

PSDE5011-Assignment1-

EW_Dyer

by Emyr Dyer

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TIME SUBMITTED	11-MAR-2018 11:37PM (UTC+0000)	WORD COUNT	2691
SUBMISSION ID	84480335	CHARACTER COUNT	19352

HND Electrical & Electronic Engineering

Control System Analysis, Modelling, Simulation and Practical Testing

PSDE5011 – Control and Instrumentation

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Submission Date: 11/03/2018

Word Count: 2664

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1 RESEARCH

1.1 WHAT IS A TRANSDUCER?

This device is used to change energy from one form, to an electrical signal. The types of energy that can be converted from include Thermal, Mechanical, Chemical, Electromagnetic, Acoustic, and Light. The conversion of measured energy to an electrical signal is proportional, which can be identified in datasheets accompanying the component. Dynamic Range needs to be considered, which is the ratio between the biggest and the smallest amplitude, that an energy signal can be measured, as an excessively precise transducer that measures too high a signal can be wasteful in terms of application and cost. Noise is also a consideration where thermal characteristic of the medium under measurement, can introduce interference in the transformed energy signal (John A. Allocca, 2011).

1.2 TYPES OF FLOW METERS

While there are many distinct types of flow transducer available, depending on the application be it fluid or gas, as well as density of that fluid or gas. Considerations need to be made on how the Flow Meter is connected to the controlling system, for example the transmission medium between the sensor and a PLC, and distance between devices. Other considerations include how the devices are calibrated, part lifespan and supply, as well as maintenance complexity.

1.2.1 Paddle Wheel

A mechanically simple solution, the paddle wheel can be used with an optical transducer to detect breaks in the beam which forms pulses. With a greater fluid flow, the frequency of the pulses correspondingly increases, thus giving a measurement of the fluid flow. An issue with a paddle wheel is that it is not as reliable with gasses/vapours, which when flowing in a closed pipe may not affect the paddle wheel as effectively as fluid. Paddle wheels may also lose accuracy from slow flow, which would also have difficulty in turning the paddle wheel (Liptak, 1993).

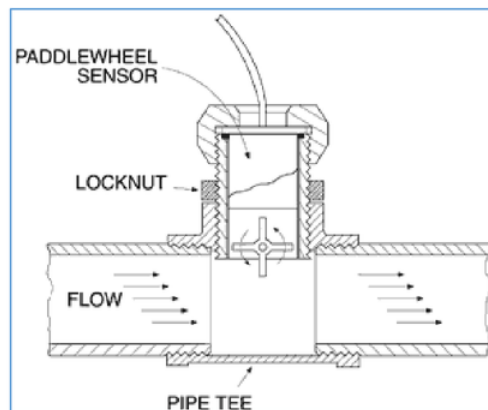


Figure 1.1: Paddle Wheel Meter

1.2.2 Turbine

Turbines are more effective with measuring gas/vapour as well as fluids. Unlike a paddle, the turbine turns on an axis in-line with the flow. Turbines also suffer from loss of accuracy due to slow flow. As is in most fluid pumping systems, there needs to be a filter in front of the turbine, to protect from

debris such as fragments from damaged parts or particulates left over from other processes. To detect the turning of the turbine, a magnetic pickup is used which detects the passing of the turbine blades, from which a frequency can be taken which ties to flow rate (Jones, 1995).

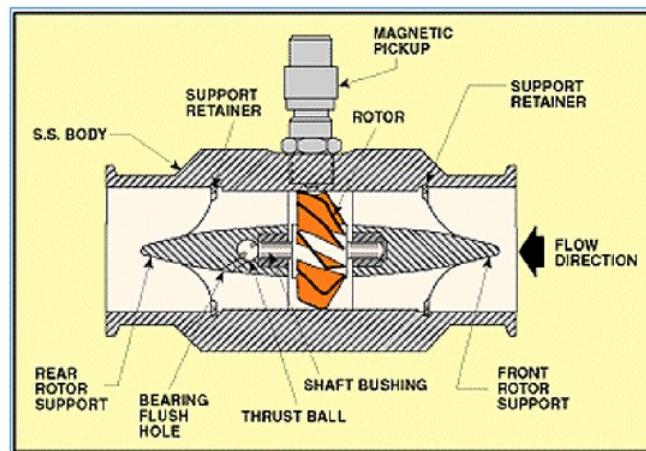


Figure 1.2: Turbine Flow Meter

1.2.3 Ultrasonic Flow Meter

Made of a tube that has no physical impedance of fluid flow, the external surface of the tube has disc shaped transducers that form ultrasonic waves via radial oscillation. The transducer discs also pick up the waves, so that outgoing and incoming waves are detected. Flow Velocity is measured by measuring the time difference (nanoseconds) taken by the waves to travel through the liquid, with the thickness of the tube accounted for (Liptak, 2003).

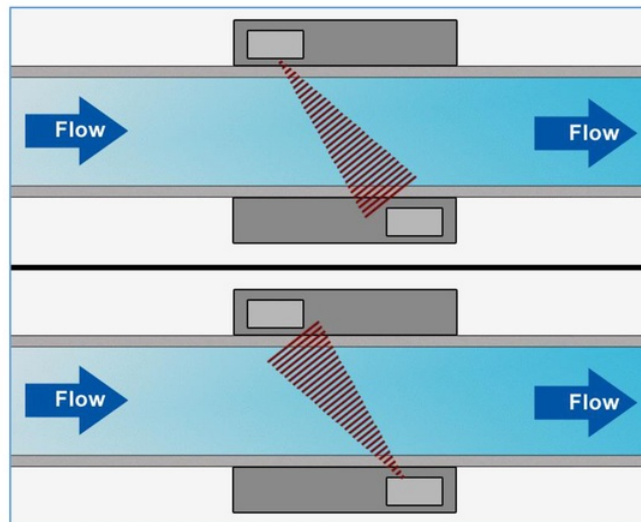


Figure 1.3: Ultrasonic Flow Meter

1.3 SIGNAL CONDITIONING

Simply put, Signal Conditioning is the processing of an electrical signal, which offers clarity when reading as an input to a control system. A few processes tend to be carried out, to modify the signal. The signal may be amplified to take a Millivolt signal into a Volt signal which is easier to measure using a controller. The Input and Output can have different means of transmitting the signal, to eliminate interference, for example the output signal could be translated to a type that is not used with the inputs. There can be compensation for any excitation to operate the device used for measurement (Analog Devices, inc, 1980).

1.4 APPLICATION IN THE BYTRONIC FLOW CONTROL SYSTEM

In the case of the Flow Control System, a Paddle Wheel is used to measure the flow rate in the closed pipe system. To process the transducer signals, a LM2917 Frequency to Voltage Converter is used (Texas Instruments, 2016), which translates the mV frequency input signal from the transducer to a 0-5V range, which at maximum value represents a flow of 2 Litres per Minute. The 0-5V signal is taken into a PLC as feedback into the PID process, which then calculates the new corrected speed at which the pump should operate.

1.5 CALDWELL METHOD

With a First Order system, the 63.2% point of the curve is identified which gives τ , which as part of the total process is;

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

When working with a second order system, the method used is to interpret the system as a product of two separate first order systems, which is shown with the following equation.

$$G(s) = \frac{1}{(\tau_1 s + 1)(\tau_2 s + 1)}$$

Using an existing Process Reaction Curve procured from running the system to be improved, τ_1 and τ_2 can be found. From the PRC, the maximum 100% peaked value is identified and the position at which the curve reaches 73%, this value is identified as t_y , which is calculated using

$$t_y = 1.32 \times (\tau_1 + \tau_2)$$

By identifying the fractional response at $\frac{\tau_1 + \tau_2}{2}$, the graph shown in Figure 1.4 is used to find $\frac{\tau_2}{\tau_1 + \tau_2}$ which is then used to find τ_1 (Caldwell, 1959).

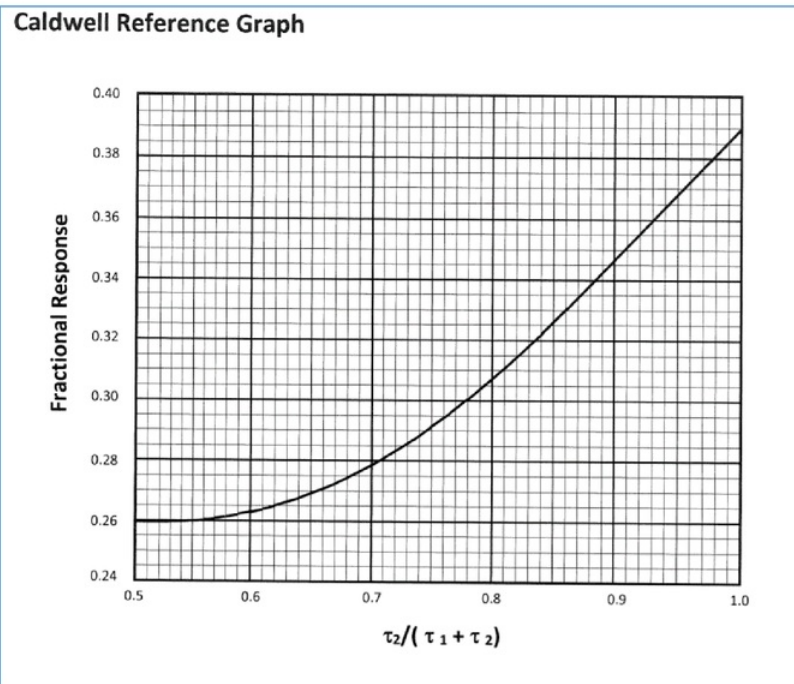


Figure 1.4: Caldwell Reference Graph

1.6 ZIEGLER-NICHOLS METHOD

Developed by John G. Ziegler and Nathaniel B. Nichols, the method identifies the values for a PID controller. First step is to procure a Process Reaction Curve to identify the dead time before a significant response is identified, the time taken to reach the maximum peak ($\Delta y\%$), and the Gradient. Using that data, a table is used to find PID.

Control Mode	K_p	K_i	K_d
<i>P</i>	$\Delta c / RL$		
<i>PI</i>	$0.9 \Delta c / RL$	$K_p / 3.33L$	
<i>PID</i>	$1.2 \Delta c / RL$	$K_p / 2L$	$0.5 K_p L$

This method is a fast means of determining PID values, however there is significant Overshoot in reaching the Peak as well as a sharp climb (Levine, 1996).

2 FLOW CONTROL SYSTEM

2.1 BYTRONIC FLOW CONTROL SYSTEM BEHAVIOUR ANALYSIS

On running the Bytronic Flow Control system when configured as open-loop, the characteristics shown in Figure 2.1 were recorded using a PicoScope. The Dead Time measured as Δ was recorded as 43.29ms. The performance shown in the curve of the Flow Control System is that of a system that has already been tuned, however an attempt will be made to find a more optimal tuning using MATLAB Simulation and the Caldwell Method. A data file called 'Flow_Log_2.txt' which contained a 1 column array of values for the curve.

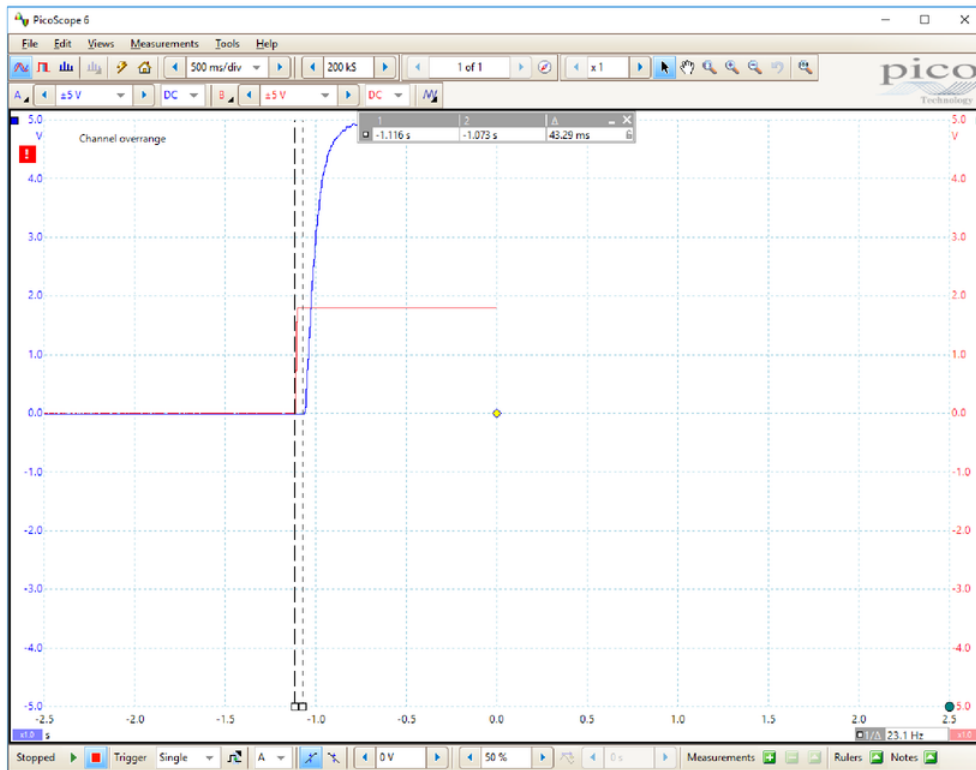


Figure 2.1: Open-loop measurement

In MATLAB, the script shown in Figure 2.2 was coded to produce a curve.

```
hold off
%load data from file first into array
load flow_log_2.txt;
flow_rate = flow_log_2(:,1);
plot(flow_rate); %untweaked plot data from txt file
hold on
grid on
```

Figure 2.2: flowrate script

In running the script, the following curve was produced as shown in Figure 2.3. Using a pointer tool within MATLAB, an attempt was made to identify the 73% point of the curve. As there were only so

many data points, an educated estimation was made of what the 73% point would read as, and the value was judged to be 112.6.

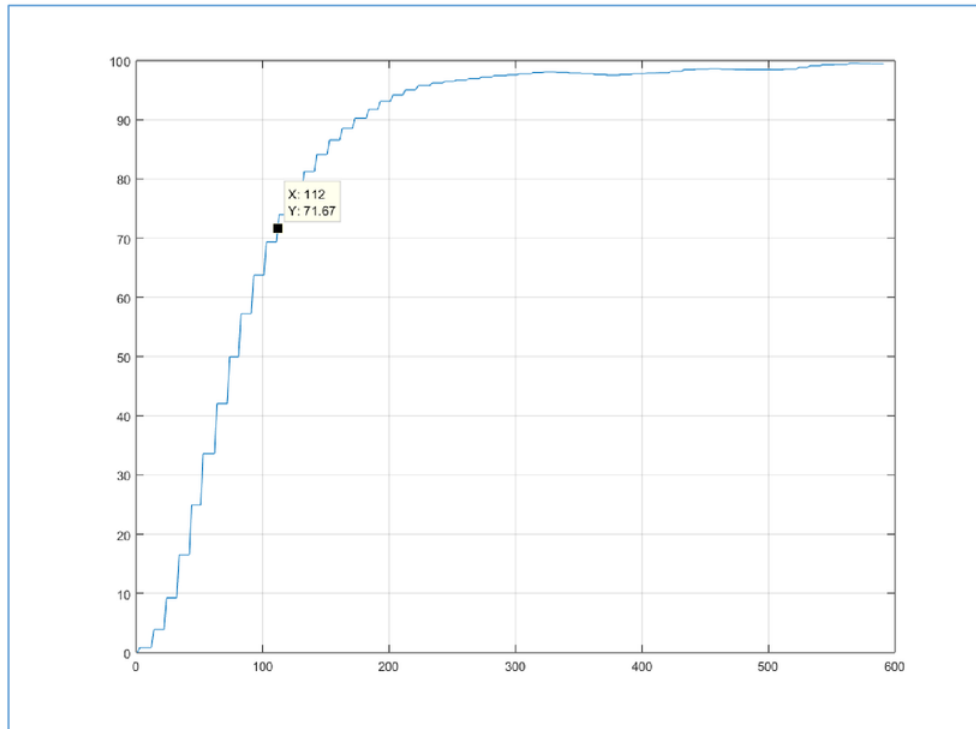


Figure 2.3: Simulated performance from actual data

Using the identified 73% identified value, it was then possible to identify the t_y of this curve and the τ_1 and τ_2 mathematically.

$$t_y = 1.32 \times (\tau_1 + \tau_2) \therefore \tau_1 + \tau_2 = \frac{t_y}{1.32}$$

To find the Fractional response at time $\frac{\tau_1 + \tau_2}{2}$,

$$t_y = 112.6 \therefore \tau_1 + \tau_2 = \frac{112.6}{1.32} = 85.3\text{ms or } 0.0853\text{s}$$

$$\tau_1 = \frac{85.3}{72} = \tau_2 = 42.65\text{ms or } 0.04265\text{s}$$

$$\tau_1 \tau_2 = 0.001819$$

With τ_1 and τ_2 calculated, the Transfer Function for further simulation could be found as follows;

$$T.F. = \frac{1}{\tau_1 \tau_2 s^2 + (\tau_1 + \tau_2)s + 1} = \frac{1}{0.001819s^2 + 0.0853s + 1}$$

good

An attempt was made to produce a curve that would be improved over the readings of the Actual System. Perceived improvement was negligible however.

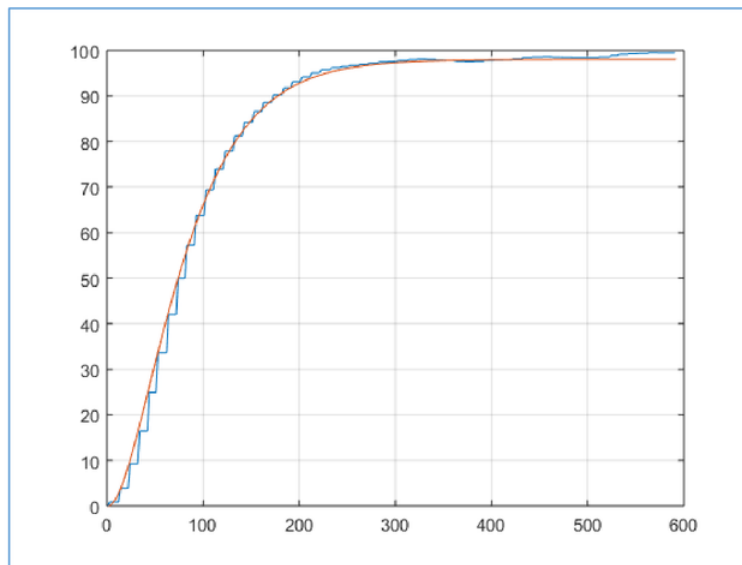


Figure 2.4: Attempted TF Tuning

2.2 SIMULINK MODEL

Using the Transfer Function identified in the previous analysis of the Flow Control System, the following Plant was assembled in Simulink.

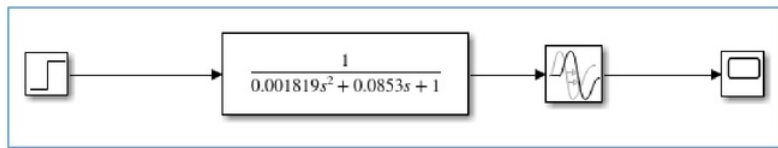


Figure 2.5: Transfer Function Simulink Model

The determined Transfer Function was added to the Model as shown in Figure 2.6.

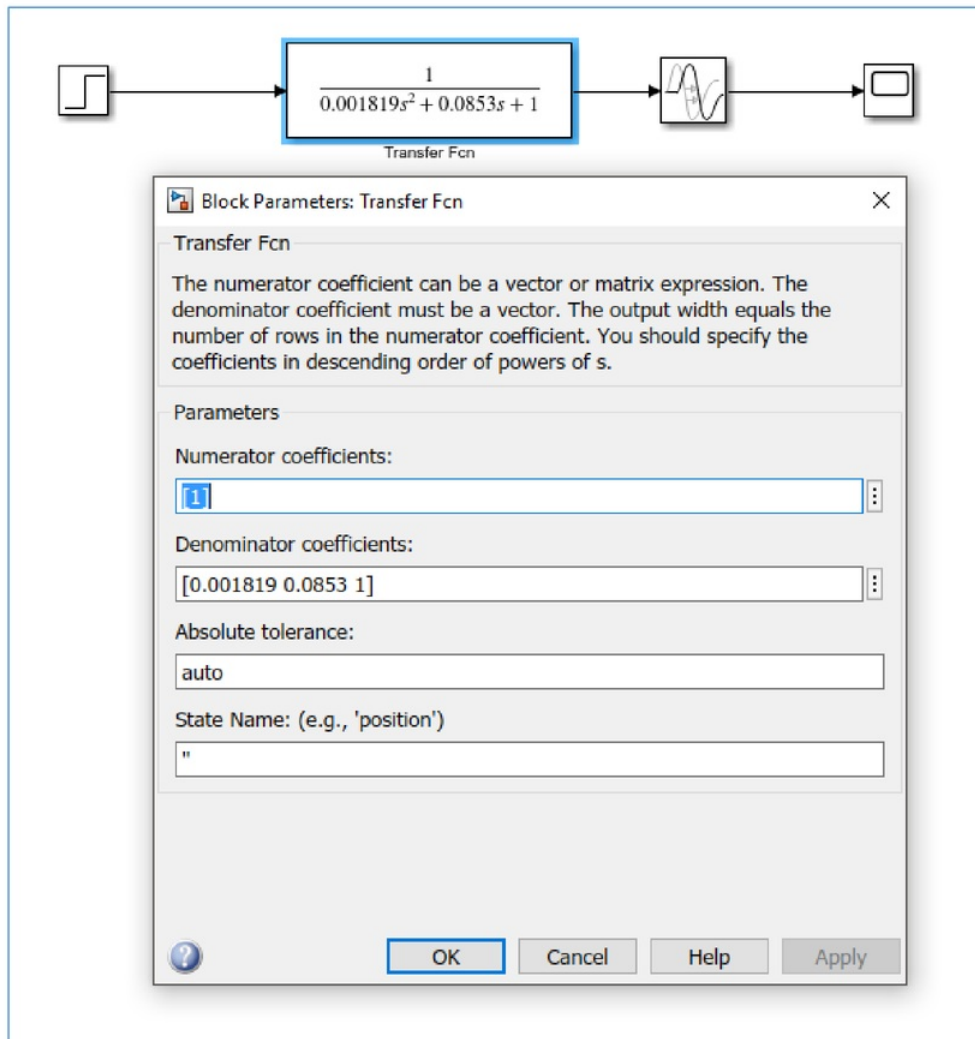


Figure 2.6: Simulink Transfer Function

The Fractional Response time found during the analysis was added into a Transport Delay to effectively simulate the manifest delay in the actual Flow Control System.

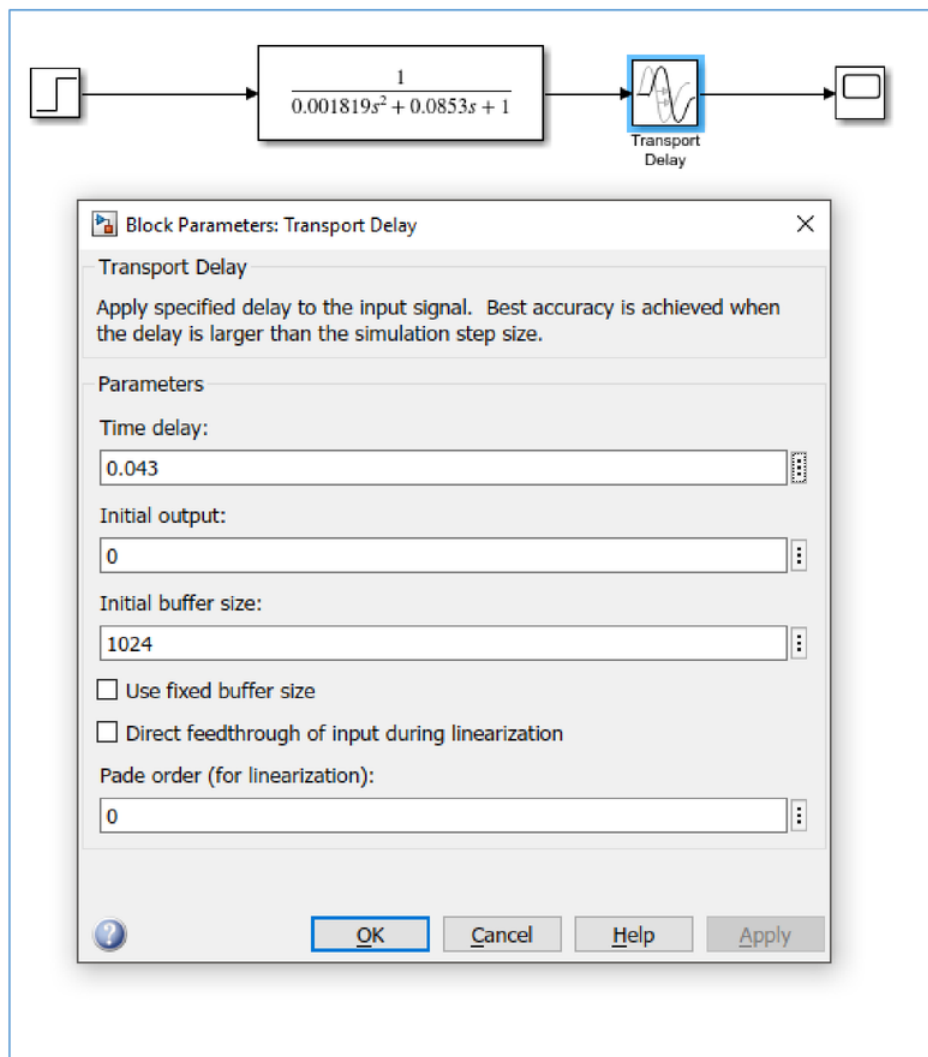


Figure 2.7: Transport Delay

A step time of up to 50 was added to the model to provide a finite value to reach.

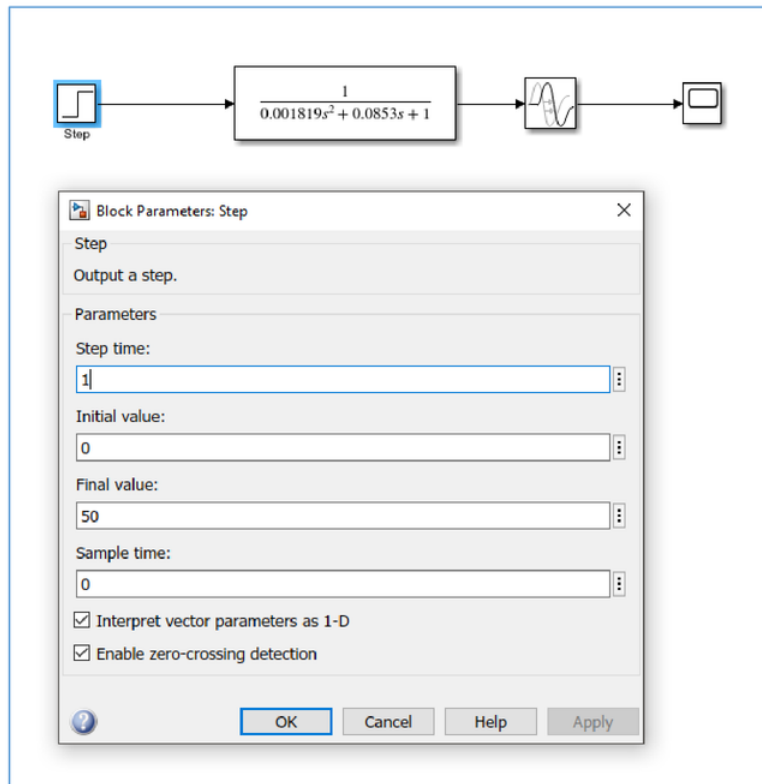


Figure 2.8: Step Input

Looking at the Process Curve shown in Figure 2.9 of the Transfer Function, the t_y is identified as 129ms, which was determined by using $50 \times 0.73 = 36.5$ to find the point on the curve.

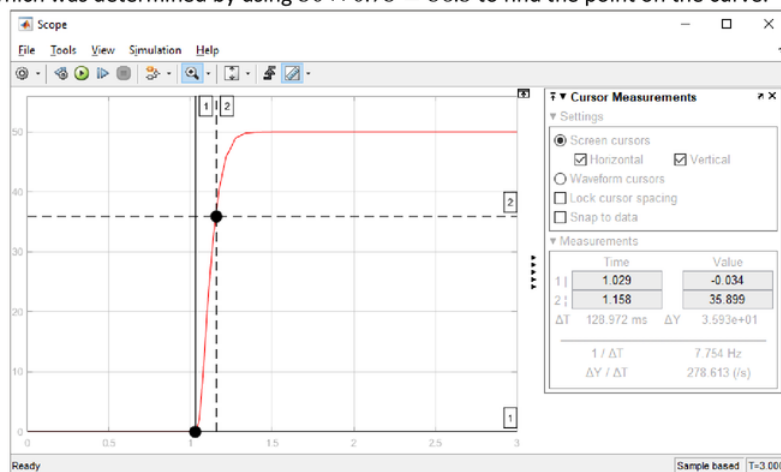
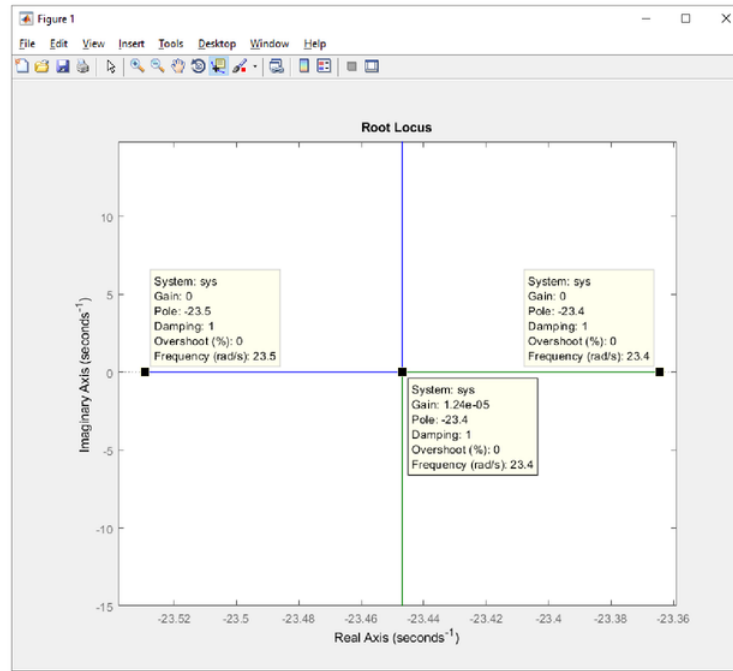


Figure 2.9: Response Curve of Simulink Model

2.3 MATHEMATICAL ANALYSIS OF MODEL

Putting the Transfer Function into MATLAB and running a Root Locus resulted in the output in Figure 2.10.



You could have shown the Matlab code to produce this graph

Figure 2.10: Root Locus of Transfer Function

For the Transfer Function used in the Model, there are two poles at -23.365 and at -23.53. There are two zeroes as 's' heads towards infinity. As both poles are on the negative side of 0, it can be said that the system is stable. To mathematically prove the simulation, the following calculations were carried out.

$$G(s) = \frac{K_1}{0.001819s^2 + 0.0853s + 1}$$

$$T.F = \frac{\frac{K_1}{0.001819s^2 + 0.0853s + 1}}{1 + \frac{K_1}{0.001819s^2 + 0.0853s + 1}} = \frac{K_1}{0.001819s^2 + 0.0853s + 1 + K_1}$$

$$\text{or } T.F. = \frac{K_1}{0.001819s^2 + 0.0853s + (K_1 + 1)}$$

Then by setting the denominator (Gain) to 0, the roots of a quadratic equation are given.

$$\therefore s = \frac{-0.0853 \pm \sqrt{0.0853^2 - 4 \times 0.001819 \times (K_1 + 1)}}{2 \times 0.001819}$$

$$\text{so } s = -23.365 \text{ or } -23.529$$

As can be seen the calculated values closely match the visually estimated values of the simulation.

2.4 ADDING THE PID CONTROLLER

To refine the model further, feedback is added with the help of PID.

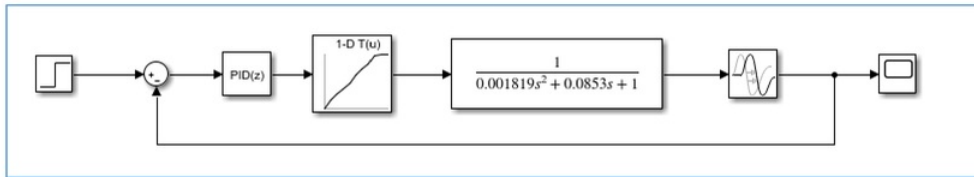


Figure 2.11: Complete Model

For reasons unknown to the Author, the Auto-tune feature of Simulink would not produce suitable values for PID, instead suitable values were picked and then altered manually until a reasonable curve could be observed. The settings in Figure 2.12 were the settled upon values for the Simulation.

Block Parameters: PID Controller

PID Controller

This block implements continuous- and discrete-time PID control algorithms and includes advanced features such as anti-windup, external reset, and signal tracking. You can tune the PID gains automatically using the 'Tune...' button (requires Simulink Control Design).

Controller: PID Form: Parallel

Time domain:

☐ Continuous-time

☒ Discrete-time

Discrete-time settings

Integrator method: Forward Euler

Filter method: Forward Euler

Sample time (-1 for inherited): 0.001

Main PID Advanced Data Types State Attributes

Controller parameters

Source: internal [Compensator formula](#)

Proportional (P): 0.06997

Integral (I): 3.19518

Derivative (D): 0.00204

☒ Use filtered derivative

Filter coefficient (N): 2.32257

Select Tuning Method: Transfer Function Based (PID Tuner App) [Tune...](#)

$$P + I \cdot T_s \frac{1}{z-1} + D \frac{N}{1 + N \cdot T_s \frac{1}{z-1}}$$

Initial conditions

Source: internal

Integrator: 0

Filter: 0

External reset: none

☐ Ignore reset when linearizing

OK Cancel Help Apply

Figure 2.12: PID settings

Suitable values for the Lookup Table were added to better simulate the performance of the pump, so at the breakpoint of 1, the simulated value is 0.25.

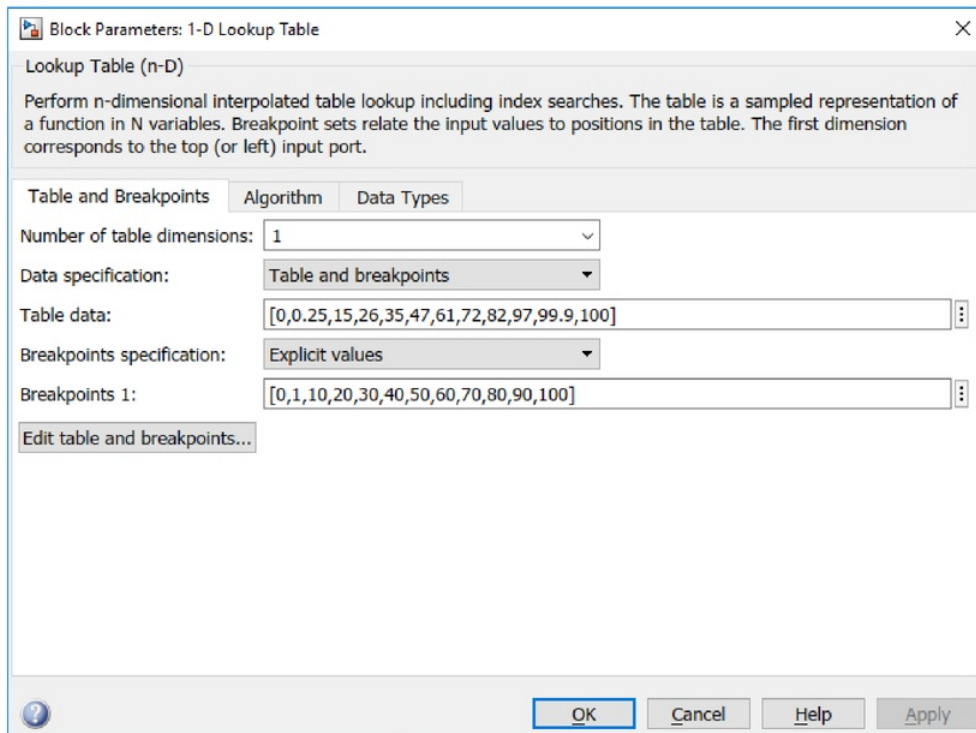


Figure 2.13: Lookup Table

The Model was set to P mode and autotuned (Figure 2.14).

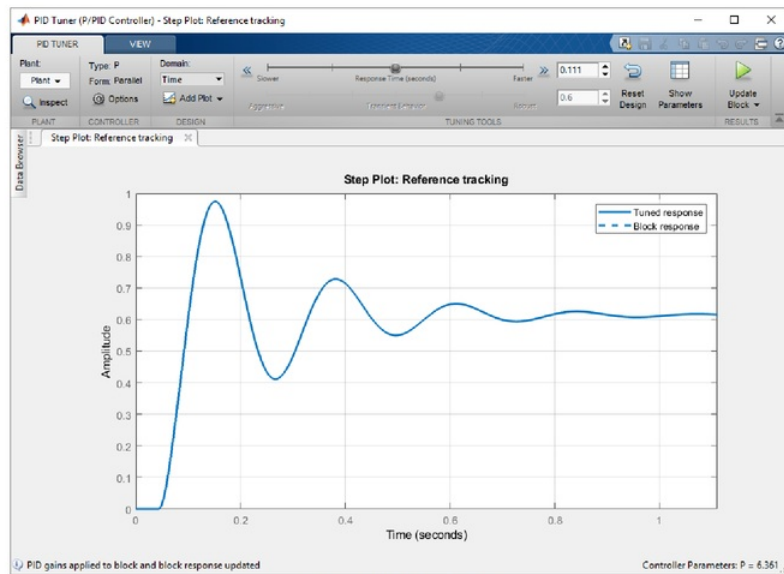


Figure 2.14: P Mode Tune

The scope showed oscillations (Figure 2.15).

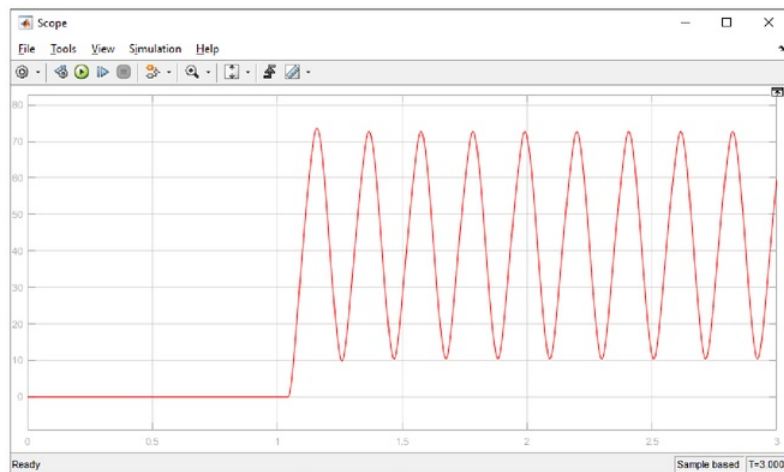


Figure 2.15: P Mode Scope

The Model was updated to PI Mode (Figure 2.16).

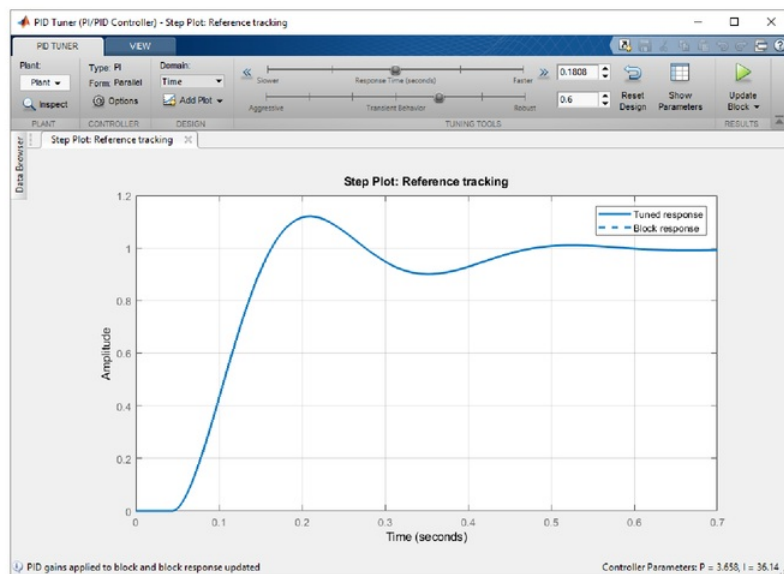


Figure 2.16: PI Mode Tune

The Scope reading showed no improvement through auto tuning (Figure 2.17).

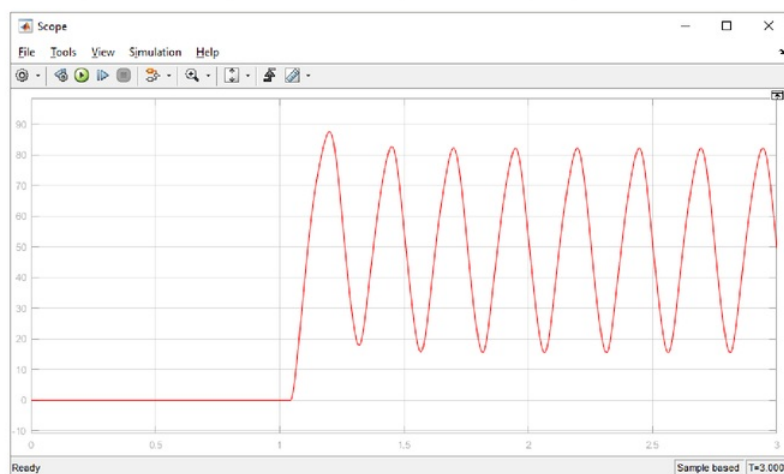


Figure 2.17: PI Mode Scope

The Model was then set to PID mode and autotuned (Figure 2.18).

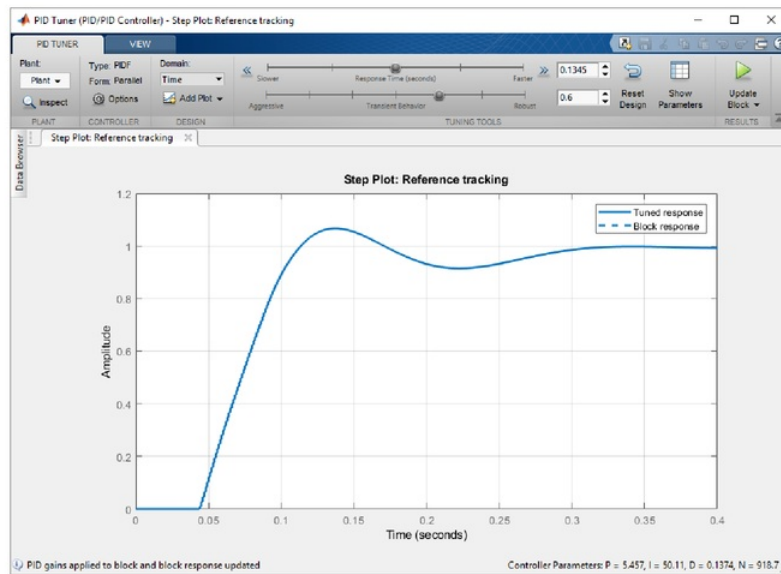


Figure 2.18: PID Mode Tune

On this scope it is easier to observe an overshooting and then 'settling' of the oscillations, showing an issue with the tuning capability of this Model.

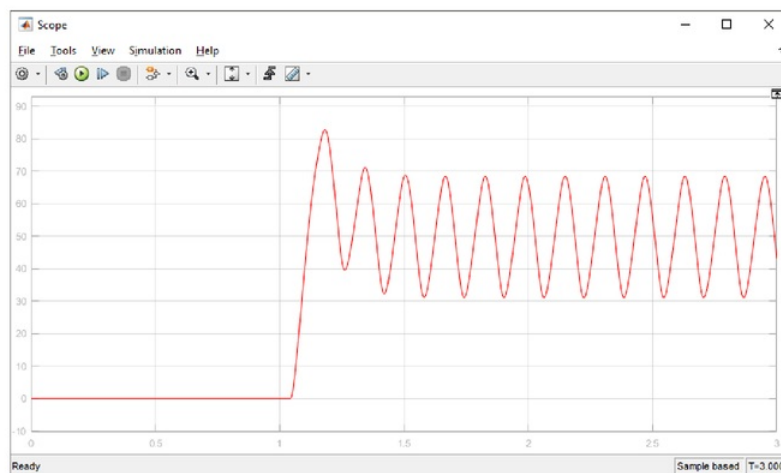


Figure 2.19: PID Mode Scope

Using the manual tunings in Figure 2.12, the Model was run again to produce the following output shown in Figure 2.20 and Figure 2.21. Using the same Calculation from before to find the 73% point, it could be seen that the time taken to reach this point is less than that taken by the actual Flow Control System as the simulated time is 291.6ms.

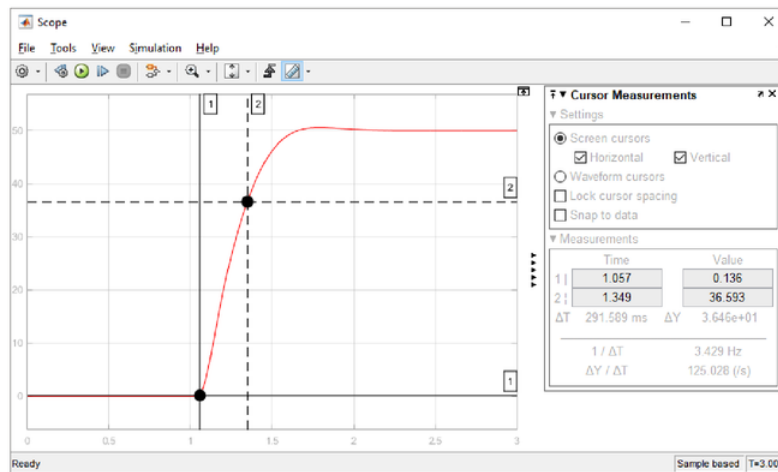


Figure 2.20: Optimised Curve

Unlike the actual System, there is an overshoot before settling at about 1s. Ideally there should be overshooting at all as the system should be critically damped.

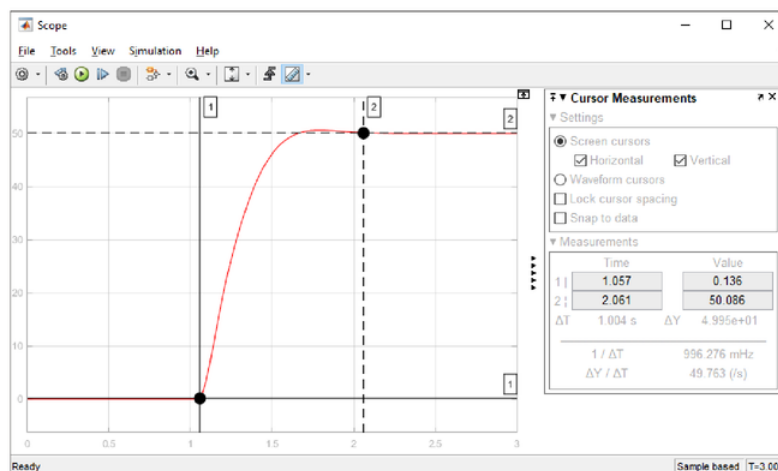


Figure 2.21: Optimised Curve Settled

2.5 FINDING K_p , K_i , AND K_d

Using the ideal selected values from before of $P=0.06997$, $I=3.19518$, and $D=0.00204$, the HMI for the Bytronic Flow Control System was set to rounded values, and the Flow Process was started.

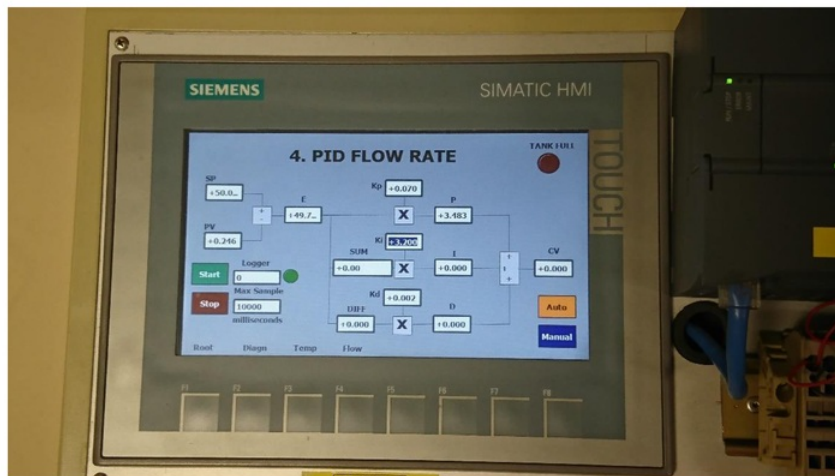


Figure 2.22: Set HMI

Various adjustments were attempted, but the initial values from the simulation offered the best result. The issue with the result is that the Dead Time is greater in Figure 2.23 than Figure 2.1.

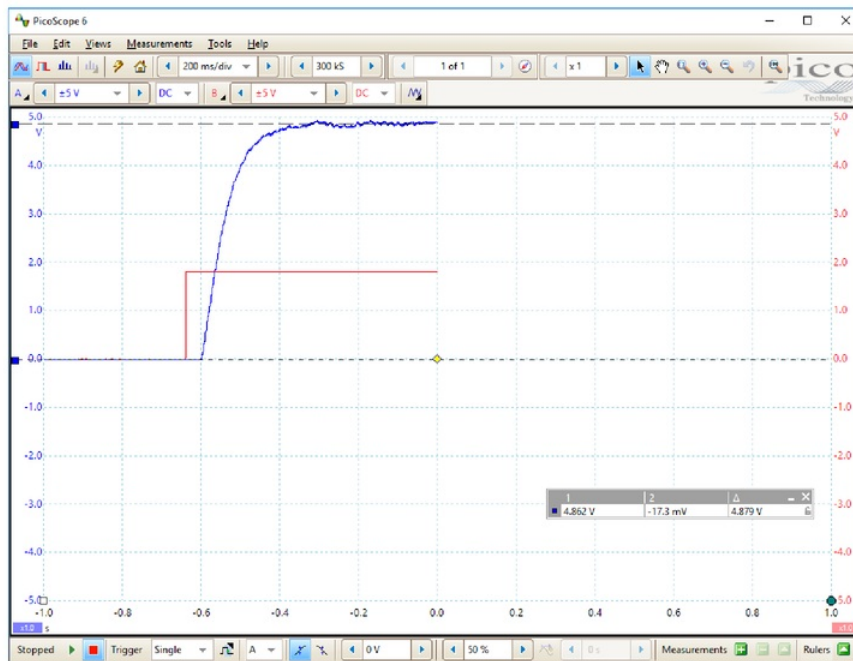


Figure 2.23: Measured Output

2.6 THE ZIEGLER-NICHOLS METHOD

Following on by using the previous output, the Ziegler-Nichols method would be attempted to see if it was possible to duplicate the Simulation results. By adding (dotted) lines to the curve, it was possible to identify the characteristics of the curve which could be used to determining values for PID control. The issue with the values identified, is that they were not like the Caldwell values identified through the previous processes.

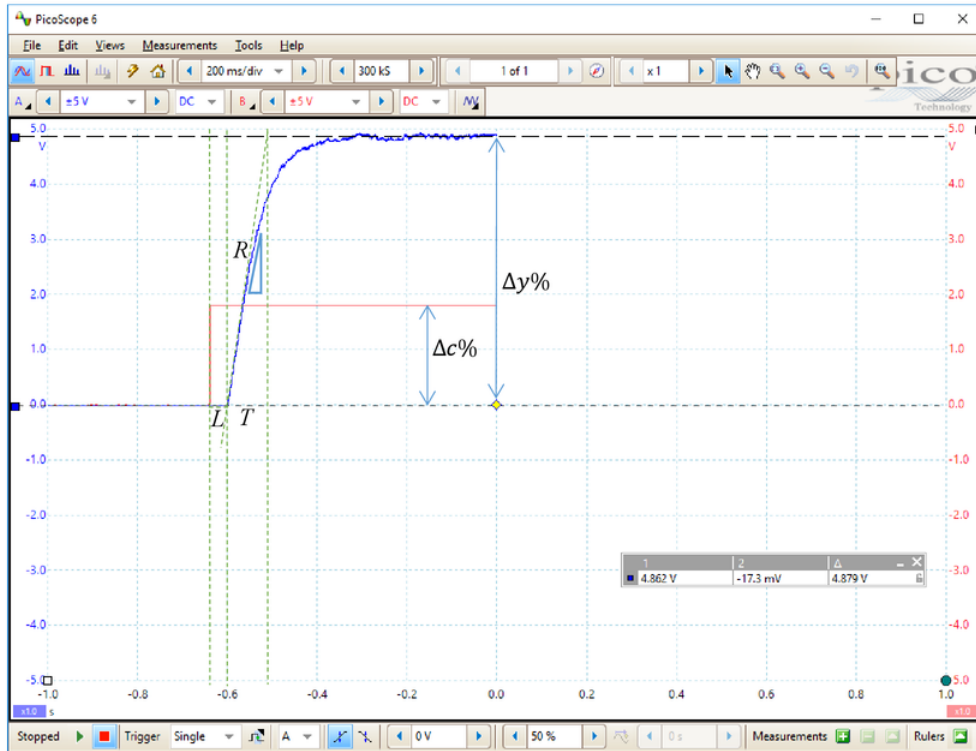


Figure 2.24: Response Curve

$$\Delta_c = 1.8V, T = 0.0875s, L = 0.0375, \Delta_y = 100\%, R = 1.1429 \times 10^3$$

$$P \quad K_p = \frac{1.8}{(1.1429 \times 10^3) \times 0.0375} = 0.042$$

$$PI \quad K_p = 0.9 \times \frac{1.8}{(1.1429 \times 10^3) \times 0.0375} = 0.038$$

$$K_i = \frac{0.038}{3.33 \times 0.0375} = 0.304$$

$$PID \quad K_p = 1.2 \times \frac{1.8}{(1.1429 \times 10^3) \times 0.0375} = 0.05$$

$$K_i = \frac{0.05}{2 \times 0.0375} = 0.667$$

$$K_d = 0.5 \times 0.05 \times 0.0375 = 0.0009$$

You should have inputted these tuned values into the system and measured the response for comparison

3 OVERALL CONCLUSIONS AND RECOMMENDATIONS

What has been gleaned from the process of analysing an existing process and attempting to improve on performance using simulation tools is that the Caldwell method is vastly superior to the Zeigler Nichols method.

The nature of the Zeigler Nichols' method which uses a table of rules to determine the set points for PID, may be useful for a quick configuration, however the performance less than satisfactory in comparison to the Caldwell method, because in the simulation of the Caldwell produced Transfer Function and PID control, there was no significant oscillation bar the small overshoot. It should be stated that the Zeigler Nichols method was carried out on the performance curve produced by Simulated PID applied to Actual System, leading to a compounded inaccuracy.

Not correct, you have used the actual process reaction curve to tune with Ziegler-Nichols

MATLAB and Simulink functioned very well, bar the complication with the autotuned function, which at this point the author considers that there may have been an issue with the Lookup table and its dataset used to simulate the characteristics of the pump.

The narrow change in variation of the poles, and stability indicated by the root locus simulation in MATLAB along with the mathematical calculation to verify was good.

When it came to transfer the Simulated PID values to the Bytronic Flow Control System, the performance was in the author's determination, inferior to the original PID settings, which again may be the result of a faulty Lookup Table in the Simulation offering a different scaling factor which did not truly represent the pump in the system.

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[Accessed 18 February 2018].

6 IMAGE SOURCES

Figure 1.1: Paddle Wheel Meter

Figure 1.2: Turbine Flow Meter

Figure 1.3: Ultrasonic Flow Meter

<http://www.newport.ca/images/products/h28p2.gif>

Modified from

<https://www.omega.co.uk/techref/images/fi5.gif>

<http://www.alicat.com/wpinstall/wp-content/uploads/2012/05/time-of-flight-flow-meter.gif>

PSDE5011-Assignment1-EW_Dyer

GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

Instructor

40/100

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Text Comment. error, you meant divide by 2 which is what you have done

Text Comment. good

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Text Comment. You could have shown the Matlab code to produce this graph

PAGE 15

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Text Comment. You should have inputted these tuned values into the system and measured the response for comparison

Text Comment. Not correct, you have used the actual process reaction curve to tune with Ziegler-Nichols

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EMYR DYER

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RESEARCH-INFORMED LITERATURE



Section 1: Your research - Good evidence of reading, appropriate and relevant information gathered. (16/20) Section 4: Your use of Harvard for citing and listing - a range of sources used and referenced appropriately. (3/5)

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KNOWLEDGE AND UNDERSTANDING



Section 2: Explanation of the control system and model - Good explanation given which included the

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transport delay and LUT. (11/15)

ANALYSIS



Sections 2 and 5: Analysis of model, simulation and practical testing - Having correctly obtained the model transfer function, you correctly analysed it mathematically and produced a root locus diagram. However, there is more that could have been said. Good evidence of testing using simulation and practical with results clearly presented. (15/20)
Section 3: Conclusions and recommendations - Brief conclusions offered but no recommendations. (5/10)

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PRACTICAL APPLICATION AND DEP.



Sections 2: Development of the model, use of Simulink – Good explanation of model development and use of Simulink. (9/10) Sections 2: Practical tuning – Good but no use made of the Ziegler-Nichols results. (4/5) Section 2: Presentation of results - Well presented. (5/5)

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SKILLS FOR PROFESSIONAL PRAC.



All sections - well structured, present and written. (8/10) MARK CAPPED TO 40% DUE TO LATE SUBMISSION.

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