

Sam Harries - Assignment 1

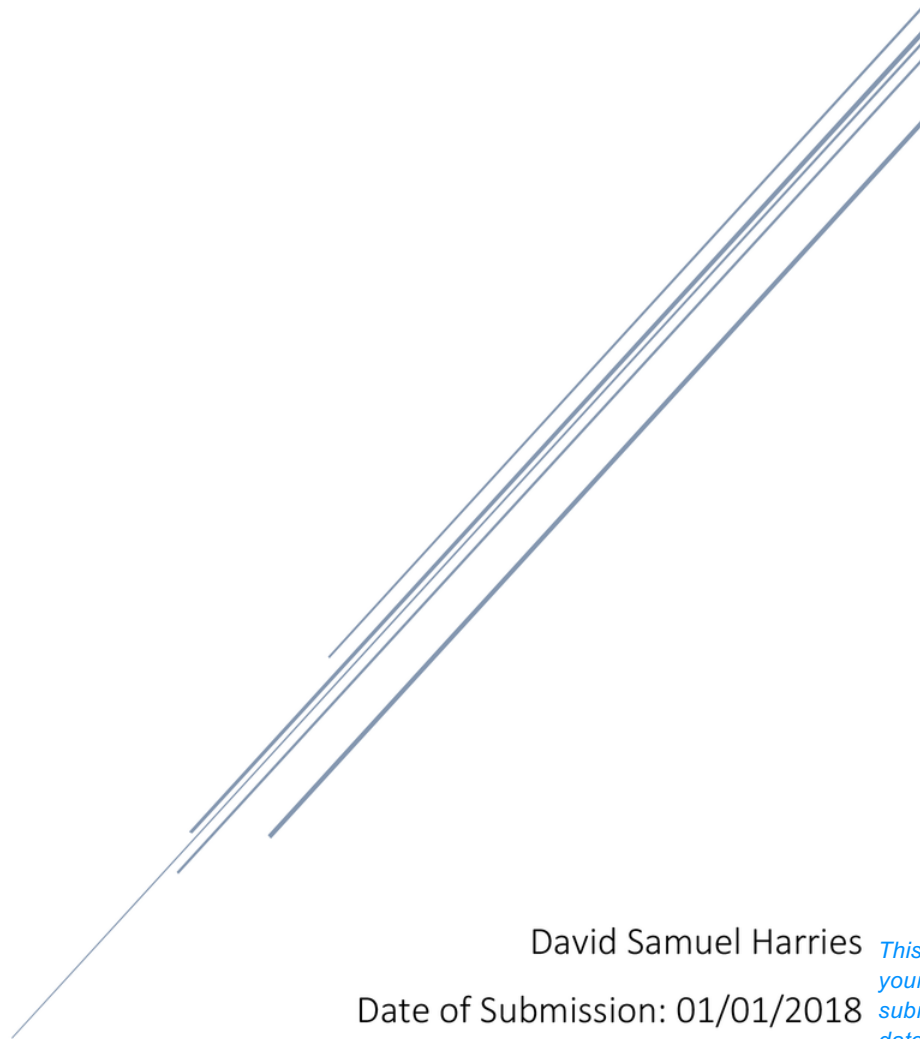
by David Harries

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HND Electrical and Electronic Engineering

PSDE5011

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



David Samuel Harries *This was not
your actual
submission
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1 – RESEARCH

1.1 FLOW MEASUREMENT

Flow measurement can be done using a variety of different methods all of which convert the movement of a fluid into an electrical signal which can then be read by a PLC, microcontroller or computer. These methods are done through the use of transducers and signal conditioning.

“A transducer is defined as a sensing device used to convert a physical phenomenon into electrical, pneumatic or hydraulic output signal.” (Transducers Engineering, 2016). For flow rate, the physical phenomenon is the movement of water, which in this case gets converted into an electrical signal.

1.2 METHODS OF FLOW MEASUREMENT

As previously stated there are many methods of measuring the flow of a fluid. There are multiple categories for which these methods can be sorted in to;

- Mechanical
- Pressure-Based
- Variable-Area
- Optical
- Open-Channel
- Thermal Mass
- Vortex Flow
- Sonar Flow
- Electromagnetic, Ultrasonic and Coriolis Flow Meters
- Laser Doppler Flow Measurement

Transducers are used within many of these methods in order to produce a readable electrical signal. A few of these methods are discussed below.

1.2.1 Electromagnetic Flow Meter

The basic physics of this principle can be traced back to Michael Faraday who created Faraday's law of electromagnetic induction. This law states that “an electric current produces a magnetic field and, conversely, how a changing magnetic field generates an electric current in a conductor.” (Science, 2018). This principle was later applied to liquids flowing in pipes and allowed for the advent of the electromagnetic flow meter. discovered

An electromagnetic flow meter consists of two field coils located on opposite sides of a pipe. These are each connected to ‘pole shoes’ which allow the electromagnetic field generated by the field coils to cover the entire cross section of the pipe. This can be seen in **Figure 1.a**. When the liquid within the pipe is flowing, a potential difference proportional to the flow velocity perpendicular to the flux lines is generated. Two electrodes which can pick up voltages are located perpendicular to the flow can be seen in **Figure 1.b**. As the conducting liquid flow through the pipe, the magnetic field applies a force to the charged particles. As a result, the positively and negatively charged particles are separated and gather on opposite sides of the pipe. This forms an electrical voltage which is detected by the two electrodes. Auxiliary transducers are installed to clean the

voltages on the electrodes so that a readable electrical signal is produced. Finally, the electromagnetic field is pulsed in order to cancel out any stray voltages from within the pipeline.

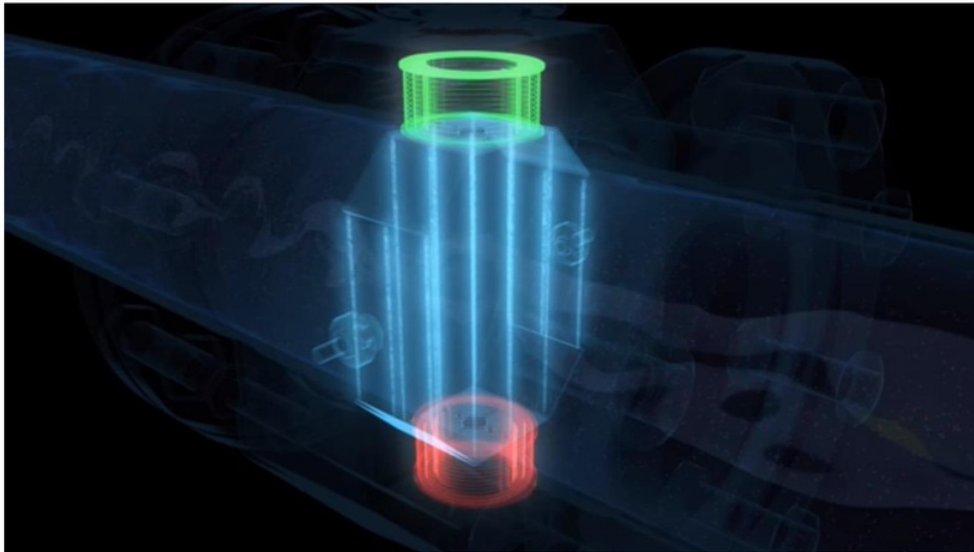


Figure 1.a



Figure 1.b

An example of an Electromagnetic Flow Meter is the 'Proline Promag P300'. This flow meter is specially designed to operate with chemical and process applications that use corrosive liquids and high temperatures. Due to its bidirectional measuring principle, the P300 flow meter is practically independent of pressure, viscosity, temperature and density. This allows for a large variety of applications. The P300 can be seen in **Figure 1.c**.



Figure 1.c

The benefits of this flow meter are that;

- It can be used with a variety of fluids as long as they are conductive.
- There are no moving parts, requires no maintenance.
- No pressure loss due to cross-section constriction which provides energy-saving flow measurement.
- Complete access to diagnostic and process information.

(Endress.com, 2018)

In order to compare with other flow meter types, information from the P300 data sheet can be found in **Figure 1.d**.

Current input	0/4 to 20 mA (active/passive)
Current span	▪ 4 to 20 mA (active) ▪ 0/4 to 20 mA (passive)
Resolution	1 μ A
Voltage drop	Typically: 0.6 to 2 V for 3.6 to 22 mA (passive)
Maximum input voltage	$\leq$ 30 V (passive)
Open-circuit voltage	$\leq$ 28.8 V (active)
Possible input variables	▪ Pressure ▪ Temperature ▪ Density
Status input	
Maximum input values	▪ DC -3 to 30 V ▪ If status input is active (ON): $R_i > 3 \text{ k}\Omega$
Response time	Adjustable: 5 to 200 ms
Input signal level	▪ Low signal: DC -3 to +5 V ▪ High signal: DC 12 to 30 V
Assignable functions	▪ Off ▪ Reset the individual totalizers separately ▪ Reset all totalizers ▪ Flow override

Figure 1.d

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Another property of the P300 is that its nominal maximum diameter is 24" or 600mm. This can be seen as a limitation for this type of flow meter. These figures were found in the datasheet and can be seen below.

Typically $v = 0.01$ to 10 m/s (0.03 to 33 ft/s) with the specified accuracy

Flow characteristic values in SI units

Nominal diameter		Recommended flow min./max. full scale value ($v \sim 0.3/10$ m/s)	Factory settings		
[mm]	[in]		Full scale value current output ($v \sim 2.5$ m/s)	Pulse value (~ 2 pulse/s)	Low flow cut off ($v \sim 0.04$ m/s)
		[dm ³ /min]	[dm ³ /min]	[dm ³]	[dm ³ /min]
15	½	4 to 100	25	0.2	0.5
25	1	9 to 300	75	0.5	1
32	–	15 to 500	125	1	2
40	1 ½	25 to 700	200	1.5	3
50	2	35 to 1 100	300	2.5	5
65	–	60 to 2 000	500	5	8
80	3	90 to 3 000	750	5	12
100	4	145 to 4 700	1 200	10	20
125	–	220 to 7 500	1 850	15	30
150	6	20 to 600 m ³ /h	150 m ³ /h	0.03 m ³	2.5 m ³ /h
200	8	35 to 1 100 m ³ /h	300 m ³ /h	0.05 m ³	5 m ³ /h
250	10	55 to 1 700 m ³ /h	500 m ³ /h	0.05 m ³	7.5 m ³ /h
300	12	80 to 2 400 m ³ /h	750 m ³ /h	0.1 m ³	10 m ³ /h
350	14	110 to 3 300 m ³ /h	1 000 m ³ /h	0.1 m ³	15 m ³ /h

Nominal diameter		Recommended flow min./max. full scale value ($v \sim 0.3/10$ m/s)	Factory settings		
[mm]	[in]		Full scale value current output ($v \sim 2.5$ m/s)	Pulse value (~ 2 pulse/s)	Low flow cut off ($v \sim 0.04$ m/s)
		[dm ³ /min]	[dm ³ /min]	[dm ³]	[dm ³ /min]
400	16	140 to 4 200 m ³ /h	1 200 m ³ /h	0.15 m ³	20 m ³ /h
450	18	180 to 5 400 m ³ /h	1 500 m ³ /h	0.25 m ³	25 m ³ /h
500	20	220 to 6 600 m ³ /h	2 000 m ³ /h	0.25 m ³	30 m ³ /h
600	24	310 to 9 600 m ³ /h	2 500 m ³ /h	0.3 m ³	40 m ³ /h

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Figure 1.e

(Technical Information Proline Promag P 300, 2018)

1.2.2 Ultrasonic Flow Meter

The ultrasonic flow meter uses a differential transit time method to calculate flow rate. This method uses a principle discovered by John William Strutt which proved that the propagation of sound waves changed as they moved through solids, liquids and gasses.

Within the ultrasound flow meter are pairs of sensors that can each emit and receive ultrasonic signals. When a ultrasonic signal is detected by a sensor a voltage is created. The transit times of these signals are then calculated. These sensors can be seen in **Figure 1.f**.

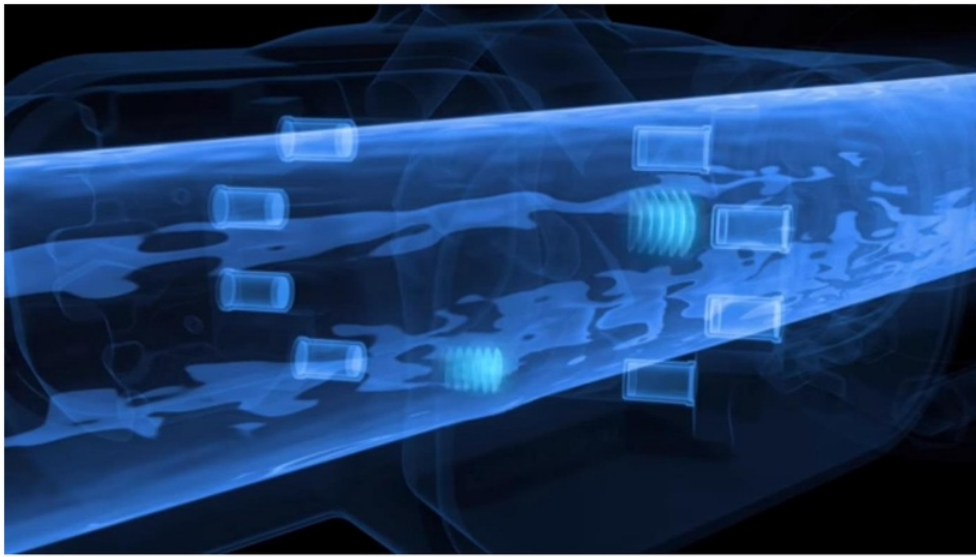


Figure 1.f

As shown above, the pairs of sensors are located at an angle to the direction of flow. This is because when there is no flow, the speed of the ultrasonic signals in both directions is the same. However, when there is a flow in one direction, the ultrasonic signals moving in the same direction have a lower transit time as they move faster. The ultrasonic signals moving against the direction of flow instead have a much larger transit time as they move slower. Using the differential transit time of both sets of ultrasonic signals, the flow rate can then be calculated.

An example of an ultrasonic flow meter is the Proline Prosonic Flow B200. This flow meter is designed to be used in the measurement of wet biogas. The B200 can be seen in **Figure 1.g**.



Figure 1.g

The benefits of using this flow meter are that:

- Its measuring principle is unaffected by the composition of the gas it's measuring. Therefore it can measure a wide variety of different gasses.
- It has an integrated real-time methane fraction measurement. This allows the flowmeter to determine the quality of the flowing gas as well as its flow rate.
- Safe operation as there is no need to open the device.
- Diagnostic and process information is completely accessible.
- Optimised for low pressure gas.

(Endress.com, 2018)

In order to compare to the electromagnetic flow meter, information from the B200 datasheet can be found in **Figure 1.h**.

Current input	4-20 mA (passive)
Resolution	1 μ A
Voltage drop	Typically: 2.2 to 3 V for 3.6 to 22 mA
Maximum voltage	≤ 35 V
Possible input variables	Pressure

Figure 1.h

Response time	• The response time depends on the configuration (damping). • Response time in the event of erratic changes in the flow: after 1 000 ms 95% of the full scale value.
---------------	---

Figure 1.i

(Technical Information Proline Prosonic Flow B 200, 2018)

From this information it can be seen that the current input for both the electromagnetic flow meter and the ultrasonic flow meter is 4-20mA. This is because the flow meter might be located at a remote location far from the plant. If the flow meter was to use a 0-10V range it could suffer from interference and signal loss due to volt drops in the cable. Therefore 4-20mA is used instead.

The resolution for both meters is 1 μ A meaning that between 4-20mA is 16,000 potential readings in 1 μ A increments.

The first major difference between these flow measurement methods is that for the electromagnetic flow meter there are more possible input variables in comparison to the ultrasonic flow meter. The electromagnetic flow meter allows for pressure, temperature and density as input variables whereas the ultrasonic flow meter only allows for pressure. This suggests that the electromagnetic flow meter is suited to any applications that require temperature and density monitoring.

Another major difference between the two flow meters is that the response time for the electromagnetic flow meter ranges between 5 and 200ms, and the response time for the ultrasonic flow meter potentially up to 1000ms. This difference suggests that the electromagnetic flow meter is suited to systems that require faster measurements.

Finally, the nominal maximum diameter of the pipe for each flow meter is different. This can be seen in **Figure 1.j**.

Nominal diameter		Velocity		Effective volume flow	
[mm]	[in]	[m/s]	[ft/s]	[m ³ /h]	[ft ³ /h]
50	2	1 to 30	3.28 to 98.4	9 to 269	316 to 9495
80	3	1 to 30	3.28 to 98.4	20 to 611	720 to 21592
100	4	1 to 30	3.28 to 98.4	34 to 1032	1215 to 36443
150	6	1 to 30	3.28 to 98.4	76 to 2290	2695 to 80862
200	8	1 to 30	3.28 to 98.4	131 to 3925	4620 to 138596

Figure 1.j

From this it can be seen that the electromagnetic flow meter is more suitable for larger pipelines as the nominal maximum diameter of the ultrasonic flow meter is only 200mm compared to 600mm.

However, despite all these differences both flow meters are targeted towards specific applications due to their core principles of operation. The electromagnetic flow meter is specifically designed to be used with fluids and the ultrasonic flow meter is designed to be used with gasses.

1.2.3 Turbine Flow Meter

Another type of flowmeter is the turbine flow meter. Unlike the previous two flow meters, this operates using a mechanical principle. The flow meter uses a transducer to convert the mechanical kinetic energy of a turbine's rotation into an electrical signal. The transducer used in this case is a frequency to voltage converter.

This type of flow meter is used within the bytronic rig in G8. Its principle of operation is illustrated in **Figure 1.k**.

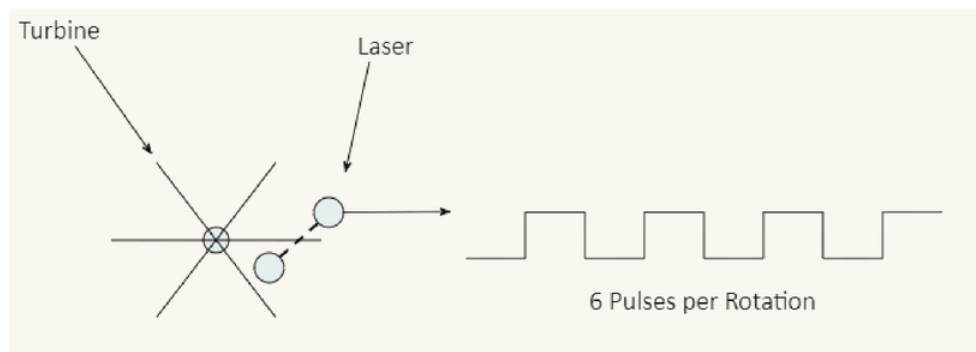


Figure 1.k

The turbine has six spokes which when breaking the laser create a pulse. These pulses create a frequency that in turn gets converted into a voltage signal. This signal is then conditioned and sent to a PLC. This signal is used as a control loop for a PID controller in the PLC. "Proportional-Integral-Derivative (PID) control is the most common control algorithm used in industry and has been universally accepted in industrial control." (Ni.com, 2018)

The PID controller uses the electrical signal produced by the transducer as a feedback loop. The PID controller aims to control the flow rate in the byronic rig. To do this it has a set point, and uses the feedback loop from the transducer to calculate the error. The further from the set point the flow rate is, the greater the error. The PID then tries to reduce the error by increasing or decreasing the flow rate until it reaches the set point.

The transducer used in the byronic rig to measure the flow is the LM2917 tachometer. From the datasheet it can be seen that the response time of the LM2917 is determined by external circuitry. This can be seen in **Figure 1.1**.

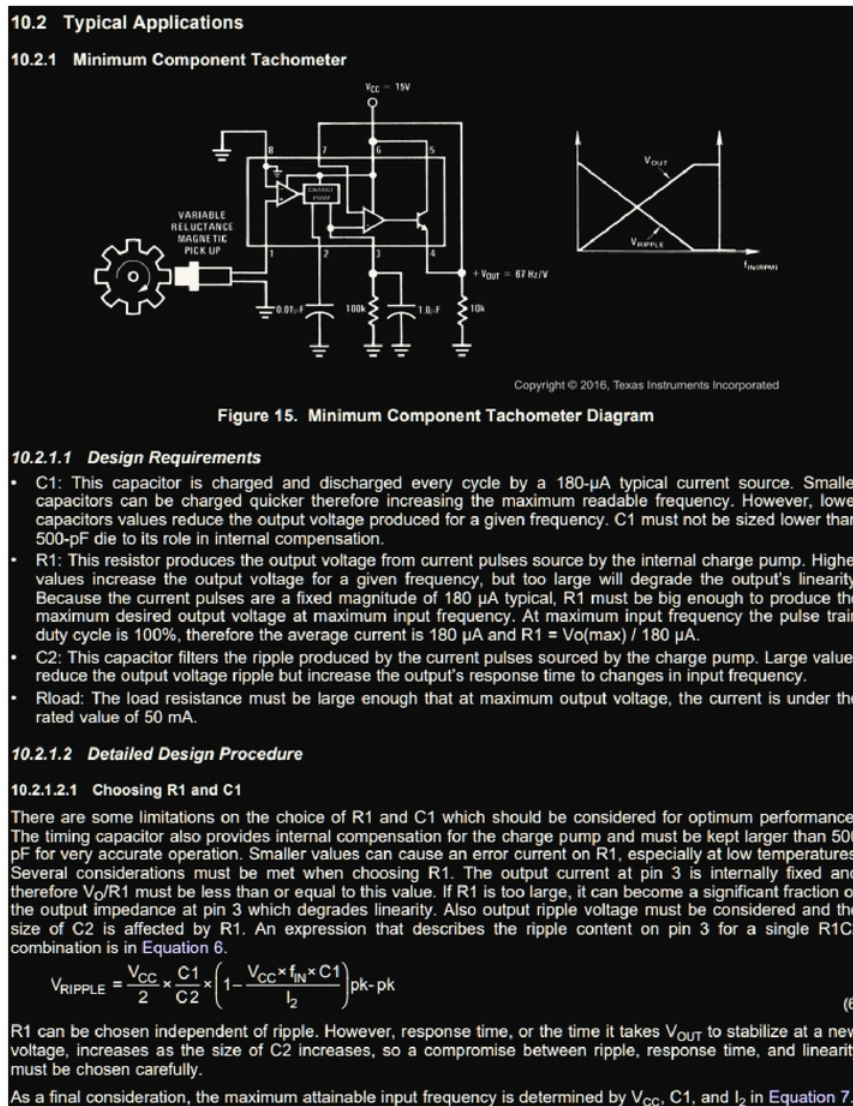


Figure 1.1

Within the design requirements it states that capacitor C2 is the component that determines the response time. In order to keep the tachometer accurate a value of 500pF or larger must be

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used. Finally, it can be seen that the response time increases as the value of C2 increases. Therefore the response time is variable which can be a useful factor to consider when choosing this method of flow measurement.

When the signal from the transducer is input to the PID controller, the PID increases or decreases the voltage output to a pulse width modulator (PWM). This PWM increases or decreases the average voltage to the pump which in turn increases or decreases the speed of the pump. As the electrical signal gets closer to the set point, the voltage to the pump gets moderated so that it continues to run at the set speed.

If the set point was to be decreased for example, the feedback loop would tell the PLC that the pump is running to fast. Therefore, the PLC would output less voltage to the PWM which would in turn reduce the average voltage to the pump, slowing it down until it reaches the set point once again.

(LM2907 and LM2917 Frequency to Voltage Converter, 2018)

1.3 SIGNAL CONDITIONING

"Signal conditioning is the technique of making a signal from a sensor or transducer suitable for processing by data acquisition equipment." (Windmill Software, 2018). For example, if a transducer was to output an electrical signal in mV, the signal may have to first be amplified so that it could be read properly.

The importance of signal condition cannot be understated; therefore it is the first step when it comes to data acquisition. Without it, some signals would not produce accurate measurements which could cause systems to not operate as intended.

There are many methods of signal conditioning. These can be seen listed below:

- Amplification
- Excitation
- Linearization
- Cold-Junction Compensation
- Filtering
- Isolation
- High Impedance
- RMS Signal Conditioning

1.3.1 Amplification

In systems that use the 0-10V range to create electrical signals, amplification can be used to amplify the voltage to a suitable level for digitisation. This method of signal conditioning is typically used when a transducer such as a thermocouple outputs very small voltages. Having a signal below the mV range gets hard to read therefore by amplifying it to be within 0-10V it becomes much easier and accurate to use.

Likewise, if a voltage signal happens to be larger than 0-10V, it can be reduced through the use of a resistor network as shown in **Figure 1.m**. This is called *Attenuation*.

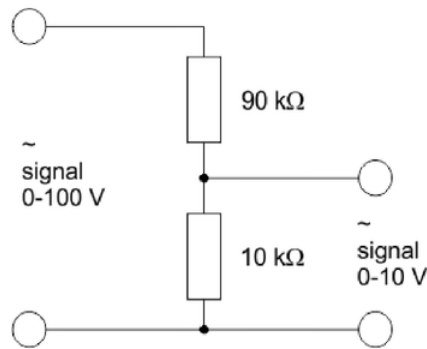


Figure 1.m

1.3.2 Excitation

Transducers such as RTDs require an external power supply to excite them in order to operate. Typically these transducers are connected to a low voltage DC supply, however sometimes they require AC if they are measuring something capacitive. Excitation is often a requirement when measuring pressure, temperature, luminosity, force and vibration.

1.3.3 Linearization

Linearization is required when a signal produced by a transducer doesn't have a linear relationship to what it is measuring. An example of a transducer that often requires linearization is a thermocouple. Linearization is the process of interpreting the signal provided by a transducer into something linear that can be read.

1.3.4 Cold-Junction Compensation

Cold-junction compensation often called CJC is once again commonly used with thermocouples. The principle of operation for a thermocouple is that it measures temperature as the difference in voltage between two different metals. Therefore, another voltage is created at the connection between the thermocouple and the DAQ.

"CJC improves your measurement accuracy by providing the temperature at this junction and applying the appropriate correction." (Adtech-inst.com, 2018)

1.3.5 Filtering

Filtering is a method of signal conditioning that is used to remove unwanted noise within a specific frequency range. A common application of filtering is using lowpass filters to reduce high frequency noise from electrical measurements in 50Hz power. Alternatively, filtering is used to prevent aliasing from high frequency signals.

1.3.6 Isolation

Isolation signal conditioning is done by transmitting the electrical signal created by the transducer to a device such as a computer without a direct electrical connection. This is commonly done through the use of transformers, optical devices or capacitive coupling.

1.3.7 High Impedance

Some transducers have extremely high output impedance cannot supply a high enough current to use a standard voltage input. In cases like this the use of an amplifier distorts the input signal to the point where it is no longer useable. In order to avoid this, they should be connected to voltage measuring circuits which have very high input impedance.

1.3.8 Bridge Completion

“Bridge completion is required for quarter- and half-bridge sensors to comprise a four resistor Wheatstone bridge. Strain gage signal conditioners typically provide half-bridge completion networks consisting of high-precision reference resistors.” (Adtech-inst.com, 2018).

By completing the bridge configuration, the resistors provide a fixed reference for detecting very small changes in voltage across the active resistor in the bridge. **Figure 1.n** shows a table which states which method of signal conditioning is used for different types of transducers.

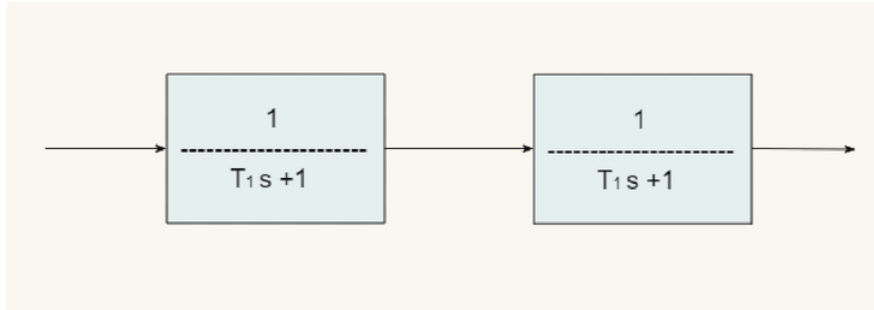
	Amplification	Attenuation	Isolation	Filtering	Excitation	Linearization	CJC	Bridge Completion
Thermocouple	✓		✓	✓	✓	✓		
Thermistor	✓		✓	✓	✓	✓	✓	
RTD	✓		✓	✓	✓	✓		
Strain Gage	✓		✓	✓	✓	✓		✓
Load, Pressure, Torque (mV/V)	✓		✓	✓	✓	✓		
Load, Pressure, Torque (±5 V, ±10 V, 4-20 mA)	✓		✓	✓	✓	✓		
Accelerometer	✓		✓	✓	✓	✓		
Microphone	✓		✓	✓	✓	✓		
Proximity Probe	✓		✓	✓	✓	✓		
INDRAUT	✓	✓	✓	✓	✓	✓		
High Voltage		✓	✓					

Figure 1.n

(Ni.com, 2018)

1.4 CALDWELL MODELLING METHOD

The Caldwell method of modelling a system is one of the ways to model a 2nd order system. This is done by assuming that a 2nd order system can be represented as a combination of two unconnected 1st order systems. This can be seen in



This can be expressed as:

$$G(s) = \frac{1}{(T_1s + 1)(T_2s + 1)}$$

In order to use this transfer function, values for T_1 and T_2 must be obtained. In order to get these values a process reaction curve must be created. This is done by recording the measurements from a transducer and plotting them on a graph.

When the process reaction curve is obtained, the Caldwell Method can be used to determine the values for T_1 and T_2 . At the time (x axis) where the curve reaches 73% of the final value (y axis) can be taken note of. This time is labelled t_y and can be used to calculate $(T_1 + T_2)$ through the use of the following formula:

$$t_y = 1.32 \times (T_1 + T_2)$$

Once $(t_1 + t_2)$ is calculated the fractional response time can be calculated by:

$$\text{Fractional Response Time} = \frac{(T_1 + T_2)}{2}$$

By finding where the response is on the y axes at the fractional response time, a Caldwell reference can be taken using a Caldwell Reference Graph as shown in *Error! Reference source not found.* With this reference value T_1 and T_2 can both be calculated:

$$\text{Caldwell Referece} = \frac{T_2}{(T_1 + T_2)}$$

Thus, the transfer function is completed. This transfer function can then be put into Simulink and tuned to obtain starting values for a PID controller.

Caldwell Reference Graph

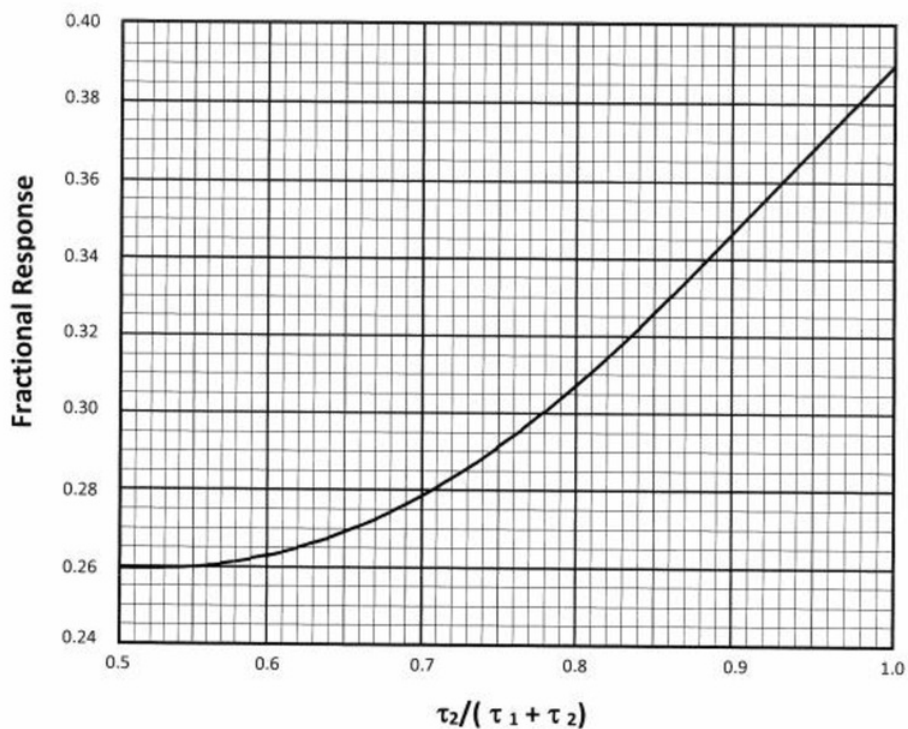


Figure 1.o

1.5 ZIEGLER – NICHOLS TUNING METHODS

The process reaction curve tuning method and the ultimate cycle criteria are methods of tuning a PLC named after Ziegler and Nichols. Both require prior experiments to obtain a process reaction curve.

A test step signal is used as an input to the system and the output is monitored and plotted on a graph. The graph produced is called the process reaction curve. From an existing process reaction curve parameters can be derived that can be used to calculate k_p , k_i and k_d .

This is done by drawing a tangent along the maximum gradient of the curve. The time between the start of the step input and the point at which the tangent intersects the x axis is labelled L which represents the system's Lag. The time in which the tangent exceeds the final value to the L point is named T for time. These two values can be used to determine the gradient of the tangent. This can be seen below where R is the gradient and Δy is the change in the y axis.

$$R = \frac{\Delta y}{T}$$

An example of this tangent can be seen in **Figure 1.p**.

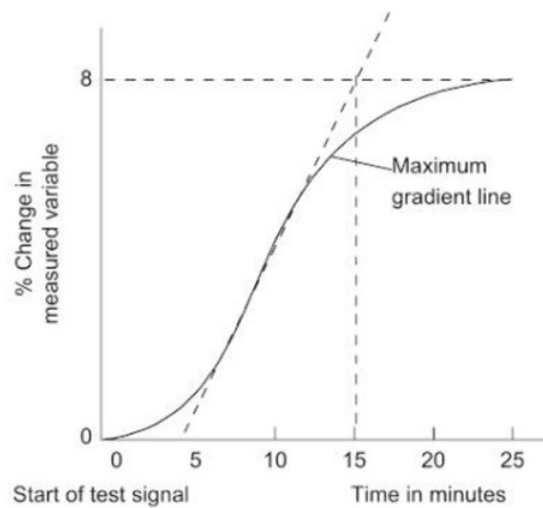


Figure 1.p

Once R and L are obtained, the values for K_p , K_i and K_d . These calculations can be seen in **Figure 1.q**.

Type of controller	K_p	T_i	T_d
P	P/RL		
PI	$0.9P/RL$	$3.3L$	
PID	$1.2P/RL$	$2L$	$0.5L$

Figure 1.q

Using these values, the parameters for a PID controller are found which can then be used as a starting point for tuning. "The basis behind the ultimate cycle criteria is to give a closed-loop response for a system which exhibits a quarter amplitude decay." (Bolton, 2004) This can be seen in

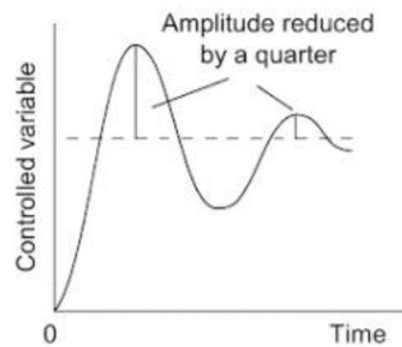


Figure 1.r

When comparing the Ziegler-Nichols method to the Caldwell method for tuning, using Simulink to get tuned values for the PID proves to be much better for providing initial tuning values.

2 FLOW CONTROL SYSTEM MODELLING, SIMULATION AND TESTING

2.1 BYTRONIC FLOW SYSTEM

The first step of creating a flow control system is to take a log of the flow from the bytronic rig, and create a model that replicates the process reaction curve. Using Caldwell, a transfer function is created that will be used in a Simulink model for the bytronic system.

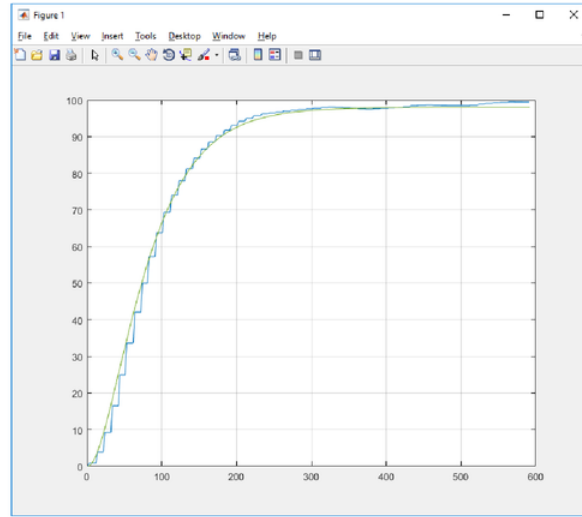


Figure 2.a

Figure 2.a shows the process reaction curve produced by the open loop configured bytronic flow rig. This is depicted by the blue line. The green line is plotted using the transfer function derived from the Caldwell Method below. The 73% point of the reaction curve occurs as 112.5ms on the x axis. This value is used in the following equation.

$$112.5 = 1.32 \times (T_1 + T_2) \quad \therefore (T_1 + T_2) = \frac{112.5}{1.32} = 85.227$$

$$\text{Fractional Response Time} = \frac{(T_1 + T_2)}{2} = \frac{85.227}{2} = 42.6$$

Using the Caldwell Reference Graph, a value of 0.5 was obtained. This is used below.

$$T_2 = 0.5 \times (T_1 + T_2) = 0.5 \times (85.227) = 41.6\text{ms}$$

$$\therefore T_1 = 41.6\text{ms}$$

With these values, the transfer function can be completed.

$$G(s) = \frac{1}{(T_1 s^2 + 1)(T_2 s + 1)} = \frac{1}{1.731 \times 10^{-3} s^2 + 85.227 \times 10^{-3} s + 1}$$

With this mathematical model completed, a Simulink model can be created to emulate the bytronic system.

2.2 SIMULINK MODEL

With the transfer function complete, an open-loop Simulink model can be created. This is shown in **Figure 2.b**.

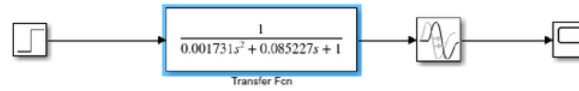


Figure 2.b

The Simulink model is connected to a step input which can be seen in **Figure 2.c** and a scope in order to see the output. The output can be seen in **Figure 2.d**.

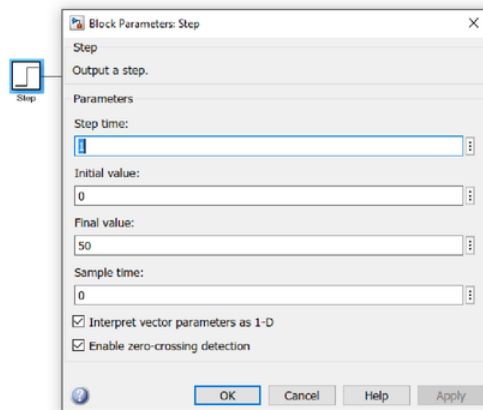


Figure 2.c

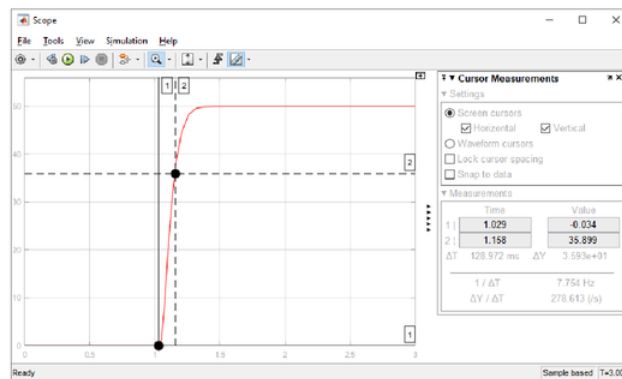
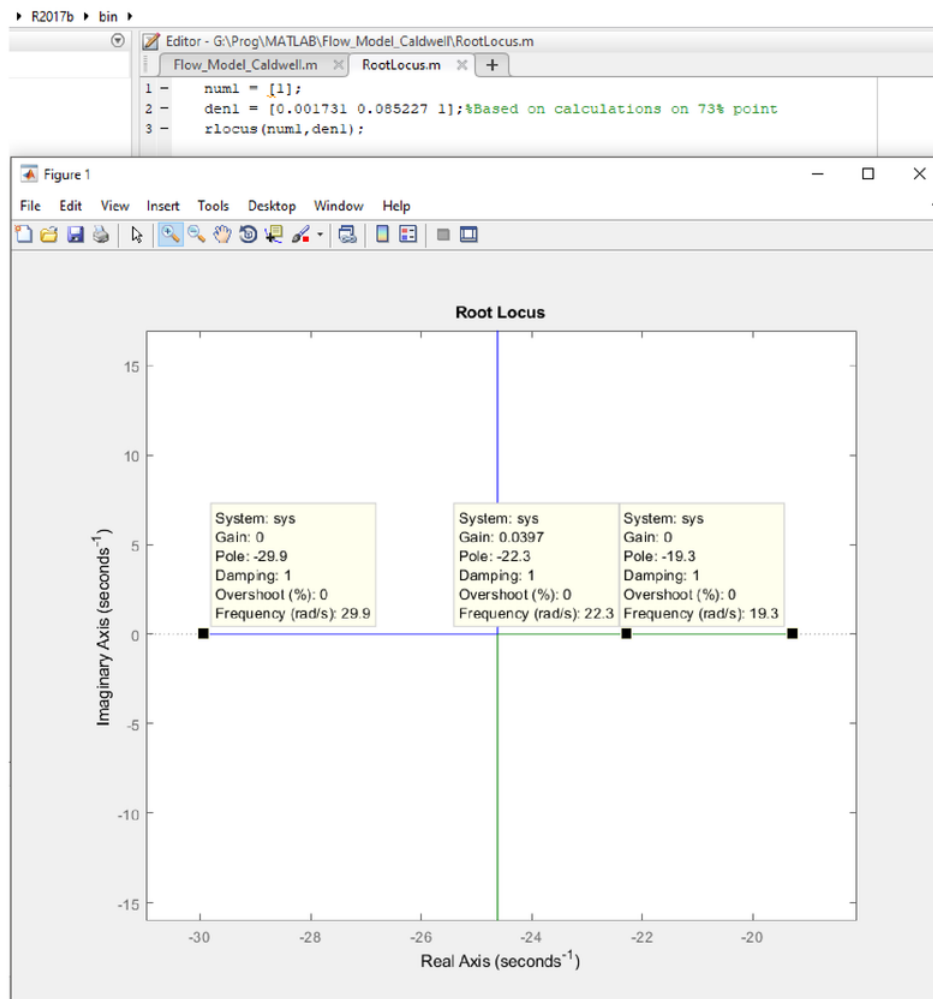


Figure 2.d

From **Figure 2.d** it can be seen that the model creates a response that resembles that of the flow log. However, the step input is set to have a final value of 50 rather than 100. The produced graph has reached the 73% of final value mark at 35.899ms. This can be proven by taking 73% of 50 which is 36.5.

2.3 MATHEMATICAL ANALYSIS

In order to test the transfer function a root locus analysis was taken using MATLAB to determine whether the system is stable or unstable. The result can be seen in



From this root locus analysis, it can be seen that there are two poles. This is expected as the number of poles corresponds with the highest power of 's' in the denominator. **Figure 2.d** shows both poles are within the negative plain and move to infinity along the y axis. This means that the poles never enter the positive plain. Therefore, this system is stable.

2.4 P, PI AND PID CONTROLLERS

In order to get the ideal response a controller must be added to the system which operates off a feedback loop. The potential controllers that can be used are P, PI and PID controllers. **Figure 2.e** shows three systems one with a P controller, one with a PI controller and one with a PID controller.

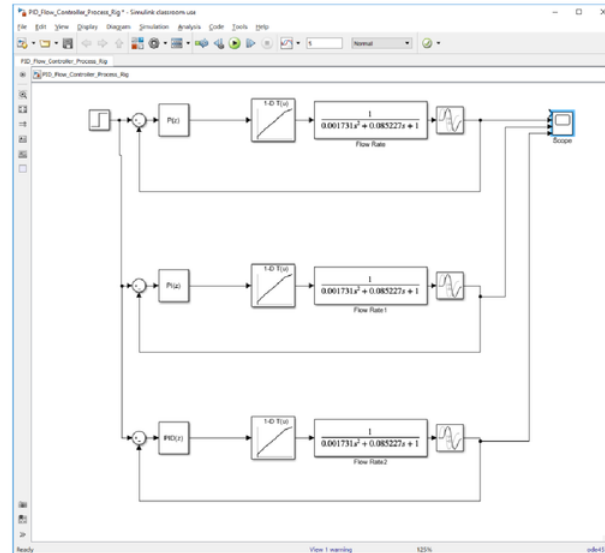


Figure 2.e

A lookup table is also connected before the transfer function. The lookup table (LUT) acts as a scaling factor and uses the following values:

Input	Output
0	0
1	0.25
10	15
20	26
30	35
40	47
50	61
60	72
70	82
80	97
90	99.9
100	100

The LUT is used to amend the model so that it acts like the pump. For example, if 50 is input, 61 is output to the pump.

Each of the systems is connected to a scope to show the output for the system. **Figure 2.f** shows the outputs of all three systems.

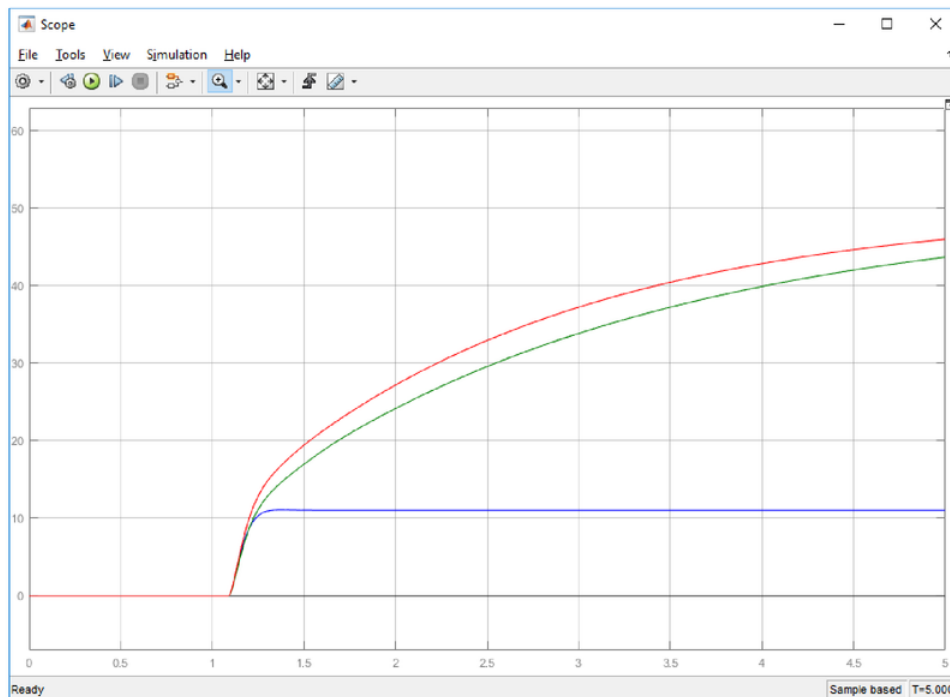


Figure 2.f

The blue line represents the system which has a P controller. It can be seen that it has a very large steady state error as the line enters steady state at 12 on the x axis. The system should have a steady state at 50 since that is the final value of the step input. The PI controller has corrected the steady state error; however the response time is very slow. This suggests that the i value corrects the steady state error. Finally, the PID controller once again has reduced steady state error; however it rises slightly faster than that of the PI controller. The values used in each of the controllers are the tuned values from Simulink. To further illustrate the effect of each of the controllers, multiple simulations with each of the controllers can be found below.

Firstly, a transfer function of $\frac{1}{s^2+10s+20}$ is used with a unit step input. When tuned this system should operate at a set point of 1. **Figure 2.g** shows the response without any controllers.

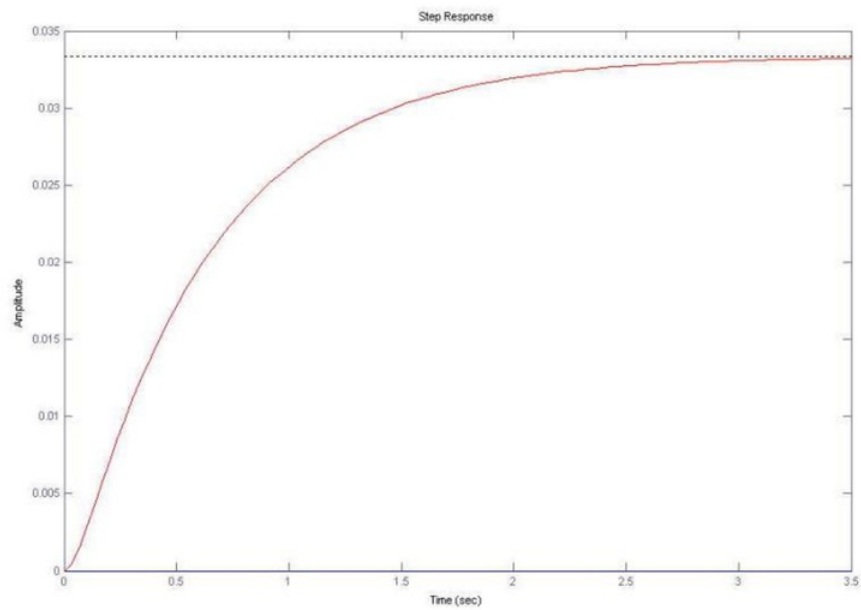


Figure 2.g

As shown above, the steady state error (e_{ss}) = 0.965 and the rise time (t_r) = 3 seconds. This steady state error is way too high and the rise time is too long. **Figure 2.h** shows the system using a P controller where $K_p = 10$.

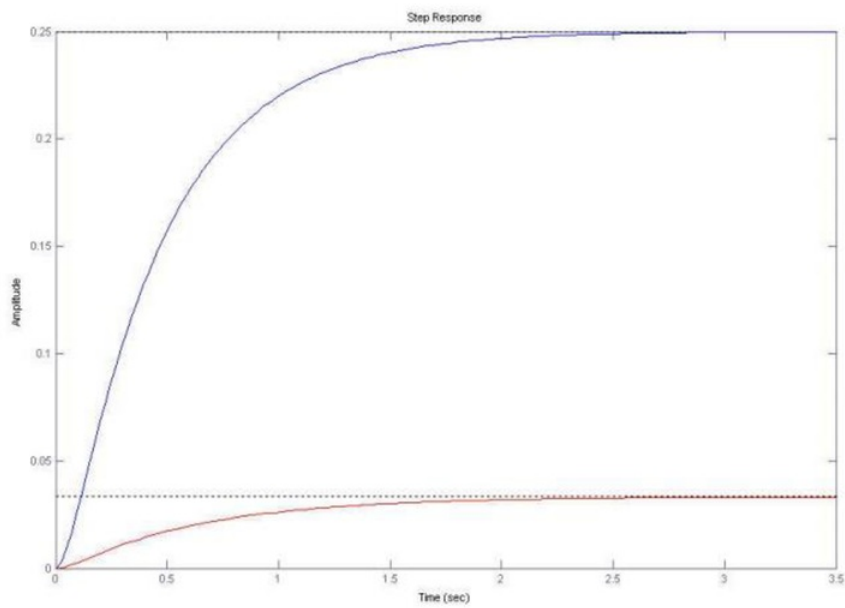


Figure 2.h

Right away it can be seen that the addition of the P controller response improved the steady state error, and the rise time decreased. However it still isn't ideal. **Figure 2.i** shows the same system however $K_p = 100$.

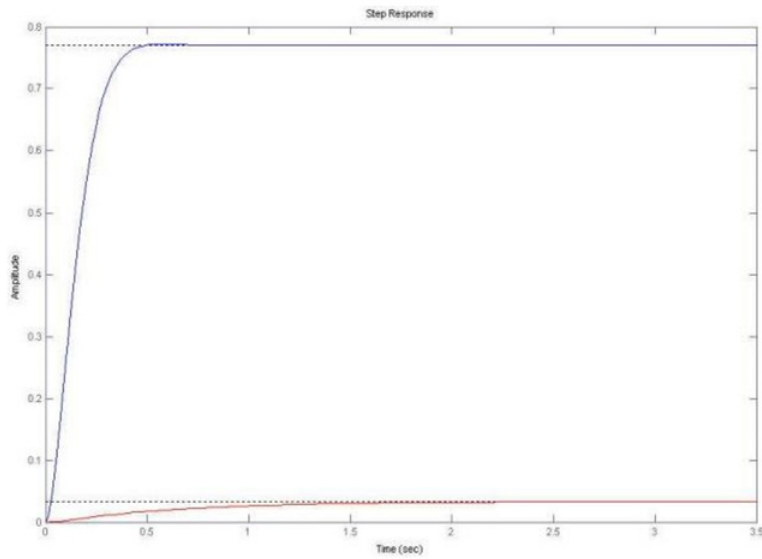


Figure 2.i

In this simulation the $(e_{ss}) = 0.23$ and $(t_r) = 0.5s$. Both of these are huge improvements from the initial uncontrolled process reaction curve.

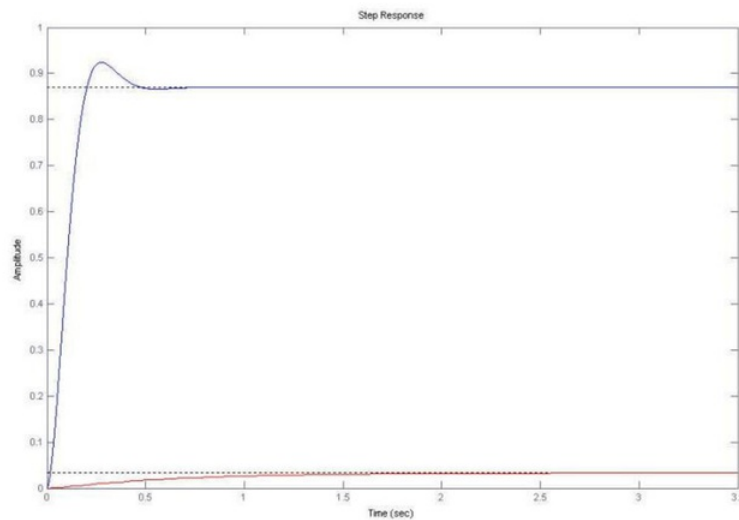


Figure 2.j

Figure 2.j shows the same system where $K_p = 200$. It shows that the response now has slight overshoot, however the $(e_{ss}) = 0.13$ and $(t_r) = 0.5s$. These simulations allow the following conclusions to be made:

- Increasing K_p reduces the rise time
- Increasing K_p reduces the steady state error
- When increased past a certain point K_p causes an overshoot

The next series of simulations will use a PI controller to see the effects of K_i on the output response. **Figure 2.k** shows the system with $K_p = 200$ and $K_i = 100$.

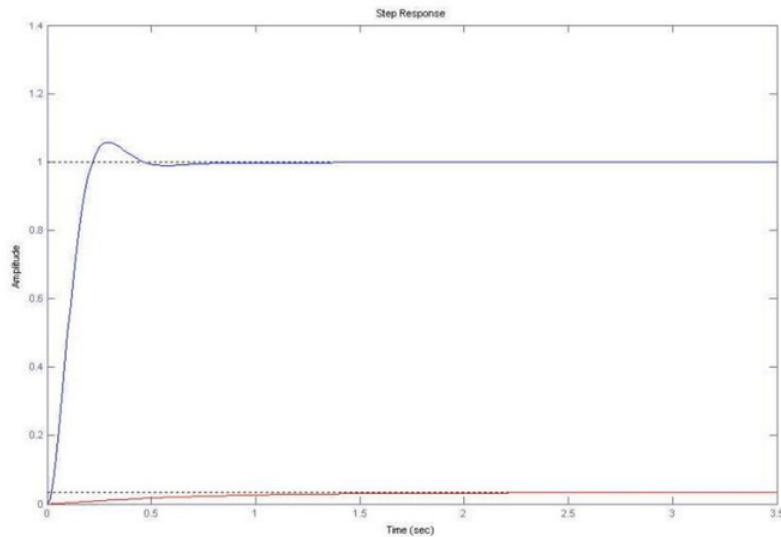


Figure 2.k

From the above response it can be seen that when K_i is introduced the (e_{ss}) is eliminated, $(t_r) = 0.3s$ and the settling time $(t_s) = 0.7s$. However the overshoot still occurs. Figure 2.l shows the system when $K_p = 200$ and $K_i = 200$.

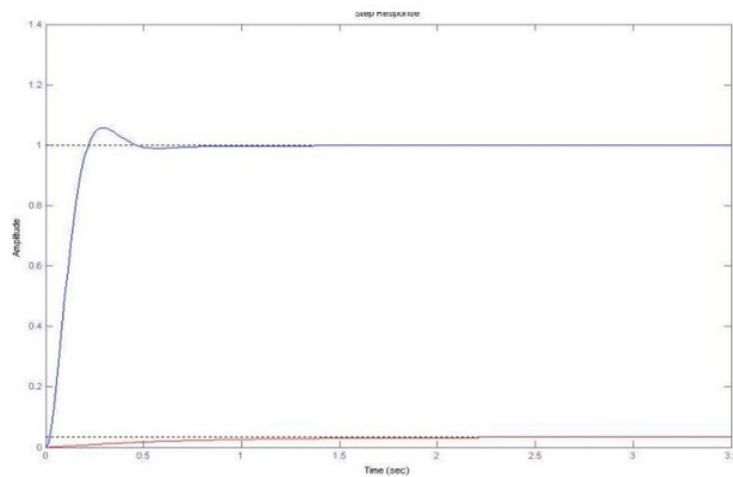


Figure 2.l

As shown, there are no significant changes to the response after K_i was increased. Therefore the following conclusions can be made:

- Increasing K_i slightly reduces rise time
- After a certain threshold K_i will only increase overshoot
- The use of K_i completely corrects the steady state error

The final simulation will add K_d to the system to create a PID controller. The output response can be seen in **Figure 2.m** $K_p = 200$, $K_i = 200$ and $K_d = 10$

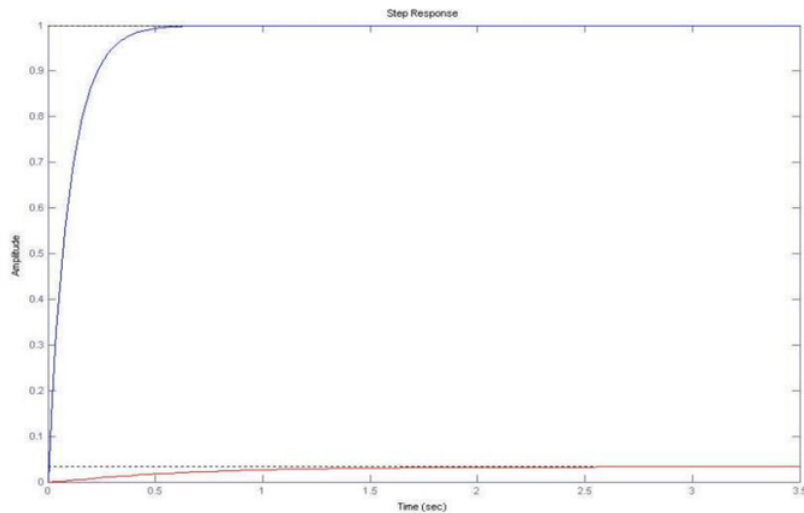


Figure 2.m

Everything from the previous simulations remained unchanged, except the addition of K_d removed the overshoot from the response. Therefore the following conclusions can be made with regards to K_d .

- The use of K_d removes / decreases overshoot.

It can be seen from **Figure 2.m** that through the use of a PID controller and well-tuned K_p , K_i and K_d values the output response of a system can be controlled to a large degree of accuracy. This allows for engineers to fine tune the response of a system to suit what they need.

(P, PD, PI, PID CONTROLLERS, 2012)

2.5 CALDWELL MODEL PID CONTROLLER

In order to make an accurate model of the bytronic rig, a PID controller is used to control the output of the PLC which will in turn control the pump. Initially the PID controller will use tuned values from Simulink as a starting point. After that two more sets of values will be used to fine tune the system which will then be practically tested and measured using a Pico scope. The Simulink models can be seen in **Figure 2.n**.

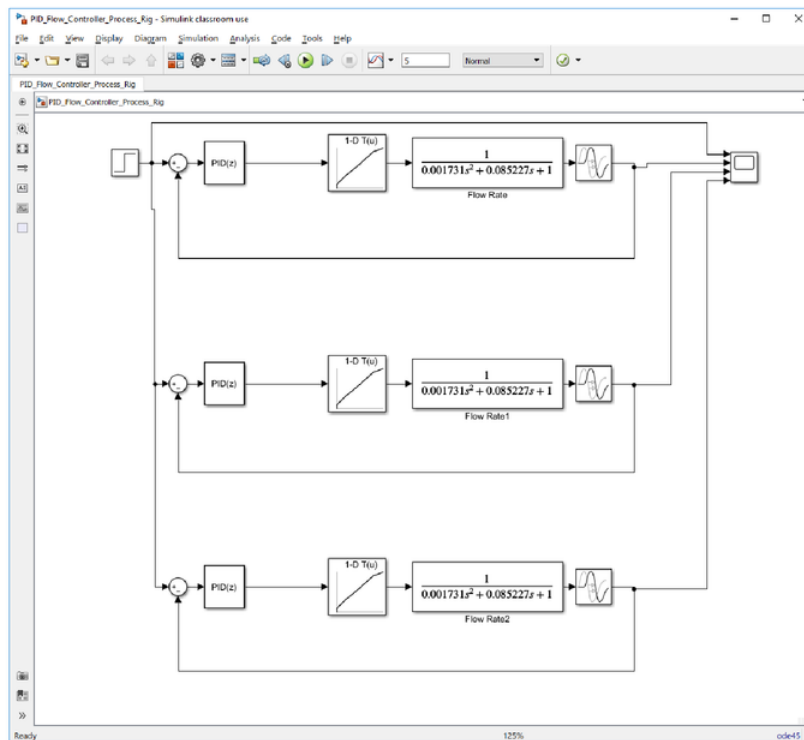


Figure 2.n

Figure 2.n shows that there are three identical models all connected to a step input, and a scope on the output. Each model has a PID controller which has its own tuning values, a Lookup table (which was previously discussed), the transfer function derived using the Caldwell Method, and a delay.

The topmost PID controller uses tuned values for Kp, Ki and Kd. The other two use manually tuned values. These values can be found in the table below.

	Kp	Ki	Kd
Simulink Tuned (Blue)	0.0499235217277656	0.553564552439402	0
Manual Tuning 1 (Green)	0.5	4.5	0.05
Manual Tuning 2 (Red)	0.5	5	0.05

Through the use of the scope the output responses for each of these models can be seen in **Figure 2.o**.

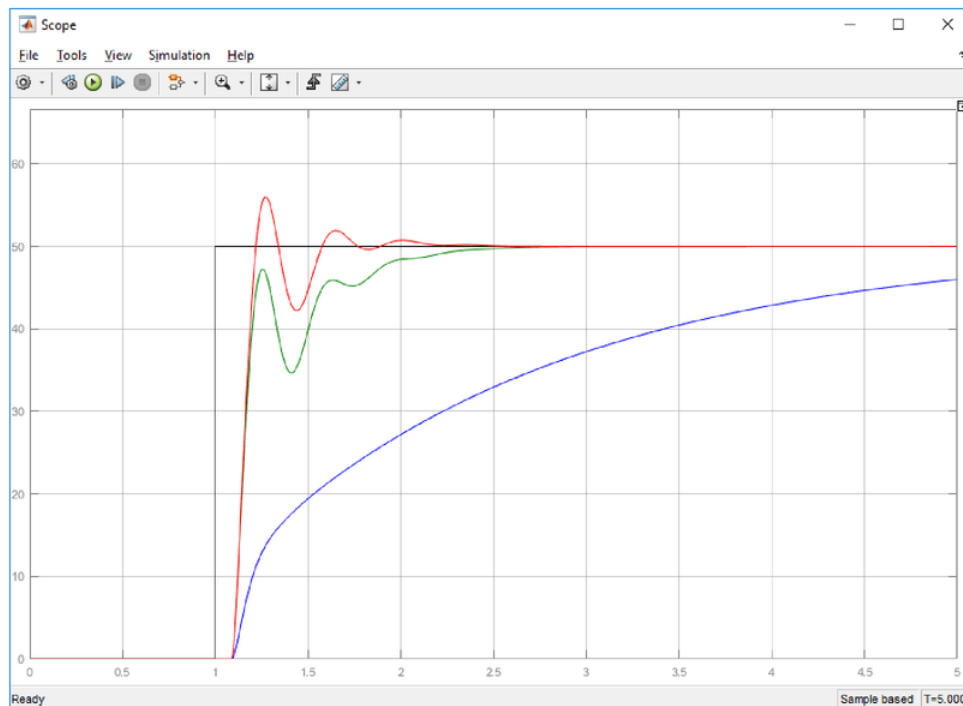


Figure 2.o

The blue line produced on the scope from the output shows the response for the Simulink tuned PID controller. It shows a very slow response, and a very slow rise time. Through extrapolation it can be assumed that it does eventually reach the set point meaning it does not have any steady state error. However, it is not safe to make assumptions so these values need to be tweaked in order to make a better response.

The first change to these values was to make $K_p = 0.5$, $K_i = 4.5$ and $K_d = 0.05$. These values produced the green line on the scope. Instantly it can be seen that the rise time, and time to reach steady state is much faster. However, the response could further be improved. For the red line K_p and K_d were kept the same, and K_i was changed to equal 5. This change brings the response slightly closer to a desired response.

The next step of this practical experiment was to test the three different tunings on the bytronic rig. The first test used the Simulink tuned values and can be seen in **Figure 2.p**.

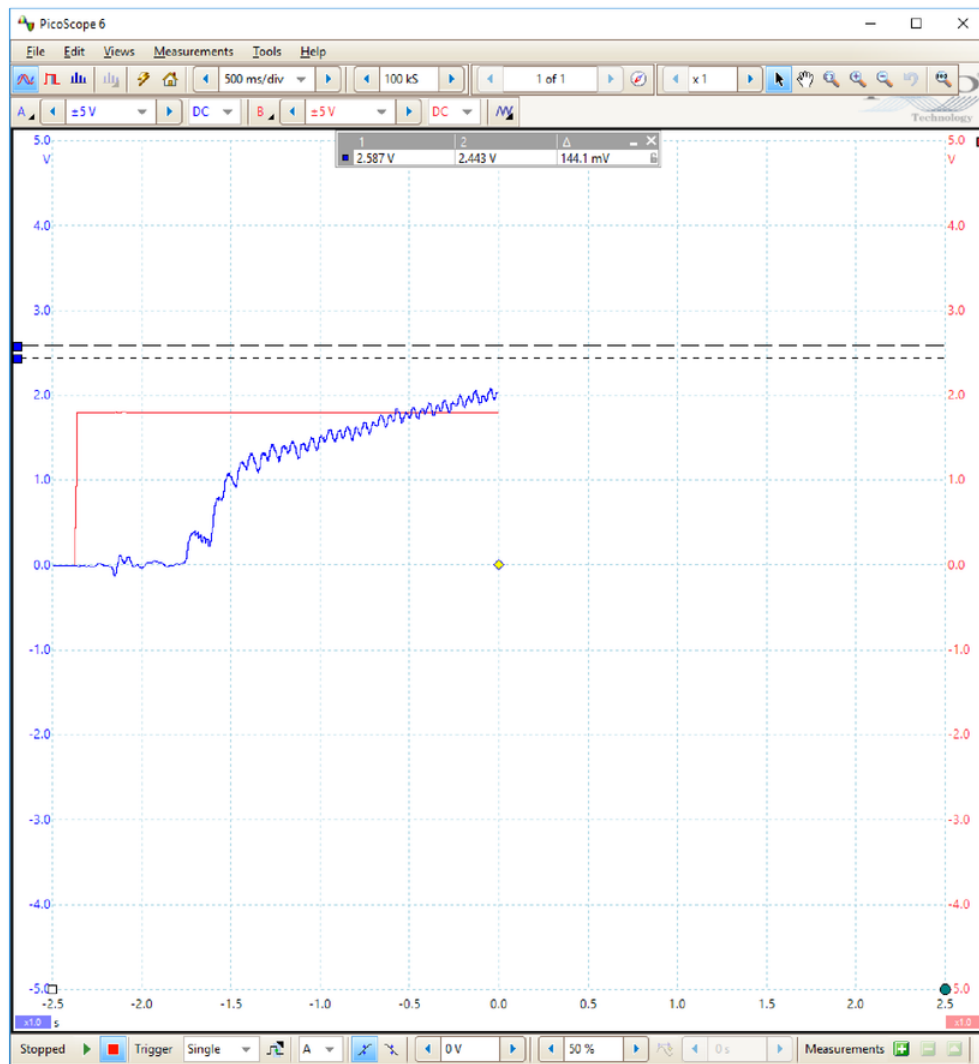


Figure 2.p

The above response almost perfectly mimics the simulation's response as it has a slow rise time, and slowly tends towards the set point. **Figure 2.q** shows the process reaction of the green tuning values.

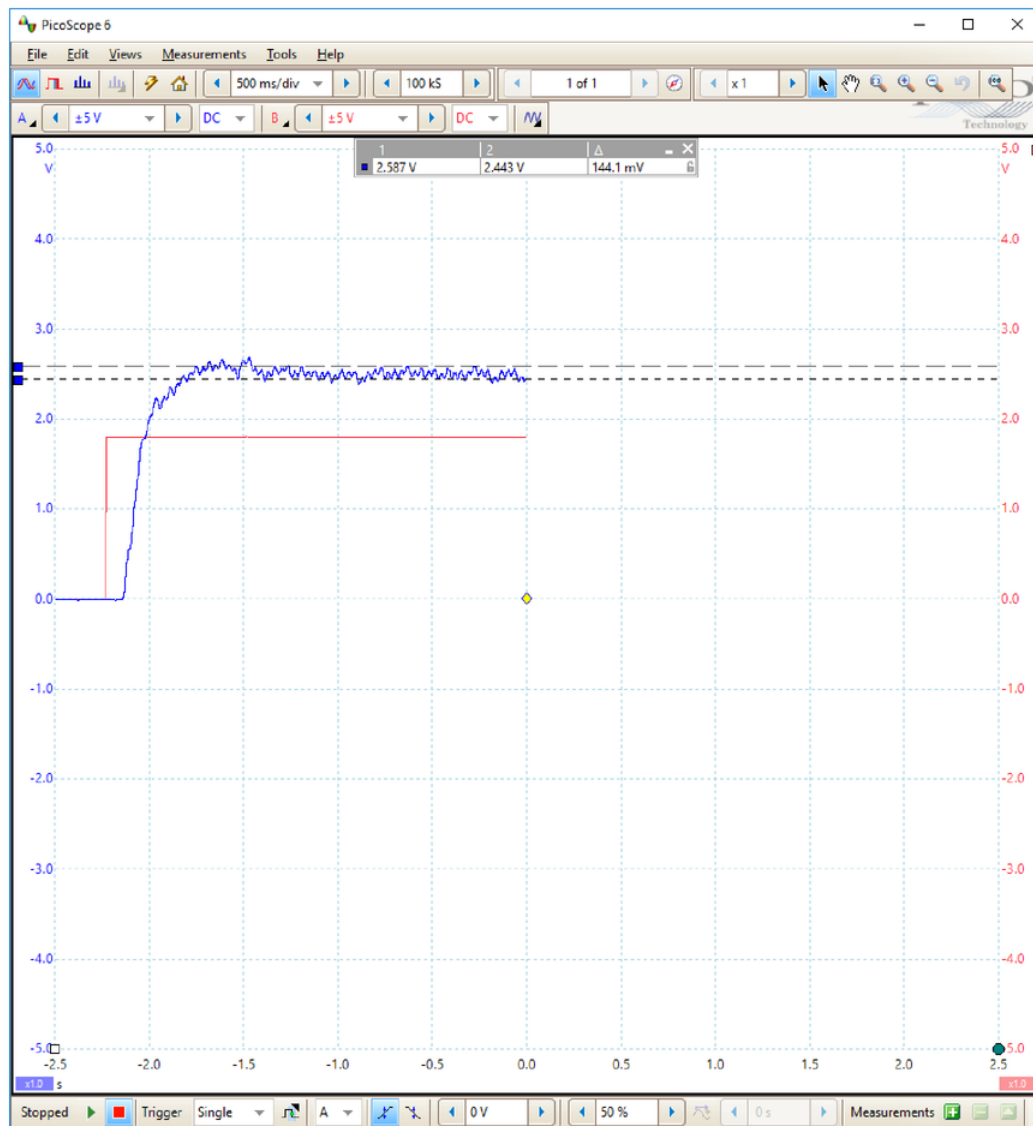


Figure 2.q

As expected, the rise time of the response is much faster and steady state is achieved with no error quickly. The steady state stays within the 5% error band at the 50% set point which is ideal operation. However, as the rising signal tends towards the set point, the gradient decreases rather early which can be improved. **Figure 2.r** shows the process reaction curve for the red tuning values.

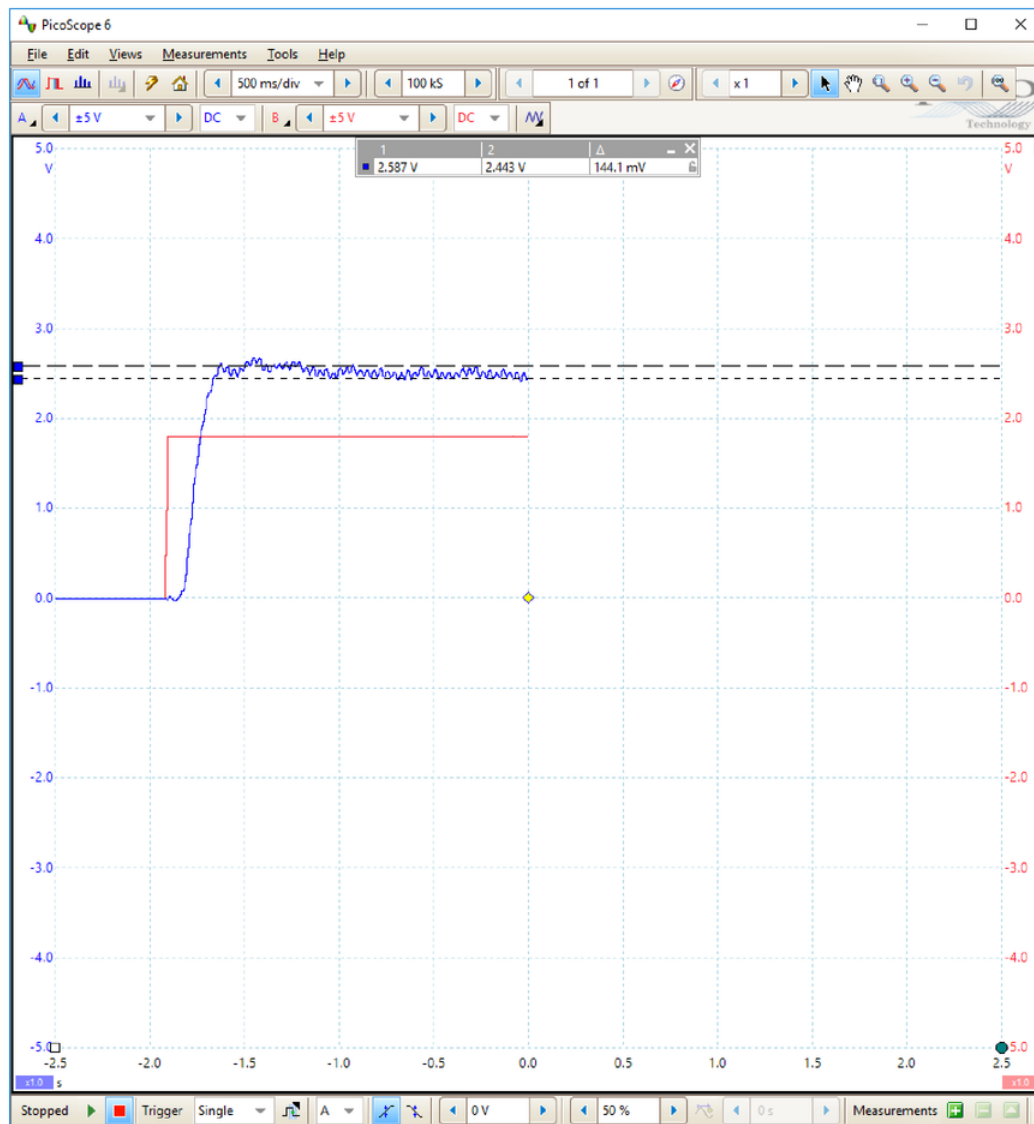


Figure 2.r

This final measurement shows a very fast rising time which stops rising as soon as the set point is achieved. There is also a lot less variation within the 5% band which means the steady state error has been improved slightly. Potential improvements to this will be discussed in **Section 3.0**.

2.6 ZIEGLER-NICHOLS METHOD OF TUNING

The final part of this practical experiment is to use the Ziegler-Nichols method of tuning to compare with the prior tuning results. This is done using the method stated in **Section 1.5**. The calculations for this set of tuning values can be seen below **Figure 2.s**.

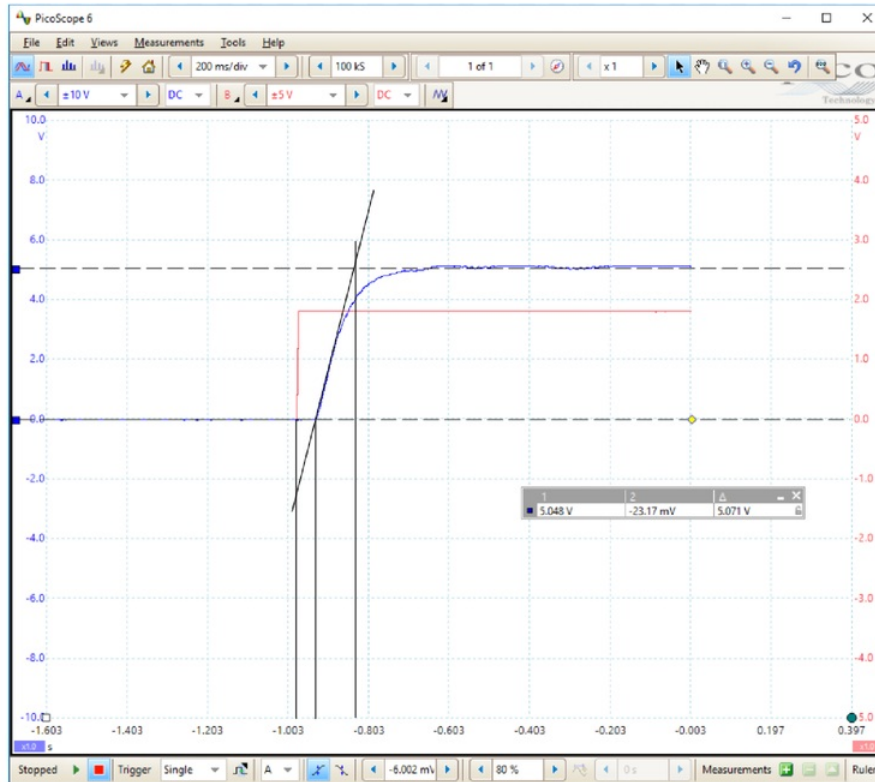


Figure 2.s

Using a ruler L was measured to equal 0.05s and T was measured to equal 0.1s. From this the gradient was calculated:

$$R = \frac{\Delta y}{T} = \frac{100}{0.1} = 1000$$

Using the values for R and L , K_p , K_i and K_d could be calculated using the formula stated in **Figure 2.t**.

Type of controller	K_p	T_i	T_d
P	P/RL		
PI	$0.9P/RL$	$3.3L$	
PID	$1.2P/RL$	$2L$	$0.5L$

Figure 2.t

$$Kp = 2.4$$

$$Ki = 24$$

$$Kd = 0.06$$

With these values input to the Simulink model, a process response is produced. This can be seen in **Figure 2.u**.

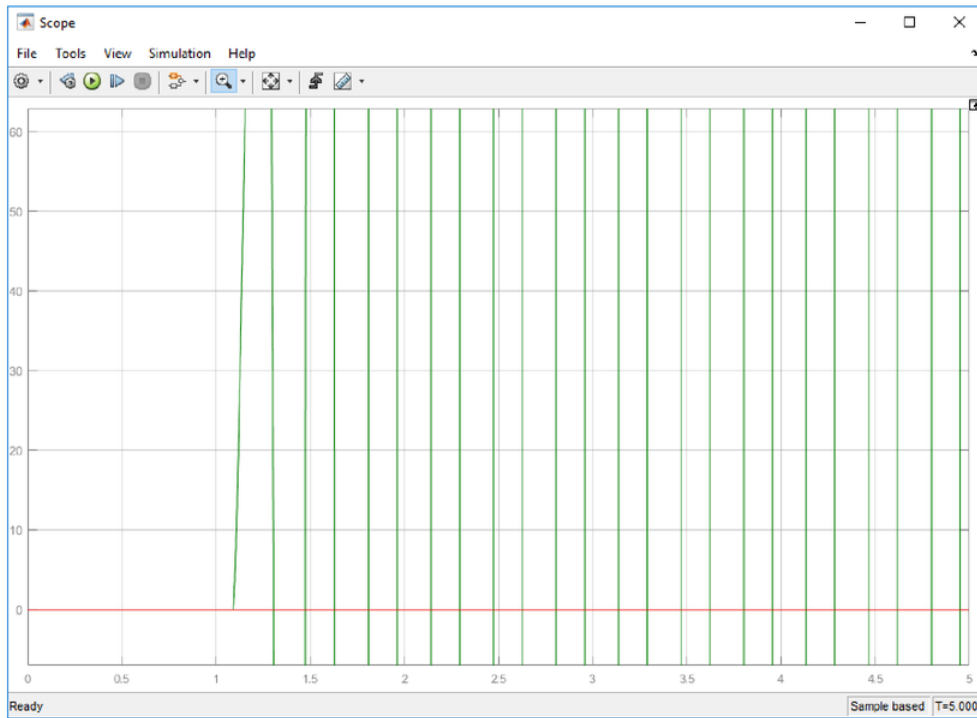


Figure 2.u

This response shows an oscillating signal which is not desirable at all. When tested on the bytronic rig a similar result was obtained. This can be seen in **Figure 2.v**.

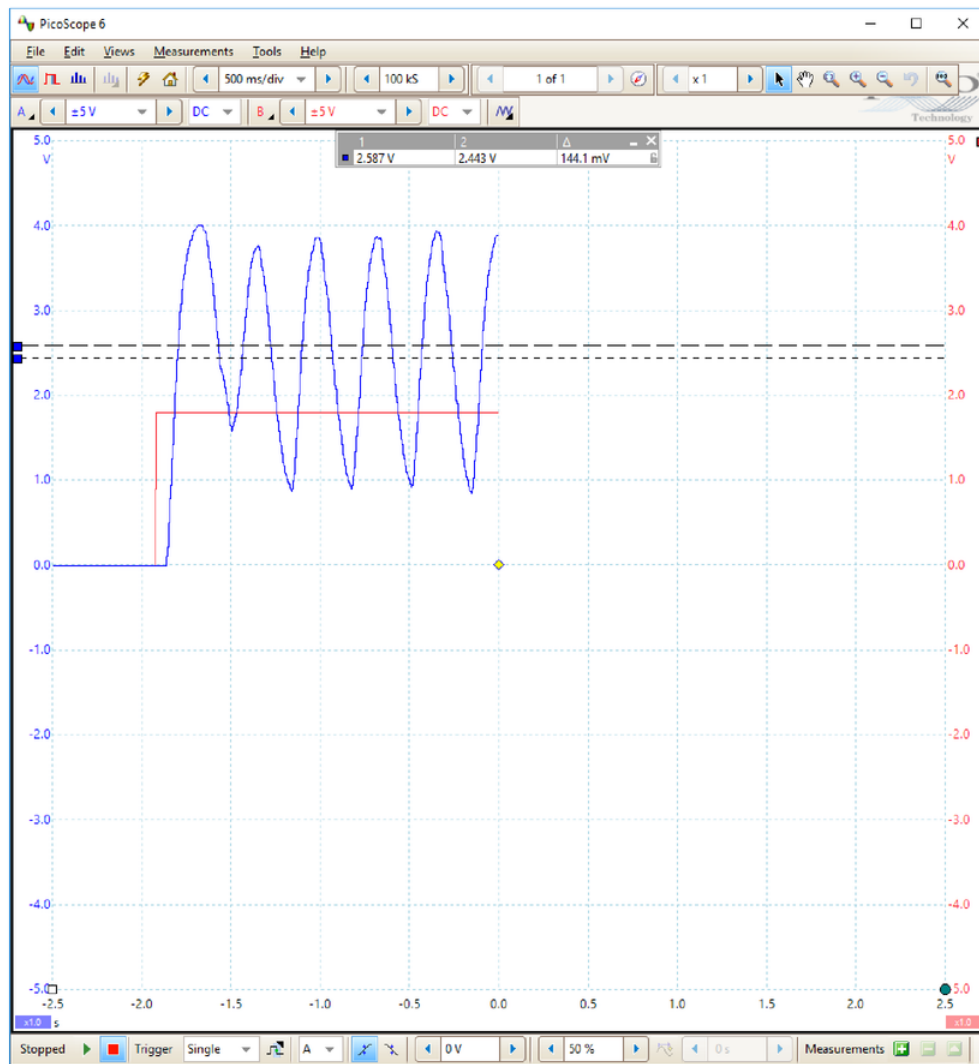


Figure 2.v

As shown, the signal has massive over shoot, and continues to oscillate. With the oscillation trend it is safe to say it could possibly have infinite settling time and will never reach steady state. Therefore these values for tuning are not very useful for starting values.

3 CONCLUSIONS AND RECOMMENDATIONS

First of all a lot was learned about the various types of transducer and their applications. There are many different types of transducer that each have advantages and disadvantages when it comes to certain applications. For example the electromagnetic flow meter is much more applicable to fluids than the ultrasonic flow meter. However, the ultrasonic flow meter is specialised in measuring the flow of gasses.

A great deal was also learned about signal conditioning and its importance when it comes to data acquisition. Without proper signal conditioning measurements provided by transducers may not be accurate or even readable.

As shown through multiple sections of the report, the two methods of tuning a PID controller were compared. Firstly, the Caldwell method was used to create a transfer function which was then used in Simulink to generate tuned values for a PID controller. These values proved to be rather close starting values for the tuning process. In comparison the values obtained from the Ziegler-Nichols method were much less useful as to get a reasonable response the values must be changed drastically. The method itself was also time consuming and if to be repeated for more process reaction curves would waste a lot of time, resources and materials in a practical application.

The simulations that were used to illustrate the effect of K_p , K_i and K_d was a very useful experience as knowing the effect of each makes tuning much less time consuming and more efficient. For example, in the future if there is an overshoot, increasing K_d could potentially fix the response. Likewise, if there is a steady state error then K_i should be increased to correct the error.

Using this information the tuned values used in **Section 2.5** in the practical experiment could further be tuned to produce a much better simulated response, and therefore potentially produce a better response on the Bytronic rig. However, the final response for the practical experiment turned out to be very good. So improving the tunings further isn't of utmost importance.

As a recommendation, it would be interesting to change some of the properties of the bytronic rig itself to see how that would affect the process response curve. A potential change could be to change the diameter of the pipe, or even use different transducers such as an electromagnetic flow meter. This would create an opportunity to further learn about the differences between the various transducers and how they might potentially produce different responses.

4 CITATION LIST

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5 APPENDICIES

Sam Harries - Assignment 1

GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

Instructor

63/100

PAGE 1

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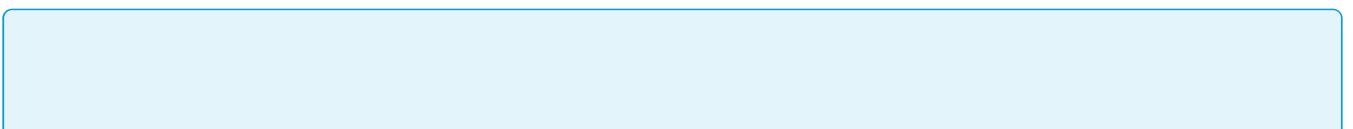
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GRADING FORM: CSG-RUBIC



RESEARCH-INFORMED LITERATURE



Section 1: Your research - Good evidence of reading and clear explanations given. However, you must not paste in large sections from sources as an image, cite them instead. Some images need more detailed explanations. (12/20) Section 4: Your use of Harvard for citing and listing. A wide range of sources cited and listed correctly. (4/5)

16

KNOWLEDGE AND UNDERSTANDING



Section 2: Explanation of the control system and model - Generally well explained but there are some errors and some information is unclear. For example, you have not explained why the LUT was needed nor the inclusion of the transport delay. (11/15)

11

ANALYSIS



Sections 2 and 5: Analysis of model, simulation and practical testing - Some analysis provided and practical testing. However, an additional section for a different model has been added with no reason given. (12/20) Section 3: Conclusions and recommendations - Some conclusion and recommendations provided. Further marks were available for more details. (5/10)

17

PRACTICAL APPLICATION AND DEP.



Sections 2: Development of the model, use of Simulink – Generally good but further evidence is needed. (6/10) Sections 2: Practical tuning – You have used the model tuned values in the practical system and you have also used the Ziegler Nichols method. However, you were supposed to use the best tuned values from the model as a starting point to tune the Bytronic rig rather than experimenting with the some of the unsuitable values. (2/5) Section 2: Presentation of results - Well presented in most cases. However, the root locus diagram is difficult to understand. (4/5)

12

SKILLS FOR PROFESSIONAL PRAC.



All sections - Generally well presented and structured with list of figure. However, there are some errors, all figures should have titles and some figures need further explanations. Date at the bottom of the title page should be the actual submission date. (7/10)

7