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2017197

by Aeron Smitham

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1. Executive Summary

This report has seen an investigation into PID tuning methods and how they are implemented in control systems. The report sees the development of systematic understanding of control systems through analysis, modelling, simulation and verification of typical industrial systems. PID tuning methods were researched and then some were implemented in the tasks of level and heater control. The performance of the PID loops has been analysed critically with thorough testing, with comparisons made between simulated, measured and calculated values.

How close were they?

Research was conducted into various forms of PID tuning methods – namely: Ziegler-Nichols, Process Reaction Curve, Trial-and-Error, Frequency Response and Model-Based. These methods range from simple to complex, with the Trial-and-Error being the simplest and Model-Based being the complex.

Which was the best?

Experiments were carried out to find the best response from PID loops controlling a level tank and a heater tank – utilising the knowledge gained in the research section to pick methods to tune the most robust response. Calculations were carried out to find a mathematical model which was then used as a basis to fine-tune the final system.

How did the testing go?

This is a good summary but does not tell the whole story, you need to include conclusions otherwise it becomes a contents page in paragraph form.

2. Work plan for Life-long Learning

When undertaking this assignment, particular interest will be paid to the research of PID tuning methods and the different order systems that can be utilised in a control system.

The research of the methods of tuning will then be used to choose one for use in the practical part of this assignment. The chosen method will be utilised on the level control of the tanks and on the temperature control of the heater.

An investigation will be undertaken into the control of the level and heating of the process tank to find a calibration curve, time constant, gain and tuned values. A simulation will be created to compare theoretical, practical and simulated results.

A good plan

3. Research (1000)

Paragraphs should be fully justified text as required in the brief

3.1. Method 1 – Ziegler & Nichols

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The Ziegler-Nichols tuning method is a traditional approach to establishing the parameters of a PID controller for a control system. The method consists of firstly bringing the control system to an unstable operating point and then altering the controller parameters based on the resulting oscillations (C Dorf & H Bishop, 2017). The method gives the values of the proportional gain, integral gain, and derivative gain, which can then be used to fine-tune the control system for the required response (Circuit Digest, 2022). This method is considered simple and effective, but it can lead to poor performance in some cases, and more advanced tuning methods such as model based can be used. The Ziegler-Nichols tuning method involves the following steps (Bennett, 2022):

1. Start with a high proportional gain: Set the proportional gain to a high value to create an unstable operating point.
2. Observe the response: The system should exhibit oscillations that become larger as the gain is increased.
3. Measure the oscillation period: Measure the time period of the oscillations and record the value.
4. Calculate the ultimate gain and ultimate period: Based on the oscillation period, the ultimate gain and ultimate period can be calculated using formulas specified in the Ziegler-Nichols method.
5. Determine the PID gains: Finally, the proportional gain, integral gain, and derivative gain are determined based on the ultimate gain and period.

3.2. Method 2 – Process Reaction Curve

The process reaction curve method is a graphical approach to tuning PID loops that involves creating a step response of the system and analysing the resulting behaviour. Here's how it works (Ellis, 2012):

1. Step input: A step change is made to the process input, such as a setpoint change, and the response of the process is recorded.
2. Plotting the response: The process response is plotted over time, showing how the process output changes in response to the step input.
3. Characterizing the response: The response curve is analysed to determine important parameters such as the process gain, dead time, and time constant.
4. Calculating PID gains: Based on the process response curve, the PID gains can be calculated to achieve the desired response characteristics.

This method provides a graphical understanding of the system behaviour and allows the user to see how changes in the PID parameters affect the system response (Franklin & David-Powell, 2020). It can also provide more accurate results than rule-of-thumb methods such as Ziegler-Nichols, especially for systems with non-linear or time-varying behaviour. However, it does require more data collection and analysis, and may not be suitable for systems with limited data or where the step input may have a large impact on the process (IPCOS, 2023).

The process reaction curve method provides more insight into the behaviour of the system compared to methods such as Ziegler-Nichols. This allows for more precise tuning of the PID controller. The PID parameters can be adjusted to achieve a desired overshoot, settling time, or stability margin. The process reaction curve method can also be used to fine-tune the PID gains after they have been initially set using another method (Johnson & Moredi, 2010).

3.3. Method 3 – Trial & Error

The trial-and-error method of PID tuning involves adjusting the PID gains and observing the system's response until the desired performance is achieved. This method can be used in conjunction with rule-of-thumb methods, such as Ziegler-Nichols, to fine-tune the PID gains after they have been initially set. Here's how the trial-and-error method works (Johnson & Moredi, 2010): Correctly cited

1. Initialize PID gains: Start with an initial set of PID gains, such as those obtained from a rule-of-thumb method or estimated based on previous experience.
2. Observe the response: Run the process with the initial PID gains and observe the system's response. This can involve monitoring the process output, error, or control signal over time.
3. Adjust the PID gains: Based on the observed response, adjust one or more of the PID gains (such as the proportional, integral, or derivative gain) and run the process again.
4. Repeat steps 2 and 3: Repeat the process of observing the response and adjusting the PID gains until the desired performance is achieved.

The trial-and-error method is a simple and intuitive approach that can be used to fine-tune the PID gains for a specific process. However, it can be time-consuming and may not result in the optimal PID gains. In addition, it can be difficult to determine when the desired performance has been achieved, especially for complex or non-linear systems. For these reasons, it may be more effective to use a more structured approach such as the process reaction curve or frequency response analysis method (Nise, 2019). Correctly cited

3.4. Method 4 – Frequency Response Method

The frequency response method of PID tuning involves analysing the frequency response of the process and using the information obtained to tune the PID gains. This method can be used to obtain a good set of PID gains for complex or non-linear systems where trial and error or rule-of-thumb methods may not be effective. Here's how the frequency response method works (PID Explained, 2020): [Correctly cited](#)

1. Excite the process: Apply a known input signal, such as a step or sinusoidal signal, to the process and observe the system's response.
2. Measure the frequency response: Use the input and output signals from the excitation to measure the frequency response of the process. This can be done using techniques such as Bode plots, Nyquist plots, or frequency response functions.
3. Determine the process dynamics: Based on the frequency response, determine the dynamics of the process in terms of its transfer function, poles, and zeros.
4. Tune the PID gains: Use the process dynamics to determine the optimal PID gains that provide the desired performance in terms of stability, transient response, and steady-state error. This can involve selecting the appropriate control structure (such as proportional, integral, derivative, or PI-D) and adjusting the PID gains accordingly.
5. Verify the results: Verify the performance of the PID controller by running the process with the tuned PID gains and observing the response.

The frequency response method of PID tuning is a more structured and systematic approach that can provide a good set of PID gains for complex or non-linear systems. However, it requires a good understanding of control theory and a high level of technical expertise. In addition, the excitation of the process can have an impact on its behavior and may not always be feasible (Seborg, 2017). [Correctly cited](#)

3.5. Method 5 – Model Based Tuning

Model based PID is a method of tuning the PID parameters based on a mathematical model of the process. The model can be obtained using methods such as system identification, linearization, or simulation. The PID tuning method can be seen below:

1. Model the process: Develop a mathematical model of the process that accurately represents its behavior over a range of operating conditions. The model can be linear or nonlinear, and may involve state-space representations, transfer functions, or dynamic models.
2. Simulate the process: Use the mathematical model of the process to simulate its behavior under different operating conditions and input signals.
3. Tune the PID gains: Use the simulation results to determine the optimal PID gains that provide the desired performance in terms of stability, transient response, and steady-state error. This can involve adjusting the PID gains until the simulation results match the desired performance, or using optimization techniques to find the optimal PID gains.
4. Verify the results: Verify the performance of the PID controller by running the process with the tuned PID gains and observing the response.

Model-based PID tuning provides a systematic and structured approach to tuning the PID gains, especially for complex or non-linear systems. It allows for the exploration of different operating conditions and control strategies and can provide a good set of PID gains that are robust to process variability and measurement noise. However, the accuracy of the model is crucial for the success of the model-based PID tuning method, and a high level of technical expertise is required to develop and use the mathematical model. The benefits of model-based PID tuning include (Seborg, 2017):

Correctly cited

- Increased accuracy: Model-based PID tuning provides a more precise method of tuning the PID gains, compared to rule-of-thumb or trial-and-error methods, as it considers the complex dynamics of the process.
- Improved performance: This tuning can result in improved performance in terms of stability, transient response, and steady-state error, as the optimal PID gains can be determined based on the specific requirements of the process.
- Robustness: The PID tuning can provide a set of PID gains that are robust to process variability and measurement noise, as the performance can be evaluated under different operating conditions and disturbances.
- Flexibility: This allows for the exploration of different control strategies and the selection of the best strategy for the process. This can result in improved control performance and increased efficiency.

- Systematic approach: A structured and systematic approach is used to tuning the PID gains, reducing the risk of error and improving the reliability of the control system.

Overall, model-based PID tuning can provide improved control performance, increased accuracy, and increased robustness compared to other tuning methods. However, it requires a high level of technical expertise and a good understanding of the process dynamics, as well as the availability of a mathematical model of the process (Woolf, 2009). Correctly cited

Good conclusions

Where is your P&ID diagram and control diagram for this loop?

4. Level Control of the Process Tank

4.1. Investigation into Instruments

The parts in the control loop are a capacitive level transducer, proportional valve, bypass valve, pump, drain valve, vent valve and a level switch.

4.2. Calibration Curve

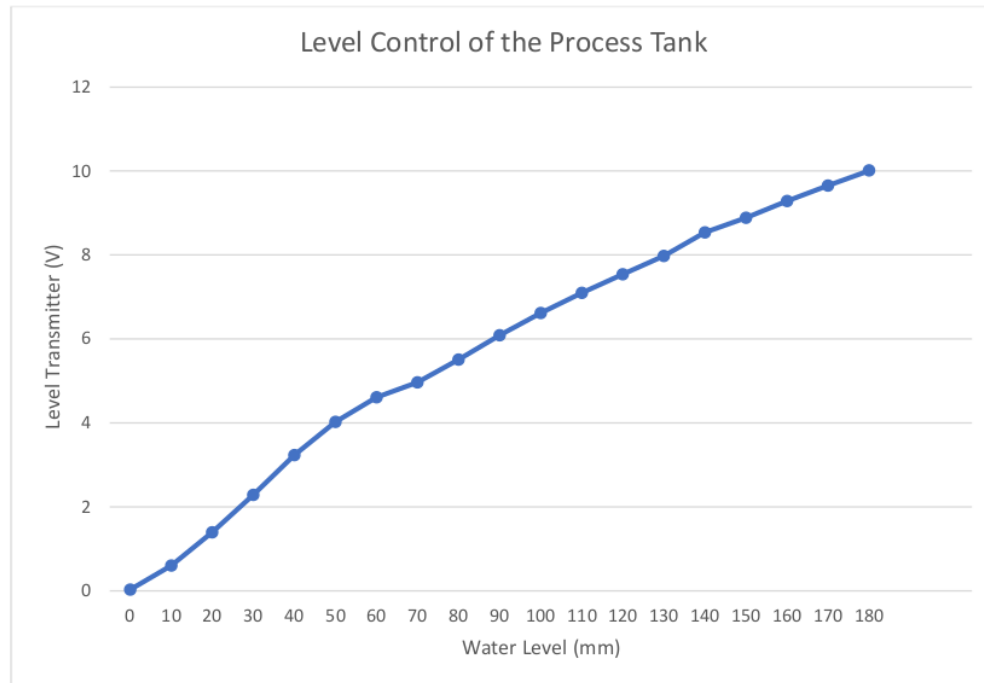


Figure 1

As can be seen in figure 1, the calibration curve of the level transmitter is not exactly linear but almost is. The zero and span of the transducer are exact, with the voltage at 0mm being 0.03V, and at 180mm the voltage was 10.01V. The maximum level the sensor can read is 180mm as it maxes out at 10V. *What is the static sensitivity?*

The linearity error in the calibration could be due to the human error element of trying to stop the level by eye. The point between 60mm and 70mm is where the linear trend is interrupted, as before and after these points the trend is linear. This can be seen in table 2 in the appendix as it has the smallest voltage increase of any step of 10mm in level, with the voltage increase being 0.35V. The repeatability of this method is poor due to there being an acceptable band either side of each point to the operator. This will also differ from person to person, with one value being acceptable to one and not acceptable to the other.

4.3. Time Constant

	VP	VL	VF	h Level (m)	q Flow Rate (m3/sec)
A	5.3	7.53	4.16	0.118	69.33x10 ⁻⁶
B	5.8	8.91	4.41	0.149	73.5x10 ⁻⁶

Table 1

$$\text{Area of Vessel} = 0.01767\text{m}^3$$

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

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

$$R = 0.031 \div 4.17 \times 10^{-6} = 7431.1$$

$$\tau = 0.01767 \times 7431.1 = 131.361 \text{ seconds}$$

$$K = \Delta VL \div \Delta VP$$

$$K = 1.38 \div 0.5 = 2.77$$

4.4. Time Constant Experiment

An experiment was carried out to find a second time constant value and compare with the calculated value. This was carried out on the CE117 Process Trainer by filling the level tank above the heating element and changing the level setpoint to measure the response of system.

The time constant in the experiment was found to be 131.15s, which is quite accurate when compared with the calculated value of 131.361s, proving that the calculations were correct. This can be seen in figure 2 of the appendix.

4.5. Simulink Model

A mathematical model of the system was created on Simulink with the transfer function below used:

$$TF = \frac{2.77}{131.361s + 1}$$

The original values of the system gave a poor response but with the tuning function of Simulink a more robust and faster rise time was possible. The tuned values can be seen in figure 3 of the appendix. The graphical response can be seen in figure 4 of the appendix.

4.6. Implementation on CE117

The PID values found on Simulink were then implemented on the level control of the CE117 to see if the mathematical model would work on a real system. The graphical response can be seen in figure 5 of the appendix.

What values did you choose for Kp, Ki, and Kd?

4.7. Analysis of Results

In conclusion, the results of the investigation were mixed, with some values matching up as expected – such as the time constant – and others showing significant discrepancy – namely the response of the PID loops, with the model-based PID loop showing a robust and fast response but when put into practice it gave a poor response with several oscillations. This suggests that while certain aspects of the experiment were successful, there are still areas to improve on. Further investigation and analysis may be necessary to determine the reasons for the mismatched results, but one issue could be the transfer function with perhaps the gain value being incorrect. Nevertheless, the findings show valuable information and insight into PID tuning methods.

The graph of the system responses to disturbance could have been placed in the report here

Where is your P&ID diagram and control diagram for this loop?

5. Temperature Control of the Heater Tank

5.1. Investigation into Instrumentation and Actuators

The parts in the control loop are a heating element, RTD, cooling fan, capacitive level transducer, proportional valve, bypass valve, pump, drain valve, vent valve and a level switch.

5.2. Time Constant

A step increase of the temperature setpoint was initiated on the CE117 with the time constant recorded. The time constant was 579 seconds, which can be seen in figure 6 in the appendix. The gain was calculated to be 0.1516.

5.3. Simulink Model

something missing in the denominator

A Simulink model was based on the transfer function: $\frac{0.1516}{579s}$. The PID values were then tuned to find a robust and fast response. This can be seen in figure 7 of the appendix.

5.4. Implementation on CE117 *What values did you choose for Kp, Ki, and Kd?*

The Simulink model and its PID values were then implemented on the CE117. Unlike the level control, the Simulink model provided an accurate response when implemented on the real system. This can be seen in figure 9 of the appendix, with a slight overshoot and then a settling down at the setpoint.

5.5. Analysis of Results

The results of the experiment were consistent with the expectations and hypotheses of the model based PID tuning method. This indicates that the methods and procedures used were effective and produced reliable results. The findings provide strong support for the use of mathematical models as methods of tuning PID loops. The results of this study can be used as a foundation for future investigation into mathematical models and process reaction curves. Overall, this experiment was a success.

6. Conclusions and Recommendations

In this assignment, various tasks were undertaken to gain a critical understanding of control systems, and how their behaviour can be used to evaluate their performance. The report has distinct sections, with one being the research into various PID tuning methods, and a second section which consists of investigating and testing a control system – primarily the level and temperature of the CE117 Process Trainer equipment. A section of the testing was to relate to the research and find the best method of PID tuning for the tasks, while Simulink was utilised to model the PID tuning for the control system.

In the research section, five methods of tuning PID loop parameters were investigated, with their merits and faults compared. These methods were: Trial and Error, Process Reaction Curve, Ziegler-Nichols, Lambda and Model-Based. Each of these methods have similarities but are also quite different – with the Trial and Error and Model-Based being two differing methods. Trial and Error requires an engineer to spend time at the machine being tuned and guesstimating what parameters to change and by how much – which could be a long and arduous process which causes significant downtime. The Model-Based however, can be tuned offline with software such as Simulink, to create a model of the machine which can be tuned and altered without any impact to production. The model can then be downloaded to a PID controller – causing minimal downtime. The only pitfall of the model method is that it must be set up exactly as the real system it is modelling, other wise there is a chance of a spurious performance.

The other section of the assignment required the investigation and testing of the level and temperature control of the CE117 Process Trainer. The different instrumentation and actuators were investigated for both the process tank and heater tank. For the level control task, a calibration curve was found by the team via the manual controls, with an issue encountered with the zero and span being set up incorrectly. This was rectified and the zero and span matched the voltage levels of the 0-10V level transmitter and the time constant was calculated for the system and compared with a measured value. With these complete, a model of the system was simulated where a PID loop was tuned to gain the best performance and was then implemented on the level control system.

For the heater tank, a similar process was followed with the time constant, and gain of the system found by conducting an experiment, with the gain being 0.152 and the time constant of 579s found by increasing the step input. As with the level control, a simulation was created with the transfer function of $\frac{0.1516}{579s+}$ used as the mathematical model, and was tuned for the

incomplete

best performance. This tuned loop was then implemented on the heater tank and was confirmed to be correct by adding a disturbance into the system via the water-cooling fan.

A proposal for this assignment would be to create a task where the student must work on their own to create a custom system that requires a PID loop, where they control each part of the task. A PID loop could be created for a motor test rig which could then encounter disturbances – simulating a rolling mill or conveyor. The response of the motor from these disturbances to reduce the speed error could be plotted on a graph to analyse the performance of the PID loop. This complete set up of the PID loop would give the student greater understanding and confidence in the use and configuration of drives which could then be taken to the workplace.

7. Team Working

The students were split up into teams of 3 to complete the practical tasks for both the level and heater control. For these tasks, the team had different roles. The roles were as follows:

- Reading of the transmitter voltage value and logging of results
- Operation of the actuators
- Reading of the actual level

The operator controlled the opening of the valve to allow flow of water into the tank and worked together with the reader of the actual tank level who notified the operator when to cease operation of the valve, or if more water was required. The actual level reader also had to release water from the tank if the level was too high. The actual level reader also worked together with the transmitter voltage reader by notifying them when a certain value was reached. This value was then compared with the voltage value, and both values were logged in a spreadsheet table, which was then used to create a graph displaying the calibration curve. The team members remained in the same role and this setup proved effective as everyone was accustomed with their job, allowing the team to succeed in promptly completing the tasks.

How did you treat each other?

Correct method of listing.

8. Works Cited

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Good range of sources

9. Appendix

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

Table 2

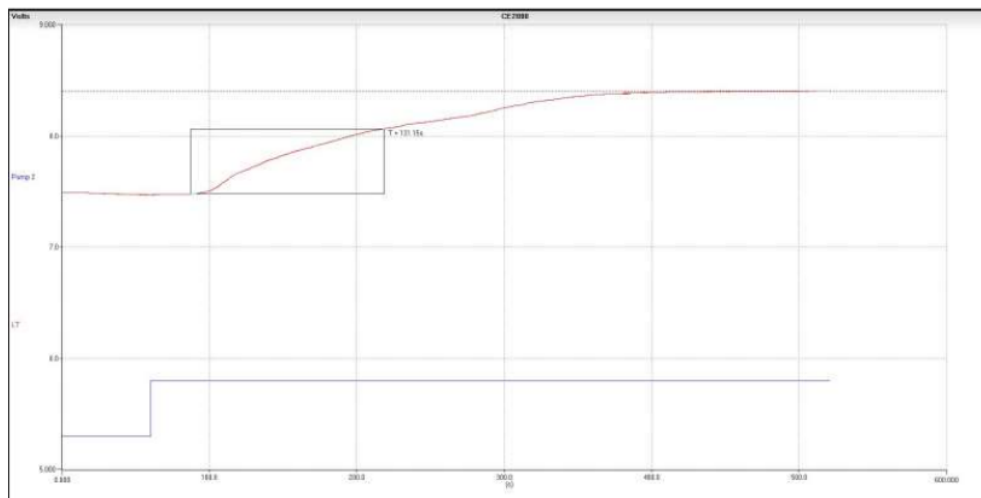


Figure 2

Source: internal

Proportional (P): 5.53918599887614 0.25419

Integral (I): 0.180643793060317 0.0085629 ☐ Use I*Ts (optimal for codegen)

Derivative (D): 10.6852634627152 0.51833

Filter coefficient (N): 0.222762193196001 0.19283 ☒ Use filtered derivative

Automated tuning

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

Figure 3

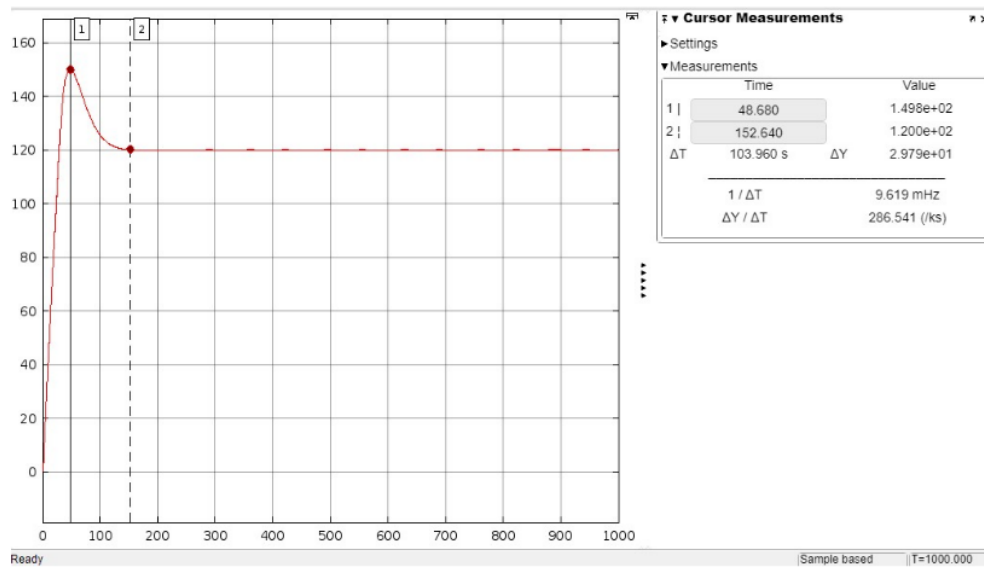


Figure 4

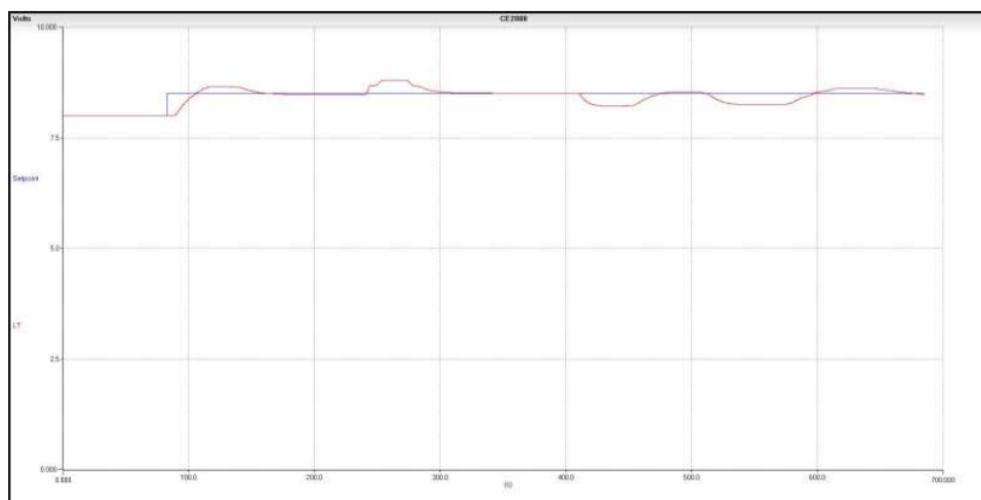


Figure 5

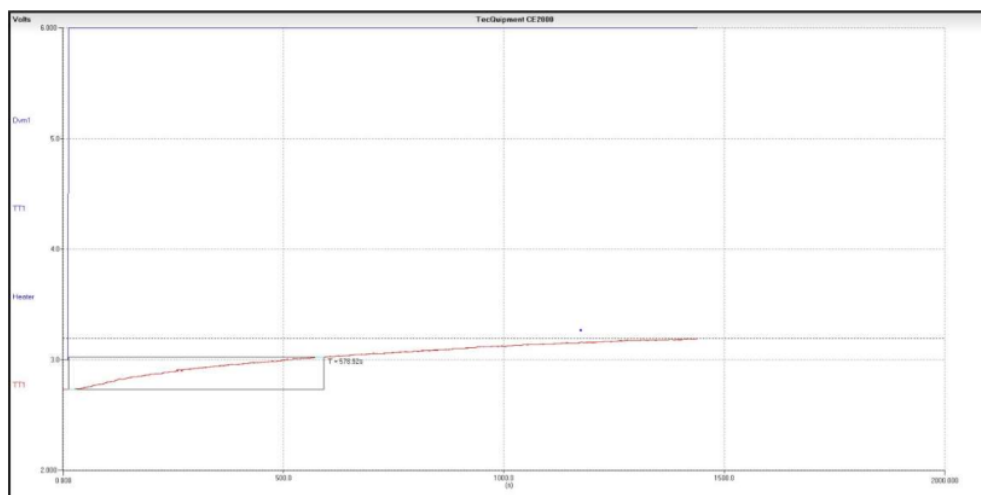


Figure 6

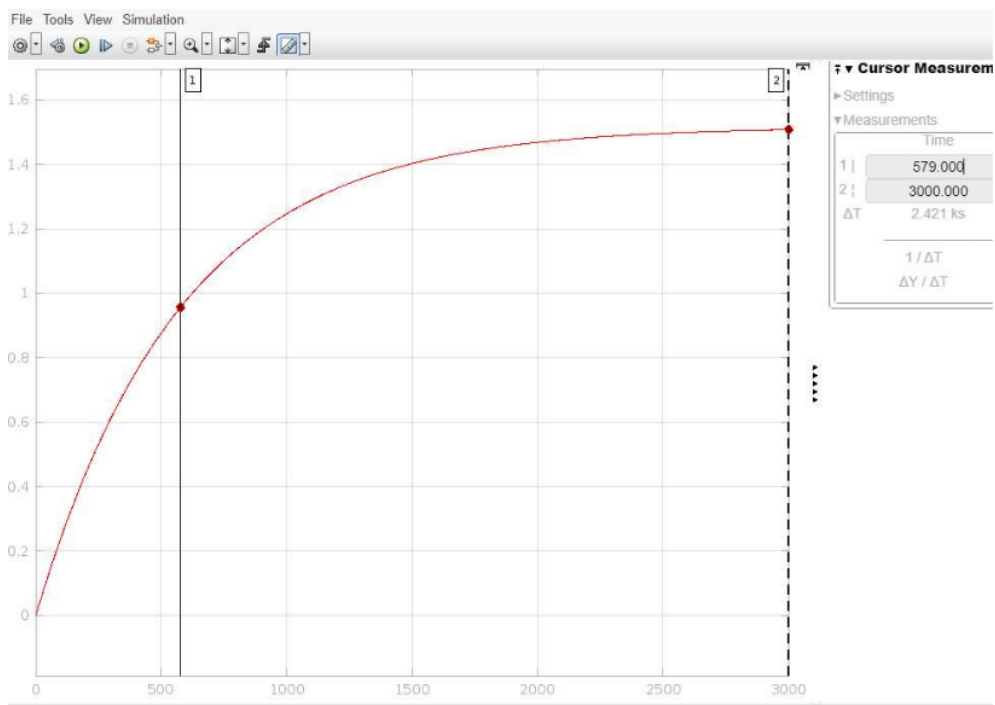


Figure 7

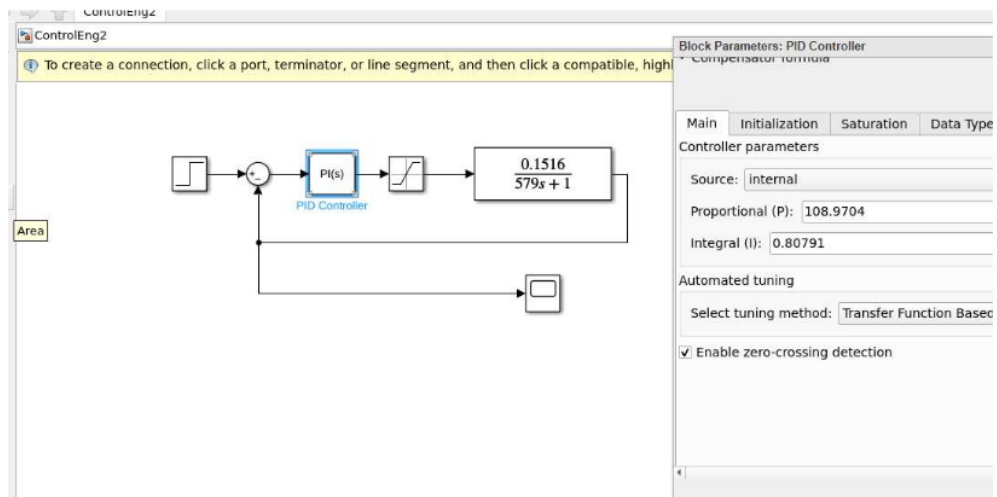


Figure 8

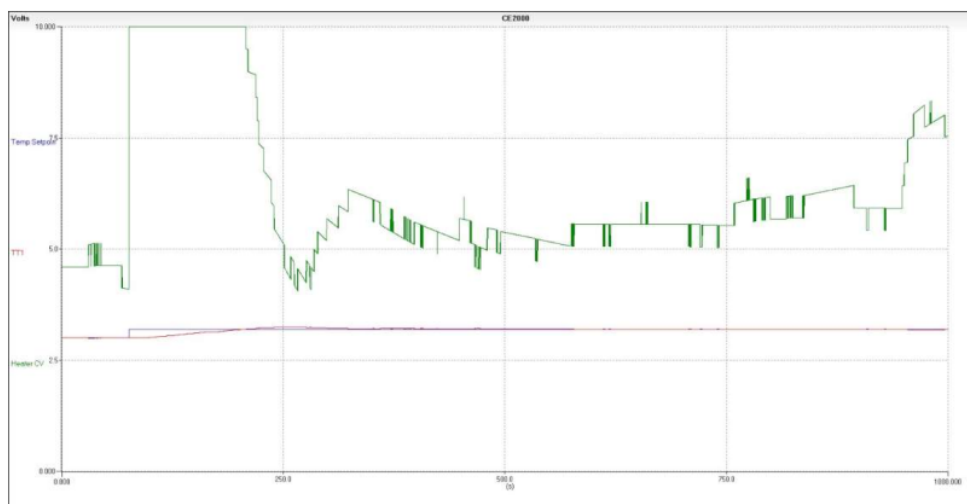


Figure 9

FINAL GRADE

GENERAL COMMENTS

Instructor

70/100

PAGE 1

PAGE 2

PAGE 3

Text Comment. How close were they?

Text Comment. Which was the best?

Text Comment. How did the testing go?

Text Comment. This is a good summary but does not tell the whole story, you need to include conclusions otherwise it becomes a contents page in paragraph form.

PAGE 4

Text Comment. A good plan

PAGE 5

QM

Paragraphs should be fully justified text as required in the brief

Text Comment. You have lost your formatting

PAGE 6

QM

Correctly cited

Citation method conforms to Harvard standard, well done.



Correctly cited

Citation method conforms to Harvard standard, well done.



Correctly cited

Citation method conforms to Harvard standard, well done.

PAGE 7



Correctly cited

Citation method conforms to Harvard standard, well done.



Correctly cited

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PAGE 10



Correctly cited

Citation method conforms to Harvard standard, well done.



Good conclusions

You have shown understanding here from these observations and deductions

PAGE 11

Text Comment. Where is your P&ID diagram and control diagram for this loop?

Text Comment. What is the static sensitivity?

PAGE 12

Text Comment. What values did you choose for K_p , K_i , and K_d ?

PAGE 13

Text Comment. The graph of the system responses to disturbance could have been placed in the report here

PAGE 14

Text Comment. Where is your P&ID diagram and control diagram for this loop?

Text Comment. something missing in the denominator

Text Comment. What values did you choose for K_p , K_i , and K_d ?

PAGE 15

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PAGE 16

PAGE 17

Text Comment. How did you treat each other?

PAGE 18

QM

Correct method of listing.

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

QM

Good range of sources

You have demonstrated reading from a good range of sources shown by your list below

PAGE 19

PAGE 20

GRADING FORM: NEW CSG-RUBRIC

AERON SMITHAM**70****1. ENGAGEMENT WITH LITERATURE**

Very good evidence of reading from a wide range of sources cited correctly and listed correctly using the Harvard method. 14/20

14**2. KNOWLEDGE AND UNDERSTANDING**

Clear 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. However, you have not included any P&ID diagrams or control diagrams in your investigations. 12/20

12**3. COGNITIVE AND INTELLECTUAL**

Very good analysis of results in your Level Control of the Process Tank and Temperature Control of

14

the Heater Tank experiments with clear conclusions and recommendations presented.
14/20

4. PRACTICAL APPLICATION

 Very good use of equipment and presentation of results in your Level Control of the Process Tank and Temperature Control of the Heater Tank experiments. 16/20

16

5. TRANSFERABLE SKILLS

 Very good report style, presentation, use of grammar, spelling and punctuation. Good executive summary, (but more could have been said), good work plan and explanation of team working (though you could have explained how you treated each other). Word count not exceeded.
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