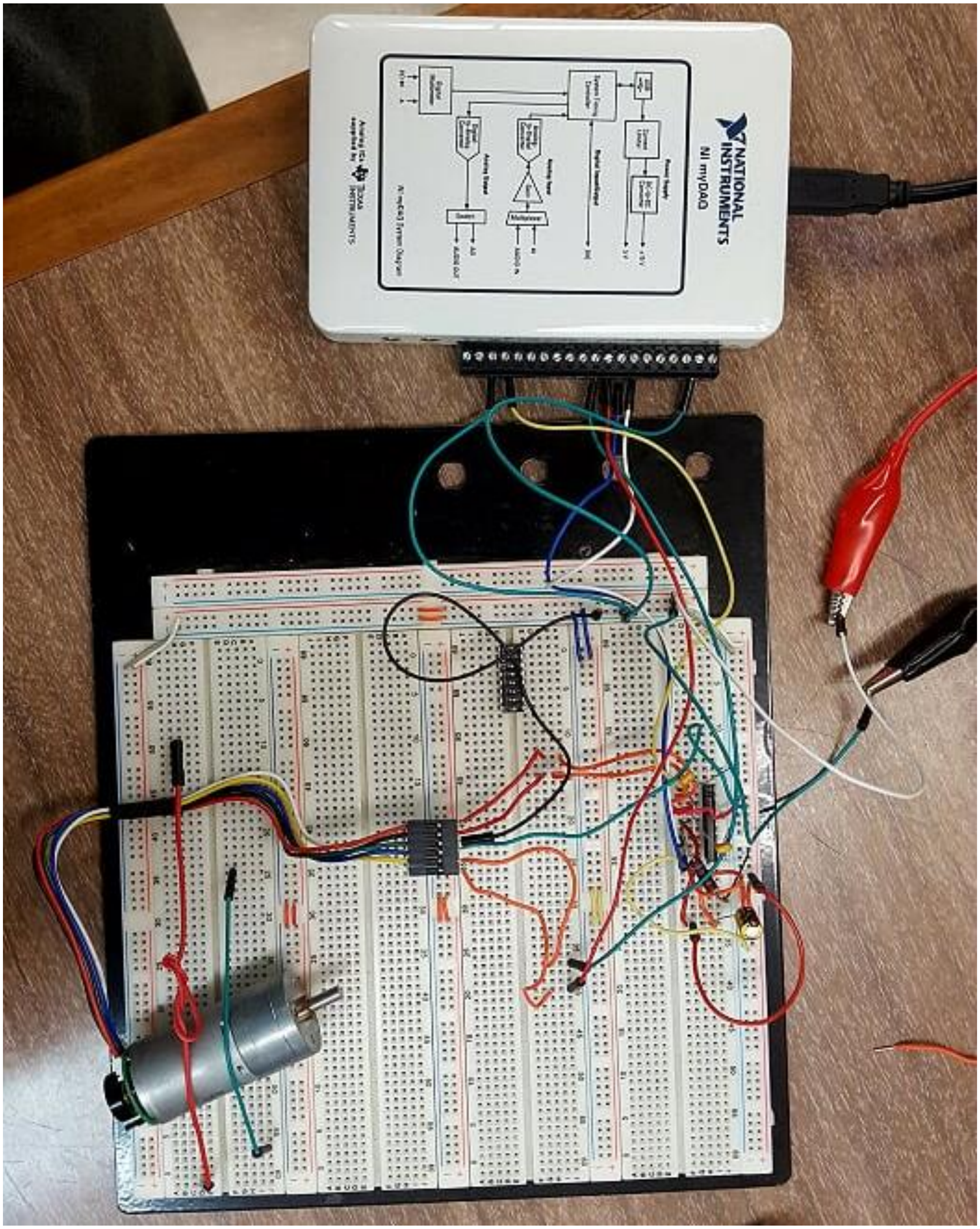

Figure B2

Appendix C: Software Setup

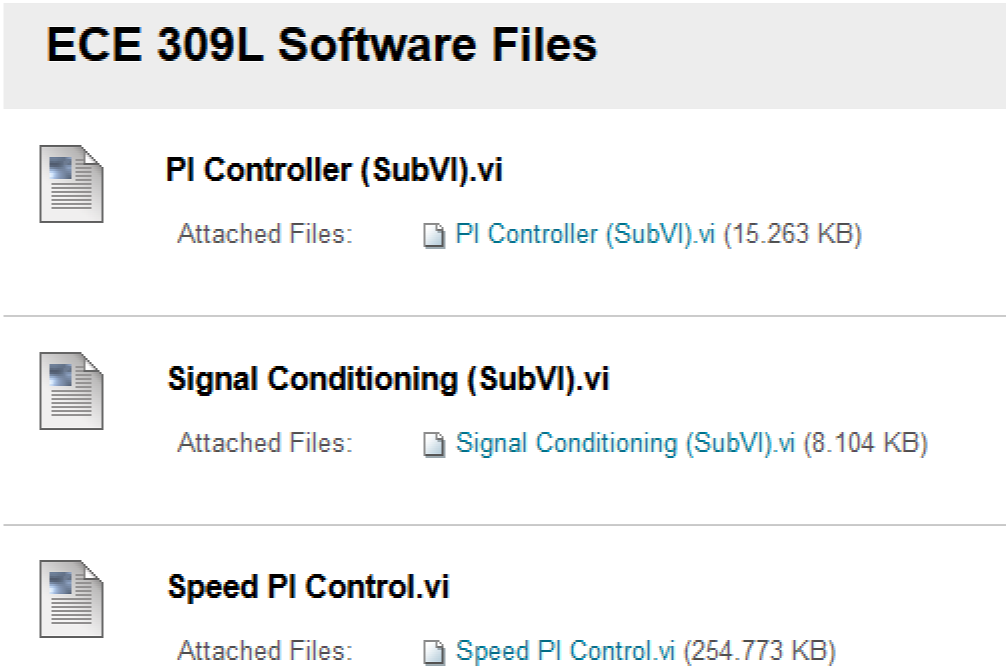

Figure C1

Files used for the initial setup of the LabView software that is used for the project: the first two files are supporting modules for the overall driving file Speed PI Control. Putting these files in the same directory so that the program knows where to the main and supporting files. The naming of said files also will cause issues. After this is done opening the files will open the following windows:

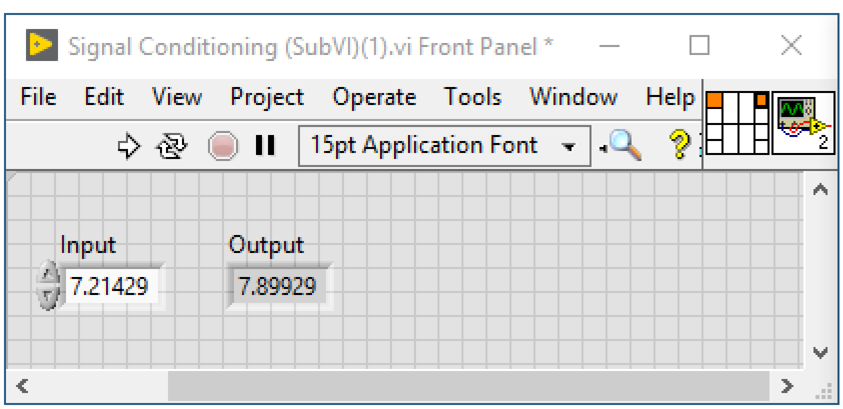

Figure C2

Appendix C Continued

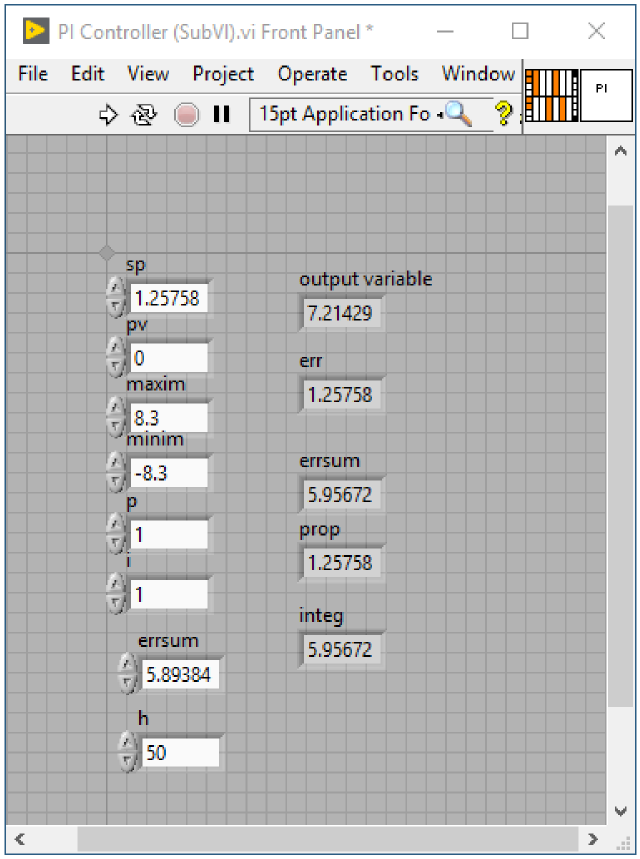

Figure C3

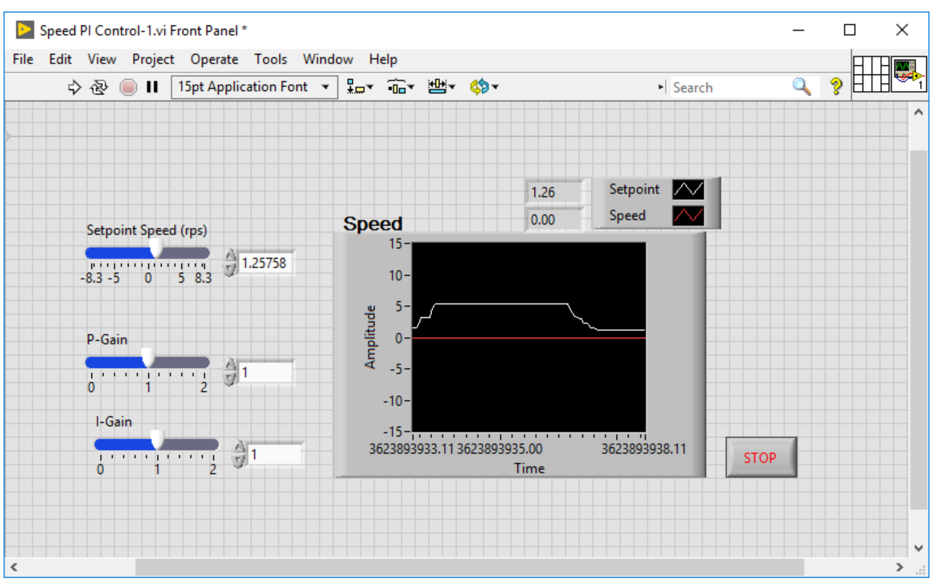

Figure C4

Appendix D: TE Tuning Method

In this tuning method we are tracking the response of the motor in real time. This allows us to tune the motor in a manner that enables us to pinpoint an optimal response for a given set of PID parameters. In this case P-Gain and I-Gain are adjusted to get a response that suits the designer's constraints, in our case a decent rise time and settling time.

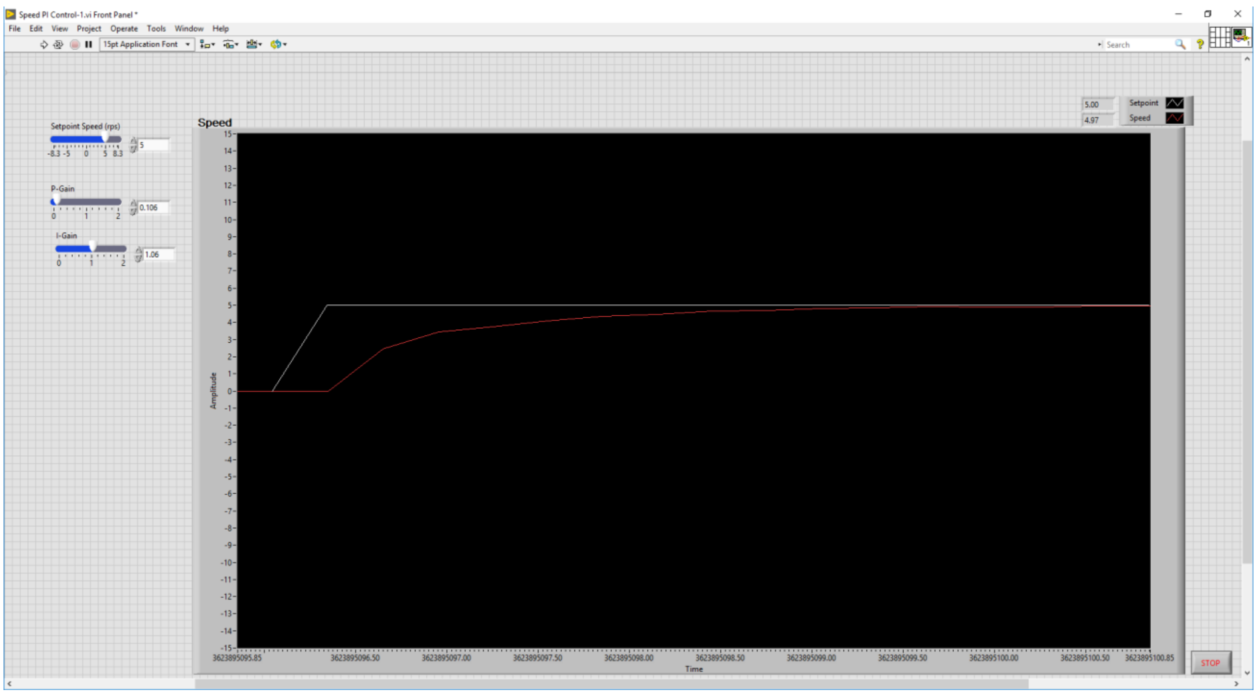

Figure D1

The sampling rate and the gear ratio are adjusted accordingly. A higher sampling rate will yield a smoother response as the system is able to take more data and therefore adjust in a more controlled manner. Increasing the P-Gain will yield a faster rise time. Increasing the I-Gain will adjust how fast this system approaches zero error, this effect therefore elongates the amount of time it takes to reach that set point. Once the motor is adjusting or responding in the preferred manner take down the parameters for the P and I gain.

Appendix E: The Mathematical Model

The system model was derived from the mathematical equations describing the voltage V applied and the rotational speed of the shaft Θ ("DC Motor Speed: System Modeling", 2018).

Using this knowledge, a transfer function was developed with the given variables in mind:

(J)	moment of inertia of the rotor	0.01 $kg * m$^2
(b)	motor viscous friction constant	0.1 $N * m * s$
(K_E)	electromotive force constant	0.01 $V / rad / sec$
(K_T)	motor torque constant	0.01 $N * m / Amp$
(R)	electric resistance	1 ohm
(L)	electric inductance	0.5 H

Table E1

Transfer Function Model

$$P(s) = \frac{\dot{\Theta}(s)}{V(s)} = \frac{K}{(Js+b)(Ls+R)+K^2} \qquad [\frac{rad/sec}{V}] \tag{1}$$

Appendix F: Frequency Response Analysis

For the frequency response analysis, we perform the analysis on an open-loop system using equation (1). This in turn will allow us to see how the closed loop system will behave. Considering things like gain and phase margin will allow us to see the type of play we have for stability. The Open Loop frequency response also has a good indication of how the close loop transient response will behave with respect to the response speed and the percent overshoot.

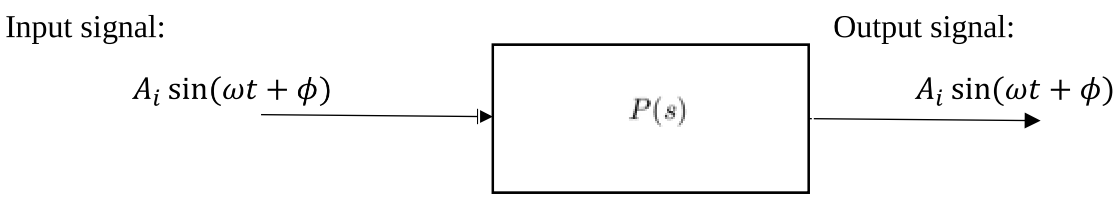

Figure F1

For the analysis MATLAB was used, the code has been omitted for now. Essentially it makes the transfer function and proportional gain was added to the system to bring it over the 0-dB line, this in turn would allow for a margin to be seen readily. The target phase margin was ~ 60 degrees. With these two parameters and a whole arsenal of Bode Plots to analyze, close loop transient response can easily be made. In this case a phase margin of 59.2 deg and a gain margin of 70 dB . We can also gather the bandwith from here as the conditions for this are satisfied as well. Data will have to be inspected.

Appendix F Continued

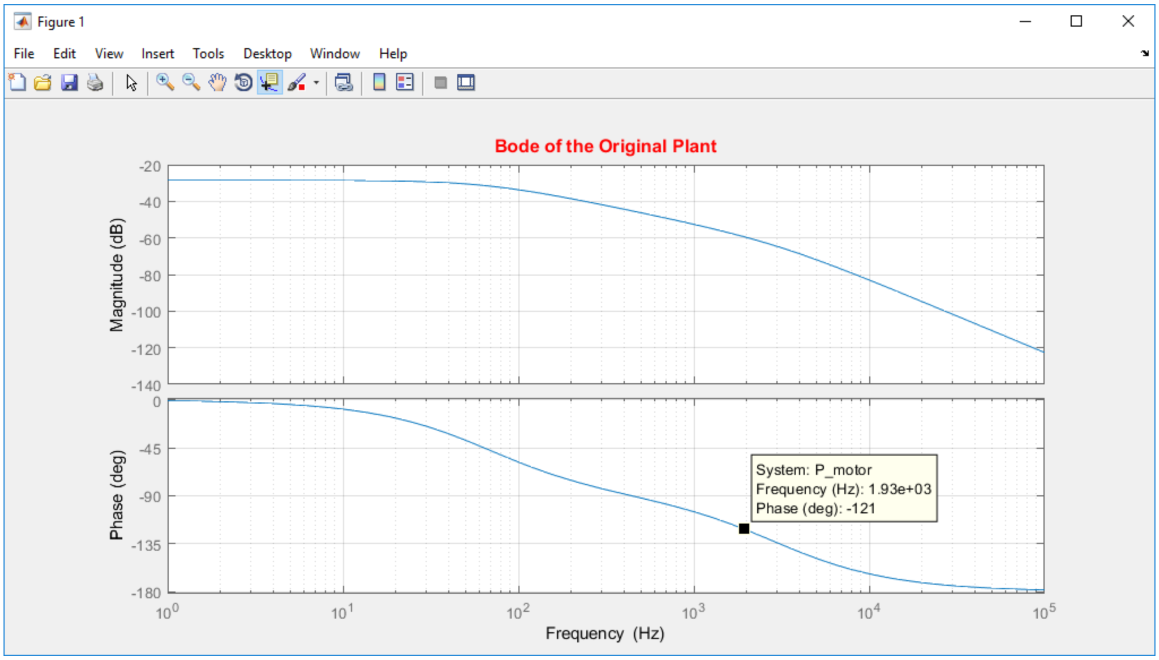

Figure F2

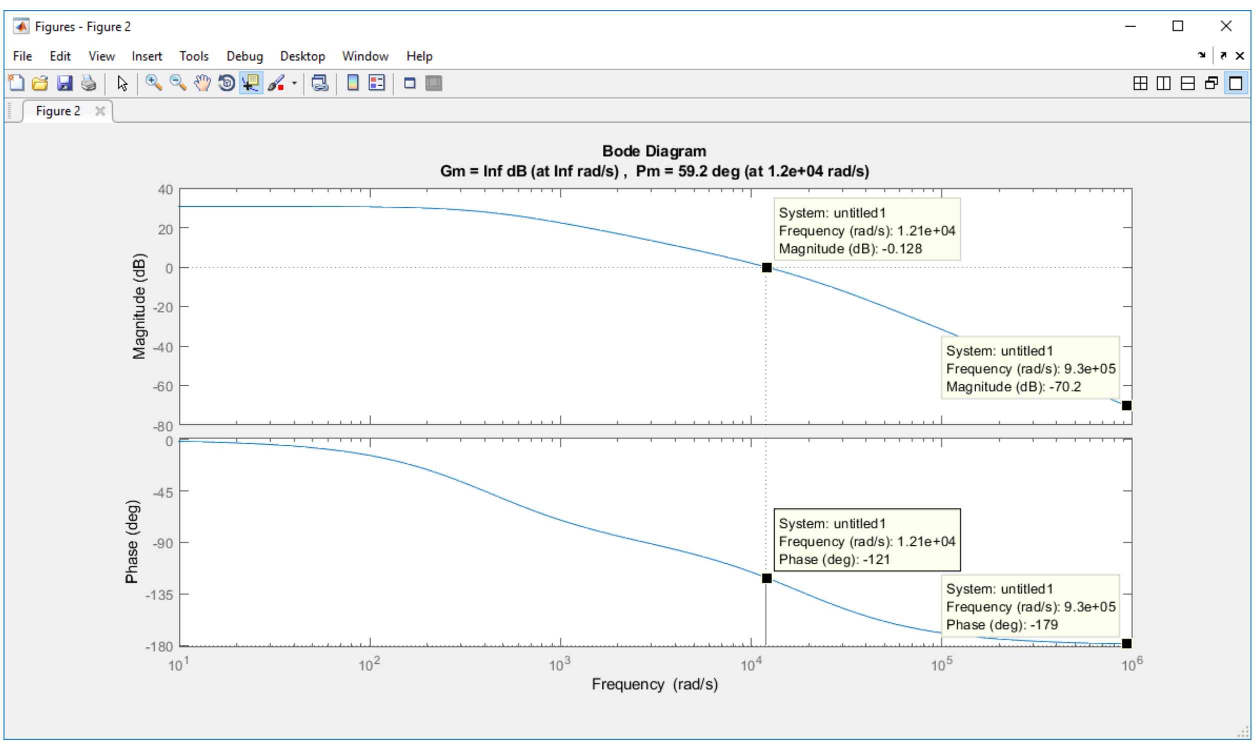

Figure F3

Appendix G: Automation of Matlab

```
%setup transfer function definition
J = 2.5277e-6;
b = .047;
Kt = .015; %using the assumption that Kt = Ke
Ke = .0214;
R = 8.5;
L  =
20.4e-3; s
= tf('s');
P_motor = Ke/((J*s+b)*(L*s+R)+Ke^2);

%Setup options for bode plot
opts = bodeoptions('cstprefs');
opts.FreqUnits = 'Hz';
opts.Grid = 'on';
opts.Title.String = 'Bode of the Original Plant';
opts.Title.Color = [1 0 0];
opts.Title.FontSize = 12;

%Open-Loop plant transfer function Bode Plot
figure(1);
bode(P_motor,opts);
%Raising the system so that it can have a crossover frequency %chosen
frequency %  %was arbitrary as there was no target phase margin
[mag, phase, w] = bode(P_motor, 100);

%exact phase margin for gain crossover f of 100
ph_marg = 180 + phase;
%exact magnitude at crossover f
exact_mag = 20*log10(mag);
%exact magnitude is my P-Gain in dB or P-Gain of 1/.0079 = 126.58 will

%yield an open-loop gain of 1 at f cross
%proportional gain C is 1 divided the magnitude of processed magnitude
C = 1/mag;
figure(2);
margin(C*P_motor);

%saving the new system
withG = (C*P_motor);

%PID Tuner setup with a baseline reference of shifted system
Tune = pidtune(C*P_motor,'PI'); pidTuner(C*P_motor, Tune);
```

Appendix G Continued

The following Matlab script code was produced through the two different weeks we went over frequency response analysis, this made it possible to reproduce most of the work covered in those weeks and some in the previous weeks. This also enabled us to easily refer back to previous results and compare the new data with old, were we could gather some insight. We also noticed that our model would reach closer values when we performed the tuning in Matlab with consideration to a crossover frequency. Another great thing about this was the fact that we could now look at any other parameters for our transfer function and see the direct effect of that change. For example, when the magnitude of the dominant pole in the function was brought closer to the imaginary axis the phase change would increase to a range of 0 to 180 and would show the characteristics of a two-pole system, very different with the final function.

Appendix H: Matlab PID Tuner

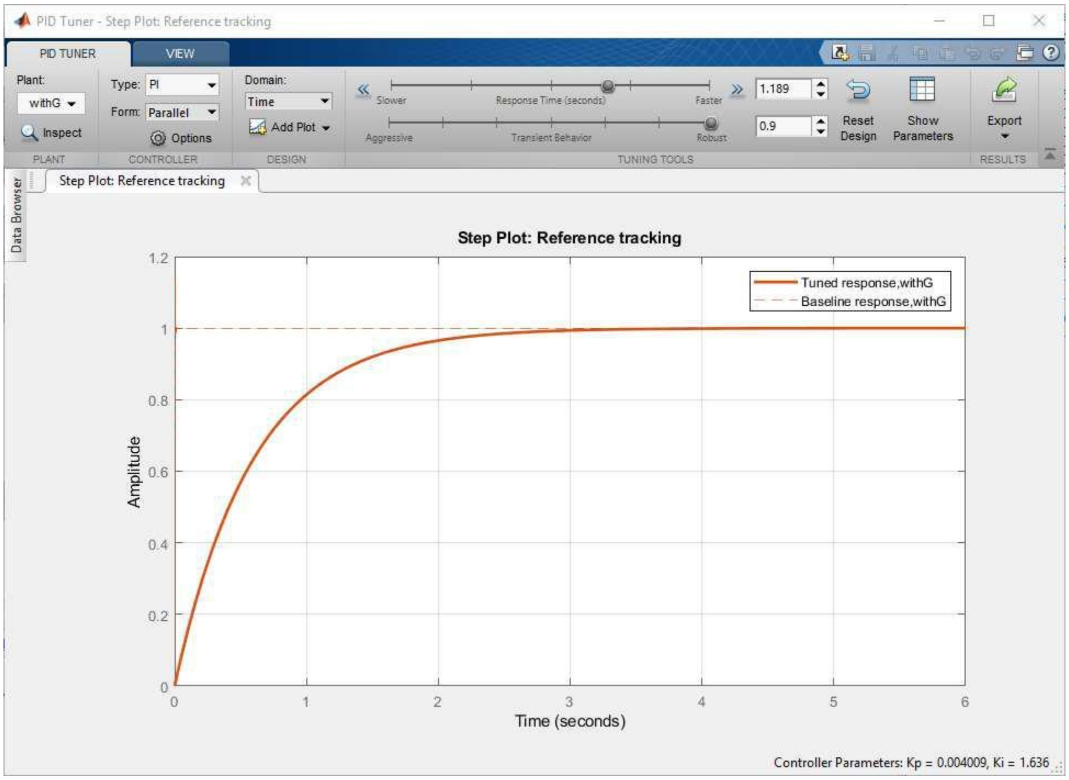

Figure H1

Controller Parameters

	Tuned	Baseline
Kp	0.0040091	1.0888
Ki	1.6357	1246.7789
Kd	n/a	n/a
Tf	n/a	n/a

Performance and Robustness

	Tuned	Baseline
Rise time	1.31 seconds	0.00189 seconds
Settling time	2.33 seconds	0.00708 seconds
Overshoot	0 %	13.5 %
Peak	1	1.13
Gain margin	Inf dB @ Inf rad/s	Inf dB @ Inf rad/s
Phase margin	90 deg @ 1.68 rad/s	60 deg @ 746 rad/s
Closed-loop stability	Stable	Stable

Figure H2

Appendix H Continued

When using the PID Tuner we found that there were two different implementations of the PID, parallel and standard form. These different implementations differ in how the variables are processed for the controller. However, in our case there was no real discrepancy in the different methods. What did affect the tuner was the plant that was being tuned, when we tuned the plant that had no crossover frequency, we got KI and KP that were simply too large, hence the importing and tuning of the model with crossover frequency. This was our solution to that hurdle, and it worked out well as the values extracted from Matlab were very close to the values in the TE Tuning method. The real time analysis is shown in Figure H3 and the corresponding data as well.

Appendix H Continued

Time (sec)	Time - Setpoint	Amplitude - Setpoint	Amplitude - Speed
0.340	3625149972	2	0.971
0.540	3625149973	2	1.2623
0.740	3625149973	2	1.4565
0.940	3625149973	2	1.60215
1.140	3625149973	2	1.7478
1.340	3625149973	2	1.8449
1.540	3625149974	2	1.89345
1.740	3625149974	2	1.942
1.940	3625149974	2	1.89345
2.140	3625149974	2	1.99055
2.340	3625149974	2	1.99055
2.540	3625149975	2	1.99055
2.740	3625149975	2	1.99055
2.940	3625149975	2	1.99055
3.140	3625149975	2	1.99055
3.340	3625149975	2	1.99055
3.540	3625149976	2	1.99055
3.740	3625149976	2	1.99055
3.940	3625149976	2	2.0391
4.140	3625149976	2	1.99055
4.340	3625149976	2	1.99055
4.540	3625149977	2	1.99055
4.740	3625149977	2	1.99055
4.940	3625149977	2	2.0391

Table H1

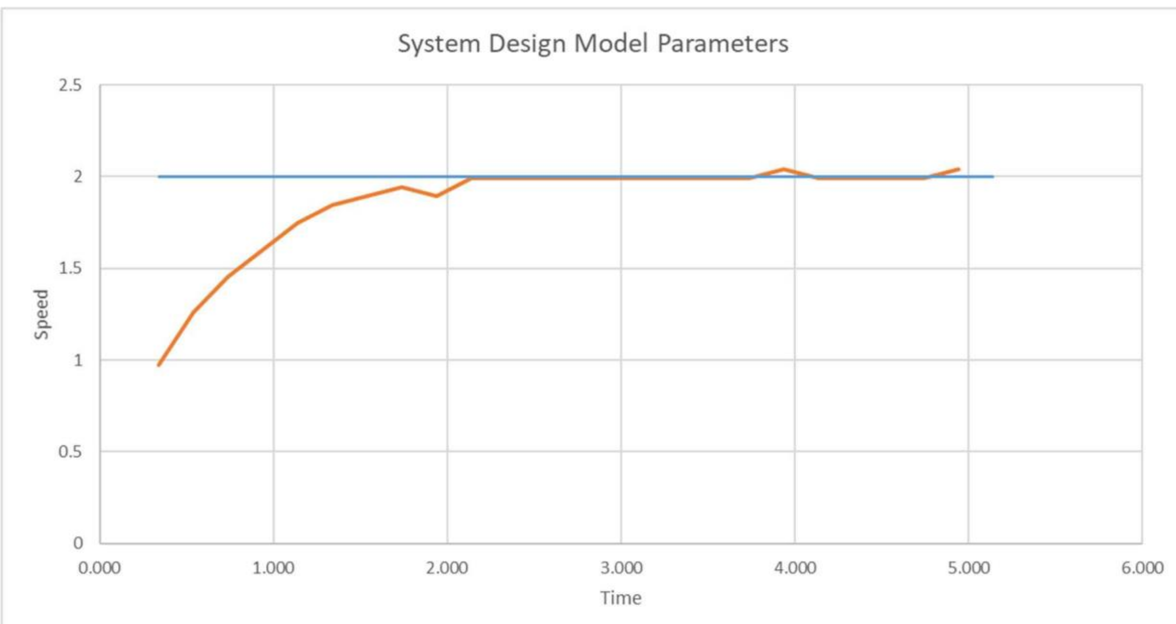

Figure H3

Appendix I: Load Setup

The load was a simple elevator that would carry weight up and down. It consisted of a platform made of wood that had 3 holes on both sides placed in a triangle to evenly distribute the weight that the elevator would encounter later. Then yarn was applied to simulate a cable like structure, a knot was made and then a one piece of yarn would be winded and un-winded to bring the elevator up and down. A clamp was used as our foundational support to hold the motor in place. For the weight quarters were used, exactly 20 at maximum load and 10 for half the load. Weighing in at about 114 g plus the weight of the platform the elevator would stagnate a little at maximum load but overall it was able to perform adequately enough, with minor changes to the controller.

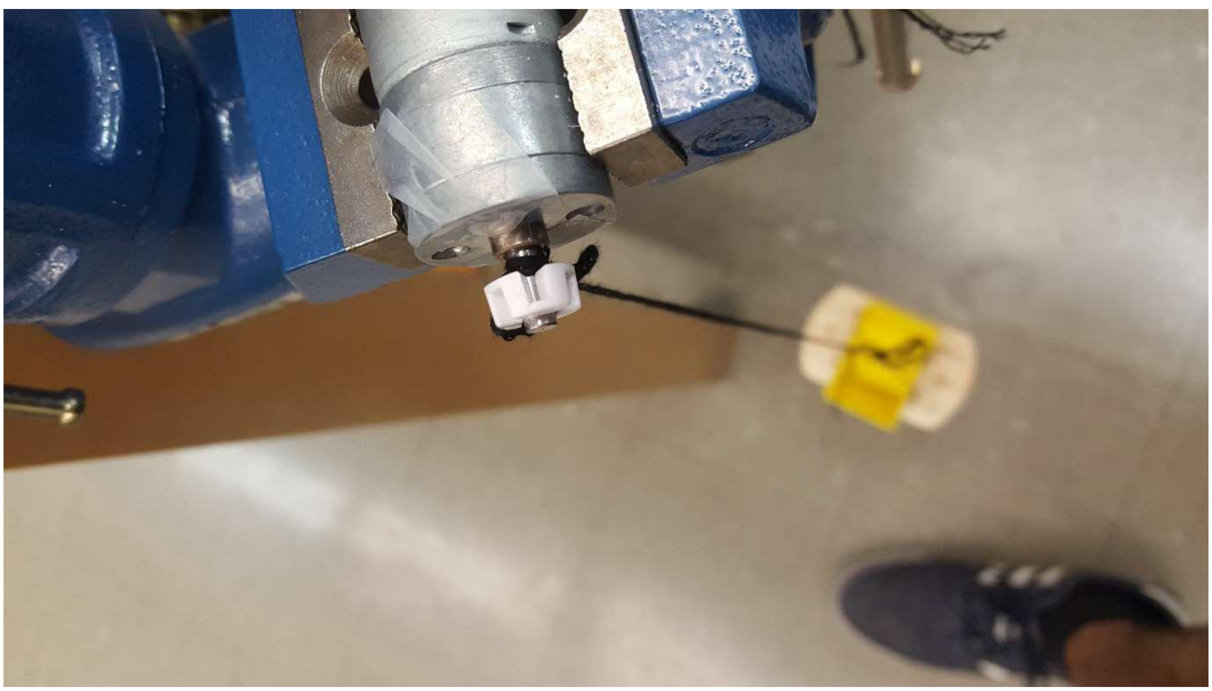

Figure I1

Appendix I Continued

Figure I2

Appendix J: TE Tuning Vs. PID Tuner Matlab

We found that the control parameters from the tuning we had done in previous weeks was working well but the motor needed a small amount of compensation for the fact that now it was not just spinning in the air. The friction of the yarn as it winded and gravity to work against we decided that the response needed a stronger integral value so that the motor would perform in the given time constraints that we had decided on. Our “rise time” was satisfied but a settling time was never really met. Hence the increase in integral control as to reduce the amount of time the motor kept underperforming. The data with just using the TE Tuning method is presented next.

Time - Setpoint	Amplitude - Setpoint	Time - Speed	Amplitude - Speed	Time
3626304645	3	3626304645	2.2333	-0.19
3626304646	3	3626304645	1.5536	0.01
3626304646	3	3626304646	2.1362	0.21
3626304646	3	3626304646	2.4275	0.41
3626304646	3	3626304646	2.67025	0.61
3626304646	3	3626304646	2.7188	0.81
3626304647	3	3626304646	2.8159	1.01
3626304647	3	3626304647	3.15575	1.21
3626304647	3	3626304647	3.3985	1.41
3626304647	3	3626304647	3.25285	1.61
3626304647	3	3626304647	3.1072	1.81
3626304648	3	3626304647	3.0101	2.01
3626304648	3	3626304648	2.913	2.21
3626304648	3	3626304648	2.86445	2.41
3626304648	3	3626304648	2.913	2.61
3626304648	3	3626304648	2.86445	2.81
3626304649	3	3626304648	2.913	3.01
3626304649	3	3626304649	2.913	3.21
3626304649	3	3626304649	2.86445	3.41
3626304649	3	3626304649	2.96155	3.61
3626304649	3	3626304649	2.96155	3.81
3626304650	3	3626304649	2.96155	4.01
3626304650	3	3626304650	2.913	4.21
3626304650	3	3626304650	2.913	4.41
3626304650	3	3626304650	2.86445	4.61

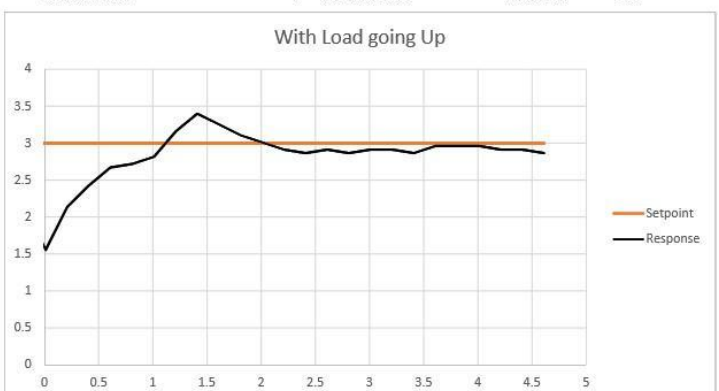

Figure J1

Appendix J Continued

Time - Setpoint	Amplitude - Setpoint	Time - Speed	Amplitude - Speed	Time
3626304763	-3	3626304763	-1.89345	0
3626304764	-3	3626304764	-2.913	0.21
3626304764	-3	3626304764	-2.47605	0.4
3626304764	-3	3626304764	-3.25285	0.61
3626304764	-3	3626304764	-2.913	0.81
3626304764	-3	3626304764	-3.44705	1.01
3626304765	-3	3626304765	-3.54415	1.21
3626304765	-3	3626304765	-3.54415	1.41
3626304765	-3	3626304765	-3.44705	1.61
3626304765	-3	3626304765	-3.44705	1.81
3626304765	-3	3626304765	-3.2043	2.01
3626304766	-3	3626304766	-3.1072	2.21
3626304766	-3	3626304766	-3.1072	2.41
3626304766	-3	3626304766	-3.2043	2.61
3626304766	-3	3626304766	-3.1072	2.81
3626304766	-3	3626304766	-2.913	3.01
3626304767	-3	3626304767	-3.0101	3.21
3626304767	-3	3626304767	-2.96155	3.41
3626304767	-3	3626304767	-3.05865	3.61
3626304767	-3	3626304767	-3.1072	3.81
3626304767	-3	3626304767	-3.25285	4.01
3626304768	-3	3626304768	-3.3014	4.21
3626304768	-3	3626304768	-3.3014	4.41
3626304768	-3	3626304768	-3.15575	4.61

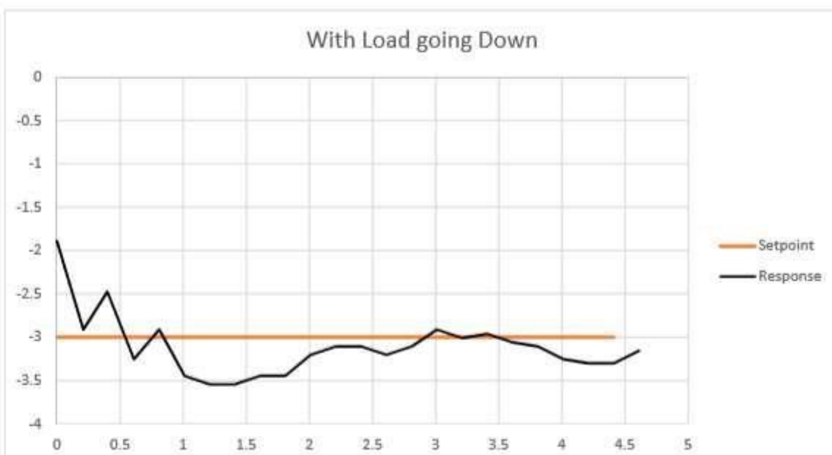

Figure J2

For Figure J1, %OS = 8.3%, Ts = 2.6 s, Tr = 1.4s, and an Ess = .14.

For Figure J2, %OS = 16%, Ts= 2.6 s, Tr = 1.4s, and an Ess = .3

Appendix J Continued

Time - Setpoint	Amplitude	Time - Speed	Amplitude - Speed	Time
3626304139	3	3626304139	2.2333	0
3626304139	3	3626304139	2.3304	0.2
3626304139	3	3626304139	2.57315	0.4
3626304139	3	3626304139	2.7188	0.6
3626304139	3	3626304139	2.76735	0.8
3626304140	3	3626304140	2.913	1
3626304140	3	3626304140	3.0101	1.2
3626304140	3	3626304140	3.1072	1.4
3626304140	3	3626304140	3.05865	1.6
3626304140	3	3626304140	3.05865	1.8
3626304141	3	3626304141	2.96155	2
3626304141	3	3626304141	3.0101	2.2
3626304141	3	3626304141	2.96155	2.4
3626304141	3	3626304141	2.913	2.61
3626304141	3	3626304141	2.86445	2.8
3626304142	3	3626304142	3.0101	3.01
3626304142	3	3626304142	2.913	3.2
3626304142	3	3626304142	2.96155	3.4
3626304142	3	3626304142	2.96155	3.6
3626304142	3	3626304142	2.96155	3.81
3626304143	3	3626304143	2.86445	4
3626304143	3	3626304143	2.96155	4.2
3626304143	3	3626304143	2.913	4.41
3626304143	3	3626304143	2.913	4.61

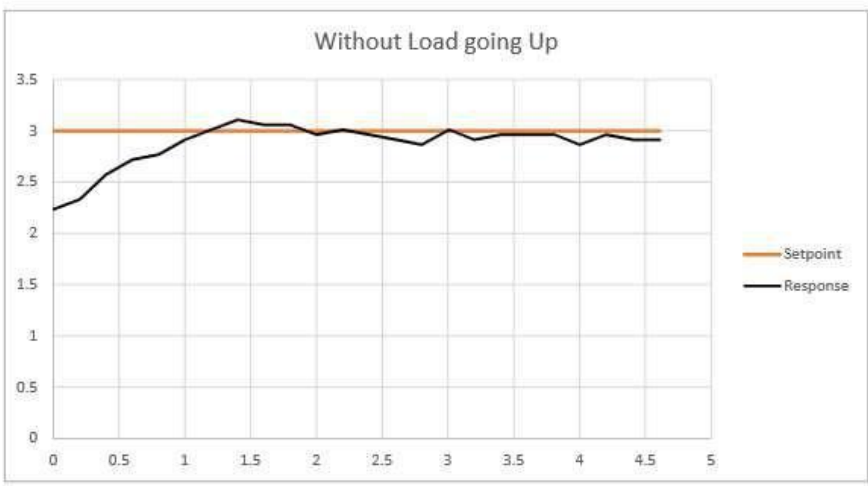

Figure J3

Appendix J Continued

Time - Setpoint	Amplitude	Time - Speed	Amplitude - Speed	Time
3626304399	-3	3626304399	0	-0.14
3626304399	-3	3626304399	-0.6797	0
3626304399	-3	3626304399	-2.18475	0.21
3626304400	-3	3626304399	-2.5246	0.4
3626304400	-3	3626304400	-2.6217	0.61
3626304400	-3	3626304400	-2.86445	0.81
3626304400	-3	3626304400	-2.913	1.01
3626304400	-3	3626304400	-3.05865	1.21
3626304401	-3	3626304400	-2.96155	1.41
3626304401	-3	3626304401	-3.05865	1.61
3626304401	-3	3626304401	-3.0101	1.81
3626304401	-3	3626304401	-3.0101	2.01
3626304401	-3	3626304401	-2.96155	2.21
3626304402	-3	3626304401	-3.1072	2.41
3626304402	-3	3626304402	-3.0101	2.61
3626304402	-3	3626304402	-3.05865	2.81
3626304402	-3	3626304402	-3.05865	3.01
3626304402	-3	3626304402	-3.1072	3.21
3626304403	-3	3626304402	-3.1072	3.41
3626304403	-3	3626304403	-3.0101	3.61
3626304403	-3	3626304403	-3.05865	3.81
3626304403	-3	3626304403	-3.05865	4.01
3626304403	-3	3626304403	-3.05865	4.21
3626304404	-3	3626304403	-3.05865	4.41
3626304404	-3	3626304404	-3.05865	4.61

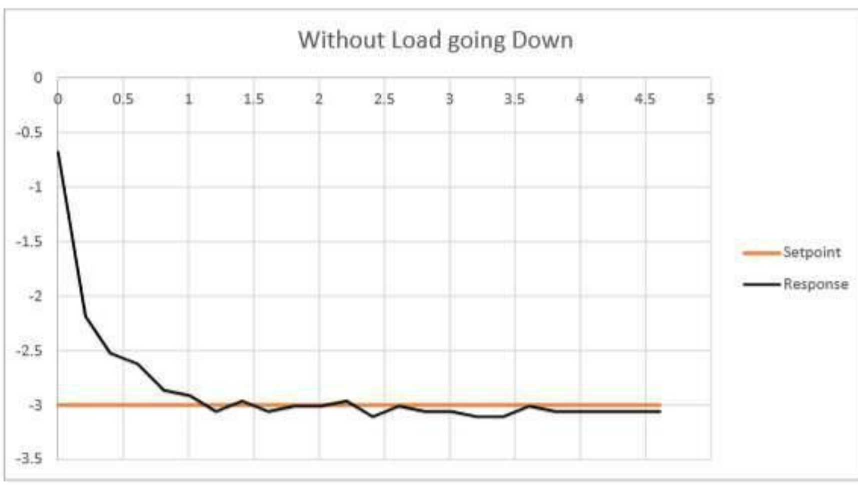

Figure J4

For Figure J3, %OS = 3.3%, Tr = 2.6 s, Ts = 1.4, and an Ess = .087.

For Figure J4, %OS = 2%, Tr = 1.6 s, Ts = 1.4, and an Ess = .06.

Appendix J Continued

This is the data for the PID tuner parameters.

Time - Speed	Amplitude - Speed	Time - Speed	Amplitude - Speed		Time
3626350915	0.647333	3626351054	-0.712067	139.08	0
3626350915	0.712067	3626351054	-0.7768	139.23	0.15
3626350915	0.712067	3626351054	-0.7768	139.38	0.3
3626350915	0.647333	3626351055	-0.841533	139.53	0.45
3626350916	0.841533	3626351055	-1.10047	139.68	0.6
3626350916	1.10047	3626351055	-1.42413	139.83	0.75
3626350916	1.3594	3626351055	-1.5536	139.98	0.9
3626350916	1.61833	3626351055	-1.81253	140.13	1.05
3626350916	1.7478	3626351055	-1.942	140.28	1.2
3626350916	1.942	3626351055	-2.1362	140.43	1.35
3626350916	2.07147	3626351056	-2.20093	140.58	1.5
3626350917	2.1362	3626351056	-2.3304	140.73	1.65
3626350917	2.3304	3626351056	-2.45987	140.88	1.8
3626350917	2.3304	3626351056	-2.58933	141.03	1.95
3626350917	2.45987	3626351056	-2.58933	141.18	2.1
3626350917	2.5246	3626351056	-2.7188	141.33	2.25
3626350917	2.5246	3626351056	-2.7188	141.48	2.4
3626350918	2.58933	3626351057	-2.7188	141.63	2.55
3626350918	2.58933	3626351057	-2.78353	141.78	2.7
3626350918	2.7188	3626351057	-2.78353	141.93	2.85
3626350918	2.65407	3626351057	-2.84827	142.08	3
3626350918	2.7188	3626351057	-2.84827	142.23	3.15
3626350918	2.78353	3626351057	-2.913	142.38	3.3
3626350918	2.78353	3626351058	-2.913	142.53	3.45
3626350919	2.78353	3626351058	-2.84827	142.68	3.6
3626350919	2.78353	3626351058	-2.84827	142.83	3.75
3626350919	2.78353	3626351058	-2.97773	142.98	3.9
3626350919	2.84827	3626351058	-2.913	143.13	4.05
3626350919	2.84827	3626351058	-2.97773	143.28	4.2
3626350919	2.913	3626351058	-2.97773	143.43	4.35
3626350920	2.78353	3626351059	-2.913	143.58	4.5
3626350920	2.913	3626351059	-2.97773	143.73	4.65
3626350920	2.913	3626351059	-2.913	143.88	4.8

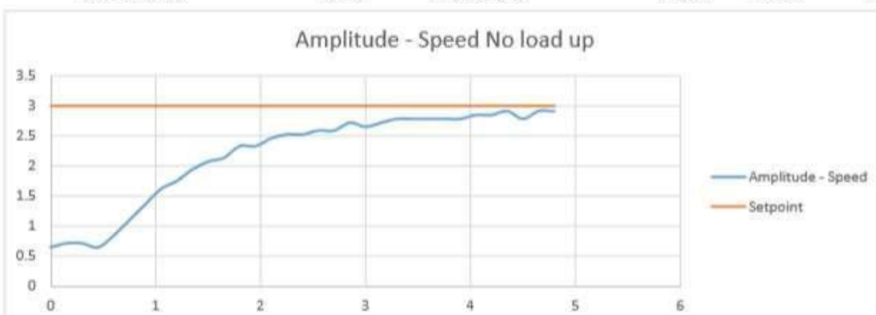

Figure J5

Appendix J Continued

Time - Speed	Amplitude - Speed	Time - Speed	Amplitude - Speed		Time
3626351318	0.453133	3626351661	-0.5826	342.55	0
3626351318	0.517867	3626351661	-0.712067	342.7	0.15
3626351319	0.453133	3626351661	-0.7768	342.85	0.3
3626351319	0.453133	3626351661	-0.841533	343	0.45
3626351319	0.712067	3626351661	-0.971	343.15	0.6
3626351319	1.10047	3626351662	-1.03573	343.3	0.75
3626351319	1.3594	3626351662	-1.10047	343.45	0.9
3626351319	1.5536	3626351662	-1.1652	343.6	1.05
3626351320	1.7478	3626351662	-1.1652	343.75	1.2
3626351320	2.1362	3626351662	-1.3594	343.9	1.35
3626351320	2.5246	3626351662	-1.3594	344.05	1.5
3626351320	2.65407	3626351663	-1.10047	344.2	1.65
3626351320	2.65407	3626351663	-1.03573	344.35	1.8
3626351320	2.7188	3626351663	-1.29467	344.5	1.95
3626351320	2.7188	3626351663	-1.48887	344.65	2.1
3626351321	2.78353	3626351663	-1.7478	344.8	2.25
3626351321	2.78353	3626351663	-1.87727	344.95	2.4
3626351321	2.7188	3626351663	-2.07147	345.1	2.55
3626351321	2.7188	3626351664	-2.26567	345.25	2.7
3626351321	2.58933	3626351664	-2.3304	345.4	2.85
3626351321	2.65407	3626351664	-2.45987	345.55	3
3626351322	2.7188	3626351664	-2.5246	345.7	3.15
3626351322	2.7188	3626351664	-2.5246	345.85	3.3
3626351322	2.7188	3626351664	-2.65407	346	3.45
3626351322	2.7188	3626351664	-2.65407	346.15	3.6
3626351322	2.7188	3626351665	-2.65407	346.3	3.75
3626351322	2.84827	3626351665	-2.78353	346.45	3.9
3626351322	2.7188	3626351665	-2.78353	346.6	4.05
3626351323	2.7188	3626351665	-2.84827	346.75	4.2
3626351323	2.84827	3626351665	-2.84827	346.9	4.35
3626351323	2.78353	3626351665	-2.84827	347.05	4.5
3626351323	2.84827	3626351666	-2.84827	347.2	4.65
3626351323	2.84827	3626351666	-2.913	347.35	4.8
					5

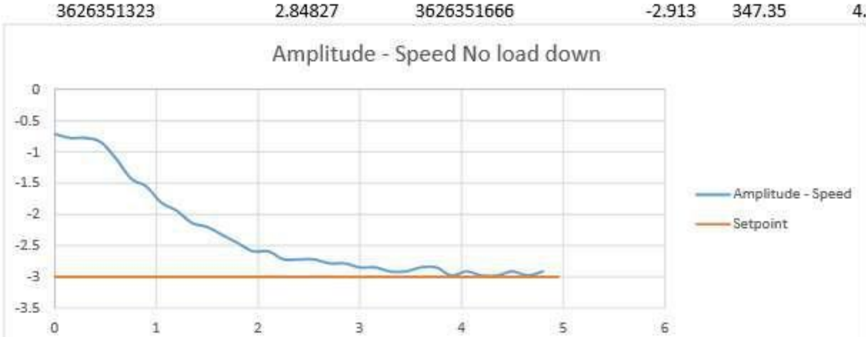

Figure J6

Appendix J Continued

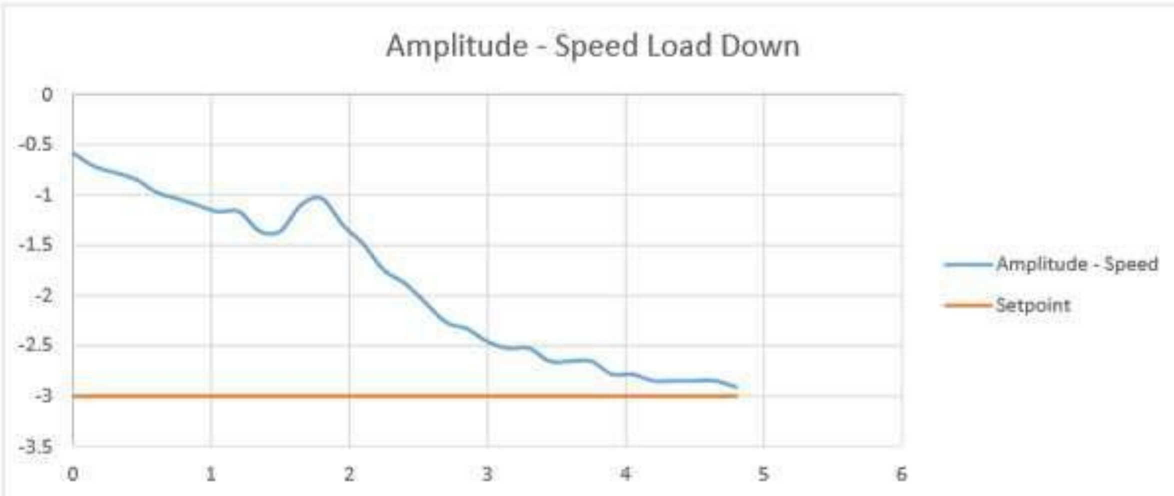

Figure J7

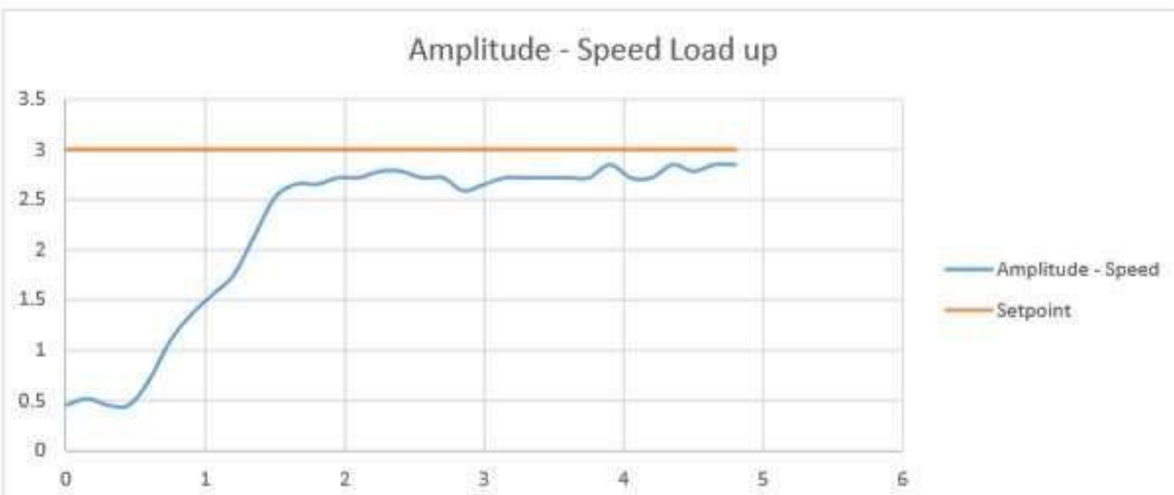

Figure J8

For Figure J5, %OS = 0%, Tr = 4 s, Ts = 2.8 s, and an Ess = .087.

For Figure J5, %OS = 0%, Tr = 3.4 s, Ts = 2.4 s, and an Ess = .087.

For Figure J5, %OS = 0%, Tr = 5 s, Ts = 2.8 s, and an Ess = .087.

For Figure J5, %OS = 0%, Tr = 4.1 s, Ts = 1.7 s, and an Ess = .016.

Appendix J Continued

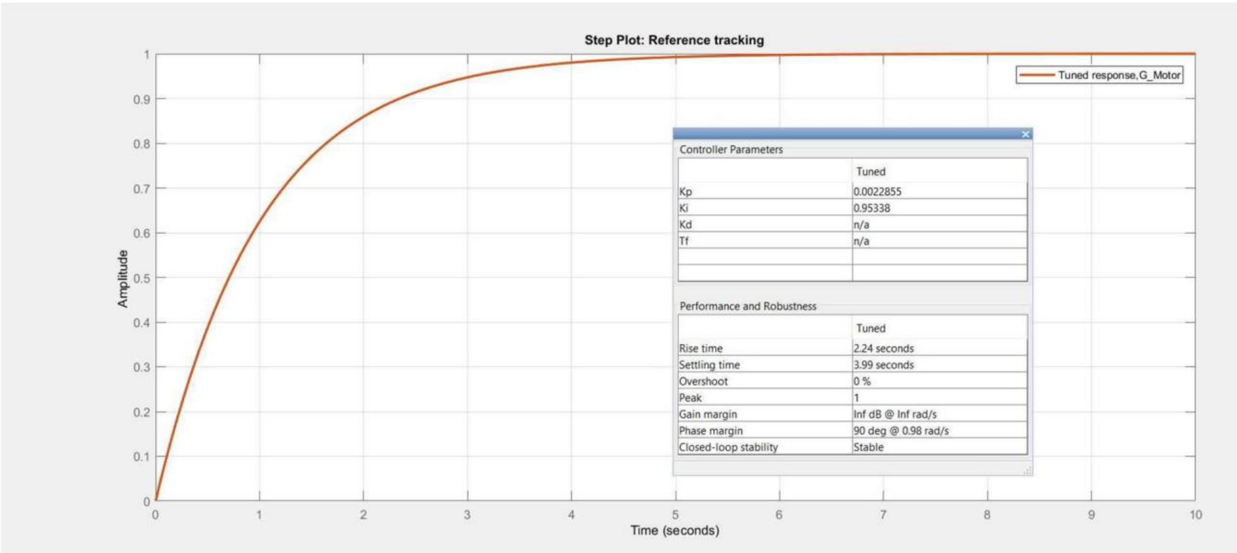

Figure J9

Appendix K: Accumulated Grades

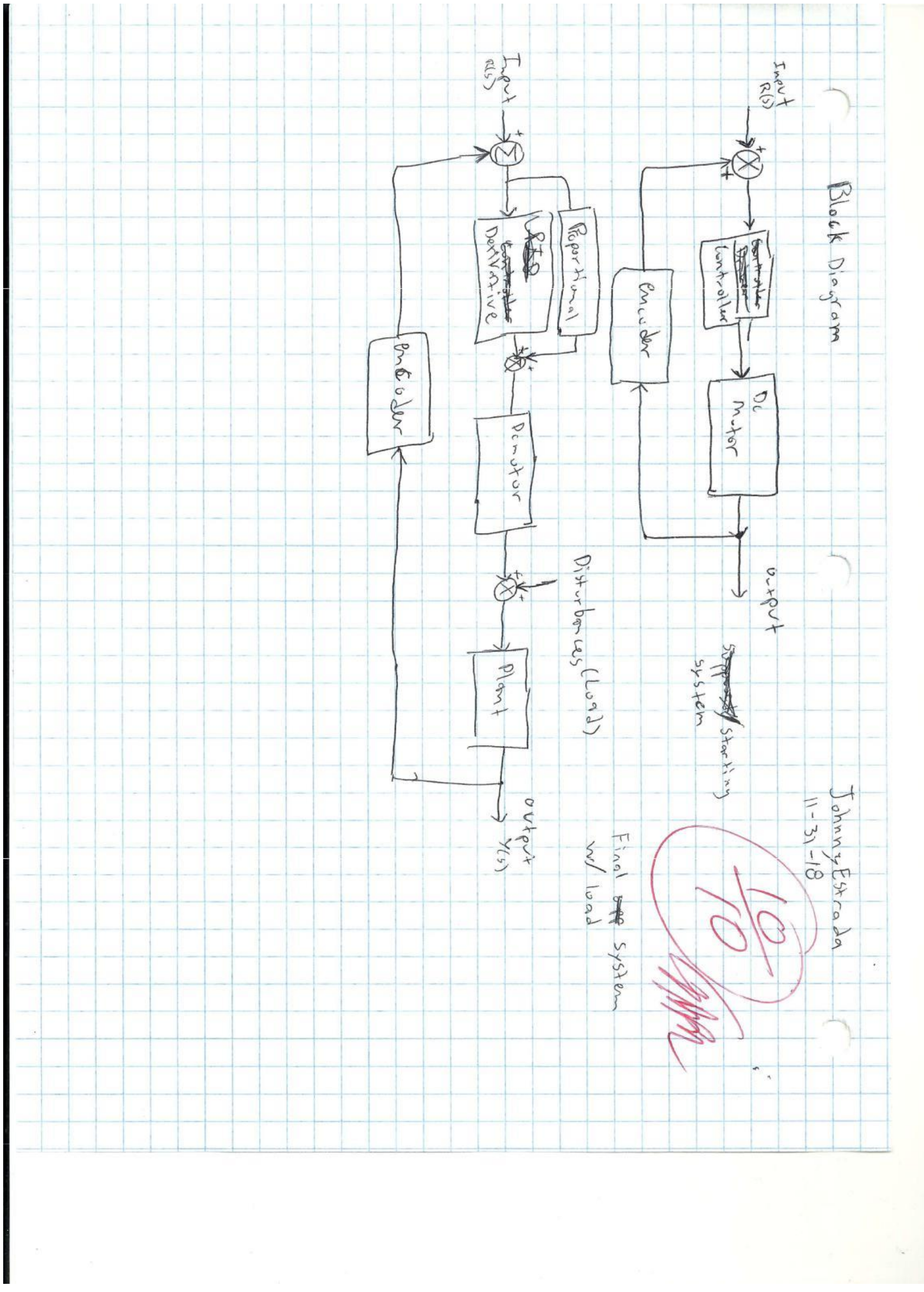

Figure K1

Appendix K Continued

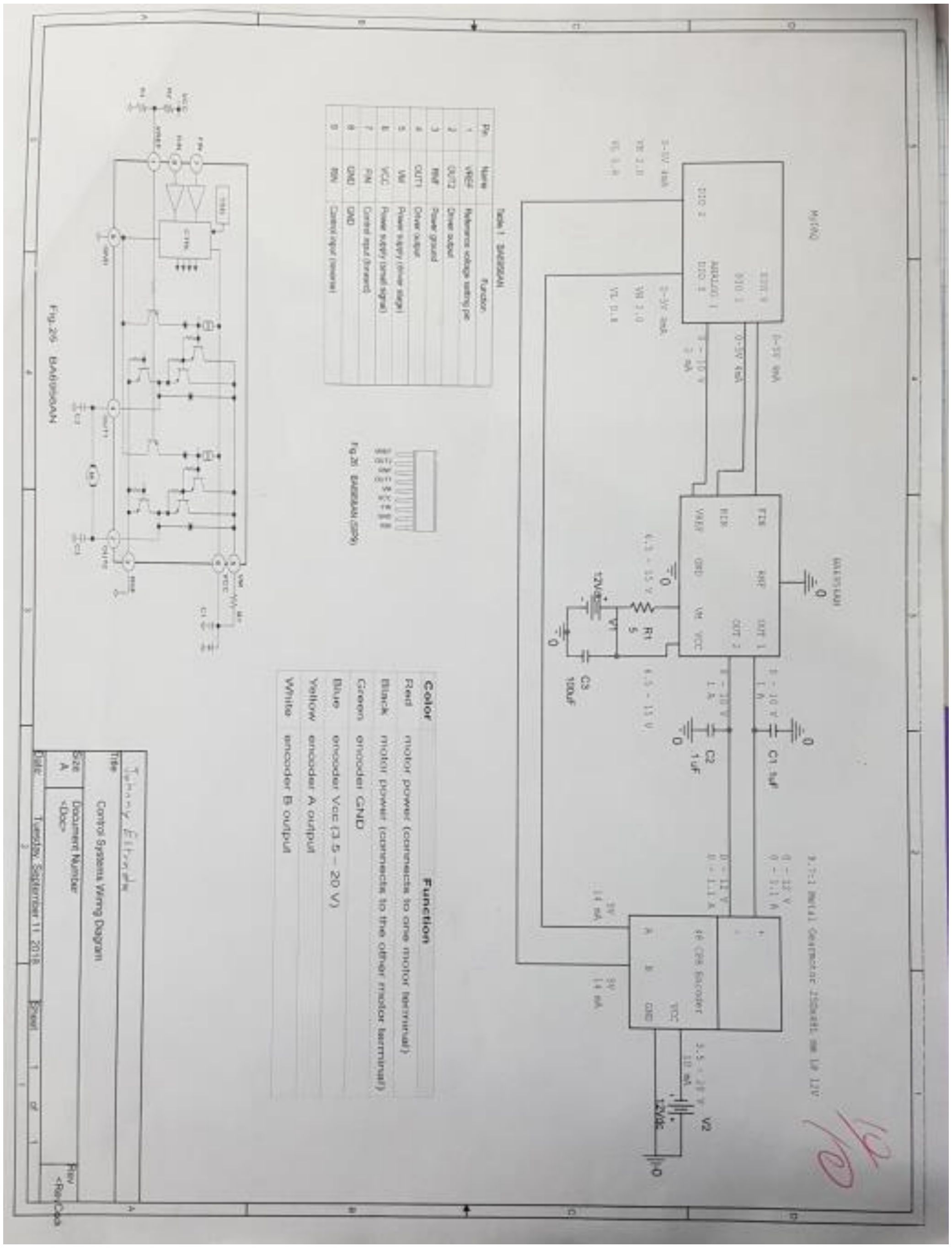

Figure K2

Appendix K Continued

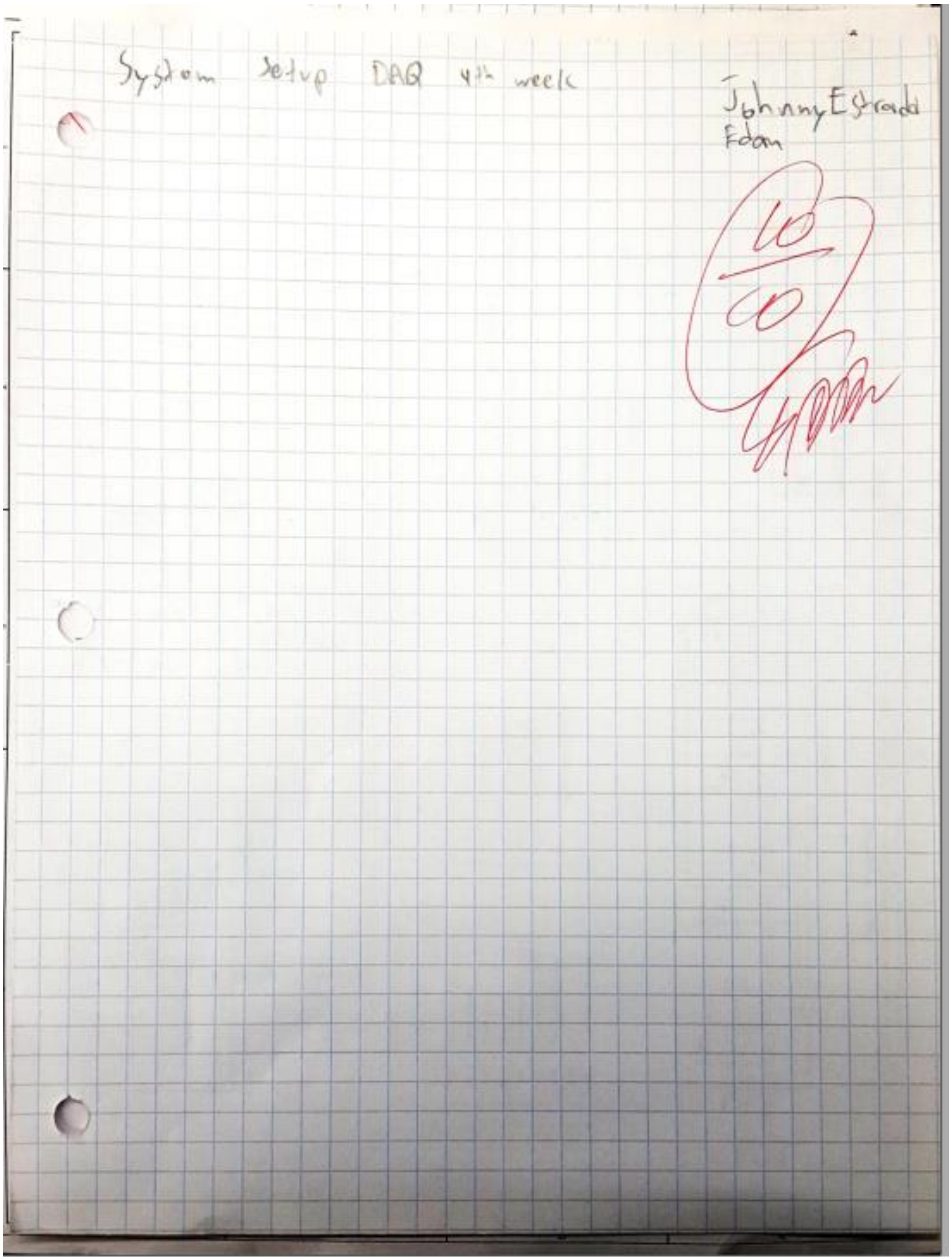

Figure K3

Appendix K Continued

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Time - Setpoint	Amplitude - Setpoint	Time - Speed	Amplitude - Speed
3621516186	1	3621516186	1.02291
3621516186	1	3621516186	0.987636
3621516187	2	3621516187	0.987636
3621516187	2	3621516187	1.30509
3621516187	2	3621516187	1.48145
3621516188	2	3621516188	1.62255
3621516188	2	3621516188	1.69309
3621516188	2	3621516188	1.76364
3621516188	2	3621516188	1.83418
3621516189	2	3621516189	1.86945
3621516189	2	3621516189	1.90473
3621516189	2	3621516189	1.90473
3621516189	2	3621516189	1.94
3621516190	2	3621516190	1.97527
3621516190	2	3621516190	1.97527
3621516190	2	3621516190	1.97527
3621516191	2	3621516191	1.97527
3621516191	2	3621516191	1.97527
3621516191	2	3621516191	2.01055

kx 1.9 .476

↑ ~~.64~~

kp= 0

ki =29.1~

will yield a response (step)

%OS= 0

Ess= .03

Ref=2

Rise time = ~2s — rise time less than or eq to 2s

Transient Repsone ≈ 4s

settles less than 3 s

k P-Gain = .103

k I-Gain = 1.06

transfer Function

$$\frac{.103s + 1.06}{s}$$

Cont i- time PID Controller

Link →

mathworks.com/discovery/pid-control.html

Figure K4

Appendix K Continued

Torque = J x a

$J = D \times L \times .077 \times 10^{-6} = [kg \cdot m^2]$

$D \downarrow$ 4mm $L \downarrow$ 12.5 mm

10/10

$.004\,cm \cdot .0125\,cm \cdot .077 \times 10^{-6} = 3.85 \times 10^{-12}$

$\frac{1}{2} m r^2 = \frac{1}{2} (.095\,Kg$

.00126385 mass [kg] using density of steel

$2.5277 \times 10^{-9} = J$

$r = .2\,cm$

$P(s) = \frac{\theta(s)}{V(s)} = \frac{K}{(Js+b)(Ls+R)+K^2} \left[\frac{rad/sec}{V}\right]$

b=.047
J= 2.5277×10^{-9} should be -6
L= 20.4×10^{-3} H
R= 8.5 Ω

b. $T = bw$

$.009627 = b(.2046)$

$b = \boxed{.047}$

$(2.5277 \times 10^{-9} s + .047)$

$\times (20.4 \times 10^{-3} s + 8.5)$

$\frac{}{K}$

$5.15651E{-11} x^2 + 9.588214E{-4} x$

$s = -\frac{b}{J}$

$5.15651 \times 10^{-11} s^2 + 9.10285 \times 10^{-4} s + .3995$

+.4209

121 - 143

$\omega_n = .648$

Figure K5

Appendix K Continued

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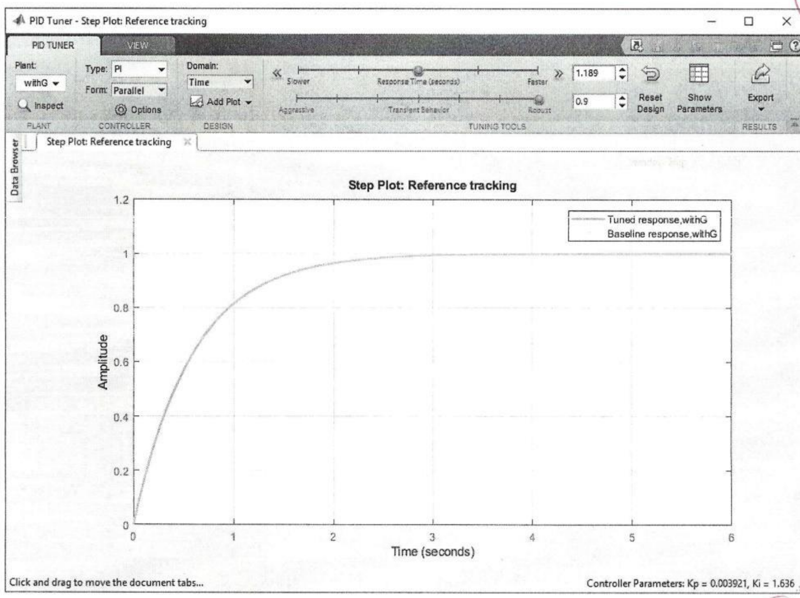

Controller Parameters

	Tuned	Baseline
Kp	0.0039214	0.99679
Ki	1.6357	1247.4686
Kd	n/a	n/a
Tf	n/a	n/a

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Performance and Robustness

	Tuned	Baseline
Rise time	1.31 seconds	0.00196 seconds
Settling time	2.33 seconds	0.00716 seconds
Overshoot	0 %	13.8 %
Peak	1	1.14
Gain margin	Inf dB @ Inf rad/s	Inf dB @ Inf rad/s
Phase margin	90 deg @ 1.68 rad/s	60 deg @ 735 rad/s
Closed-loop stability	Stable	Stable

Figure K6

Appendix K Continued

Time (sec)	Time - Setpoint	Amplitude - Setpoint	Amplitude - Speed
0.340	3625149972	2	0.971
0.540	3625149973	2	1.2623
0.740	3625149973	2	1.4565
0.940	3625149973	2	1.60215
1.140	3625149973	2	1.7478
1.340	3625149973	2	1.8449
1.540	3625149974	2	1.89345
1.740	3625149974	2	1.942
1.940	3625149974	2	1.89345
2.140	3625149974	2	1.99055
2.340	3625149974	2	1.99055
2.540	3625149975	2	1.99055
2.740	3625149975	2	1.99055
2.940	3625149975	2	1.99055
3.140	3625149975	2	1.99055
3.340	3625149975	2	1.99055
3.540	3625149976	2	1.99055
3.740	3625149976	2	1.99055
3.940	3625149976	2	2.0391
4.140	3625149976	2	1.99055
4.340	3625149976	2	1.99055
4.540	3625149977	2	1.99055
4.740	3625149977	2	1.99055
4.940	3625149977	2	2.0391
5.140	3625149977	2	

System design parameters
first run through

Figure K7

Appendix K Continued

October 31, 2018

Johnny Estrada
Edan Nankin

10/10

Time constant = $\frac{1}{a}$

Settling time = $4\frac{1}{a}$

$7 = 2\zeta\omega_n$

$\frac{d^2y}{dt^2} + 3\frac{dy}{dt} + 2y = 0$

$(s^2 + 3s + 2)$ = characteristic eq

or $(s^2 + 2\zeta\omega_n s + \omega_n^2)$

$\omega_n = \sqrt{2}$

$\zeta = 3$

1) How to run controller

a location

$a\ \frac{R}{L} = \frac{8.5}{20.4\times10^{-3}}$

$\frac{1}{2.4\times10^{-3}} =$

$T_{const} = \frac{1}{R/L} = 4(2.4\times10^{-3})$

$T_{settle} = 9.6\times10^{-3}$ s

$\omega_n = \sqrt{.4209} = .649$

T_{settle} is $(T_{const} \times 4)$

Figure K8

Appendix K Continued

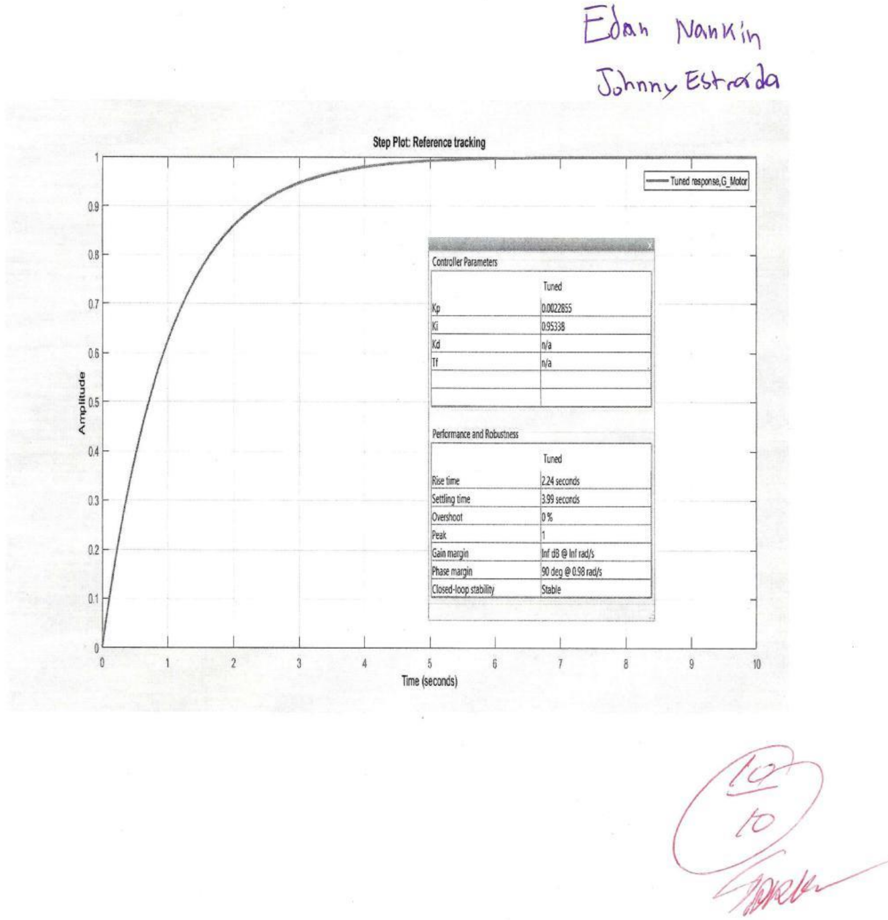

Figure K9

Appendix K Continued

Edan Nankin
Johnny Estrada

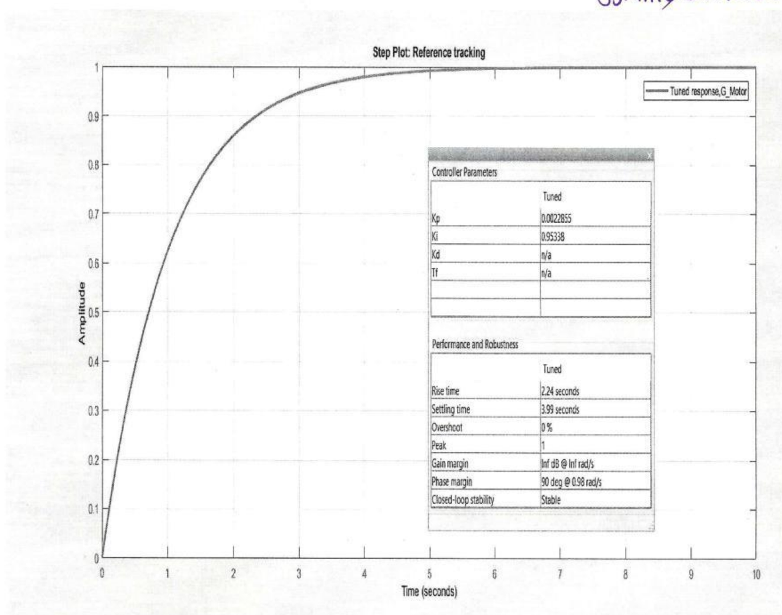

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Figure K9

References

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