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by Harri Jones

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1. Executive Summary

The aim of this assignment is to develop a systematic understanding of control system theory and practice through analysis, modelling, simulation, design and verification of typical industrial systems.

Research was carried out on PID tuning methods to determine which one would be suitable for the assignments practical tests, one method in particular was chosen: model-based tuning. This method was chosen due to its overall efficiency and fast, accurate tuning, this will give a deeper understanding of the system being used.

The CE117 Process Trainer's instrumentation and control actuators were investigated in the process tank loop, with these a P&ID diagram was created to depict its operation. Along with this a control block diagram was created. A linear calibration curve was created by increasing the voltage of the level transducer which increased the water level of the tank. The time constant of the system was calculated along with the gain, these were compared to with simulated values which were very similar. Tuned values were obtained from a mathematical model based on the results, these values were then implemented to the CE117 Process trainer to perform the tests. Disturbances were added to see how the system would perform and how it would regulate back to its setpoint.

The CE117 Process Trainer's instrumentation and control actuators were also investigated in the heater loop. P&ID diagrams along with control block diagrams were created. The time constant and gain were found by carrying out an experiment involving changing the voltage and measuring the temperature in voltage. With this experiment a mathematical model based on the results was created, a PID control loop was added and tuned for the best performance. The tuned values were then user for the control method on the CE117 Process trainer. The purpose of this was to tune it to regulate the water temperature of the heater tank to a suitable setpoint.

This is a very good summary

2. Work plan for Life-long Learning

The task will be approached by beginning with the Research to gain a better understanding of the subject and help decide which method to use for the first order systems investigated. The tuning method can then be used on the practical tasks 3 & 4 and these results will be recorded and discussed. After completing the practical, a conclusion and recommendations will be made at the end.

The assignment ^{will give} gave an understanding of how to tune a first order system using the model-based tuning method. Five different methods ^{will be} were investigated and compared. The ability to create P&ID diagrams ^{will be} was obtained by creating them for both investigated loops in the system. Equations ^{will be} were used to find the time constants and gains of each loop and the results were used to create simulated versions from mathematical models. A wider understanding of Simulink ^{will be} was achieved by learning how to tune a PID controller. The tuned values ^{will then be} were then added to the system and the performance was monitored and analysed. Disturbances implemented to see how the system would perform or react to the disturbances, some created an impact and others did not.

Plans should be written in the future tense and should not be a reflection

3. Research

3.1 - Trial and Error method

This is one of the simpler methods of tuning a PID controller. The integral and derivative terms are set to zero first and the proportional gain must be increased until the control loop output oscillates at a constant rate. Increasing the proportional gain [Correctly cited](#) could make the system quicker providing it doesn't make the system unstable. (Omega, 2020) When the P-response is quick enough the integral term must be set, making the oscillations reduce gradually. Set the 'P' and 'I' parameters to the desired values with a minimal steady state error, the derivative gain can be increased to the point where the system reacts faster to its set point. When the derivative term is increased the overshoot of the controller response will decrease. (ElectronicsHub, 2015) [Correctly cited](#)

1. Set integral 'Ti' and derivative 'Td' control actions to minimum effect.
2. Controller gain 'Kc' needs to be increased till desired performance is obtained.
3. Integral time 'Ti' needs to be adjusted to eliminate the offset.
4. Derivative time 'Td' needs to be adjusted to give the largest stability margin possible (least degree of oscillations).
5. Kc must be adjusted to maintain selected performance objective.

(K.Vassiljeva, 2015) [Correctly cited](#)

3.2 – Model Based method

Model-based PID tuning is method of tuning the parameters of a PID controller by using a mathematical model of the system. The parameters of the PID controller are estimated using the mathematical model, these estimated [Correctly cited](#) are then used to tune the controller for improved control performance. (Rao, 2023) . The main advantage to this method is that the dynamics of the system [Correctly cited](#) o account which results in a more accurate and stable control. (SCSolutions, 2018) The method can be very useful in situations where it's expensive or difficult to obtain direct measurements of the systems performance. This can result in a more efficient and improved performance comparing to the commonly used trial and error method. (IncaTools, 2020) [Correctly cited](#)

3.3 – Ziegler-Nichols method

The Ziegler-Nichols tuning method is considered a classic control theory technique which is used for determining the PID parameters. The method is a model free one which relies on step response data which is obtained from the system being controlled. (John Gerry, 2003) A step input is injected into the system and the response is measured; this is then used to calculate the optimal PID controller parameters. The method is widely used in control applications found in industries due to its robustness and ease of use. (Microstar Laboratories, 2021)

With The closed-loop tuning method 'Kc' can be calculated by using the ultimate gain value 'Ku' and the ultimate period of oscillation 'Pu'. The method is considered simple and can be refined to gain a more accurate approximation of the controller. The controller constants 'Kc', 'Ti' and 'Td' can be obtained in a system with feedback. To determine 'Ku', the proportional only gain, causes an indefinite oscillation at steady state must be found. The 'I' and 'D' controller gains are set to zero to determine the value of 'P'. The ultimate period 'Pu' is the time required for one full oscillation to complete while at steady state. The constants of the controller 'P', 'PI' or 'PID' can be found by using 'Ku' and 'Pu'. (Patel, 2020) Correctly cited

3.4 – Cohen-Coon method

The Ziegler Nichols method is used to get slow, steady state response, the Cohen-Coon method corrects this. When a large dead time (process delay) which is relative to the open loop time constant occurs, a large process delay is required; making it practical, or else large controller gains will be predicted. This is suitable for first order models which have a time delay due to controller not instantly responding to the disturbance. (Bennett, 2022) Correctly cited

The method involves the use of gain scheduling, which occurs by adjusting the controller parameters based on the process's operating conditions. A systematic approach is provided for determining the optimal PID parameters for the process and operating conditions. This results in improved stability and performance of the control system. (Opticontrols, 2011) Correctly cited

The Cohen-Coon method is used only on self-regulating processes. Control loops such as speed, pressure, flow and composition contain self-regulating processes. A self-regulating process will always stabilize at the point of equilibrium, depending on the process design of the controller output. The process will stabilize to a new point of equilibrium if the controller output is set to a different value. (DataForth, 2016) Correctly cited

3.5 – Lambda method

The lambda method is a model-based tuning method involving the use of the transfer function of a process in order to tune the parameters of a PID controller. Based on the concept of 'process reactivity' which is a measure of how fast a process responds to a change in disturbance or setpoint. (Vandoren, 2013) This concept can be used to determine the optimal values for the proportional, integral and derivative gains of the PID controller. This method is considered easy to use and providing accurate and fast tuning results. The lambda method is commonly used on systems which have a fast response time. (Coughran, 2018)

3.6 Chosen method.

From the 5 methods researched, the Model-based tuning method was chosen. This method was chosen due the many advantages it possesses. The method eliminates the need for multiple trial and error tests to determine the optimal control parameters, this saves time and reduces the chance of damaging the system doing the tuning process. Another advantage is that by creating a model based mathematical model of the system a deeper insight into the systems behaviour can be provided which allows for the ability to identify potential limitations or design problems. Additionally, this method is reusable meaning that once it has been developed it can be reused for future tuning which will save time and effort for new projects.

Overall, the model-based tuning method results in efficient, fast and accurate tuning, improved control performance and the ability to gain a deeper understanding of the system being controlled. Good conclusions

4. Level Control of the Process Tank

4.1. Investigating CE117 Process Trainer

Figure 1 shows the P&ID diagram, this regulates the level in the process tank.

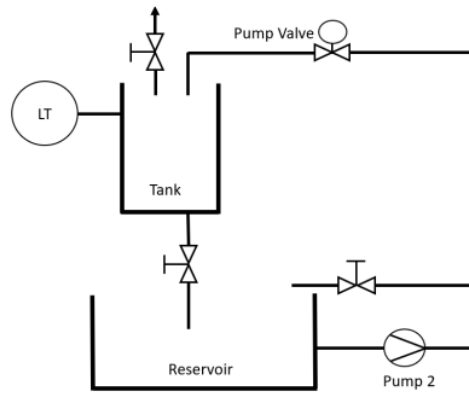


Figure 1 - Level control P&ID Diagram

The process tank consists of a transparent cylinder which has a scale to view the level of water in the tank, this is read in mm. When the reservoir is filled with water, pump 2 drives the water up through the pump valve and into the process tank. The water can then be drained back into the reservoir via the drain valve. The reading from the level transmitter goes through a signal conditioner, changing the level (mm) to voltage (V) from a scale of 0-10V.

Figure 2 below shows the control block diagram for the process tank.

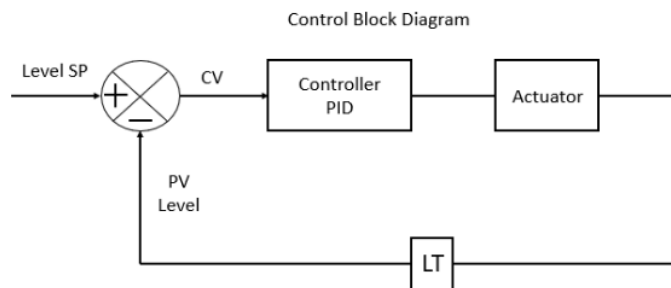


Figure 2 - Control Block Diagram

The block shows that the controller can vary the actuator (pump 2 on figure 1) which is then read by the level transmitter LT. This is then fed back to the accumulator which continues to the control variable and then continuing the loop.

4.2 Finding calibration curve.

The calibration curve for the level transmitter was created by taking the measurements of the level. Figure 3 shows the calibration curve of the level control of the process tank.

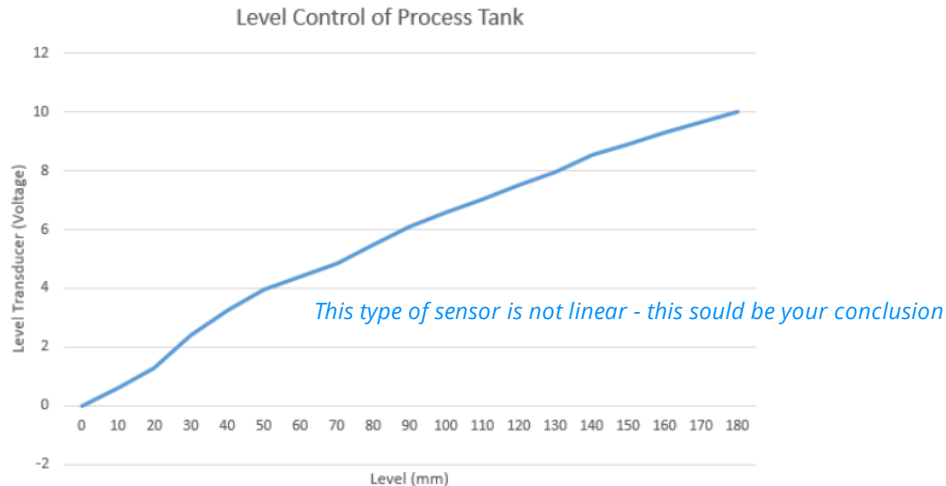


Figure 3 - Level Control calibration curve

Looking at the graph, it shows that as the level rises the ^{voltage} temperature rises. The graph is almost linear however this is potentially due to human error as the pump had to be shut off manually and the reading was taken visually by looking at the measurements on the tank.

4.3 Calculating the time constant.

The time constant (Tau) was found by carrying out an experiment where the level of water in the tank was increased from 0.118m to 0.149mm. Figure 4 shows that as the level increases the VP, VL, and q increase. With these values the outflow resistance (R) can be calculated which is used in the time constant equation.

	VP (Flow Rate - Volt)	VL (Flow Rate - L/Minute)	h (Level - m)	q (Flow Rate - M ³ /sec)
Level A	5.3	7.525	0.118	69.33x10-6
Level B	5.8	8.91	0.149	73.5x10-6
Difference			0.031	4.17x10-6
Area = $\pi r^2 = 0.01767m^3$				
$R = \Delta h / \Delta q = 0.031 / 4.17 \times 10^{-6} = 7434.1$				
$\tau = A \times R = 0.01767 \times 7434.1 = 131.361s$				

Figure 4 - Task 4 Practical

See appendix 9.2.1 for time constant calculation.

4.4 Time constant and gain experiment

The gain can be found by dividing the delta output variable with the delta input variable (delta is the change in the variable).

See appendix 9.2.2 for the Gain (K) calculation. To find the gain, voltage is needed. The 62mm obtained was changed to 6.2V *gain has no units*

See appendix 9.2.1 for the Time constant (T)

	Time Constant (s)	Gain (V)
Calculated	131.361	6.2V
Measured	131.15	N/A

The time constants are almost identical, the measured has a slight minor difference and this is possibly due to the placement of the indicator on the software.

To carry out this experiment to find the time constant, pump 2 was set to 5.5V and the valve was set to 10V which is when it's fully open. The pump voltage was carefully adjusted until the level stabilized above the heat exchanger. Once the level remained stable the height and flow rate were measured (Level A). The pump voltage was increased by 0.5V. The level was monitored until it became stable, the height and flow rate were measured (Level B).

See appendix 9.2.3 for time constant measurement.

4.5 Simulation

A simulation was created from the mathematical model based on the results obtained. A PID control loop was added and tuned for the best performance. (See appendix 9.2.4 for PID control)

A tuning graph and parameters were obtained from the PID (See appendix 9.2.5) the graph shows a slight overshoot in which a peak of 1.15 amplitude is reached at 50 seconds which slowly decreases, regulating at around 1 amplitude at 140 seconds. The PID values obtained were then used for the Process Trainer control method.

what were your tuned values?

4.6 CE117 Process Trainer control method

The control method was implemented on the CE117 Process trainer using the tuned values. These values were used as a starting point, and the tune would regulate the process tank water to a suitable setpoint (8). Disturbances were created to see how this it would regulate it back to the setpoint.

Disturbances:

1. The setpoint was increased from 8V to 8.5V.
2. The valve was slightly closed.
3. The valve was placed back to its original place.
4. The flow in of the valve was decreased from 7V to 6V.

Appendix 9.2.6 shows the performance of the CE117 process trainer with the tuned values. Each disturbance is highlighted.

4.7 Results

Disturbance	Comment
1	Upon raising the setpoint to 8.5V there water rises gradually for around 30 seconds, overshooting the setpoint before decreasing and regulating back to the setpoint.
2	Closing the valve created an overshoot which steadies out before decreasing back down to the setpoint.
3	The 3 rd disturbance creates an undershoot which occurs for around 40 seconds before increasing back to the setpoint.
4	The 4 th disturbance creates the longest undershoot which happens for around 60 seconds before returning to the setpoint where it overshoots slightly and regulates back down to 8.5.

A good explanation of the disturbances

5. Temperature Control of the Heater Tank

5.1 Investigating CE117 Process Trainer.

The heater loop consists of a heater tank and heat exchanger loop. Cold water is pumped through the heat exchanger, the steam enters the coiled tube which heats the water. The temperature of the water is fed back to the PID controller by a thermal sensor. The PID controller is used to adjust the water temperature by changing the percentage open of the steam valve. (See appendix 9.3.1 for P&ID diagram). The diagram contains temperature transmitters (to monitor the temperature) and flow transmitter (to monitor the flow after pump 1).

For the control block diagram (see appendix 9.3.2) 'G' represents the feed forward elements, 'H' the feedback elements, 'R' the input signal and 'Y' the output signal. The controller uses a proportional control strategy with a tuneable gain of K_p .

5.2 Finding time constant and gain of the system

A voltage of 3 and 6 were applied to the heater. The temperature values of these were both taken to find the gain. Figure 5 shows the results obtained, from the experiment. The results show that when the heater voltage is increased the voltage of the temperature sensor raises.

With the gain was calculated by dividing the delta of h and t, the delta is the rate of change.

There is no level in this experiment

	Δh (Heater - V)	Δt (Temperature - V)
Level A	3	2.73
Level B	6	3.185
Difference	3	0.455
Gain = $\Delta t / \Delta h = 0.152$		

Figure 5 - Finding Gain

A graph was produced (see appendix 9.3.3) when the heater voltage was set to 6V. The temperature reached 3.185V over almost 1500 seconds. With this graph the time constant was able to be found. The time constant obtained was 578.92s.

5.3 Simulation.

A simulation of the system was created on Simulink by using a mathematical model based on the results obtained (See appendix 9.3.4). A PID control loop was added and tuned for the best performance.

A graph was produced showing the tuned PID controller (see appendix 9.3.5). The values obtained were then used for the control method. The graph shows the amplitude rising to around 1.04 at around 250 seconds, creating an overshoot before slowly decreasing to an amplitude of 1 over the next 550 seconds.

5.4 Implementing control method.

The recently tuned values were used on the CE117 Process trainer as a starting point. The starting temperature of the water in the heater tank was 30 degrees. Multiple disturbances were carried out to see how the system would react.

Disturbances:

What were your tuned values?

1. Setpoint was changed from 30° to 32° (3V to 3.2V)
2. Pump 2 and the fan were put on –
3. Pump 1's voltage was increased to 7V –
4. The voltage of both pumps 1 and 2 were placed to 3V from 10V.

5.5 Results

Disturbance	Comment
1	Upon increasing the temperature setpoint from 3V to 3.2V the temperature gradually increases to 32° at around 210 seconds then overshooting for around 80 seconds before regulating back down to 32°.
2	No real changes – temperature remains at 32°.
3	Increasing the voltage of pump 1 to 7V created a slight disturbance however this is barely noticeable.
4	Increasing the pumps voltage to 10V made the temperature exceed the setpoint until decreasing back down to 32°

5. Conclusions and Recommendations

Research was carried out on five different PID loop tuning methods. Once the methods were researched one was chosen as the method for the first order system investigated in this assignment. In this case model-based tuning was selected due to its advantages and overall efficiency and accuracy.

Investigation was carried out on the CE117 Process Trainer, this includes creating P&ID diagrams and control block diagrams which show how the level in the process tank is regulated. A calibration curve was found by adjusting the voltage of the level transducer which gave an almost linear graph proving that as the voltage is increased the level increases. The time constant for the system was calculated and measured; the difference was miniscule. An experiment was carried out to find the gain of the system by comparing the values at two different water levels. A simulation was then created using a mathematical model based on the results obtained. The system was tuned by adding a PID control loop. The tuned values obtained were used on the CE117 Process trainer to regulate the water level. Disturbances were added to see how the system would perform and regulate back to the setpoint.

A second investigation was carried out on how the temperature of the water in the heater tank is regulated on the CE117 Process Trainer. A P&ID diagram and control block diagram were created showing the operation of the heater loop. An experiment was carried out to find the time constant and gain of the system, this was achieved. With the results obtained a simulation was produced from a mathematical model. A PID control loop was added and tuned for the best performance. These tuned values obtained were then implemented on to the CE117 Process Trainer as a starting point. Once again disturbances were added to see how the system would manage under different circumstances.

A recommendation would be to perform another researched tuning method for example the Ziegler-Nichols method. This would allow them to be compared, viewing their advantages and disadvantages. This could be beneficial in expanding the users knowledge on PID tuning.

A good set of conclusions

7. Team Working

Parts of the assignments practical tests involved team working to carry out experiments, this has allowed for different perspectives, knowledge and skills to be used throughout which allows for creative and innovative solutions. Each member had a responsibility, and it is important to have a clear understanding of these responsibilities. For example, during the calibration curve practical one person was operating the potentiometer changing the voltage, one person was measuring the level of water in the tank and the other member was tabulating the results. Communication is also key throughout these tasks as every member must be kept informed and any issues can quickly be addressed.

How did you treat each other?

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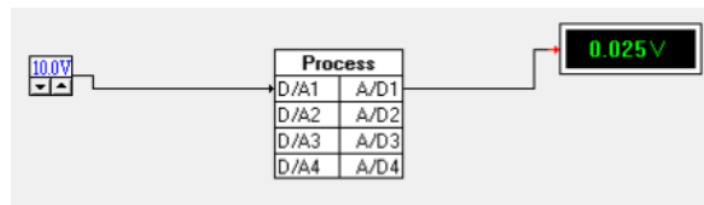
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9. Appendix

Level (mm)	LT (Voltage)
0	-0.02
10	0.6
20	1.3
30	2.38
40	3.22
50	3.95
60	4.39
70	4.84
80	5.49
90	6.08
100	6.59
110	7.03
120	7.54
130	7.98
140	8.54
150	8.9
160	9.3
170	9.66
180	10



9.2

9.2.1

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

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

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

$$\tau = \text{Area} \times R$$

$$= 0.01767 \times 7434.1 = 131.361 \text{ sec}$$

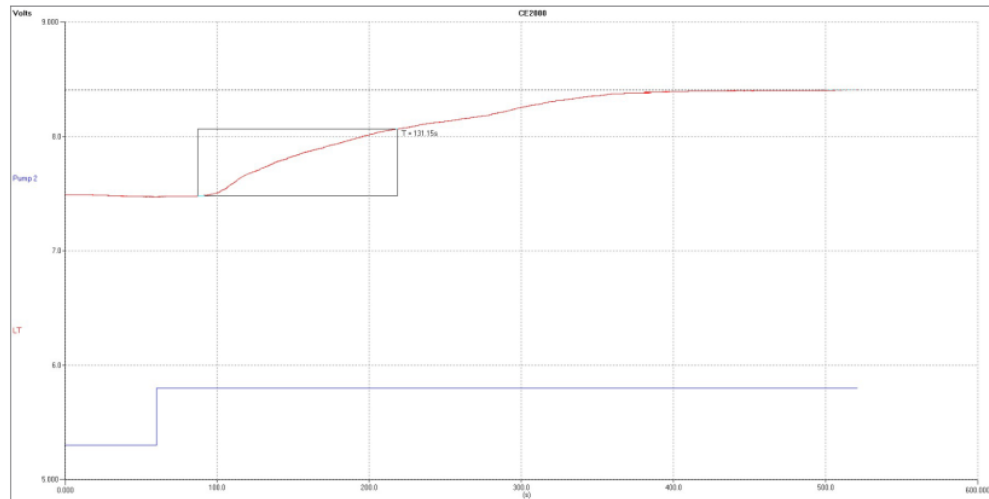
9.2.2

gain has no units

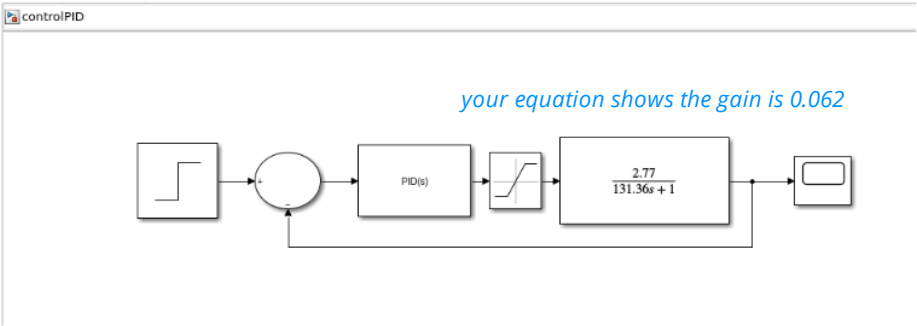
$$K = \frac{\Delta h}{\Delta VP} = \frac{0.031}{0.5} = 62 \text{ mm}$$

the gain should be 0.062
if these values are correct

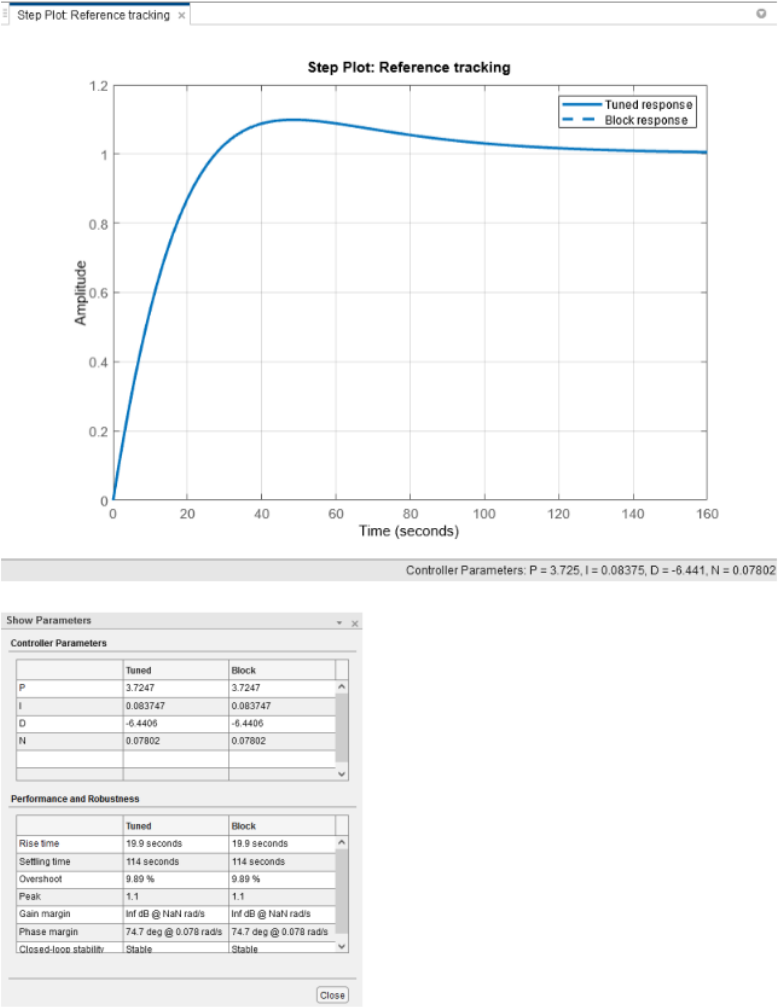
9.2.3



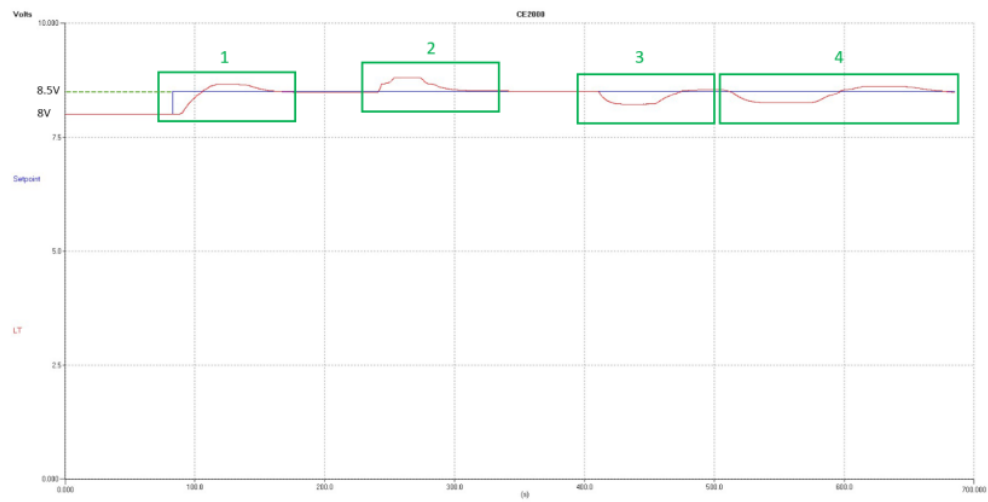
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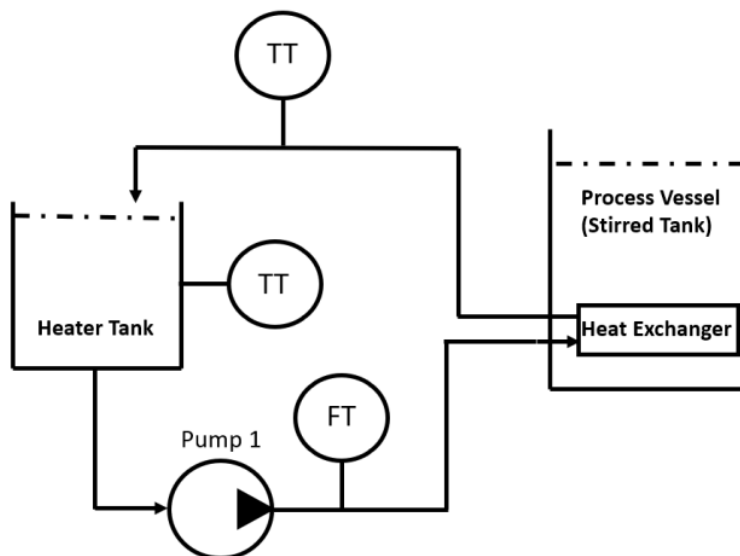
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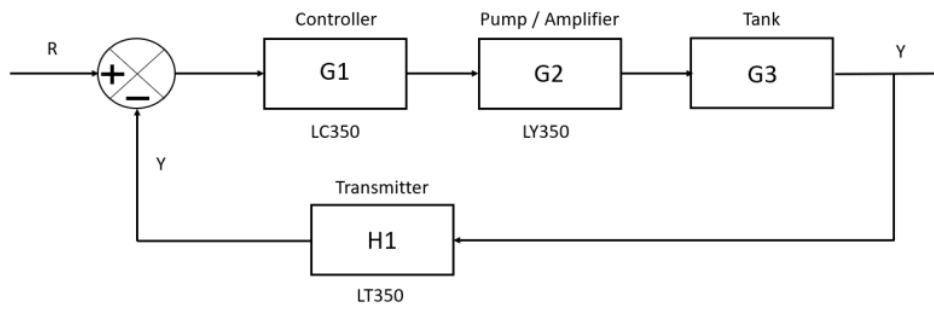
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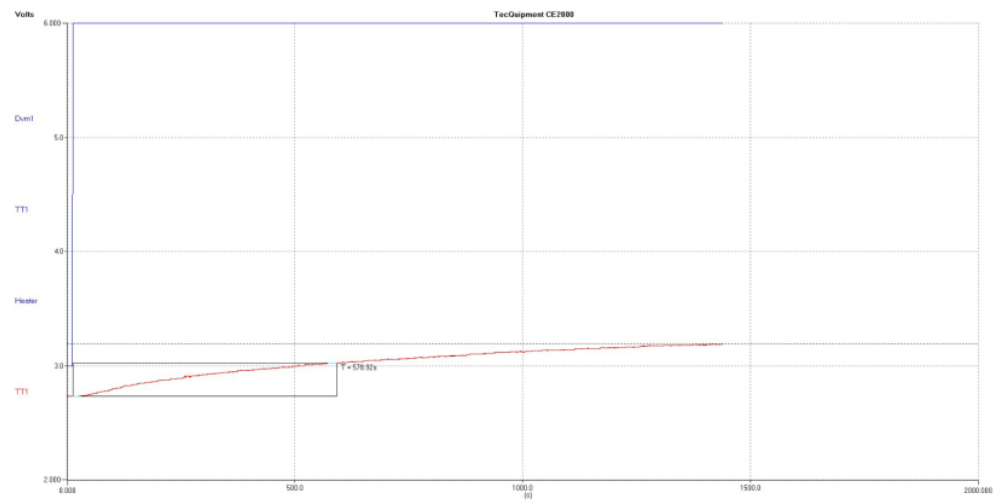
9.3.1



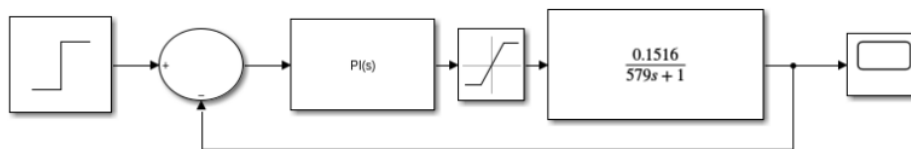
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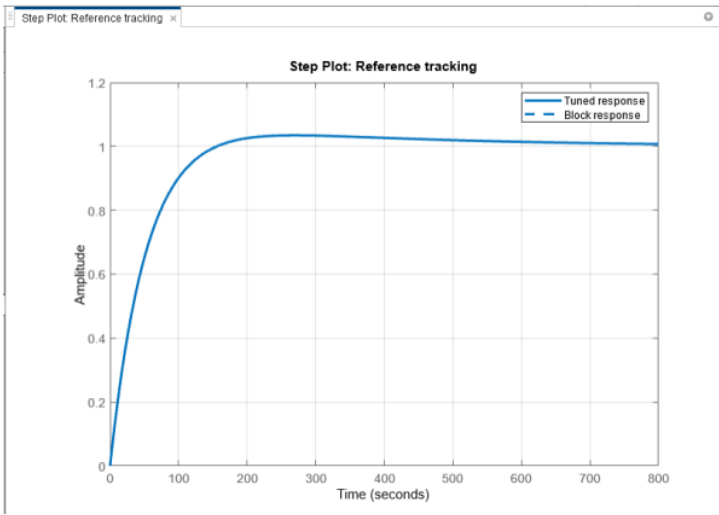
9.3.3



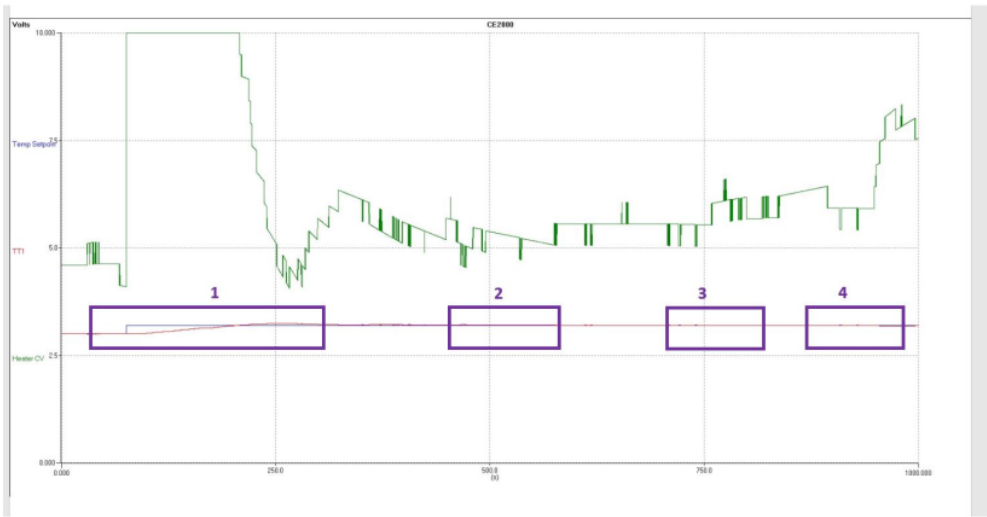
9.3.4



9.3.5



9.3.6



FINAL GRADE

GENERAL COMMENTS

Instructor

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PAGE 1

PAGE 2

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Good Structure

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PAGE 3

PAGE 4

PAGE 5

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Punctuation Error

Punctuation error

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PAGE 6

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PAGE 7

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Correctly cited

Citation method conforms to Harvard standard, well done.

QM

Correctly cited

Citation method conforms to Harvard standard, well done.

QM

Correctly cited

Citation method conforms to Harvard standard, well done.

QM

Correctly cited

Citation method conforms to Harvard standard, well done.

QM

Correctly cited

Citation method conforms to Harvard standard, well done.

QM

Correctly cited

Citation method conforms to Harvard standard, well done.

PAGE 8

QM

Correctly cited

Citation method conforms to Harvard standard, well done.

QM

Correctly cited

Citation method conforms to Harvard standard, well done.

QM

Correctly cited

Citation method conforms to Harvard standard, well done.



Correctly cited

Citation method conforms to Harvard standard, well done.

PAGE 9



Good conclusions

You have shown understanding here from these observations and deductions

PAGE 10

PAGE 11

Text Comment. This type of sensor is not linear - this could be your conclusion

Text Comment. voltage

PAGE 12

Text Comment. gain has no units

Text Comment. what were your tuned values?

PAGE 13

Text Comment. A good explanation of the disturbances

PAGE 14

Text Comment. incorrect, this is an electric heater

Text Comment. which type?

Text Comment. electric heating element is controlled by a solid state relay

Text Comment. There is no level in this experiment

PAGE 15

Text Comment. What were your tuned values?

PAGE 16

Text Comment. Matlab Simulink Model

Text Comment. A good set of conclusions

PAGE 17

Text Comment. How did you treat each other?

PAGE 18

QM

Good range of sources

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

QM

Correct method of listing.

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

PAGE 19

PAGE 20

PAGE 21

Text Comment. gain has no units

Text Comment. the gain should be 0.062

Text Comment. if these values are correct

PAGE 22

Text Comment. your equation shows the gain is 0.062

PAGE 23

PAGE 24

PAGE 25

GRADING FORM: NEW CSG-RUBRIC

HARRI JONES

1. ENGAGEMENT WITH LITERATURE

-  Report section 3 and 8 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

-  All report sections and particularly sections 3, 4 and 5 Generally good evidence of understanding in your report overall but this is not always the case in your Research and your explanation of your Level Control of the Process Tank and Temperature Control of the Heater Tank experiments since there are some misconceptions. 10/20 **10**

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. 12/20 **12**

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. 12/20

12

5. TRANSFERABLE SKILLS



All report sections, but particularly sections 1, 2, 7 and word count penalty. Good report style, presentation, use of grammar, spelling and punctuation. Clear executive summary, good work plan (reflection not needed in a plan) and explanation of team working(though you have not said how you treated each other). Word count not exceeded. 13/20

13