

M5X00940 (QQ) Asst 2, Kenny Johnston

by Kenny Johnston

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Instrumentation and Control

Technical Report

Module M5X00940

Positional Control Systems:

How far, how quick and how bumpy?

For Dr Stephen Mosey

By

Kenny Johnston (P148567)

To investigate the performance of positional controllers four designs were presented for construction and analysis. Each increasingly complex design was constructed and tested with the aim of finding both stable and unstable performance. An electronic learning aid, using a plug-board connecting system, was used to build, calibrate and test each circuit design. It was found that each controller had both benefits and drawbacks, and proved that more complex systems do not always function better than less developed ones. The main conclusion drawn from the investigation was that while no one controller type is perfect, each have specific characteristics that make them suited to certain types of control solutions. From the first, simplest design, it was seen that preconceptions were incorrect and some results were quite unexpected.

1. Introduction

A control system is designed to automate a function, or sequence of functions, with one or more variable inputs which are acted upon by operational parameters or 'rules' which have been developed to ensure the output will only vary within acceptable parameters. The automation of this function, or sequence of functions, may be desired for safety reasons, a human presence while manufacturing toxic or explosive compounds, in extreme temperatures or harsh working environments, perhaps the function is laborious, repetitive, time consuming or requiring a high degree of accuracy. Automation may increase productivity or reduce cost.

The re-filling of a toilet cistern is a control system operation: The input (water) is subject to control (float arm controlled valve) which produces the desired output (full cistern) to within a desired tolerance (correct fill level). This operation is completed without the need for human intervention and has a repeatable, within tolerance, result. A failure in the control method will produce out of tolerance results – a dry cistern or a wet floor.

There are several types of control systems Sometimes used individually, but mostly in a combination to produce a desired result. P controllers are designed such that "the output has a linear relationship with the input".^[1] An Integral Controller "drives the system to a zero steady-state error."^[2] Whereas a Derivative controller "acts on the derivative or rate of change of the control error", as a result, they "will produce large control signals in response to high frequency control errors such as set point changes (step command)"^[3]

2. Method

An L J Create™ Transducer and Instrumentation Trainer (D1750)^[3] as seen in Figure 1 was provided with the associated Curriculum Manual, Chapter 18 “Practical Control Systems”^[4].

The instructions in Sections 18.3 to 18.6 inclusive provided circuits to construct for P, PI, PD and PID positional control systems. Each circuit was constructed, tested and each result recorded for analysis.

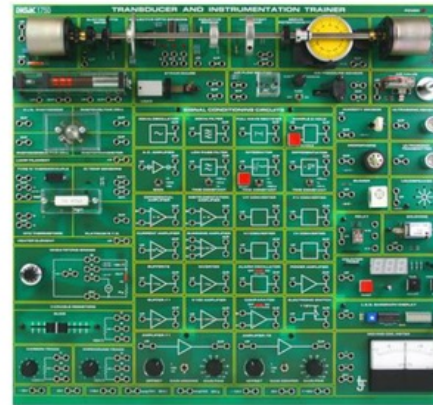


Figure 1: L J Create D1750 Trainer

3. Results

Each of the four circuits shown in Figures 2, 4, 5 & 6 were constructed in turn. At the start of each test procedure, Variable Amplifier 1 was calibrated for a system gain ($G(s)$) of 1, Variable Amplifier 2 for a gain of 1 providing a near-zero output of 0.03V – centring the moving coil meter on zero, the 10kΩ potentiometer set for 0V output, and the servo potentiometer dial reset to read zero degrees.

3.1 Proportional (P) Controller

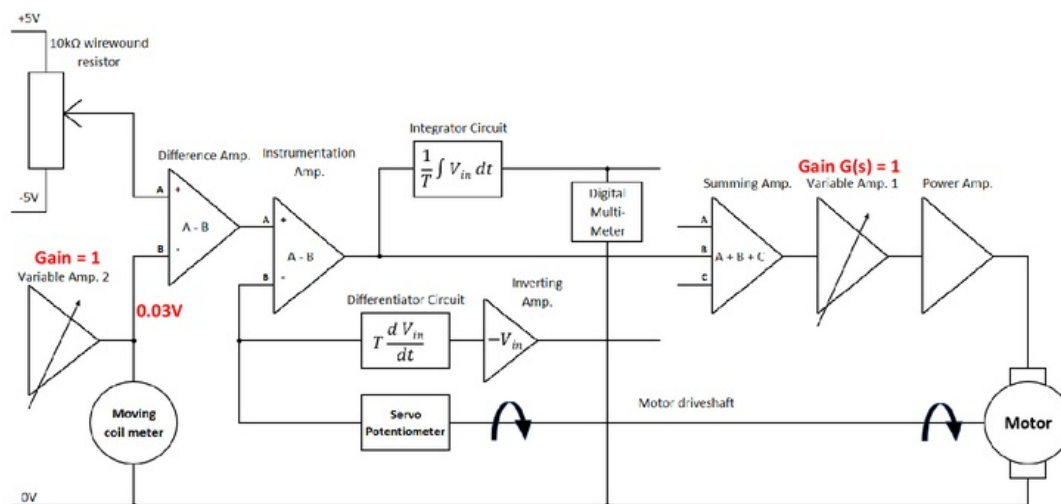


Figure 2: Proportional Controller circuit diagram

The circuit shown in Figure 2 was constructed and tested under the criteria laid out in Chapter 18.4 of the Curriculum Manual^[4].

When the 10k Ω pot. was rotated slowly to its fullest extents clockwise and anti-clockwise, the motor turned slowly, rotating the drive-shaft, causing the servo pot. to rotate in turn. The servo pot. dial indication was read and the recorded in Table 1.

Variable Amplifier 1 Gain $G(s) = 1$	Positive rotation (Clockwise)	Negative rotation (Anti-clockwise)
Max. Servo Pot. Dial reading (Degrees)	148.5	215

Table 1: P controller results when $G(s) = 1$

The 10k Ω pot. was reset to the central position and Amplifier 1 gain, $G(s)$ was increased to 5. As the pot. was rotated slowly to each of its settings, the servo pot. dial was read. Note how the clockwise rotation results do not match the anti-clockwise results.

Pot. Control Setting	1	2	3	4	5	6	7	8	9	10
Forward (1)	214	213	222	248	293	348	037	078	138	145
Forward (2)	210	211	220	262	294	348	033	079	121	147
Reverse (1)	210	243	287	332	002	048	091	128	146	147
Reverse (2)	210	248	284	333	013	064	106	131	153	152

Table 2: Servo Pot. readings when $G(s) = 5$

The distinct differences between clockwise and anti-clockwise rotation results are more obvious when plotted against the Pot. control settings, as shown in the graph below. Note: The dial readings are plotted as ± 0 degrees, not absolute values.

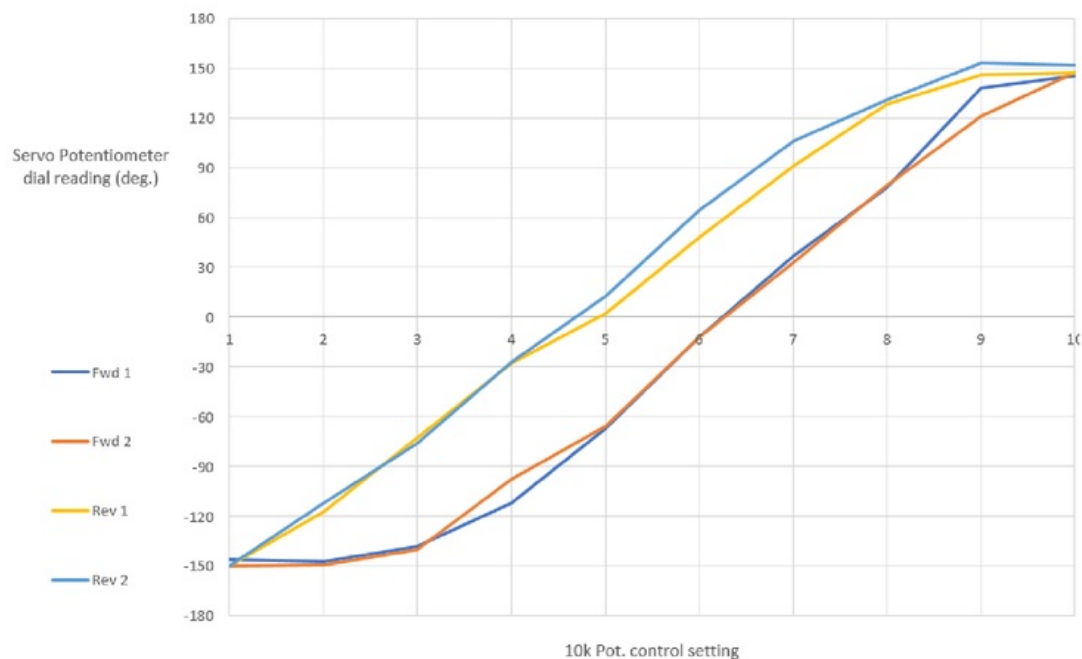


Figure 3: Servo Pot. rotation versus Potentiometer setting graph when $G(s) = 5$

Amplifier 1 gain, $G(s)$, was then set to 10 and the dead-band over which the system does not respond was recorded. This was repeated for gain values of 5 and 1. The results are shown in Table 3 below.

Amplifier 1 Gain, $G(s)$	$10 \times 1.0 = 10$	$10 \times 0.5 = 5$	$10 \times 0.1 = 1$
Dead-band (deg.)	6	13	75

Table 3: Dead-band readings when $G(s) = 10, 5$ and 1 respectively

3.2 Proportional – Integral (PI) Controller

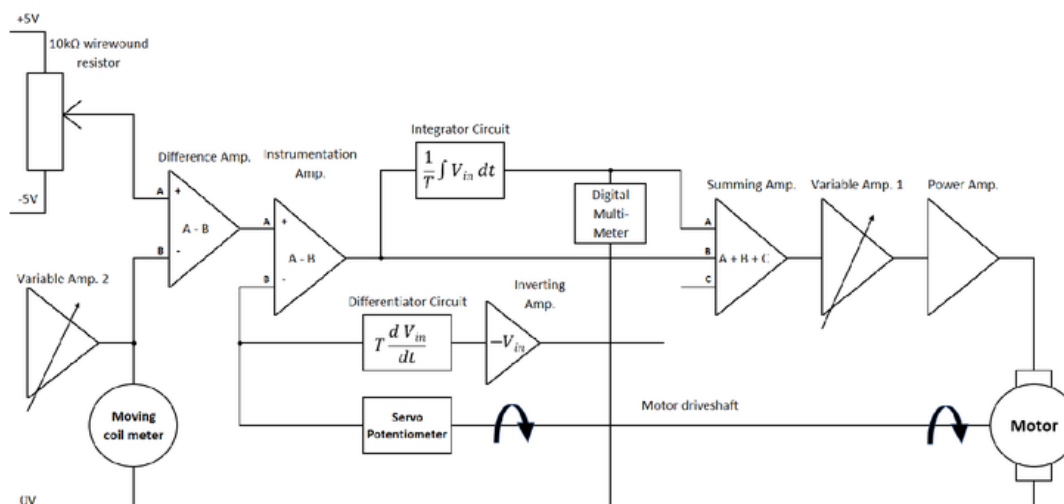


Figure 4: PI Controller circuit

The PI circuit shown in Figure 4 was constructed and tested under the criteria laid out in Chapter 18.4 of the Curriculum Manual^[4]. Initially, Variable Amplifier 1 was set for a system gain of 1. The tests were repeated for system gains of 5 and 10. The results obtained are detailed in Table 4 below. Note the Integrator portion of the circuit has now been connected.

Amp 1 gain	1			5			10		
Amp 2 gain	DMM (V)	MCM (V)	Servo Pot. behaviour	DMM (V)	MCM (V)	Servo Pot. behaviour	DMM (V)	MCM (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	Slow rise to max. rotn. at 7V	?	3	?

Table 4: PI Controller response to a Step Input change with set system gains.

3.3 Proportional – Derivative (PD) Controller

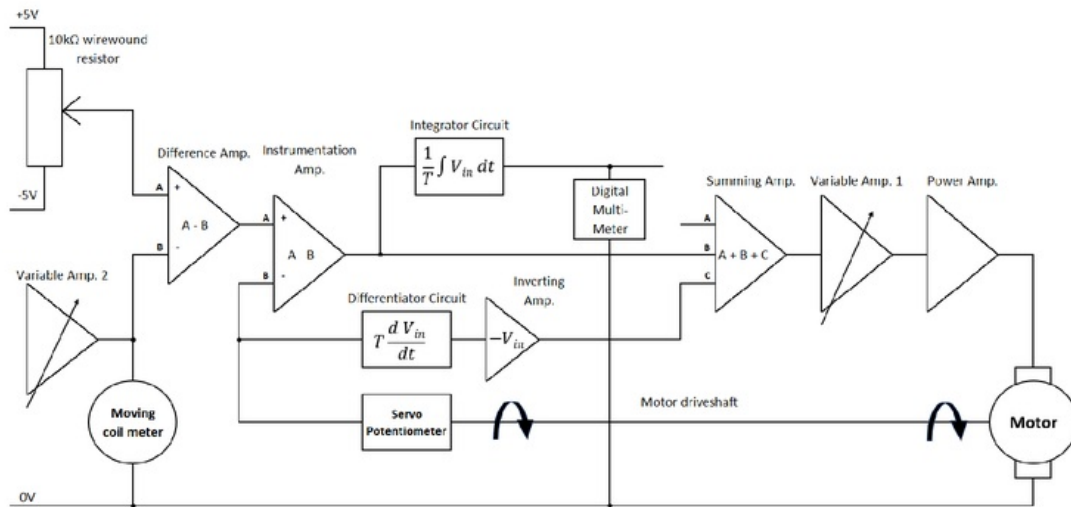


Figure 5: PD Controller circuit

The circuit shown in Figure 5 was constructed and tested in accordance with Section 18.5 of IT02^[4]. Note that the Integrator portion of the circuit has been disconnected and the Differentiator circuit connected.

The Differentiator time constant was set to 10 seconds and Amp 2 gain – providing the step input of zero to -3v – was switched back and forth between 1 and 100. The servo potentiometer dial was seen to rotate rapidly, followed by a rapid stop with approximately 5 overshoots, before slowly returning to zero.

The Differentiator time constant was then changed to 1 second and Amp 2 switched as previously. The servo potentiometer dial began to rotate slowly at first, slowly accelerated to maximum speed.

The Differentiator time constant was then changed to 0.1 seconds and Amp 2 switched as before. The servo potentiometer dial began to turn slowly, then rapidly accelerated to maximum speed.

3.4 Proportional – Integral – Derivative (PID) Controller

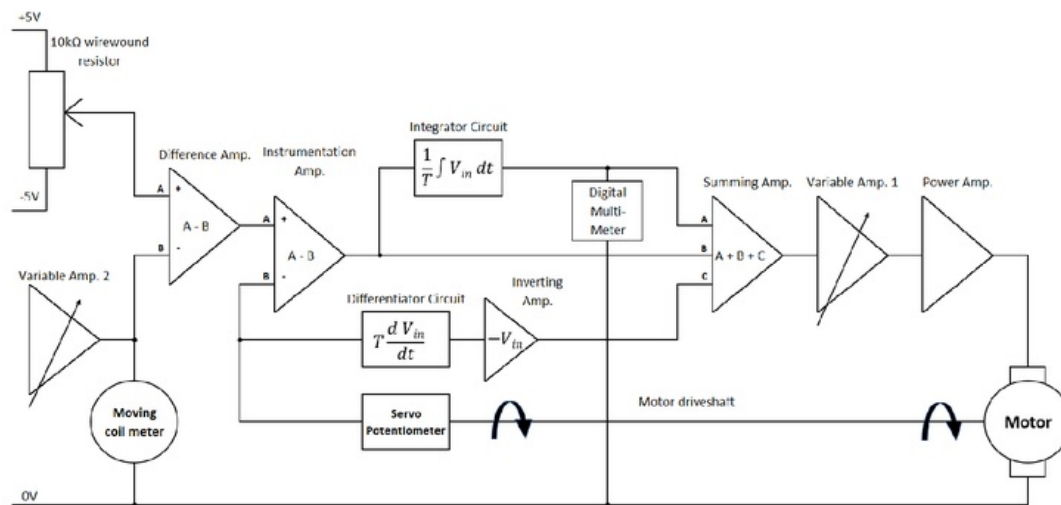


Figure 6: PID Controller circuit

The circuit shown in Figure 5 was constructed and tested in accordance with Section 18.6 of IT02^[4]. Note the reconnection of the Integrator portion of the controller. Table 5, below, shows the results obtained and the observations gathered when the Integrator and Differentiator time constants were tested in various combinations.

Test	Integrator time constant	Differentiator time constant	Continuous running (Yes/No)	Response Time (Slow/Med/Fast)	Number of Oscillations
1	10s	1s	No	Slow	Infinite
2		100ms	No	Medium	Nil
3		10ms	No	Fast	3
4	1s	1s	No	Slow	Infinite
5		100ms	No	Medium	Nil
6		10ms	No	Fast	4
7	100ms	1s	No	Slow	Infinite
8		100ms	No	Medium	4
9		10ms	Yes	Fast	Stable

Table 5: PID behaviour using different time constants.

It was noted that each test conducted using a common Differentiator time constant – tests 1, 4 and 7, tests 2, 5 and 8 and tests 3, 6 and 9 all produced very similar behaviour in the servo pot. dial but these were significant enough to warrant further testing that might provide more data for analysis. Therefore, the tests were re-ordered and conducted as shown in Table 6, over.

Test	Integrator time constant	Differentiator time constant	Continuous running (Yes/No)	Response Time (Slow/Med/Fast)	Number of Oscillations
1	10s	1s	No	Slowest	Infinite
4	1s	1s	No	Slowish	Infinite
7	100ms	1s	No	Slow	Infinite
2	10s	100ms	No	Medium/slow	Nil
5	1s	100ms	No	Mediumish	Nil
8	100ms	100ms	No	Medium/fast	4
3	10s	10ms	No	Fast	3
6	1s	10ms	No	Fastish	4
9	100ms	10ms	Yes	Fastest	Stable

Table 6: PID behaviour using different time constants and re-ordered testing.

4. Discussion

4.1 Proportional (P) Controller

Initially, the P controller behaved exactly as expected. The controlling input – the 10k Ω potentiometer – was turned back and forth, producing a respective change in the observed output – the servo pot. dial. However, it was quickly noticed that the dial did not return to the initial zero setting when the pot. was returned to the centre position.

Additionally, the forward and reverse results – shown in Figure 3 – demonstrated the ‘dead band’ phenomenon. (“The range through which an input can be varied without initiating a response.”^[5]) This response was investigated further with different system gain settings. The results in Table 3 demonstrate how the dead-band phenomenon is inversely proportional to the system gain. This was not expected as it was presumed that errors margins would increase with gain. Observed results demonstrated that a high gain P controller will have a rapid speed and a large overshoot response. Lower system gains respond less rapidly but also with less of an overshoot.

4.2 Proportional – Integral (PI) Controller

The PI controller circuit produced some thought-provoking results. It was assumed that the addition of an Integral control function would stabilise the system and result in a reduction of error in the controller output. The results recorded in Table 4 demonstrate that a low gain system produces the most stable output. A higher system gain does produce a more rapid response in the output, but also induces instability in the output causing the motor to continuously run. The time constant which the Integrator function operates with was also used to test the characteristics of the controller. When the time constant was varied, it was found that the longer the delay, the more stable the output.

4.3 Proportional – Differential (PD) Controller

The PD controller was expected to have a rapid initial response, but the residual behaviour was not speculated on. A short time constant produced caused a slow rotation initially which rapidly built up to maximum speed. The time constant was increased and, as before, initially rotation was slow, but increased only slowly to maximum speed. The time constant was increased again but when the step input was applied, the servo pot. dial moved rapidly then slowed rapidly, with increasingly dampened oscillations before coming to a complete stop. It has been demonstrated that Derivative control is only operational when there is as change in output and that an increased time constant increases the damping effect of that output signal.

4.2 Proportional – Integral – Differential (PID) Controller

The final element in our Positional Controller analysis was the construction of a PID circuit. The results shown in Tables 5 & 6 show that of all nine Integrator and Differentiator time constant combinations only one created a continuously running motor. Three of the other combinations produced a continually oscillating motor and a further three produced a limited oscillation before coming to a complete halt. The remaining two combinations caused the motor to move to the desired position and halt. The testing procedure dictated that the Integrator time constant remain fixed while the Differentiator time constant was switched and the responses recorded. After completing these tests, it was noticed that there were similarities in the controller performance when the Differentiator time constants were the same. The tests were re-organised and repeated (Table 6). This shows that an increase in Differentiator time constant causes the controller to act more slowly but also creates an infinite oscillation. A short time can be stable, but can also cause continuous rotation. Table 6 shows how a medium Differentiator time constant is the most stable with any combination of Integrator time constant.

5. Conclusion

Proportional controllers are stable, lack accuracy and have a significant error in the dead-band portion of the controller response. The Integrator control circuit provided a level of instability and inaccuracy with an increasing time constant but with a reduced dead-band. The Differentiator control circuit performed well, producing a rapid response with a longer time constant applied, smaller values caused instability in the output. When all three controllers are combined in a PID circuit the stable responses are only available with medium response speeds. Too slow or too fast can produce unwanted output responses. Positional controllers are not perfect in operation but each type performs well in specific areas and within certain user desired parameters, there is no single positional controller that will solve all problems.

6. References

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4. LJ Create. "An Introduction to Transducers and Instrumentation" Internet: <https://www.scribd.com/document/246850840/Manual-for-D1750-pdf> [13/06/17]
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FINAL GRADE

GENERAL COMMENTS

Instructor

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GRADING FORM: SMU GENERIC_GJ

KENNY JOHNSTON

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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.

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

19.5

PRACTICAL APPLICATION AND DEP.

 A very good application of a range of methods, materials, tools and/or techniques. Very good consideration of the context of the application, with perceptive use of examples, where relevant. Evidence of some innovation and creativity.

6.6

SKILLS FOR PROFESSIONAL PRAC.

 Can communicate well, confidently and consistently in a suitable format. Work is coherent and fluent and is well structured and organised.

3.25