

Original mark agreed
66%
L Williams

1302736

by Jason Booth

Submission date: 08-Feb-2023 10:23PM (UTC+0000)

Submission ID: 196934013

File name: 19735_Jason_Booth_1302736_180901_401763361.pdf (1.4M)

Word count: 4870

Character count: 29182

Course: HND/BSc (Hons) Electrical and Electronic Engineering

Module: SGEE5009 Control Engineering

Assignment: Process Control Systems

Name: Jason Booth

University number: 1302736

Date submitted: 08/02/2023

Word count: 2745

Contents

Good Structure

1. Executive Summary	5
2. Work Plan for Life-long Learning.....	6
3. Research	7
3.1 Ziegler and Nichols	7
3.2 Model-based Method	8
3.3 Trial and Error Method	8
3.4 Cohen-Coon	8
3.5 Kappa-tau	9
3.6 Justification on tuning method for this assignment	10
4. Level Control of the Process Tank	11
4.1 Investigation into Instruments and Actuators	11
4.1.1 Capacitive Level Sensor	11
4.1.2 Flow Transmitter	11
4.1.3 Pump	11
4.1.4 Proportional Valve.....	11
4.2 P&ID Diagram, Control Block and Operation.....	11
4.3 Finding the Calibration Curve for the Level Transmitter.....	12
4.4 Time Constant & Gain Calculations.....	13
4.5 Measured Time constant and Gain of System through Experiment.....	14
4.6 Simulation.....	15
4.7 Implementation on the CE117 Process Trainer.....	15
5. Temperature Control of the Heater Tank.....	17
5.1 Investigation into Instruments and Actuators.....	17
5.1.1 RTD	17
5.1.2 Heat Exchanger	17
5.1.3 Cooling Fan	17
5.2 P&ID Diagram, Control Block and Operation.....	17
5.3 Time Constant & Gain Calculation and Measurements	18

5.4	Simulation.....	18
5.5	Implementation on the CE117 Process Trainer.....	19
6.	Conclusion and Recommendations.....	21
7.	Team Working	24
8.	Works Cited	25
9.	Appendix.....	27
9.1	CE117 Process Trainer.....	27
9.2	Level Sensor Calibration Curve Results.....	28
9.3	Tuned PID Simulation Response (Level Control)	29
9.4	TecQuipment CE2000 Software and Function Block (Temperature Control)	30
9.5	Measured Time Constant (Temperature Control)	31
9.6	Level Control Response on CE117 Process Trainer with Disturbances	32
9.7	Tuned PID Parameters (Level Control)	33
9.8	Tuned PID Simulation Response (Temperature Control)	34
9.9	Temperature Control Response on CE117 Process Trainer with Disturbances.....	35

Figure 1 - Process reaction curve.....	7
Figure 2 – Process Transfer Function with Kappa	9
Figure 3 – Nyquist Curve of a Process and the corresponding kappa.	10
Figure 4 – Control Block diagram	11
Figure 5 – Process Tank Level Control P&ID Diagram.....	12
Figure 6 - Function Block	13
Figure 7 - Transmitter Calibration Curve	13
Figure 8 – Parameters	13
Figure 9 – Measured Time Constant	14
Figure 10 – Matlab Control Block	15
Figure 11 – Tuned/Untuned Response	15
Figure 12 - Level Control Response with Disturbances	16
Figure 13 - Temperature Control P&ID diagram	17
Figure 14 - Control Block Diagram for Temperature Control System	18
Figure 15 – Rate of Change Table	18
Figure 16 - Temperature Control Matlab Model.....	19
Figure 17 – Tuned & Untuned Response	19
Figure 18 - Tuned PID Temp Control System.....	20
Figure 19 – Level Control Time Comparison Table	21
Figure 20 – PID Tuning Comparison (Level Control)	22
Figure 21 - PID Tuning Comparison (Temperature Control)	22

1. Executive Summary

Research was conducted in various methods of tuning PID loop parameters and comparison drawn between them and to justify the method used in this assignment. The instruments and actuators used on the CE117 process trainers ^{were} investigated and short explanations carried out. A P&ID diagram and control block was drawn up for both level control and temperature control and explanation of its operation. Using manual control, a calibration curve for the level transmitter was generated to determine the performance. By performing a step input to the level control and temperature control, results were measured between the change of the two, to calculate the gain and time constant. The time constant is compared with measured and calculated to prove theory. A model of the system is created on matlab to simulate the performance and gain tuned PID parameters to improve the response and compare against tuned and untuned PID values. Tuned PID values were implemented on the CE117 process trainer to analyse the response of the system when a setpoint is entered. The system was analysed how well it behaves to disturbances by overfilling the tank and draining the tank by manual valves for the level control. Temperature control, disturbances were created by switching the cooling fan on/off. Comparisons and conclusions were made of the experiments through graphs and tables by determining how well the system responds to these changes resulting in underdamped and critically damped responses.

A good summary but avoid letting it become a contents list

What were your conclusions?

2. Work Plan for Life-long Learning

Before undertaking practical experiments to satisfy tasks underlined in this assignment it is best to get an understanding of the topic, therefore extensive research ^{will be} is carried out to understand the different approaches and methods that can be implemented to obtain a tuned PID system for open-loop systems and closed loop systems. The researched tuning methods will be compared to see which methods are better for different applications. Technical analysis of experiments will be conducted and compared with theoretical results to back up the theory used, and conclusions drawn in a summarized format.

You could have said more

3. Research

3.1 Ziegler and Nichols

According to Dorf, Ziegler-Nichols tuning method is a more analytic method whereby the PID control gains are gathered by trial-and-error using step responses obtained via simulation, or through actual testing on the process. (2017, p. 481) *page numbers are only need for direct quotations*

Ziegler and Nichols consist of two PID tuning methods. The first method is based on closed-loop concepts requiring the computerization of the ultimate gain and ultimate period. The second method is based on open-loop concepts relying on reaction curves. (Dorf, 2017, p. 485) *page numbers are only need for direct quotations*

Ziegler and Nichols (1942, 1943) approach to tuning PID controllers is an extended and revised version of the Callender et al. (1936) by recognizing that the step responses of many process control systems exhibit a process reaction curve shown in figure 1 below which can be generated from a step response. (Franklin, 2019, p. 238)

The process reaction curve exhibits an S shape (figure 1) which is characteristic of many systems and is approximated by the step response of a plant with transfer function :

$$\frac{Y(s)}{U(s)} = \frac{Ae^{-st_d}}{\tau s + 1}$$

The above transfer function is for a first-order system with a time delay or “transportation lag” of t_d sec. The constants in the above equation are determined by applying a step response to the process. (Franklin, 2019, p. 238)

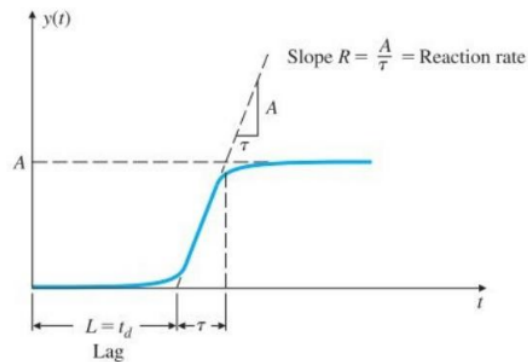


Figure 1 - Process reaction curve

According to Vishakha Vijay Patel, Ziegler Nichols are widely used in tuning PID controllers when plant dynamics are not known but can also be applied to plants where the dynamics are known. She states that, “Ziegler and Nichols proposed rules for determining values of

proportional gain K_p , integral time T_i , and derivative time T_d based on the transient response characteristic of a given plant.” (2020) *since this is a direct quote, page numbers are needed*

3.2 Model-based Method

IncaTools states that

if this is a direct quote, it should begin with ... states that .. and end with page numbers

According to IncaTools, “Model-based tuning or optimization-based PID tuning allows you to obtain your P, I, and D parameters optimally. Your control objectives (disturbance rejection and set point tracking) together with a model of your system and the engineering specifications of the closed loop behaviour determine the final set of tuning parameters.” (2020)

According to Inca

IncaTools says, using this method allows to work according to a structured tuning process that takes into consideration how the control engineer wants the process to behave and controls. They say that rule-based methods such as Ziegler-Nichols give reasonable results but are not able to give structured process and productions results as model-based PID tuning method. (2020)

3.3 Trial and Error Method

IPCOS states that

According to IPCOS, the “trial-and-error method is a heuristic tuning method that general rules are following to obtain approximate or qualitative results.” (2016) *page ?*

With knowledge of PID parameters, the trial-and-error method is relatively easy. It is often used after existing set of parameters are gained through rule-based tuning methods, then small tweaks can be implemented to improve the system response. (IPCOS, 2016)

quotes needed following ... states that

IPCOS states that when using this method for new PID loops, you must start with a rough and safe initial guess and must consider the PID terms and what they actually do to prevent a system going unstable. (2016)

According to Kuyvenhoven, “for an exceptionally responsive system the Trial-and-Error method is often used after the Ziegler-Nichols or Cohen-Coon so as to enhance the rough results of these two methods.” He states that the system will result in a finely tuned control system with the cooperation of these methods. (2002)

3.4 Cohen-Coon

According to OptiControls, “the Cohen-Coon tuning rules are second in popularity to the Ziegler-Nichols tuning rules. Cohen and Coon published their tuning method in 1953, 11 years after Ziegler and Nichols.” (2012)

This method of tuning PID controllers corrects the slow, steady-state response generated by Ziegler-Nichol’s method where there is a large dead time relative to the open-loop time constant. To make this method practical, a large process delay is necessary otherwise large gains will be predicted. (Bennett, 2022)

According to Bennet, Cohen-Coon method can only be used on first order systems with time delay because the controller doesn't respond instantaneous to disturbances from step inputs. (2022)

Bennett states that, "The Cohen-Coon method is classified as an 'offline' method for tuning, meaning that a step change can be introduced to the input once it is at steady-state. Then the output can be measured based on the time constant and the time delay and this response can be used to evaluate the initial control parameters." (2022)

According to Smuts, Cohen-Coon method achieves a quarter-amplitude damping response. This type of damping provides fast disturbance rejection but tends to be very oscillatory, also frequency interacts with similarly tuned loops. This damping-type tuning leaves the loop vulnerable to going unstable if the process gains or dead time doubles in value. This is prevented by reducing the controller gain by half which will prevent the loop from oscillating and provide an acceptable stability margin. (2011)

3.5 Kappa-tau

According to IPCOS, this method is in improvement of the Ziegler-Nichols method with design to counteract the high proportional gains and rules that provide poor results for systems with long normalized dead time. (2016)

A transfer function $G_p(s)$, kappa is a process parameter which is a gain ratio and is defined in figure 2 below. (Norberg, 1999)

$$\kappa = \left| \frac{G_p(i\omega_u)}{G_p(0)} \right| = \frac{1}{K_p K_u}$$

Figure 2 – Process Transfer Function with Kappa

Norberg says that kappa indicates the difficulty to control the process, and a kappa value closer to 1 means a more difficult process to control. A way to see this is by adding dead time to the process, making it harder to control, which will widen the Nyquist curve towards a circle, and kappa will increase, as seen in figure 3 below. (1999)

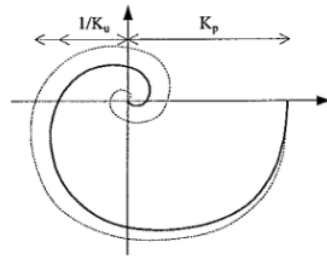


Figure 3 – Nyquist Curve of a Process and the corresponding kappa.

Ziegler-Nichol's type of tuning is used, and kappa is used as an additional tuning parameter. This method is based on constrained optimisation, where load-disturbance rejection is optimised with constraints on robustness/stability margin. (Norberg, 1999) Correctly cited

3.6 Justification on tuning method for this assignment

Cohen-coon and the model-based approach are both used to determine the PID parameters. Cohen-coon involves applying a step-input when it's at steady-state and measuring the time constant and time delay to evaluate initial control parameters. This can be used to build a model on matlab. This approach takes longer to achieve, however the outcome in the end will be vastly superior as the tuning parameters are automatically determined through simulation and responses can be analysed through testing to determine the response whether being unstable, stable, overdamped, underdamped, critically damped, before being implementing on real-life system, making it safer. Good conclusions

4. Level Control of the Process Tank

4.1 Investigation into Instruments and Actuators

4.1.1 Capacitive Level Sensor

Capacitive level sensors are used for wide variety of solids, liquids and slurries. It works on the same principle as a capacitor. Measurement is made by applying high radio frequency signal to the capacitive level probe. The probe forms one plate of the capacitor and the vessel wall forms the other plate of the capacitor. The high radio frequency signal applied to the probe produces a current flow through the dielectric process material in the vessel from the metal probe to the vessel wall. When the level in the tank drops, the dielectric constant drops causing a drop in the capacitance reading and minute drop in current flow and in the case of a continuous measurement the 4-20mA signal will change. (Instrumentation Tools, 2015) Correctly cited

4.1.2 Flow Transmitter

RS Components state that "....." (2023, page ?)

According to RS Components, "The water passes a free running turbine in a specially shaped chamber. The rate of rotation of the turbine is proportional to flow rate and the number of revolutions is proportional to the total amount of liquid passed. The passage of each turbine blade cuts a powerful beam of infra-red light, this blocking is detected electronically." (2023)

4.1.3 Pump

Used to raise the water level in the vessel by transferring the water to the vessel. Does this by drawing water into the pump by suction through an inlet point. The inlet point has a lower rate of pressure than the outlet points. It increases the rate of water to create a vacuum. The outlet point has a high-pressure level which forces out the water. (RS Components, 2023)

4.1.4 Proportional Valve

Uses 0-10 volts to control and adjust the flow rate from 0 to 100%. (RS Components, 2023)

4.2 P&ID Diagram, Control Block and Operation

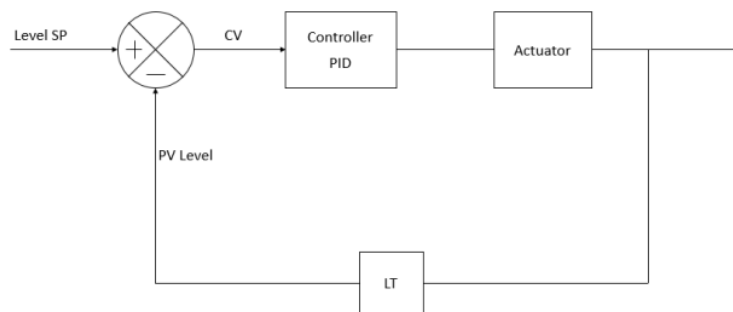


Figure 4 – Control Block diagram

The setpoint is entered by the operator which goes into the positive side of a summing junction and a level transmitter to provide negative feedback. The summing junction calculates the difference between these two inputs called the error and sends a control variable to the PID controller which outputs to the actuators to perform level control. Figure 4 above is a closed-loop control system by introduction of negative feedback.

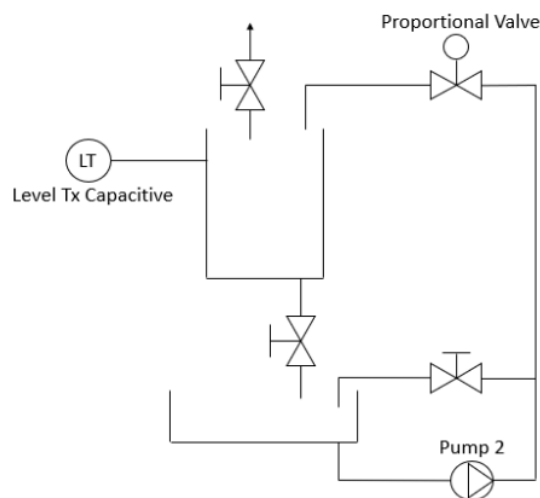


Figure 5 – Process Tank Level Control P&ID Diagram

The liquid in the reservoir is transferred to the vessel by pump 2 which is controlled via the controller using PWM to allow increased/decreased flowrate. The proportional valve is an analogue output that restricts or allows more flow of liquid into the vessel which is controlled via the controller. A manual bypass valve is situated on the leg between pump 2 and proportional valve to return the water being pumped back into the reservoir. A manual valve is situated at the bottom of the vessel to drain the vessel empty. A level transmitter is used inside the vessel to detect the level of liquid and to provide feedback to the controller to allow automatic level control. The level transmitter, proportional valve and pump 2 work together with the controller to provide automatic level control.

4.3 Finding the Calibration Curve for the Level Transmitter

Using manual control, the water level is increased to 180 millimetres in stages of 10 millimetres measuring the output voltage from the level transmitter. Image of the CE117 Process Trainer can be seen in appendix 9.1 The software uses a special function block as shown in figure 6 below.

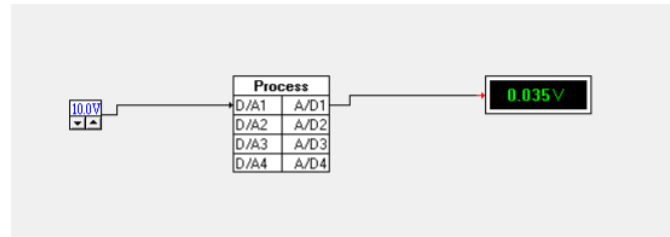


Figure 6 - Function Block

The results are tabulated and can be seen in appendix 9.2. The results are used to generate a calibration curve which can be seen in figure 7 below.

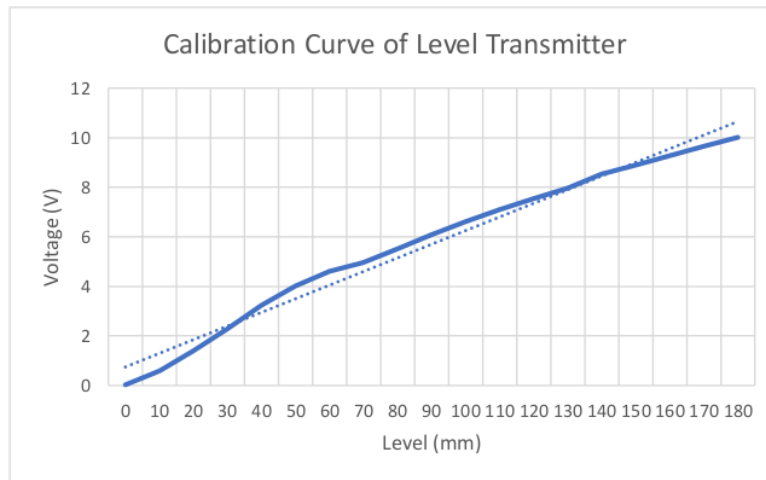


Figure 7 - Transmitter Calibration Curve

4.4 Time Constant & Gain Calculations

Automatic control was switched on and water filled the tank to just above the heating element inside the tank. A step input of 0.5V was applied to the pump to increase the level to 149mm. Voltage of the pump, transmitter, flow along with level and flow rate can be seen in figure 8 below.

	V_P	V_L	V_F	h level (m)	q flow rate m^3/sec
A	5.3	7.525	4.16	0.118	69.33×10^{-6}
B	5.8	8.91	4.41	0.149	73.5×10^{-6}

Figure 8 – Parameters

The rate of change R is calculated by:

$$\Delta h = 0.149 - 0.118 = 0.031$$

$$\Delta q = 73.5 * 10^{-6} - 69.33 * 10^{-6} = 4.17 * 10^{-6}$$

$$R = \frac{\Delta h}{\Delta q} = \frac{0.031}{4.17 * 10^{-6}} = 7434.1$$

To calculate time constant, the area of the vessel is needed. This is calculated by:

$$A = \pi r^2$$

The radius of the tank is 0.075m.

$$A = \pi * 0.075^2 = 0.01767m^3$$

Time constant is calculated by:

$$\tau = Area * R$$

$$\tau = 0.01767 * 7434.1$$

$$\tau = 131.361 \text{ seconds}$$

The gain is calculated by:

$$K = \frac{\Delta V_L}{\Delta V_P} = \frac{1.385}{0.5} = 2.77$$

4.5 Measured Time constant and Gain of System through Experiment

A step input was applied to the system to generate the open-loop response as seen in figure 9 below.

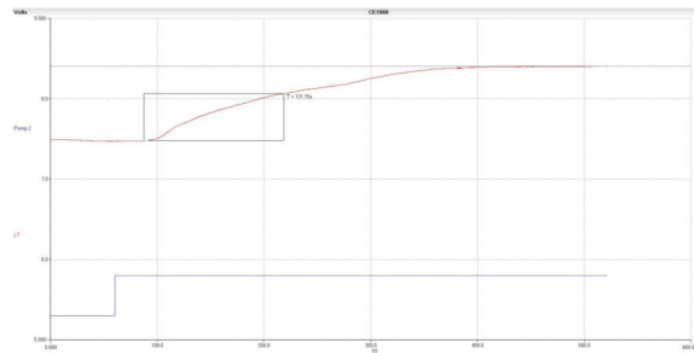


Figure 9 – Measured Time Constant

Analysing the response, the time constant measures at 131.15 seconds, giving an error of 211ms between measured and calculated.

4.6 Simulation

A control block was created in MultiSim as seen in figure 10.

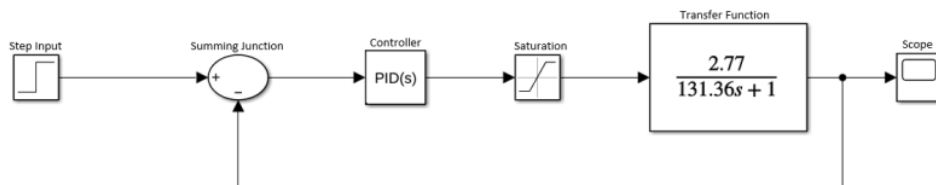


Figure 10 – Matlab Control Block

The response generated is seen in figure 11 below represented by the dashed line, and the tuned response by the solid blue line. A close-up view can be seen in appendix 9.3.

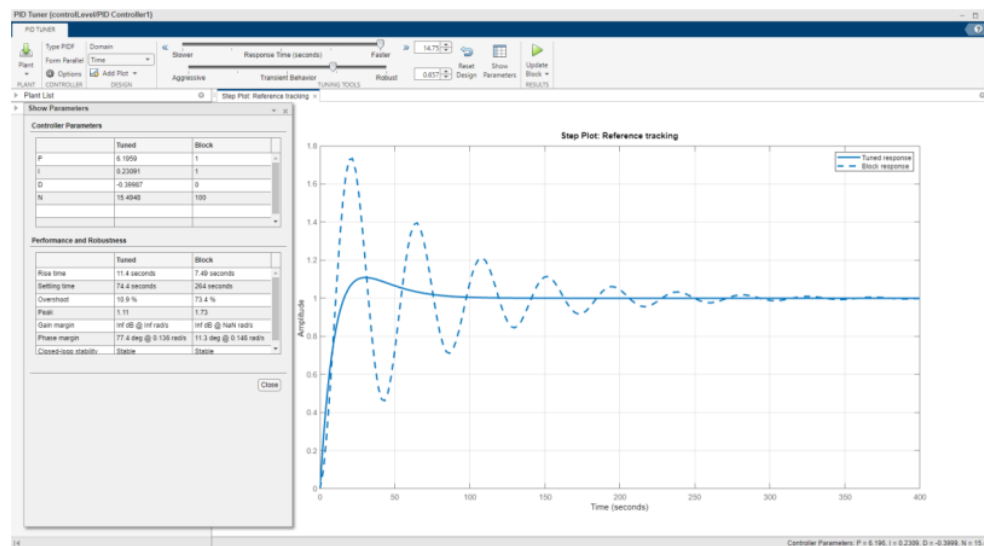


Figure 11 – Tuned/Untuned Response

4.7 Implementation on the CE117 Process Trainer

The tuned PID parameters were entered on the CE117 process trainer. A setpoint was selected and disturbances applied to the system. The response can be seen in figure 12 below. A larger image can be seen in appendix 9.6.

What were your tuned values of K_p, K_i and K_d?

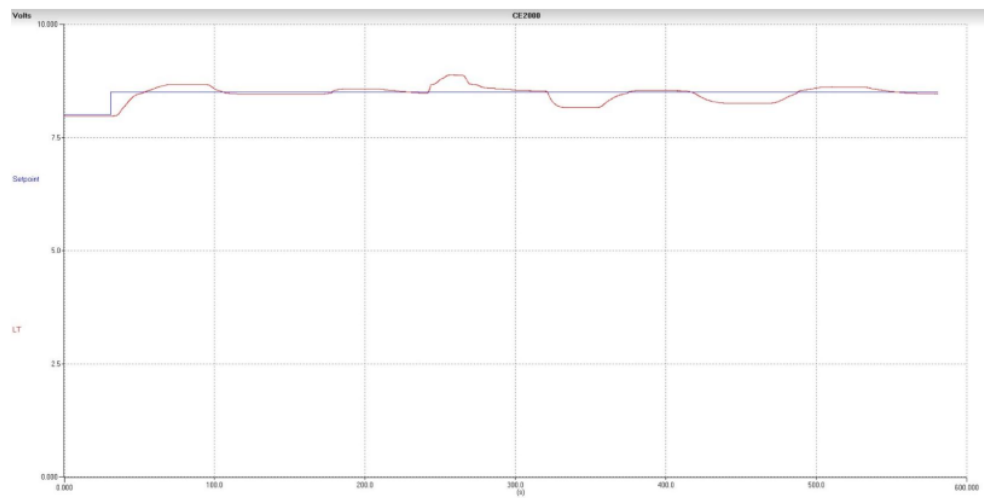


Figure 12 - Level Control Response with Disturbances

Each disturbance needs to be explained.

5. Temperature Control of the Heater Tank

5.1 Investigation into Instruments and Actuators

5.1.1 RTD

Resistance temperature detectors are used in the process to measure and monitor the temperature in the vessel. They are also known as PT100 due to the material platinum being used at the tip of the device which gives a resistance value of 100Ω at 0°C . As the temperature increases so does the resistance in a linear formation.

5.1.2 Heat Exchanger

An electric current is passed through a series of wires inside the exchanger by excitation. As current passes it generates heat. A PWM control signal is used to vary the on-off time to control the temperature.

5.1.3 Cooling Fan

A cooling fan is used to cool the system, it does this by attaching propellers to a DC motor shaft to suck air in and blow out. The motor is controlled similar to the heat exchanger using PWM control.

5.2 P&ID Diagram, Control Block and Operation

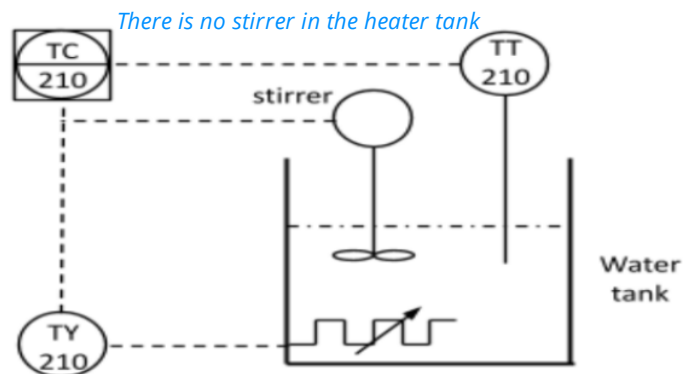


Figure 13 - Temperature Control P&ID diagram

Water is heated inside the heater tank by the electric heater and pump 1 sends the water through the heat exchanger and circulates back to the heat exchanger. TT 210 senses the water temperature inside the tank and provides negative feedback to the summing junction seen in figure 14. The error is calculated between SP and PV and sends CV to the PID controller to control the heat by PWM signal to the electric heater.

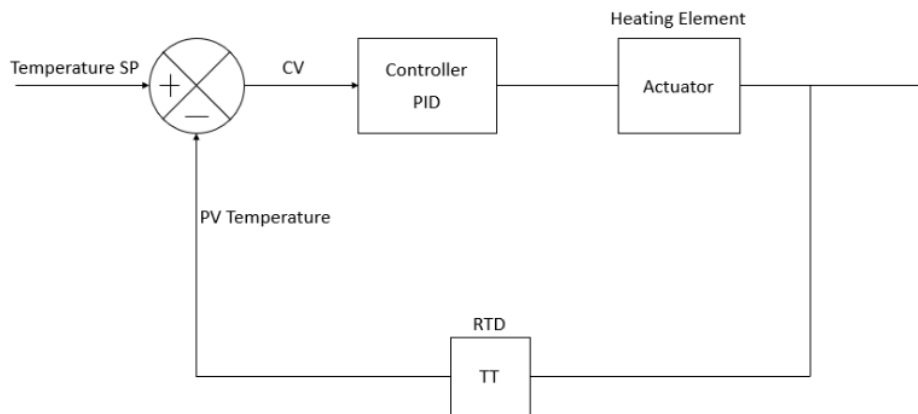


Figure 14 - Control Block Diagram for Temperature Control System

5.3 Time Constant & Gain Calculation and Measurements

Automatic level control was switched on to maintain water level above the element. Heating control was switched on using the TecQuipment CE2000 equipment and software seen in appendix 9.4. Point A in the table below results the ambient temperature of the water. Point B the heater voltage is doubled, and the temperature transmitter measures 3.185 volts as seen below.

	Vh Heater Voltage (V)	Vt Temperature Voltage (V)
A	3	2.73
B	6	3.185

Figure 15 – Rate of Change Table

The gain was calculated by:

$$K = \frac{\Delta V_T}{\Delta V_H} = \frac{3.185 - 2.73}{6 - 3} = 0.15167$$

From the experiment, the time constant was measured at 578.92 seconds by analysing the response of the system which can be seen in appendix 9.5.

5.4 Simulation

A model based on the results was created on matlab seen in figure 16 below.

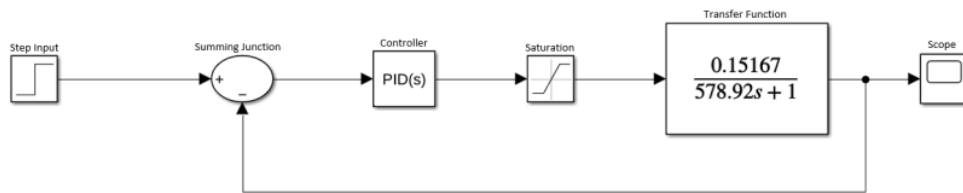


Figure 16 - Temperature Control Matlab Model

The response generated is seen in figure 17 below represented by the dashed line, and the tuned response by the solid blue line.

What were your tuned values of Kp, Ki, Kd?

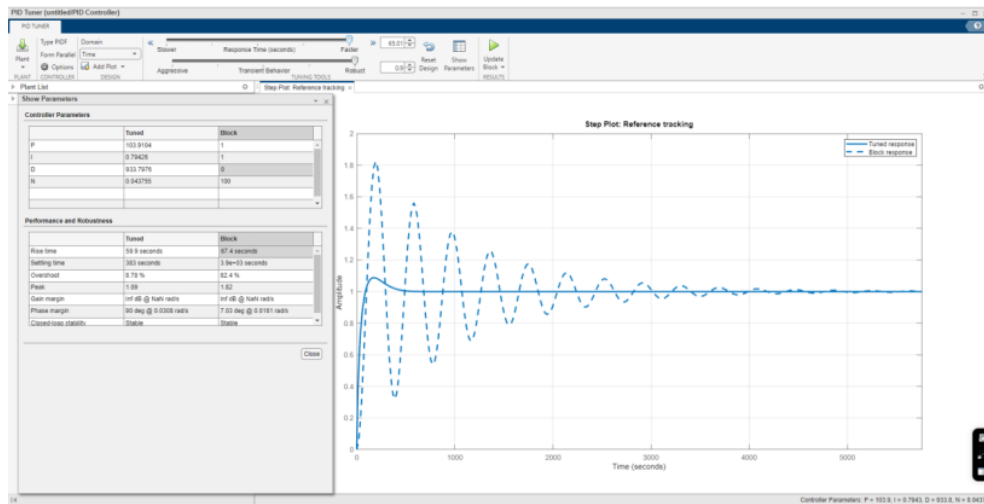


Figure 17 – Tuned & Untuned Response

5.5 Implementation on the CE117 Process Trainer

The generated PID values through simulation was implemented on the CE117 Process Trainer.

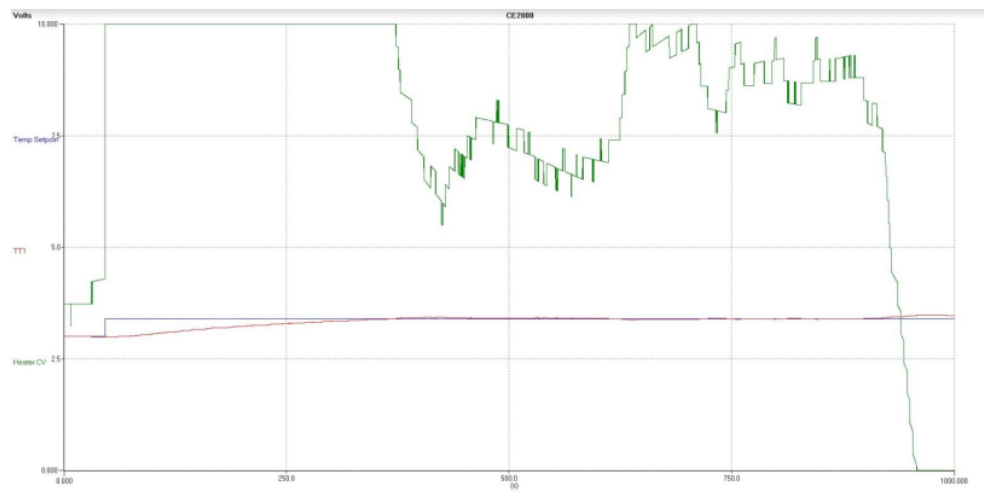


Figure 18 - Tuned PID Temp Control System

Analysing figure 18 above, a setpoint was entered and the temperature of the water rises until it meets temp setpoint. Disturbances are added to analyse the reaction performance.

Explain the disturbances

6. Conclusion and Recommendations

Ziegler-Nichols is found to be the most researched and used method in tuning PID loops parameters. Many other rule-based methods are simply modified versions of the Ziegler-Nichols method to overcome the steady-state response given by the Ziegler-Nichols method when there is a large dead time (process delay) relative to the open loop time constant. A model-based approach is superior as the system response can be predicted through simulations before implementing making it safer.

Level Control

Analysing the table below for the level control system, the time constant is near identical between calculated and measured, giving a minuscule error of 0.211, which can probably be reduced by rounding less figures in the calculation.

Time Constant Comparison			
	Calculated	Measured	Error
Time Constant (s)	131.361	131.15	0.211

Figure 19 – Level Control Time Comparison Table

This proves the calculations and theory to be 100% correct, accurate and reliable to implement similar procedures in other first order systems. The gain of the system is measured by the change of level voltage and pump voltage, which was needed to create a model for simulation, without knowing this a model could not be created.

Analysing figure 11, the matlab model of the system with initial PID parameters set to default (1,1,0) resulted in an underdamped response with many oscillations that didn't settle until 264 seconds, which if implemented would create an imprecise system and take extremely long to reach setpoint and very unreliable to disturbances.

PID Tuning Comparison			
	Tuned	Untuned	Difference
Rise Time (s)	7.49	11.4	-3.91
Settling Time (s)	74.4	264	-189.6
Overshoot (%)	10.9	73.4	-62.5
Peak	1.11	1.73	-0.62
Closed-loop Stability	Stable	Stable	

Figure 20 – PID Tuning Comparison (Level Control)

Analysing the table above, the tuned parameters achieve a far better response and is superior in every possible aspect. The settling time is now only 74.4 seconds, reducing the time by 189.6 seconds. Also, the overshoot is reduced by 62.5% to only 10.9%, eliminating the oscillations which can be seen in appendix 9.3.

Figure 12, the level does not take long to reach the setpoint and maintain level around the setpoint. Adding disturbances such as increasing water in the tank and draining it with manual valves, which can be seen by the spikes and drops of the red line, the system reacts sharply to reach the setpoint with very slight overshoot. This results in a robust system that is tuned excellently and behaves well to disturbances.

Heat Control

Applying a step input to the temperature control system is needed to measure the change between ambient temperature (A) and setpoint (B) as seen in figure 15, which is needed to calculate the gain. The measured time constant was found to be 578.92. As said previously, these parameters were crucial in building a model on matlab for simulation purposes.

Analysing the graph on figure 17, with PID set to default (1,1,0), the system resulted an underdamped response with many oscillations and taking even longer to settle than level control.

PID Tuning Comparison			
	Tuned	Untuned	Difference
Rise Time (s)	59.9	67.4	-7.5
Settling Time (s)	383	3900	-3517
Overshoot (%)	8.78	82.4	73.62
Peak	1.09	1.82	-0.73
Closed-loop Stability	Stable	Stable	

Figure 21 - PID Tuning Comparison (Temperature Control)

Were there stars involved?

Table above, the difference between untuned and tuned is astronomical. Settling time is reduced by 3517 seconds and overshoot by 73.62%. Therefore, it can be said that with tuned PID values the system response is far more precise and reliable than untuned – which if implemented on the CE117 process trainer, would take forever to reach the setpoint and would make the system unreliable to disturbances. Looking at appendix 9.8, the tuned response has

zero oscillations with minimal overshoot which is expected from the table above and results in a critically damped response.

This explanation should also have been given earlier

Analysing the response on appendix 9.9, the temperature reaches the setpoint at roughly 350 seconds. At this point the heater voltage is adjusted by the controller to maintain the temperature at the setpoint. At approximately 625 seconds, a disturbance is applied by the cooling fan which causes the temperature to drop but the system responds sharply by adjusting heater voltage to maximum. At 900 seconds, the cooling fan is switched off and the temperature rises, but the system counteracts this by removing voltage to the heater. This results in a robust system that is tuned excellently and behaves well to disturbances.

The untuned values are based on initial tuned value from Matlab and can't be used for comparison. You should instead have explained why the model based method is preferred over other approaches.

You could have tried some guessed values and plotted the responses in Matlab and compared with the tuned ones.

7. Team Working

Working part of a team was vital in carrying out the experiments in a smooth, accurate and timely manner. If this had not been done, then then the experiments would have taken much longer than anticipated as many measurements had to be taken from various instruments and actuators. Teamwork reduces the chances of making mistakes as these can be easily spotted by other members. Each team member had a vital role to play in the group, as they were each given specific tasks to do such as recording values, open/closing valves to allow more flow, increasing voltage to certain actuators, etc.

How did you treat each other?

8. Works Cited

Beall, J., 2016. *Loop tuning basics: Complex process responses*. [Online]

Available at: <https://www.isa.org/intech-home/2016/september-october/features/loop-tuning-basics-complex-process-responses>

[Accessed 05 02 2023].

Bennett, J., 2022. *PID Tuning via Classical Methods*. [Online]

Available at:

[https://eng.libretexts.org/Bookshelves/Industrial and Systems Engineering/Book%3A Chemical Process Dynamics and Controls \(Woolf\)/09%3A Proportional-Integral-Derivative \(PID\) Control/9.03%3A PID Tuning via Classical Methods](https://eng.libretexts.org/Bookshelves/Industrial_and_Systems_Engineering/Book%3A_Chemical_Process_Dynamics_and_Controls_(Woolf)/09%3A_Proportional-Integral-Derivative_(PID)_Control/9.03%3A_PID_Tuning_via_Classical_Methods)

[Accessed 10 11 2022].

Dorf, R. C., 2017. *Modern control systems*. 13th ed. Essex: Pearson Education.

Franklin, G. F., 2019. *Feedback Control of Dynamic Systems*. 8th ed. New York: Pearson Education.

incatools, 2020. *Explore the 3 PID tuning methods*. [Online]

Available at: <https://www.incatools.com/pid-tuning/pid-tuning-methods/#:~:text=Achieving%20optimal%20performance%20entails%20selecting,%2C%20and%20model%2Dbased%20tuning.>

[Accessed 10 11 2022].

Instrumentation Tools, 2015. *Capacitance Level Measurement Working Principle*. [Online]

Available at: <https://instrumentationtools.com/capacitance-level-measurement-working-principle/>

[Accessed 04 02 2022].

IPCOS, 2016. *The Guide to PID tuning*. [Online]

Available at:

<https://f.hubspotusercontent10.net/hubfs/7060164/Offers/Ebook/The%20guide%20to%20PID%20tuning.pdf>

[Accessed 05 02 2023].

Johnson, M. A. & Moradi, M. H., 2005. *PID Control New Identifications and Design Methods*. 1st ed. Glasgow: Springer.

Kuyvenhoven, N., 2002. *PID Tuning MethodsAn Automatic PID Tuning Study with MathCad*. [Online]

Available at: <https://docplayer.net/29945248-Pid-tuning-methods-an-automatic-pid-tuning->

[study-with-mathcad.html](#)

[Accessed 05 02 2023].

Norberg, A., 1999. *Kappa Tuning-Improved relay auto-tuning for PID controllers*. [Online]

Available at:

<https://lup.lub.lu.se/luur/download?func=downloadFile&recordId=8848459&fileId=8859538>

[Accessed 04 02 2023].

OptiControls, 2012. *Cohen-Coon Tuning Rules*. [Online]

Available at: <https://blog.opticontrols.com/archives/383>

[Accessed 05 02 2013].

Patel, V. V., 2020. *Ziegler–Nichols Tuning Method - Understanding the PID Controller*, s.l.: Resonance.

RS Components, 2023. *RS PRO Radial Flow Turbine Flow Meter for Liquid, 1.5 L/min Min, 30 L/min Max*. [Online]

Available at: <https://au.rs-online.com/web/p/flow-sensors/0257133>

[Accessed 03 02 2023].

Smuts, J., 2011. *Process Control for Practitioners*. [Online]

Available at: <https://blog.opticontrols.com/archives/383>

[Accessed 05 02 2023].

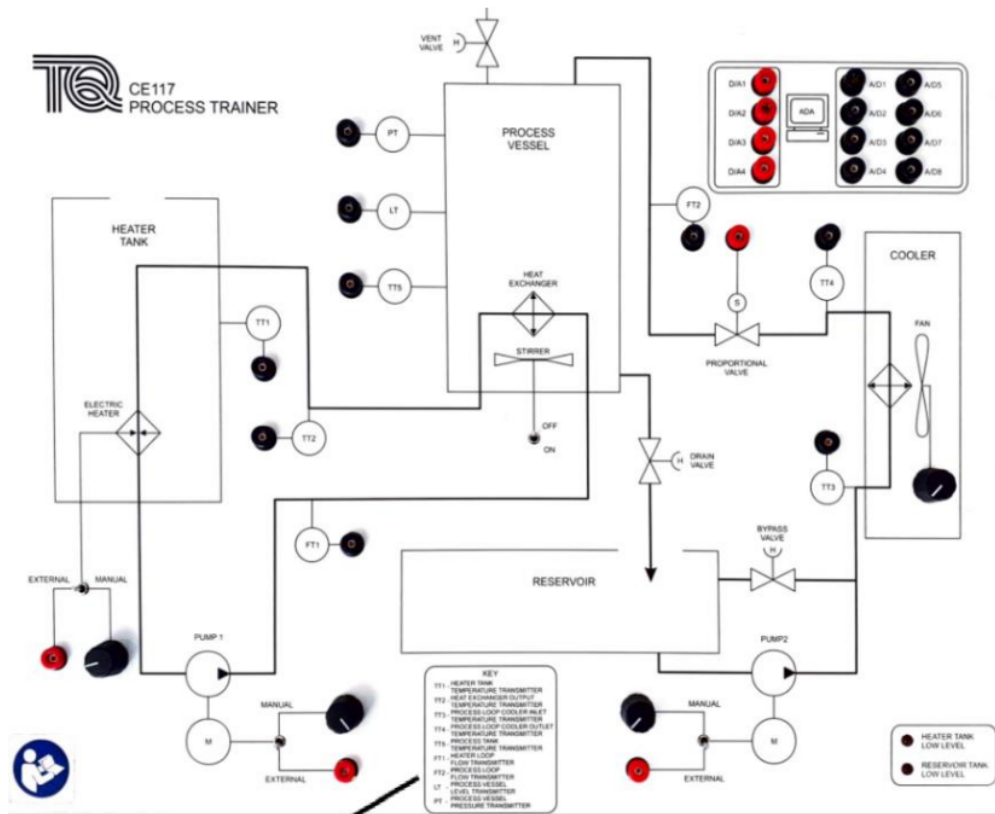
Vandoren, V., 2013. *Fundamentals of lambda tuning*. [Online]

Available at: <https://www.controleng.com/articles/fundamentals-of-lambda-tuning/>

[Accessed 05 02 2023].

9. Appendix

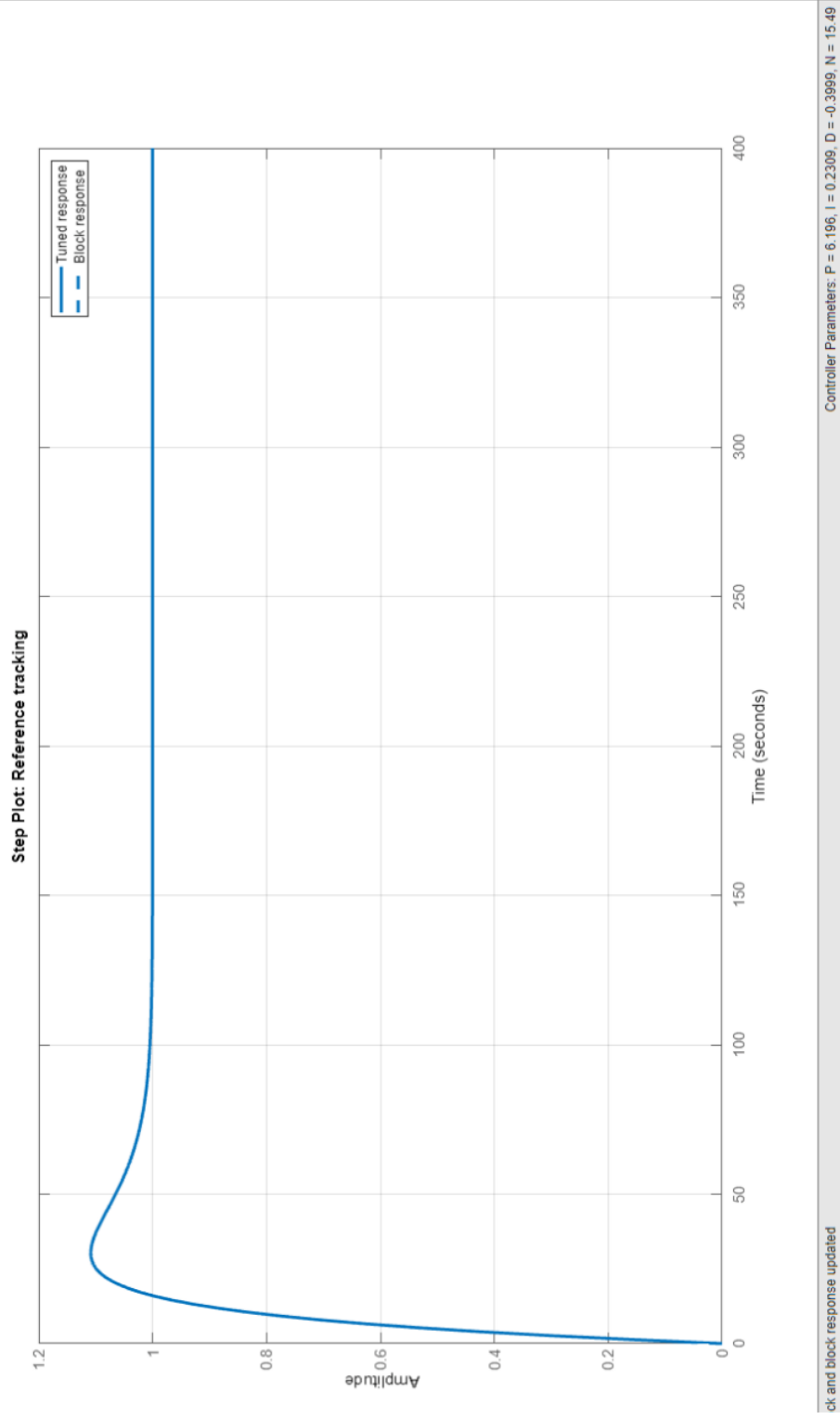
9.1 CE117 Process Trainer



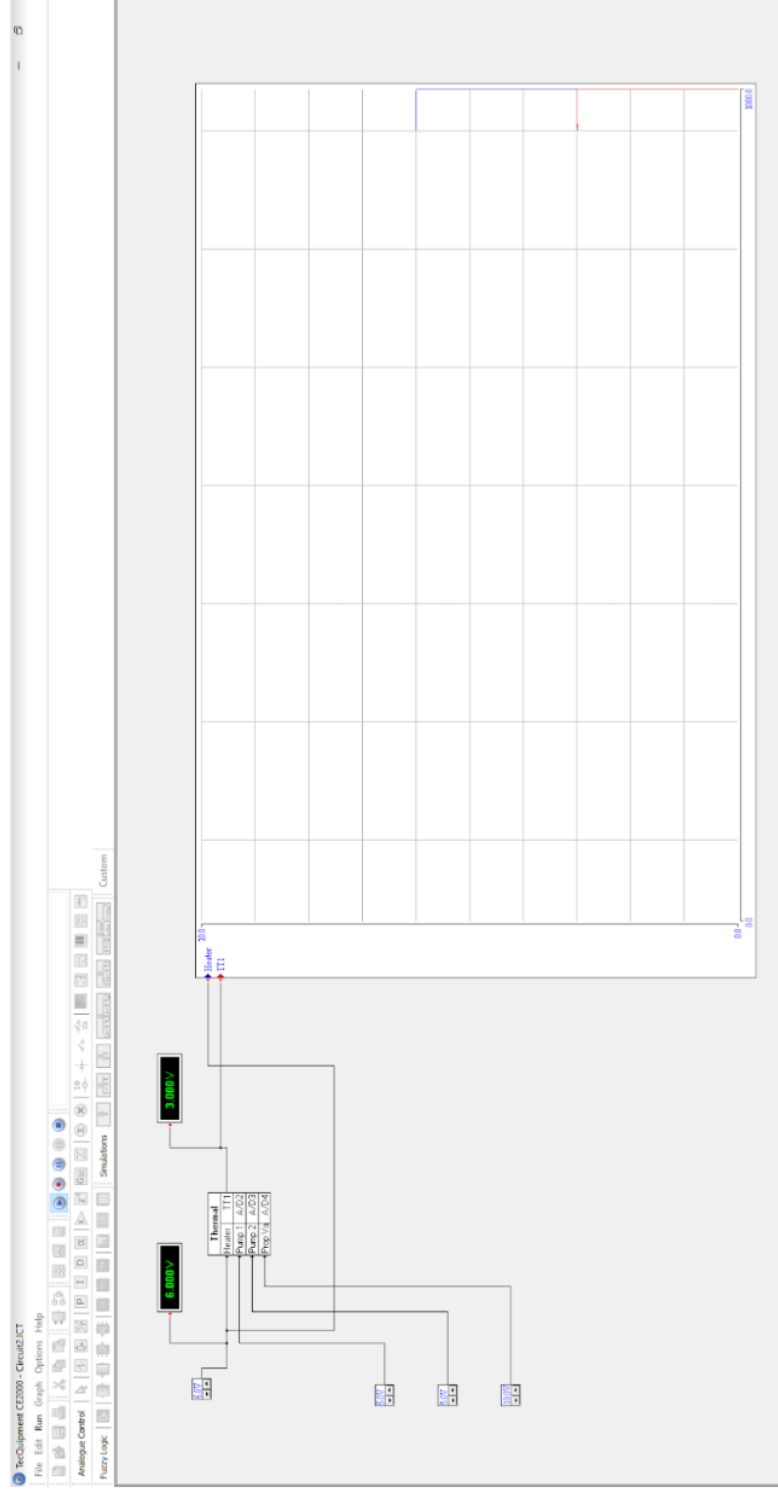
9.2 Level Sensor Calibration Curve Results

Water Level inside the Process Vessel (mm)	Level Transmitter Output (V)
0	0.03
10	0.6
20	1.39
30	2.285
40	3.23
50	4.025
60	4.61
70	4.965
80	5.51
90	6.085
100	6.62
110	7.095
120	7.54
130	7.975
140	8.54
150	8.89
160	9.285
170	9.655
180	10.015

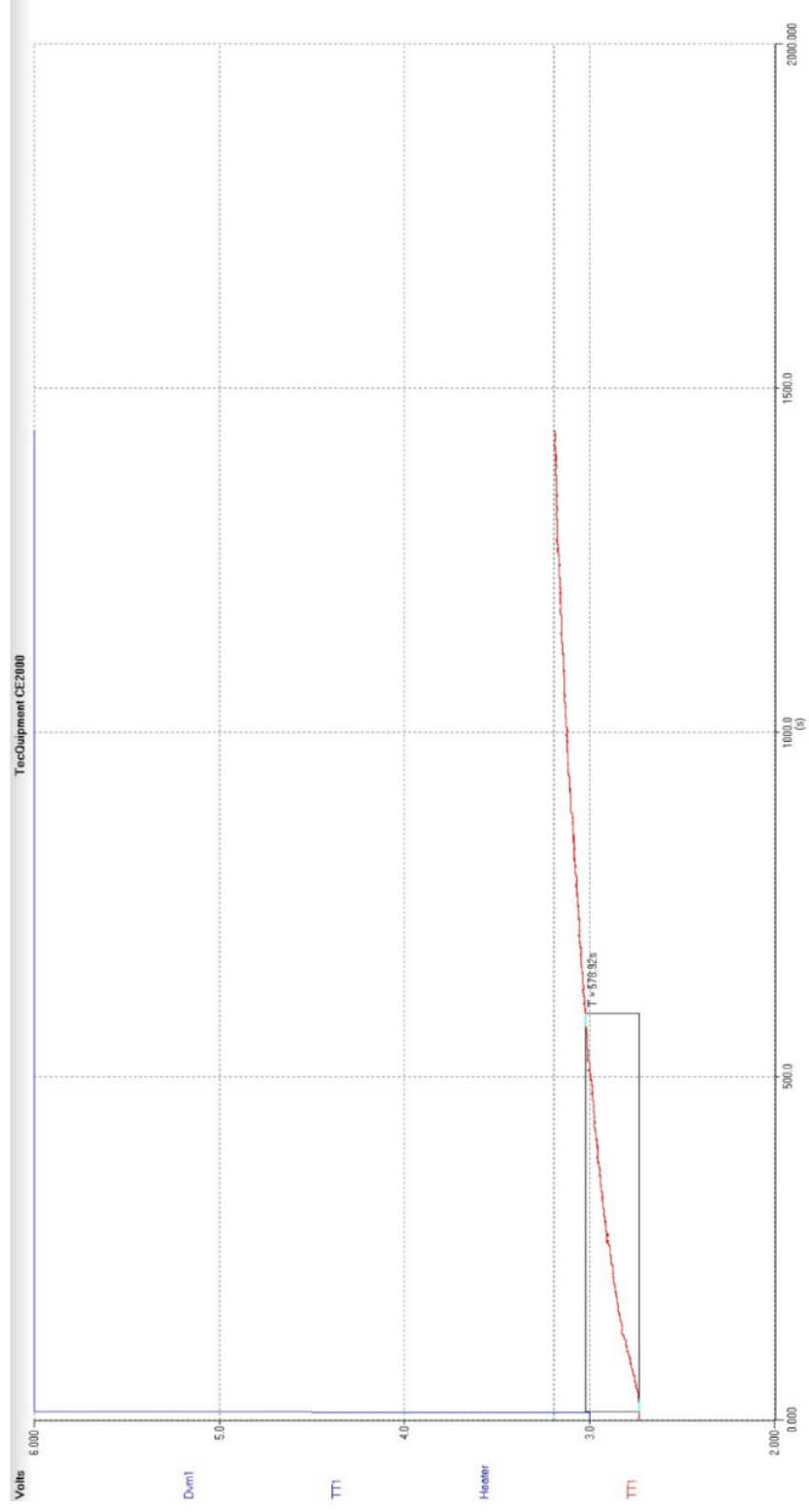
9.3 Tuned PID Simulation Response (Level Control)



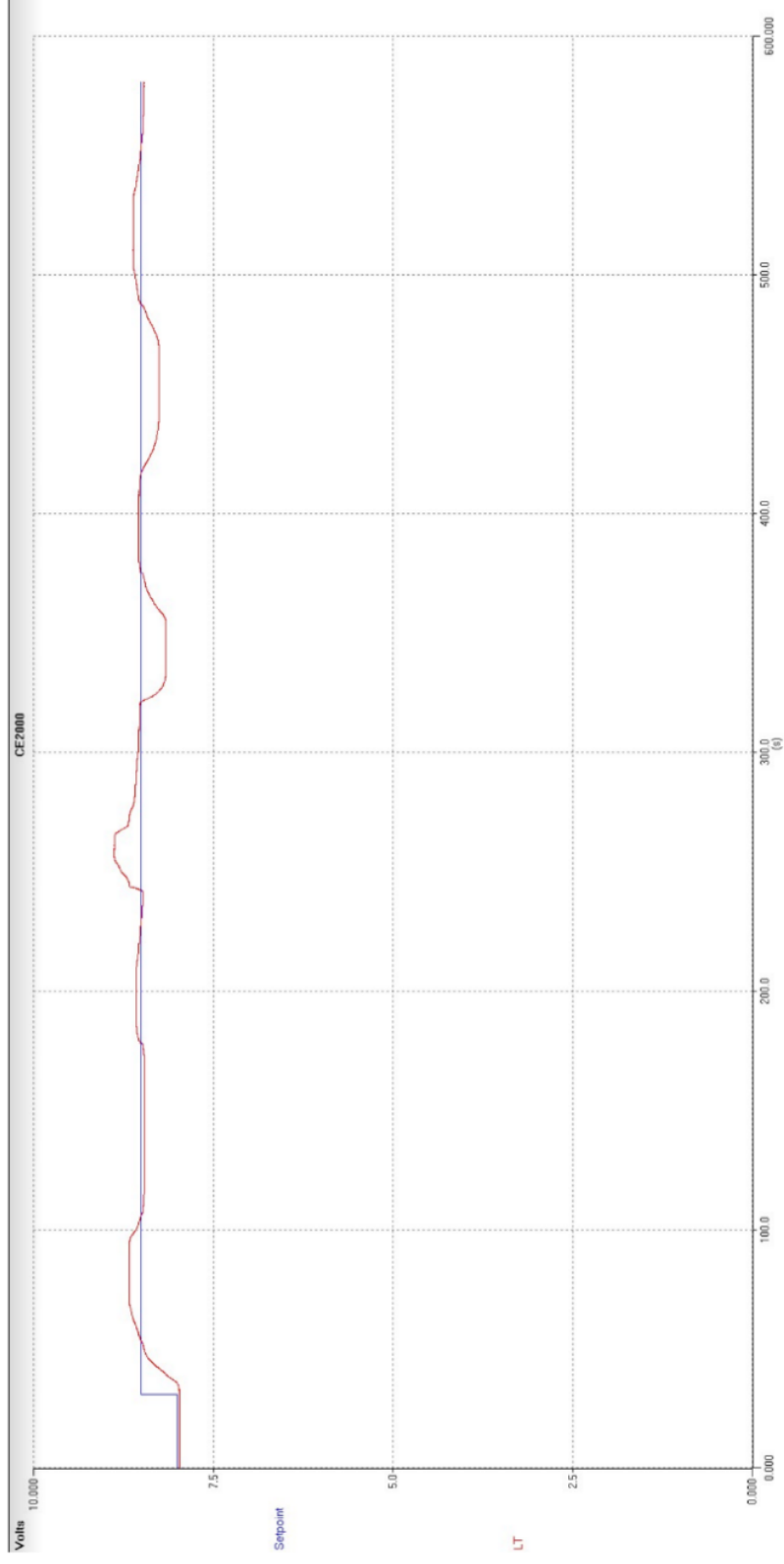
9.4 TecQuipment CE2000 Software and Function Block (Temperature Control)



9.5 Measured Time Constant (Temperature Control)



9.6 Level Control Response on CE117 Process Trainer with Disturbances



9.7 Tuned PID Parameters (Level Control)

Block Parameters: PID Controller

PID 1dof (mask) (link)

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
Sample time (-1 for inherited): -1

▼ Compensator formula

$$P + I \frac{1}{s} + D \frac{N}{1 + N \frac{1}{s}}$$

Main Initialization Saturation Data Types State Attributes

Controller parameters

Source: internal

Proportional (P): 6.19586271706423 6.1959

Integral (I): 0.230905800263055 0.23091 ☐ Use I*Ts (optimal for codegen)

Derivative (D): -0.399867730175572 -0.39987

Filter coefficient (N): 15.4947805224087 15.495 ☒ Use filtered derivative

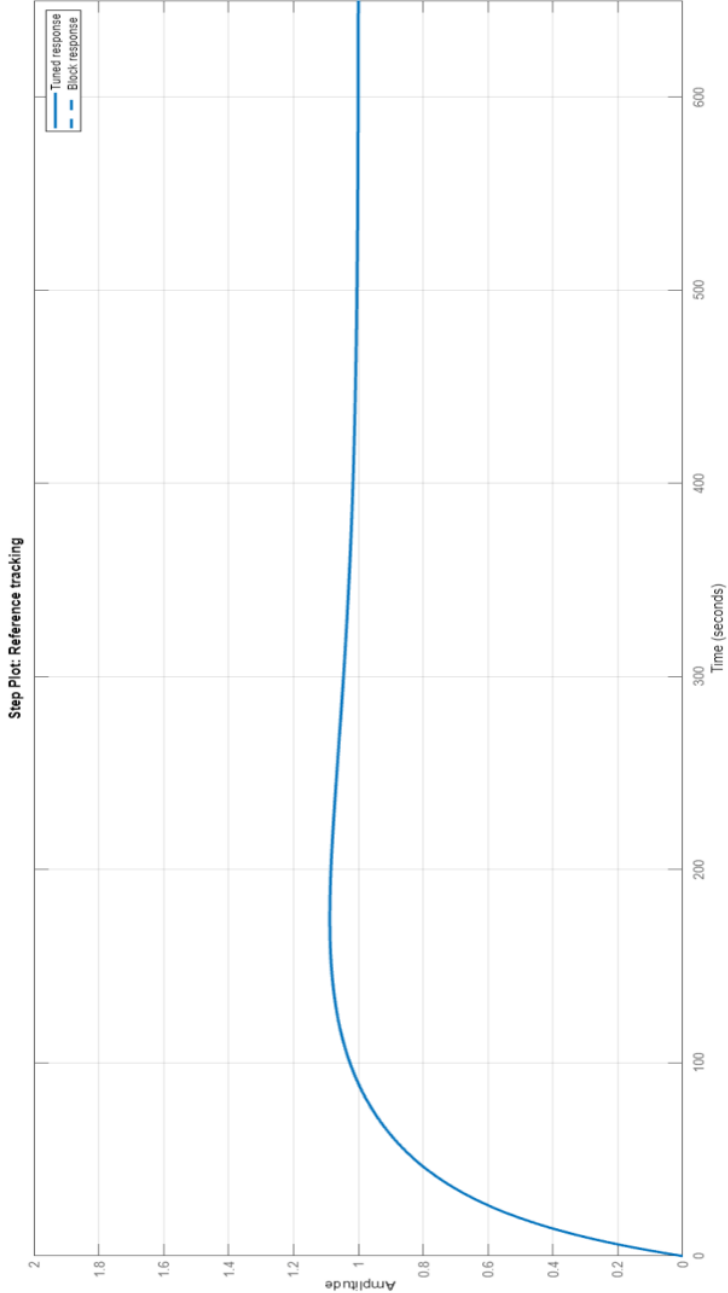
Automated tuning

Select tuning method: Transfer Function Based (PID Tuner App) Tune...

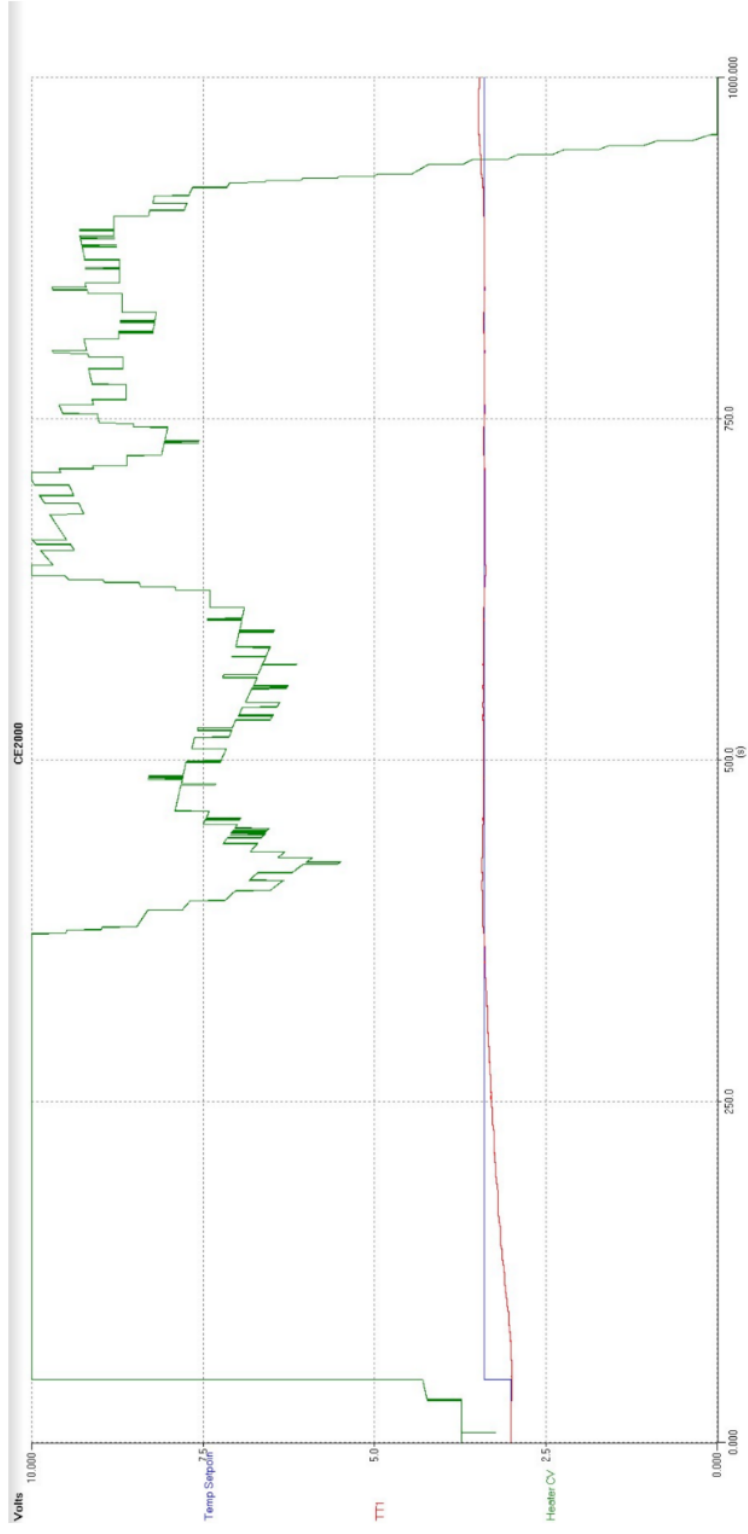
☒ Enable zero-crossing detection

OK Cancel Help Apply

9.8 Tuned PID Simulation Response (Temperature Control)



9.9 Temperature Control Response on CE117 Process Trainer with Disturbances



FINAL GRADE

GENERAL COMMENTS

Instructor

66/100

PAGE 1

PAGE 2

QM

Good Structure

Report is structured exactly as stated in the assignment brief.

PAGE 3

PAGE 4

PAGE 5

Text Comment. were

Text Comment. A good summary but avoid letting it become a contents list

Text Comment. What were your conclusions?

PAGE 6

Text Comment. will be

Text Comment. You could have said more

PAGE 7

Text Comment. page numbers are only need for direct quotations

Text Comment. page numbers are only need for direct quotations

PAGE 8

Text Comment. since this is a direct quote, page numbers are needed

Text Comment. if this is a direct quote, it should begin with ... states that .. and end with page numbers

Text Comment. IncaTools states that

Text Comment. According to Inca

Text Comment. IPCOS states that

Text Comment. page ?

Text Comment. quotes needed following ... states that

PAGE 9

PAGE 10

QM

Correctly cited

Citation method conforms to Harvard standard, well done.

QM

Good conclusions

You have shown understanding here from these observations and deductions

PAGE 11

QM

Correctly cited

Citation method conforms to Harvard standard, well done.

Text Comment. RS Components state that " " (2023, page ?)

PAGE 12

PAGE 13

PAGE 14

Text Comment. What were your tuned values of K_p , K_i and K_d ?

Text Comment. Each disturbance needs to be explained.

Text Comment. There is no stirrer in the heater tank

Text Comment. What were your tuned values of K_p , K_i , K_d ?

Text Comment. Explain the disturbances

Text Comment. Were there stars involved?

Text Comment. This explanation should also have been given earlier

Text Comment. The untuned values are based on initial tuned value from Matlab and can't be used for comparison. You should instead have explained why the model based method is preferred over other approaches.

Text Comment. You could have tried some guessed values and plotted the responses in Matlab and compared with the tuned ones.

Text Comment. How did you treat each other?



Wide Range of Sources

You have shown good evidence of reading from a wide range of sources.



Correct method of listing.

You have listed your sources correctly according to the Harvard method.

PAGE 26

PAGE 27

PAGE 28

PAGE 29

PAGE 30

PAGE 31

PAGE 32

PAGE 33

PAGE 34

PAGE 35

GRADING FORM: NEW CSG-RUBRIC

JASON BOOTH

66

1. ENGAGEMENT WITH LITERATURE



Report section 3 and 8 Good evidence of reading from a wide range of sources cited often but not always correctly and listed correctly using the Harvard method. Page numbers are only need for

12

direct quotations. You have provided pages number when not directly quoting but no page numbers when you are. Also, direct quotes should begin with ... states that .. while non direct quotes can be ... according to 12/20

2. KNOWLEDGE AND UNDERSTANDING

-  All report sections and particularly sections 3, 4 and 5 Good evidence of understanding in your report overall and particularly in your Research and your explanation of your Level Control of the Process Tank and Temperature Control of the Heater Tank experiments. 12/20 **12**

3. COGNITIVE AND INTELLECTUAL

-  Report sections 4, 5 and 6 Good analysis of results in your Level Control of the Process Tank and Temperature Control of the Heater Tank experiments with clear conclusions and recommendations presented. 14/20 **14**

4. PRACTICAL APPLICATION

-  Report sections 4 and 5 Good use of equipment and presentation of results in your Level Control of the Process Tank and Temperature Control of the Heater Tank experiments. 14/20 **14**

5. TRANSFERABLE SKILLS



All report sections, but particularly sections 1, 2, 7 and word count penalty. Generally good report style, presentation, use of grammar, spelling and punctuation. Clear executive summary (but is a content list in parts), good work plan (could have said more) and explanation of team working (could have said how you treated each other). Word count not exceeded. 14/20

14