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Executive Summary

This report investigates process control systems using the CE2000 rig, focusing on the calibration and control of parameters like level, temperature, and flow. The experiments involve researching PID (Proportional-Integral-Derivative) control and various tuning methods to optimize system performance. The CE2000 rig simulates real-world process control applications, with key components including flow transmitters, level transmitters, pressure transmitters, temperature sensors, electric heaters, and proportional valves.

The report shows some of the PID tuning methods: Trial and Error, Ziegler-Nichols, Cohen-Coon, Kappa-Tau, and Lambda Tuning, each offering varying levels of precision and suitability for different types of systems. Trial and Error is the simplest but time-consuming, while Ziegler-Nichols and Cohen-Coon are more systematic, with the latter offering better stability for systems with larger delays. Kappa-Tau is used for first-order systems with dead time, and Lambda Tuning allows for flexible response adjustments, minimizing oscillations.

Experiments on the rig involved calibrating the level transmitter, which improved accuracy after adjusting the system based on voltage readings at specific water levels. The second experiment involved controlling the process tank level by adjusting pump voltage and recording the resulting data. The Simulink model was used to simulate the system's response with PID control and autotuning, helping to reduce oscillations and optimize control.

The analysis of disturbances (e.g., changes in pump speed, valve position) demonstrated how the PID system adjusted to maintain stability.  The report concludes that proper calibration, PID tuning, and regular maintenance are essential for achieving optimal control system performance. Team collaboration throughout the experiments ensured efficient data collection and analysis.

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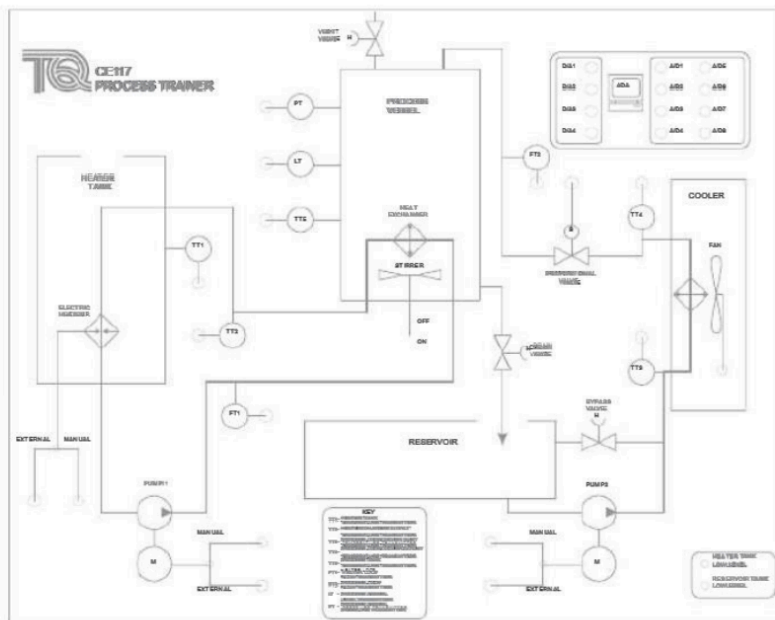
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Work plan for Life-long Learning

Firstly, research will be carried out to gain an understanding on the upcoming experiments. So, this will include information on PID the components in the rig with all the parameters  2 need. Then a comparison of tuning methods will be made to see which one would be most applicable to use. Then starting the first experiment will be calibrating the level transmitter. After that experiment has been completed moving on to level control of the process tank. With comparison tables and calculation all being provided to compare results and see how successful the experiments will be. From all the information gathered conclusions and recommendations  3 can be drawn.

Research

To explain the image  4 above there are two loops that feed the process vessel, the first loop pumps with pump 1 water with manual or automatic mode through the flow transmitter then through the heat exchanger changing the temperature in the process vessel then passes through the heater tank with the electrical heater changing the temperature of the water depending on inputs. The heater tank is controlled by a temperature transmitter and this will change the temperature of the tank. The other temperature transmitter in the pipes controls the temperature by measuring what temperature it was before entering the heater. Then the loop will finally reach the pump again and repeat the process. On the other loop it can be in either manual or automatic mode. It takes water from the reservoir and pumps it through pump 2 the bypass valve will allow more water to get pumped around. Then the water goes through a temperature transmitter which will then cool the water by using a fan in the cooler. After that the water will reach the process vessel while passing a flow transmitter and a proportional valve which can be adjusted  5 So, when the water is in the process vessel it can either be stored there or the drain valve can be used. (TecQuipment. (n.d.))



Components

Flow transmitter - A flow transmitter measures the flow rate of liquid in the rig. After this the flow transmitter creates electric readings from the signals it has received. Flow transmitters are normally used in automation machines like the one in this experiment. (www.transmittershop.com. (n.d.).)

In the rig a rotary flow transmitter is used which works by the rotor blades reflecting infrared and electrical pulses are made by each rotation being measured by the flow monitor which counts the pulses with its pulse accumulator. Pulse constant is used to convert rotations per second to volume a minute. (Single Use Rotary Flow Meters. (n.d.))

Level transmitter - The level transmitter will measure the level of liquid in the vessel and convert the readings into signals. There are a few types of level transmitters like; Differential Pressure (DP) Level Transmitter, Guided Wave Radar (GWR) Level Transmitter, Ultrasonic Level Transmitter and Capacitance Level Transmitter. (Instrumentation Editor (2023)) The capacitance level transmitter which is used in the rig works by as the water level increases within the vessel capacitance increases between the rod and vessel walls, this will result in having a bigger output. (control.com. (n.d.))

Pressure transmitter - The pressure transmitter measures the pressure of liquids. Then after the measurements these can be converted into signals for control. A pressure transducer is normally involved and generates a low power signal from sensing the pressure, then is amplified by the transmitter and sent to the control system. There are multiple pressure transmitters some are; gauge pressure, absolute pressure, and differential pressure.
(T, R. (2022))



Temperature Transmitter - In the rig that will be used in the following experiments a RTD temperature transmitter will be used. The transmitter works by increasing the temperature of the metal this will cause electricity to flow quicker. A current goes through the sensor and then the resistance is measured by an element which has the current going through it.
(peaksensors.com. (2023))



Electric Heater - The electrical heater converts the electrical energy into heat, this can be used to modify temperatures to your liking. Types of electrical heaters include; Electric Water Heaters. (www.iqsdirectory.com. (n.d.))
The electrical heater is controlled by the amount of power inputted so it can be adjusted manually or with auto modes like PID control.



Proportional valve - The function on the proportional valve is to control liquid by modifying the valve to how much fluid is needed. The proportional valve offers precise control by allowing fine adjustments and tuning to pressure and flow rates. This valve is normally used in hydraulic systems, automation or where accurate flow and pressure regulation is needed. And the valve is beneficial to a system as it is efficient, accurate and stable.
(Dolphinfluidics.com. (2016))

Item		Analogue Signal	Conversion Details
PRT Temperature Transmitters (Platinum Resistance Thermometers)	TT1	0 - 10 V Output Linear	10°C per Volt 0 V = 0°C 10 V = 100°C
	TT2		
	TT3		
	TT4		
	TT5		
Flow Transmitters	FT1 FT2	0 - 10 V Output	1 L/min per Volt 0 V = No flow
Level Transmitter	LT	0 - 10 V Output Non Linear	0 V = Empty Vessel 10 V = Maximum Level
Pressure Transmitter	PT	0 - 10 V Output	100 mbar per Volt 0 V = 0 mbar (gauge)
Electric Heater		0 - 10 V Input	75 W per Volt 0 V = Heater Off 10 V = 750 W Maximum Power (Nominal)
Proportional Valve	S	0 - 10 V Input	0 V = Closed 10 V = Open
Pump 1 Pump 2		0 - 10 V Input	0 V = No Flow 10 V = Maximum Flow

TecQuipment. (2008) CE117 Process Trainer User Guide. The image shows the transmitters with all the technical data and signals.

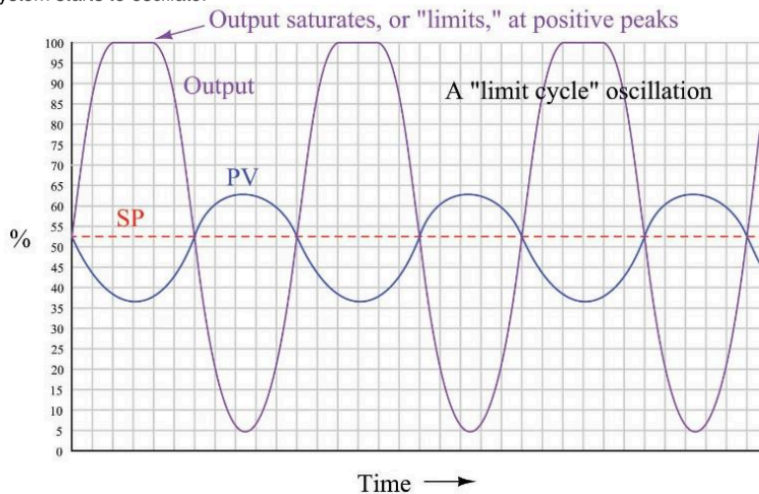
Types of ways to tune PID

Trial and error PID tuning method

The manual way is changing P.I.D until the targets for the system have been found. This method requires a lot of time because of all the trial-and-error attempts this means that the system must be highly dependent. This is very ineffective because all the person must find all the parameters by observing the responses and adjusting them until the right parameters have been found (Bennett, J. (2020))

Ziegler-Nichols tuning method

This method was found in the 1940s. This is one of the more popular tuning methods. There are two variations to using this method, one being the frequency response and is used by setting the integral and derivative to zero and then increasing the proportional gain until the system starts to oscillate.



The image shows how the process variable is forced to oscillate around the setpoint. Which also causes the output to reflect oscillation. In this case PV would be the PID control, setpoint is the wanted level of water in the tank and the output is the current water level.

$$K_p = 0.6K_u$$

$$\tau_i = \frac{P_u}{2}$$

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$$\tau_d = \frac{P_u}{8}$$

(Kuphaldt, T.R. (2019))

K_p = proportional gain

K_i = $1 / T_i$

K_d = $1 / T_d$

P_u = the period of variable of oscillations

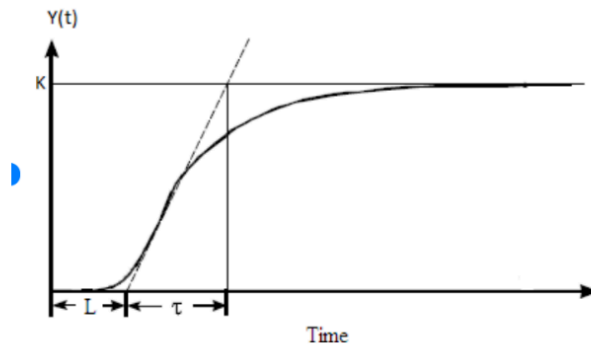
The other variation is the step response which is done by introducing a small step input into the system and recording the output. This response is known as the "process reaction curve", this should give a smooth curve. Then determine the parameters;
 Process gain (k) = the change in output / change of input after the system stabilises.
 Dead time (L) = this is the time delay at the start before the system responds to the step input.

Time constant = 63% of the time taken to reach the final steady state value.

Then calculating the PID parameters will be next by using the values just calculated you be able to work out the proportion gain, integral time and derivative time. (TrueGeometry (2024))



Process reaction graph



Process reaction curve of the step response of the system

(ResearchGate (2017))

Cohen-Coon tuning method

Cohen-Coon tuning method is a more advanced method than the Ziegler-Nichols Tuning Method and is used for systems with a larger time delay. This method is more stable and precise because it uses more process data when calculating the parameters. Apply a step input then extract key process parameters like process gain (K), dead time (L) and time constant (T) then using these formulas;

$$K_p = \frac{1}{K} \left(1.35 \frac{T}{L} + 0.27 \right)$$

$$T_i = \frac{T}{1.35 + 0.54 \frac{L}{T}}$$

$$T_d = 0.5 \frac{L}{1 + 0.5 \frac{L}{T}}$$

You should have the variables to then calculate the parameters for PID. Using the equations above. These parameters can be seen on the process reaction graph. (www.ni.com. (n.d.))

Kappa-Tau tuning method

Kappa-Tau Tuning Method is done by using a first order system with a dead time. When a step change is applied the output response will be able to give the values of the process gain, time constant and dead time. From that data just gathered PID will be able to be calculated.

(Snayush (2022))

Lambda tuning method

Lambda tuning method is one of the popular methods used for smooth and stable results when dealing with time delay. This method consists of a closed loop time constant which can adapt the system to have a slower or faster output. The key features of this method is that you can change how fast the system responds. There are minimum oscillations making it a smooth control. (Vandoren, V. (2013))

Comparison

Trial and error are the most basic but takes the most time. Ziegler-Nichols is basic and causes oscillations because of the aggressive control. Cohen-Coon is a better version of ziegler-nichols by the output being smoother. But it does have more complex calculations needed. The kappa-tau uses a first order system which means it is used for more basic systems. Lastly, Lambda Tuning has more flexibility when controlling the response speed and is typically used for slower response systems. So, depending on the system will depend on what method is needed because of all the different drawbacks and advantages each comes with. (Kuphaldt, T.R. (2019))

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CE2000

The image below shows the CE2000 rig which the experiments will be performed on.

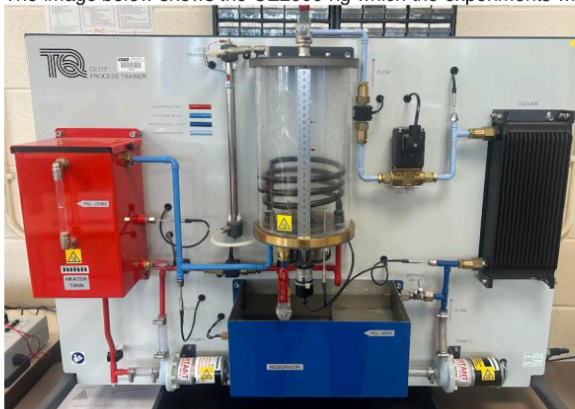
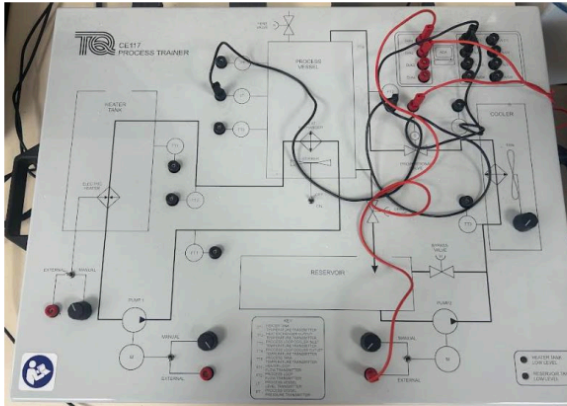
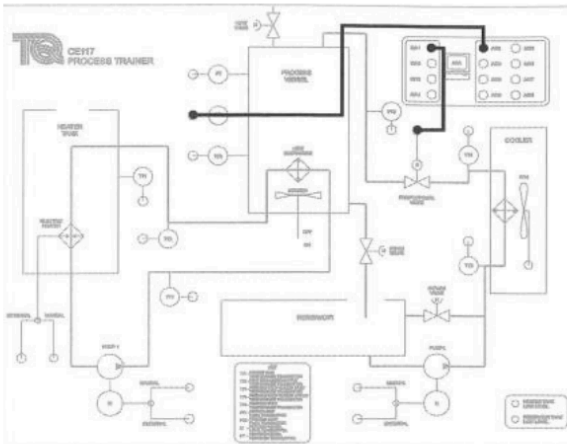


Image shows the interface board wired.

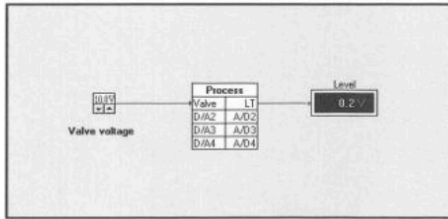


Level Transmitter Calibration

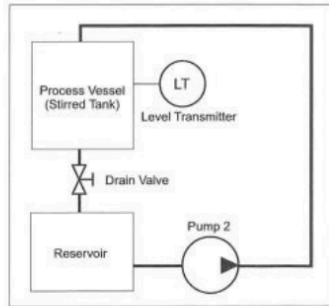
This diagram shows the interface module that will be used for all the upcoming experiments.



CE2000 software was set up for the level transmitter calibration. Every time the water level fills up the voltage will increase because the plates are getting closer in the vessel. Manual control is used on the pump so that it could be stopped every 10mm to record the voltage of the level.



The shows a diagram of the experiment



Procedure

Firstly, I wired the interface module ready for the experiment. Once that was done I setup the software (CE2000) on the computer and the experiment was ready to start. So, I opened the valve to let water pour in and stop it on every 10 mm, to fill in the table. After, I completed the first time it was done again but I calibrated the rig by using a screwdriver on the level calibration to adjust the values to make it more accurate for the second run. After all results were recorded, tables and graphs were then created using excel to compare data.

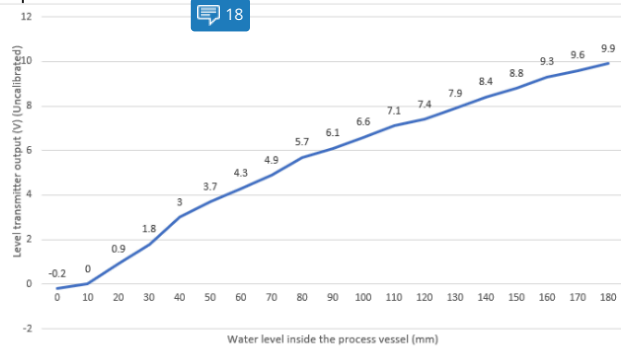
Results & Graphs

Water level inside the process level was tested for every 10mm to find out the level of the transmitter output, which will start around 0v and end around 10v.

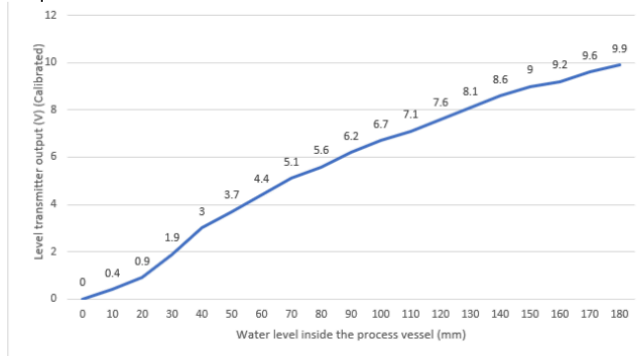
Water level inside the process vessel (mm)	Level transmitter output (V) (Targeted)	Level transmitter output (V) (Calibrated)	Error
0	0	0	0
10	0.9	0.4	-0.5
20	1.8	0.9	-0.9
30	2.8	1.9	-0.9
40	3.7	3	-0.7
50	4.5	3.7	-0.8
60	5.3	4.4	-0.9
70	5.9	5.1	-0.8
80	6.5	5.6	-0.9
90	7.1	6.2	-0.9
100	7.6	6.7	-0.9
110	8	7.1	-0.9
120	8.5	7.6	-0.9
130	8.9	8.1	-0.8
140	9.3	8.6	-0.7
150	9.6	9	-0.6
160	9.8	9.2	-0.6
170	9.9	9.6	-0.3
180	10	9.9	-0.1

This table shows the results of the experiment with targeted values and calibrated. The error shows how the uncalibrated doesn't have accurate measurements, so then calibration was done so the results would show accurate readings

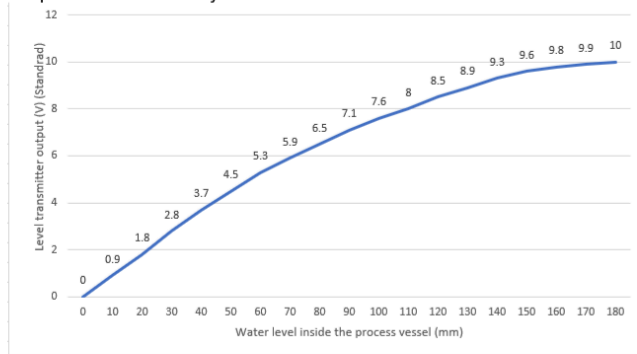
Graph shows the uncalibrated results.



Graph shows the calibrated results.



Graph shows the factory standard results.



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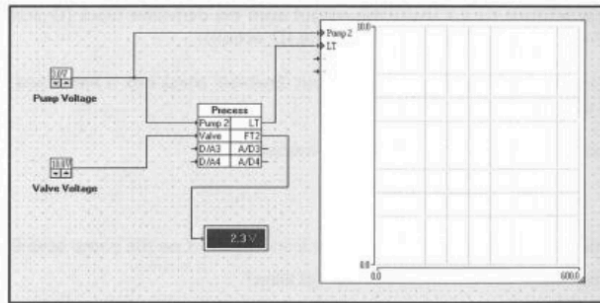
From the table this graph was created showing as the water increases inside the vessel the level transmitter output increases meaning that the voltage would rise as well. From comparing the calibrated results in the experiment to what the standard results are it is noticeable that all the readings are out by an average of 0.7v, this means that the results could have been better and this could of been down to many factors like the rig, how old the equipment is, are all the sensors working correctly and many others.

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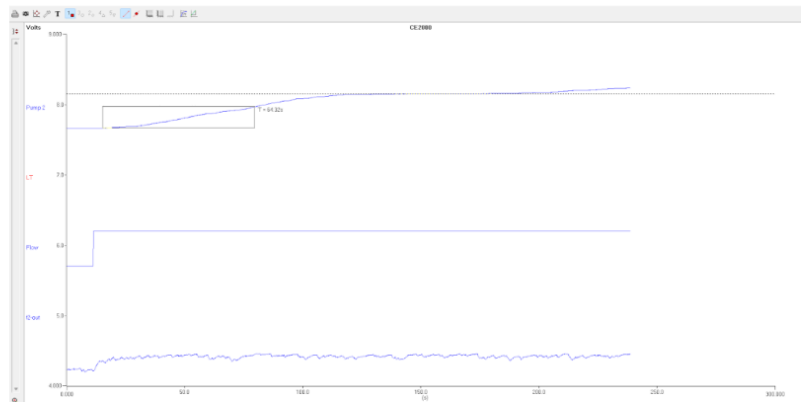
Level Control of the Process Tank

Procedure

CE2000 was used to track level and flow voltage by changing the pump voltage. Firstly, the pump voltage started at 5.7v and waited for the water to stop raising but tracking on software a graph while this was happening. Then when the graph became steady all the data was recorded in tables and then the value voltage was increased to 6.2v and repeated until the graph steady again. Then from all the data we can work out the errors and see how efficient the rig and data is.



This shows how the software was used and how the experiment started off. As the experiment went on the graph started to plot itself.



Calibrating the level transmitter made it so that when the level control was done the results would be accurate and reliable

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Calculations

To calculate the time constant and ensure results are accurate.

Find the area of the vessel which was 150mm internal diameter. Secondly convert the steady state levels from the vessel into metres. Flow rates need to be then converted into $\text{m}^3 / \text{second}$. Then outflow resistance will need to be calculated. Following with the time constant all formulas are below.

	VL	VF	h(M)	$q(\text{m}^3/\text{sec})$
A	5.7	4.2	0.116	70×10^{-6}

B	6.2	4.4	0.133	73×10^{-6}
---	-----	-----	-------	---------------------

$$\text{Vessel radius} = 7.5\text{cm} = 0.075\text{m}$$

$$\text{Area of vessel} = \pi r^2 = 0.01767\text{m}^2$$

$$1\text{v} = 1\text{L} / \text{min}$$

$$R = \frac{\Delta h}{\Delta q} = \frac{0.017}{3 \times 10^{-6}} = 5666.67$$

$$\tau = A \times R = 5666.67 \times 0.01767 = 100.13 \text{ secs}$$

$$1\text{L} / \text{min} = \frac{0.001\text{m}^3}{60} / \text{sec}$$



$$q1 = 4.2 \times \frac{0.001}{60} = 70 \times 10^{-6} \text{m}^3 / \text{sec}$$

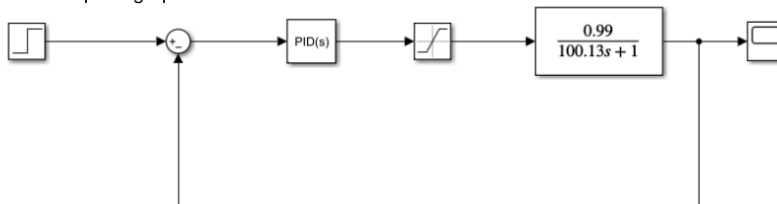
$$q2 = 4.4 \times \frac{0.001}{60} = 73 \times 10^{-6} \text{m}^3 / \text{sec}$$

K = Level voltage / Pump Voltage

Simulink

A Simulink was created on MatLab which consisted of;

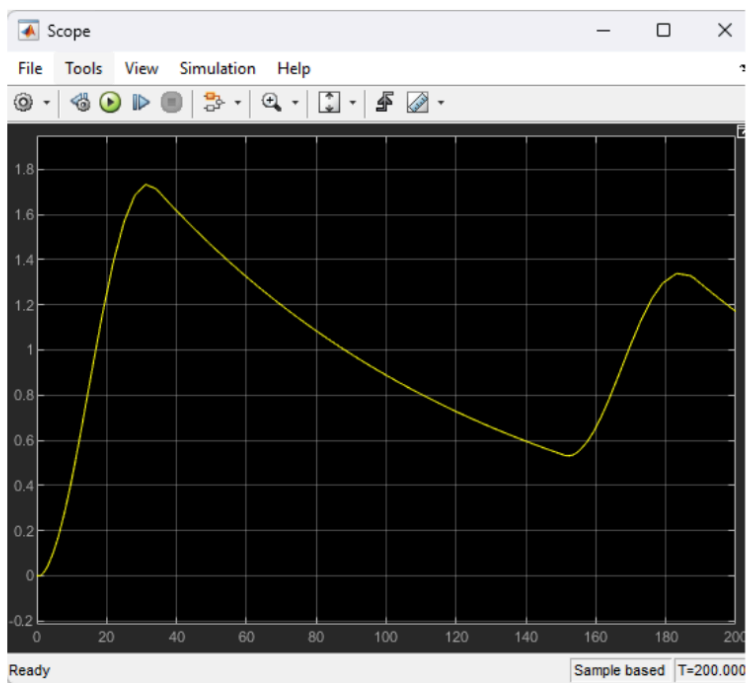
- Step which supplies voltage
- Summing block which calculates the error between the setpoint and current level in the tank
- The PID controller which processes the error and provides an outcome (tunable with auto tuning)
- Saturation block limits the voltage to 10v so safety of the equipment.
- Transfer function to simulate the system
- Scope to graph the results.



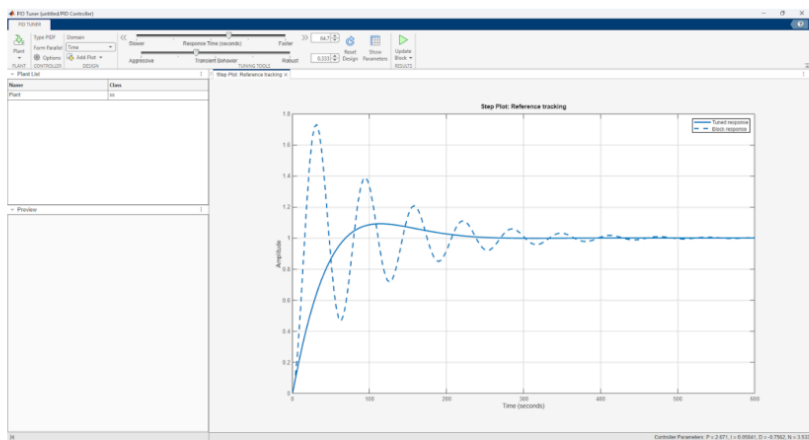
Step input from pump

Initial time = 5.7v

Final time = 6.2v



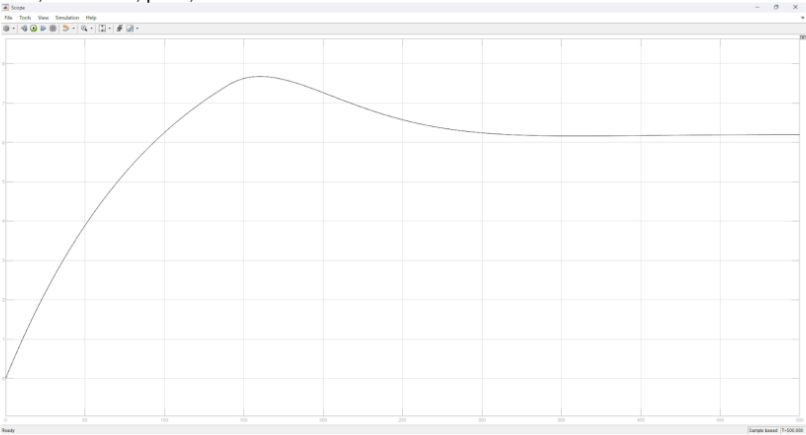
This is the response of the simulink with no PID autotune as you can see the graph is oscillating and showing a bad reading.



To resolve the oscillating autotuning using PID is necessary. With autotuning you can adjust the sliders to fit your need, making it slower, faster, aggressive or robust.

Show Parameters			
Controller Parameters			
	Tuned	Block	
P	2.6712	1	
I	0.058413	1	
D	-0.75617	0	
N	3.5325	100	
Performance and Robustness			
	Tuned	Block	
Rise time	49.7 seconds	11.1 seconds	
Settling time	209 seconds	385 seconds	
Overshoot	9.15 %	73 %	
Peak	1.09	1.73	
Gain margin	Inf dB @ Inf rad/s	Inf dB @ NaN rad/s	
Phase margin	72.3 deg @ 0.0309 rad/s	11.4 deg @ 0.0994 rad/s	
Closed-loop stability	Stable	Stable	

For the experiment 'D' can't be too high for a value so when autotuning the graph this was a key parameter. Also, with this table you can see other important data like rise time, setting time, overshoot, peak, etc.

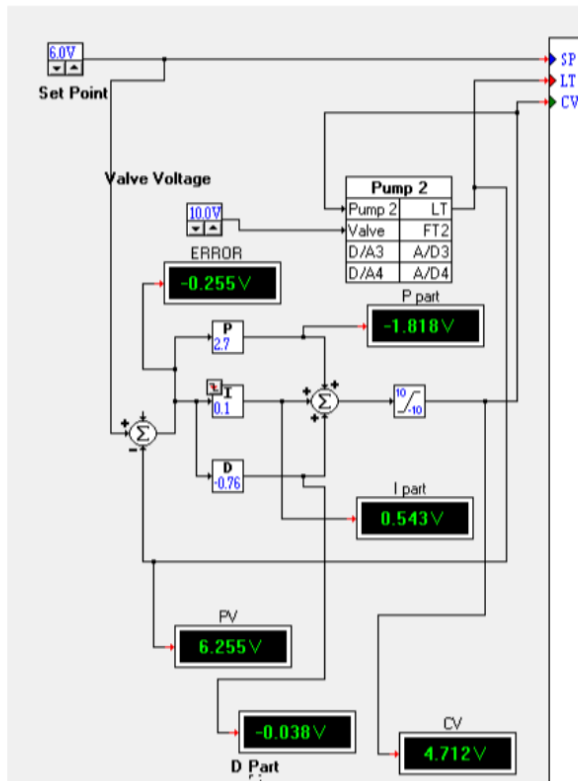


After autotuning was complete this was the final result of the graph. As shown the graph has now lost the oscillations and has a better curve.

Method

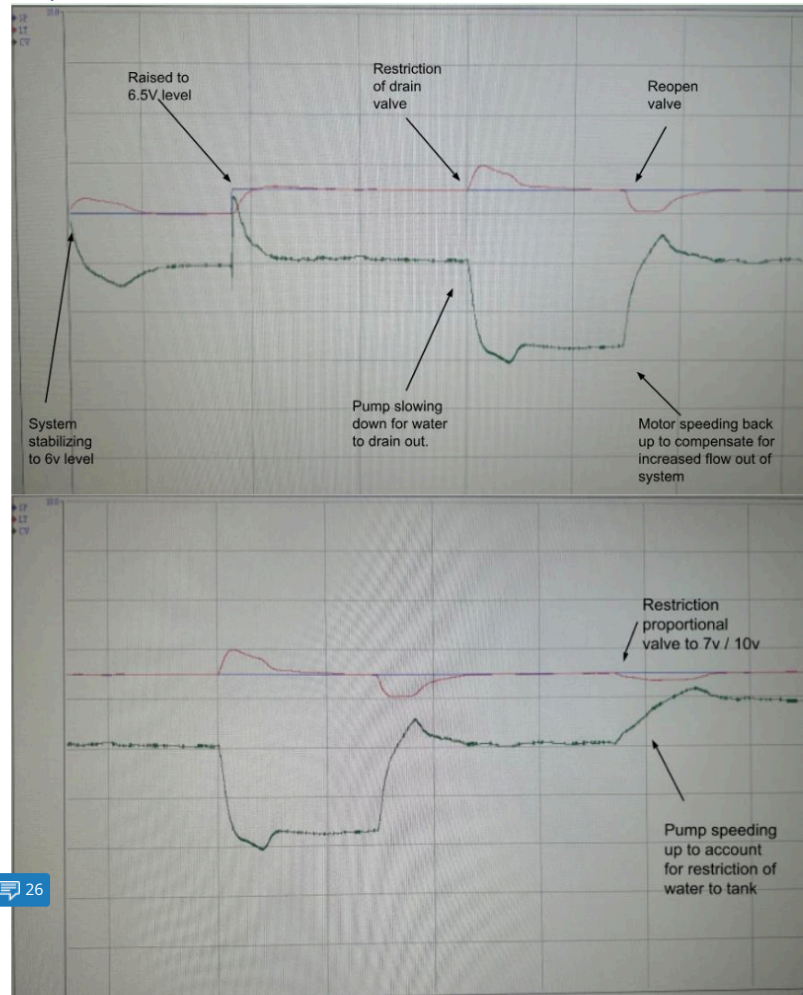
Input P.I.D values into circuit then press record, let the graph settle then add the first disturbance by changing the setpoint to 6.5v. The second disturbance is to restrict the drain by closing the drain valve. The third disturbance is to reopen the drain valve. Fourth disturbance is restricting the inflow by lowering the proportional valve to 8v from 5v

Circuit



The circuit shows a P.I.D system for level and pump system. Inserted values of parameters from above to the circuit ready for it to create a graph from different disturbances and show how it affects the rig.

Graph



Analysis

Above shows the graph of how the P.I.D dealt with the disturbances that were tested.

Setpoint = blue

Level = red

Control = green

From graphing all the disturbances this is what was apparent;

First disturbance - The step change caused the pump to increase the work rate and there was an overshoot in the graph but after waiting it settled.

Second disturbance - Restricting the valve increased the level so then the controller stopped the pump and the graph undershoot but after a while settled.

Third disturbance - Reopening the valve caused the level to decrease meaning the controller increased the pump voltage to compensate. The graph then showed a slight overshoot and finally settled.

Fourth disturbance - Restricting the inflow caused the level to decrease making the controller increase the pump making the graph overshoot for a while until it settled.

Next time when done make sure to pre-record to get a better-quality graph by using auto graph it will also cut all noise out and size your graph.

Noise was noticeable this could be because of the age of the equipment, insufficient shielding on the cables or the PID isn't working smoothly.

Conclusions and Recommendations

To conclude the CE2000 shows how all the parts of the system like flow, level and the other sensors/transmitters work together with the control elements like the heaters and valves to manage the level, temperature and flow. Then the CE2000 was used to experiment with and it showed how calibration and tuning helps get the best performance out of a system.

By using the tuning methods, I could reduce oscillations, smooth the output and keep improving on the result. Trying to achieve the best results possible by even fine tuning the graphs on MATLAB Simulink.

Team Working

Teamwork has been used in the experiments by one person taking measurements, adjusting rig and using the software - this was rotated for each experiment. By working in the team ideas and skills were combined ensuring that the experiment and results would be accurate and quicker.

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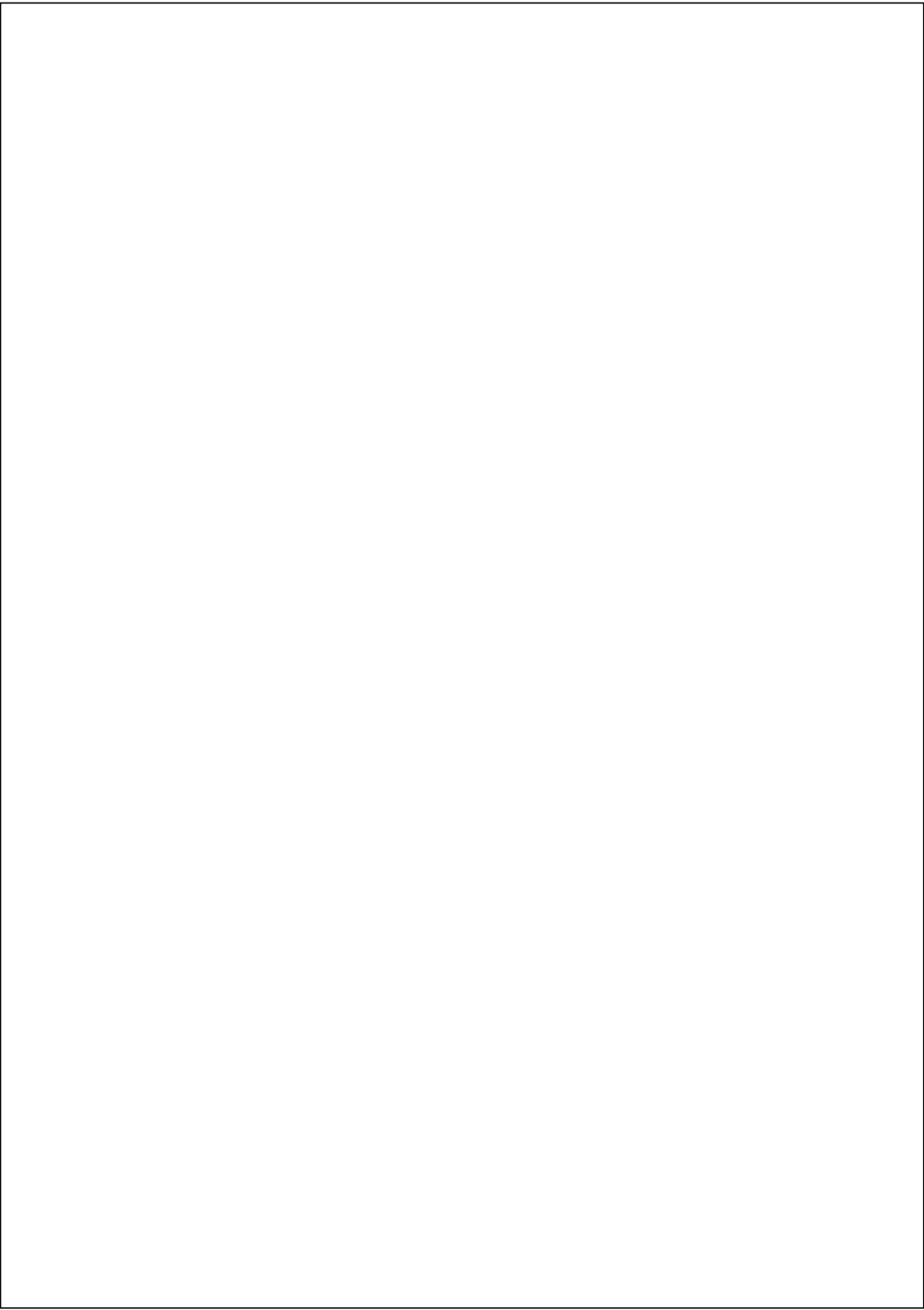
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47 /100

PAGE 1

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Comment 1

WW

PAGE 3

PAGE 4



Comment 2

Gr



Comment 3

typo



Comment 4

what image?



Comment 5

adapted to what?

PAGE 5



Comment 6

poor quality image



Comment 7

A bit confusing.



Comment 8

inaccurate, needs further explanation, why?



Comment 9

rather vague



Comment 10

again inaccurate, what happens to the resistance as temperature increases?



Comment 11

rather vague



Comment 12

Ku?



Comment 13

How?



Comment 14

what about the method you used?



Comment 15

inaccurate description of level transducer



Comment 16

this needs more detail



Comment 17

much more accuracy than this is needed.



Comment 18

why uncalibrated?



Comment 19

simply graph the ideal vs calibrated



Comment 20

rather vague reasons



Comment 21

what errors?

PAGE 14



Comment 22

and yet they were not....

PAGE 15



Comment 23

this is vastly different to the one measured from the process reaction curve...

PAGE 16

PAGE 17



Comment 24

too vague

PAGE 18



Comment 25

10V not 5V

PAGE 19



Comment 26

annotation is good, a shame the image is of poor quality

PAGE 20



Comment 27

I am not seeing much overshoot



Comment 28

Again too vague. This is far too brief of an analysis for the amount of and depth of experiments undertaken.

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PAGE 23

KAI WHITE

47

1. ENGAGEMENT WITH LITERATURE

An appropriate amount of literature used in the research element. Some innaccuracy and vagueness exists. 6/10

6

2. KNOWLEDGE AND UNDERSTANDING

Limited but adequate knowledge demonstrated there are some errors and some show a lack of understanding. 15/30

15

3. COGNITIVE AND INTELLECTUAL

Largely descriptive work with superficial use of critical evaluation and anlysis of concepts. 7/10

7

4. PRACTICAL APPLICATION

A good and appropriate use of methods, there are some areas to improve see comments. 14/30

14

5. TRANSFERABLE SKILLS

Satisfactory use of language for the most part, communication is mostly appropriate, the report structure is ok. 5/10

5