

2221112

by William Utting

Submission date: 14-Nov-2024 06:19PM (UTC+0000)

Submission ID: 242697501

File name: 18983_William_Utting_2221112_183567_1418020760.pdf (1.22M)

Word count: 4640

Character count: 22291

Name: William Utting
University Number: 2221112
Module Code: SGEE5014
Assignment Title: Process Control Systems
Date Submitted: 14/11/2024
Word Count: 2677

Table of Contents

Work Plan for Lifelong Learning	3
Executive Summary	4
Research	5
Hardware Investigation	5
Heater Tank Loop	6
Process Vessel Loop	7
PID Tuning Methods	10
Process Reaction Method	10
Ultimate Sensitivity Method	10
Relay Autotuning Method	11
Kappa Method	11
Level Transmitter Calibration	13
Level Control of the Process tank	15
Method	15
Measuring and Calculating the Time Constant	16
Determining the Transfer Function of the System	17
Modelling and Tuning the System	18
Testing the Tuned Controllers on the Process Trainer	22
Conclusions	26
Recommendations	26
Team Working	27
Appendix A: User Guide Figures	28
Citations	30

Work Plan for Lifelong Learning

Research on the training rig will be completed using documents from TecQuipment to ensure the information gathered is as accurate as possible. To inspect the individual components in depth their model numbers can be used to find datasheets. Methods of tuning proportional integral and derivative control (PID) will be researched to explore the response of the most suitable tuning.

The calibration and control of the tank will be worked on in a group. This allows discussion and debate over the best control tuning which may improve the final system. Having multiple people checking each stage also reduces the human error in calibration which will benefit the final system.

Conclusions on the characteristics of the system can then be made and recommendations on how to improve can be suggested.

Executive Summary

The CE117 Process Trainer rig has its hardware and control loops investigated. Different methods of tuning a PID controller are researched to provide a range of tuning methods to choose from. To prepare the Process Trainer rig the level sensor is calibrated to ensure following measurements of the level are correct. To find the level control loop's time constant and gain a step change in the pump's voltage is used to gather relevant data. The control loop is then simulated and autotuned within the MatLab pro¹. A tuning method from the research is then applied to compare against autotuning. Conclusions and recommendations are drawn from a set of data gathered from a series of disturbances input into the system.



Hardware Investigation

[illegible]

Figure 1 - P&ID (reproduced from: TecQuipment (2008). Pg 11)

Heater Tank Loop

To gain an understanding of how each loop functions, the instrumentation used within it must be analysed. The heater tank loop is shown on the left of Figure 1. Focusing in on the loop provides the view shown in Figure 2.

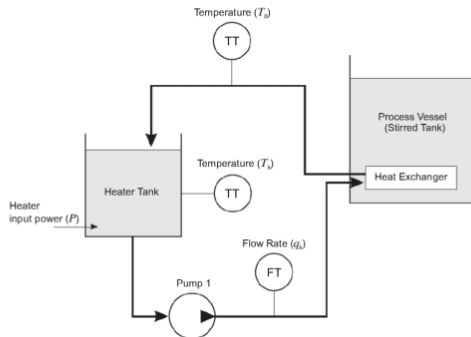


Figure 2 - Heater Tank Loop (reproduced from: TecQuipment (2008). Pg 26)

The control loop components are described in Table 1.

Component	Analogue Signal	Conversion Details	Description
Electrical Heater	0–10V	75W per 1V (0–750W)	
Heater Tank	Non-Electrical Component		Stainless steel. Includes sight glass for water level.
Thermal Switch			Mounted in the heater tank as a safety backup. Set to open at 70°C.
Float Switch			Mounted in the heater tank as a safety backup. Set to shut off the pump below the minimum water level to protect the heating element.
Heat Exchanger	Non-Electrical Component		Coil of copper pipe.
Pump	0–10V Input	0 to Max Flow	Variable speed DC motor driven.
TT1	0–10V Linear Output	10°C per 1V (0–100°C)	Platinum resistance thermometer.
TT2	0–10V Linear Output	10°C per 1V (0–100°C)	Platinum resistance thermometer.

FT1	0–10V Output	1 L/Min per V (0V = 0L/Min)	
-----	--------------	-----------------------------	--

Table 1 - Heater Loop Component Specifications (adapted from: TecQuipment 2008. Pg 10 & 16)

The heating control loop operates by heating water in the heater tank at a controlled rate, then pumping the heated water through a heat exchanger in the process vessel and back to the heater tank. The power consumption of the electrical heater can be controlled to vary the rate of heating in the tank. The water's flow rate is measured after the pump to gain a real time reading to compare to the input voltage of the pump. The temperature of the water is then measured in the return pipe to the heater tank to determine the approximate amount of heat transfer to the process vessel and the heat loss throughout the piping.

There are two safety backups within the loop to ensure the equipment is not damaged while in use: a thermal switch in the heater tank shuts off the electrical heater if the temperature becomes too high; and a float switch is set to turn off the pump if the water level in the tank falls below the level of the heating element (TecQuipment 2008. Pg 10).

Manual and automatic controls can be switched between on the electrical heater and pump as seen in Figure 1.

Process Vessel Loop

This loop controls the level of water in the process vessel and provides feedback on the pressure and temperature of the vessel. The temperature feedback can be used in the heater tank loop to control the temperature of the process vessel. The pressure feedback can be used by the heater tank loop and the process vessel loop to control the pressure in the process vessel. The process vessel control loop is shown in Figure 3.

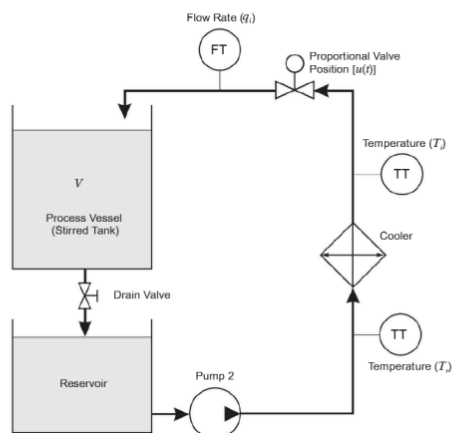


Figure 3 - Process Vessel Loop (reproduced from: TecQuipment (2008). Pg 24)

The control loop components are detailed in Table 2.

Component	Analogue Signal	Conversion Details	Description
Processing Vessel	Non-Electrical Component		Clear tank with manual level reading attached. Water is pumped in, heated, pressurised and drained out.
Drain Valve	Non-Electrical Component		Opened to drain or provide a constant flow out of the process vessel.
Bypass Valve	Non-Electrical Component		Opened to bypass the loop and pump water from the reservoir directly back into itself.
Vent Valve	Non-Electrical Component		Can be closed to allow pressure fluctuation in the vessel or opened for atmospheric pressure.
Proportional Valve	0–10V Input	0V: closed 10V: fully open	Allows further control of flow in the system.
Stirrer		On/ off, no variable control	Ensures movement of water around the heat exchanger.
Reservoir	Non-Electrical Component		Stores water for the loop and provides a place for the process vessel to drain.
Float Switch			Mounted in the reservoir to turn the pump off if the water level falls below a minimum level.
Cooler		Turns fan on when powered, fans speed can be changed	Heatsink with a fan to disperse heat.
Pump	0 - 10V Input	0 to Max Flow	Variable speed DC motor driven.
PT	???		No information is provided in the handbook.
LT	0 - 10V Non-Linear Output	0V - Vessel Empty 10V - Vessel Full	Capacitance level sensor.

TT3	0–10V Linear Output	10°C per 1V (0–100°C)	Platinum resistance thermometer.
TT4	0–10V Linear Output	10°C per 1V (0–100°C)	Platinum resistance thermometer.
TT5	0–10V Linear Output	10°C per 1V (0–100°C)	Platinum resistance thermometer.
FT2	0–10V Output	1 L/Min per V (0V = 0L/Min)	

Table 2 - Heater Loop Component Specifications (adapted from: TecQuipment (2008). Pg 9 & 16)

The process vessel loop's flow rate can be controlled in two ways: the flow of water into the vessel can be controlled by either the pump or the proportional valve. The pressure of the vessel is controlled by the level in the vessel which is affected by the heat exchangers and the pump/ proportional valve. The temperature of the water in the vessel is controlled by the heater tank loop; the speed of the fan over the cooler and the flow rate in/ out of the vessel. The temperature, pressure and level sensors in the vessel can be used as feedback for the control of each variable. Each variable can also be independently controlled by eliminating the others. Pressure is eliminated by opening the vent valve; temperature by turning the heater tank loop off and the cooling fan off; and level by closing the drain valve and turning the pump off.

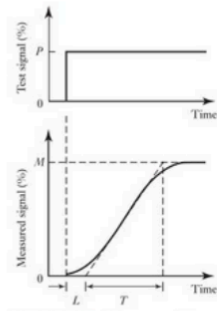
Temperature sensors TT3 and TT4 can be used to measure the cooling effectiveness of the cooler and fan. This will provide more data to control the temperature of the vessel. The stirrer in the vessel can be used to disperse temperature from the heat exchanger evenly through the water in the vessel. To manually fill the tank the pump is switched into manual mode.

The only safety feature in the vessel loop is the float switch in the reservoir. This turns the pump off when the water in the reservoir falls below a minimum level, thus protecting the pump from running dry (TecQuipment (2008). Pg 9).

PID Tuning Methods

Process Reaction Method

The process control method takes the response of a system with no control action, disturbs the system with a test signal, and uses the gradients' intersection with the time axis and the time of the start time of the test signal to calculate the lag of the response. The proportion of the input disturbance test signal's magnitude relative to the settled system's magnitude and the proportion of the output's magnitude relative to the settled system's magnitude are used with the lag to calculate the PID controller's constants (Bolton, W (2018). Pg 564). Figure 4 shows how the parameters are taken from the system's response



Control mode	K_p	T_i	T_d
P	P/RL		
PI	$0.9P/RL$	$3.33L$	
PID	$1.2P/RL$	$2L$	$0.5L$

Figure 5 - Process Reaction Tuning Table (reproduced from: Bolton, W (2018). Pg 564) where L is lag, R is the proportion of the test signal to the measured signal, P is the test signal percentage

Figure 4 - Labeled Test Response (reproduced from: Bolton, W (2018). Pg 564) where L is lag, T is rise time, M is the percentage of the measured signal compared to the test signal.

Ultimate Sensitivity Method

To tune a system using the ultimate sensitivity method, the proportional gain is increased to the value where the system begins to oscillate constantly. The period of oscillations is then measured when their amplitude is at its minimum. These values are then used in a set of calculations to determine the gain values of the integral and derivative components (Franklin G F, Powell D J & Emami-Naeini A (2019). Pg 240).

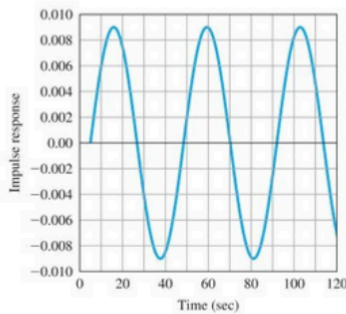


Figure 6 - Constant Oscillations

Ziegler-Nichols Tuning for the Regulator $D_c(s) = k_p(1 + 1/T_i s + T_d s)$, Based on the Ultimate Sensitivity Method

Type of Controller	Optimum Gain
P	$k_p = 0.5K_u$
PI	$\begin{cases} k_p = 0.45K_u \\ T_i = \frac{P_u}{1.2} \end{cases}$
PID	$\begin{cases} k_p = 1.6K_u \\ T_i = 0.5P_u \\ T_d = 0.125P_u \end{cases}$

Figure 7 - Ultimate Sensitivity Tuning Table

(reproduced from: Franklin GF,
Powell DJ, Emami-Naeini A (2019). Pg 240)

(reproduced from: Franklin GF, Powell DJ &
Emami-Naeini A (2019). Pg 240)

Relay Autotuning Method

This method uses a relay to step the system through a range of frequencies. When the system has a phase lag of π , the period of oscillations can be used to estimate the ultimate time period. The estimated ultimate gain can then be calculated from the equation in Figure 8. Using the ultimate gain the ultimate sensitivity method is applied (Hang CC, Astrom KJ & Wang QG (2002). Pg 145).

$$k_u = \frac{4d}{\pi a} \quad (1)$$

where d is the relay amplitude and a is amplitude of the process output.

Figure 8 - Ultimate Gain Equation (reproduced from: Hang CC, Astrom KJ & Wang QG (2002). Pg 145)

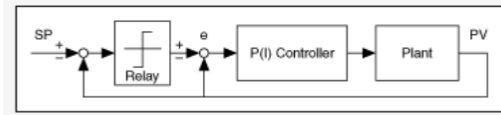


Figure 9 - Relay Autotuner (reproduced from: National Instruments (2024))

Kappa Method

This version of the method is based on the ultimate sensitivity method. The ultimate gain is found through a process of relay autotuning, calculating the desired oscillation amplitude then adjusting the relay amplitude. In addition, the static gain of the system must be found. By following the equation in Figure 10, the kappa value is calculated. Before finding the parameters for the PID controller, the maximum sensitivity (M_s) should be decided. By using the table in Figure 11, the values for the 'a' parameters in the kappa functions is determined based on the M_s . Using the kappa value and the four kappa functions, then rearranging for the quotients, the parameters K , T_i , T_d and b can be found. These can then be used in the controller as K_p , K_i and K_d . b is used as a constant to apply a setpoint offset in the system (Norberg, A (1999). Pg 15–32).

$$\kappa = 1/K_p K_u$$

Figure 10 - Kappa Calculation (reproduced from: Norberg, A (1999). Pg 21)

$f_{K,n,Td}(\kappa) = a_0 \cdot e^{(a_1\kappa + a_2\kappa^2 + a_3\kappa^3)}$ $f_b(\kappa) = a_0 + a_1\kappa + a_2\kappa^2 + a_3\kappa^3$									
		PI				PID			
		a_0	a_1	a_2	a_3	a_0	a_1	a_2	a_3
$f_K(\kappa)$ K / K_u	$M_r=1.2$	0.0255	5.24	-6.53	2.67	0.119	1.25	-1.52	0.580
	$M_r=1.3$	0.0368	5.02	-6.29	2.57	0.166	0.918	-0.961	0.324
	$M_r=1.4$	0.0510	4.43	-5.59	2.33	0.169	2.32	-3.30	1.48
	$M_r=2.0$	0.108	3.43	-4.16	1.66	0.283	1.91	-2.34	0.938
$f_b(\kappa)$ b	$M_r=1.2$	1.00	0.00	0.00	0.00	0.459	0.426	-0.182	-0.0164
	$M_r=1.3$	1.00	0.00	0.00	0.00	0.459	0.426	-0.182	-0.0164
	$M_r=1.4$	1.00	0.00	0.00	0.00	0.123	0.256	1.24	-0.932
	$M_r=2.0$	0.641	-2.47	3.14	-1.31	0.00	0.00	0.00	0.00
$f_n(\kappa)$ T_i / T_u	$M_r=1.2$	1.50	-7.36	8.95	-3.60	1.17	-5.89	6.87	-2.57
	$M_r=1.3$	1.50	-7.36	8.95	-3.60	1.17	-5.89	6.87	-2.57
	$M_r=1.4$	1.50	-7.36	8.95	-3.60	1.17	-5.89	6.87	-2.57
	$M_r=2.0$	1.50	-7.36	8.95	-3.60	1.17	-5.89	6.87	-2.57
$f_{Td}(\kappa)$ T_d / T_u	$M_r=1.2$	-	-	-	-	0.499	-6.12	7.64	-3.15
	$M_r=1.3$	-	-	-	-	0.499	-6.12	7.64	-3.15
	$M_r=1.4$	-	-	-	-	0.499	-6.12	7.64	-3.15
	$M_r=2.0$	-	-	-	-	0.499	-6.12	7.64	-3.15

Figure 11 - Table of Tuning Formulas (reproduced from: Norberg, A (1999). Pg 61)



Level Transmitter Calibration

To ensure that the level transmitter is reading the correct level of the tank, a level calibration operation must be conducted. The user guide from TecQuipment provides a procedure to follow (Appendix A: Figure A1). Following the procedure involves checking the level reading when empty then full; then adjusting the zero point to read 0V when the level is 0 and adjusting the span (range) to scale the output voltage between 0V and 10V. This can be done by adjusting the nuts on the side of the process trainer (See Appendix A: Figure A2). The characteristics of the level transmitter can then be observed by taking voltage readings of the level transmitter for every 10mm the level rises. This is tabulated then graphed to visualise the data.

A CE117 process training rig was calibrated at Coleg Sir Gar Graig campus, following the TecQuipment procedure (Table 3).

Table 3 - Raw Data for the Characteristics of the Level Sensor.

*Data from TecQuipment (2008) pg 50.

Level of water in tank (mm)	Factory Tested Voltage (V)*	Uncalibrated Voltage (V)	Calibrated Voltage (V)
0	0	-0.2	0
10	0.9	0	0.4
20	1.8	0.9	0.9
30	2.8	1.8	1.9
40	3.7	3	3
50	4.5	3.7	3.7
60	5.3	4.3	4.4
70	5.9	4.9	5.1
80	6.5	5.7	5.6
90	7.1	6.1	6.2
100	7.6	6.6	6.7
110	8	7.1	7.1
120	8.5	7.4	7.6
130	8.9	7.9	8.1
140	9.3	8.4	8.6
150	9.6	8.8	9
160	9.8	9.3	9.2

170	9.9	9.6	9.6
180	10	9.9	9.9

As shown in Figure 12, the ideal relationship between the level and the voltage output from the sensor (blue line) is a smooth non-linear relationship. The difference between the ideal and the actual (yellow and red lines) relationships could be due to the age of the training rig (corrosion on the capacitive plates). In addition, there may have been a change in the component used and the user guide used across a range of different rig versions that were slightly different. The rougher curve of the actual values is, most likely, due to parallax and human error when reading the level.

Factory Tested Voltage (V), Uncalibrated Voltage (V) and Calibrated Voltage (V)

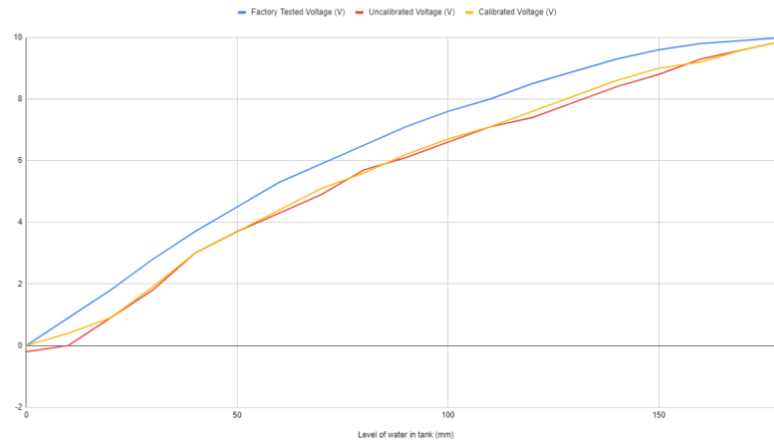


Figure 12 - Level Calibration Graph (adapted from: TecQuipment (2008). Pg 58). Blue, TecQuipment data; yellow and red, experimental data.

The calibrated data set begins at 0V and ends at 10V, whereas the uncalibrated data set begins slightly lower. This is due to a small error in the zero point and span that the rig was set to prior to the calibration.



Level Control of the Process Tank

The process tank loop is shown in Figure 3. The level within the tank can be regulated using pump 2 or the proportional valve. To affect the flow rate in and out of the tank, the manual drain valve, the bypass valve (not shown in diagram; connected between pump 2 and TT) and the proportional valve can be used. A capacitive level transmitter is mounted alongside the tank to provide a voltage output. For a more in-depth explanation of the operation of the process vessel loop, refer to the Research section.

Method

For the purpose of controlling the level of water in the tank, the pump's voltage was the variable that was controlled. The valves were used to provide disturbances in the system so that the reaction of the controller can be observed.

To reduce potential stresses on the training rig while testing different tuning methods, a simulation will be conducted using Matlab's Simulink software. To acquire the transfer function that represents the control loop on the rig, an initial test must be conducted to determine the time constant.



Measuring and Calculating the Time Constant

A step input was fed into the system and an open loop response was observed (Figures 13 and 14). The pump's voltage, level sensor's voltage, flow rate and level were measured before and after the step change and recorded in Table 4.

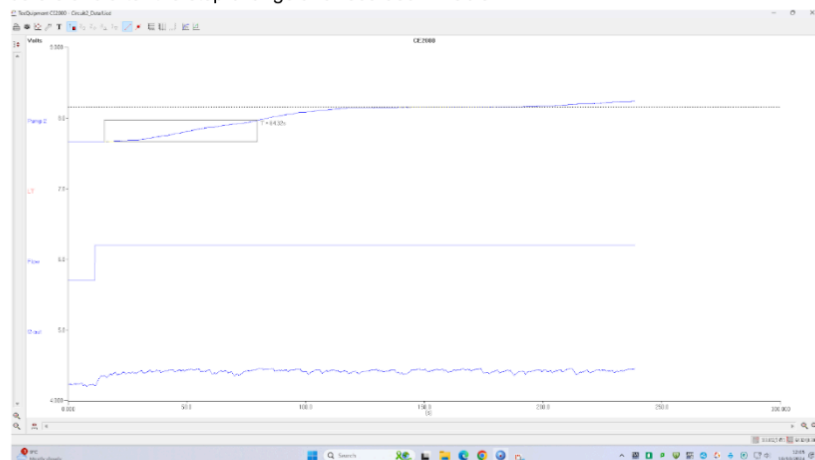


Figure 13 - Open Loop Response to a Step Change in Pump's Voltage During Operation of a CE117 Process Trainer Rig at Coleg Sir Gar Graig campus.



Figure 14 - Zoomed-in Graph of the Open Loop Response to the Step Change of Pump Voltage Displayed in Figure 13.

	Pump's Voltage (V) V_p	Level Sensor's Voltage (V) V_L	Flow Sensor's Voltage (V) V_F	Level (m) h	Flow (m^3/s) q
Before Step Change	5.7	6.8	4.2	0.116	70×10^{-6}
After Step Change	6.2	8.16	4.4	0.133	73×10^{-6}

Table 4 - Readings of the Level and Flow Sensors after a Step Change in Pump Voltage

The time constant is measured at 63.2% of the level setpoint, giving 64.32s. To double check that the time constant has been measured correctly, it can be calculated from the set of known values of the rig shown in Figures 13, 14 and the test results from table 4, as follows:

$$\begin{aligned} \text{flow at 5.7V} \\ q_1 &= 4.2 \times \frac{0.001}{60} = 70 \times 10^{-6} \text{ m}^3 / \text{sec} \\ \text{flow at 6.2V} \\ q_2 &= 4.4 \times \frac{0.001}{60} = 73 \times 10^{-6} \text{ m}^3 / \text{sec} \end{aligned}$$

$$\begin{aligned} \Delta q &= 3 \times 10^{-6} \\ \Delta h &= 0.017 \end{aligned}$$

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

$$\tau = 0.017 \times 5666.67 = 100.13\text{s}$$

where q is flow, h is the water level in the tank, R is the change in flow in relation to the change in height, and τ is the time constant. As the calculations show, there is a large difference between the measured and calculated values. In this case, the calculated values are likely the most accurate. This is due to stopping the system before it had settled at a constant value.

Determining the Transfer Function of the System

Since there is no existing control in the system and a PID controller is being introduced into it, the system was modelled as a class 1 system with the integral being in the control block. There is no modification to the feedback signal, therefore the system also has unity gain.



Figure 15 - General Control Block Diagram for the System. PID, proportional integral derivative controller; s , Laplace constant.

From the system's response to a step change the order of the system was determined to be a first order. The gain of the system was calculated by taking the difference of the level sensor's voltage over the difference of the pump's voltage (Values in Table 4). This provides a gain of 0.99. These values were substituted into the general equation of a first order system as follows:

General Equation for a First Order System :

$$\begin{aligned} &\frac{K}{\tau s + 1} \\ \text{Substituting the Systems Values :} \\ &\frac{0.99}{100.13s + 1} \end{aligned}$$

Modelling and Tuning the System

Now that the Laplace transfer function for the tank has been found, the final model of the system can be simulated (Figure 16).

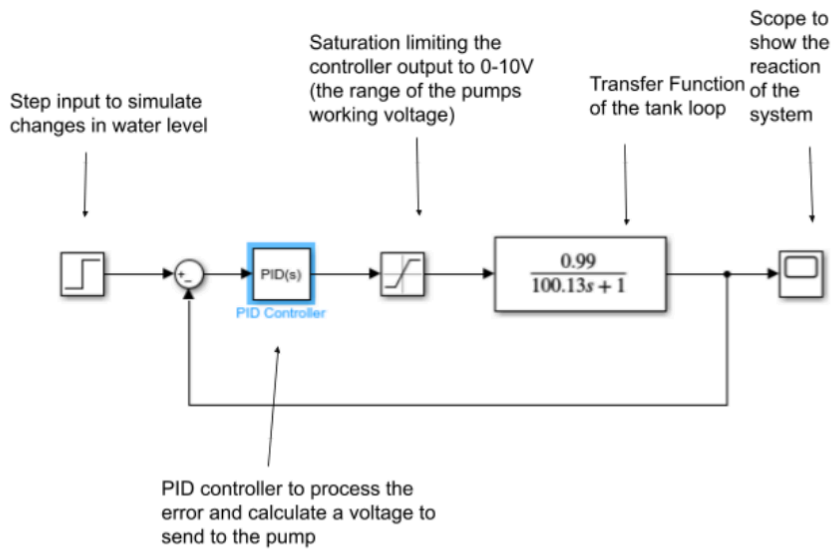


Figure 16 - Final Control Block Diagram of the System. PID, proportional integral derivative controller; s, Laplace constant.

The reaction of the tank to a step of 5V at PID control is shown in Figure 17.

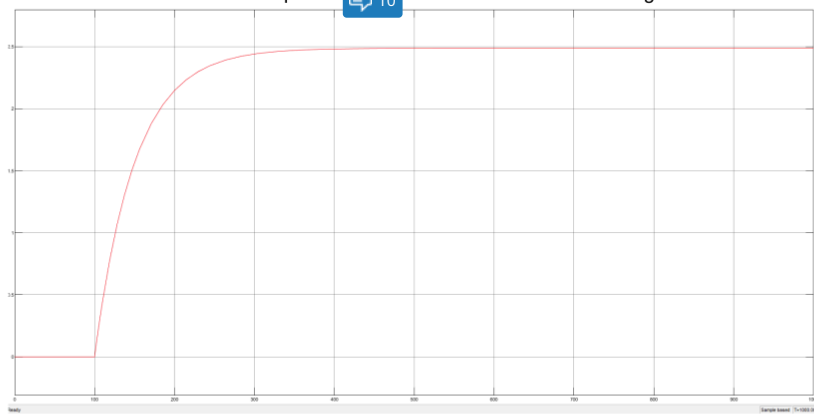


Figure 17 - System's Response to a 5V Step Change without PID Control, as Measured at Coleg Sir Gar Graig Campus.

There is a steady-state error of half of the target voltage. To eliminate the error, integral control is required. The PID controller can be implemented and tuned to achieve the desired response. The most accessible method of tuning is the in-built application in Matlab (Figure 18).

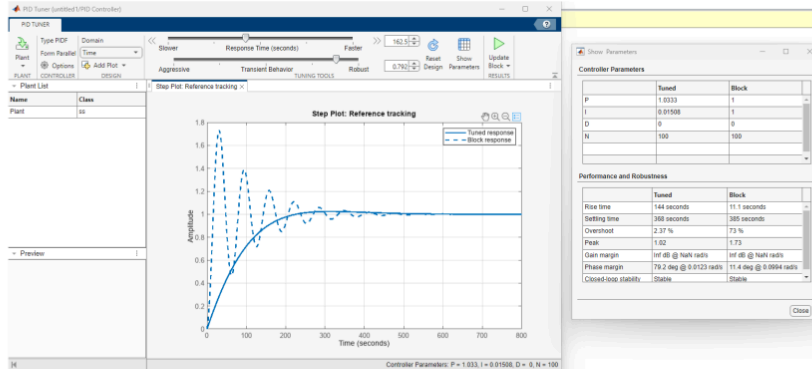


Figure 18 - Autotuning the Controller within Matlab using Data Gathered at Coleg Sir Gar Graig Campus

Without tuning, the controller overshoots and oscillates until the response decays to a steady state. The tuning of the controller is aimed to eliminate overshoot and oscillations; therefore, the values have been set to produce a robust response (Figure 19). This changes the controller to PI control.

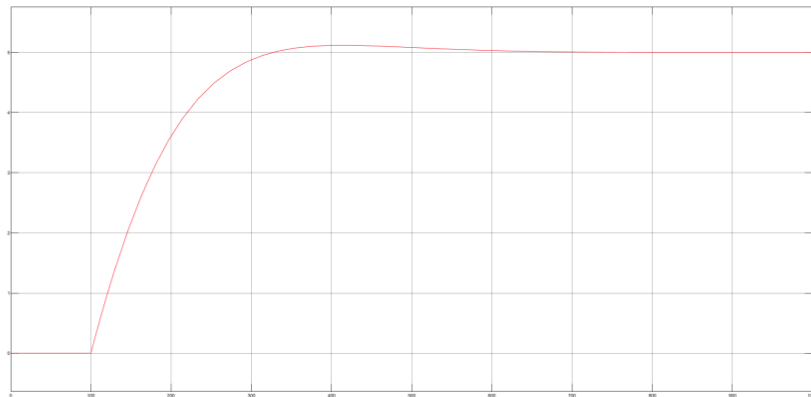


Figure 19 - A Robustly Tuned Controller's Response to a Step Change (Data Gathered at Coleg Sir Gar Graig Campus)

To provide further choice of the tuning of the controller, the ultimate sensitivity method was attempted. However, it became clear that the system did not have a fast enough response to oscillate by only using the proportional gain; therefore, the integral and derivative gain was set to 1 to achieve oscillations (Figures 20 and 21). Upon reflection, a different method of tuning should have been applied.

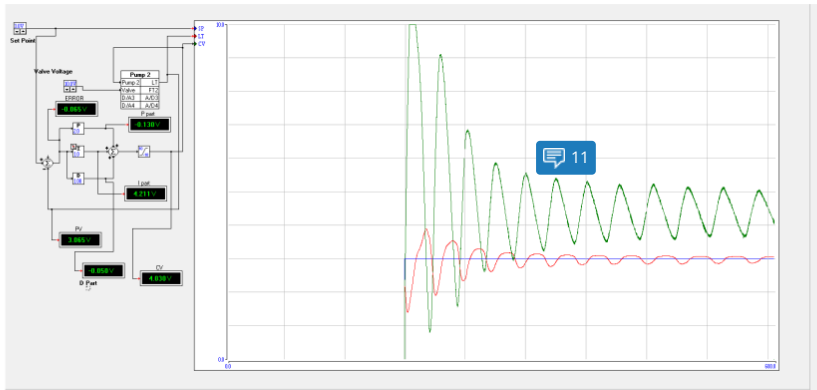


Figure 20 - Constant Oscillations within the CE117 System

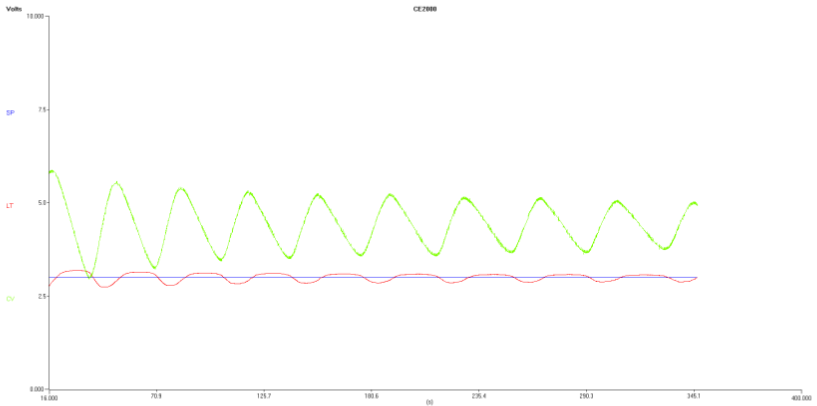


Figure 21 - Zoomed-in Oscillations of the CE117 System

By applying the set of equations found in the research of the ultimate sensitivity method, the proportional, integral and derivative values were calculated as follows:

The period of oscillations is measured to be 32.88s

$$K_p = 1.6(2) = 3.2$$

$$T_i = 0.5(32.88) = 16.44$$

$$K_i = \frac{1}{16.44} = 0.0608$$

$$T_d = 0.125(32.88) = 4.11$$

$$K_d = \frac{1}{4.11} = 0.2433$$

12

Where K_p is the proportional gain; T_i is the integral's time constant; T_d is the derivative's time constant; K_i is the integral gain; K_d is the derivative gain

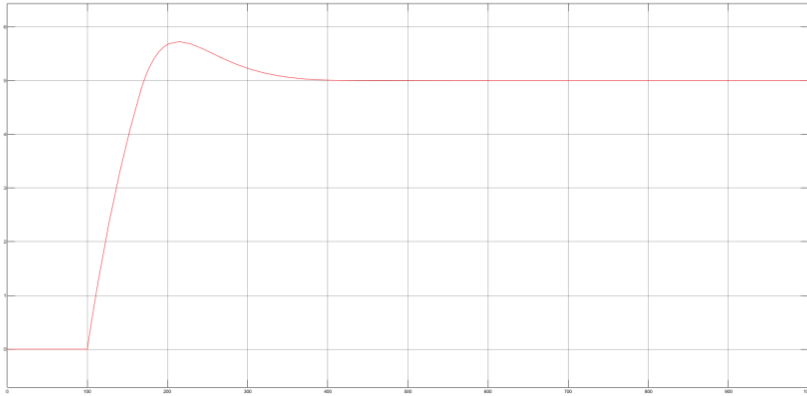


Figure 22 - Second Method's Tuned Response of the PID Controller to a Step Change

Compared with the first tuning method used, these values of the PID controller provide a quicker initial response, which causes an increase in overshoot.

13

Testing the Tuned Controllers on the Process Trainer

To test the performance of the controller, different disturbances were input into the system. The first disturbance was turning the system on: this required the tank to be filled to the level setpoint of 5.7V. Secondly, a disturbance of  14 change in the level setpoint to 6.2V was made. The third disturbance was to restrict the outflow valve of the tank. A fourth disturbance occurred when the outflow valve was returned to fully open, and a final disturbance of a restriction of the flow into the tank was conducted.

The autotuned controller was tested (Figure 23).

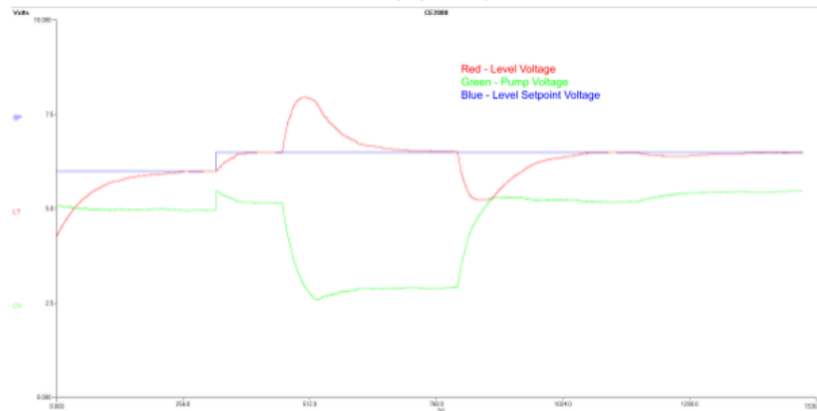


Figure 23 - Autotuned Controller's Response to Disturbances When Used On the CE117 Process Trainer (green line)

To have a set of data to compare to, the version of ultimate sensitivity tuning was tested (Figure 24).

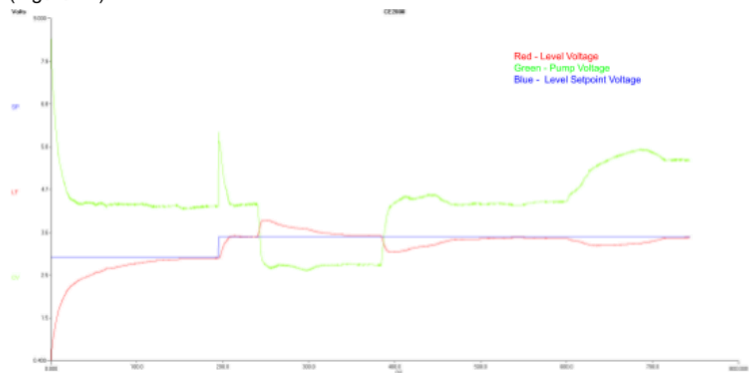


Figure 24 - Modified Ultimate Sensitivity Controller's Response to Disturbances When Used on the CE117 Process Trainer (green line)

The lower level setpoint voltage in the second tuning method has not affected the results enough to not be able to compare  15 two tuning methods. This is seen in the similar resting pump voltage to maintain the level.

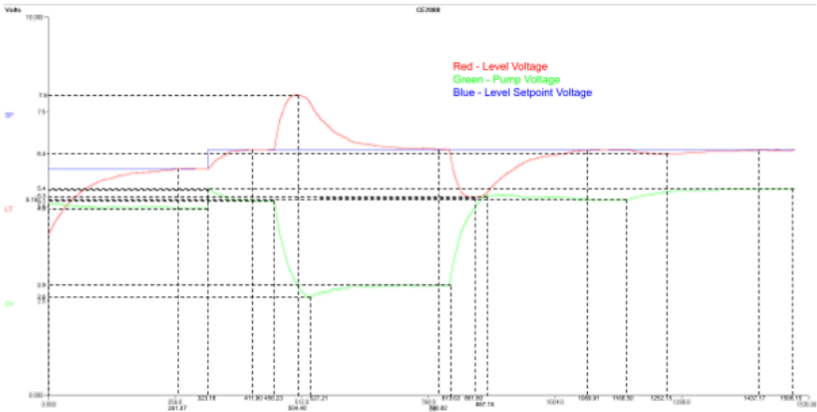


Figure 25 - Labelled Graph of Figure 23

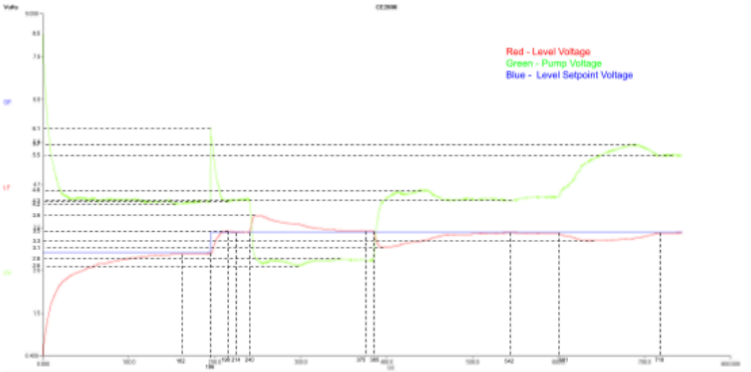


Figure 26 - Labelled Graph of Figure 24

The labelled graphs are used to create Table 5.

 16

Table 5 - Analysis of the Two Controller's Responses to Different Disturbances

Disturbance 1: Turning Rig on	Autotuned Controller	Adapted Ultimate Sensitivity Tuned Controller
Time to Settle	261s	162s
Peak Level	5.7V	3V
Peak Pump Voltage	5.1V	8.5V
Pump Voltage Range	0.2V	4.3V
Disturbance 2: Level Setpoint Step Change		
Time to Settle	88s	18s
Peak Level	6.2V	3.5V
Peak Pump Voltage	5.4V	6.1V
Pump Voltage Range	0.3V	1.8V
Disturbance 3: Outflow Valve Restriction		
Time to Settle	334s	135s
Peak Level	7.9V	3.9V
Level Deviation from SP	1.7V	0.4V
Lowest Pump Voltage	2.6V	2.6V
Pump Voltage Range	0.3V	0.2V
Disturbance 4: Returning Outflow Valve to Maximum		
Time to Settle	276s	157s
Lowest Level	5.3V	3.1V
Level Deviation from SP	0.9V	0.4V
Peak Pump Voltage	5.3V	4.6V
Pump Voltage Range	0.15V	0.3V

Disturbance 5: Inflow Valve Restriction		
Time to Settle	268s	117s
Lowest Level	6.4V	3.3V
Level Deviation from SP	0.2V	0.2V
Peak Pump Voltage	5.4V	5.7V
Pump Voltage Range	0V	0.2V

The readings from the graphs show how the different methods of tuning a PID controller interact with the tank process loop. If the pump's motor is low powered or the process loop is running constantly the robust autotuned control would be better suited to the task; the motor is driven without rapid changes or large peaks in speed. The slow draining and filling of the tank also supports this choice of tuning: there is no need for rapid reactions to changes in the level.

However, if there are too many disturbances while the process loop is running the second set of tuned parameters would be better suited to the application. In comparison to the first tuned controller, the second controller reacts much faster and achieves a steady state in much less time. This causes there to be less deviation from the level's setpoint. On the downside, this method drives the pump's motor erratically which could cause damage.



Conclusions

A tuning method cannot be expected to be applied to a system and function with the most efficiency if the characteristics of the system have not been investigated. Different tuning methods have different criteria that need to be met by the system if they are to function at their highest efficiency. In this case the ultimate tuning method cannot be used with this tank process loop. The level of the tank does not react fast enough to changes in flow to cause oscillations so the optimum gain cannot be found. This is why the second set of tuned parameters had to be found through a modified method.

Once suitable tuning methods are found for the system the hardware and day to day operation of the process loop can also be considered to ensure the best tuning method for the application is found. These external factors include how many hours the system will be working for; how robust the motors and other hardware is; the type of environment the system will be used in and the accuracy and precision required of the system.

For this system the robust autotuned controller is the better choice. This is due to the lower strains on the pump's motor; the low amount of disturbances the system will face and the slow reaction time of the tank's level to the disturbances.

Recommendations

The process reaction tuning method would have provided a fairer comparison than the altered ultimate sensitivity method. This method should be tested before arriving at a final set of tuned parameters.

More accurate measurements of the graphs could have been taken if the x and y axis scales had been less and the measurements were taken in the CE117 program.

While the process loop was running the pump's motor reached high temperatures. It would benefit the rig's operating life expectancy if the pump was cooled with a fan or the water, or a more powerful pump was installed.



Team Working

It was essential to work as a team during this exercise due to the amount of time required to conduct tests on the process loop. This ensured that everyone had the data required to analyse the performance of the system and the different tuning methods used. Working as a team helped while calibrating the level transmitter as it was much easier to read and record results while the process loop was running.

Working in a group also helped when trying the ultimate sensitivity method; the modifications made to the method were suggested while trying to understand why the method was not working.

Appendix A: User Guide Figures

Figure 1 - Level Calibration Method

Procedure 4 - Level Transducer Characteristic and Calibration

- 1) Create a blank results table similar to Table 6.
- 2) Start the CE2000 software and load file 'exp1-4.ict'. Make sure that the reservoir water level is correct.
- 3) Connect the CE117 Mimic Panel as shown in Figure 44. Analogue signals will pass from the ADA section to the valve and from level transmitter LT. The software will display the level rise in the process vessel.
- 4) Switch Pump 2 to 'Manual' control and set its control to minimum. Run the software and apply a full 10 V to the valve (fully open). Close the process loop bypass valve and the process vessel drain valve. Open the air vent valve.
- 5) Use the manual control of Pump 2 to slowly increase the level in the process vessel. At each 10 mm step, record the level transmitter reading (in volt). The reservoir slowly empties, so as the process vessel level reaches a level of around 180 mm, the reservoir low water level switch will operate and stop the pump.
- 6) Plot a chart of Level Transmitter Output on the vertical axis against the water level of the process vessel on the horizontal axis. Your curve is the characteristic of the level transmitter.

Note: The level transducer is calibrated by TecQuipment to give outputs of 10 V and 0 V (± 0.05 V) at the 180 mm and 0 mm levels on the process vessel. If it does not, your lecturer must re-calibrate the transducer.

Question

- Is the Level Transmitter characteristic linear?

Water Level inside the Process Vessel (mm)	Level Transmitter Output (V)
0	
10	
20	
30	
40	
50	
60	
70	
80	
90	
100	
110	
120	
130	
140	
150	
160	
170	
180	
190	
200	

Table 6 Blank Results Table for Experiment 1 Procedure 4

Figure 2 - Adjustment nuts of Span and Zero



(TechQuipment. 2008)

Citations

TecQuipment. (2008) CE117 Process Trainer User Guide.

Bolton, W. (2018) Mechatronics: Electronic Control Systems in Mechanical and Electrical Engineering. 7th edn. Llanelli: Pearson Education.

Franklin GF, Powell DJ & Emami-Naeini A. (2019) Feedback control of dynamic systems. 8th edn. Llanelli: Pearson Education.

Hang CC, Astrom KJ & Wang QG. (2002) Relay feedback auto-tuning of process controllers — a tutorial review, *Journal of Process Control*, 12(1), pp 143-162.

National Instruments (2024). PID Autotuning Technique. [online] LabVIEW User Manual. Available at:
<https://www.ni.com/docs/en-US/bundle/labview/page/pid-relay-autotuning-technique.html>
[Accessed 15 Oct. 2024].

Norberg, A. (1999) Kappa Tuning - Improved relay auto-tuning for PID controllers. Masters Thesis: Lund Institute of Technology, Lund, Sweden.

83/100

PAGE 1

PAGE 2

PAGE 3

PAGE 4



Comment 1

what is this called - process reaction curve



Comment 2

good summary

PAGE 5

PAGE 6

PAGE 7

PAGE 8

PAGE 9

PAGE 10



Comment 3

M or R? unclear

PAGE 11

PAGE 12



Comment 4

An excellent level of research which is focused and concise but to the point.

PAGE 13



Comment 5

potentiometer screw adjustment

PAGE 14



Comment 6

You have not calculated errors or given an observation of the amount of error and if it is acceptable.

PAGE 15



Comment 7

and gain

PAGE 16

PAGE 17



Comment 8

recommendation here?



Comment 9

these are big assumptions

PAGE 18



Comment 10

why 5V? or was it 0.5V as per the process reaction experiment?

PAGE 19

PAGE 20



Comment 11

a legend is needed with this chart

PAGE 21



Comment 12

Excellent work



Comment 13

A table to compare would be a good idea

PAGE 22



Comment 14

Turning it on should not be considered as one of the disturbances.

**Comment 15**

Why not use the same setpoint ?

**Comment 16**

Very good work, a shame the images are blurred.

**Comment 17**

A good and useful comparison.

**Comment 18**

Excellent set of recommendations

GRADING FORM: NEW CSG-RUBRIC

WILLIAM UTTING

83

1. ENGAGEMENT WITH LITERATURE

An extensive range of credible literature has been engaged with and benefits the report tremendously. The author uses key information and has used a high level of referencing skills. 16/20

16

2. KNOWLEDGE AND UNDERSTANDING



Excellent and detailed knowledge is demonstrated both in the instrumentation and control aspects of the report. Your application and understanding is well shown. 16/20

16

3. COGNITIVE AND INTELLECTUAL



Excellent critical evaluation and a high level of reasoned arguments for the most part, save a few unexplained assumptions. 17/20

17

4. PRACTICAL APPLICATION



Advanced level skills applied in the practical, in particular the control tuning. The errors for the calibration could have been included and referred to the subsequent tasks. 16/20

16

5. TRANSFERABLE SKILLS



Work is exceptionally coherent and professional. Presentation for the most part is excellent. 18/20

18