

assignment 1

by Joseff Jones

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HND Electrical and Electronic Engineering

PSDE5011 – Control and Instrumentation

Assignment 1 – Control System Analysis,
Modelling, Simulation and Practical Testing

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Table of Contents

1. Research.....	4
1.1. Flow Measurement Using a Range of Transducers and Signal Conditioning Methods	4
1.2. The Flow Measurement System and Control Loop used in the Bytronic Process Rig	8
1.3. The Caldwell Method of Modelling Control Systems from Process Reaction Data.....	9
1.4. Ziegler-Nichols Methods of Tuning a PID Controller from Process Reaction Data	11
2. Flow Control System Modelling, Simulation and Testing	15
2.1 - Modelling	15
2.2 - Simulation	19
2.3 – Testing.....	23
3. Conclusion and Recommendations.....	27
4. Citation List	28
5. Appendices.....	29

Table of Figures

Figure 1 - Basic Measurement System Block Diagram.....	4
Figure 2 - Venturi Tube Visual from solitaryroad.com.....	5
Figure 3 - Turbine Flow Meter Graphic from www.pwagroup.com.au	6
Figure 4 - Ultrasonic Time of Flight Flowmeter Graphic from (en.supmea.com)	7
Figure 5 - Caldwell Process Reaction Data - 73% of Max Potential	9
Figure 6 - Caldwell Process Reaction Data – Fractional Response at $T_1+T_2/2$	10
Figure 7 - Ziegler-Nichols Process Reaction Curve.....	11
Figure 8 - Flow Measurement System Process Reaction Curve.....	12
Figure 9 - Simulink Complete System Model.....	15
Figure 10 - Step Input Parameters.....	16
Figure 11 - Lookup Table Values	16
Figure 12 - Transfer Function Parameters	17
Figure 13 - Transport Delay from Process Reaction Curve	18
Figure 14 - Transport Delay Parameters	18
Figure 16 - Simulink Tuned Values.....	20
Figure 17 - Most Optimal Simulated Parameters	20
Figure 18 - Ziegler-Nichols PID Parameters	21
Figure 19 - Simulation Results.....	22
Figure 20 - Practical Test #1	23
Figure 21 - Practical Test #2	24
Figure 22 - Practical Test #3	25
Figure 23 - Practical Test #4	26

1. Research

Research into several areas related to systems was carried out in order to gain an understanding of measurement, modelling, and tuning to be able to compare theory with simulation and practical results, which were carried out later on and are included in section two of the report.

1.1. Flow Measurement Using a Range of Transducers and Signal Conditioning Methods

Flow, whether that be liquid or gas flow, is a physical quantity that can vary depending on many factors, most of which can be controlled from within systems. Because of this, measuring flow is an important aspect of any system involving liquids or gases, and so comes the demand for a measurement system.

Design of a Basic Measurement System

A basic measurement system involves using a sensing element, signal conditioner, signal processor and a display, to - measure a physical quantity or property, transform it into a signal more suitable for processing, make it more comprehensible for an observer of the system, and then display it to the observer, respectively. The figure below shows the design of a basic measurement system, whether that be for flow or otherwise.

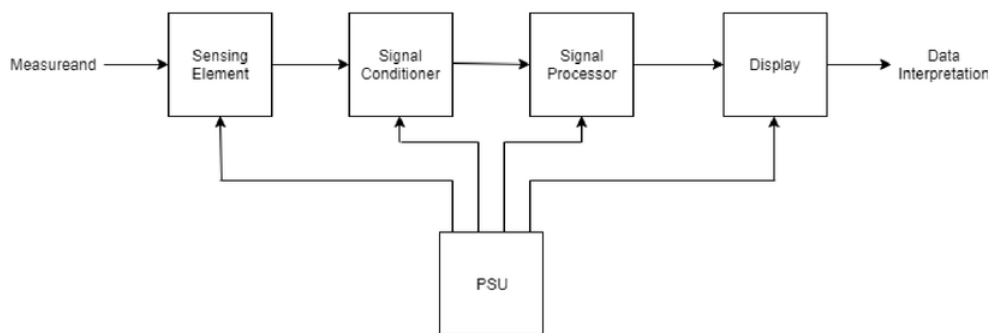


Figure 1 - Basic Measurement System Block Diagram

The sensing element converts the measureand (the physical quantity or property being measured) into an electrical signal; this electrical signal is either analogue, where it's measured in current or voltage, or digital, where it's often measured in binary. Because the sensing element's measurements are raw values, the signal conditioner is used to convert those raw values into values more easily processed by the signal processor (an example is an ADC which converts analogue to digital, or a filter which removes any parts of the signal that might be unnecessary). The signal processor then converts those processed value into values which are more legible to the observer. The output value of the signal processor is then sent to the LCD, which is typically an LCD/HMI in modern systems, or needle for older systems. The power supply is required to power the parts of the system, where each part is connected to a common zero volts. Bentley states that depending on the system, each element of the measurement system may occur more than once or may even be missing. [Cite your source](#)

Types of Transducers used for Flow Measurement

Measurement of flow is an important aspect in a wide-range of industries including those where there are systems for food, chemicals and oil. Methods of flow measurement differ depending on the types of transducers used and vary in accuracy, precision, resolution, sensitivity, cost and several other characteristics. Some of the most common types of transducers for flow measurement are pressure, electromagnetic, and ultrasonic.

Pressure – Pressure transducers are used in a method called differential pressure. In a pipe, the volume of fluid passing through a specific point is determined by $A * v$, where A is the cross-sectional area and v is the velocity. If that pipe is then constricted with the same volume of fluid passing through, the velocity then increases to compensate; velocity is therefore inversely proportional to cross-sectional area. Because the velocity is increased when passing through the constricted pipe there must be an acceleration, this acceleration is caused by a force which comes from the pressure in the fluid dropping due to the constriction (this is called the venturi effect). At a basic level, the differential pressure method involves purposely constricting a pipe to create this increased pressure and then measuring the difference between pressures at the non-constricted point and the constricted point of the pipe with pressure transducers, then using that difference to measure the flowrate. Bolton states that “the relationship between the pressure drop and the volume rate of flow is non-linear, i.e. the flow rate is not directly proportional to the pressure difference but to the square root of the pressure difference” (2015, p. 27). There are a number of devices that make use of differential pressure to gauge flowrate, the most fundamental type being the venturi tube; the figure below shows a diagram of a venturi tube.

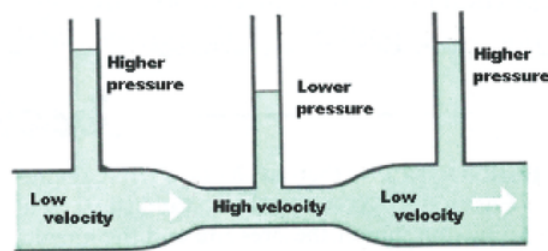


Figure 2 - Venturi Tube Visual from solitaryroad.com

Generally, the venturi tube is strictly used with liquids because gas is more compressible than liquid and therefore produces inaccurate readings. The venturi tube is capable of being as accurate as $\pm 0.5\%$ and is very robust but isn't the cheapest of options as far as differential pressure devices go.

A typical pressure transducer might measure in mV/bar. Because the transducer would produce a mV output, a suitable signal conditioning method to use would be an amplifier, to convert the mV into V; specifically, a 4-20mA isolated CM008 signal conditioner from Pico Technology might be used, as these are typically paired with pressure transducers.

Magnetic Flow Transducers – magnetic flow transducers are paired with a device called a turbine flowmeter for flow measurement. Turbine flowmeters consist of a multi-bladed rotor made of ferromagnetic material which is placed in a stream or tube with flow, suspended in a position so that the axis of the rotor is parallel to the direction of flow. The principle of the turbine flowmeter is that the flow will rotate the ferromagnetic blades at a velocity proportional to flow rate, these blades then induces an AC voltage across a coil connected in the housing of the turbine flowmeter. The frequency of the induced AC voltage can then be used to determine the flowrate in the tube, as the frequency of the voltage is proportional to the flow velocity. The figure below shows a diagram of a turbine flowmeter, where the pickup is the magnetic flow transducer.

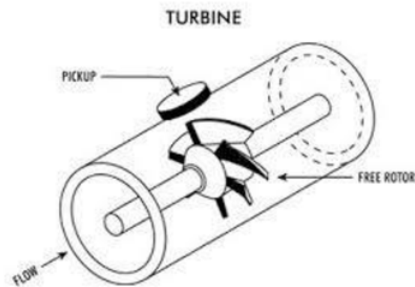


Figure 3 - Turbine Flow Meter Graphic from www.pwagroup.com.au

The turbine flowmeter is very reliable but is relatively expensive; Bolton states that it “has an accuracy of about $\pm 0.1\%$ ” (2015, p. 29). A suitable signal conditioner for the turbine might be an ADC, to convert the analogue output into a digital for further processing.

Ultrasonic Flow Transducers – this type of transducer is used in a device known as an ultrasonic time of flight flowmeter which uses ultrasonic waves to measure the flow rate of a fluid. There are two configurations for an ultrasonic time of flight flowmeter in a pipe – the first is to have a pair of ultrasonic transmitters on one side of the pipe and a pair of ultrasonic receivers (or transducers) on the other side. The other configuration is to have a transmitter and a receiver on a single side of the pipe with a reflector on the other side. With both configurations, the transmitters/receivers/reflector are angled so that one beam of ultrasonic waves is moving in the direction of flow and one beam is moving against the direction of flow. The receivers then either measure the flowrate of the travelling liquid by averaging the travelling time of the ultrasonic waves or by estimating the frequency shift using the Doppler effect. Figure 4 visualises this.

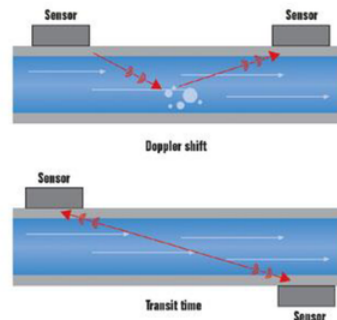


Figure 4 - Ultrasonic Time of Flight Flowmeter Graphic from (en.supmea.com)

Bolton states that “Ultrasonic methods can be used for pipes from 75mm to 1500mm diameter, with fluid velocities from about 0.2m/s to 12m/s with an accuracy of about $\pm 1\%$ or better” (2015, p. 30). A suitable signal conditioner for ultrasonic flow transducers might be an amplifier to make a weak signal bigger.

1.2. The Flow Measurement System and Control Loop used in the Bytronic Process Rig

The Bytronic process rig uses a turbine flowmeter with the LM2917 tachometer as the transducer to measure flowrate by turning frequency to volts. The LM2917 tachometer is

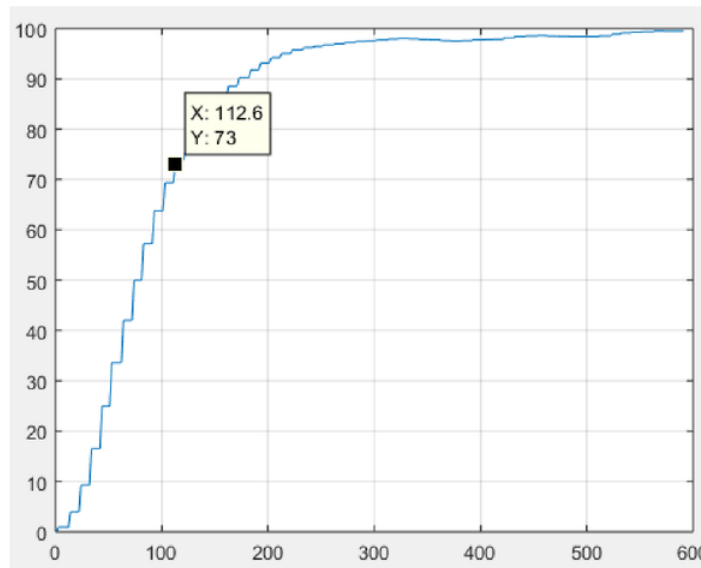
The signal produced from that is then conditioned so that it is outputting a 0-5V range to the PLC, so that the PLC can use PWM to control the speed of the flow. The whole system can be monitored on a control console; the control console also allows values of derivative gain, proportional gain and integral gain (denoted as k_d , k_p and k_i respectively) to be altered. According to the bytronic.net website, the console also includes fault switches and test points from all transducers.

1.3. The Caldwell Method of Modelling Control Systems from Process Reaction Data

In order to derive the transfer function needed to model, simulate and test a control system, a method called the Caldwell method is used. This method involves using process reaction data, measuring specific points of the reaction data, and some calculations to derive the transfer function. This method was used during the assignment to model the flow control system, an explanation of how it was done is shown below.

Modelling the Flow Control System Using Caldwell's

The first part of the Caldwell method is to look at the process reaction data and determine the point at which the system is at 73% of its max potential; this has been done and shown in the figure below.



This is the research section and should only refer to published sources. Your actual model development should come in the next section.

Figure 5 - Caldwell Process Reaction Data - 73% of Max Potential

What's to be observed from this data is at what time the system is at 73% of the max potential – as seen in the figure above, the result is 112.6, but that's in milliseconds and so the actual value is 0.1126s – this value is denoted as t_y . The next step is determine the value of $T1 + T2$ by dividing t_y by a set value of 1.32.

$$T1 + T2 = \frac{t_y}{1.32} = \frac{0.1126}{1.32} = 0.0853s$$

These calculations belong in the next section.

The next step is to find the fractional response at the time $\frac{T1+T2}{2}$.

$$\frac{T1 + T2}{2} = \frac{0.0853}{2} = 0.04265s$$

The value of 0.04265s was marked on the process reaction data to determine the point at which this occurs, shown in the figure below.

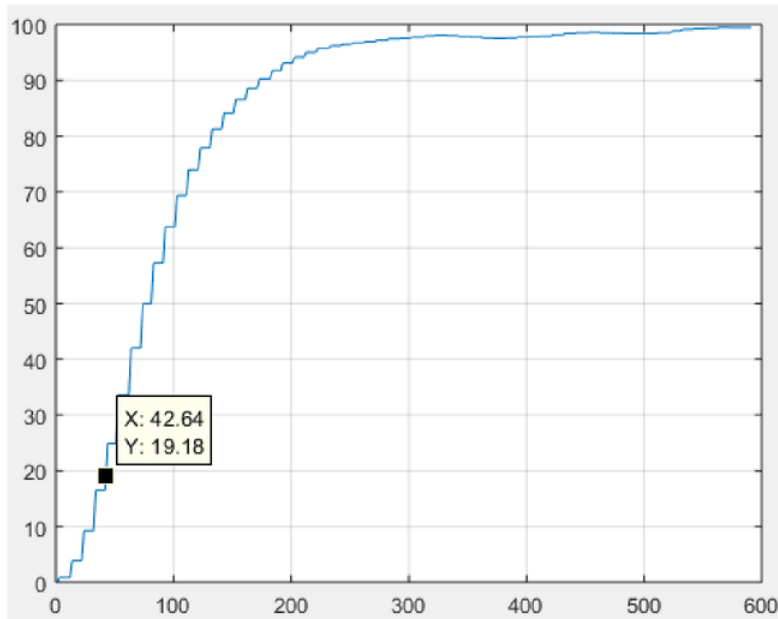


Figure 6 - Caldwell Process Reaction Data – Fractional Response at $T_1+T_2/2$

The fractional response at 0.04265s is 0.1918.

In the appendices of this report is a Caldwell reference graph, that graph shows that the width of $\frac{T_2}{(T_1+T_2)} = 0.5$. From this, it can be deduced that:

$$T_2 = 0.5 * (T_1 + T_2) = 0.5 * 0.0853 = 0.04265s$$

From this, T_1 can also be determined:

$$T_1 = (T_1 + T_2) - T_2 = 0.0853 - 0.04265 = 0.04265s$$

The last part of the transfer function is determined by multiplying T_1 with T_2 :

$$T_1 * T_2 = 0.04265 * 0.04265 = 1.82ms$$

The transfer function for this system is therefore: $\frac{1}{T_1 T_2 s^2 + (T_1 + T_2)s + 1} = \frac{1}{0.00182s^2 + 0.0853s + 1}$

an 's' is missing here

1.4. Ziegler-Nichols Methods of Tuning a PID Controller from Process Reaction Data

Ziegler-Nichols methods are useful for working out derivative gain, proportional gain and integral gain (denoted as k_d , k_p and k_i respectively) for tuning PID systems; these determine how a system behaves when faced with a quick change or disturbance. Ziegler-Nichols tuning methods also help to determine whether proportional, proportional-integral, proportional-derivative or proportional-integral-derivative control is to be used. Bolton states that "Proportional control gives a fast response with oscillations which die away to leave a steady state error. Proportional plus integral control has no steady state error but is likely to show more oscillations before settling down. Proportional but integral plus derivative control has also no steady state error, because of the integral element, and is likely to show less oscillations than the proportional plus integral control. The inclusion of derivative control reduces the oscillations" (2015, p. 112).

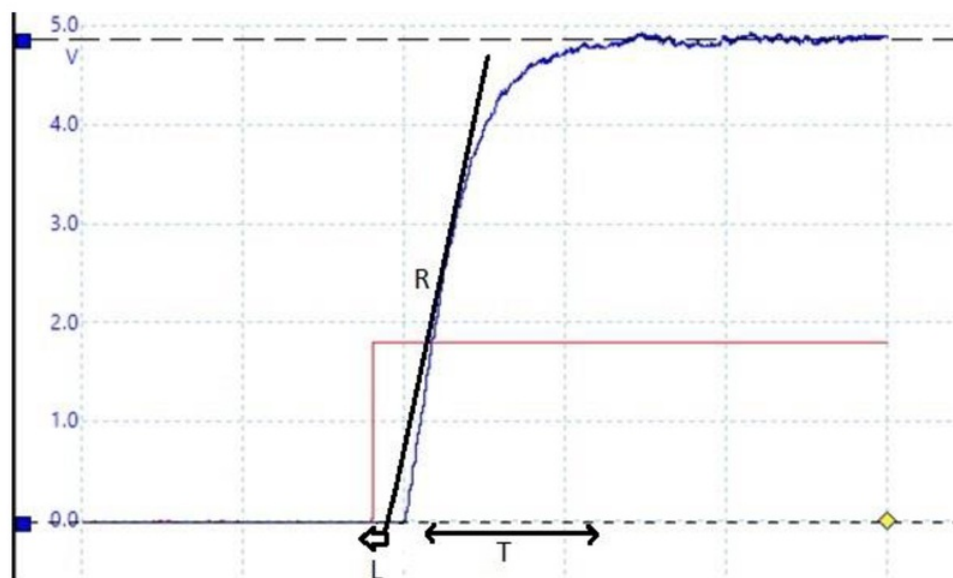
Good

Both Ziegler-Nichols methods involve first gathering process reaction data.

Process Reaction Curve

The first Ziegler-Nichols method is commonly called the process reaction curve - the process reaction curve method of tuning a PID controller involves applying a step signal directly to the correction element of the system in open-loop mode so that no control action happens and then plotting a graph from the process variable – this graph is called the process reaction curve, and an example of which is shown in the figure below.

Citation Needed



This belongs to the next section. Use only published sources in your research section.

Figure 7 - Ziegler-Nichols Process Reaction Curve

The above process reaction curve was obtained using Picoscope software – the red line indicates the step input, and the blue line indicates the response. The maximum gradient of the response, R , is called the reaction rate and the time between the step input and the maximum gradient, L , is called the input lag. T is the time it takes to reach peak value.

To determine derivative gain, proportional gain and integral gain (denoted as kd, kp and ki respectively) from the process reaction curve, the following table is used.

Type of Controller	Kp	Ki	Kd
P	$\Delta C/RL$		
PI	$0.9\Delta C/RL$	$Kp/3.33L$	
PID	$1.2\Delta C/RL$	$Kp/2L$	$0.5KpL$

[Cite your sources](#)

ΔC is the max value of the step input, R is determined using $\frac{\Delta y}{T}$ which is calculated using $\Delta y = \frac{(y2-y1)}{yrange} \times 100$ where y2 is the max value of the reaction curve, y1 is the initial value of the reaction curve and yrange is the range of the two.

This method was the method used to tune the flow measurement system later in the assignment – the process reaction curve used is shown below.

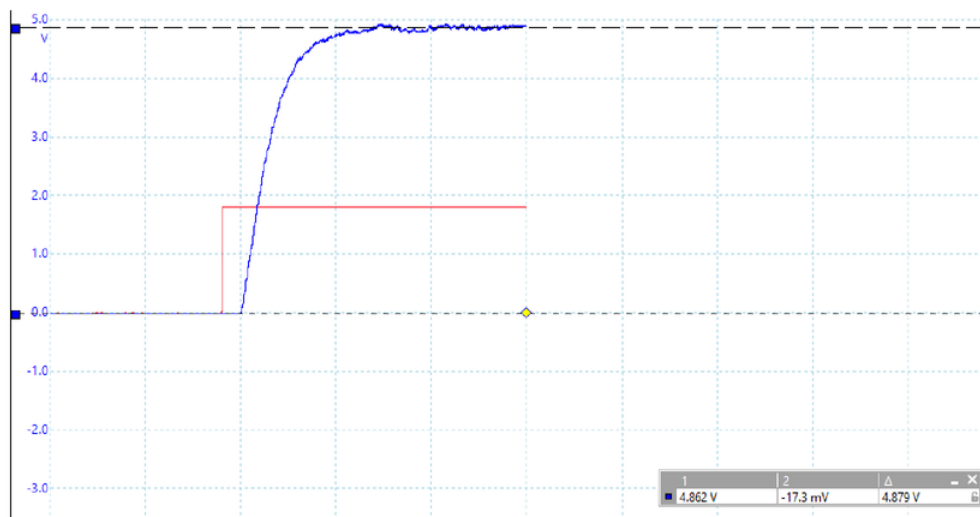


Figure 8 - Flow Measurement System Process Reaction Curve

The above process reaction curve was measured using a ruler to determine the necessary values, those values are shown below. The first step was to determine Δy .

$$\Delta y = \frac{(y2 - y1)}{yrange} \times 100 = \frac{(5 - 0)}{5} \times 100 = 100\%$$

Now that Δy had been obtained, R could be calculated by measuring T.

$$R = \frac{\Delta y}{T} = \frac{100}{0.07} = 1428.6$$

ΔC was measured to be around 1.8V, which was 36%. L was measured to be ~0.01s. All of these values could be used in the table to determine necessary values for P, PI and PID systems.

Determined Values for P, PI and PID Systems

P

$$K_p = \frac{\Delta C}{RL} = \frac{36}{1428.6 * 0.01} = 2.52$$

PI

$$K_p = 0.9 \frac{\Delta C}{RL} = 0.9 * \frac{36}{1428.6 * 0.01} = 2.268$$

$$T_i = 3.33 * 0.01 = 0.0333s$$

$$K_i = \frac{2.268}{0.0333} = 68.1$$

PID

$$K_p = 1.2 \frac{\Delta C}{RL} = 1.2 * \frac{36}{1428.6 * 0.01} = 3.02$$

$$T_i = 2 * L = 2 * 0.01 = 0.02s$$

$$T_d = 0.5 * L = 0.5 * 0.01 = 0.005s$$

$$K_i = \frac{K_p}{T_i} = \frac{3.02}{0.02} = 151$$

$$K_d = \frac{T_d}{K_p} = \frac{0.005}{3.02} = 0.0017$$

In theory, these values should be able to be used to tune the system to a good standard, but inaccuracies in measurements or errors in calculations could mean that these results could be poor.

Ultimate Cycle

The second Ziegler-Nichols method is commonly called the ultimate cycle tuning method – this method is used on closed-loop systems (unlike the process reaction curve method) and the integral and derivative functions are minimized to their least effective values. Proportional gain, k_p , is then set to a minor value and then gradually increased with the purpose of determining at which points oscillations in the controlled variable occur. The point at which oscillations occur is then noted and labelled the critical value of the proportional gain K_{pc} and the periodic time of the oscillations are measured.

Citation
Needed

At this point, the system is set to manual operation and run under its typical operating conditions and all control modes except for proportional gain, k_p , are turned off. Proportional gain is then set to a small value, the controller is set to automatic mode, and then a low set-point change (of about 5%) is introduced; the response of the system is then observed, and the process is repeated until the response shows oscillations which are stable.

For a system with quarter amplitude decay (the method used to eliminate error between the set-point and process variable) the controller settings can then be derived from the table below.

Type of Controller	K_p	K_i	K_d
P	$0.5K_{pu}$		
PI	$0.45K_{pu}$	$T_u/1.2$	
PID	$0.6K_{pu}$	$T_u/2$	$T_u/8$

For a PID system with minimal to no overshoot, the controller settings can then be derived from the table below.

Type of Controller	K_p	T_i	T_d
PID, 1/4 Decay	$0.6K_{pu}$	$T_u/2$	$T_u/8$
PID, some overshoot	$0.33K_{pu}$	$T_u/2$	$T_u/3$
PID, no overshoot	$0.2K_{pu}$	$T_u/3$	$T_u/2$

Cite your sources

Summary

Both methods are simple to do, can be done with pen and paper without the need for simulation tools, but a practical rig with measurement instruments is still necessary and especially with the process reaction curve, the results can be very inaccurate. These methods are not completely optimal, but the results obtained can be used to estimate the general area of optimal values – some trial and error done afterwards will most likely yield better results. The process reaction curve method is most applicable when it is possible to operate the system in open-loop mode, the ultimate cycle method should be used when the system cannot be run in open-loop mode or is more convenient for it to not be run in open-loop mode.

Citation Needed

2. Flow Control System Modelling, Simulation and Testing

One of the objectives of this assignment was to “investigate by simulation and by practical experiment a second order system and its associated instrumentation”, this part of the report covers all of the modelling, simulation and testing done to complete this objective.

2.1 - Modelling

The modelling for the system was done using Matlab’s Simulink function, which allows the simulation of models using graphical blocks which represent actual parts of systems, and the Caldwell method, which was used to derive the necessary transfer function. The figure below is what the finished system looked like on Simulink and is typical of how a second-order system would look (excluding the specific values).

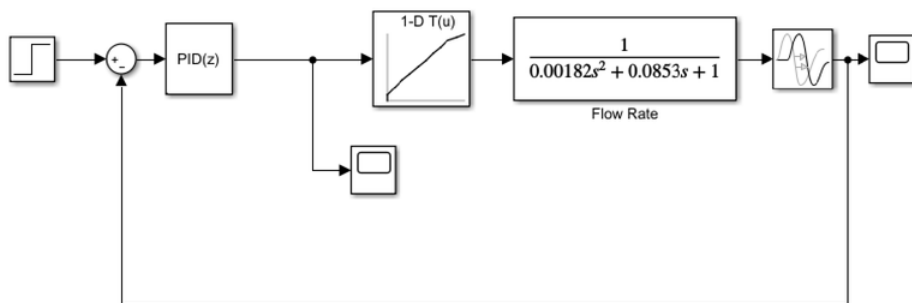


Figure 9 - Simulink Complete System Model

Each block has its own values which are used to allow accurate modelling to be carried out – the first block to be placed was the step input block.

Step Input Block

The stop input block is used to produce the step input which is used to test the process reaction curve later. The initial value was set to 0, and then after 1s the value would be set to 50.

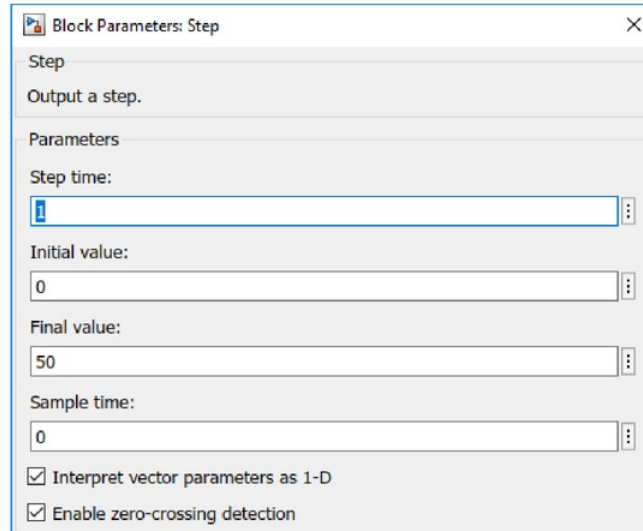


Figure 10 - Step Input Parameters

Lookup Table Block

The lookup table block had its table data obtained by taking crude readings from the flow measurement system's behaviour at specific breakpoints (0, 1, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100).

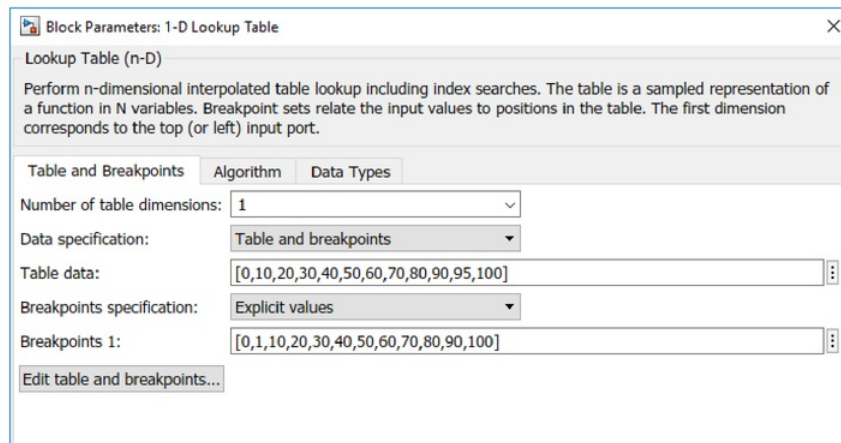
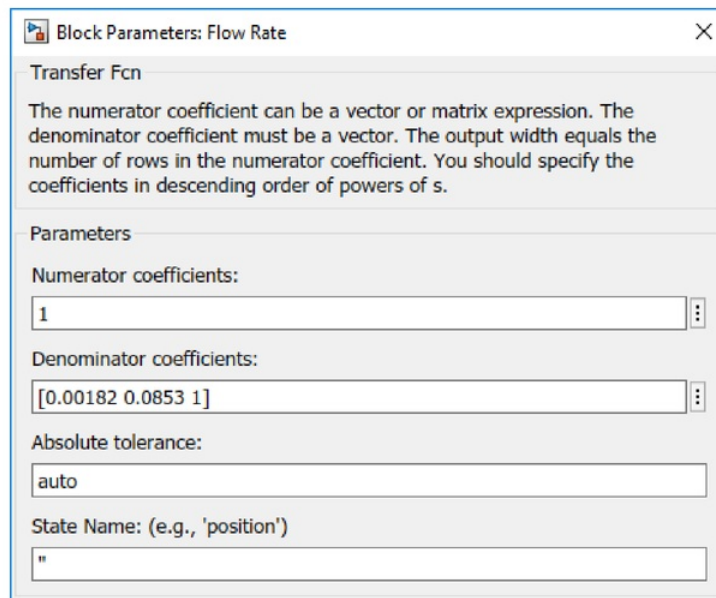


Figure 11 - Lookup Table Values

Transfer Function Block

In section 1.3 of the report, the Caldwell method was used to derive the transfer function for the system – the transfer function block is where this transfer function's numerator and denominator are stored.



Block Parameters: Flow Rate

Transfer Fcn
 The numerator coefficient can be a vector or matrix expression. The denominator coefficient must be a vector. The output width equals the number of rows in the numerator coefficient. You should specify the coefficients in descending order of powers of s.

Parameters

Numerator coefficients:

Denominator coefficients:

Absolute tolerance:

State Name: (e.g., 'position')

Figure 12 - Transfer Function Parameters

Transport Delay

The value for the transport delay was taken from a crude response from a former model, and was determined by working out the difference between the step input and the process reaction curve (red and blue lines, respectively, on the figure below). The difference was worked out using two markers which were placed on the process reaction curve.

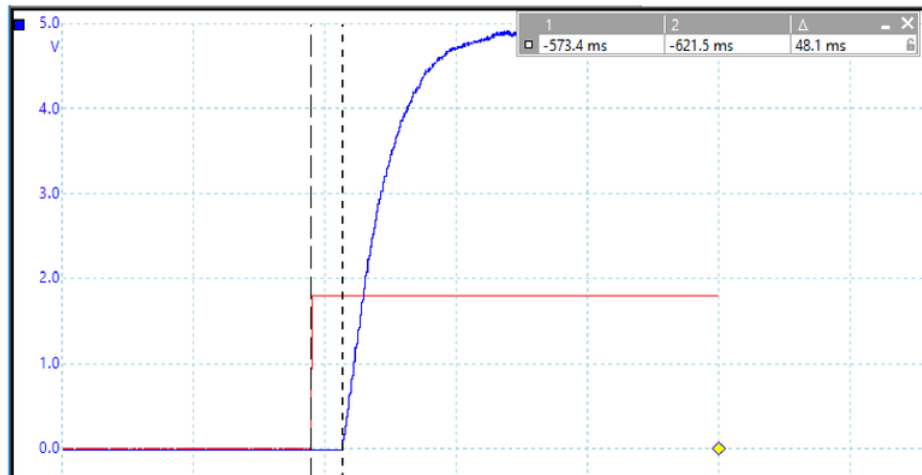


Figure 13 - Transport Delay from Process Reaction Curve

The transport delay can be observed to be 48.1ms, as seen in the box on the top left of the figure. This value is then input to the transport delay block on Simulink in the "Time delay" section.

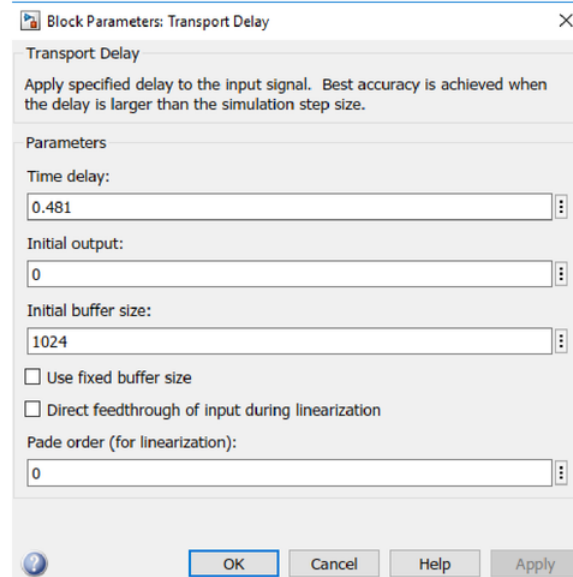


Figure 14 - Transport Delay Parameters

2.2 - Simulation

Three versions of tuning were carried out for the system – one was from the tuning function within Simulink, the other was from trial and error tuning, using the initial Simulink's tuned value as a reference point, and the final is from further trial and error tuning done in an attempt to obtain optimal values. In order to efficiently simulate and compare each system, the template of the system was duplicated twice, and the values of the PID controllers were altered in each – shown in the figure below.

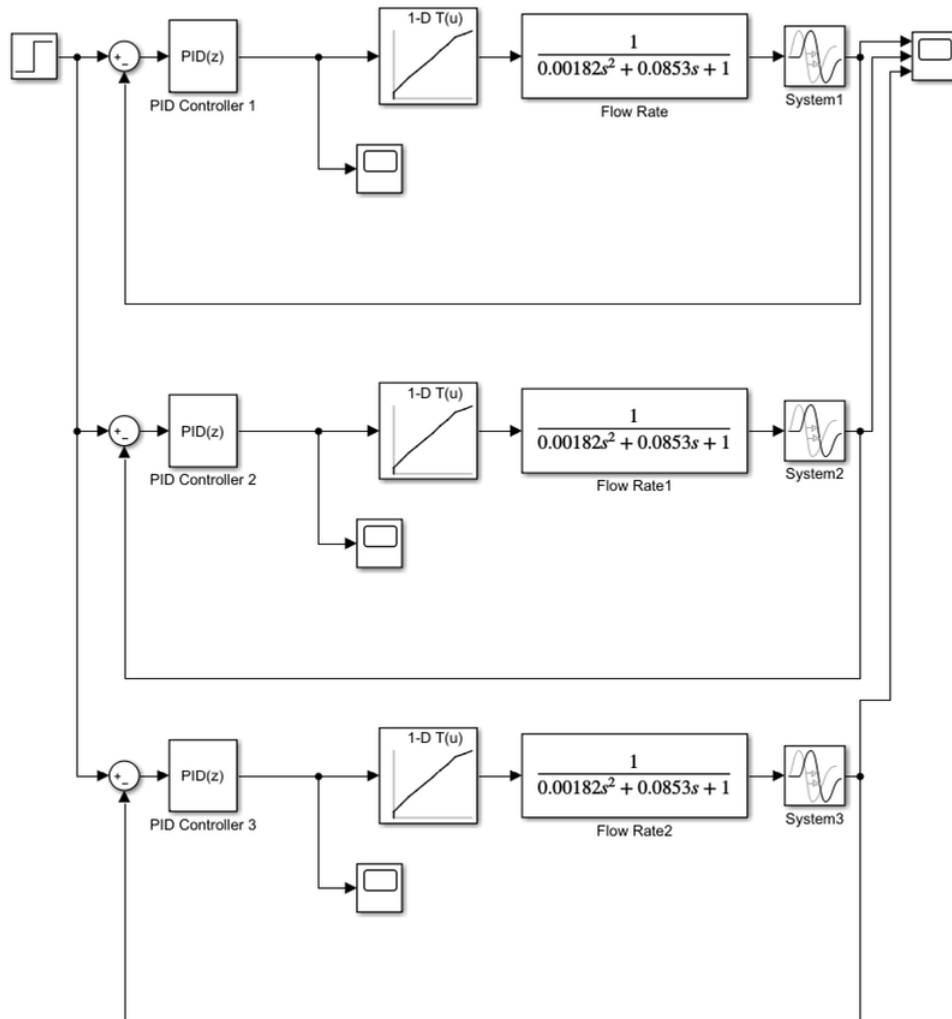


Figure - Simulink Model for Simulation

The first PID controller had its parameters determined by the “Tune” function within Simulink, those PID values can be seen in the figure below.

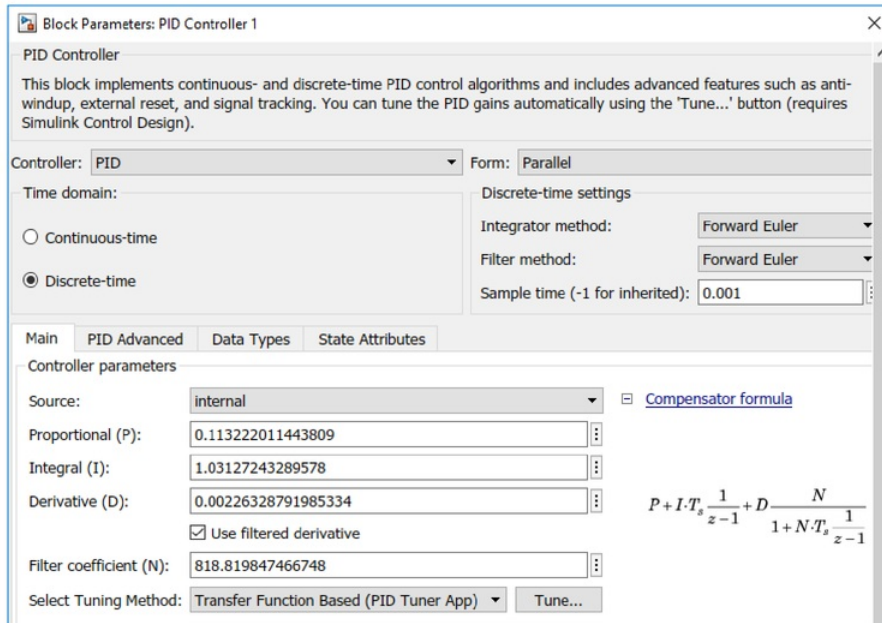


Figure 15 - Simulink Tuned Values

The second PID controller’s parameters were determined after trial and error after testing with Simulink’s tuned results and were the most optimal results found.

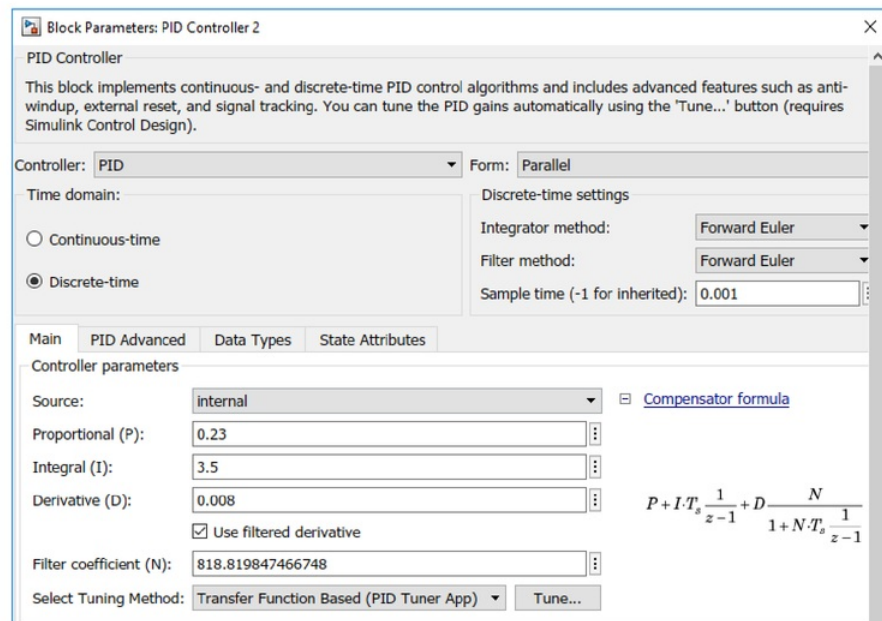


Figure 16 - Most Optimal Simulated Parameters

The third PID controller had its parameters derived from trial and error in an attempt to attain even better results.

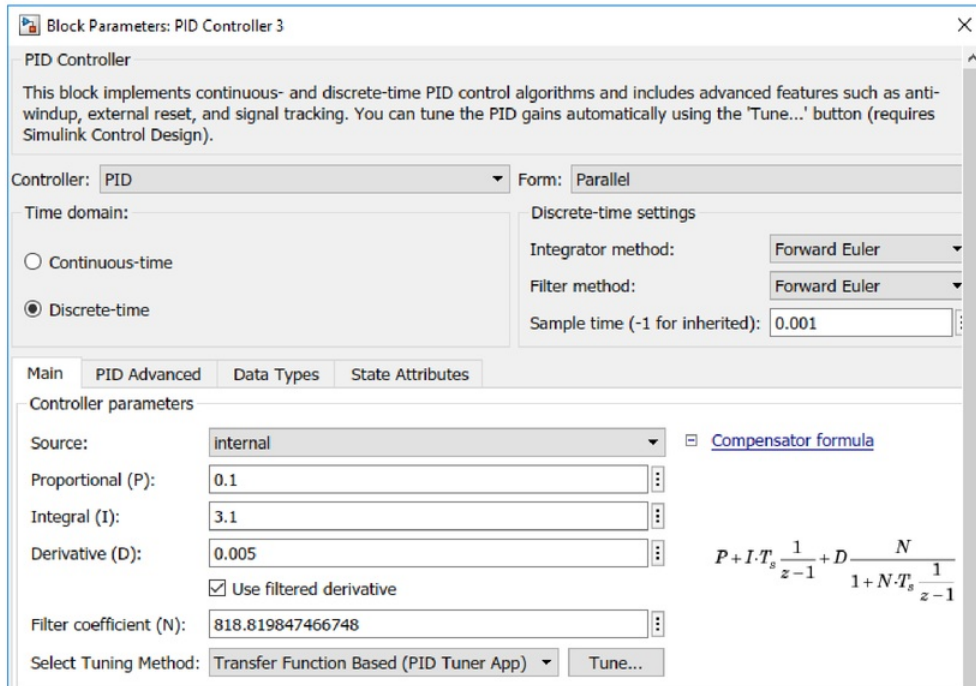


Figure 17 - Ziegler-Nichols PID Parameters

Results

The results of the Simulink's "Tune" feature are vastly different to the Ziegler-Nichols process reaction curve's results – as can be seen in the figure below.

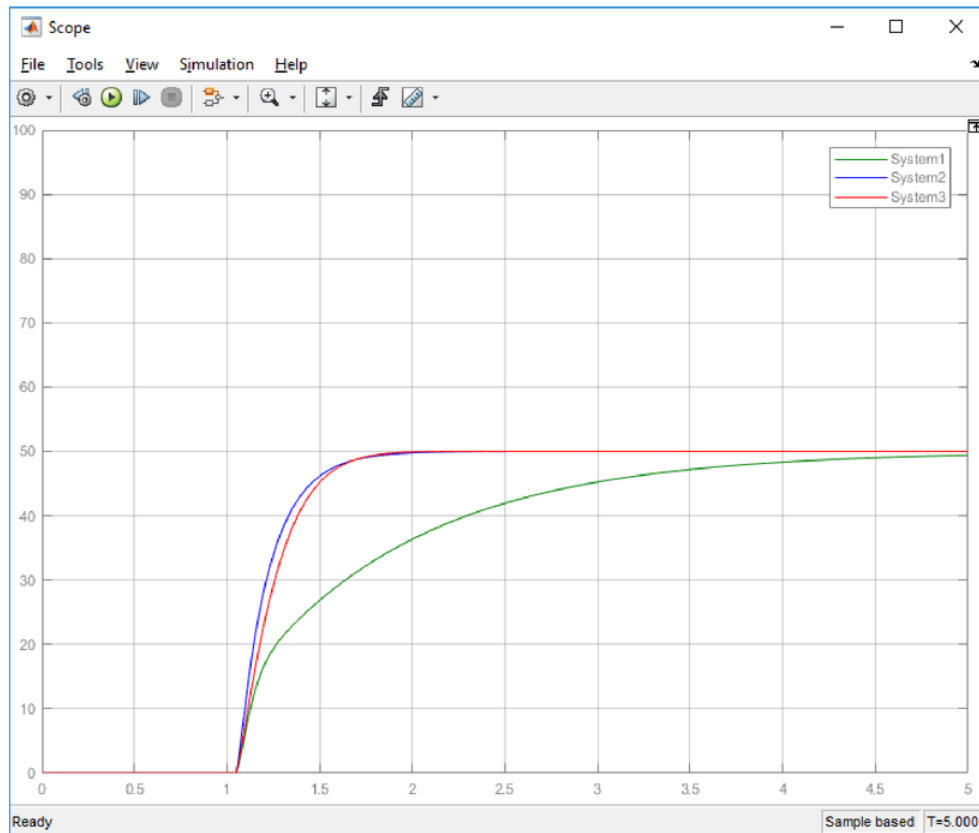


Figure 18 - Simulation Results

Simulink's "Tune" parameters produced a rather lacklustre response curve (shown as the green line) for the system – there was very little overshoot, but the system took a long time to reach max potential. The third system's parameters produced a much steeper response curve (shown as the red line) than Simulink's suggested parameters, with no visible overshoot. The optimal parameters, obtained after some trial and error, produce an even steeper response curve (shown as the blue line) and produced no visible overshoot.

2.3 – Testing

The optimal results obtained from the simulation were then used practically on the flow measurement system to produce a response curve to compare with the simulation. The values for K_p , K_i and K_d were 0.23, 3.5 and 0.008, respectively.

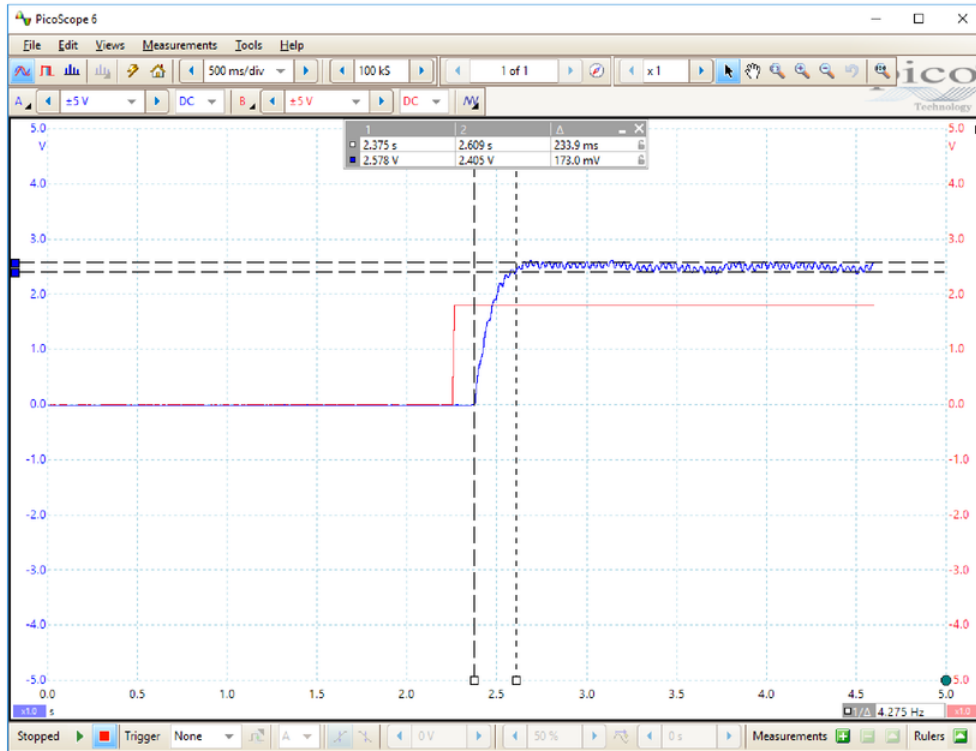


Figure 19 - Practical Test #1

The response time for these optimal results from the simulations was 233.9ms.

Values of K_p , K_i and K_d were then manually altered on the practical system in an attempt to try and improve the response curve – The values for K_p , K_i and K_d were 0.23, 3.6 and 0.01, respectively.

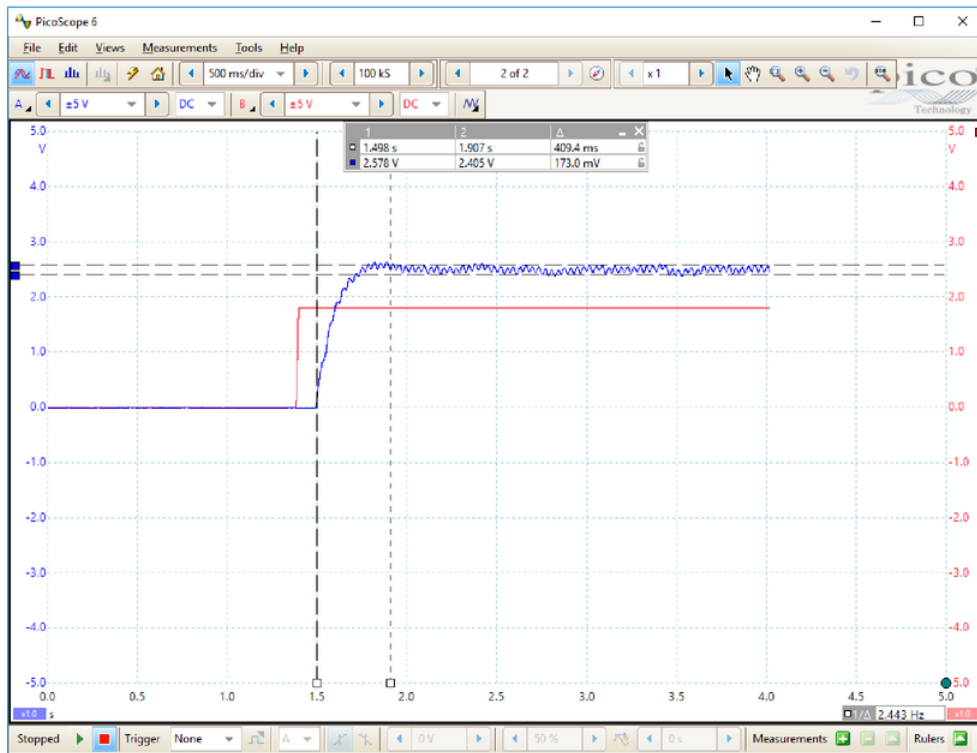


Figure 20 - Practical Test #2

The response for these altered results was 409.4ms, and so was worse.

Values of K_p , K_i and K_d were then manually altered once again on the practical system in an attempt to try and improve the response curve – The values for K_p , K_i and K_d were 0.1, 3.6 and 0.01, respectively.

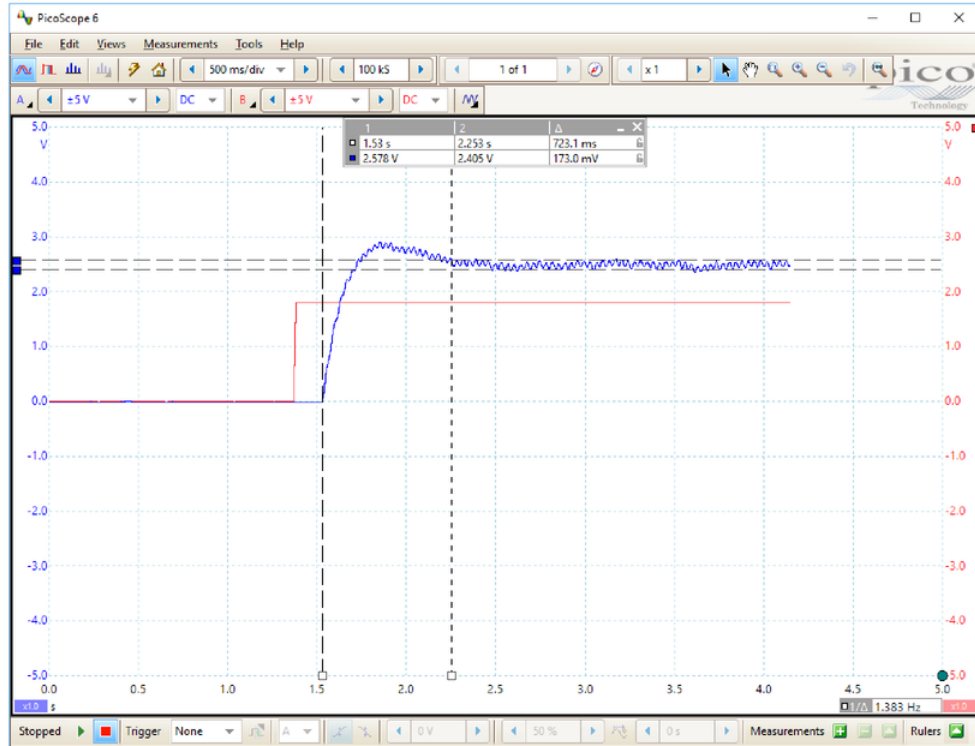


Figure 21 - Practical Test #3

The response time for these further-altered results was 723.1ms, and so was worse again.

Values of K_p , K_i and K_d were then manually altered a final time on the practical system in an attempt to try and improve the response curve – The values for K_p , K_i and K_d were 0.02, 3.55 and 0.009, respectively.

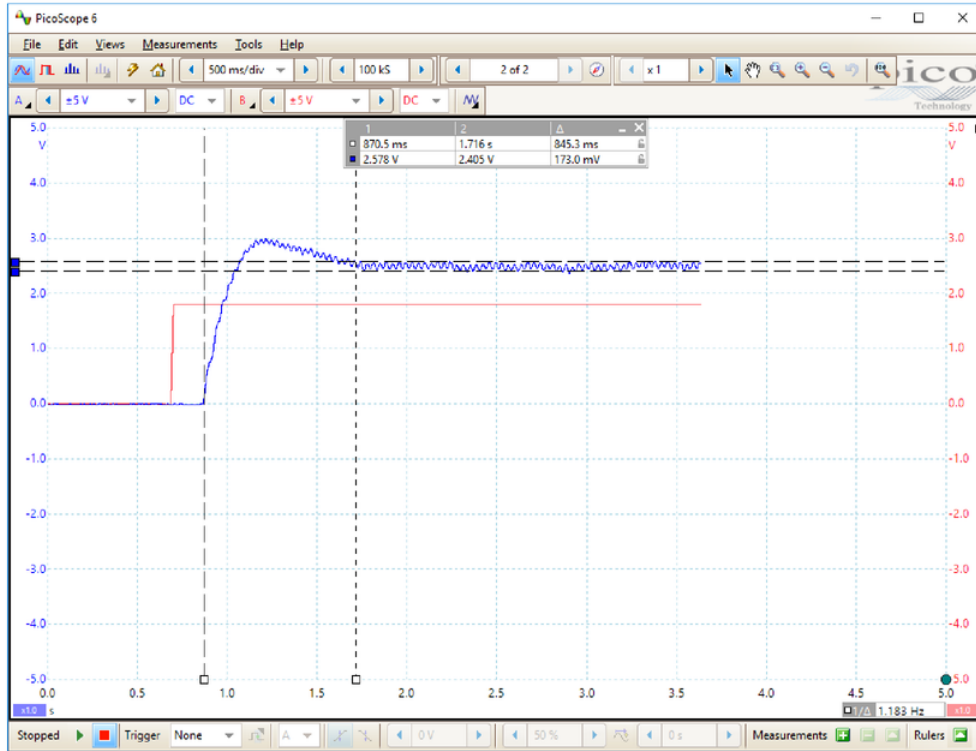


Figure 22 - Practical Test #4

The response time for these further-altered results was 845.3ms, and so was the worst of all the results.

Summary

Of all the practical results, the parameters yielded from the best simulation resulted in the steepest response curve of all the practical results, thus proving that the simulation worked as expected, and that the trial and error parameters produce a better response curve than the Simulink's "Tune" feature.

3. Conclusion and Recommendations

The research done towards the beginning of the assignment provided important knowledge about the tasks ahead – specifically, the research done towards transducers, signal conditioning methods and the Bytronic process rig helped when trying to understand the actual Bytronic process control unit later on while testing, with regards to understanding its fundamentals and how it operated. The Caldwell method of system modelling was of significant importance as it was what allowed the process rig to be simulated accurately, due to the derivation of the transfer function to be used in Simulink. The research into Ziegler-Nichols methods were interesting, and one of the methods was *You did not test the values practically!* actually carried out (process reaction curve method) but the results produced, when simulated, a system that would be incredibly unreliable and would falter under operating conditions. This could have been because of inaccuracies in the readings obtained for the process reaction curve (as there's no mathematical way of proving that the steepest gradient is found), mismeasurements with measuring tools, or errors in calculations – in conclusion, this method is unreliable, but easy to do with pen and paper and doesn't necessarily require simulation software. Caldwell modelling is superior to Ziegler-Nichols process reaction curve tuning because it's quicker, much more accurate, and the results aren't as open to interpretation.

The flow control system was modelled using Simulink, which proved an useful platform for developing and simulating a reliable model to be experimented with. The in-built "Tune" feature for tuning the PID was not reliable, but did produce results which were in the right ball-park and could be altered to produce a desired output for the system. Simulink software, or simulation software in general, is important because it allows the process rig to be tested off-site, with no risk of damages occurring or a threat of danger. The simulation results produced translated over to the practical rig very well, and the best simulation results yielded the best possible results for the process rig of all of the results.

The aims of the assignment were to investigate by simulation and practical experiment, a second order control system – I feel like this has been achieved and sufficient evidence has been presented in the report to prove that; the objectives of the assignment were also met.

One recommendation that could be made about the assignment would be to include more functionalities of the Bytronic process rig (such as temperature control) to be modelled, simulated and tested, and to see how transferrable the experience in developing models would be between different parts of the rig.

4. Citation List

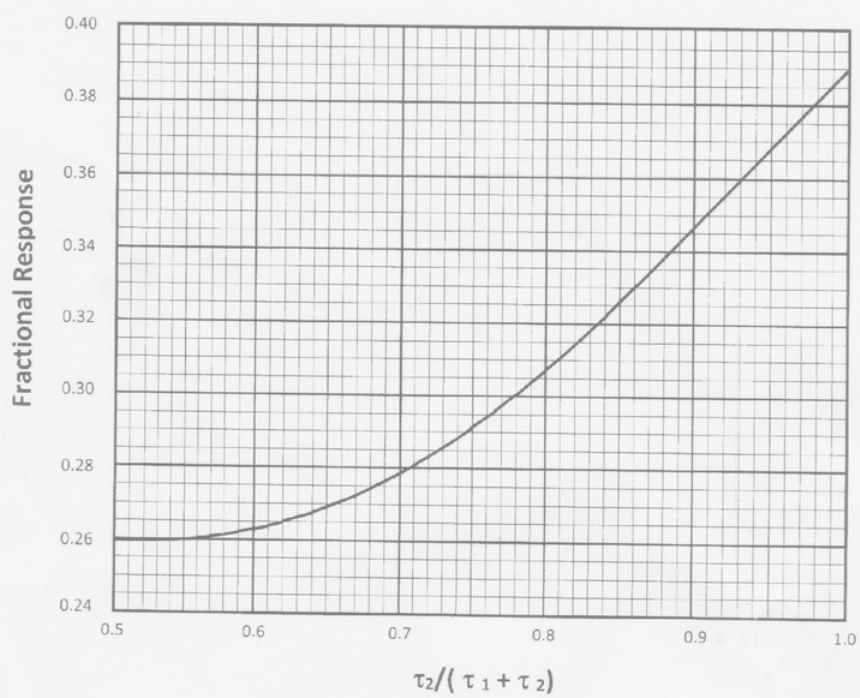
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You have
missed out the
fact that some
of these
sources are
online and you
have not given
the date they
were
accessed.

5. Appendices

The following page shows the Caldwell Reference Graph referenced in section 1.3 of the report.

Caldwell Reference Graph



assignment 1

GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

Instructor

69/100

PAGE 1

PAGE 2

PAGE 3

PAGE 4

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PAGE 5

PAGE 6

PAGE 7

PAGE 8

PAGE 9

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Text Comment. These calculations belong in the next section.

PAGE 10

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PAGE 11

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Citation Needed

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PAGE 15

PAGE 16

PAGE 17

PAGE 18

PAGE 19

PAGE 20

PAGE 21

PAGE 22

PAGE 23

PAGE 24

PAGE 25

PAGE 26

PAGE 27

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GRADING FORM: CSG-RUBIC

JOSEFF JONES**69****RESEARCH-INFORMED LITERATURE**

Section 1: Your research - Good evidence of reading from a range of sources. However, you have confused this section with model development and Ziegler Nichols tuning. Your research should be based on published sources only not on experimental results. The reason is =so that you can compare theory with practice later in the report. (10/20) Section 4: Your use of Harvard for citing and listing. A range of sources used but not always cited and listing method used is not exactly Harvard. You must remember to switch on this option within MS Word. (2/5)

12**KNOWLEDGE AND UNDERSTANDING**

Section 2: Explanation of the control system and model - Well explained. (12/15)

12

ANALYSIS



Sections 2 and 5: Analysis of model, simulation and practical testing - No mathematical analysis was carried out on the model transfer function. However, there is good evidence of testing and tuning though only PID controllers have been used (P and PI are missing). Values obtained by Ziegler-Nichols method have not been implemented. (12/20)
Section 3: Conclusions and recommendations - Good overall conclusions and one recommendation. (7/10)

19

PRACTICAL APPLICATION AND DEP.



Sections 2: Development of the model, use of Simulink – This is clearly explained including the LUT and the transport delay. (10/10) Sections 2: Practical tuning – Good but not complete. Ziegler Nichols has not been implemented. (3/5) Section 2: Presentation of results - Very good. (5/5)

18

SKILLS FOR PROFESSIONAL PRAC.



All sections - Well presented, structured and written. (8/10)

8