

LEVEL 4 ASSESSMENT SPECIFICATION

Student name:	Kelly Williams	Student ID number:	
Programme:	HNC Instrumentation Engineering		
Module:	Instrumentation, Automation and Control		
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Lecturer:	Jason Pointer	Internal Verifier:	Nigel Richards
Assignment Title:	Control Systems	Word count (or equivalent):	2000
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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	13.4
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	29
Task 1 - 76%. Task 2 - 76%. Task 3 - 68%. Task 4 - 70%. Excellent knowledge and understanding of the basic underlying concepts and principles for each task.		
3. Cognitive and Intellectual Skills	10	6.8
Sound evaluation of the underlying concepts and principles for task 2 and 3.		
4. Practical Application Skills	20	16.8
Task 1 - 86%. Task 2 - 82%. 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	7.6
Work is coherent, very fluent and is presented professionally. Excellent layout making the assignment easy to read.		

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%)

74%

PCEE/PCPO 4011: Instrumentation, Automation & Control

CONTROL SYSTEMS
KELLY WILLIAMS

LECTURER: JASON POINTER



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Task 1

Open Loop System

An open loop circuit has no feedback path between the process variable, and the controller as shown in figure 1.1. The system relies on an input command for the output to be changed. The output does not affect the control action of the system therefore if the desired output is not obtained, there will be no feedback to the controller. The elements of the open loop circuit include a controller to process the input and determine what action is to be taken. The correction element responds to the input from the control element and will initiate the change of the variable being controlled by the required value. The process is the system which is being controlled by the variable. There is a sensor which measures certain parameters but are solely used for providing information/indication. The output action is based on the input command and will operate until provided with a further command.

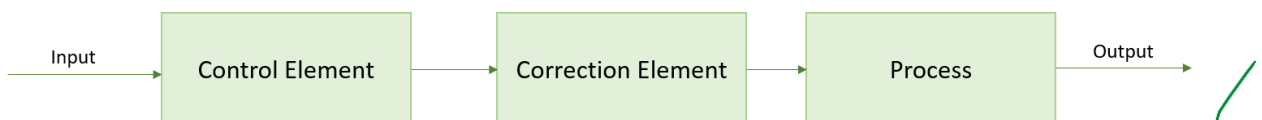


Figure 1.1 - Open Loop Control System

An application of an open loop system is a simple light switch which remains in the on or off condition until manually changed. Since there is no feedback in an open loop system, the light will remain on or off until the switch is manually operated. The system can be adjusted to include a timer where the operation is based solely on the timing set by the user. Figure 1.2 shows the open loop control system where the timer is set by the user, the switch controls the electrical connection to the light bulb and the light bulb is the output. The system operates in an open loop manner as there is no feedback to adjust the lightbulb based on the lighting conditions.

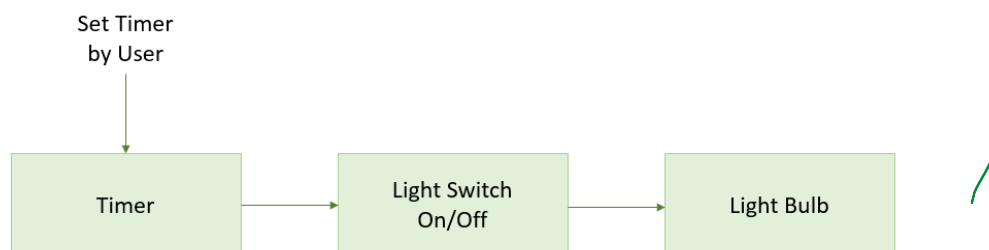


Figure 1.2 - Open Loop Control System Example

An advantage of an open loop system is that they are “relatively simple and consequently low cost with generally good reliability.” (Bolton, 1992:p.5). Open loop systems are easier to design and install than closed loop systems since there isn't the requirement of a feedback loop. However, a disadvantage to an open loop control system is their inability to monitor the output and adjust for variations in the environment or systems. Any disturbances in the system will not affect the output leading to inefficiencies. ✓

Closed Loop System

A closed loop control system is used to keep a given process variable within its predetermined limits. It allows for automatic control without the need of an operator to manually control equipment. The automatic control system aims to manage and regulate the actions of devices within the control loop. Bhattacharya (2008) describes ‘in a closed-loop system the output is fed back and compared with the input so that any necessary corrective action may be taken.’ (p.4). ✓

Figure 1.2 shows a block diagram of a closed loop control system. The first element of the system is the input to the controller which is the desired setpoint the system is required to achieve. A sensor and transducer are used to measure the system which could be temperature, level or pressure where it is then converted to an electrical signal. The comparison element compares the setpoint value of the variable being controlled with the measured value of what is being achieved. An error signal will be produced which indicates how much the measured value differs from the required value. ✓

$$\text{Error signal} = \text{reference value signal} - \text{measured value signal} \quad ✓$$

If an error is calculated, the controller will generate a control input to adjust the process. The control element decides what actions to take when an error signal has been received. The correction element may be an actuator which receives the control input, converts it into a physical action to adjust the process output. The process is the element that is being controlled and adjusted by the correction element. A process output result will be generated based on the operation of the correction element such as a level in a tank is increasing. The measurement element produces a signal related to the variable condition being controlled and provides a signal fed back to the comparison element. An example of a closed loop system is ✓

maintaining a 50% level in a tank. The setpoint would be 50% and a level transmitter would be used as the measuring element. An actuator controlling the position of a valve would be the process output which is controlled by the correction element. Figure 1.3 is an example of a process which uses a closed loop control system.

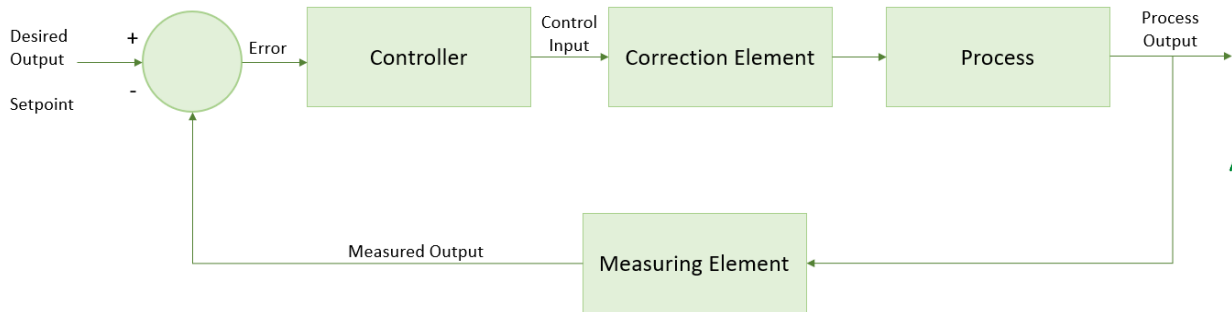


Figure 1.2 - Closed Loop Control System

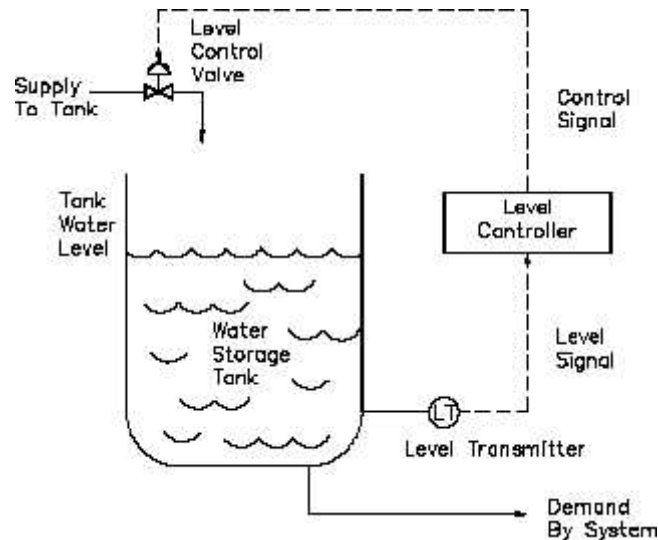


Figure 1.3 – Tank Closed Loop Control System

The feedback loop of the closed loop system is a necessary feature so that the system can react to any process changes. Negative feedback is when the signal which is fed back is subtracted from the reference value. Whereas positive feedback occurs when the feedback signal is added to the reference value.

Figure 1.4 shows a simple closed loop system where the elements are as follows:

θ_i = Input

θ_o = Output

ϵ = Error Signal

G = Open Loop Gain

H = Feedback Fraction

If θ_i is the reference value and θ_o is the actual value of the system, then the transfer function of the entire control system is

$$\text{Transfer Function} = \frac{\text{output}}{\text{input}} = \frac{\theta_o}{\theta_i}$$

The general form of a closed loop system with a negative function can be derived from the following formula:

$$\theta_o = \varepsilon \times G$$

$$\varepsilon = \theta_i - \theta_o \times H$$

$$\varepsilon = \frac{\theta_o}{G}$$

$$\frac{\theta_o}{G} = \theta_i - \theta_o \times H$$

$$\theta_o = G(\theta_i - \theta_o H)$$

$$\theta_o = G\theta_i - G\theta_o H$$

$$\theta_o + G\theta_o H = G\theta_i$$

$$\theta_o(1 + GH) = G\theta_i$$

$$\frac{\theta_o}{\theta_i} = \frac{G}{1 + GH}$$

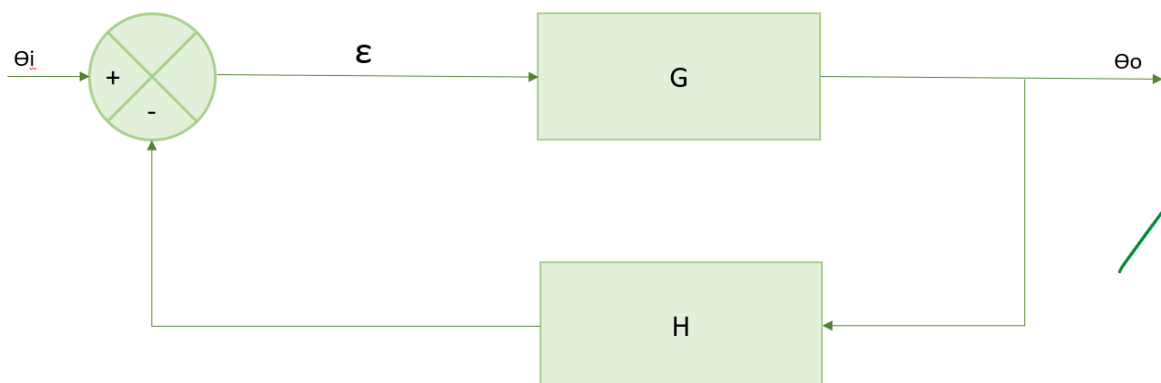


Figure 1.4 – Simple Closed Loop System

Three-Term Control

A three-term control refers to a PID controller, proportional, integral and derivative. The aim is to produce a control signal that has the capabilities to minimise the difference between the output and the desired setpoint of a system. It is used in automatic control systems such as temperature regulation and motor speed control. An industrial example of a PID controller is the fuel gas heaters at Dragon LNG. The PID controller automatically adjusts the heater output to achieve a desired temperature.

The proportional term is based on the current error between the setpoint and the measured output of the system. A correction that is proportional to the amplitude of the error is applied to help bring the output of the system back to the setpoint. The larger the error, the larger the correction applied by the proportional term. However, a value that is too high of the proportional gain can lead to an oscillating output.

Figure 1.5 shows that by increasing the K_p coefficient, the rise time can be reduced but the error will never reach zero.

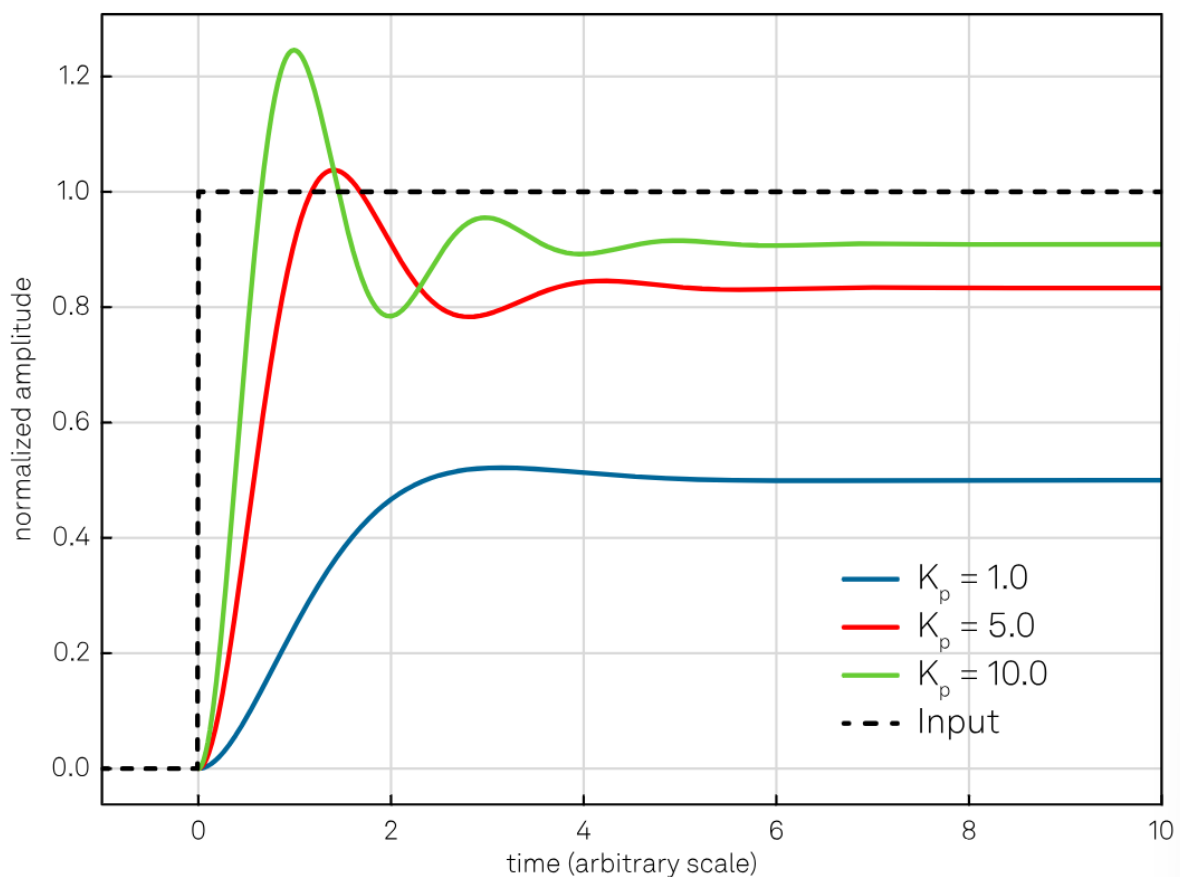


Figure 1.5 – Effects of the Proportional Action

The integral term reacts the accumulation of past errors and applies a correction that is proportional to the time integral of the error. Visioli and Vilanova (2012) explain that 'the introduction of integral action facilitates the achievement of equality between the measured value and the desired value, as a constant error produces an increasing controller output.' (p.7). The integral sums up the past errors over time and adjusts the control output to eliminate the steady state error. For example, if the error persists over time, the integral term will continue to increase so that a larger correction is applied to the output. Unlike the proportional term, the integral ensures the system output eventually reaches the setpoint, correcting any remaining error. An integral with a larger gain coefficient can eliminate the error faster than a smaller integral term. Although, if K_i is increased too much, it can lead to larger oscillations and cause an overshoot as shown by the green curve in figure 1.6.

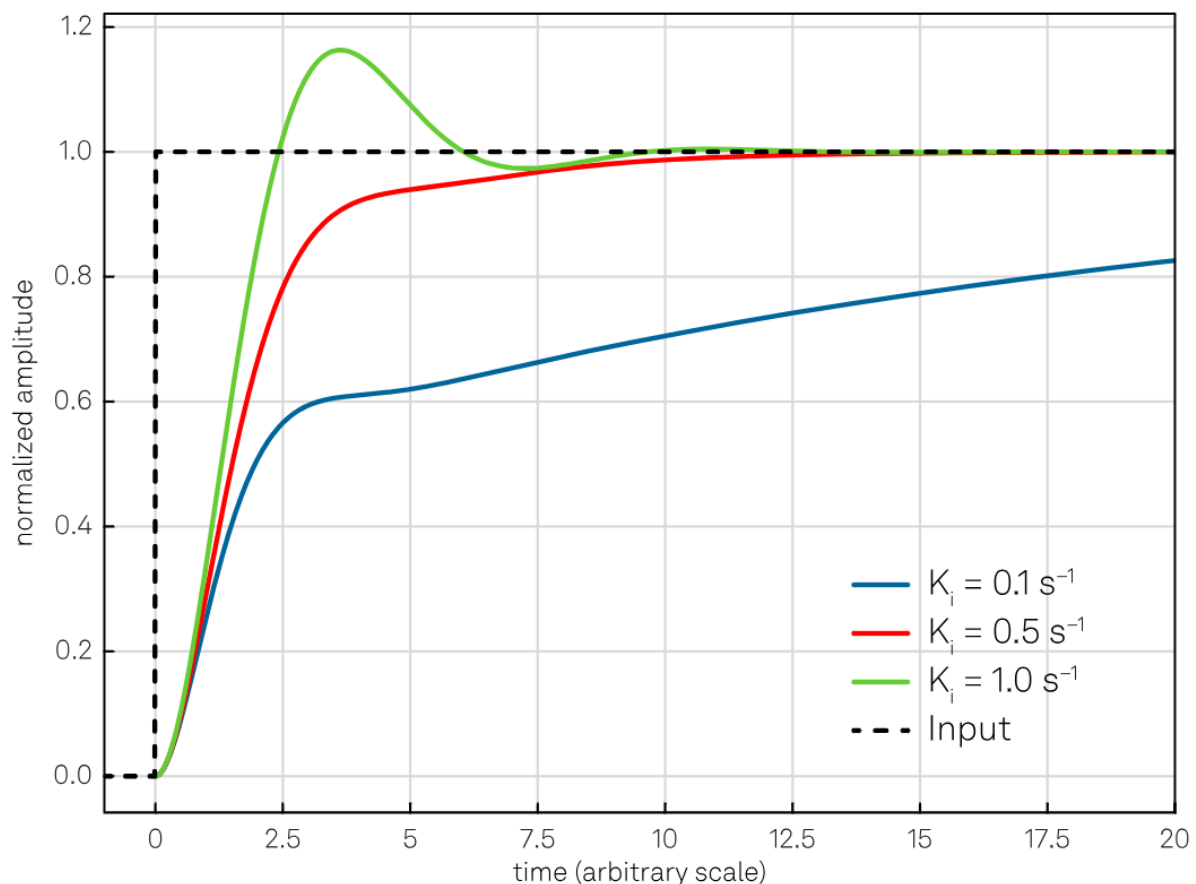


Figure 16. – Effects of the Integral Action

The derivative term reacts to the rate of change of the error and predicts the future error behaviour. The action of the derivative term is to apply a damping force to reduce overshoot and improve stability and responsiveness of the system. The aim

is to anticipate the changes in the error signal by compensating without waiting for the error to become significant or persist for some time. Figure 1.7 shows that when K_d is applied correctly, the system has a smoother response to the output eliminating oscillations. However, too large values of K_d can make the system unstable.

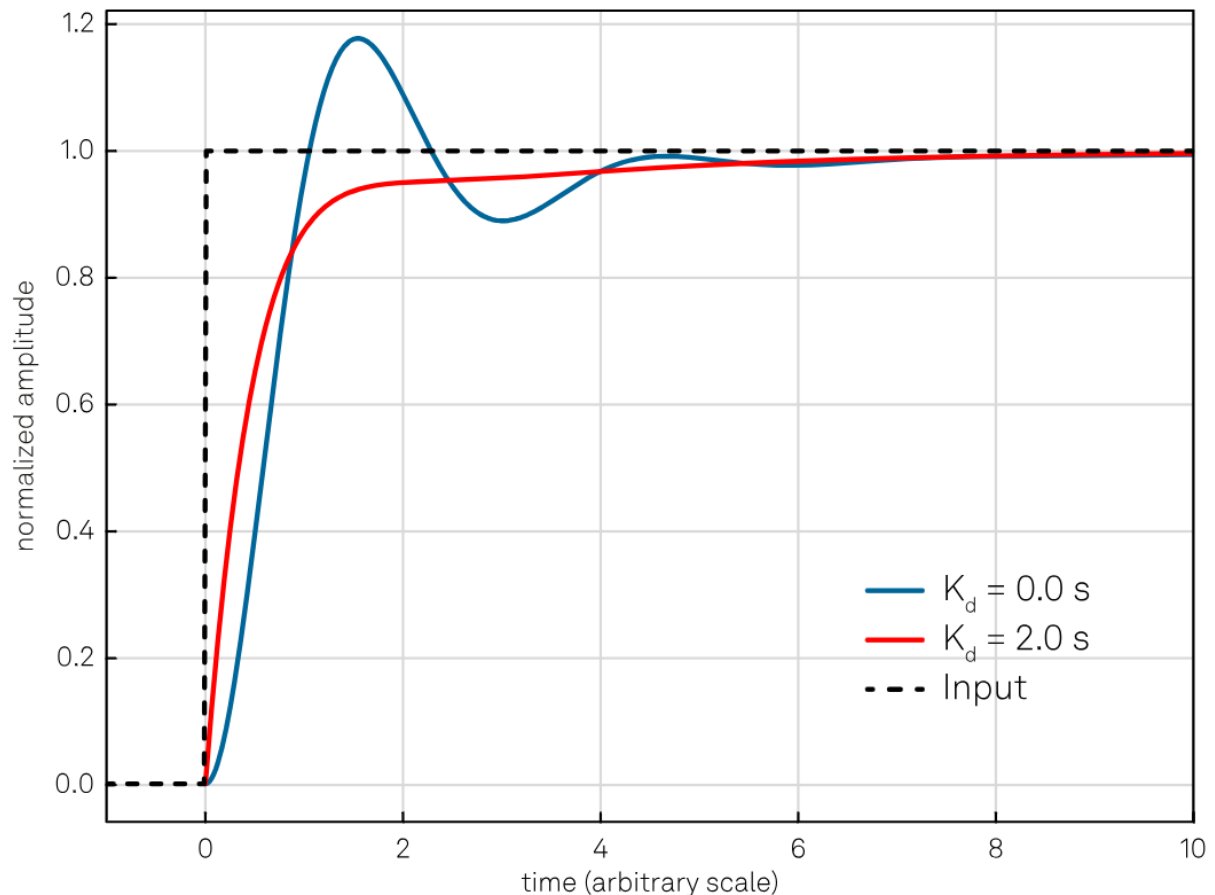


Figure 1.7 – Effects of the Derivative Action

Some applications may only require one or two of the three term control terms. Each term can be tuned to achieve the desired system response, for example to achieve a fast-settling time with minimal overshoot and a zero steady state error. The Zeiger-Nichols method is a technique used to establish the initial tuning of a PID controller.

Very well, done showed
an excellent understanding.

Task 2

Position Control

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:

$$\begin{aligned} K_A &= 1 & \omega_n^2 &= 200 \\ K_P &= 5 & \omega_n &= 14.142 \\ K_f &= 0.006 & B &= 2\zeta\omega_n I = 0.004243 \times \zeta \\ I &= 0.00015 \end{aligned}$$

Damping Conditions		B	B/I
No Damping	$\zeta = 0$	0	0
Under Damped	$\zeta = 0.38$	0.001612	10.748
Critical Damped	$\zeta = 1$	0.004243	28.284
Over Damped	$\zeta = 2.3$	0.009758	65.054

No Damping

$$\text{Let } \zeta = 0$$

$$B = 0 \times 4.242 \times 10^{-3}$$

$$B = 0 \text{ N}$$

$$\frac{B}{I} = \frac{0}{1.5 \times 10^{-4}} = 0$$

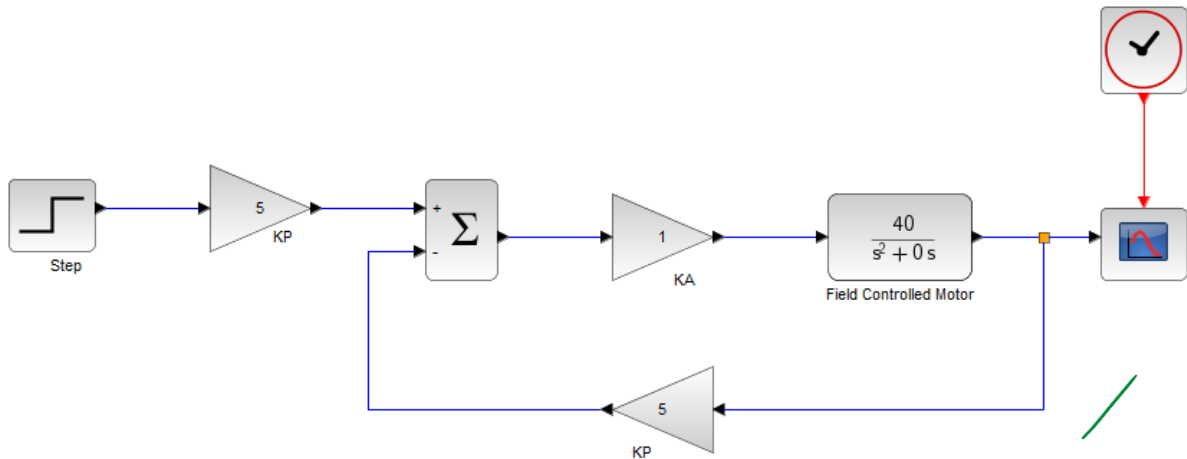


Figure 2.1 – No Damping

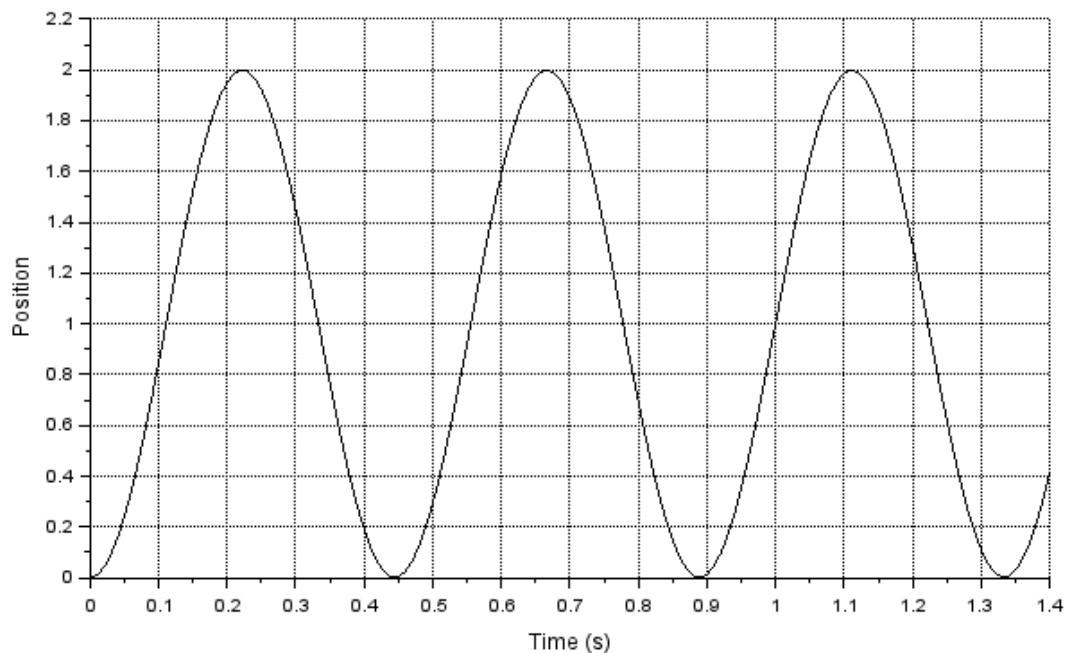


Figure 2.2 – No Damping Output

Figure 2.2 shows that when a damping ratio of 0 is applied, the system goes into full oscillation. There is no control of the system with the position control going back and forth showing no sign of settling out.

Under Damped

$$\text{Let } \zeta = 0.385$$

$$B = 0.385 \times 4.242 \times 10^{-3}$$

$$B = 1.612 \times 10^{-3} N$$

$$\frac{B}{I} = \frac{1.612 \times 10^{-3}}{1.5 \times 10^{-4}} = 10.746$$

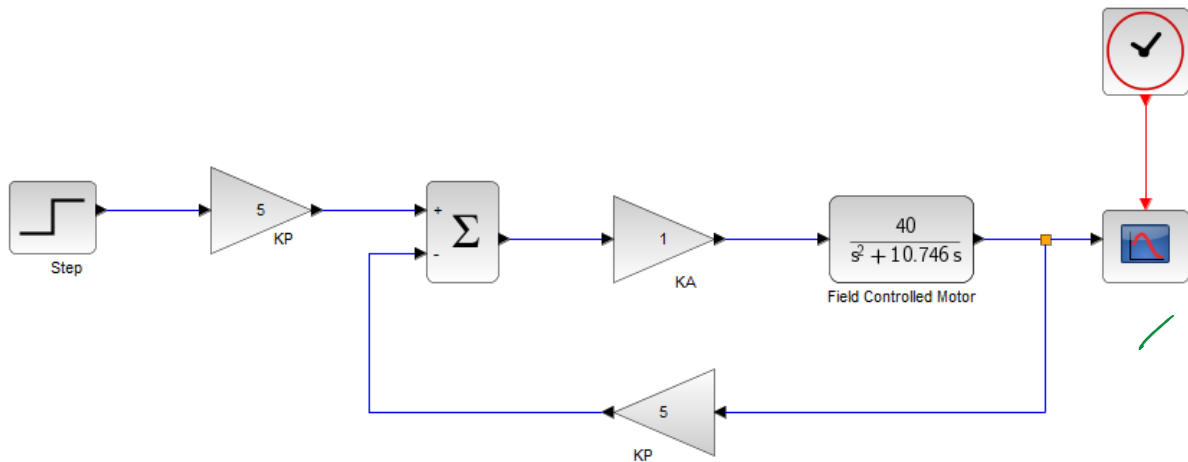


Figure 2.3 – Under Damped

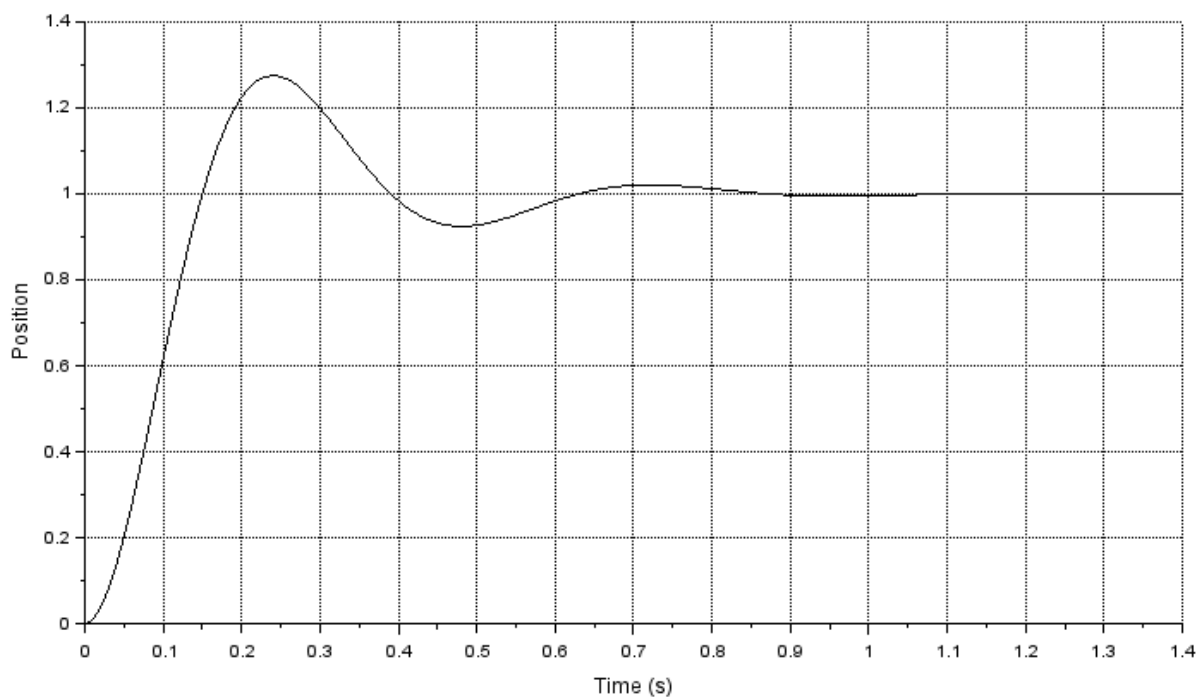


Figure 2.4 – Under Damped Output

Figure 2.4 shows the systems reaction to a damping ratio of 0.385. it can be seen that the system does reach a steady state after a period of time along with a small overshoot at the start. There is more control over the system with the desired output achieved after 0.9 seconds.



Critically Damped

$$\text{Let } \zeta = 1$$

$$B = 1 \times 4.242 \times 10^{-3}$$

$$B = 4.242 \times 10^{-3} N$$

$$\frac{B}{I} = \frac{4.242 \times 10^{-3}}{1.5 \times 10^{-4}} = 28.28$$

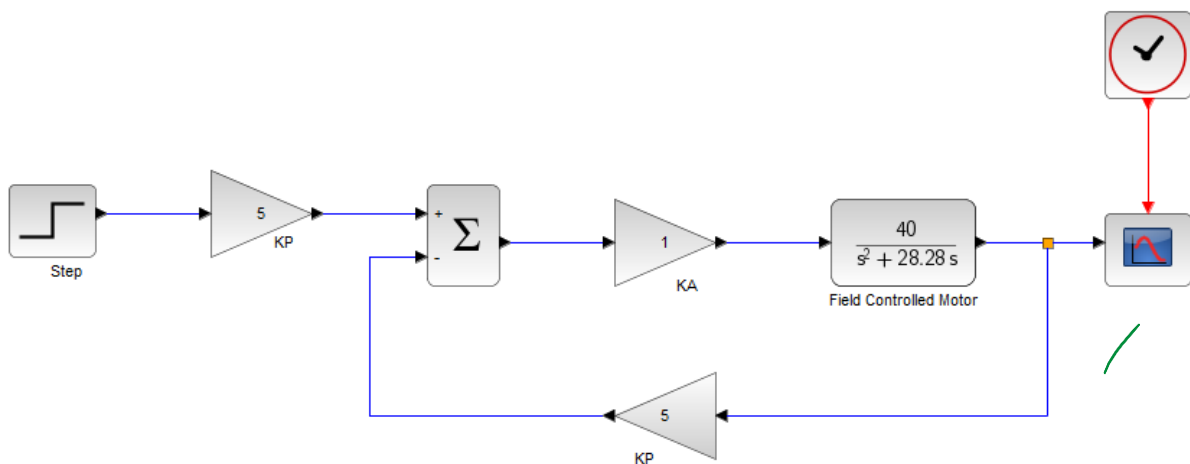


Figure 2.5 – Critically Damped

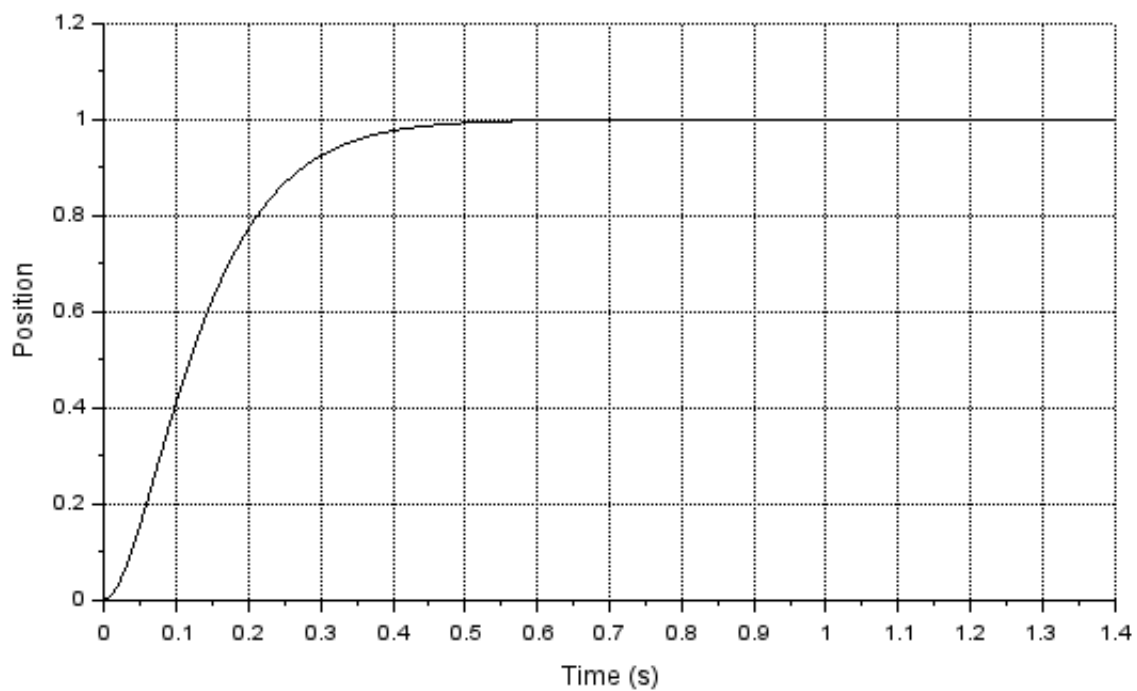


Figure 2.6 – Critically Damped Output

For the critically damped output, the damping ratio is set to 1. A smoother response is achieved with no overshoot and a fast-settling time. This is ideal for many applications where oscillations are undesirable.

Over Damped

$$\text{Let } \zeta = 2.3$$

$$B = 2.3 \times 4.242 \times 10^{-3}$$

$$B = 9.757 \times 10^{-3} N$$

$$\frac{B}{I} = \frac{9.757 \times 10^{-3}}{1.5 \times 10^{-4}} = 65.05 \quad \checkmark$$

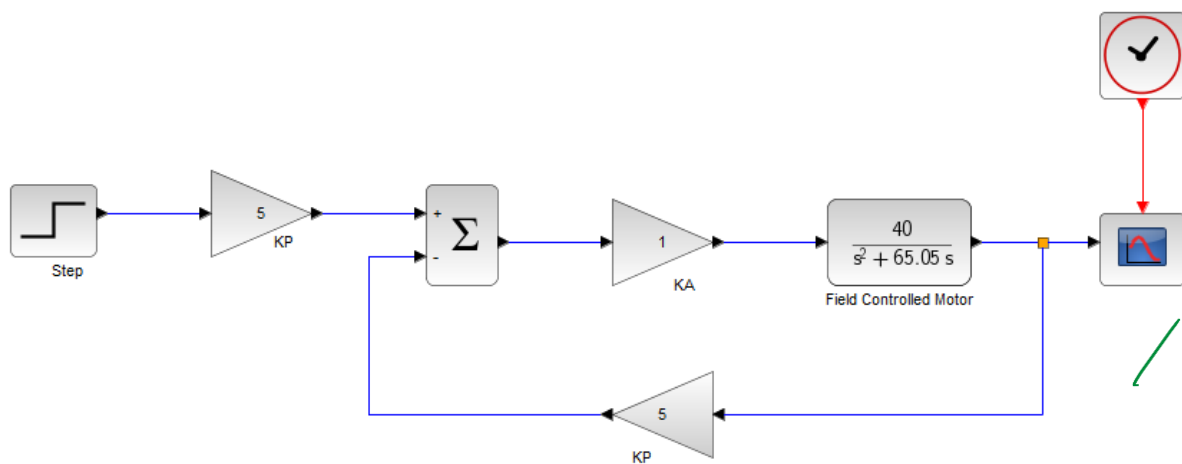


Figure 2.7 – Over Damped

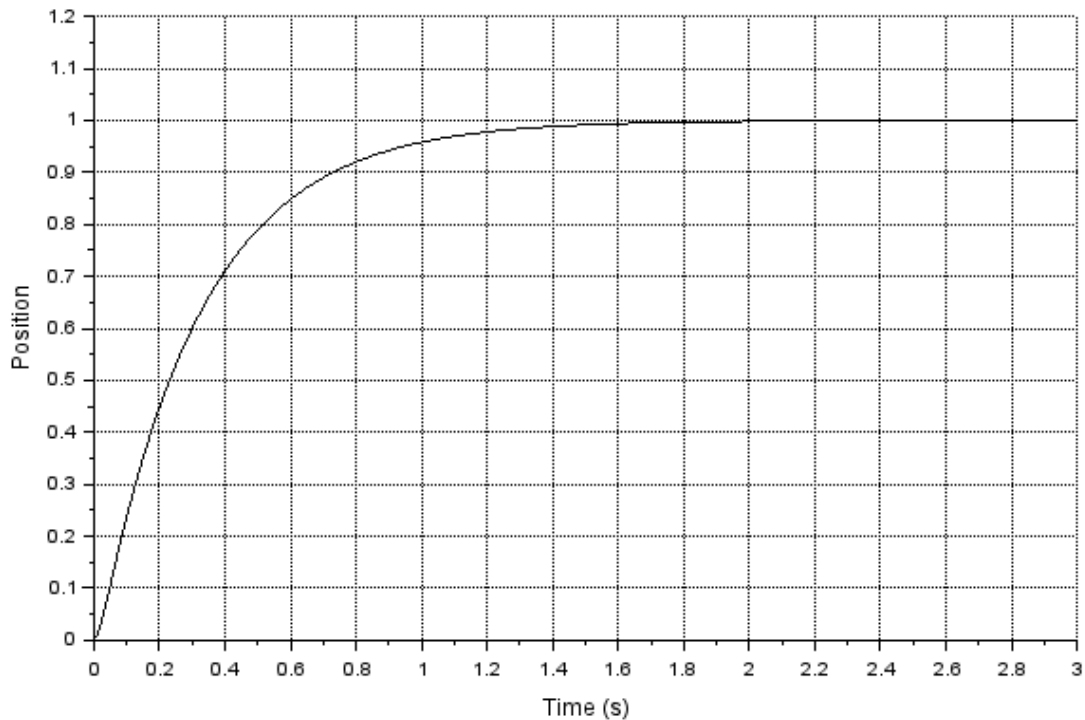


Figure 2.8 – Over Damped Output

A damping ration of 2.3 has been applied to achieve an over damped system as shown in figure 2.8. with an over damped system, no oscillations occur but there is an increase in time it takes for the equilibrium to be reached. As shown in figure 2.8, it has taken a time of 2 seconds for the position to be reached whereas the under damped system only took 0.9 seconds.

Under Damped Condition

When the damping ratio is set to 0.385, an under damped condition is established and the system responds quickly as shown in figure 2.9. The graph shows that the system has a rise time of 0.11 seconds whereas when a damping ratio of 0.87 is applied, the rise time is increased to 0.2 seconds. When the system is set up to have a damping ratio of 0.12 the system does react significantly quicker. Whereas having a damping ratio of 0.5 the system has similar rise time of 0.11 seconds to the system shown in figure 2.9.

A peak time of 0.24 seconds is achieved showing that it is quick to reach its first peak and has a percentage maximum overshoot of 27%. Compared to the graph in figure 2.12 which has a damping ratio of 0.12, the overshoot percentage is much lower but has a similar peak time of 0.23 seconds. When the damping ration is set to 0.12, there is a percentage maximum overshoot of 70% resulting in more oscillations

before the system begins to settle out. Figure 2.11 shows that when the damping ratio is 0.87, there is no overshoot of the system and has a short settling time. A 17% maximum overshoot is generated with a peak time of 0.25 seconds when the systems damping ratio is 0.5.

The settling time represents the time for the response to remain with 2% of the final value. Figure 2.10 shows the settling time to be 0.77 seconds for a system with a damping ratio of 0.385. This has a shorter settling time compared to the system shown in figure 2.12. Due to the number of oscillations produced by the system with a damping ratio of 0.12, the settling time is impacted resulting in a longer period of time before the system is within 2% of its final value. However, when the damping ratio is increased to 0.87, the settling time is quicker with an estimated time of 0.32 seconds. This shows that when the damping ratio is increased, the settling time decreases.

Overall, a damping ratio value close to zero typically had a fast rise time but will generate a high maximum percentage overshoot. A number of oscillations will occur thus resulting in a longer settling time. If the damping ratio is close to 1, there is a 0% of overshoot and has a faster settling time. However, the rise time is slower therefore the reaction time is delayed.

Good.

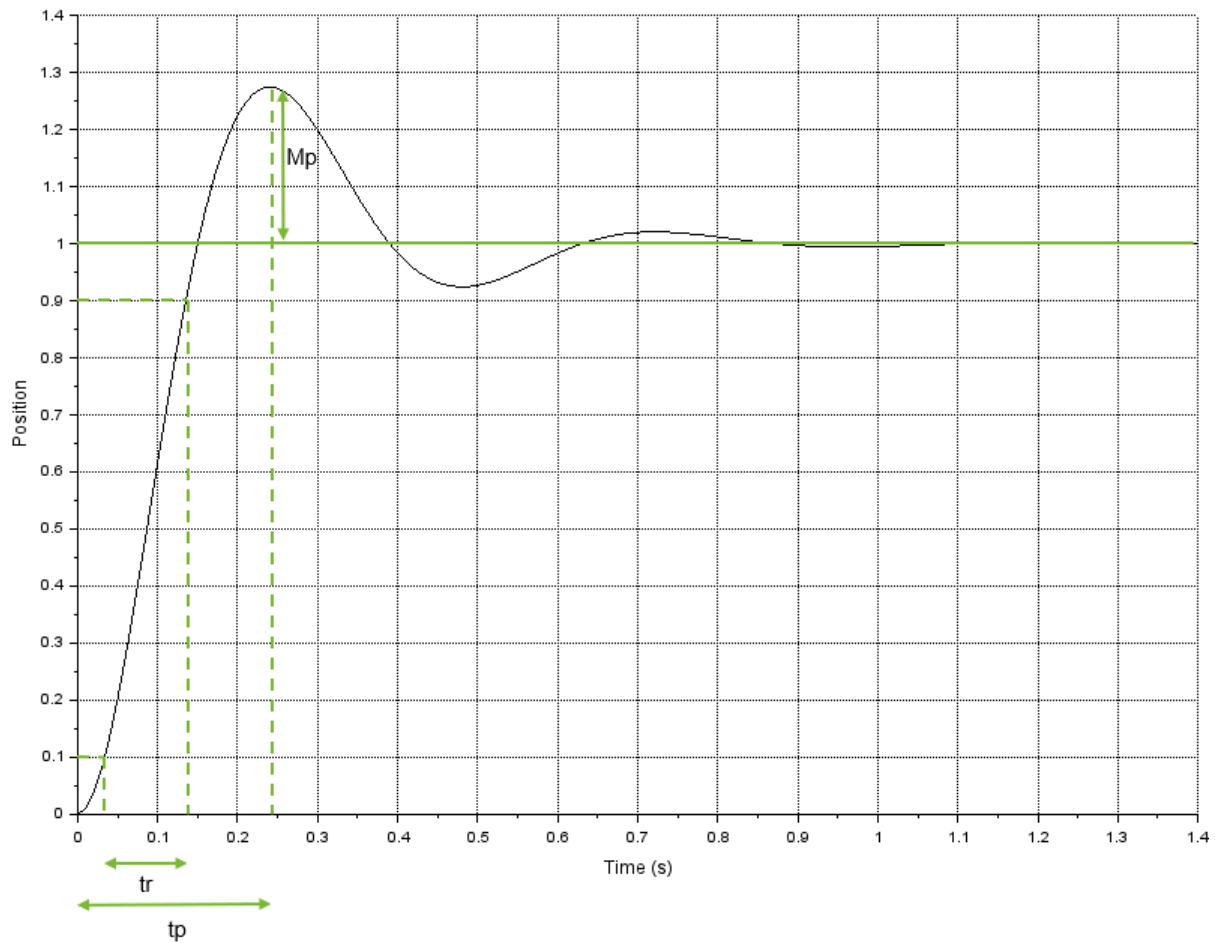


Figure 2.9 – Damping Ratio 0.385

Rise Time (t_r) = $0.14 - 0.03 = 0.11s$ ✓

Peak Time (t_p) = $0.24s$ ✓

Percentage Maximum Overshoot (m_p) = 27% ✓

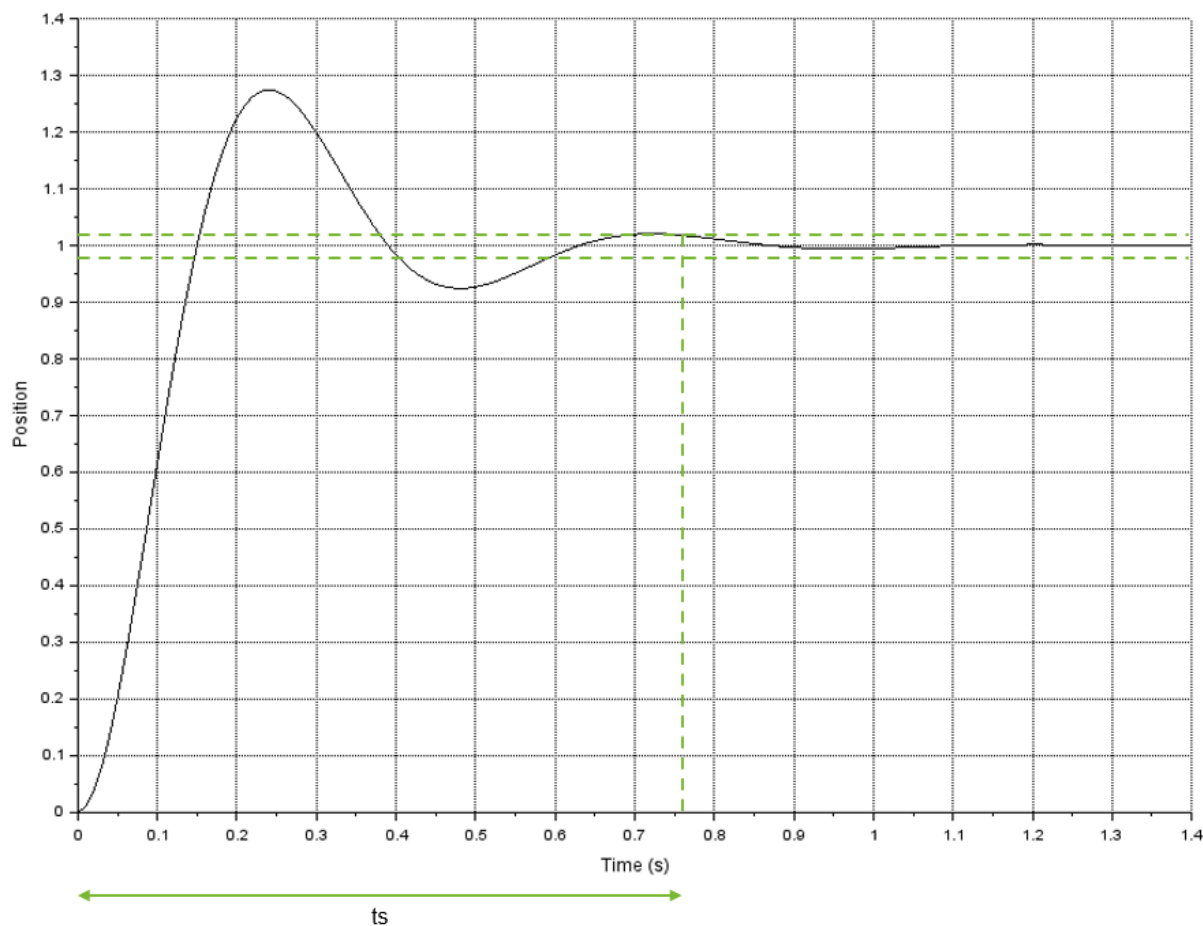


Figure 2.10 – Settling Time of Damping Ratio 0.385

Settling Time = 0.77s

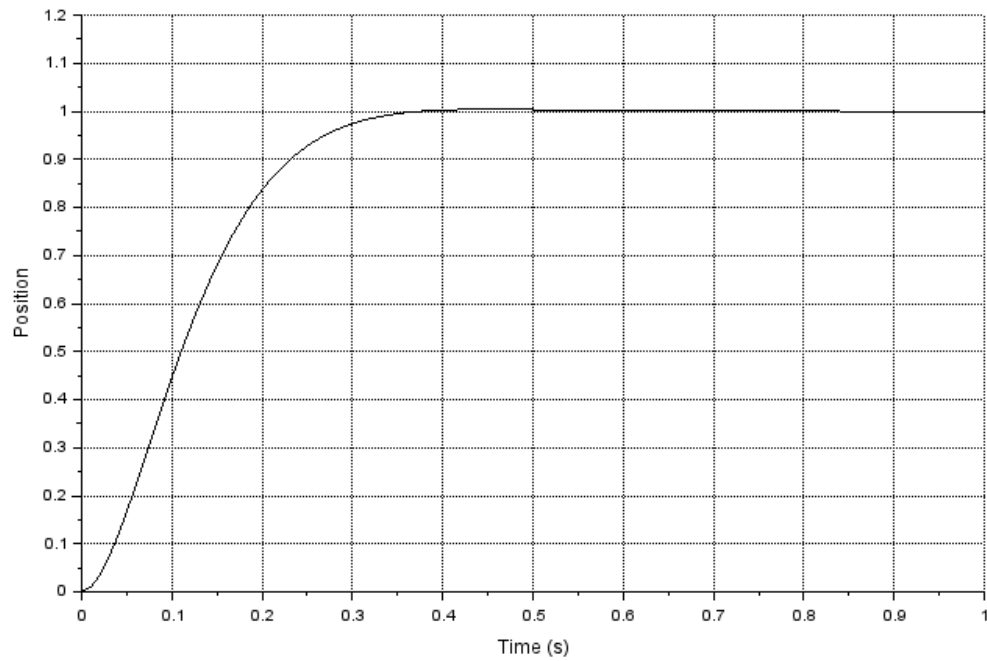


Figure 2.11 – Damping Ratio of 0.87

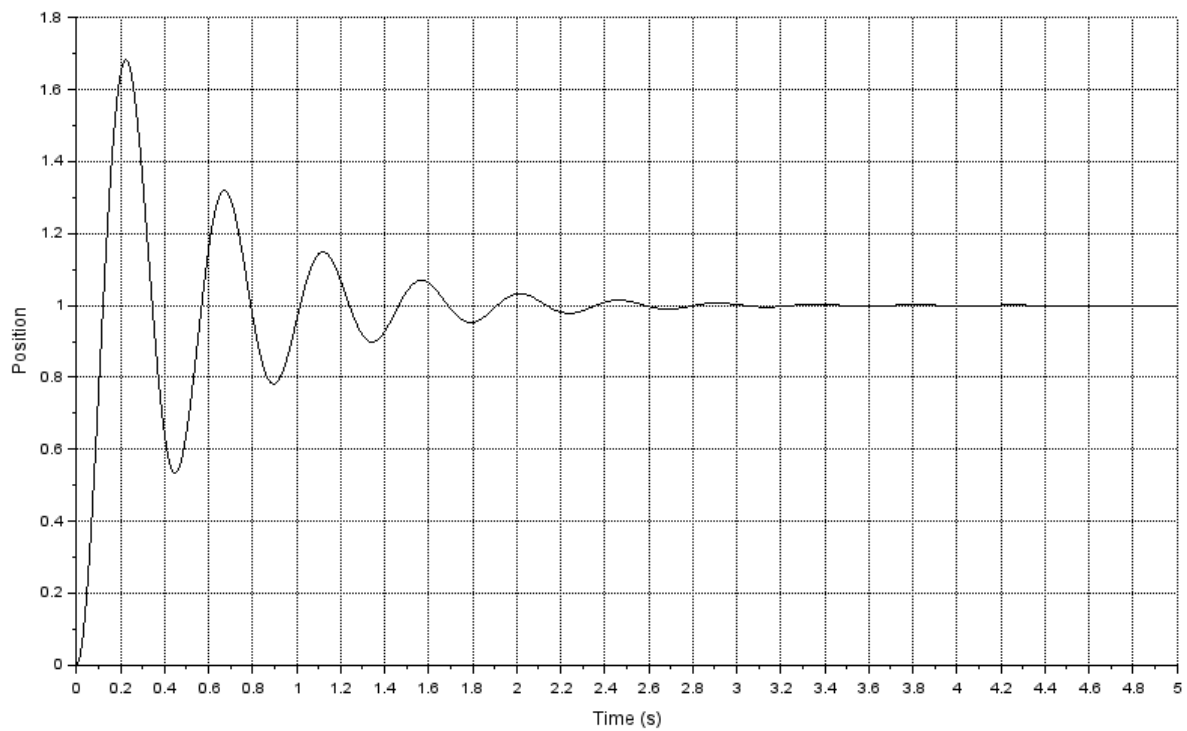


Figure 2.12 – Damping Ratio 0.12

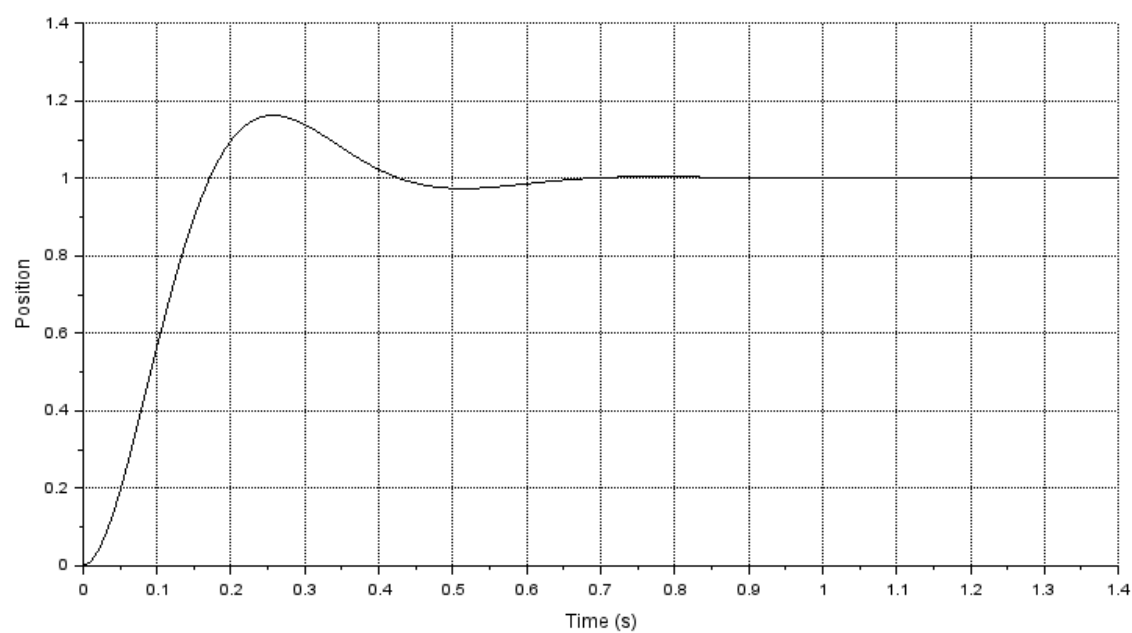


Figure 2.13 – Damping Ratio 0.5

Task 3

Tuning Techniques

Two commonly used tuning techniques for control systems include process reaction method and the ultimate cycle method. The design of a controller allows the selection of control modes to be used and the control mode settings for particular situations. This means establishing if proportional control is to be used or if a combination of proportional, integral and derivative are required and selecting the values of K_P , K_I and K_D . These values will determine how the system reacts to changes and how fast the response and settling times are.

Process reactive curve tuning is a graphical representation utilising the systems response to a step change. It is used to visually observe the systems response and extract tuning parameters. First the system is allowed to reach a steady state before applying a small step change to the input to observe the process response. The percentage of disturbance to the system can be introduced by either altering the set point of process variable. Woolf (2009) explains that 'these types of curves are obtained in open loop systems when there is no control of the system, allowing the disturbance to be recorded.' Several parameters can be measured including transportation lag T_{dead} , time for the response to occur, T , and the ultimate value the response reaches at steady state, M_u . Figure 3.1 is an example of determining these parameters for a typical process response curve subjected to a step change. To measure the normalised process gain, the following formula can be used where X_o is the size of the input step change:

$$K_o = \left(\frac{X_o}{M_u} \right) \left(\frac{T}{T_{dead}} \right)$$

This aids in understanding how responsive the system is with a higher K_o representing a more reactive process.

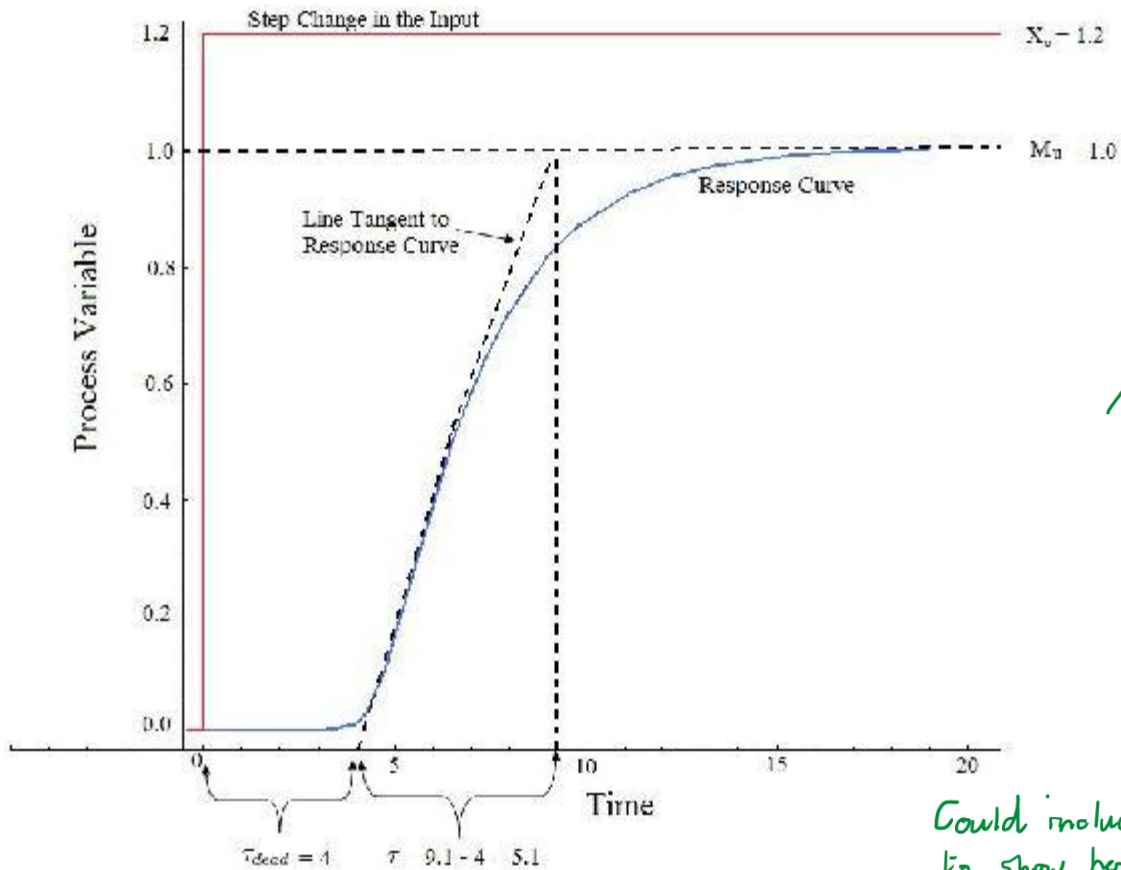


Figure 3.1 – Process Reactive Curve

Could include a table to show how the values are determined.

Ultimate cycle tuning, also known as Ziegler-Nichols method uses the action of firstly reducing the integral and derivative to a value of 0. The proportional constant K_p is gradually increased until the system output shows sustained oscillations as shown in figure 3.4. The value of the ultimate gain K_u and the time between peaks of oscillation T_u are to be recorded. The following formulars shown in table 3.1 will be used to calculate the PID parameters.

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

Table 3.1 – Settings for the ultimate cycle method

An example of this is if $K_u=10$, and $T_u=5$ seconds, then:

$$K_p = 0.6 \times 10 = 6$$



$$T_i = \frac{5}{2} = 2.5s$$

$$T_d = \frac{5}{8} = 0.625s$$

Ultimate Cycle Tuning Method

In order to determine the value for the PID controller, the system needed to be put into a non-steady state condition. The initial response of the system is shown in figure 3.2 with the gain to set to 10 and a steady state established after 12 seconds.

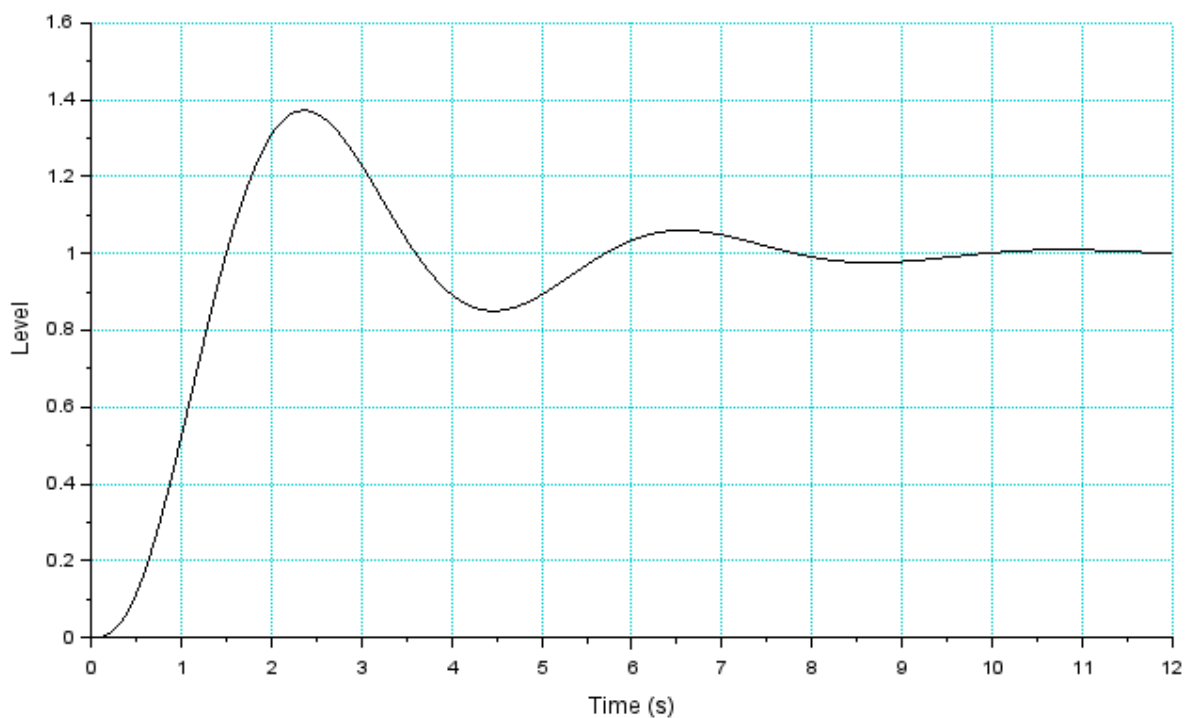


Figure 3.2 – Controller Gain Set to 10

When using the Zeigler Nichols methods, the system needs to be put into an unstable condition with continuous oscillations. Figure 3.3 shows that when the gain has been increased to 20, the system takes longer to reach a steady state but is not fully unstable. /

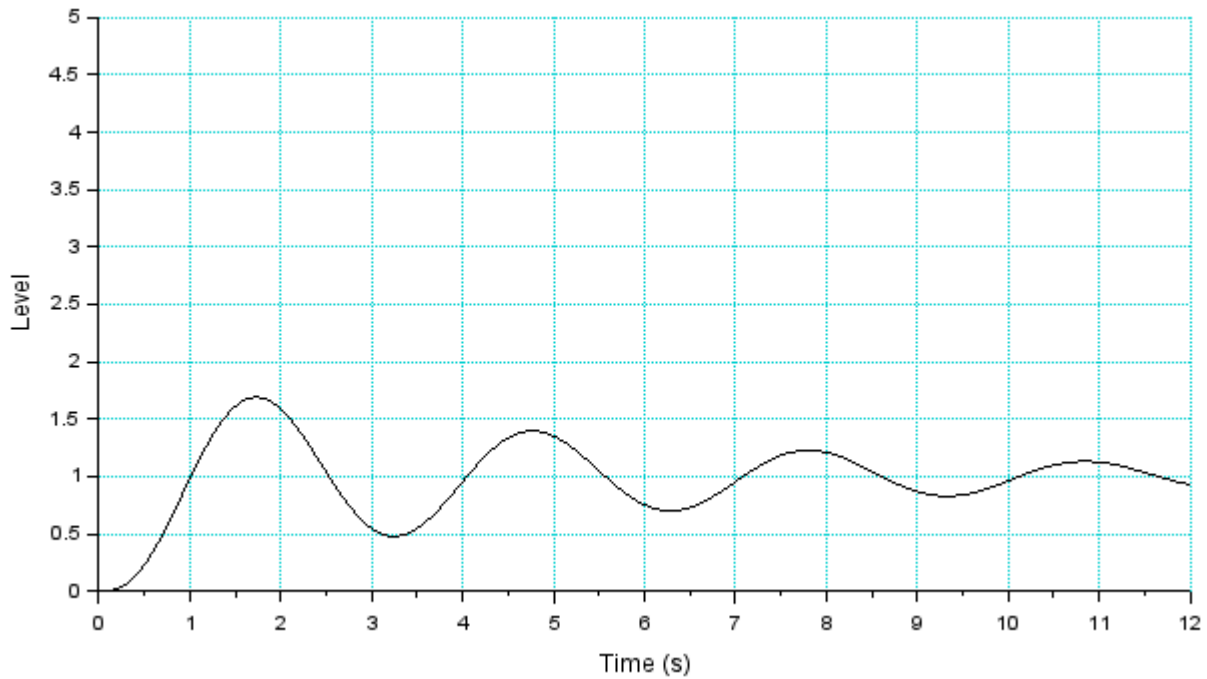


Figure 3.3 – Controller Gain Set to 20

Figure 3.4 show that when the gain has been set to 30, the system becomes unstable and goes into oscillation. Once this has been achieved, the peak-to-peak periodic time can be measured which will be used to calculate the values for the PID controller.

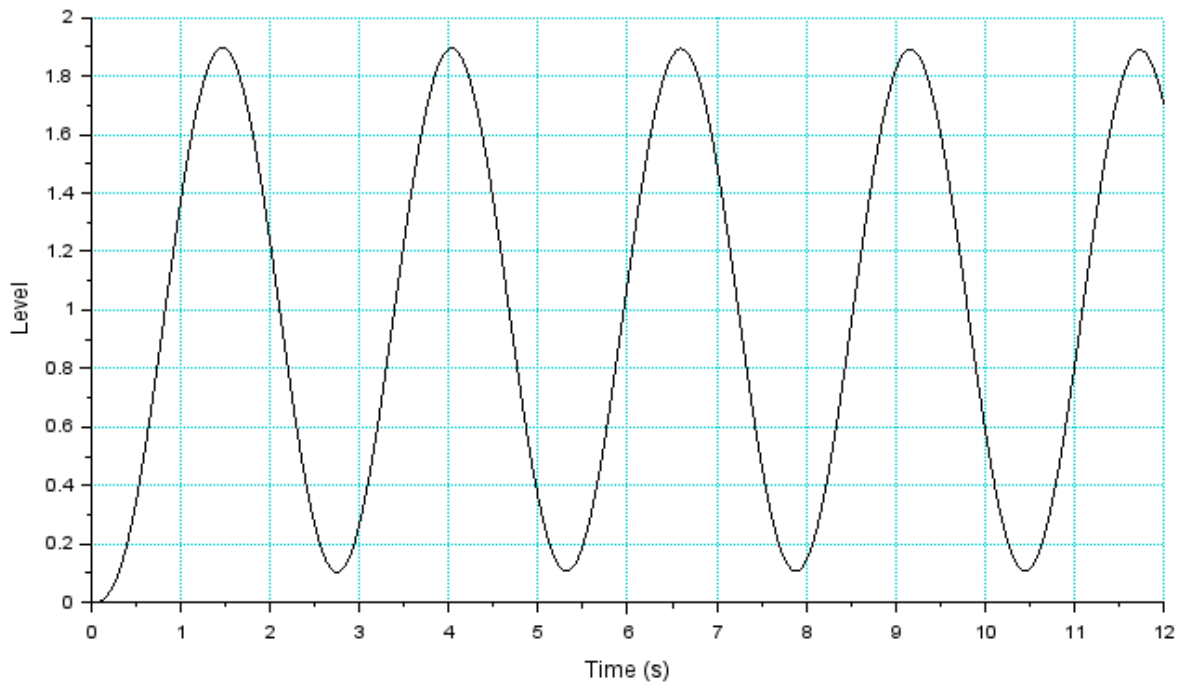


Figure 3.4 – Controller Gain Set to 30

Using figure 3.5, the peak-to-peak periodic time can be calculated as follows

$$Tu = 4.046 - 1.465 = 2.581 \text{ seconds}$$

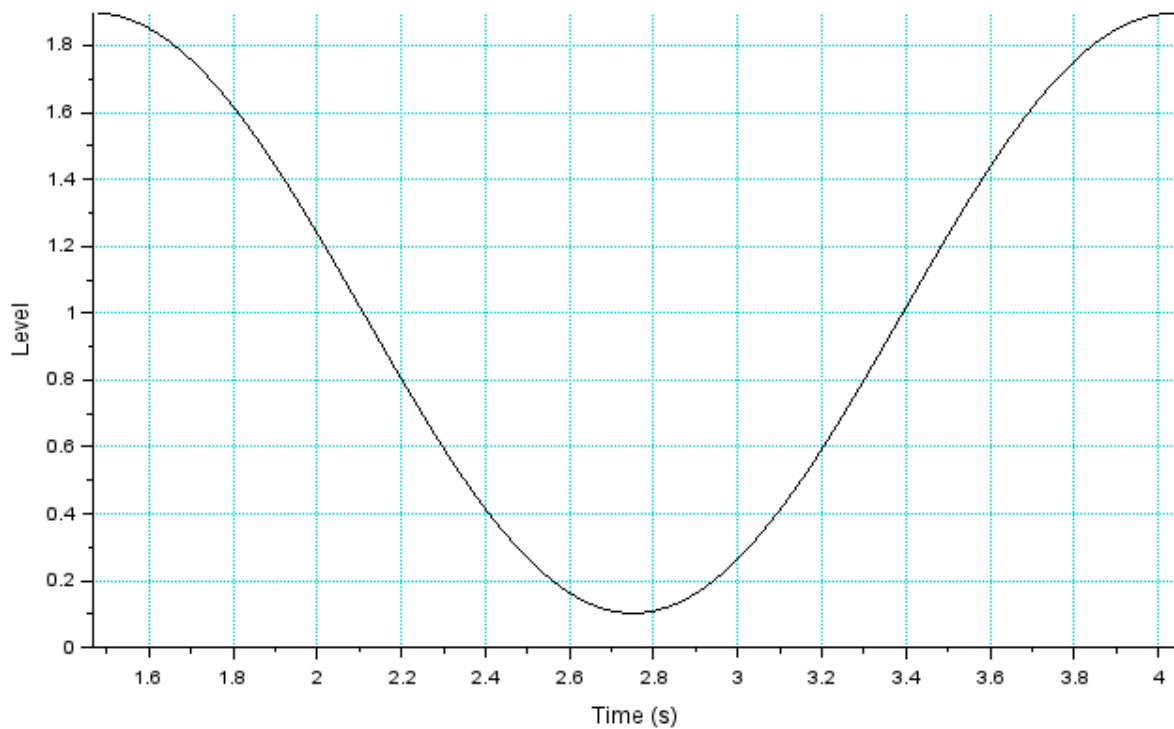


Figure 3.5 – Tu Periodic Time

The following equation have been used to determine the values for the PID controller.

$$Kp = 0.6 \times Kpu$$

$$Kp = 0.6 \times 30 = 18$$

$$Ti = \frac{Tu}{2}$$

$$Ti = \frac{2.581}{2} = 1.2905 \text{ seconds}$$

$$Td = \frac{Tu}{8}$$

$$Td = \frac{2.581}{8} = 0.322625 \text{ seconds}$$

Figure 3.6 shows the systems performance as a result of the tuned values.

Compared to the initial systems performance, the tuned results cause more of an overshoot but does have a quicker response time. The settling time has decreased,

enabling the system to gain control and reach the setpoint without any error. The peak time of the system in figure 3.6 is 1.5 seconds whereas the peak time of the initial system was 2.4 seconds. The system is able to reach its maximum peak quicker resulting in a quicker settling time. The settling time for the initial system was 7.5 seconds whereas it is roughly 5.5 seconds for the system with the tuned results. The tuned results do not have any steady state error which could cause issues with the process, levelling out at the desired position. The rise time of the tuned system can be estimated to be 0.5 seconds which is quicker than the initial system which has a rise time of 1 second.

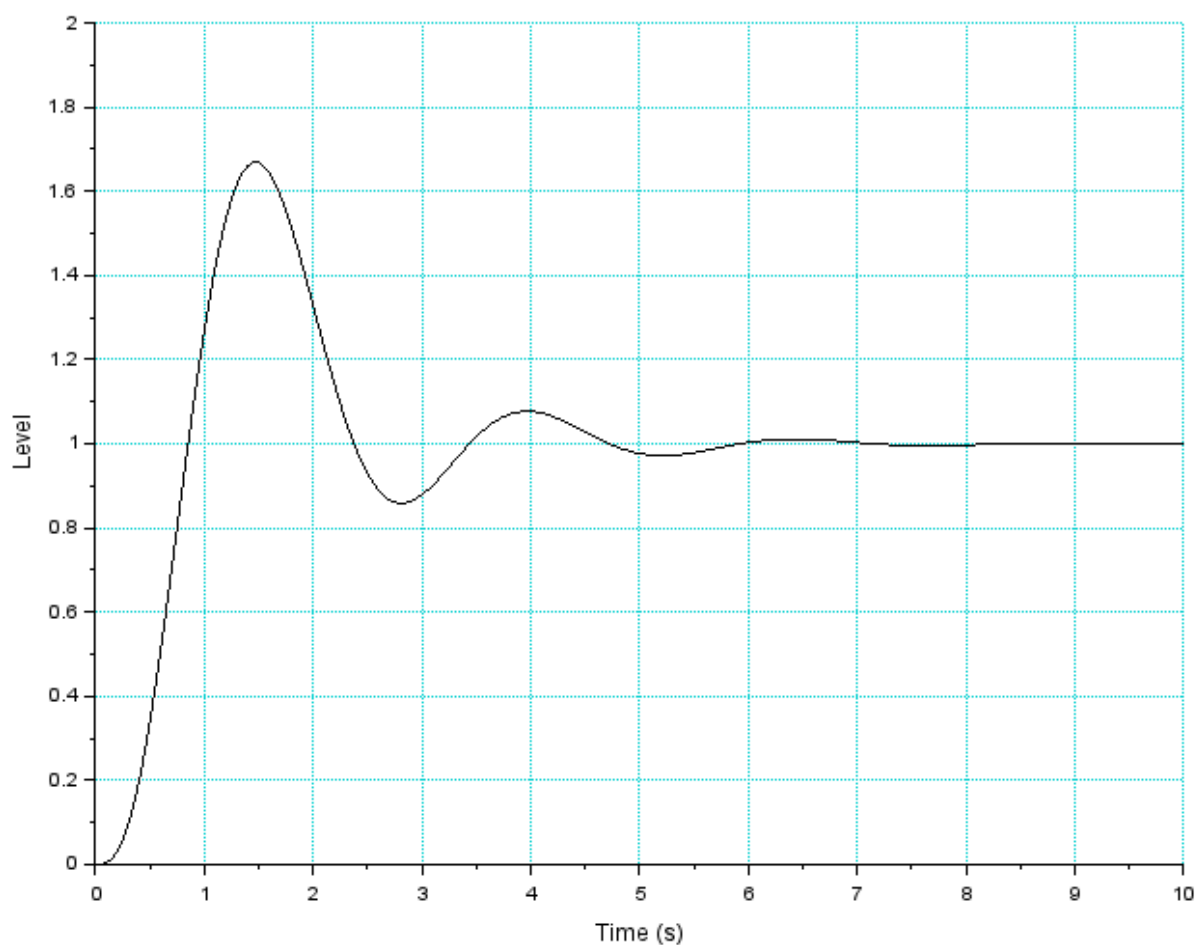


Figure 3.6 – Tuned Results

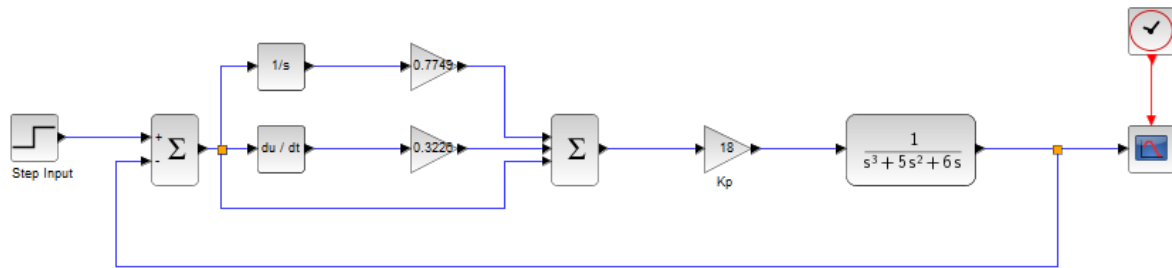


Figure 3.7 – PID Controller

Figure 3.8 shows the systems response when the T_i and T_d values are swapped. It shows that there is still an overshoot of almost 20% but there are no oscillations. The settling time has significantly increased to 8 seconds. It can be seen that with these values, the system takes longer to reach the desired output.

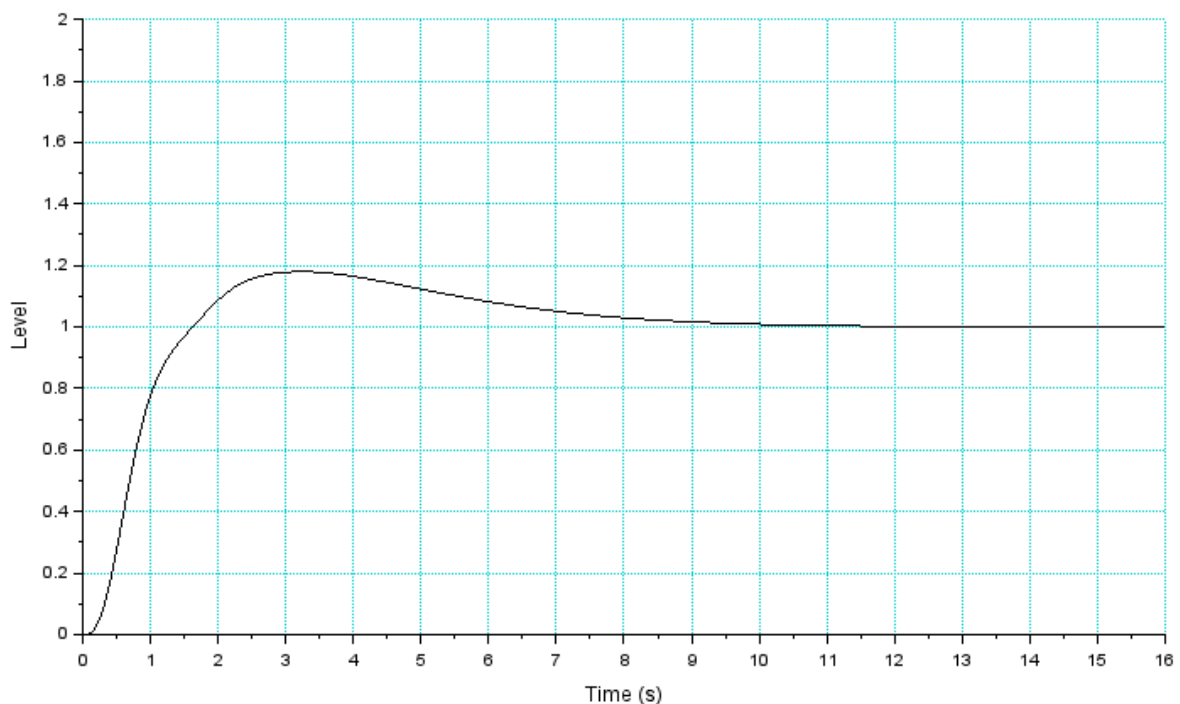


Figure 3.8

Figure 3.9 shows the effects of the values being adjusted to $T_i=1.538$ and $T_d=0.4$. when these values have been changed, it can be seen that there is still an overshoot but the system does not oscillate. At 3 seconds the system produces a slight curve representing that the system could be trying to predict that it might undershoot and correct itself. The settling for this system is quicker than the one in figure 3.8 as well as the rise time.

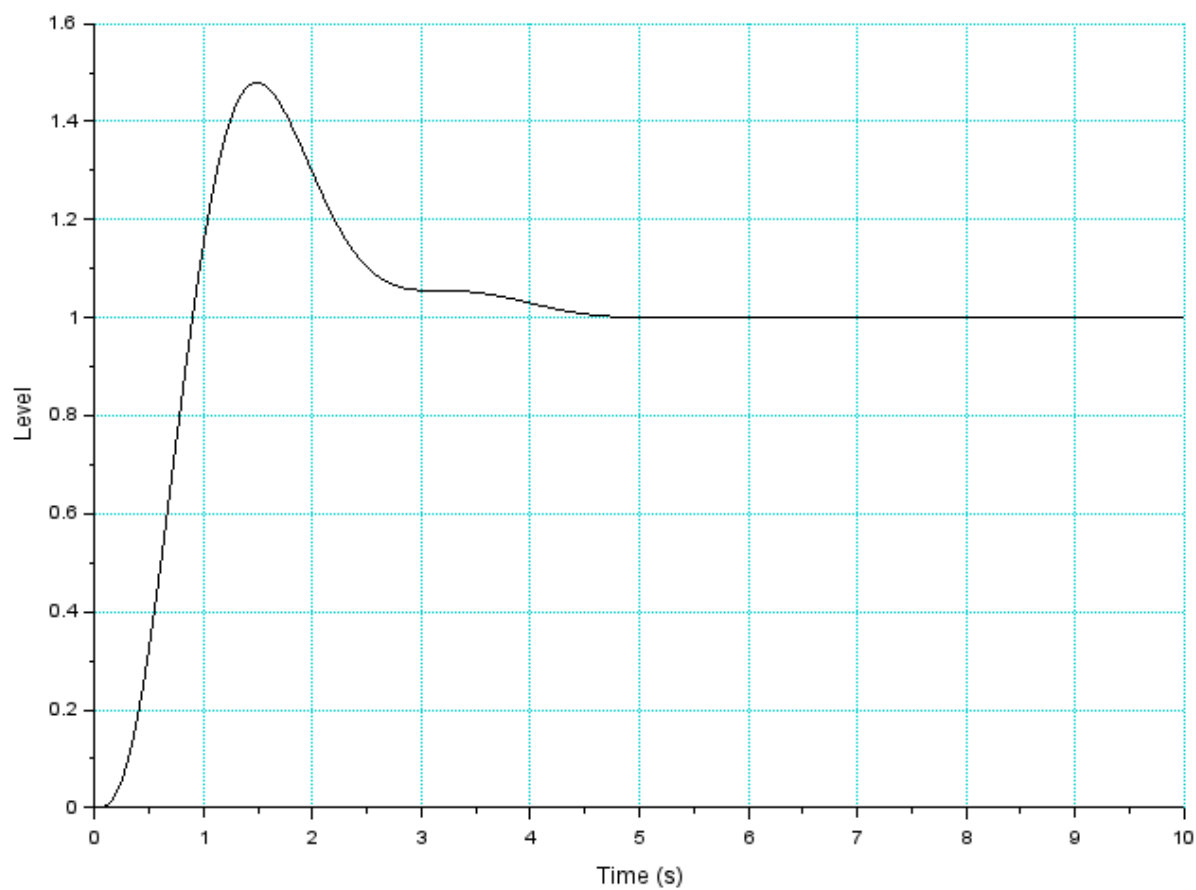


Figure 3.9

Task 4

Computerised control systems provide precise and automated control of processes and machinery by monitoring inputs and sending the correct outputs. The systems use digital processors to detect inputs, determine an appropriate action based on the program and send the outputs to control devices. The most common types of control systems include Programmable Logic Controllers (PLC), Direct Digital Control (DDC), and Distributed Control System (DCS).

A PLC is a digital computer designed for the control of manufacturing processes and machinery. The PLC will receive inputs from field devices and generate an output determined by the program as shown in figure 4.1. A CPU executes the control instructions from the program which is user-defined. They operate on a smaller scale compared to a DCS with typical applications including conveyor systems, packing machinery and assembly lines. PLC's have the capability to handle both analogue and digital signals but is determined by the number of assigned analogue and digital I/Os. Multiple programming languages can be used including ladder logic and function block diagram. PLCs can be integrated with a basic HMI or SCADA system to enable operator interface and generate a visual representation of the process. ✓

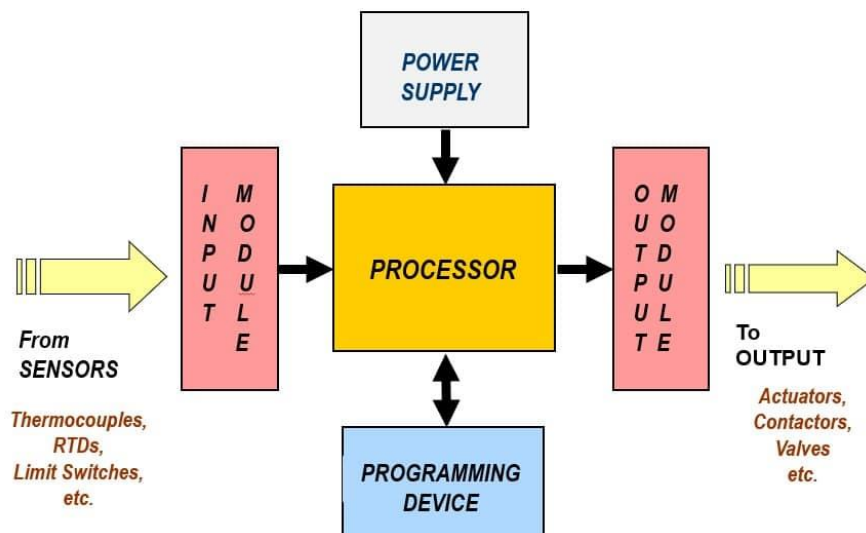


Figure 4.1 – Architecture of Programmable Logic Controller

A DDC system can also be known as building management system (BMS) and refers to the automated control of a process by computers and microprocessors with sensors. DDC focuses primarily on environmental and building control and is commonly used to regulate HVAC, lighting and energy systems. A graphical BMS

interface is used for real-time monitoring and control. Both analogue and digital I/Os are combined in one controller as shown in figure 4.2. Erickson (2025) explains that DDC and SCADA systems can be integrated so that 'the SCADA system will also give other capabilities, such as data gathering, monitoring, and identifying trouble spots for virtually any building function.' Similarly to PLCs, the DDC system is centralised to a singular process with a basic function. Redundancy for PLCs is limited but is more moderate for a DDC system as the program is configuration based.

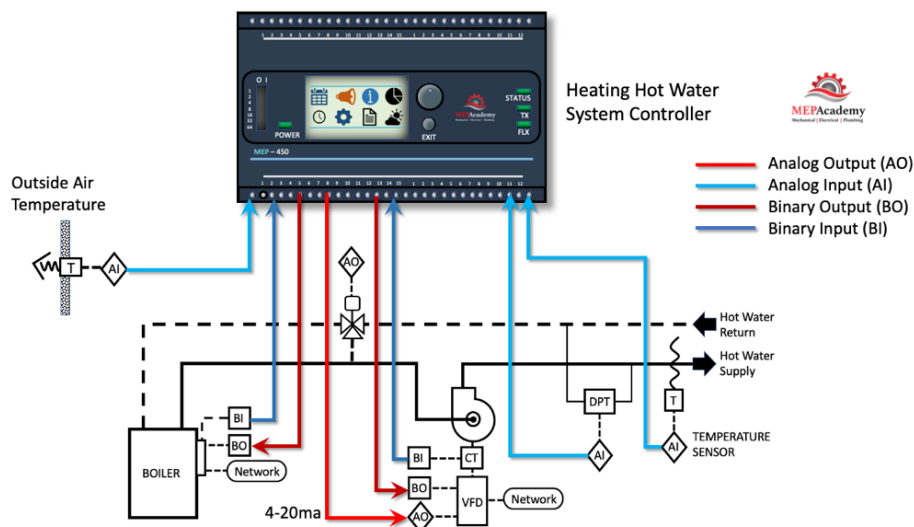


Figure 4.2 – HVAC DDC Controller for a Heating Hot Water Boiler System

Whereas PLC and DDC systems operate on a smaller scale, a DCS is designed for large-scale complex processes where different systems interact with one another as shown in figure 4.3. Control is distributed across multiple controllers which are all coordinated from a central monitoring station. DCS allows different section of an industrial process to communicate so that it can operate automatically and react to process changes. Analogue and digital field devices continuously send data to the DCS for real-time monitoring. Gillis (2023) explains that 'unlike a centralised control system that operates all machines, a DCS enables each part of a machine to have its own dedicated controller that runs the operation.' Advanced HMIs are used for monitoring and interaction with the process to allow the operator to adjust set-points and manually control the process. Additional data logging systems is not required since the DCS system has the capability to log and archive data as well as alarm

monitoring and automatic control. DCS has a high redundancy rate, reducing process downtime and increasing in efficiency.

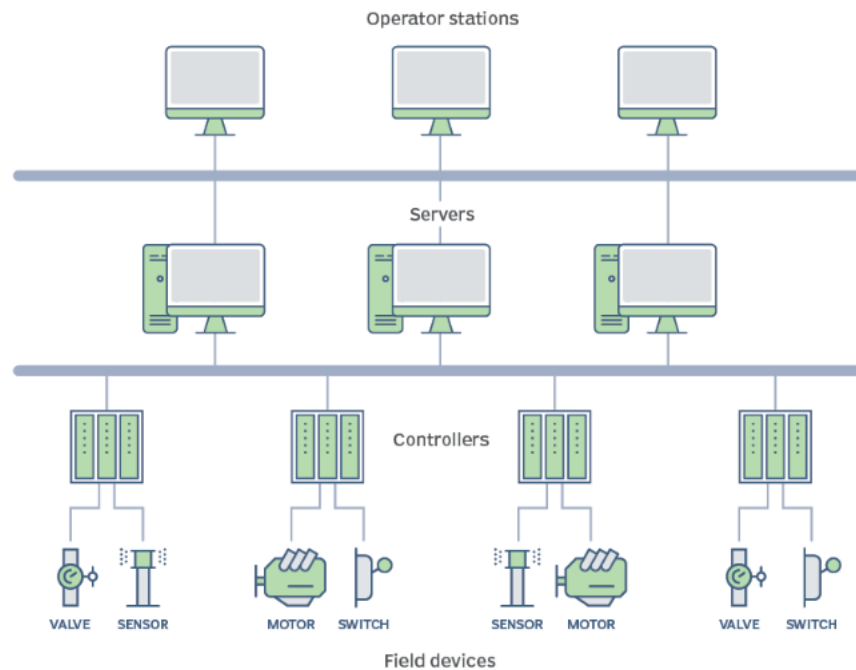


Figure 4.3 – Distributed Control System

PLCs, DDC and DCS all serve the purpose of automating control systems from an operator interface but differ significantly with their capabilities and applications. PLCs can be used in small scale processes where high-speed is required. DDC systems use a combination of analogue and digital I/Os to provide control for building services. For large scale complex systems, DCS is the preferred solution where integration between processes can be achieved.

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