EMS507U - Control System Analysis and Design

CONTROL EXPERIMENT ON WATER-LEVEL CONTROL OF A WATER TANK

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0 - Abstract
This report is about a experiment using a PID controller to manage the level of a water tank in order to examine the performance of closed-loop and open-loop control systems. Our assignments included learning about the control system, utilising MATLAB to construct a PID controller, and doing practical tests to determine the control system's efficiency. Two processes were carried out: a closed-loop test to adjust the water level using PID tuning, and an open-loop step response test measuring time constants and familiarization with the system. The outcomes demonstrated the need of PID tuning for stability, which was investigated further using simulations for ideal control circumstances.

Contents

1 - Introduction

Using the capabilities of SIMULINK software, the main goals of this project are to develop and construct a PID controller and assess its control performance in a simulated environment. In addition, the goal of this study is to provide participants with the fundamental theoretical and practical understanding required for the creation and implementation of real-time control systems. Increasing our comprehension of PID controller tuning techniques and making sure they know how to optimise controller performance to get the results we want quickly and effectively is another objective. By illustrating the use and optimization of PID controllers, a key component in automated and real-time system regulation, this work consequently advances the subject of control systems engineering.

Proportional-integral-derivative controllers, sometimes referred to as PID controllers, are essential electrical devices used in the closed-loop system of output regulation. It ensures consistent management of the principal output by continuously monitoring and correcting deviations that might compromise the intended output. This approach is essential to maintaining system stability and performance since it closely complies with the set goals.

The purpose of this experiment was to examine and clarify the behavior of a control system that is responsible for maintaining the water level in a vessel. The study was separated into two main sections. The first section examined an open loop system in which human voltage changes were required to maintain a constant water level. The next section investigated a closed loop system that automated the water level management using a PID controller.

2 - Experiment explanation

2.1 - Experiment 1 - Open loop system

The first setup of the experiment, the Pump voltage altered to calculate the time constant. An open-loop control system was used and it operates based on an input and control actions. It does not use feedback to determine whether its output has successfully attained the intended objective of the input command or operation meaning the output has no impact on how the control system behaves(Franklin et al., 2014).

In this experimental setup, a reservoir functioned as the main store for water. The Pump facilitated the transfer of water from the reservoir to the process vessel. The flow rate of this transfer procedure was accurately regulated using the CE2000 software, enabling the manual manipulation of the pump's voltage. The voltage of the flow was lower than that of the pump due to the pump's less-than-perfect efficiency. A ruler was firmly affixed to the outside of the vessel in order to gauge the water level, enabling precise measurements of its height. After the water level exceeded the minimal requirement and completely covered the coil, and once the level had become stable, the height was recorded. This is referred to as level A. Subsequently, the voltage of the pump was augmented by 0.5 V and the procedure was repeated, resulting in the acquisition of a new measurement of height, referred to as level B.

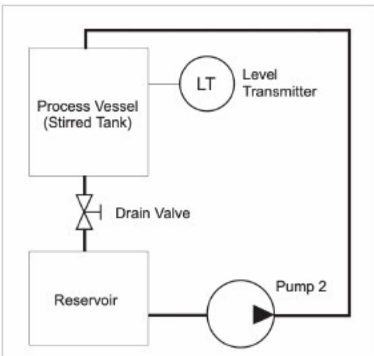


Figure 1. Schematic Diagram of open loop system (reference)

Figure 1 shows the link between the drain valve and the reservoir through a process vessel and the level transmitter. The drain valve facilitated the effective removal of water. from the vessel, resulting in a reduction in the water level. The level transmitter converts analogue data into electrical signals, effectively translating the height of the water level into measurable voltage. The software accurately captured this transformation and generated detailed data on voltage, time, and level transmitter readings. Thorough gathering of this information the time constant, could e determined which was a primary objective of the experiment.

2.2 - Experiment 2 - Closed loop system
In the closed loop system, the objective was to control the level in the process vessel using a PID controller. A closed-loop control system is characterised by the monitoring and feedback of the system's output, which enables the system to make necessary adjustments in order to obtain a desired output. The feedback loop allows the system to automatically adjust any deviations from the desired performance, hence providing improved precision and stability throughout operation (Electronics Tutorials, 2018).

A level controller has been added to Figure 2 to illustrate this. The water initially flowed through pump from the reservoir to the process vessel, following the same procedure as in part one, but with a closed loop this time. The PID controller values were modified using the CE2000 software, and the PID's setpoint values were set to 6 Volts then the values were raised to 6.5 Volts where the system began to process the data until a steady state was reached and was decreased to 6 volts let the system stabilize.

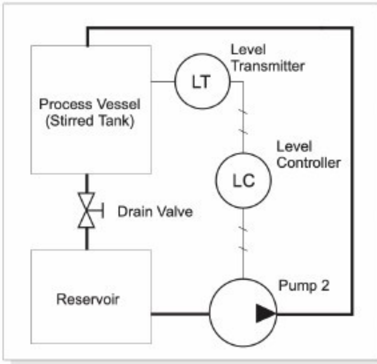


Figure 2. Schematic Diagram of closed loop system (reference)

3 - Simulations
Through the use of MATLAB and add-on Simulink, simulations could be run through the creation of block diagrams for the different experiments.

3.1 - Open loop system
For a simulation to be run, a block diagram (figure 3) was needed to be made. It is split into 3 different blocks. The first (left most block in figure 3) is the step which type of source block that outputs a signal which changes from one specified value to another at a specified time (Generate Step Function - Simulink, n.d.). It had a initial value of 4 volts and final value of 4.5 volts. The middle block is the transfer function which allows the linear relationship between an input and an output signal to be modeled (Model Linear System by Transfer Function - Simulink, n.d.). The last block is known as the scope block which graphically display signals during simulation.

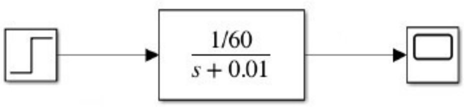
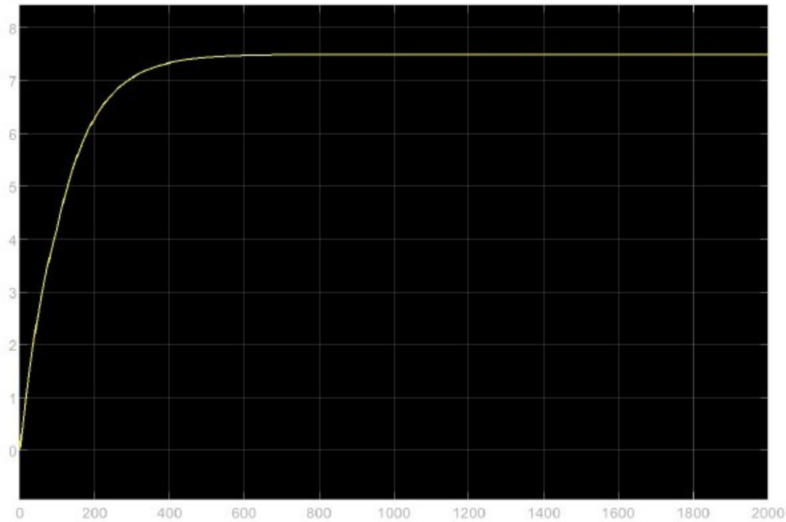


Figure 3. Block Diagram of open loop system



Graph 1. Graph using simulink for open loop system. Time (s) vs Voltage (V)

Once run, Graph 1 is created using the scope block and shows the LT (Level transmitter) value plotted against time. The LT value is rising until 500 seconds where it starts to stabilize.

3.1 - Closed loop system

Similar to the open loop system, a simulation to be run, a block diagram is needed. However more blocks are needed for like a sum, which is used to add or subtract input signals. A PID block is required which acts as a PID. There is also a mix block needed which combines multiple input signals into a single output signal by stacking them, effectively creating a vector or an array from the inputs (Combine Input Signals of Same Data Type and Complexity into Virtual Vector - Simulink, n.d.).

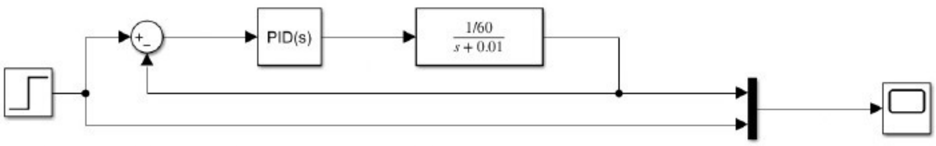
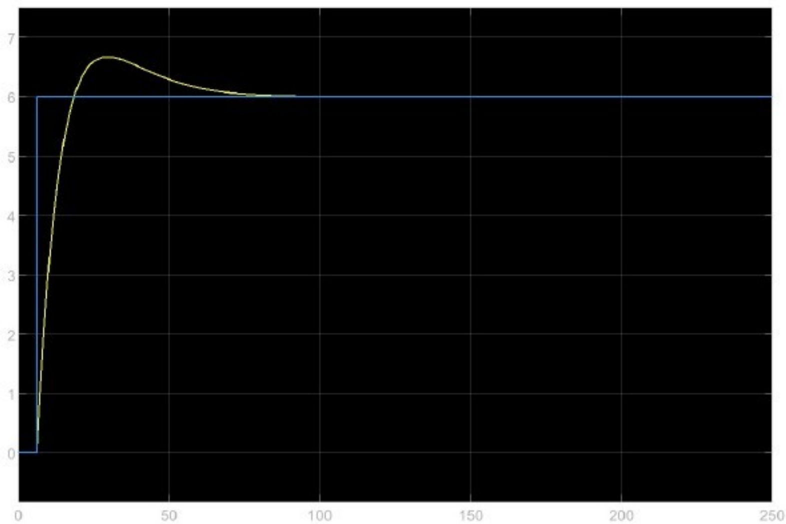
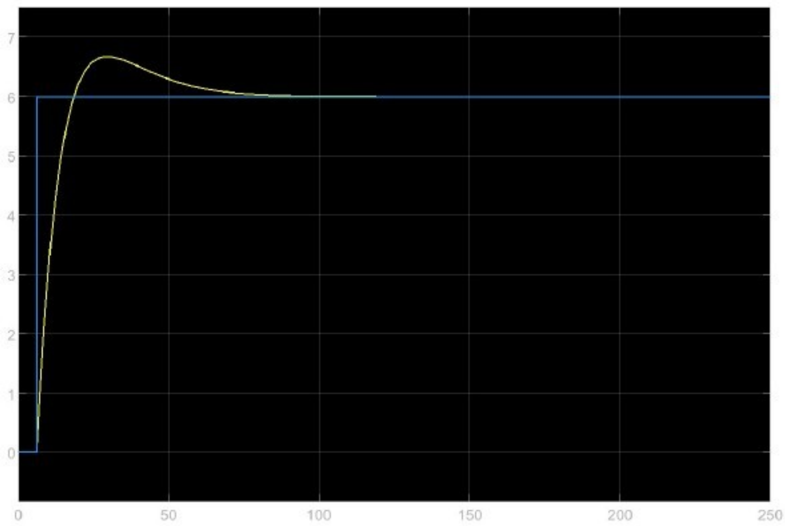


Figure 4. Block Diagram of Closed loop system



Graph 2. Graph using Simulink for closed loop system for given PID values (P=10, I=0.5 and D=0) Time (s) vs Voltage (V)



Graph 3. Graph using Simulink for closed loop system for my PID values (P=10, I=0.5 and D=0.1) Time (s) vs Voltage (V)

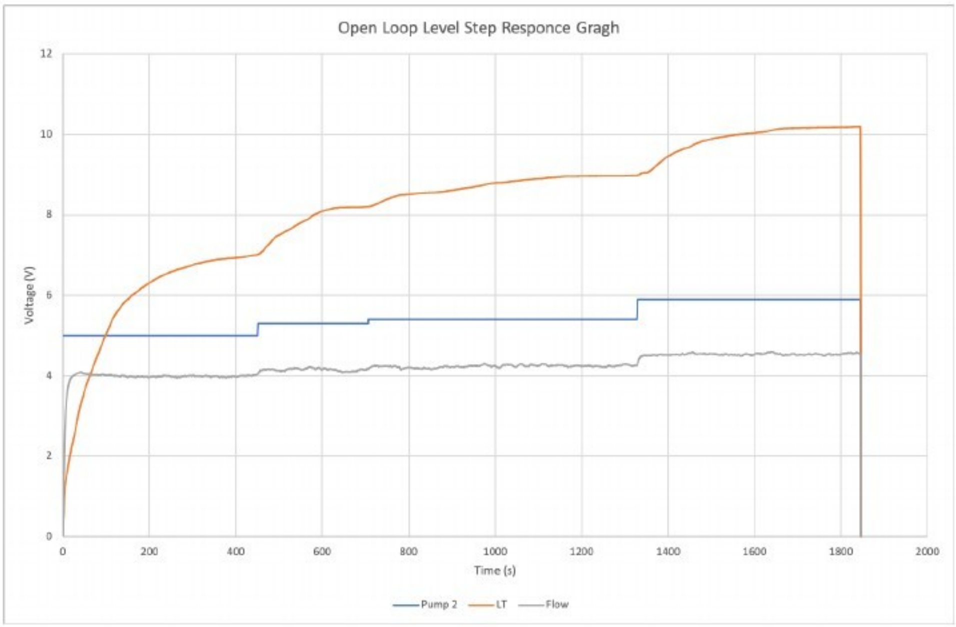
The simulation was run twice with different PID values, showing the LT (Level transmitter) value and set point plotted against time.

4 - Results

4.1 - Experiment 1 - Open loop system

Table 1 -Processed data from Open loop system experiment

	Pump Voltage (V)	Flow Voltage (V)	Flow rate (m^3/s)	Water Level (m)
Level A	5.4	4.3	7.17×10^{-5}	0.122
Level B	5.9	4.6	7.67×10^{-5}	0.158
Difference	0.5	0.3	5×10^{-6}	0.036



Graph 4 - A voltage against time graph with given PID values

To work out the theoretical time constant of the process vessel τ in seconds. First the area (S) is calculated as shown below:

$$S = \pi(\frac{D}{2})^2 = \pi * (\frac{0.15}{2})^2 = 0.017671459m^2$$

Then Calculate outflow resistance (R):

$$R = \frac{\Delta h}{\Delta q} = \frac{0.036}{5 * 10^{-6}} = 7200$$

Then finally calculating the theoretical time constant is shown below:

$$\tau = RS = 0.017671459 * 7200 = 127.2345025 \text{ s}$$

Looking at graph 4 the raw data, we could estimate the experimental time constant. It is approximately 63.2% of the time to reach Level B. We can see the LT value reaches level A at 1334s which is equal to 9V and reaches level at 1805.4s which is equal to 10.18V.

$$\Delta LT = 10.18 - 9.00 = 1.18V$$
$$9 + (1.18 * 0.632) = 9 + 0.746 = 9.746\text{V}$$

Looking at the graph we can see that at 9.746V, we see the time is 1472s.

$\tau_{experimental} = 1472 - 1334 = 138s$

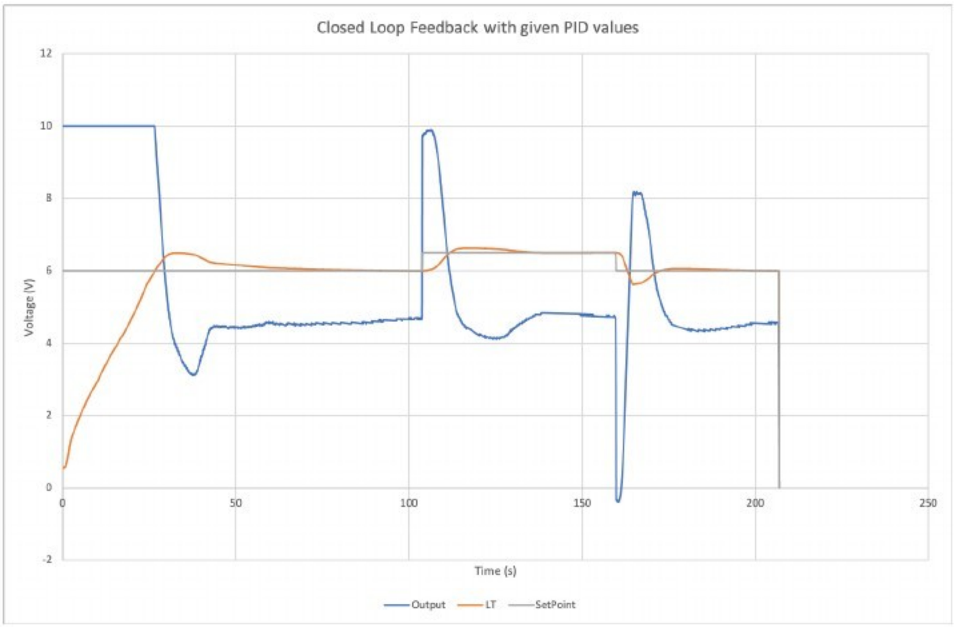
$$Percentageerrror = \frac{127.23 - 138}{127.23} * 100 = 8.4\%$$

Table 2-Processed data from Open loop system experiment

Process vessel diameter	0.15 m
Area	0.017671459 m^2
Outflow Resistance	7200
$\tau_{theoretical}$	127.2345025 s
$\tau_{experimental}$	138 s
Persentage difference	8.4%

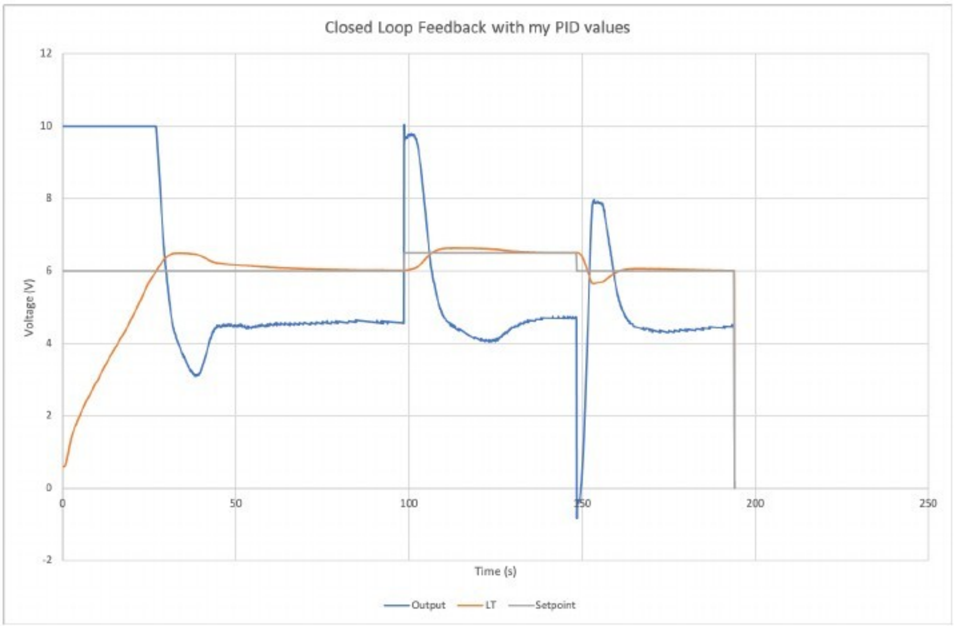
4.2 - Experiment 2 - Closed loop system

With the shift of objective to control the water levels in the process vessel with the use of a PID controller, there were multiple runs with various PID values. The first run, results shown in graph 5, had the predetermined PID values of P=10, I=0.5 and D=0.



Graph 5 - A voltage against time graph with given PID values

Following the first run, other runs were done with a slight different PID Values. The second run values were similar however there was a slight increase in the derivative value. The second run, results shown in graph 6, had PID values of P=10, I=0.5 and D=0.1.



Graph 6 - A voltage against time graph with my PID values

5 - Discussion

5.1 - Experiment 1 - Open loop system

Comparing graphs 1 and 4, we can see a nearly identical overshoot. In graph 1 we see the LT rise to 7.5 volts and begin to stabilize only taking it 500 seconds, however looking at the graph 4 we see an initial overshoot to 7 volts in 450 seconds. Once both have reached the peak initial voltage, they both begin to stabilize before the voltage is changed for the experiment.

One of the main objectives was to work out the timed constants which was achieved 2 different ways. The theoretical way was solved by multiplying the area of process vessel to the outflow resistance. This method achieved a time constant of approximately 127.23 seconds. A second way of working out the time constant was through the graphs and simulations achieved. It could be solved by finding 63.2% of the difference between the level transmitter values between level A and level B in volts and then converting into seconds. This was estimated to be 138 seconds. We can see a difference of 8.4% which could be due to many reasons. First, while the experimental setup may show non-linear characteristics, especially at different operating levels, the theoretical time constant is determined under ideal conditions assuming linear system dynamics. Second, the reported response time may be increased by the existence of unanticipated delays in the system, such as sensor lag or actuator delay. External factors may also be important, such as changes in temperature that impact fluid viscosity and, consequently, flow rate. The disparity is also a result of the pump's mechanical constraints and system inertia, which can reduce the system's responsiveness to changes in input.

However, we know that the use of a feedback controller can solve many of the issues faced. The first being stability as a Feedback controller is need to matin system stability. It prevents the system from reaching undesirable states. It also minimizes errors by monitoring the output of a system and comparing it with the desired set point, feedback control leading to more accurate and precise results. Feedback controller can also adapt to changes in the system parameters or the environment making it reduce errors.

5.2 - Experiment 2 - Closed loop system

In graphs 5 and 6, we can see two closed-loop control processes using different PID values. Overshoots, in which the output exceeds the setpoint, are visible in both graphs. This is a typical occurrence in control systems, particularly those with significant proportional gains, which can make the system respond violently to errors. My PID values (P=10, I=0.5, and D=0.1) appear to have a slightly smaller overshoot on the graph, suggesting that the derivative term's placement has assisted in the controlling oscillations. A balance between the proportional and integral proportional actions frequently causes a PID-controlled system's oscillations. Moreover, adding a derivative term appears to speed up the system's initial launch and settlement after a disturbance. This is due to the derivative term's ability to predict the rate of change of the error and apply corrective action before the error gets out of hand. Neither system appears to consistently deviate from the setpoint once it reaches a steady state. Any steady-state error is probably compensated for by the integral term (I). The fact that there is no apparent steady-state error and the integral gain is the same in both situations (I=0.5) indicates that the integral term successfully removes these mistakes. There are moments in the graphs where the output deviates sharply from the setpoint due to changes in the voltage done through the CE2000 software. The term noise describes abrupt, haphazard variations in the system's output. The derivative term can make these worse because it responds quickly to changes in the error, which could include noise. This effect shows itself in your system as jittery output signal behavior. It is a typical side effect of applying derivative control, and in real life, it can be lessened by adjusting the derivative gain or adding a filter.

Furthermore, comparing the simulation to the experiment, we can see more oscillatory compared to the simulation which could be due to several reasons. Simulations are based on mathematical models that may not capture all the complexities of a real system. Real world systems are subject to disturbances and noise that are often not considered in simulations. In an actual system, there may be delays in sensing and computation that can affect the control response.

So, we can see tuning a PID controller is often a balancing act. The derivative term can adjust the system's behavior to prevent overshoot and excessive oscillations, while the proportional term provides the system responsiveness, and the integral term guarantees the correction of steady-state mistakes. But the term also increases the system's sensitivity to measurement noise. Adding a small derivative term (D=0.1) in your PID settings seems to have had a positive effect on the control system's performance by reducing overshoot, dampening oscillations, and providing a faster response to disturbances at the expense of introducing a bit of noise in the output.

If certain errors had not been made, the outcomes might have been better. A common error is known as a parallax error where, when you attempt to read a measurement on a ruler from the incorrect angle, this usually happens. Using tools that aren't correctly calibrated or set up might also lead to inaccurate measurements. The large percentage difference between our experimental observations and the predicted theoretical ones would be much smaller if we could lower these mistakes. By taking more readings, we might further enhance our results and increase the certainty of our final data.

6 - Conclusion

The lab experience was really beneficial. We achieved all of our objectives, which included getting to know the process vessel and figuring out the time constant—a crucial goal for the initial experiment. Additionally, we compared theoretical and experimental time constants and created simulations using MATLAB. Even though the theoretical and experimental time constants differed significantly, I believe that if the experiment were redone in a more favourable environment, the results would still be improved.

The second experiment's goal was to use a PID controller to regulate the liquid level in the process vessel and track the effects on the system. We discovered that attaining optimal performance in a PID controller requires fine-tuning. Because simulations can be conducted more quickly, cheaply, and easily than experiments, using SIMULINK and MATLAB for simulations has proven to be very beneficial.

7 - References

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