

2224559

by Zeeshan Ibrahim

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Executive Summary

This assignment began with understanding the operation, calibration and control of the CE117 Process Trainer by analysing its various control loops, instrumentation and actuators. Methods of PID tuning were then researched and the optimum method of tuning was chosen to be the autotune method by using Simulink to create a model of the closed loop using its transfer function. The capacitive level transmitter was then calibrated using the CE2000 software and voltage levels were recorded at 10 mm increments and compared with manual calibration values. Results indicated non-linearity due to various factors, including parallax error, tank geometry, and fluid contaminants. These inaccuracies, especially a maximum error of 0.9V, would impact the system's performance in a closed-loop scenario. An open loop response was conducted on the level control system and various measurements were taken, which include the flow rate, level voltage and height of water in the tank. These measurements and other calculations were done to determine the steady state gain and time constant to then calculate the transfer function in order to model this in Simulink. The time constant was measured on the graph produced by the software (64.32s), but did not match the calculated time constant (91.03s), which was most likely due to not letting the level settle. The closed loop model was then configured in Simulink and the autotune feature was used to determine the best response tuning parameters. These were then applied to the CE2000 PID controller which then controlled the level control loop on the CE117 Process Trainer. The graph result showed that there was little overshoot but a slow response time, which was correctly set on the autotune feature.



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Work Plan for Lifelong Learning

Plan:

This assignment will first be approached by researching the instrumentation used in the process trainer along with their associated control loops. Methods of PID tuning will then be investigated and the best tuning method will be chosen for the closed loop task. The capacitive level transmitter will then be calibrated as this is going to be used in the loop. An analysis on this will also be done. A level control system will then be configured on the CE117 interface board and also setup in the CE2000 software to control the level in the tank using a pump and level transmitter. A model of this will also be created in Simulink to find its best tuning parameters which will then also be used in the CE2000 software for PID control.

Learning:

This assignment helped develop an understanding of process control and why calibration and accuracy is important, particularly in closed loop, where the level needs to read accurate, otherwise the system could become unstable. Studying the instrumentation gave an understanding of their properties, such as their accuracy and range. The same can be said with PID tuning methods and understanding where they can be implemented. Using simulation models and tuning it on the software also showed how simulations can be used to predict the behaviours of systems which can also reduce the risk of system instability.



Research

The process trainer this assignment is based on can be seen below:



Figure 1 - Process Trainer

When referring to the diagram below for the CE117 Process Trainer, there are multiple control loops that can be investigated:

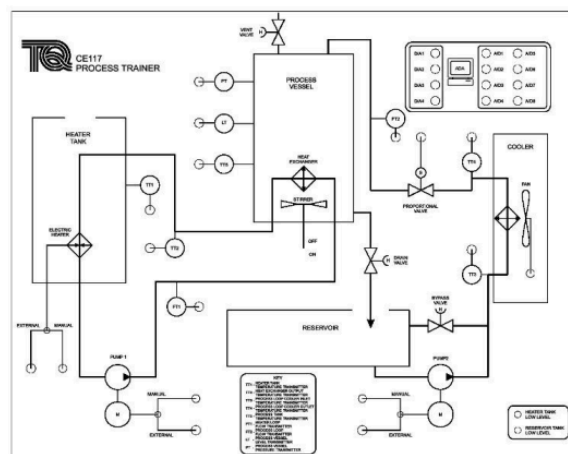


Figure 2 - Process Trainer Diagram/Interface Board

Loop 1:

This loop contains a heater tank, flow transmitter, a pump and an electric heater. The aim of this loop is to circulate hot water through the heat exchanger to heat up the process vessel tank. The flow transmitter FT1 measures the flow of water circulating and TT1 measures the temperature of water in the tank which appears to monitor temperature feedback to the heater to know how much actuation to provide. TT2 also measures the heat exchange output temperature.

Loop 2:

This loop contains another pump, a flow transmitter, two temperature transmitters, a proportional valve, a process vessel, stirrer and a reservoir. The process vessel also contains a level transmitter, pressure transmitter and another temperature transmitter. The loop pumps water through a cooler which then enters the process vessel and returns to the reservoir through the dump valve. The flow can be controlled using flow feedback from FT2, or the level can be controlled using LT depending on how it's configured in the software. The two temperature transmitters measure the temperature of water before it enters the cooler and when it exits the cooler. The pressure transmitter PT also measures the pressure in the vessel.

Instrumentation Technical Data and Properties:

TT1 TT2, TT3, TT4, TT5 – All temperature transmitters used in this experiment are RTDs (Resistor Temperature Devices) that use changes in resistance to measure temperature. The RTDs used in this experiment at platinum tip and provide a 0-10V range linear DC output signal to represent temperature and they read 0°C at 100Ω. Due to this, they provide accurate measurements compared to that of a nickel RTD (REALPARS, 2023). The graphs below visualise this:

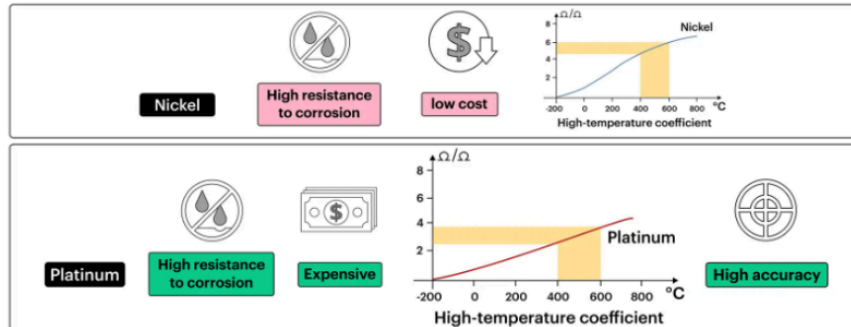


Figure 3 - RTD Platinum vs Nickel Linearity (REALPARS, 2023)

The 0-10V range also provides enough accuracy for the process trainer as they can measure to the nearest 0.1V and if a 3-wire configuration is used, it filters out the resistance of the RTD, which provides more accuracy. Their static sensitivity, however, can affect the accuracy of measurement due to requiring time to adjust to the change in temperature. RTDs have a good sensitivity when compared to a thermocouple in a means of being sensitive to slight changes in temperature and adjusting its output (REALPARS, 2023).

FT1, FT2 – These flow transmitters have a simple operation of having a rotating blade and light shines through it. The blades block the light passing through which produces pulses. The faster the blade spins, the more pulses there are, hence more flow. This makes the instrument output signal proportional to flow rate (ELCODIS, 2024). The output signal these provide on the process trainer are 0-10VDC which equates to 1L/Min per volt. They do have a high sensitivity, due to receiving infrared light pulses, however, are not accurate compared to that of a magnetic flow meter. But for the capacity of the process trainer, it is most suitable.

LT – The level transmitter being used on the process trainer is a capacitive transducer. It uses the change in dielectric (from air to water as the level rises) to provide an output signal and is a direct method of measurement. The output signal being used is also 0-10V, however it is not linear. (See more information on this in task 3).

(See next page for PID tuning methods).

PID Tuning Methods:

There are various methods of PID tuning methods that exist for optimum system performance. They are as follows:

- (1) Trial and error – This involves guessing safe tuning parameters to begin but altering them with small tweaks and testing the system. This process will repeat until a good response is acquired. It requires small process knowledge but can however be time consuming and could cause system instability (incatools, n.d.).
- (2) Ziegler and Nichols – This method involves starting the system with a small proportional gain and slowly raising it until the system generates oscillations. The value of Kp and the number of oscillations are then used in the table below to calculate the tuning parameters (Ellis, 2012).

Empty Cell	K_P	K_I	K_D
P controller	$0.5 K_{MAX}$	0	0
PI controller	$0.45 K_{MAX}$	$1.2 f_0$	0
PID controller	$0.6 K_{MAX}$	$2.0 f_0$	$0.125/f_0$

Figure 4 - Ziegler and Nichols Method (Ellis, 2012)



- (3) Kappa - Tau – This method overcomes weaknesses in the Ziegler and Nichols method, such as high proportional gains. It provides a response with less oscillations, can deal with setpoint tracking and allows alteration of the response speed (incatools, n.d.).
- (4) Autotune – This method uses algorithms to estimate the frequency response by injecting test signals into the closed loop system. The response generated is then used to compute the PID gains. The step response curve can also be altered to respond according to the user (The MathWorks, Inc., 2024).

(5) Lambda – This uses a time constant parameter to determine how fast the controller reacts. It allows for choosing the time constant and results in a zero-overshoot response (incatools, n.d.).

Lambda	K_c	T_I
PI	$\frac{T}{K_p(\lambda + L)}$	T

Typically $\lambda = 3 \cdot \max(L, T)$ (very stable loop)

Reduce λ to get a faster response

Figure 5 - Lambda Tuning Parameter (incatools, n.d.)

The autotune method of PID tuning will be used for task 4 using Simulink software, as this is the easiest form of tuning and is much less time consuming than the other methods. The response can also be adjusted to suit the process trainer. An open loop response will first be completed before configuring the system as closed loop.



Level Transmitter Calibration

This task involved calibrating the capacitive level transmitter as per procedure 4 on the TecQuipment CE117 Process Trainer using the diagram for the connections and the CE2000 software to monitor the output voltage. As this was a capacitive transducer, the values were expected to be non-linear and the maximum and minimum values were expected to be within + or – 0.1V.

The proportional valve was set to fully open to ensure no restrictions to flow. The pump was put in manual mode and controlled using the dial to increase the level in 10mm increments. Each voltage level of the capacitor was then recorded until the tank reached 180mm. The results were then compared with the values in the manual.

The connections on the interface board were made as the following:

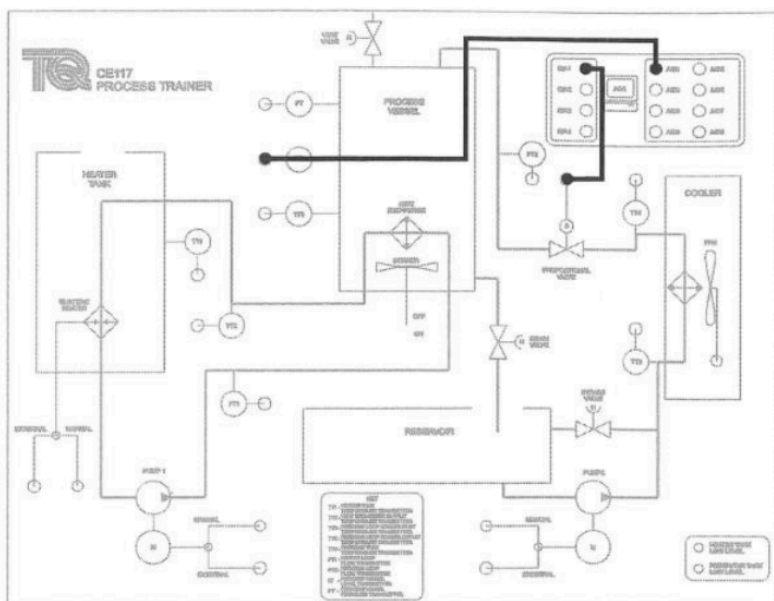


Figure 6 - Task 3 Interface Board Connections

The level voltage was then monitored on the CE2000 software and tabulated at each 10mm increment.

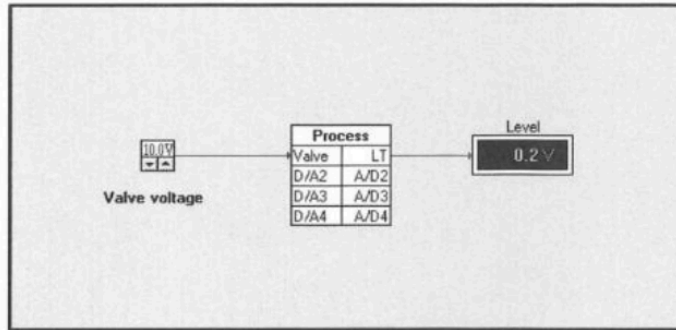


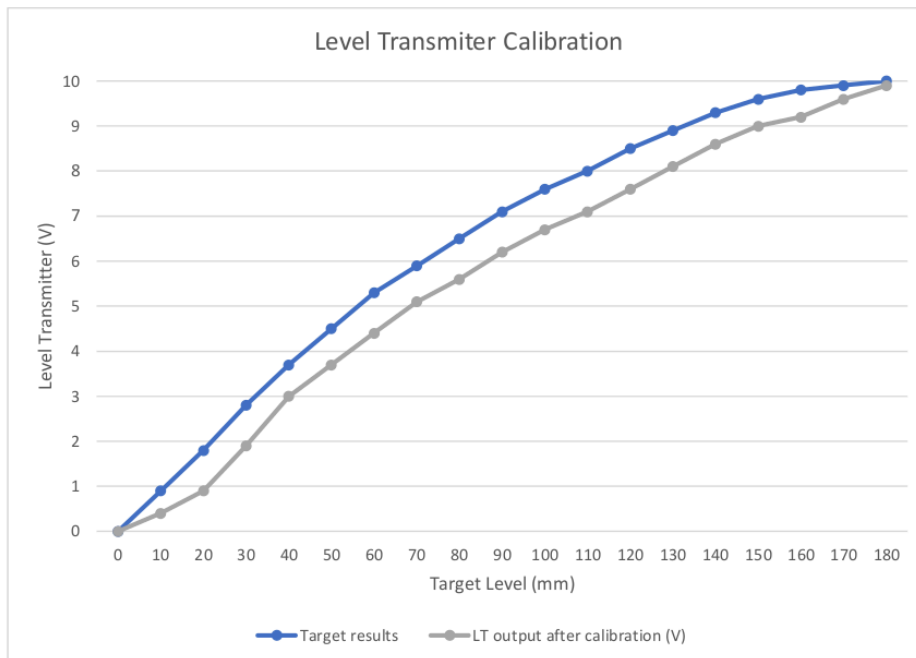
Figure 7 - CE2000 Software Level Voltage

Tabulated Results:

Table 1 - Level Transmitter Calibration Results

Target level (mm)	Target results	LT output after calibration (V)	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	8.0	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	0.6
160	9.8	9.2	0.6
170	9.9	9.6	0.3
180	10	9.9	0.1

Graph Results:



Analysis:

When reviewing the graph results, it's immediately evident that the results are non-linear. Several factors can cause the non-linearity observed. One of them simply being parallax error, which is error of the angle the observer views the level on the tank gauge. Because there is a human recording the level, the results more prone to error. Another factor that may have caused non-linear results could have been the geometry of the tank. The tank used in this experiment has a heater coil inside along with a stirrer, which means the volume of water being increased at each increment isn't proportional to the water entering the capacitive transducer. Another factor can simply be contaminants in the liquid, which can affect the dielectric of the medium. When comparing the results with the results in the manual, they follow the same relationship. The lower end of the results also tied closer to the target results in the manual. The whole graph also appeared to have a massive error compared to the target results. The largest being 0.9V which was consistent in the middle of the graph. This will have a big impact on a closed loop system, as this made the readings inaccurate.

Level Control of The Process Tank

This task involves using the level transmitter to control the pump speed as a closed loop. From investigating the P&ID below, the pump provides water to the tank and the dump valve returns water to the tank and the reservoir. The system also contains a flow transmitter and a proportional valve but aren't part of the loop control.

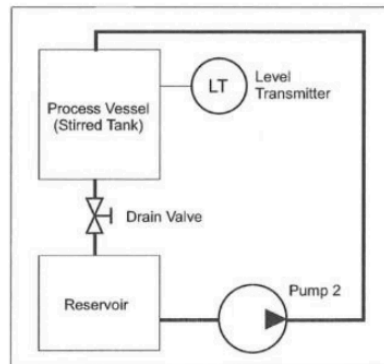


Figure 8 - Level Control P&ID Diagram

When investigating the closed loop block diagram below, the level feedback voltage coming from the level transmitter is subtracted from the setpoint, which creates an error. The error is sent to the PID controller, which will then provide a control signal to the pump to tell it how fast to run. Disturbances in the tank will then be recorded by the level transmitter and sent back to the summing junction. This process reoccurs continuously until the error is zero.

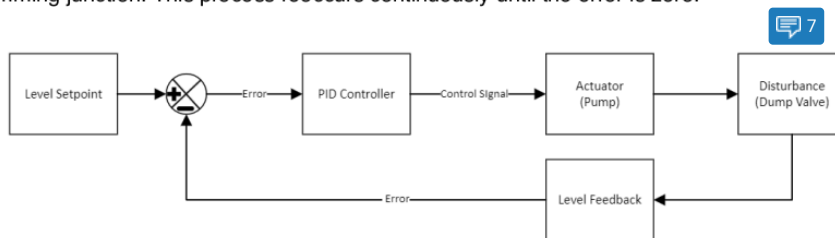


Figure 9 - Level Control PID Block Diagram

When referring back to the calibration curve in task 3 (page 14), there is a continuous error throughout the graph and the measurements that were made had a maximum of 0.9V less than the desirable results in the manual. The control can be massively affected due to this because the level being sent back to the summoning junction will be less, which means the PID will provide more actuation than required.



The system was first configured to find the open loop response with the pump set at a constant voltage and once the level value settled, the pump was provided 0.5V more and this transient response was recorded to find the time constant. The flow was also monitored.

The connections were made as shown below along with the software configuration :

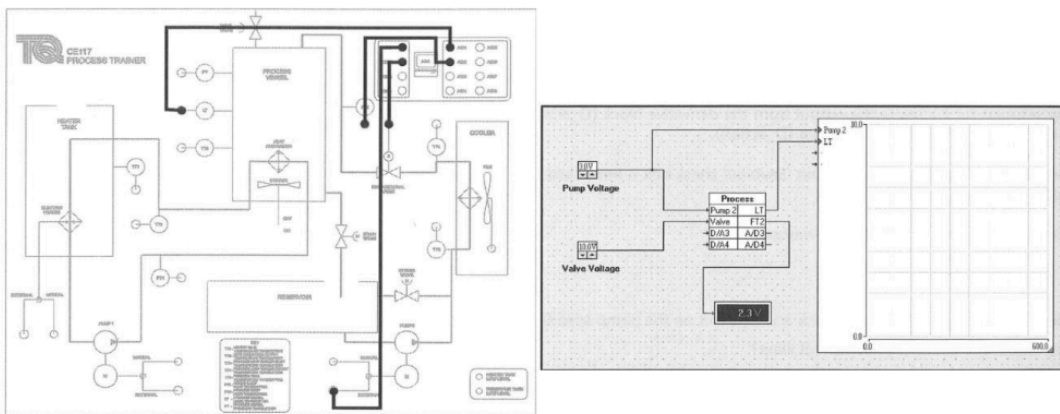


Figure 10 - Connections and Software Configuration

The pump was first set to 5.7V and the dump valve was set to open. The proportional valve was set to 10V (fully open). Water then started entering the tank and the level was being recorded. Once the level settled, the voltage output was recorded along with the flow and height on the sight gauge (Level A). The pump was then set to 6.2V and the same procedure was done once the level settled again (Level B). See tabulated results on next page.



Table 2 - Level Control Open Loop Response Results

	VP(V)	VL(V)	H(m)	q(m ³ /sec)
Level A	5.7	7.655	0.116	70 μ
Level B	6.2	8.16	0.133	73.3 μ

$$SSGain = \frac{\delta VL}{\delta vp} = \frac{8.16 - 7.6650}{0.5} = 0.99$$

Change in height = 0.017m

Change in flow rate = $3.3\mu\text{m}^3\text{s}^{-1}$

The area of the vessel was calculated to be $A = \pi r^2 h = \pi \times 0.075^2 = 0.0177\text{m}^2$

The time constant was then calculated using the following equation:

$$\tau = A \left(\frac{\delta q}{\delta h} \right) = 0.0177 \left(\frac{0.017}{3.3 \times 10^{-6}} \right) = 91.03\text{sec}$$

The open loop response time constant when the 0.5V step was applied equated to 64.32 seconds, which was 26.71 less than the calculated value. This could be due to the inaccuracy of the level transmitter as seen on the graph in page 14 and also due to not letting the level settle for long enough as the level does increase after measurements were taken:

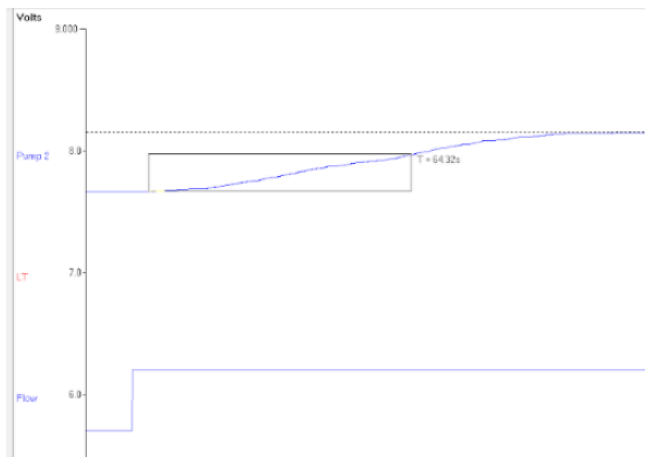


Figure 11 - Open Loop Response Process Reaction Curve

A mathematical closed loop model of the system was then created on Simulink and the transfer function was set using the calculated value of the gain and time constant:

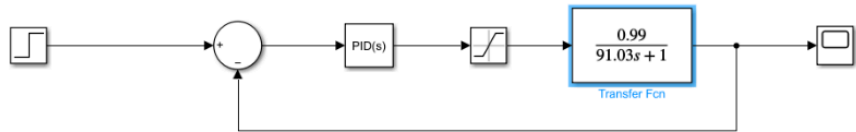


Figure 12 - Simulink Closed Loop Model

The autotune feature on Simulink was then used to obtain the best response for the system. The graph and parameters are shown below.

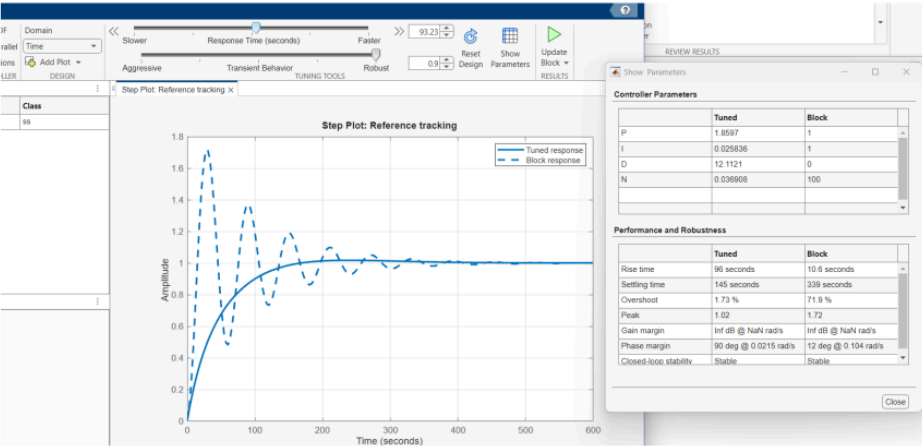


Figure 13 - Simulink Autotune Feature

The simulated response can be seen below with very little overshoot:

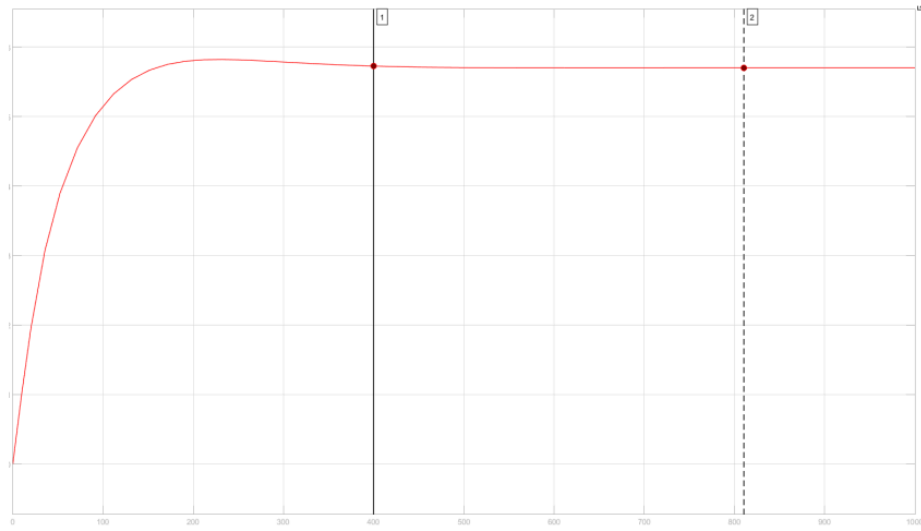


Figure 14 - Simulink Response

The tuning parameters were then integrated into the CE2000 software as shown below where it is configured as closed loop where P, I and D are summed together to give an output. The setpoint can be seen at the top. LT is then sent back to the summing junction to obtain an error.

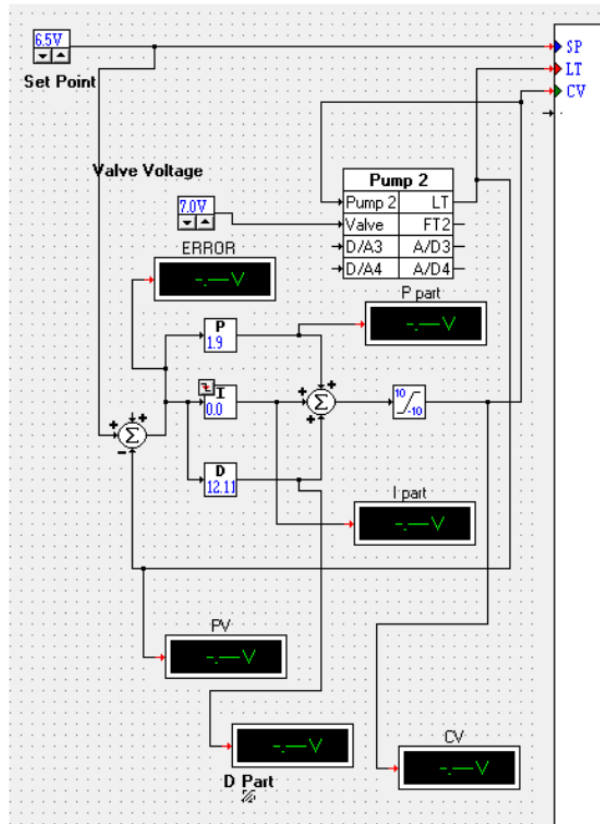
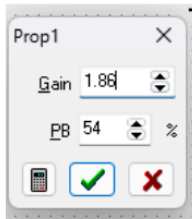


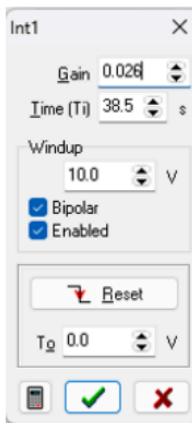
Figure 15 - CE2000 Software Configuration

The tuning parameters were set as the same values in the Simulink model:



$K_p = 1.86$

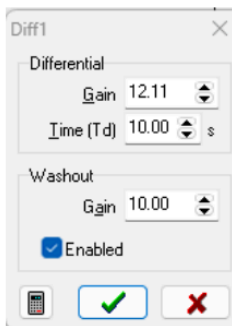
Figure 16 - K_p



$K_i = 0.026$

Integral windup was set to 10V to stop it accumulating more than it's required, otherwise a bigger control signal would be applied when pump cannot output more than 10V.

Figure 17 - K_i



$K_d = 12.11$

Washout gain was set to 10 in order to filter out gradual changes in the level and only work with faster dynamic changes.

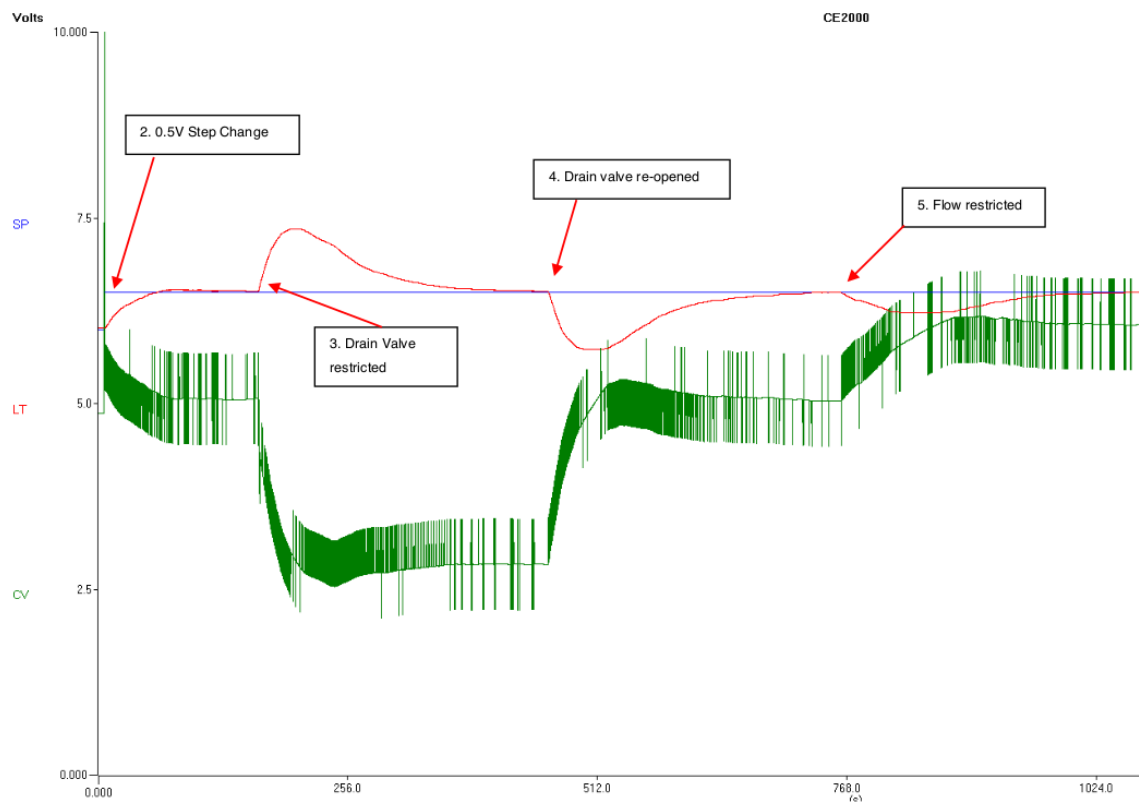
Figure 18 - K_d

Experiment Process:

1. The pump was first started at 6V.
2. A step change was then done at 6.5V.
3. The drain valve was restricted.
4. The drain valve was re-opened.
5. The flow was restricted by setting the proportional valve to 7V.

Key: Setpoint (SP) – BLUE, Level Transmitter (LT) – RED, Pump Voltage (CV) - Green

Graph Results:



Analysis:

From the graph on the previous page, it can be seen that once the 0.5V step change occurred, there was very little overshoot and the level settled, but once the drain valve was restricted, the level shot up and took a while to react before cutting off the pump, but eventually settled and did not undershoot. The opposite occurred when the drain valve was re-opened, the level dropped and took a while for the pump to react before it settled again. Once the flow was restricted, the level dropped again and also took long for the pump to react and maintain the level. For a faster response, the Kp value could be increased, along with Ki, which was already very small. Kd was probably too high and fighting with Kp, which can especially be seen at step 4 when restricting the proportional valve. The pump had plenty of room to go to full voltage to maintain the level, but it didn't, which hence means that either Kp and Ki were too low, and Kd was too high providing too much damping. When comparing the process trainer reaction with the Simulink mode, the response are similar in that there is very little overshoot but a slow response.



Overall Conclusions and Recommendations

This assignment provided an exploration of instrumentation and control systems focusing on PID tuning methods and closed loop control. It gave an understanding on how various transducers work and their applications. An understanding was also made on why instrumentation requires accuracy and calibration to ensure system stability. Using Simulink to model the system also gave an insight on how simulations can be used to model real world control systems to predict performance and accuracy.

A recommendation that can be made, is to improve the accuracy of the level transmitter by using a different type of transducer, such as an ultrasonic one which uses sound to measure the level. These are linear, accurate and not a direct method of measurement, which makes them less susceptible to failure.



Team Working

Working in a team during task 4 enabled more of an understanding of tuning methods as, other members of the team used different methods of tuning, such as the Ziegler and Nichols method. As a team, an understanding of this was developed by using this method to calculate the tuning parameters. Working as a team also gave an insight of what it is like to work in a team in the workplace where different ideas can be implemented in the same task to obtain the best outcome.

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GRADEMARK REPORT

FINAL GRADE

GENERAL COMMENTS

76/100

PAGE 1

PAGE 2



Comment 1

A good summary

PAGE 3

PAGE 4

PAGE 5



Comment 2

Good work

PAGE 6

PAGE 7

PAGE 8



Comment 3

good work on sensors here

PAGE 9

PAGE 10



Comment 4

you would need an explanation or image of the terms

PAGE 11



Comment 5

good focused research on PID tuning



Comment 6

A good analysis, what if any adjustments were made during calibration?



Comment 7

Block diagram should show the process tank and then output from there to the instrumentation, the disturbance is in the wrong place on this diagram.



Comment 8

A good observation



Comment 9

why 5.7?



Comment 10

what should have been done about this?



Comment 11

A good analysis provided.



Comment 12

Some valid recommendations.

ZEESHAN IBRAHIM

76

1. ENGAGEMENT WITH LITERATURE



An extensive range of credible material has been used to inform the research which is relevant and valid. 8/10

8

2. KNOWLEDGE AND UNDERSTANDING



Knowledge exhibits a competent critical understanding of concepts used and comprehensively addresses the main tasks. 22/30

22

3. COGNITIVE AND INTELLECTUAL



Sound critical evaluation of the concepts and ability to devise arguments which explain most findings from the experiments. 17/20

17

4. PRACTICAL APPLICATION



A very good application of methods in all aspects of the practical work. There are a few areas where the work could have been improved, see comments. 22/30

22

5. TRANSFERABLE SKILLS



Communication is professional and confident. Work is coherent and fluid. 7/10

7

