

Instrumentation & Control Assignment 2

by Christopher Budden

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Instrumentation and Control

ASSIGNMENT 2

LJ CREATE CRONTROL METHOD EVALUATION

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Instrumentation & Control

Control Method Evaluation

By

Christopher Budden

Abstract

Control systems are employed in a wide variety of engineering systems throughout industry. They bring precision and automate the process of controlling powered machinery. Closed loop feedback controllers, for example PID (Proportional-Integral-Derivative) controllers are complex in their workings, but extremely versatile in adapting to maintaining control over varying plant outputs.

This Paper is intended to investigate the characteristics, advantages and disadvantages of 4 types of closed loop feedback controllers. The investigation will experiment and record the data from a series of tasks laid out in the IT02 curriculum control manual for the LJ Create 1750 Instrumentation & Transducer trainer module. Four controllers will be put under testing and evaluation in the forthcoming sections, they are;

- Proportional
- Proportional-Integral
- Proportional-Derivative
- Proportional-Integral-Derivative

The test procedures will be referred to the manual's sub sections, results recorded and plotted. The results and discussion of the findings will be presented and evaluated for any findings during the tests. The aim of this paper is to determine the ideal control system method to utilise in a positional control system from the findings of this report.

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I. Introduction

Feedback controllers are available in various forms of control methods. The ideal closed loop feedback controllers that are commonly in use in industry are; Proportional, Proportional-Integral, Proportional-Derivative & Proportional-Integral-Derivative.

Proportional controllers are considered the most basic type of controller, in that its complexity is basic. The proportional controllers work on the fundamental of measuring the output feedback compared to the desired set-point and calculating the difference. So if the 'error' is large, then the effort to reach the desired set point will be large. The 'error' is the difference in the value of the output in comparison to the set point input. By definition proportional is;

***'Two quantities having the same or a constant ratio or relation: The quantities y and x are proportional if $y/x = k$, where k is the constant of proportionality.'**[1]*

Proportional-Integral works on the basis of summing the proportional error and the integrated samples. The Integral component samples the proportional error over a period of time ' t ' which is the time constant. Integrating a set of sample points results in the area under the curve, to which in the purpose of control systems, calculates the accumulation of proportionality error over the given time. This in turn is summed with the instance of error value that will increase the controller effort if the accumulation increases over time, this causes a quicker response rate, but as this fundamental relies on measuring past values sampled, will result in overshoots of the desired set point [2].

Proportional-Derivative differentiates a set of samples taken from the output of a sensor or a transducer; (a device that outputs measured feedback from a physical movement to an electrical value), and differentiates these samples to find the difference in 'y' divided by the difference of 'x' ($\frac{dy}{dx}$). This 'equation of a line' is applied for current trends that in turn will decrease the chances of overshoot when the target set point is nearing approach by the measured output [3].

Proportional-Integral-Derivative combines the components of Integrating and Derivation that gives a P-I-D controller versatility to be 'tuneable', in that, the time constants of the Integrator and Differentiator can be suited to a system that can balance the system of overshoots and response time-frame.

The aim of this assignment is to conduct a series of tests with 4 configurations of feedback control systems using the LJ Create 1750 Transducer & Instrumentation Trainer. Test procedures **18.3, 18.4, 18.5 & 18.6** will be adhered to in the curriculum manual IT02 from Chapter 18 of the Practical Control Systems module. The four test criteria's are sub-divided into controller types.

The forms of control system which will be trialled are;

- Proportional
- Proportional Integral
- Proportional Derivative
- Proportional Integral Derivative

II. Apparatus

In this assignment, the LJ Create 1750 Transducer and Instrumentation trainer is utilised in order to carry out the experiment and gather results upon the four variants of control systems which are;

- Proportional
- Proportional Integral
- Proportional Derivative
- Proportional Integral Derivative

The only components used for this experiment on the LJ Create trainer will be as follows;

- 10k Ω Wire Wound variable potentiometer
- Amplifier #1
- Amplifier #2
- Differential Amp
- Instrumentational Amp
- Integrator
- Differentiator
- Inverter
- Summing Amp
- Power Amp
- DC Motor
- Servo Potentiometer
- Moving Coil Meter

An additional external DVM (Digital Voltage Meter) is also used to digitally read the Integrator's output voltage.

All circuitry components will be joined via 'banana' type jumper leads which will be connected as shown in Fig. 18.3, 18.4, 18.5 & 18.6 in the IT02 Curriculum Manual [4].

III. Method

Proportional

The LJ Create will be connected as per the set-up in Fig. 18.3[4], although the Integrator and Differentiator portion will not be connected into the system for the first stage of the experiment.

The Proportional control method is set up first on the LJ Create trainer as shown in Figure 1 displayed below.

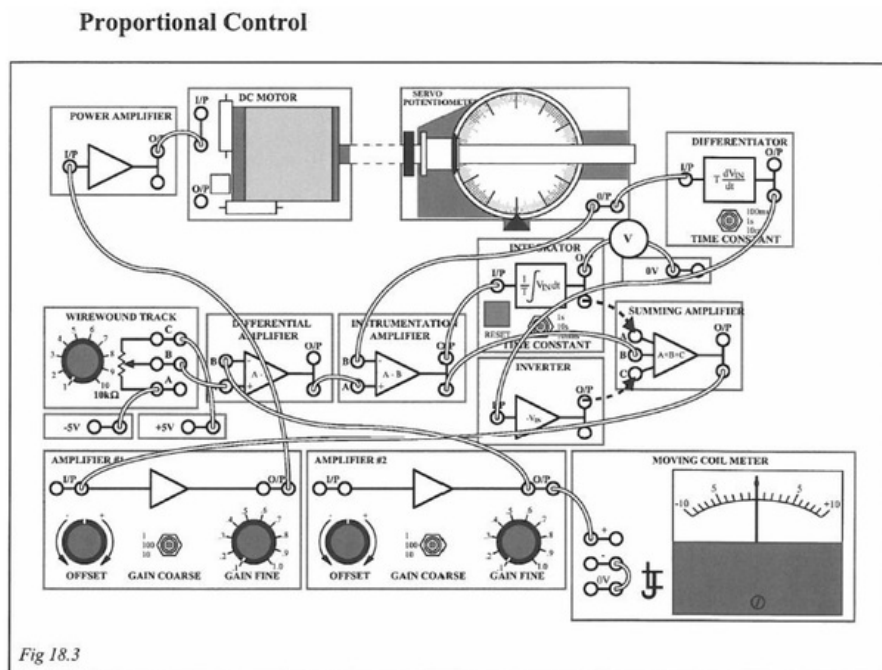


Figure 1

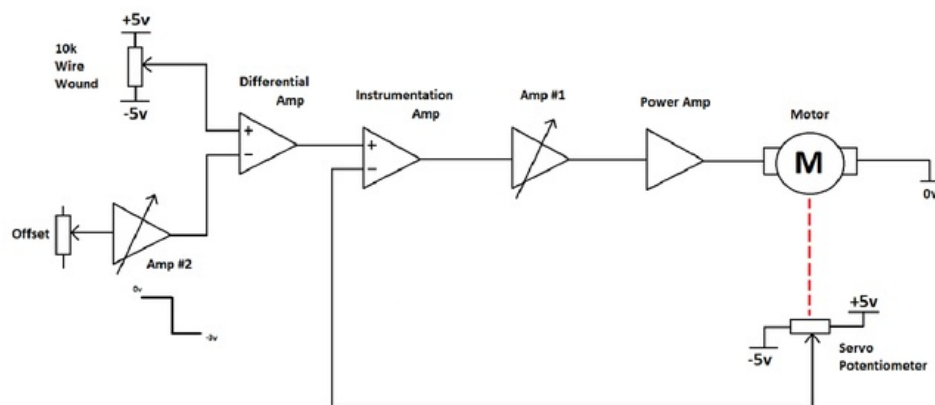


Figure 2 above shows the simplified schematic for the proportional set-up.

Once the system is set-up as per [Figure 1](#), set-up procedures are undertaken in order to set the step input levels and zero any offsets. These procedures are closely followed in section [18.3\[4\]](#). These set-up procedures comprise of setting the servo potentiometer plate to zero degrees, setting Amplifier #1 & #2 gains, the step input level (Amp #2) and overall system gain and offset (Amp #1). The gain and zero level adjustments are carried out using the moving coil meter by transferring its lead to the different component outputs of the system.

Starting at zero on the 10k Ω wire-wound resistor, the first input to the system is to rotate this so that it will in turn rotate the motors shaft in proportion to the command input. The extremities of the servo potentiometer's plate angles are then recorded for a positive and negative input. This initial visual test is carried out with Amplifier #1 gain set to 1.0 and 5.0 respectively; the response of the system is visually noted between the two gains.

The next stage will then to be record each of the 10k Ω resistor's positions (1-10) against the servo potentiometer's dial reading, record this into table [18.4\[4\]](#), then plot the collected data into graph [18.3\[4\]](#). The experiment will start from setting number 1 and increment on the 10k Ω resistor, then the same test will be carried out by decrementing the control setting positions, recording and graphing the results in order to plot the deadband of the system.

The deadband data collection of the Proportional system is then undertaken in accordance with [18.3b\[4\]](#), adjusting the gains (1, 5 & 10) and recording the results in table [18.5\[4\]](#).

The final experiment is to observe and record results from a stepped input in sections [18.3e](#), [18.3f](#) & [18.3g\[4\]](#).

Proportional-Integral

Proportional + Integral Control

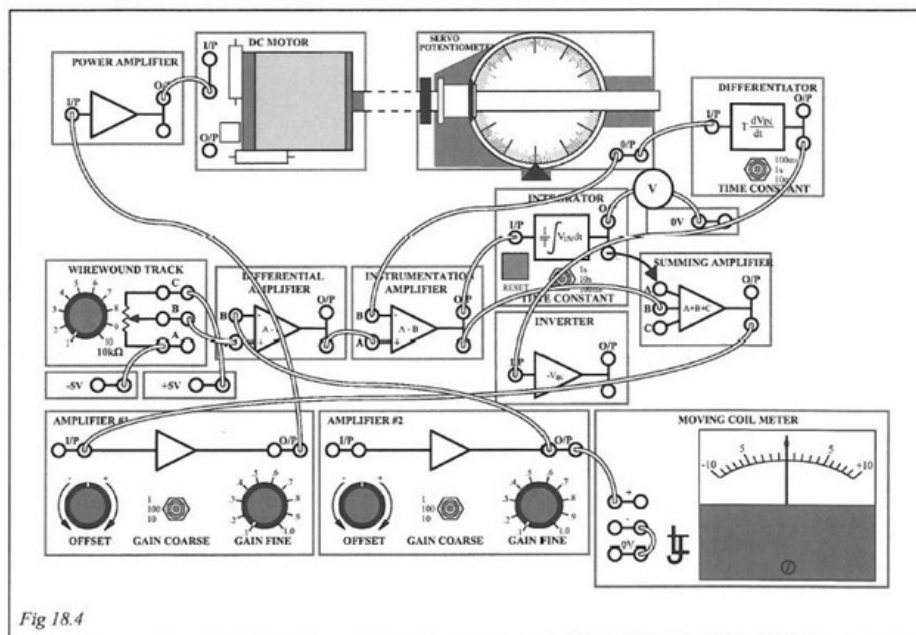


Fig 18.4

Figure 3

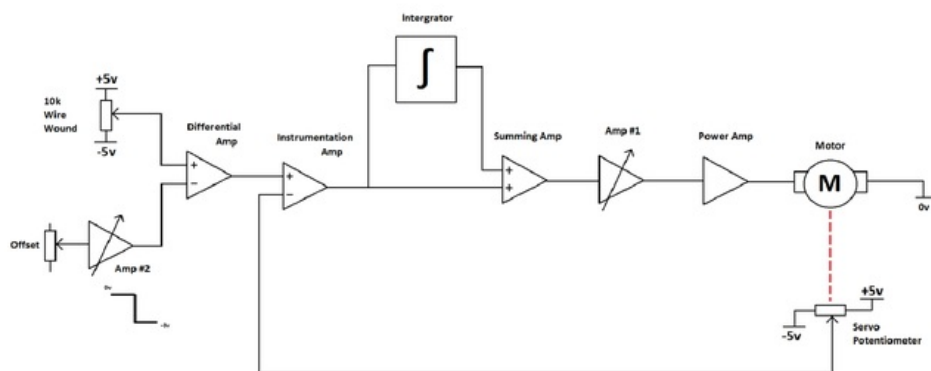


Figure 4

The next control system is the Proportional-Integral, which will be set up in accordance with **18.4[4]**, connected as shown above in **Figures 3 & 4**. The noticeable difference is that of the Integrator connected into the system. Amplifiers #1 & #2 gains, step input levels and zero adjustments are carried out, as well as the Integrator set-up, in accordance with **18.4[4]** of the set-up procedures.

The experiment carried out in **18.4a & 18.4b** is to trial and record the results of the voltage output from the integrator when Amp #2 command step input is applied. A table of results is then constructed to plot the voltage fluctuations of the integrator against the variations in the servo potentiometer's dial. Thereafter, the test will be carried out again, but with various Amp #1 gains (**18.4c, 18.4d, 18.4e & 18.4f**)[4] is conducted to compare system response speed and overshoots when Amp #1 gain is altered.

Then sections **18.4g & 18.4h**[4] is undertaken by altering the Integrator's time constant and observing the effects. A physical stimulus is also undertaken by physically moving the Hall Effect's disc and observing system response.

Proportional-Derivative

Proportional + Derivative Control

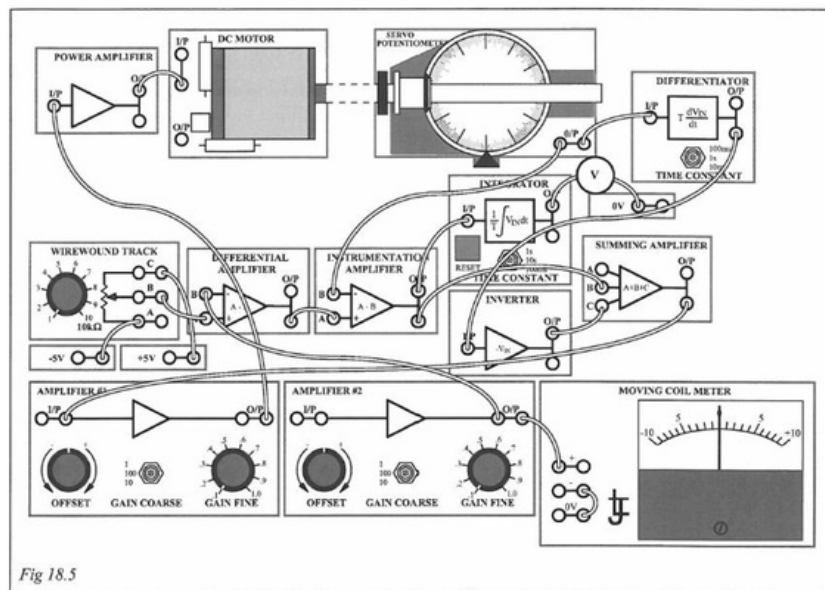


Fig 18.5

Figure 5

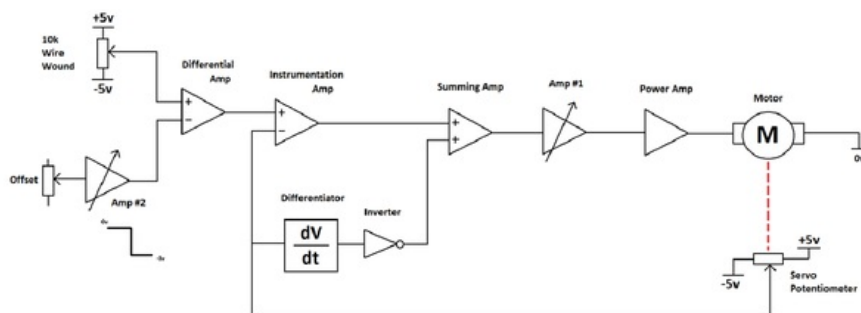


Figure 6

The Proportional-Derivative system set-up procedure is conducted in accordance to 18.5[4] & Figures 5 & 6 above. Test procedures 18.5a, 18.5b, 18.5c & 18.5d[4] is conducted to observe the return to zero of the servo's potentiometer, how the derivative control affects the system response and how altering the Differentiator's time constant alterations effects the damping of the system.

Proportional-Integral-Derivative

Proportional + Integral + Derivative Control

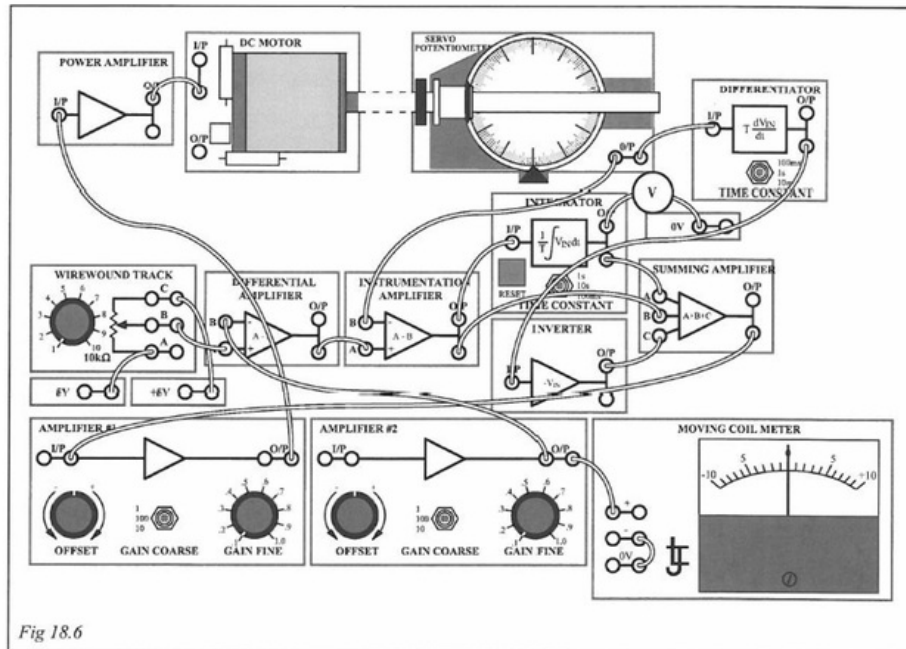


Fig 18.6

Figure 7

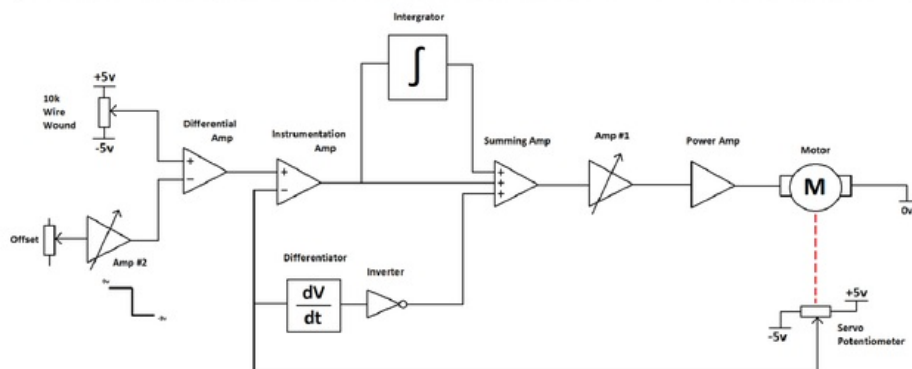


Figure 8

The Proportional-Integral-Derivative is set-up in conjunction with section 18.6[4] of the system set-up and adjustment procedures. The system will then be observed as a whole, to which includes all of the three components that form the PID controller. Results will be recorded in table 18.6[4], to which a sequence of combinations for both of the Integral and Derivatives time constants are altered. A total of 9 tests will be conducted. A decisional outcome will be made in 18.6a[4] for a desirable PID system.

IV. Results

Proportional

Following the instruction set in **18.3[4]**, the maximum dial readings are taken from the maximum extremities of the servo potentiometer dial. This is shown here in **Figure 9** with a system gain of **1.0**. The same test is carried out, but with Amp #1 gain set to **5.0**, and the system responded promptly with no lag as opposed to Amp #1 gain of **1.0** to which was.

Amplifier #1 Gain = 1.0	Positive	Negative
Maximum Dial reading (degrees)	149°	215°

Figure 9

Figure 9 shown above is the maximum angle reading from the servo dial when the 10kΩ resistor is turned positive to 10 and negative to 1, as 0/360° is zeroed in between 5 and 6 on the 10kΩ input resistor. The full range of movement taken from the results is +149° and -145°, so this shows an imbalance on the range.

The forthcoming set of results taken (**Figure 10**), is the readings from the servo dial at every control setting number. The test readings start from control setting '1' and increment to '10' and the servo dial angle is recorded into the table. Two sets of readings are taken and then averaged to improve

Control Setting	1	2	3	4	5	6	7	8	9	10
Servo-Potentiometer Dial Reading (deg.)	212	212	221	255	293.5	348	35	79	130	146
Plot	-148	-148	-139	-105	-66.5	-12	35	79	130	146
Reading 1	214	213	222	248	293	348	37	78	138	145
Reading 2	210	211	220	262	294	348	33	79	121	147

Figure 10

on the accuracy of the readings. The 'Plot' row is added to the table in order to transpose the angles into a graph format. The positive and negative values relate to either side of 0/360°

The same is carried out in reverse order, from control setting 10, and decrementing back to 1 and again, recording the servo dial readings, shown below in **Figure 11**

Control Setting	1	2	3	4	5	6	7	8	9	10
Servo-Potentiometer Dial Reading (deg.)	210	245.5	285.5	332.5	7.5	56	98.5	130	150	149.5
Plot	-150	-115	-75	-28	8	56	98.5	130	150	150
Reading 1	210	243	287	332	2	48	91	128	146	147
Reading 2	210	248	284	333	13	64	106	131	153	152

Figure 11

The readings here in **Figure 11** show that there is a deviation from the servo dial angle at each control setting compared to the first results, now the 0/360° and 0V midpoint has shifted down to between settings 4 and 5, whereas the first set of results show that the 0/360° is between controller setting 6 and 7.

Plotting these tables of results into a scatter graph visually shows that there are errors of the controller setting vs the servo dial readings. This 'gap' shown below in Figure 12 displays the systems 'Deadband' 1

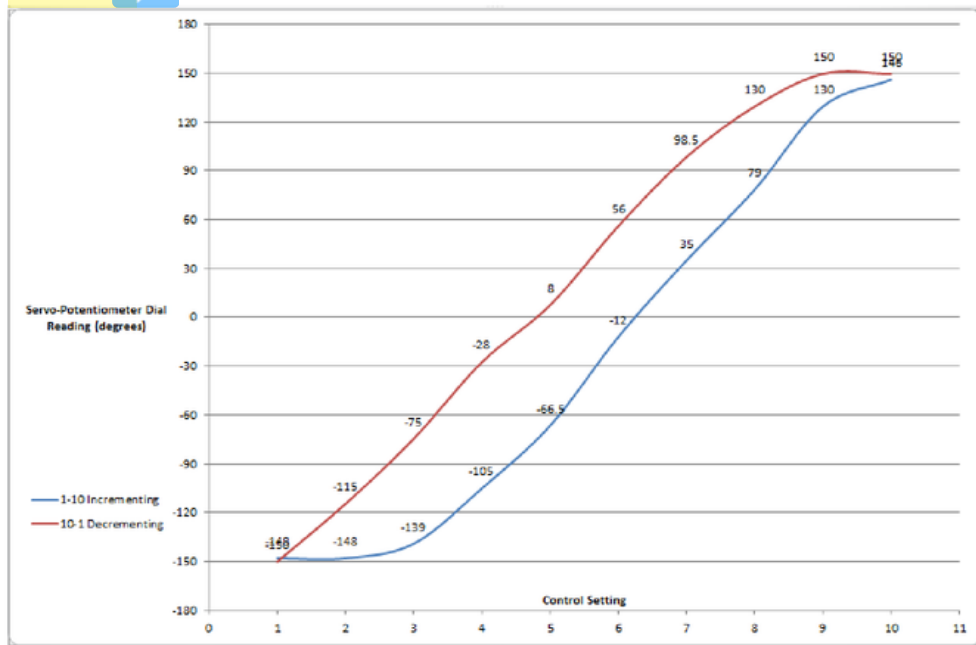


Figure 12

18.3b: The approximate control setting for 90° on the servo dial is between 6 and 8 according to Figure 12.

The deadband test is then undertaken in **18.3b-18.3d** by physically moving the motors shaft until resistance is felt (system response), in a common direction. Three tests are undertaken at three Amp #1 gains; 1, 5 & 10.

Amplifier #1 Gain	$10 \times 1.0 = 10$	$10 \times 0.5 = 5$	$10 \times 0.1 = 1$
Deadband (deg.)	6°	13°	75°

Figure 13

The results from the deadband test; shown above in Figure 13, result in a wider deadband at the lower gain, and narrower deadband at a higher gain.

18.3d: 'The value of deadband when Amp #1 gain is set to 5'; is 13°

18.3e-18.3g: The next test procedure was to command a stepped input from Amp #2 which is a 3V input. Amp #1 gain is initially set at 0.1, then 0.5 and 1.0. The test procedure requires the Amp #2 stepped input to be switched on the three variants of gains.

18.3e: 'The observed effect upon the system was that the speed of the motor was'; greatest with high gain. 2

18.3f: 'The effect of gain on the response to the stepped input was that the **overshoot** was also'; **greatest with high gain.**

The highest gain with a stepped input resulted in continuous rotation of the motors shaft. This is factored down to the momentum of the motor which caused 'overrun'.

18.3g: 'The proportional control system which has a **low gain** in the feedback loop had a'; **large deadband** and an **overdamped** response to the stepped input.

Proportional-Integral

18.4: This experiment is to observe and record the readings taken from the external DVM (Digital Volt Meter), which is connected to the output of the Integrator. This is to observe the long term effects of it when the commanded step input is switched on and off.

The table below (**Figure 14**) is the tabulated results when the stepped input from Amp #2 is switched from off (**Gain of 1**) to on (**Gain of 100**) **3V step** with varying Amp #1 Gains in the top row.

Task	18.4a & 18.4b			18.4c & 18.4d			18.4e & 18.4f		
Amp #1 Gain	1			5			10		
Amp #2 Gain	Digital Multi Meter (V)	Moving Coil Meter (V)	Servo Pot. Behaviour	Digital Multi Meter (V)	Moving Coil Meter (V)	Servo Pot. Behaviour	Digital Multi Meter (V)	Moving Coil Meter (V)	Servo Pot. Behaviour
1	Varies: -1.0 to 0.6	0	0	-0.33	0	0	0	0	0
100	Varies: -0.96 to 0.7	3	Fast → 210°, Slow → 254°	Slow Rise to 7	3	Huge Rotation	Fast Rise to 7	3	Huge Rotation
1	Varies: -1.0 to 0.75	0	0	0	0	0	0	0	0
100	Varies: -1.0 to 0.75	3	Fast → 210°, Slow → 254°	Swift Rise to 7	3	Rotation Increases to max. at 7	?	3	?

Figure 14

18.4a: 'The Integrator output voltage'; is still **varying after two minutes**, thus the servo dial was still adjusting.

18.4b: 'The Servo Potentiometer Dial setting'; **moves rapidly** towards target, **overshoots and returns.**

The test is repeated with varying gains to observe the behaviours, tabulated in **Figure 14** above.

18.4c: 'With Amp #1 gain set to **5** compared to the gain at **1**, the effect on speed of'; **response was faster.**

18.4d: 'With Amp #1 gain set to **5** compared to the gain at **1**, the effect was'; **continuous oscillation.**

18.4e: 'With Amp #1 gain set to **10** compared to the gain at **5**, the effect on speed of response was'; **faster.**

18.4f: 'With Amp #1 gain set to **10** compared to the gain at **5**, the effect was'; **continuous oscillation.**

The next task is to set Amp #1 gain to **10** overall and repeat test procedures with **10s** & **100ms** Integral time constants, and observe the overshoots of the servo dial.

18.4g: 'The time constant which gave the smallest number of overshoots was'; **10s**

The forthcoming test is to set the Integral time constant to **100ms**, Amp #1 gain set to **5** and physically displacing the motors shaft and releasing it to observe the effects in **18.4h** below.

18.4h: 'A very short time constant may result in'; **build-up of continuous running.**

Proportional-Derivative

18.5: The Proportional-Derivative experiment set-up procedure is conducted to **18.5** of this section, to where the system gain of Amp #1 is set to **1.0**. The Differentiator's time constant is set to **1s** initially, then **100ms** and **10ms** for the following tests. The stepped input from Amp #2 is applied and the following observations were observed;

18.5a: 'After the step input has been applied in both directions, the Servo Potentiometer dial reading'; **May not return to zero setting.**

18.5b. The Differentiators time constant is then set to **10ms**, then the motors shaft is physically displaced roughly $\frac{1}{4}$ turn from its stable position.

18.5b: 'Is there a tendency to re-adjust and correct the error?'; **No.**

18.5c: 'Derivative control affects the response:' **during change of output only.**

18.5d: 'Increasing the time constant of the differentiator:' **increases damping effect.**

Proportional-Integral-Derivative

18.6 The P-I-D controller is set-up in accordance to **18.6** of this section. Amp #1 is selected to gain of **1.0**. The experiment in this section is carried out to Table **18.6** of this section by applying the 3v stepped input from Amp #2, with varying Integrator and Derivative time constant sequences. The results are tabulated in **Figure 15** below.

Test	Integrator time constant	Differentiator time constant	Continuous running YES/NO	Response time SLOW/MEDIUM/FAST	Number of Oscillations	Notes
1	10s	1s	No	Slowest	∞	*[1]
2		100ms	No	Medium	Nil	
3		10ms	No	Fast	3	
4	1s	1s	No	Slowish	∞	
5		100ms	No	Mediumish	Nil	
6		10ms	No	Fastish	4	
7	100ms	1s	No	Slow	∞	
8		100ms	No	Medium	4	
9		10ms	Yes	Fastest	N/A	

Figure 15

* Notes:

[1] Moves towards target, continuously vibrates

[2] Continuously Overruns

18.6a: 'Which of the following is the most desirable characteristic for a positional control system?':
Slow response time, no oscillations.

V. Discussion

Proportional

The results from section 18.3 of the proportional system shows that the only adjustment within the system, to which is the Gain of Amp #1 (K_p), directly effects the behaviour of the system. As the results show, a low gain of 1.0 creates a time lag from the commanded input to the response of the motor. The system also failed to return back to its original position on the controller setting; therefore the controller setting midpoint and 0/360° mark on the servo dial could be seen shifting throughout the controller setting range. Figure 12 shows that the gain of 1.0 creates a large amount of deadband plotted graphically. Adjusting the gain of Amp #1 (K_p) to a higher values of 5.0 and 10.0 dramatically decreases the deadband of the proportional control system shown in Figure 13 and visually the response was more rapid.

Proportional-Integral

The proportional-Integral system results present the effect of the integrator component of the system. The table displayed in Figure 14 is the results taken from the digital volt meter of the integrators output, which can be seen that it is still varying overtime when a 3V stepped input is applied to the system with Amp #1 gain set to 1.0. To that effect, this constant 'back and forth' voltage adjustment by the integrator is the system constantly correcting itself to a finite error, which is seen as oscillations.

The same test was then preceded with different Amp #1 gains of 5 and 10 respectively. The observed results show that increasing the gain would increase the speed of the response to reach the target, but this resulted in continuous oscillations. With test 18.4g, the gain of Amp #1 is set back to 10.0 and the Integrators time constant is adjusted to 10s and 100ms and the stepped input is applied. The results from these two tests show that the higher time constant of 10s had the smaller amount of overshoots, but compromised the time taken to reach the target. This can be factored down to the greater number of samples that the Integrator applies.

Proportional-Derivative

Results from the Proportional-Derivative tests show that the Derivative component only applies when there is a change in output, and dampens the input of the system. Changing the Derivatives time constant to a longer sample value directly increases the damping rate of the system. It was also noted that when the stepped input was returned to zero, the servo dial would not return back to zero, this is due to the change in output damping the system in both directions of the stepped input command.

Proportional-Integral-Derivative

The PID system was conducted with a total of 9 tests, as the Integrator and Differentiator has 3 time constants for each, Tests 1, 4 & 7 show from section 18.6 and Figure 15 that when the Differentiator's time constant set to 1s, the system would continuously oscillate, despite the integrators time constants. Test 1 resulted in continuous vibration when it reached to the target, and

took the longest out of the 9 tests to reach it. Test 9 resulted in continuous overrunning. As the table of test results show from [Figure 15](#), the PID system can be tuned to achieve an ideal stable system.

VI. Conclusion

Proportional

- Proportional gain is directly coherent with the response speed of the output
- Increasing the gain decreased the deadband error

Proportional-Integral

- Increasing the system gain increased the response speed, but increased overshoots
- Increasing the time integrators time constant decreases the overshoots, but sacrificed speed of response

Proportional-Derivative

- Derivative control only applied when there was a change in the output
- Increasing Derivatives time constant created more 'Damping' effect.
- System would not return to zero when input was returned to zero

Proportional-Integral-Derivative

- Varying the combinations of the Integrator and Derivatives time constants create a 'Tuned' system that can acquire suitable damping and response rates.
- Very easy to create an unstable system if either time constants are inappropriately selected.
- Ideal configuration is that with no overshoot that can reach the target in quick fashion.

VII. References

[1] Proportional Definition <http://www.dictionary.com/browse/proportional>

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[4] LJ Create P P-I P-D P-I-D Controllers IT02 Curriculum Manual Chapter 18:
<http://moodle.swanseamet.uwtsd.ac.uk/course/view.php?id=2284>

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VIII. Figures

Figure 1: Proportional LJ Create Set-up

Figure 2: Proportional Schematic

Figure 3: Proportional Integral LJ Create Set-up

Figure 4: Proportional Integral Schematic

Figure 5: Proportional Derivative LJ Create Set-up

Figure 6: Proportional Derivative Schematic

Figure 7: Proportional Integral Derivative LJ Create Set-up

Figure 8: Proportional Integral Derivative Schematic

Figure 9: Proportional Maximum Dial Reading

Figure 10: Proportional Control Setting Increment Table of Results

Figure 11: Proportional Control Setting Increment Table of Results

Figure 12: Proportional Results Scatter Graph

Figure 13: Proportional Deadband Results Table

Figure 14: Proportional Integral Table of Results (18.4a →to→ 18.4f)

Figure 15: Proportional-Integral-Derivative Table of Results (18.6)

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Instrumentation & Control Assignment 2

GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

Instructor

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Comment 1

Although it is related to the deadband of the system, the graph actually shows the hysteresis of the system.



Comment 2

The questions in the instruction sheet were supposed to be used as launch pads for discussion in your report and should not have been answered directly.

PAGE 14

GRADING FORM: SMU GENERIC_GJ

CHRISTOPHER BUDDEN**55.65****RESEARCH-INFORMED LITERATURE**

References to a limited range of mostly relevant sources. Some omissions and minor errors. Referencing conventions evident though not always applied consistently. Your reference list and bibliography should be combined into a single section and each source should be individually numbered.

10.5**KNOWLEDGE AND UNDERSTANDING**

Knowledge is accurate with a good understanding of the field of study.

17.1**ANALYSIS**

Sound, logical, analytical thinking; synthesis and evaluation. Ability to devise and sustain persuasive arguments, and to review the reliability, validity &

19.5

significance of evidence. Ability to communicate ideas and evidence accurately and convincingly.
Sound, convincing conclusions / recommendations.

PRACTICAL APPLICATION AND DEP.



A good and appropriate application of standard methods, materials, tools and/or techniques. Good appreciation of the context of the application, with some use of examples, where relevant.

5.8

SKILLS FOR PROFESSIONAL PRAC.



Can communicate effectively in a suitable format, but may have minor errors. Mostly coherent work and is in a suitable structure.

2.75