

LEVEL 4 ASSESSMENT SPECIFICATION

Student name:	Beau Lawrence	Student ID number:	
Programme:	HNC Instrumentation Engineering		
Module:	Instrumentation, Automation and Control		
Module code:	PCEE4009	Contribution to Overall Module Assessment (%):	50%
Lecturer:	Jason Pointer	Internal Verifier:	Nigel Richards
Assignment Title:	Control Systems	Word count (or equivalent):	2000
Submission deadline:	15/05/25	Return date of provisional marks & written feedback:	29/05/25
Submission method:	All written assessments, where practical and possible, must be submitted via Turnitin unless otherwise instructed by the Lecturer. (Please DO NOT put this assessment specification into Turnitin or it will match many similarities with other students' submissions.) Alternative submission method (if applicable): Late submission of the assessment will result in a late penalty mark: Work which is submitted up to 1 week late will be capped at 40% for the first attempt and will be awarded a mark of 0% for re-assessment. Late submission penalties may be lifted only if there is an approved extenuating circumstances claim. Work submitted more than 1 week late will be considered as a non-submission and will not be marked. The work may be considered as a submission for reassessment if offered by an Examining Board or if there is an approved extenuating circumstances claim.		
Academic honesty / referencing:	Academic honesty is required. In the main body of your submission you must give credit to authors on whose research and ideas your work is based. Append to your submission a reference list that indicates the books, articles, etc. that you have used, cited or quoted in order to complete this assessment.		

Module Learning Outcomes (from module syllabus)

3. Demonstrate an understanding of control strategy & tuning methods to meet an industrial application process.

STUDENT FEEDBACK FORM

This section details the *extent* to which the assessment criteria are demonstrated by you, which in turn determines your mark. The marks available for each category of skill are shown. Lecturers will use the space provided to comment on the achievement of the task(s), including those areas in which you have performed well and areas that would benefit from development/improvement.

Generic Assessment Criteria	Marks available	Marks awarded
1. Engagement with Literature Skills	20	13
Engagement with a wide range of literature, including sources retrieved independently. Generally sound referencing, with very few inaccuracies or inconsistencies.		
2. Knowledge and Understanding Skills	40	25.8
Task 1 - 55%. Task 2 - 68%. Task 3 - 65%. Task 4 - 70%. Competent knowledge of the underlying concepts and principles is accurate with a good understanding of the concepts of each task but in places there needs to be more detail.		
3. Cognitive and Intellectual Skills	10	5
Good evaluation of the underlying concepts and principles for tasks 2 and 3.		
4. Practical Application Skills	20	16
Task 1 - 80%. Task 2 - 80%. An excellent application of practical work for tasks 2 and 3, very good use of Scilab to obtain the required test results for the position controller and tuned system.		
5. Transferable Skills for Life and Professional Practice	10	6.6
Work is accurate, coherent, fluent, well-structured and organised.		

Assessment Mark (Assessment marks are subject to ratification at the Exam Board. These comments and marks are to give feedback on module work and are for guidance only until they are confirmed.)

Late Submission Penalties (tick if appropriate)

Up to 1 week late (40% Max)

Over 1 week late (0%)

66%

Instrumentation, Automation and Control assignment 2

HNC Instrumentation Engineering

Lecturer - Jason Pointer



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Task 1

A - In an **open-loop system**, the input is selected based on the prior experience with the system to achieve a desired output. However, the system does not adjust the output in response to changing conditions. ✓

An **open-loop control system** operates without using feedback from the process variable. For instance, in a heat exchanger heating crude oil, the flow rate of the heating medium, like steam or hot water, is manually set by the operator. This flow rate is set by the manipulated variable and is manually adjusted to achieve a target crude oil temperature. The temperature of the crude oil leaving the heat exchanger is measured as the process variable, however, this measurement is not used to automatically regulate the heating medium flow. The desired crude oil temp, or setpoint, may be 100°C, but since no feedback is involved, the system relies on the operators manual input and not automatic adjustment in response to changes in process conditions. ✓

Basic Elements of an Open-Loop System

An open-loop system typically consists of a series of basic subsystems, as illustrated in Figure 2.

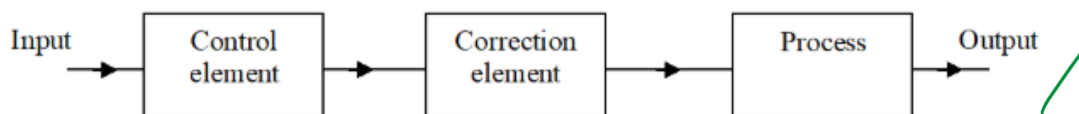


Figure 2

These items may not be distinct, separate, items of hardware but all the functions of the subsystems will be present. The overall input to the system is a signal which, based on experience, is likely to lead to the required output. The subsystems are:

- 1) Control element This element determines what action is to be taken in view of the input to the control system. ✓

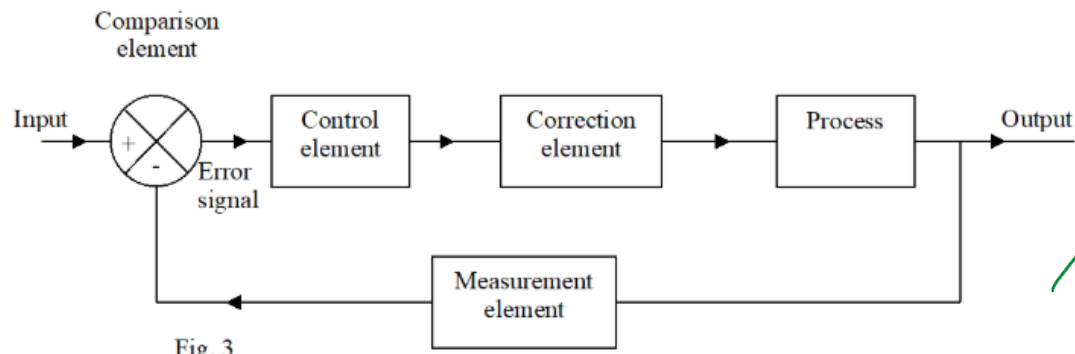
- 2) Correction element This element responds to the input from the control element and initiates action to change the variable being controlled to the required value.
- 3) Process The process or plant is the system of which a variable is being controlled.

The first two subsystems above are often combined into an element called a controller.

B- a closed-loop system includes feedback: a signal from the output is returned to the input and used to adjust it, thereby maintaining the output at a desired level despite changes in external conditions.

In this specific system, using the example of a heat exchanger, the process variable is continuously monitored and used to adjust the manipulated variable to maintain the desired setpoint. In this case, the crude oil temperature at the heat exchanger outlet is measured by a temperature sensor. This measurement is fed back to a PID controller, which compares the actual temperature with the setpoint, for example, 100°C. The controller then adjusts the flow rate of the heating medium in relation to the error (Setpoint vs Process Variable) by modulating the controller output to a control valve to increase/ decrease the heating medium input as needed. This feedback loop enables the system to respond to disturbances or changes in operating conditions, ensuring the crude oil temperature remains close to the setpoint.

A closed-loop system can be considered to consist of a number of basic subsystems arranged as shown in Fig. 3.



These items may not be distinct, separate, pieces of hardware but all the functions of the subsystems will be present. The overall input to the control system is the required value of the variable and the outcome is the actual value of the variable.

- 1) Comparison element This compares the required or reference value of the variable being controlled with the measured value of what is being achieved and produces an error signal which indicates how far the value of what is being achieved is from the required value.

Error signal = reference value signal - measured value signal

- 2) Control element: This element decides what action to take when it receives an error signal. The term controller is often used for an element incorporating the control element and the correction unit.
- 3) Correction element: This element is used to produce a change in the process to remove the error and is often called an actuator.
- 4) Process element: The process, or plant, is the system of which a variable is being controlled.
- 5) Measurement element This produces a signal related to the variable condition being controlled and provides the signal fed back to the comparison element to determine if there is an error.

A necessary feature of a closed-loop control system is a feedback loop. This is how a signal related to the actual condition being achieved is fed back to be compared with the reference signal. The feedback is said to be negative feedback when the signal which is fed back is subtracted from the reference value, i.e.

Error signal = reference value - feedback signal

Negative feedback is necessary for control to be achieved. Positive feedback occurs when the signal fed back is added to the reference value, i.e. /

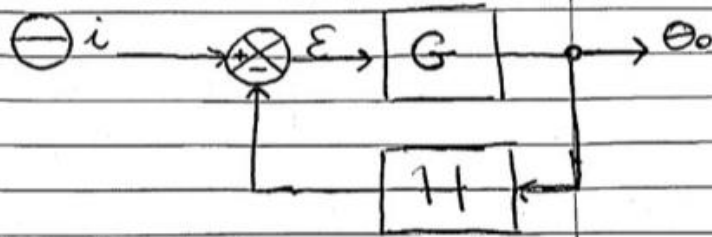
Error signal = reference value + feedback

In Fig. 3 the feedback signal is combined with the reference value at the comparison element. The comparison element is indicated by a circle with a cross, this being the general symbol for a summation element. With the comparison element there is negative feedback and so the reference value is marked as a positive signal and the feedback signal as negative so that the output from the summation element is the difference between the signals. If there was positive feedback at a summation element then both signals would be marked as being positive. /

Open-loop systems are generally simpler, more cost-effective, and reliable due to their straightforward design. However, they tend to be less accurate because they lack error correction. Closed-loop systems, while more accurate due to their ability to adjust based on feedback, can face issues such as delays in response. These delays may result in corrective actions being applied too late, potentially causing oscillations or instability. Additionally, closed-loop systems are more complex, making them costlier and more prone to failure due to the increased number of components. /

Good.

Closed loop system.



$$\Theta_o = \epsilon \times G$$

$$\epsilon = \Theta_i - \Theta_o \times H$$

$$\epsilon = \frac{\Theta_o}{G}$$

$$\frac{\Theta_o}{G} = \Theta_i - \Theta_o \times H$$

$$\Theta_o = G(\Theta_i - \Theta_o H)$$

$$\Theta_o = G\Theta_i - G\Theta_o H$$

$$\Theta_o \mp G\Theta_o H = G\Theta_i$$

$$\Theta_o (1 + GH) = G\Theta_i$$

$$\frac{\Theta_o}{\Theta_i} = \frac{G}{1 + GH}$$

Figure 4

Next time try using
Equation Editor.

C - Combining all three modes of control

- **Proportional**
- **Integral**
- **Derivative**

Allows a controller to be produced which has no steady state error and decreases the tendency for oscillations. This controller called a PID controller or three mode. The equation describing its action:

$$\text{controller output} = K_p \times \text{error} + K_i \times \text{integral of error} + K_D \times \text{rate of change of error}$$

where 'Kp' is the proportionality constant, 'Ki' the integral constant and 'KD' is the derivative constant. The above equation can also be shown as:

$$\text{PID controller output} = K_p \left(\text{error} + \frac{1}{T_i} \text{integral of error} + T_D \text{rate of change of error} \right)$$

A PID controller can be a proportional controller which has integral control to eliminate the offset error and derivative control to reduce time lags.

PID process controller

Figure 5 shows the basic elements that are typically on the front face of a three term process controller. The controller works in three modes by pressing the relevant key:

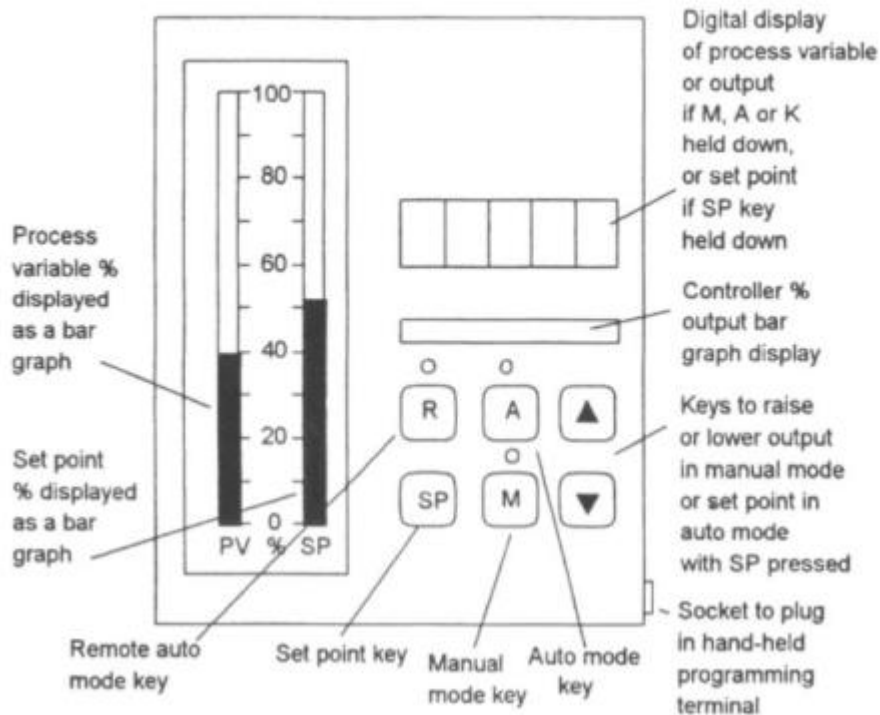


Figure 5 – front face of a three-term process controller.

1 In 'manual mode' the operator directly controls the operation and can increase/decrease the controller output signal by holding down the M key and pressing the up/down keys, A LED above the key shows when this mode has been chosen. The output will be shown on the digital display and on the bar graph display.

2 Automatic mode. The controller works as a three-term controller with a set point specified by the operator. A LED above the key shows when this mode has been selected. The digital display shows the set point value when the SP key is depressed, and the value changed by pressing the up/ down keys. The display shows the set point value in units such as $^{\circ}\text{C}$, the unit previously having been set up to give such values in the set up procedure. The set point is also shown on the vertical bar graph as a percentage.

3 Remote automatic mode. The controller is operated in a similar way to the automatic mode but with the set point established by an external signal. A LED above the key displays when this mode has been selected.

When no key is depressed, the process variable is displayed on the digital display and also on the vertical bar graph. ✓

Should really be talking about the concept of PID control.

The procedure when using the controller is to initially set the mode as manual. The set point is then set to the required value and the controller output manually adjusted until the deviation is zero and the plant thus operating at the required set point. Figure 6 shows the block diagram of the control system when it's operated in manual mode and the operator adjusting the controller output by adding in a signal, The controller can then be switched to automatic control. When this happens, the manual input signal is held constant at the value that was set in manual mode.

Switching back to manual mode from automatic mode to make some adjustment and then back

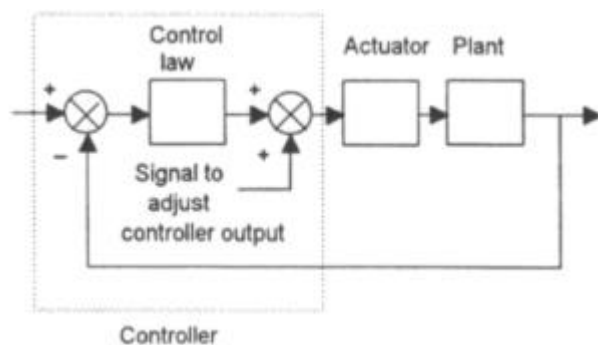


Figure 6 – block diagram

to automatic mode gain can present an issue. There can be a sudden change in controller output on the transition from manual to automatic modes, being called a 'bump' in the plant operation. This forms due to the integral element in the controller which bases its error on the time taken of the error signal input to the controller and does not take account of any manually introduced signals. Changing the manually introduced signal can result in the output from the controller in the automatic mode not being the same as that in the manual mode. To avoid this 'bump' and give a bumpless transfer, the modern controllers will automatically change or adjust the contribution to the control law from the integral element.

Modern process controllers are most often microprocessor-based controllers, though operating as though they are conventional analogue controllers. They can be programmed from connecting a hand-held terminal to them so that the parameters of the PID controller can be set efficiently.

Task 2

$$\frac{\theta_o(s)}{\theta_i(s)} = \frac{\frac{K_p K_A K_F}{I}}{s^2 + \frac{Bs}{I} + \frac{K_p K_A K_F}{I}}$$

$$\frac{\theta_o(s)}{\theta_i(s)} = \frac{\frac{5 \times 1 \times 6 \times 10^{-3}}{1.4 \times 10^{-4}}}{s^2 + \frac{Bs}{1.5 \times 10^{-4}} + \frac{5 \times 1 \times 6 \times 10^{-3}}{1.5 \times 10^{-4}}} = \frac{200}{s^2 + 6666.67Bs + 200}$$

$$\omega_n^2 = 200$$

So Steady state value = $k_{ss} = 1$

Natural frequency = $\omega_n = \sqrt{200} = 14.14 \text{ rad/sec}$

$$2\zeta\omega_n = 6666.67B$$

$$B = \frac{2 \times \zeta \times 14.14}{6666.67} = 4.243 \times 10^{-3} \zeta$$

So for critically damping $\zeta = 1$

$$B = 4.243 \times 10^{-3} \times 1$$

$$B = 4.243 \times 10^{-3} \text{ N/ms}^{-1}$$

And

$$\frac{B}{I} = \frac{4.243 \times 10^{-3}}{1.5 \times 10^{-4}} = 28.284$$

Second Order Calculation for a Servo Position Controller

Transfer Function for Position Control Servomechanism

$$\frac{\theta_o(s)}{\theta_i(s)} = \frac{K_A K_P K_F / I}{s^2 + \frac{B}{I} s + \frac{K_A K_P K_F}{I}}$$

General Equation for a Second Order System

$$\frac{\theta_o(s)}{\theta_i(s)} = K_{ss} \times \frac{\omega_n^2}{(s^2 + 2\zeta\omega_n s + \omega_n^2)}$$

Position Control Servomechanism values:

$$\begin{aligned} K_A &= 1 & \omega_n^2 &= 200 \\ K_P &= 5 & \omega_n &= 14.14213562 \\ K_F &= 0.006 & B &= 2\zeta\omega_n I = 0.004242641 \times \zeta \\ I &= 0.00015 \end{aligned}$$

Damping Conditions		B	B/I
No Damping	$\zeta = 0$	0	0
Under Damped	$\zeta = 0.28$	0.001187939	7.920
Critical Damped	$\zeta = 1$	0.004242641	28.284
Over Damped	$\zeta = 2.12$	0.008994398	59.963

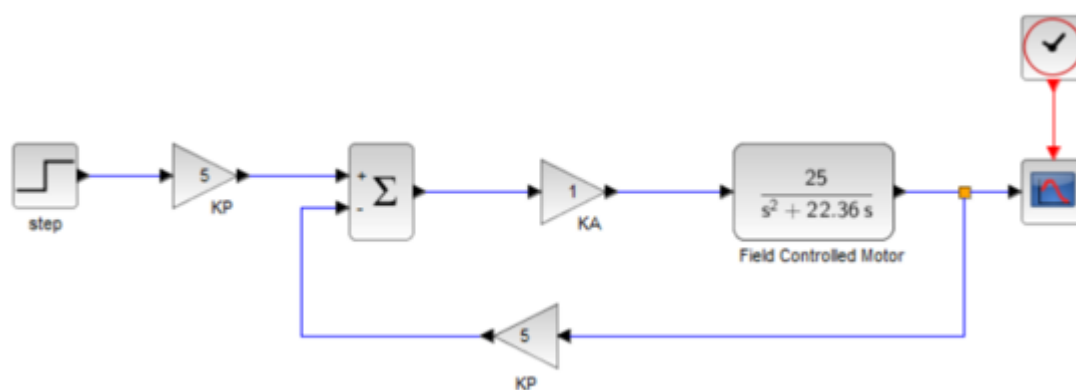


Figure 5- Example of software 'Scilab' that was used

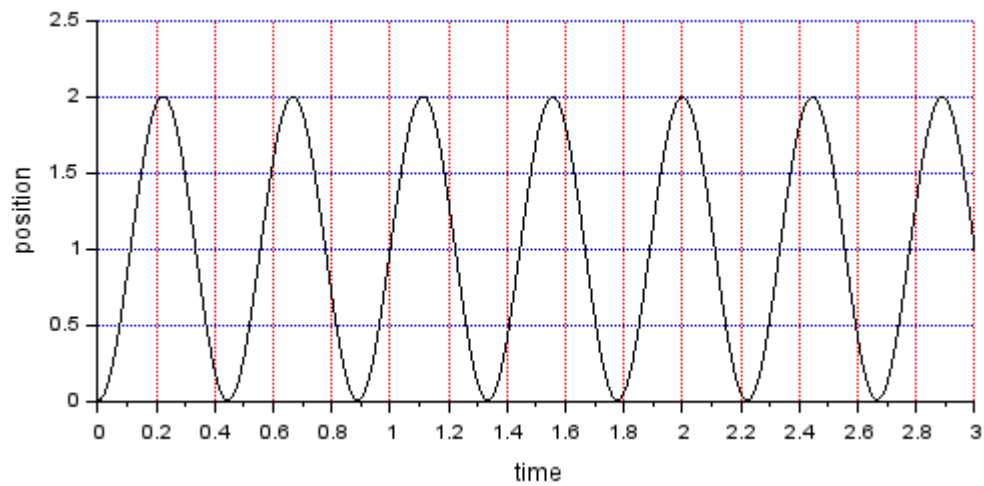


Figure 6 - The graph above demonstrates No damping at '0'.

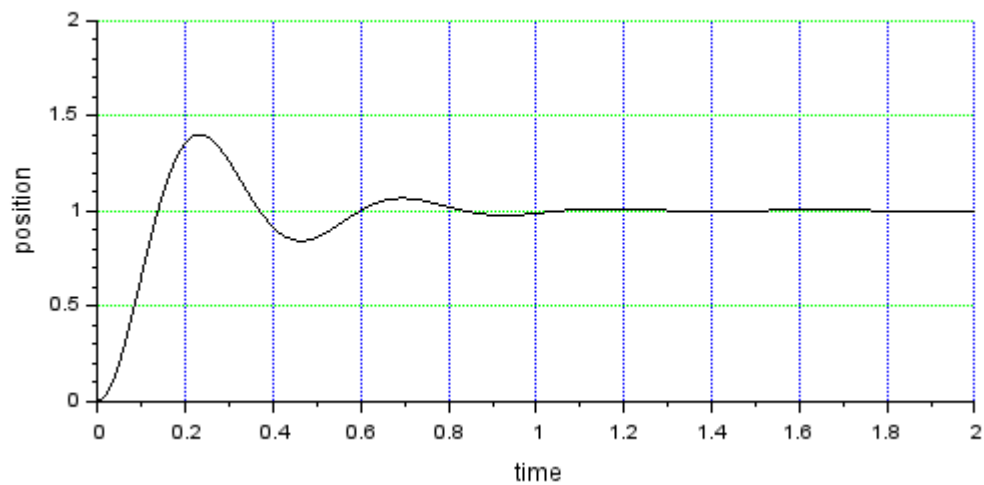


Figure 7 - Underdamped at '0.28'

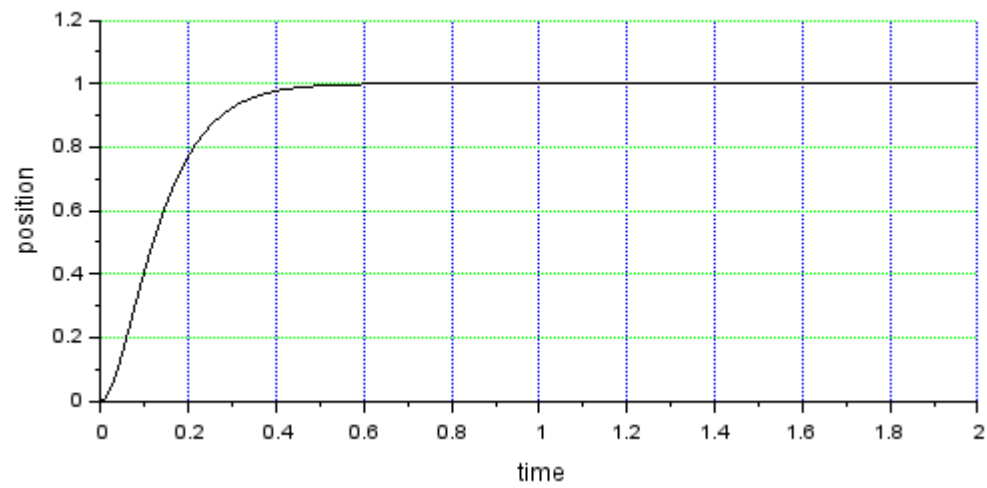


Figure 8 -Critically damped at value '1'.

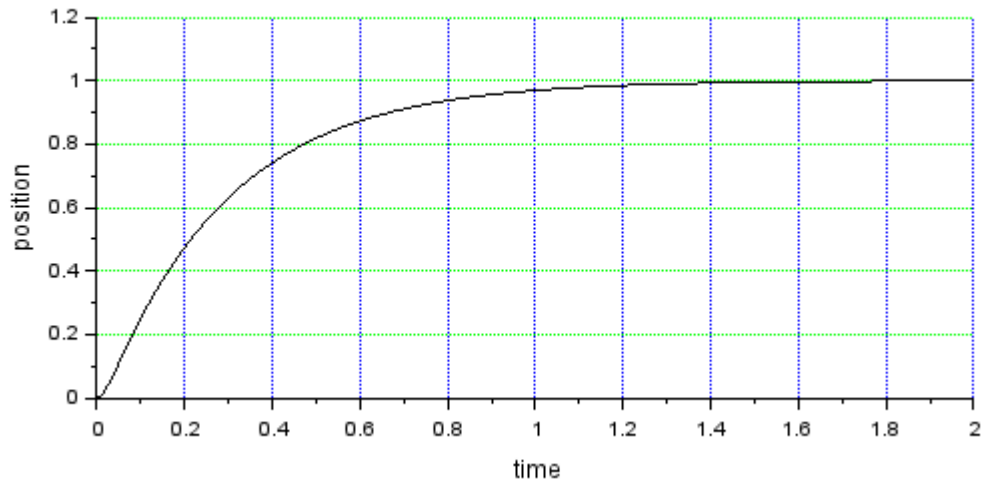


Figure 9 - Over damped at value '2.12'.

Part b)

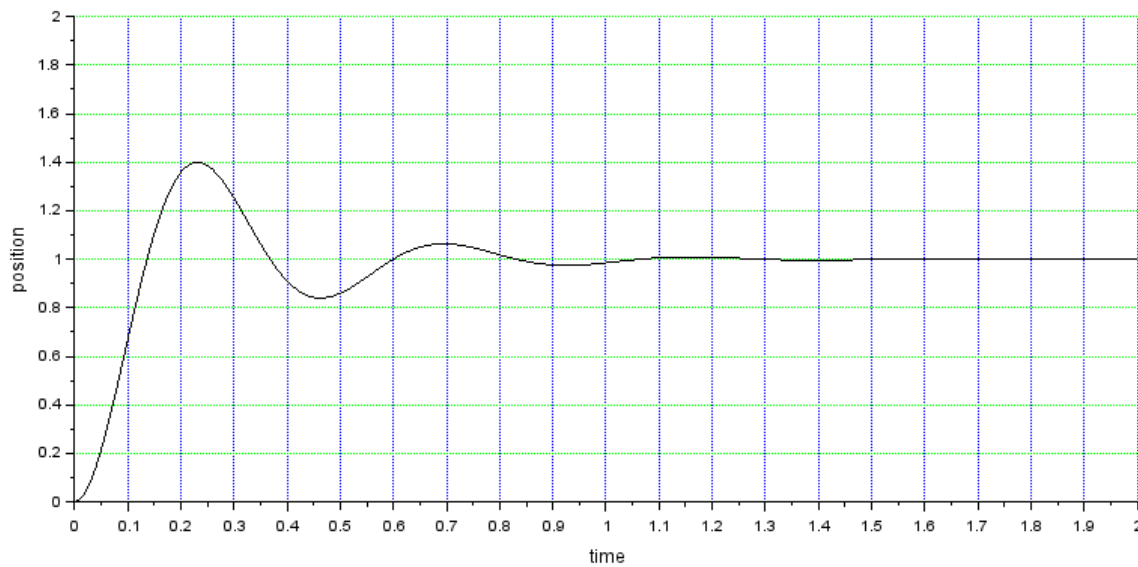


Figure 10

Underdamped at 0.28 (damping ratio)

Rise time = 0.1secs(90% position) - 0.025 (10%) = 0.075s

Peak time = 0.23s

Percentage maximum overshoot = 40%

Settling time = 0.9 secs when settling time begins to occur.

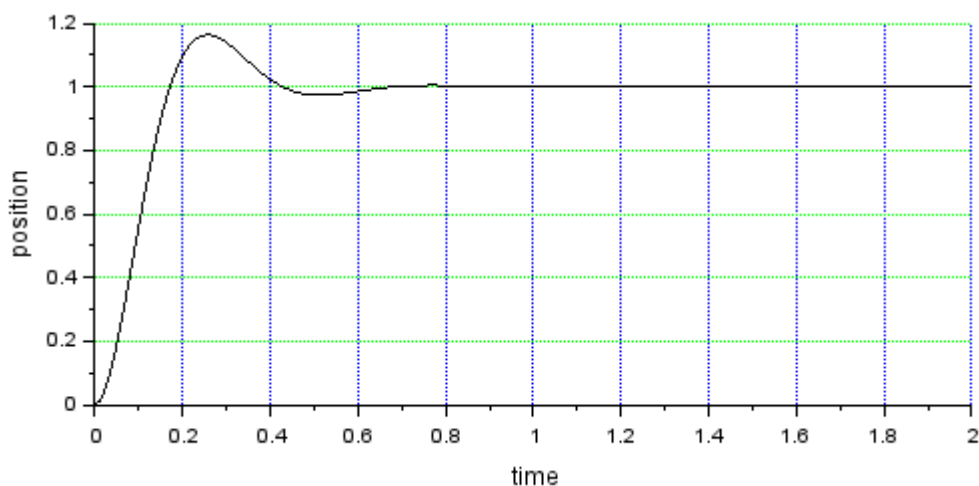


Figure 11 - Underdamped '0.5'.

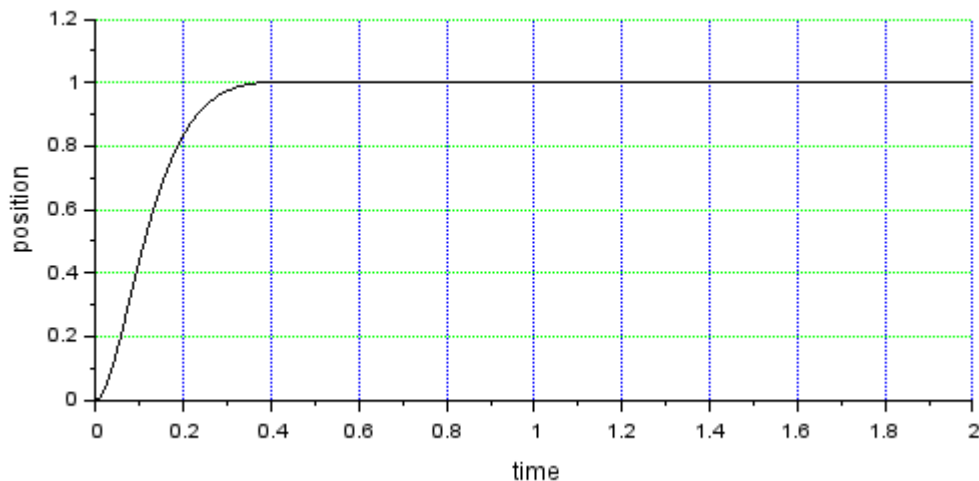


Figure 12 -Underdamped '0.87'

This shows responsiveness vs stability. Lower damping ratios result in quicker, more dynamic responses, which are often accompanied by a lot of overshoots. In comparison, higher damping ratios consequence in more stable and gradual responses, but with slower reaction times. There is also the issue of settling time, lower damping ratio means longer time to settle because of the number of oscillations this can be seen in the examples.

Selecting an appropriate damping ratio depends on the system's purpose—whether rapid performance is important, or if a smooth, stable output with minimal overshoot is more desirable. ✓

Task 3

a - Two tuning techniques used for control systems...Process Reaction and ultimate cycle tuning method

Process Reaction tuning method

The 'Process Reaction' tuning method will use specific measurements made from testing the system with the control loop open so that no control action happens. Typically, there is a break which is made between the controller and the correction unit as shown in figure 13. The test input signal is applied to the correction unit and the response of controlled variable is then worked out.

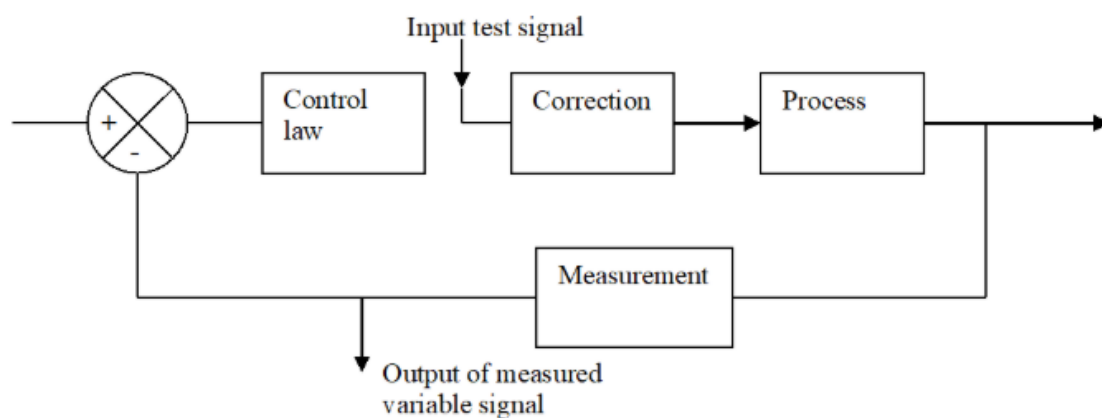


Figure 13

The test signal is a step signal with a step sized shown as the percentage change ' P ' shown in the image figure 14 in the correction unit. The response of the output controlled variable, as a percentage of the full scale range, to such an input is monitored and a graph shown in figure 15 of the variable plotted against the time. A 'process reaction curve' is what this graph shown below is called.

The tangent is shown, giving the highest or maximum gradient of that graph. The time in between the beginning of the test signal and the part where the tangent intersects the graph time axis is the lag L . The value of the highest gradient is M , shown as the percentage change of the set value of the variable per minute, Table 1 shows the criteria given by 'Ziegler-Nichols' to work out the controller settings. This criteria is to give a close loop response for the system which shows a quarter amplitude decay, shown in figure 16 that is the amplitude of the response of the

system showing oscillations which decays over time so the amplitude decreases by a quarter on each oscillation.

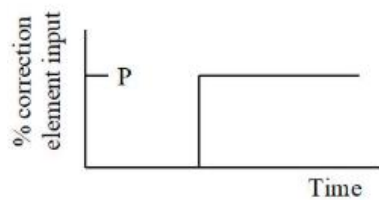


Figure 14

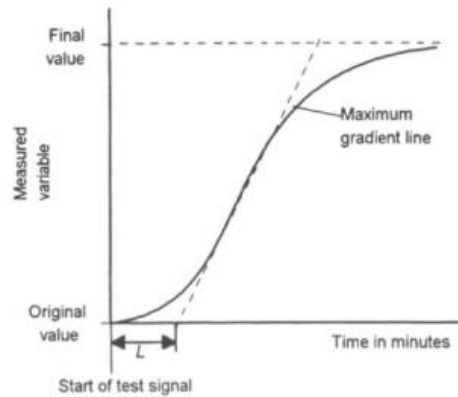


Figure 15

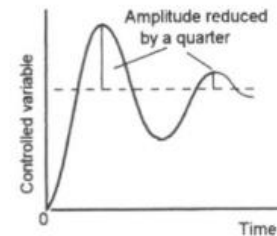


Figure 16

Table 1- Settings from the process reaction curve method

Controller Type	K_p	T_i	T_d
P	P/ML		
PI	0.9P/ML	3.3L	
PID	1.2P/ML	2L	0.5L

Ultimate cycle tuning method

In the ultimate cycle tuning method, the integral and derivative actions are firstly decreased to their less effective values. K_p is the proportional constant which is set low and gradually rises until oscillations in the controlled variable begin to happen. This important value of the proportional constant K_{pc} at which this occurs is noted and so is the periodic time of the oscillations T_c measured. The procedure:

1. Set the controller to manual operation and the plant near to its normal operating conditions.
2. Turn off control modes but the proportional.
3. Set K_p to a low value
4. Switch the controller to automatic mode and then introduce a small set-point change like 5 to 10%.
6. Observe the response.
7. Set K_p to a slightly increased value, i.e. make the proportional band narrower.

8. Introduce a small set-point change, e.g. 5 to 10%.
9. Observe response.
10. repeat 6, 7 and 8, until the response shows sustained oscillations which neither grow nor decrease. Note the value of K_p giving this condition (K_{pu}) and the period (T_u) of the oscillation.

The Ziegler and Nichols recommended criteria for controller settings for a system to have quarter amplitude decay are given by Table 2. For a PID system with some overshoot or with no overshoot, the criteria are given by Table 3.

Table 2 – settings for ultimate cycle method for quarter amplitude decay

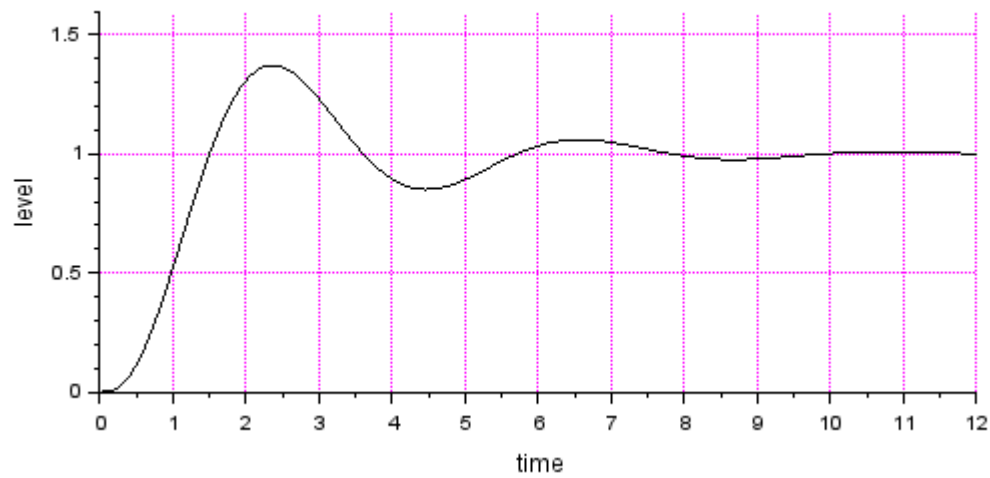
Controller Type	K_p	T_i	T_d
P	$0.5K_{pu}$		
PI	$0.45K_{pu}$	$T_u/1.2$	
PID	$0.6K_{pu}$	$T_u/2$	$T_u/8$

Table 3 – settings for ultimate cycle method for PI control

Controller Type	K_p	T_i	T_d
PID 1/4 decay	$0.6K_{pu}$	$T_u/2$	$T_u/8$
PID, some overshoot	$0.33K_{pu}$	$T_u/2$	$T_u/3$
PID zero overshoot	$0.2K_{pu}$	$T_u/3$	$T_u/2$

In task b – ultimate cycle tuning method is demonstrated.

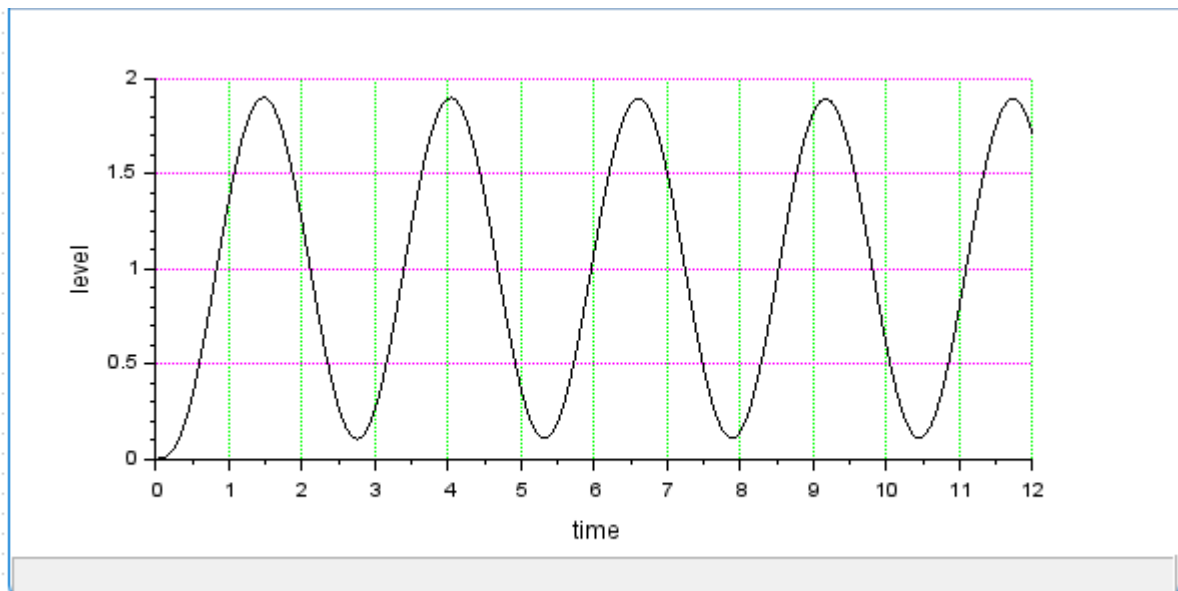
Task B



Before the tuning

Screenshots of the below shows the gain set to 30 cause full oscillation from this the periodic time was determined.

Figure18



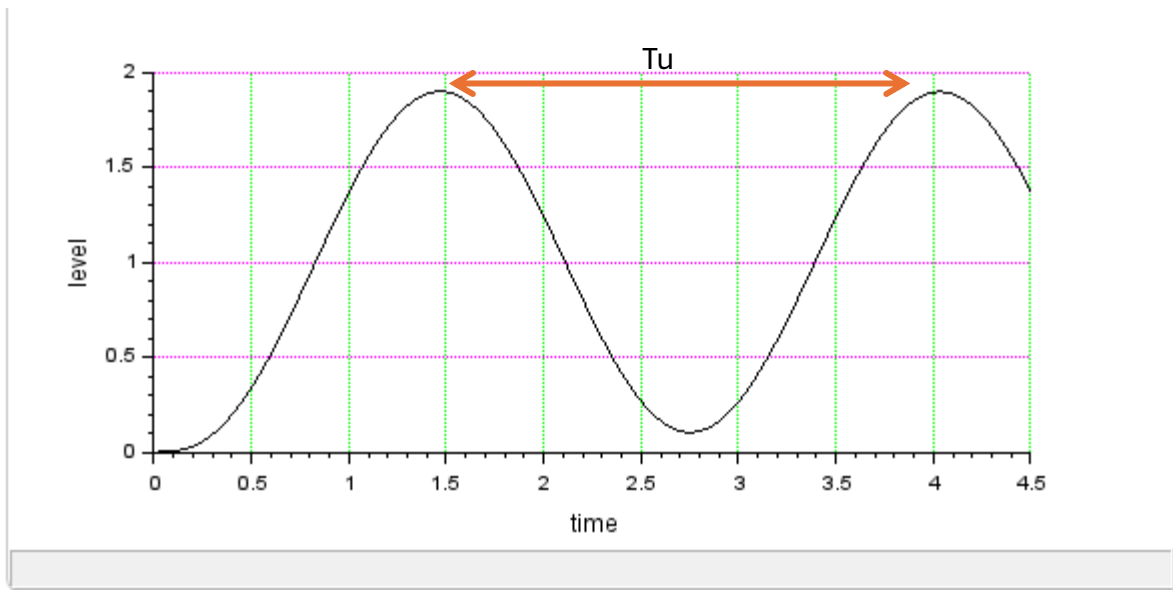
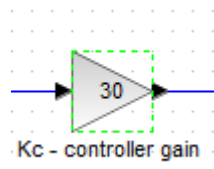


Figure 19

$$T_U = 4.01 - 1.48 = 2.53 \text{ s}$$



$$K_{pa} = 30$$

$$K_p = 0.6K_{pu} = 0.6 \times 30 = 18$$

$$T_i = T_U / 2 = 2.53 / 2 = 1.27 \text{ s}$$

$$T_d = T_U / 8 = 2.53 / 8 = 0.32 \text{ s}$$

Tuned results. Overshoot increased, but settling time has decreased. It gives a quicker result.

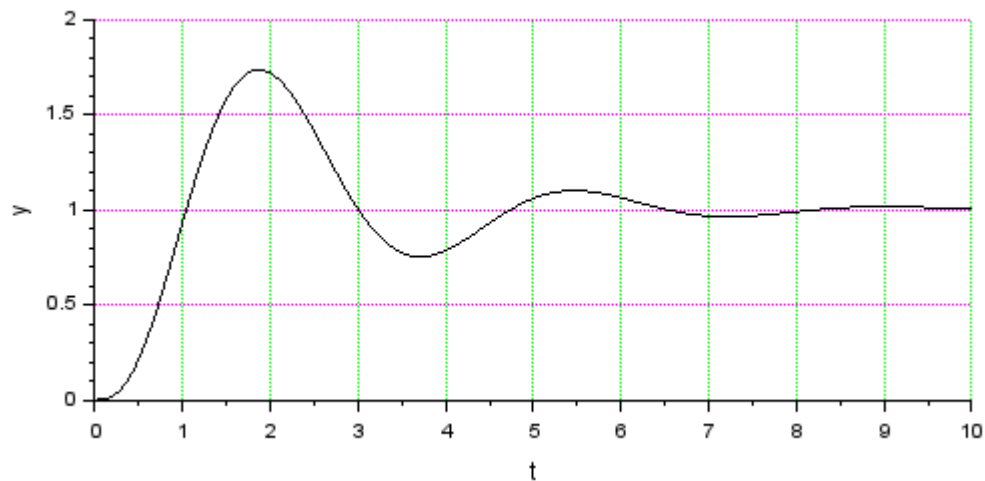


Figure 20

TD has been increased to the value of 1. In comparison, it does have less overshoot but takes long to settle.

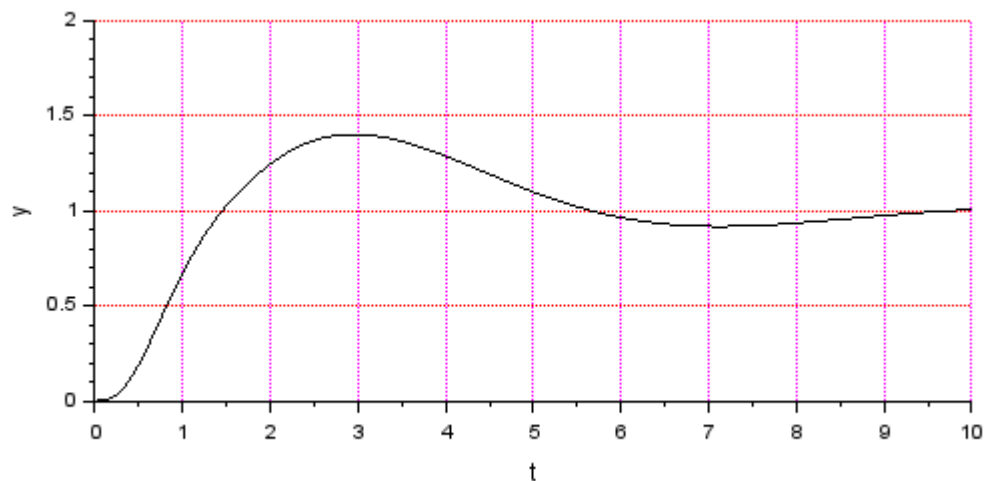


Figure 21

Made a small modification, adjusting the TI/1 value to 0.5 to show how much a small modification can impact the graph.

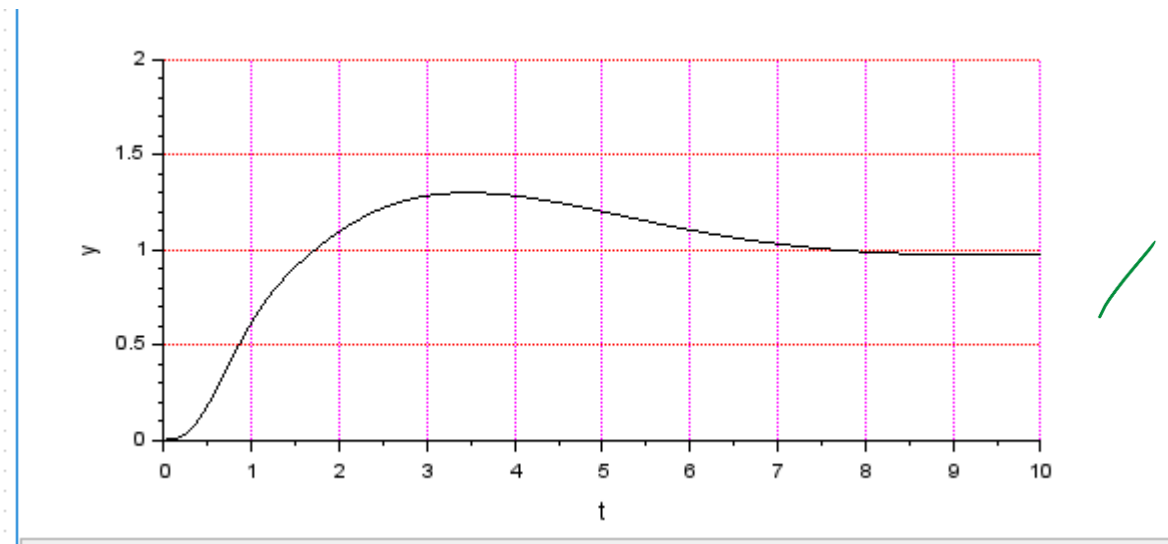


Figure 22

Task 4

Computerised control systems are extremely important across different industries like industrial, commercial, and infrastructure. These systems enable the automatic control and monitoring of processes, machinery, and environmental conditions, improving:

- Accuracy,
- Efficiency
- Safety

The three the most used types of computerised control systems are Programmable Logic Controllers, Direct Digital Control systems, and Distributed Control Systems. While each of these systems serves the core function of automation, their applications, design, and capabilities are different to one another.

Programmable Logic Controllers (PLCs)

This specific controller is an industrial digital computer which is designed to often control manufacturing processes or machinery. *'Originally developed to replace relay-based control panels in the automotive industry, programmable logic controllers offer a robust, modular, and cost effective solution for real-time control'* (Petruzelli, 2016). They consist of a central processing unit 'CPU', input/output 'I/O modules, power supply, and programming software. Logic is typically written using ladder logic or function block diagrams.

PLCs are mostly used in discrete manufacturing environments, like packaging, bottling, or conveyor systems, where deterministic response times and rugged hardware are crucial. *'Their modularity enables easy expansion and reconfiguration, which is especially beneficial in flexible manufacturing systems'* (Parr, 2013).

Although modern types of programmable logic controllers have evolved to support complex tasks like motion control and networking, they are best suited for systems that are localised and need fast, simple control logic. *'These are commonly used in conjunction with 'SCADA' - Supervisory Control and Data Acquisition systems to provide operator interface and historical data logging, though they themselves commonly lack advanced data analytics or large scaled process management features'* (Bolton, 2015).

Direct Digital Control (DDC)

Direct Digital Control systems are typically used in building automation, particularly for heating, ventilation, and air conditioning (HVAC) systems. Direct Digital control systems *'involve microprocessor-based controllers that directly control analogue and digital outputs, based on sensor inputs and programmed algorithms'* (ASHRAE, 2021). Unlike traditional analogue control systems, DDC systems digitise sensor data and utilise software algorithms to manage real time environmental conditions.

A defining feature of DDC systems is their high level of integration with building management systems (BMS). These systems will usually consist of central supervisory software, networked zone controllers, and a suite of environmental sensors (Gilani & O'Brien, 2020). These systems will typically work over standardised communication protocols like 'Modbus', enabling interoperability across different manufacturers and system components.

In comparison to PLCs, DDC systems are optimised for continuous control applications rather than discrete control. Their programming is more data driven, using setpoints, schedules, and proportional-integral-derivative (PID) control loops rather than logic sequences. Direct Digital control systems are designed for ease of configuration and remote management, which makes them suitable for energy management, occupant comfort, and operational diagnostics in larger facilities.

Distributed Control Systems (DCS)

DCS systems are hierarchical control architectures used in complex, larger scale continuous process industries like oil refining, chemical manufacturing, and power generation. This system is characterised by the distribution of control elements across a plant through networked controllers, *'which is commonly linked to a central operator interface or a 'HMI'- Human Machine Interface'* (Seborg et, 2010).

Unlike PLCs and DDC systems, which often have distinct master-slave or client-server arrangements, DCS architectures are inherently decentralised. *'Each controller can execute advanced control functions locally, reducing the dependency on the central node and increasing system reliability and scalability'* (Zhao et al., 2021). Communication in the Distributed control system networks is typically carried out over high-reliability protocols like 'Foundation Fieldbus' or 'Profibus'.

The strengths of DCS is their ability to handle complex control strategies, extensive data logging, and advanced process visualisation. These systems provide integrated redundancy, high fault tolerance, and rich data analytics—features essential in processes where downtime is costly or more dangerous (Marlin, 2010). In comparison to PLCs, DCSs they are more expensive and require higher upfront engineering effort, but their lifecycle cost efficiency and maintenance make them appropriate for long term continuous operations.

Comparison table shown below

Feature	PLC	DDS	DCS
Primary application	Discrete manufacturing	Building automation (HVAC)	Continuous process industries
Architecture	Centralised with modular I/Os	Centralised with networked controllers	Decentralised with distributed control
Scalability	Medium	High (in buildings)	Very High
Fault Tolerance	Limited	Moderate	High (with redundancy)
Cost	Low to medium	Medium	High
Programming complexity	Moderate	Low to moderate	High
Most suitable for...	Local, fast response tasks	Environmental control in facilities	Large, mission-critical operations

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