

LEVEL 4 ASSESSMENT SPECIFICATION

Student name:	Scott Dowler	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	13.6
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	28
Task 1 - 67%. Task 2 - 75%. Task 3 - 76%. Task 4 - 62%. Excellent knowledge and understanding of the basic underlying concepts and principles for each task.		
3. Cognitive and Intellectual Skills	10	6.5
Sound evaluation of the underlying concepts and principles for task 2 and 3.		
4. Practical Application Skills	20	16.9
Task 1 - 85%. Task 2 - 84%. 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	7.5
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%)

73%

HNC Instrumentation Electronics

PCEE4011 – Instrumentation, Automation and Control

Assignment 2 – Control Systems

Submission Date – 15/05/2025

Scott Dowler

Lecturer: Jason Pointer

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Task 1 – Control Types

a) Open-Loop System

An open-loop system (also known as a non-feedback control system) is a type of control system where the output of the system does not provide any form of feedback or comparison to the input of the system. An open-loop system works by using an input signal which is processed through a controller and an output is generated to achieve a set point. What makes this an open-loop system is that there is no verification or correction to ensure that the desired output has been achieved. As a result, open-loop systems have no automatic correction or adjustment based on the real output as the system will assume that the output will correctly match the input command (Bolton, 2006). ✓

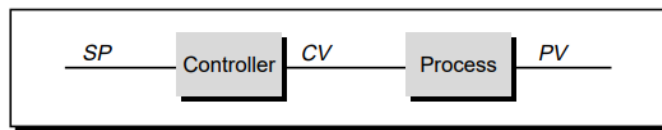


Figure 1 - Open-Loop Control System (Bryan & Bryan, 1997)

“In an open-loop control system the output from the system has no effect on the input signal to the plant or process. The output is determined solely by the initial setting. In a closed-loop control system the output does have an effect on the input signal, modifying it to maintain an output signal at the required value” (Bolton, 2004). ✓

An example of an open-loop system could be a control valve using a current-to-pressure (I/P) transducer. In this system a PLC or another controller sends a 4-20mA analogue signal to the I/P which is representative of the desired valve position (4mA = fully closed, 20mA = fully open). The I/P converts the 4-20mA signal into a proportional pneumatic 3-15psi signal. ✓

This 3-15psi pneumatic signal is used to control the valve, opening and closing as the input signal is manually changed. As the valve opens and closes, the process is affected such as the flow rate or pressure however, there is no verification or measurement used to confirm how the process has changed or if the valve has moved using a valve position feedback arm or downstream flow transmitter. ✓

This is an open loop system because it assumes that if a 9psi (50%) signal is sent to the valve then it will move to that position without measuring if the flow is affected or by measuring the valve travel. If the process conditions change such as the supply flow or pressure, then the valve will not correct itself to maintain a set flow or pressure downstream of the valve (Bolton, 2004). ✓

b) Closed-Loop System

Set Point / Input – This is the desired value of the controlled process which the system will aim to reach.

Comparison Element – This compares the inputted set point to the measured value and produces an error signal to determine how far the measured value is from the set point.

Control Element– This controls the correction element deciding what action to take when an error signal is detected.

Correction Element – This alters the process to reach the set point by removing the error.

Process – The actual process such as steam.

Measuring Element – This measures the value of the output and produces a signal fed back into the comparison element to determine if there is an error.

Measured Value – This is the measured output of the process.

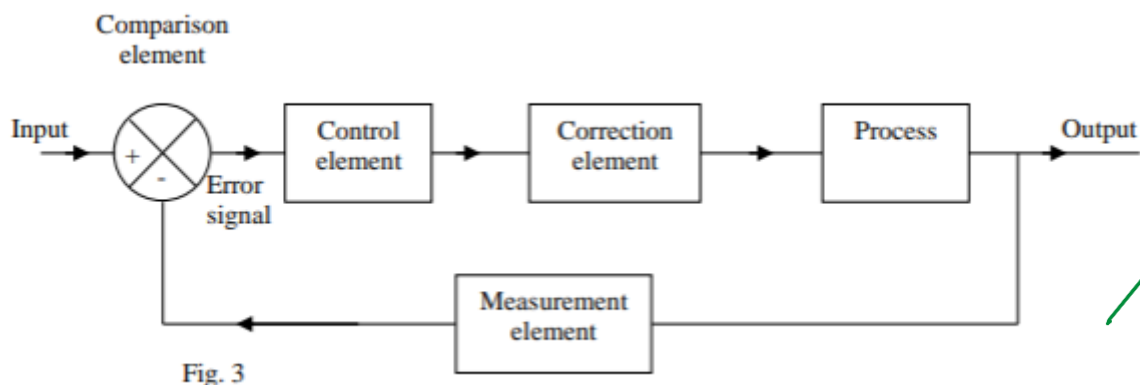


Figure 2 - Closed-Loop Control System Block Diagram

An example of a closed-loop control system could be a temperature controller on a distillation column. In this instance, a desired temperature would be set as your input for the system to achieve. The controller would be implemented into the PLC or DCS which would compare the measured value from a local temperature instrument to the set point to determine if there is any error. If an error is detected a correction element such as a fuel gas valve will be automatically adjusted to reduce the error. The output in this example would be the current measured value of temperature and the local temperature instrument would be the measurement element, which is providing feedback (Bolton, 2006), (Bryan & Bryan, 1997).

Good industrial example.

$$\theta_0 = \varepsilon \times G$$

$$\varepsilon = \theta_i - \theta_0 \times H$$

$$\varepsilon = \frac{\theta_0}{G}$$

Need to state what you are doing and also need to include a block diagram to show the terms being used.

$$\frac{\theta_0}{G} = \theta_i - \theta_0 \times H$$

$$\theta_0 = G(\theta_i - \theta_0 \times H)$$

$$\theta_0 = G \times \theta_i - G \times \theta_0 \times H$$

$$\theta_0 + G \times \theta_0 \times H = G \times \theta_i$$

$$\theta_0(1 + G \times H) = G \times \theta_i$$

$$\frac{\theta_0}{\theta_i} = \frac{G}{1 + GH}$$

c) Three-Term Control

A three-term controller, also known as a Proportional-Integral-Derivative (PID) Controller is used in many closed-loop control systems to continually modify the output of the system to maintain a desired set point. This is done by minimising the error between the set point and the process variable. Proportional, Integral, and Derivative control actions are provided using input variables such as temperature and pressure (Bryan & Bryan, 1997). ✓

A PID controller receives process variables in analogue form before calculating the difference between the set point and the true value to find the error. This error is used within its control algorithm for a three step, simultaneous, corrective action using the control variable output. ✓

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

(ScienceDirect, 2015).

First, a Proportional control action is calculated that is proportional to the current error value based on an output control variable. If there is a large current error, then the corrective action will be strong but if there is a small error then there will not be much control action. This is a fast response but can cause a steady state error. ✓

Next, an Integral control action is formulated for additional compensation to the output control variable. The result of this is a change in the process variable in proportion to the error over a period of time. This functions by summing the error over time and correcting for past accumulated errors which ensure that the output is reached, and the set point is maintained by eliminating offset. This will reduce any steady state error caused by the Proportional action, but many cause a slower response or overshoot. ✓

Finally, a Derivative control action is initiated which adds even more compensation to the control output. This change is proportional to the rate of change of error. This control action effectively predicts future error based on the current rate of change of error. The compensation that it provides acts as damping, reducing any overshoot and improving the stability of the system which helps to prevent any oscillation (Bolton, 2004). ✓

The following equation defines one of the control algorithms implemented by a PID module:

$$V_{\text{out}} = K_p E + K_i \int E dt + K_d \frac{dE}{dt}$$

where:

K_p = the proportional gain

$K_i = \frac{K_p}{T_i}$, which is integral gain (T_i = reset time)

$K_d = K_p T_d$, which is derivative gain (T_d = rate time)

$E = SP - PV$, which is error

V_{out} = the control variable output

Figure 3 - PID Module Equation (Bryan & Bryan, 1997)

Task 2 – Position Servo Control

a)

$$\frac{\theta_o(s)}{\theta_i(s)} = \frac{K_A K_P K_f / I}{\left(s^2 + \frac{sB}{I} + \frac{K_A K_P K_f}{I} \right)}$$

$$K_A = 1$$

$$K_P = 5 \text{ Vr}^{-1}$$

$$K_f = 6 \text{ mAV}^{-1}$$

$$I = 1.5 \times 10^{-4} \text{ Kgm}^2$$

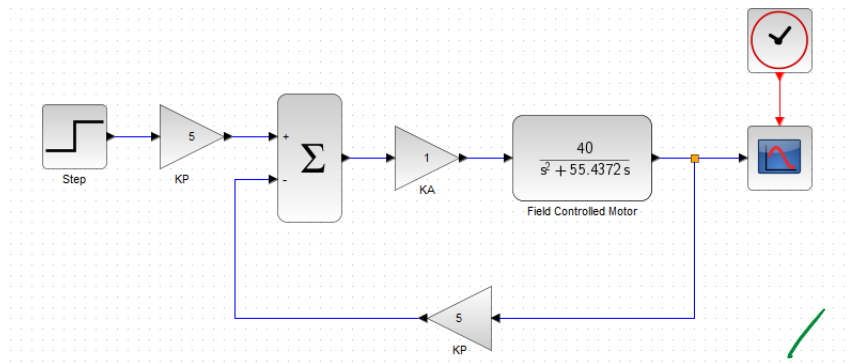


Figure 4 - Position Servo Control Block Diagram

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

$$\frac{200}{s^2 + 6666.67 \times Bs + 200}$$

Standard Equation for a 2nd order system

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

$$K_{ss} = \text{steady state gain} = 1$$

$$\omega_n^2 = \text{natural frequency} = 200$$

$$\omega_n = \sqrt{200} = 14.14 \text{ rad/s}$$

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

$$B = 2\zeta \times 14.14 / 6666.67$$

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

No Damping ($\zeta=0$)

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

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

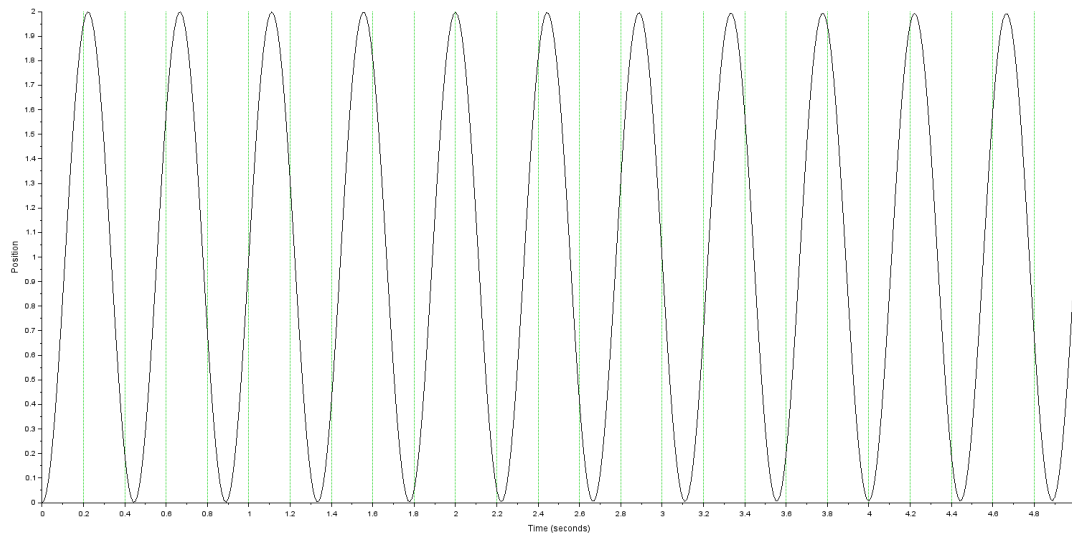


Figure 5 - No Damping $\zeta = 0$

Under Damped ($0 < \zeta < 1$)

$$B = 0.71 \times 4.242 \times 10^{-3} = 3.011 \times 10^{-3} \text{ N}$$

$$\frac{B}{I} = \frac{3.011 \times 10^{-3}}{1.5 \times 10^{-4}} = 20.073$$

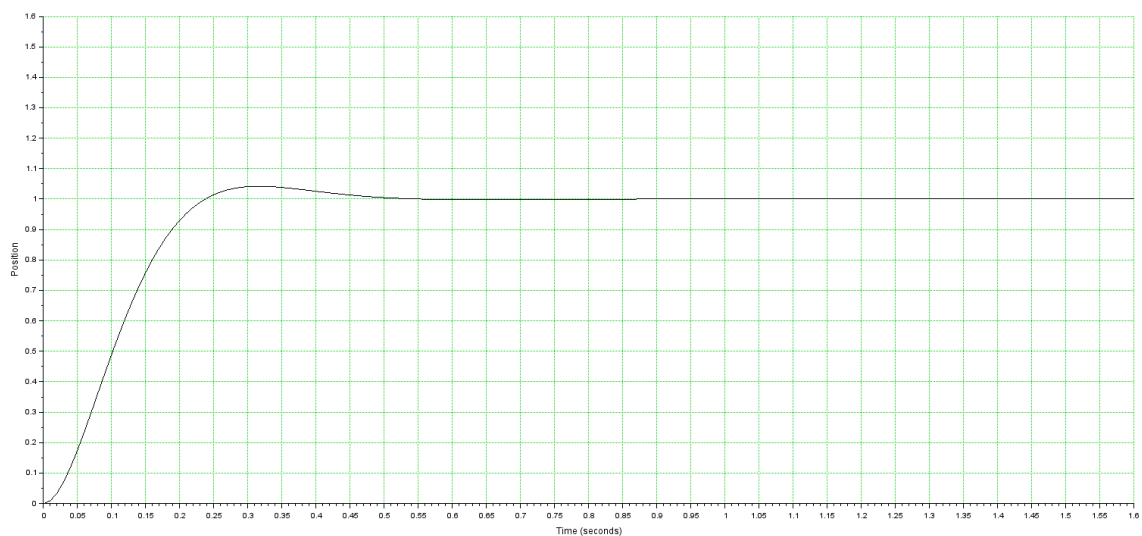


Figure 6 - Under Damped $\zeta = 0.71$

Critically Damped ($\zeta=1$)

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

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

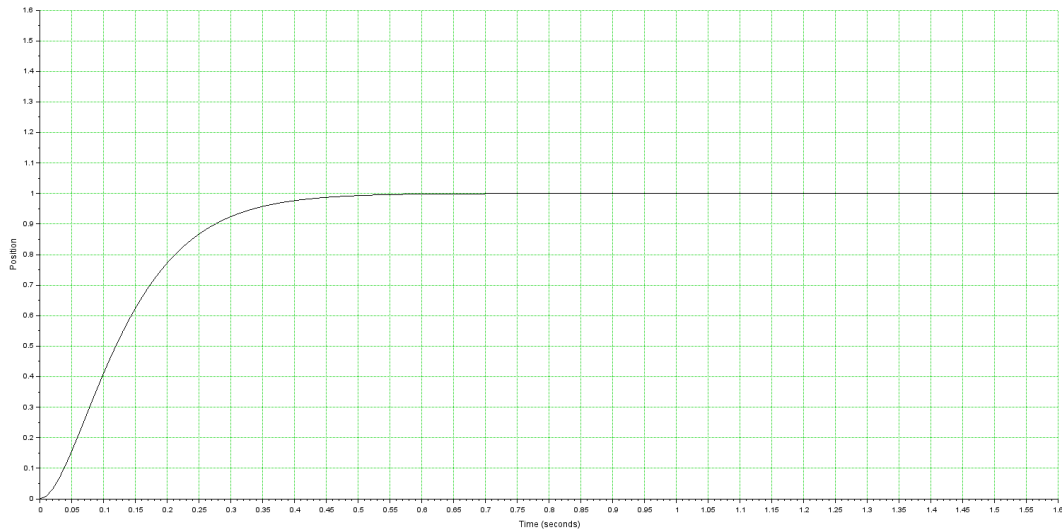


Figure 7 - Critically Damped $\zeta = 1$

Over Damped ($\zeta > 1$)

$$B = 1.96 \times 4.242 \times 10^{-3} = 8.314 \times 10^{-3} \text{ N}$$

$$\frac{B}{I} = \frac{8.314 \times 10^{-3}}{1.5 \times 10^{-4}} = \mathbf{55.427}$$

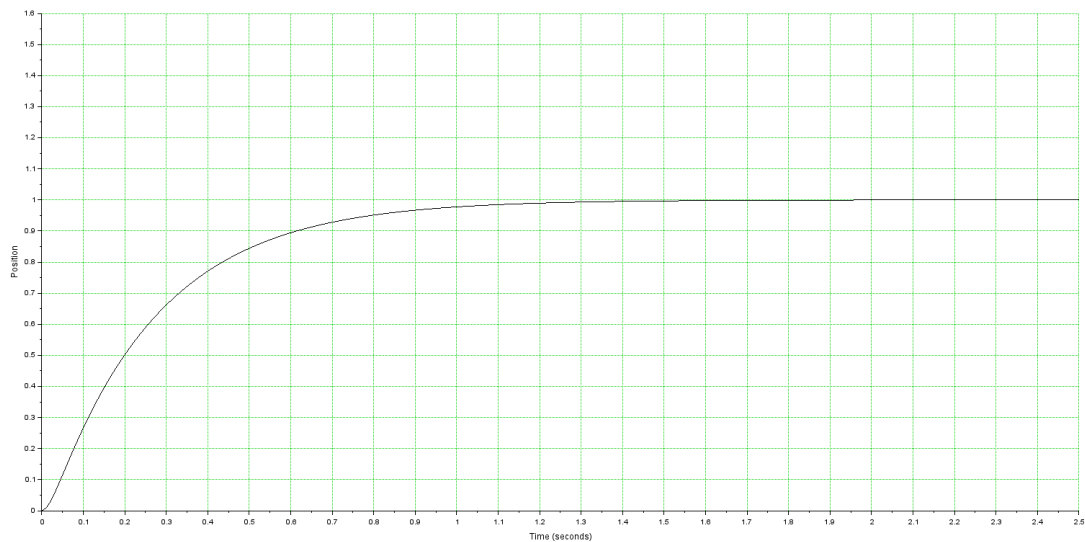


Figure 8 - Over Damped $\zeta = 1.96$

well done.

b)

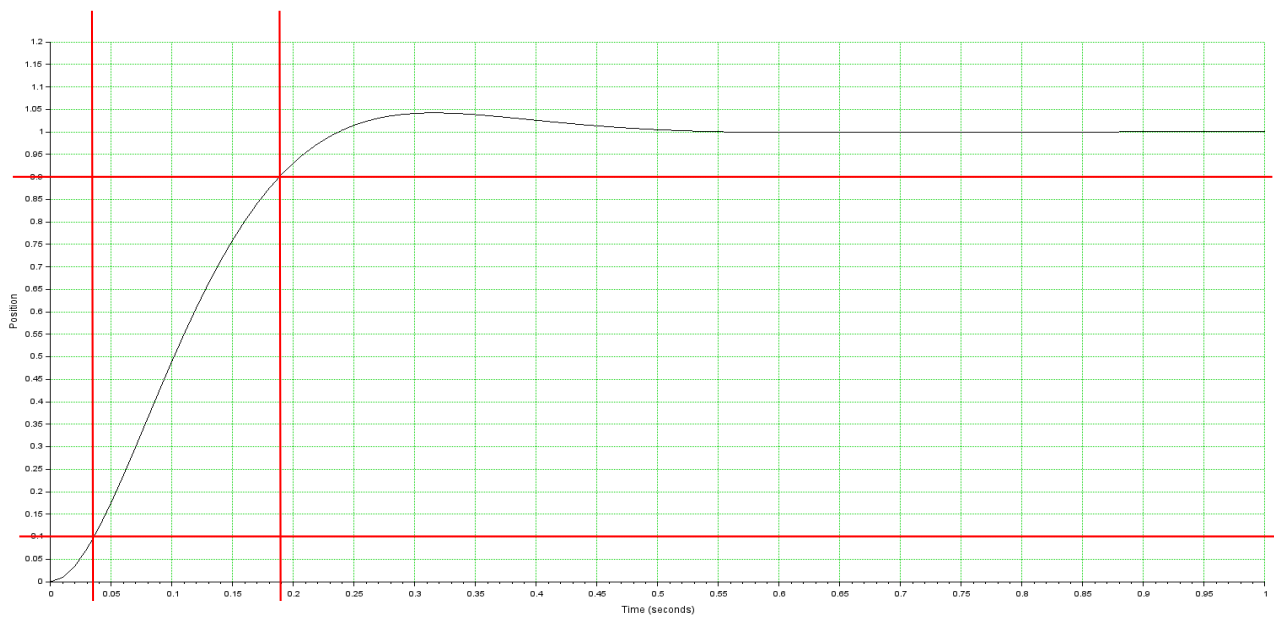


Figure 9 – Rise Time

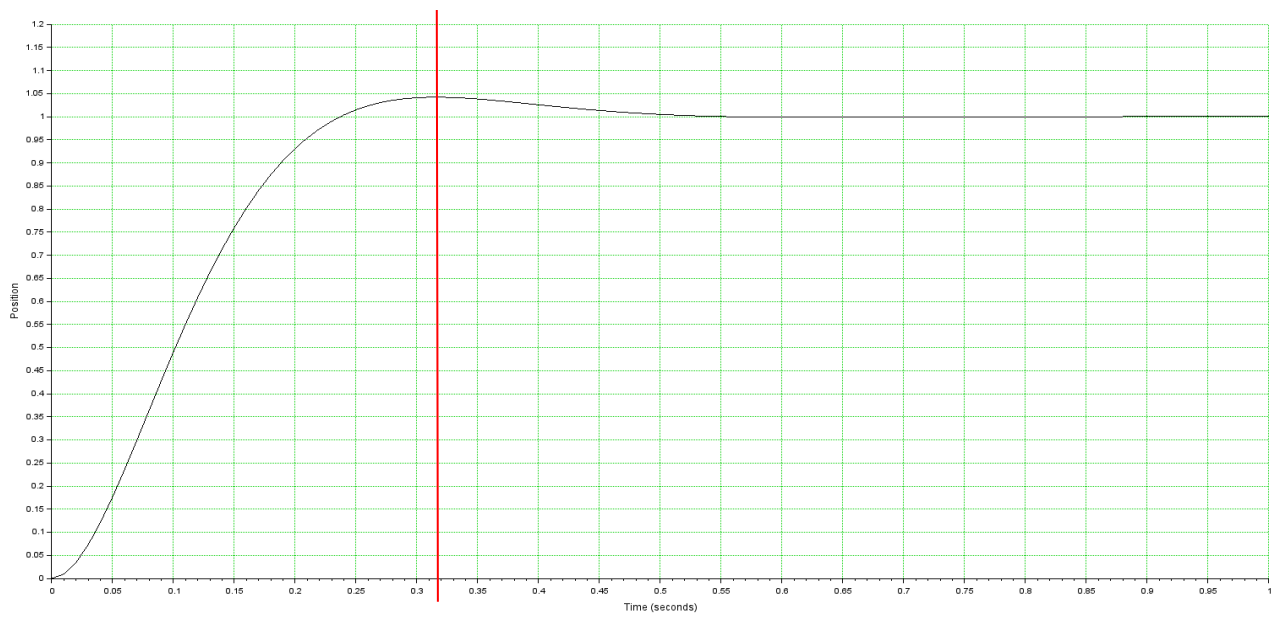


Figure 10 – Peak Time

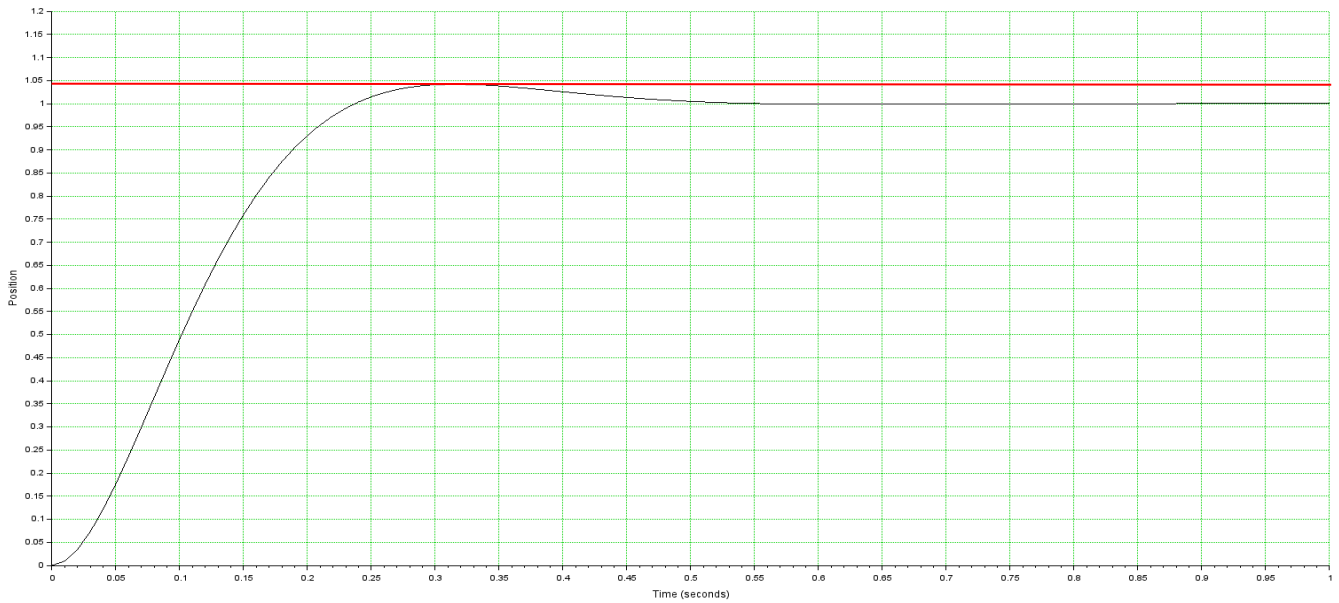


Figure 11 – Percentage Maximum Overshoot - 5%

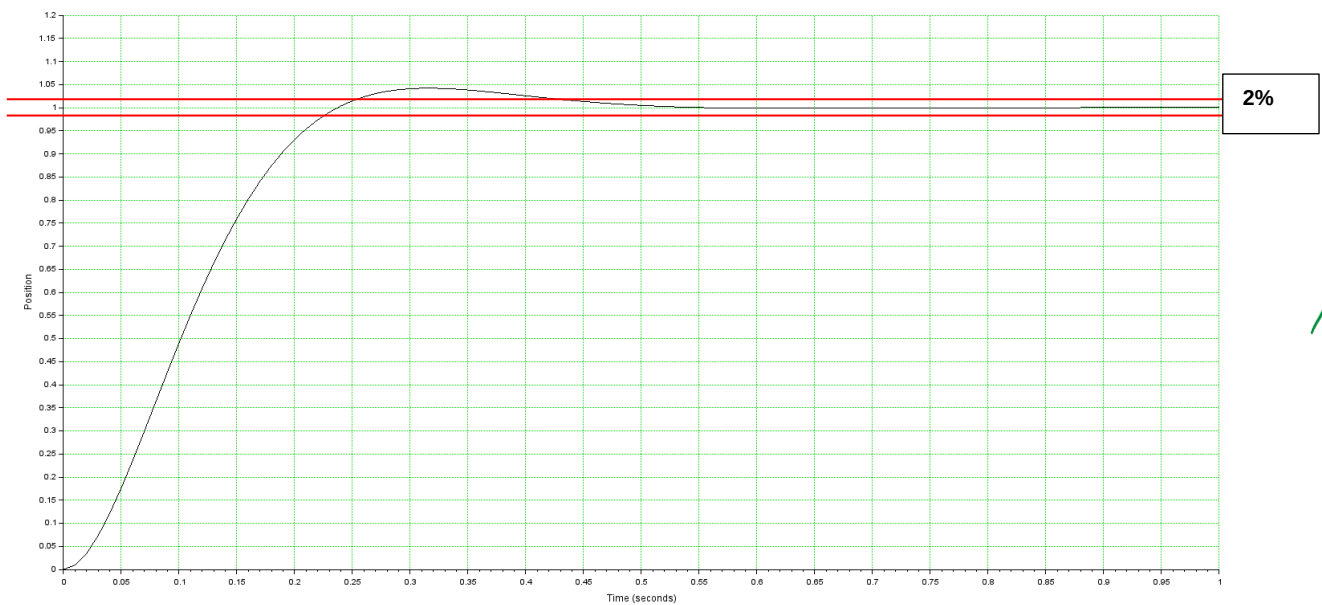


Figure 12 - Settling Time

Settling Time = **0.43 seconds**

Rise Time = $0.19 - 0.035 = 0.155$ seconds

Peak Time = **0.32 seconds**

Maximum Percentage Overshoot = **5%**

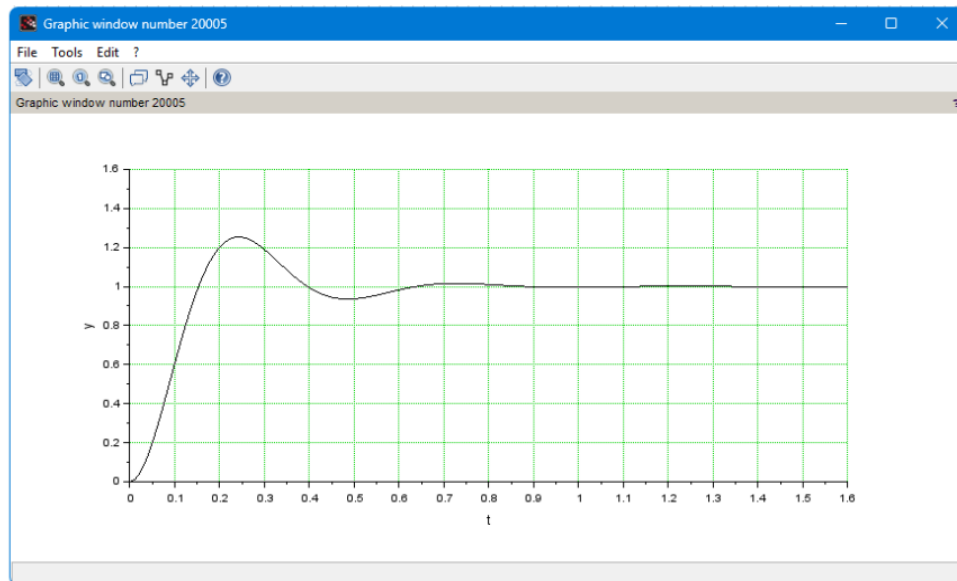


Figure 13 – $\zeta = 0.4$

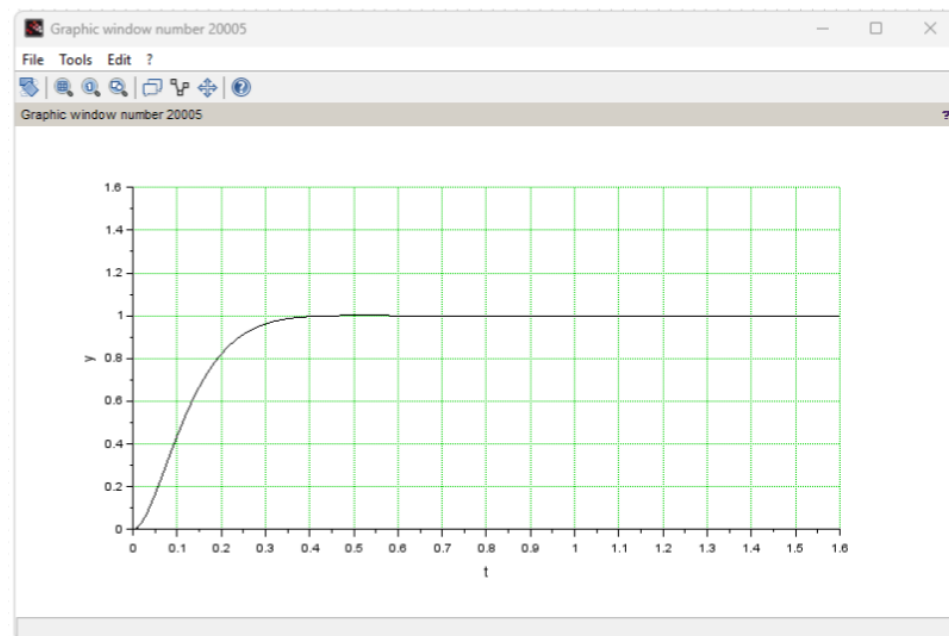


Figure 14 - $\zeta = 0.9$

Figures 13 and 14 above show the change in response within the same system when the value of B is changed for the under damped system. Figure 13 shows how the response changes as the value of B becomes closer to 0. As can be seen, there is far more oscillation and greater overshoot and undershoot on the system. The rise time does improve but the settling time takes much longer. There is also a much greater maximum percentage overshoot

Figure 14 shows how the response changes as the value of B becomes closer to 1. The image shows there is next to no overshoot/undershoot and no oscillation. It also shows that there is a longer rise time, but the settling time is much less.

Task 3 – Tuning

a)

Ultimate Cycle Tuning

The ultimate cycle tuning method is a method developed by Ziegler and Nichols. This method begins with all integral and derivative actions being reduced as far as possible with the proportional action being reduced to a low value. The controller should be in manual operation at the time. Once the proportional action is set low and the integral and derivative actions are turned off then you can switch the controller back to automatic and watch the response. Next, increase the proportional action and observe the response again. Repeat until the response given is full sustained oscillations with no growth or decay. Record the gain and the periodic time of the oscillations (Bryan & Bryan, 1997).

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

Figure 15 - Ultimate Cycle Tuning Settings (Bolton, 2004)

Next, use the table in Figure 15 to calculate the correct settings for the type of controller that you are using. An example of this is given in Task 4b.

Process Reaction Tuning

The process reaction tuning method is another tuning method developed by Ziegler and Nichols. This method uses measurements made while the control loop is open, this is so that there is no accidental control loop. The break in the control loop often occurs between the controller and the correction unit or by placing the loop into manual control.

Next, a test input signal is applied to the correction unit to determine the response of the controlled variable. This test signal is a step signal with a step size which is expressed as a percentage, P in the correction unit. The Process Reaction Curve is a graph (Figure 17) plotted using the output of the response of the controlled variable against time. A tangent is drawn to determine the maximum gradient of the curve. The difference in time between the start of the test signal and the point that the tangent intersects the graph is the lag, L and the maximum gradient value is M. To determine the settings for the controller, Figure 16 shows the correct way to calculate them (Bolton, 2004).

Type of controller	K_p	T_i	T_d
P	P/RL		
PI	$0.9P/RL$	$3.3L$	
PID	$1.2P/RL$	$2L$	$0.5L$

Figure 16 - Process Reaction Tuning Settings (Bolton, 2004)

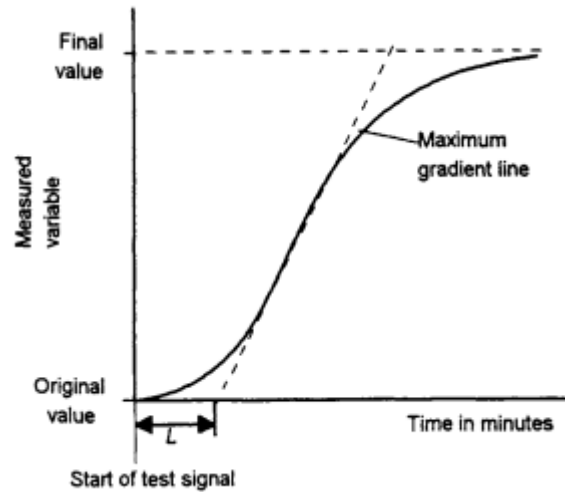


Figure 17 - Process Reaction Graph (Bolton, 2004)

b)

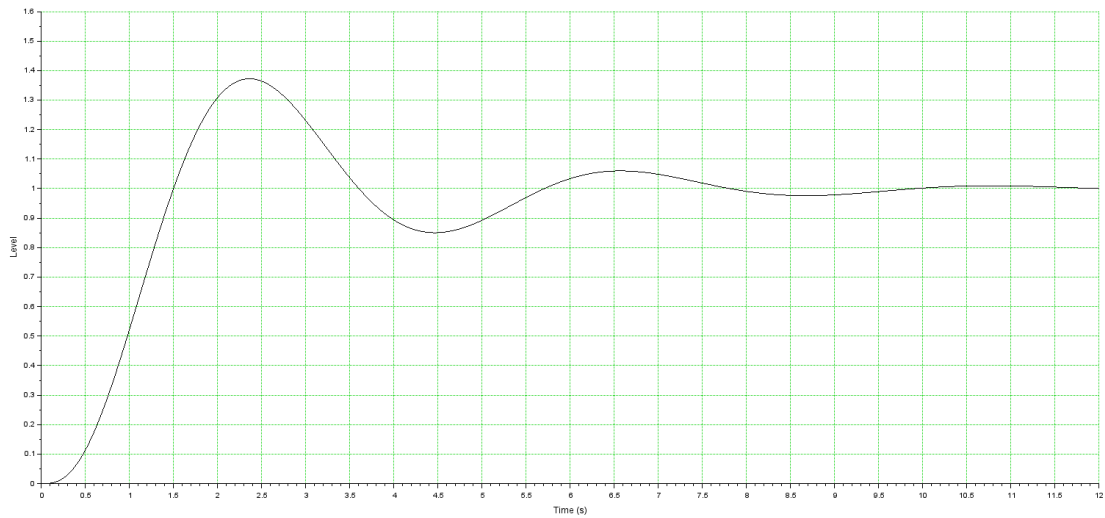


Figure 19 - Gain = 10, initial response with no tuning

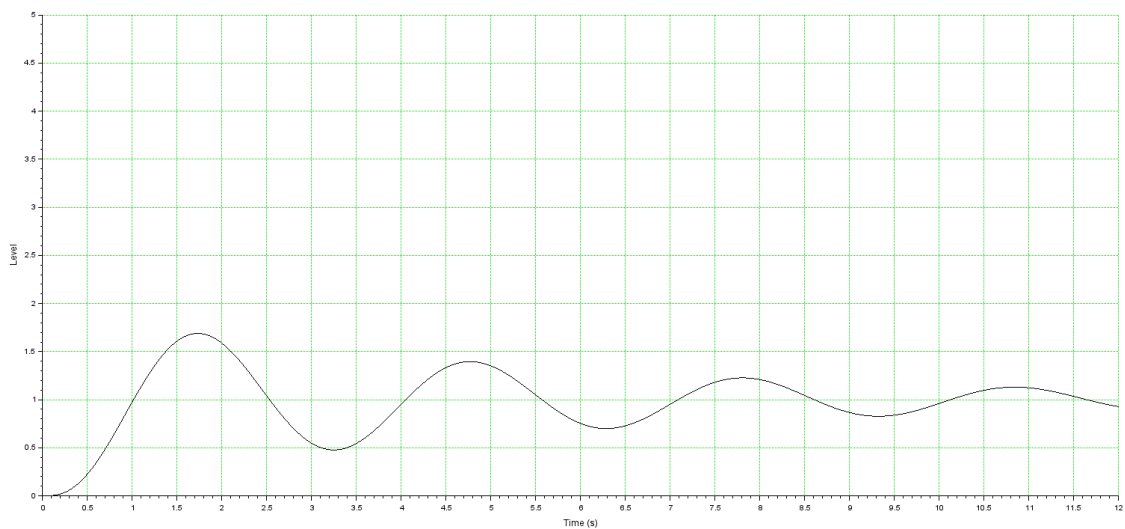


Figure 18 – Gain = 20

Figure 18 shows the initial response of the pre-tuned controller with no PID control with a gain (K_{pu}) of 10. This response has overshoot, undershoot, a long settling time and is not particularly good. Following the ultimate cycle tuning method, we increased the gain to 20 as can be seen in Figure 19. This response has changed leading to more oscillations and a longer settling time. ✓

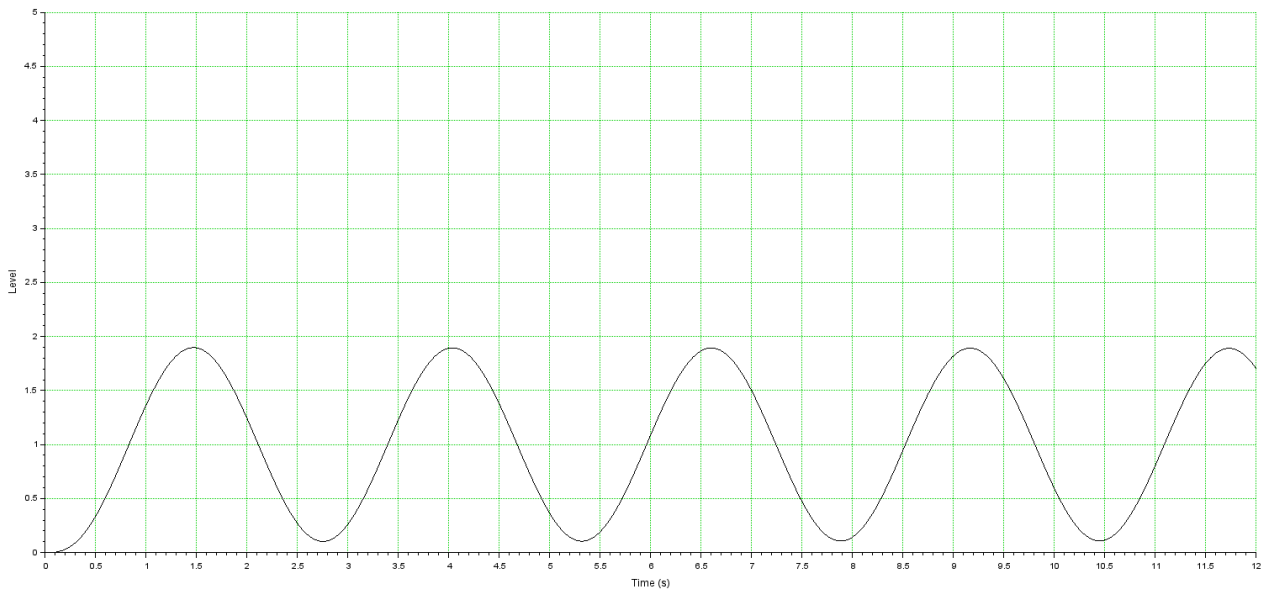


Figure 21 - Gain = 30

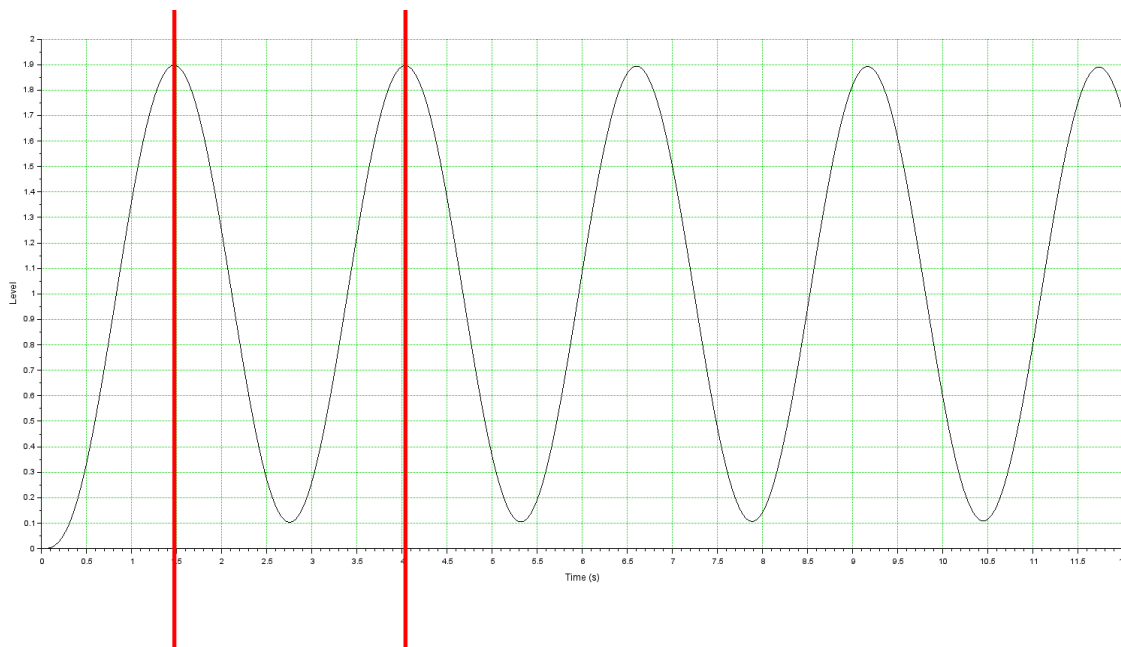


Figure 20 - Measuring Periodic Time, Gain (K_{pu}) = 30, T_u = 2.55

Continuing to follow the ultimate cycle tuning method, the gain was increased until there were full, sustained oscillations that do not grow, or decay as shown in Figure 20. Figure 21 shows the same response as Figure 20 and is used to calculate the periodic time (peak-to-peak). This periodic time value (T_u) is used to calculate the ideal tuning with a PID controller.

Using the values of the gain (K_{pu}) = 30, periodic time (T_u) = 2.55⁵, and the multiplication factor = 0.6 (given value) we can calculate the value to start with in our PID controller.

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

$$T_I = \frac{T_u}{2} = \frac{2.55}{2} = 1.275$$

$$\frac{1}{T_I} = \frac{1}{1.275} = \mathbf{0.784}$$

$$T_D = \frac{T_u}{8} = \frac{2.55}{8} = \mathbf{0.31875}$$

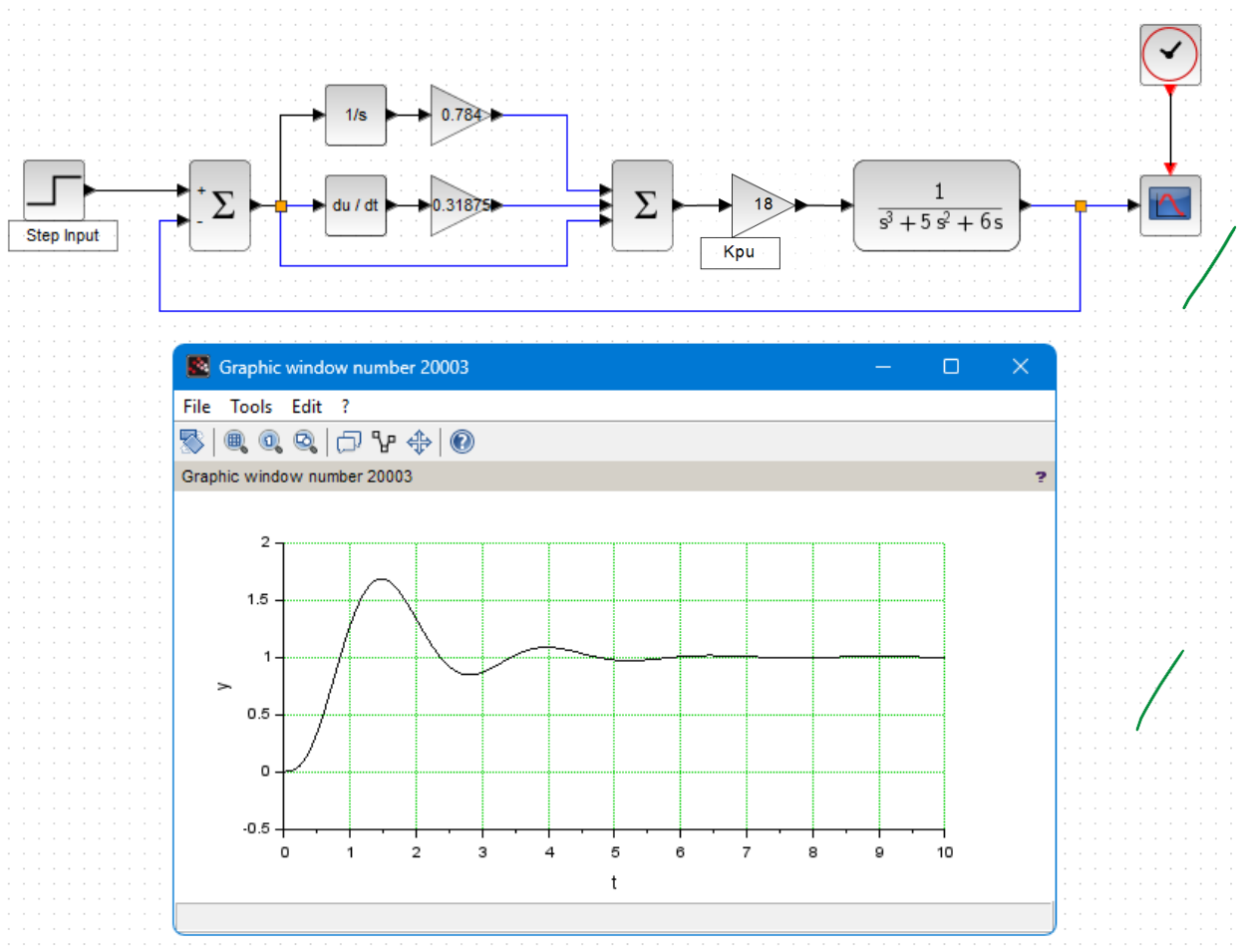


Figure 22 – Modified System with PID Controller

Next, the system was modified to include a PID controller which can be seen in Figure 22. The initial response from the modified system was not as good as expected, it is slightly better than the initial system but from here it is much easier to manually tune by adjusting the values we calculated until an ideal response is created.

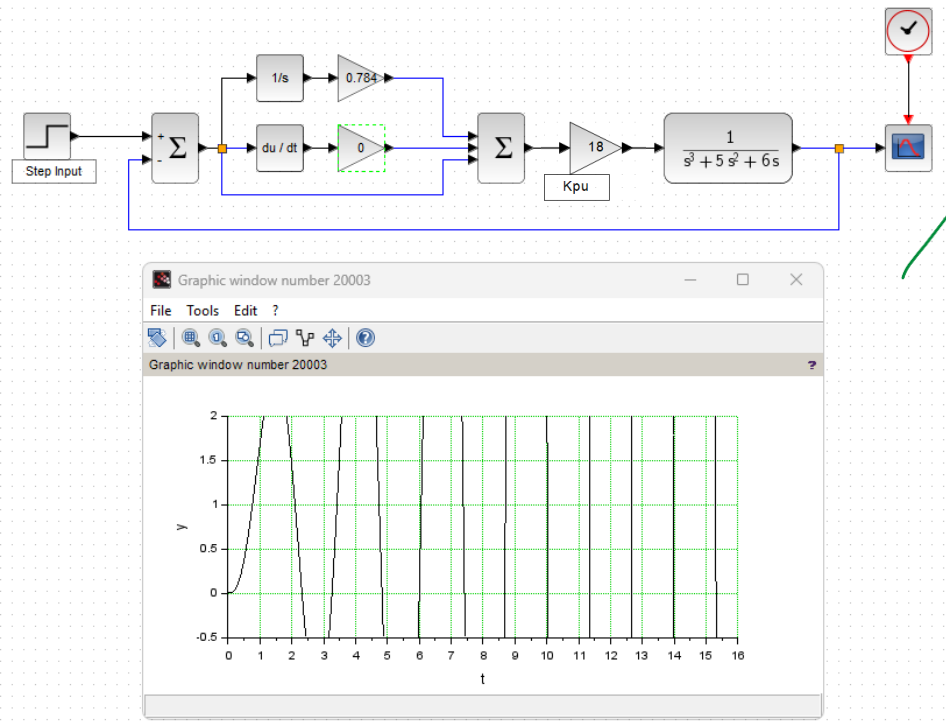


Figure 23 - Decreased T_D to 0

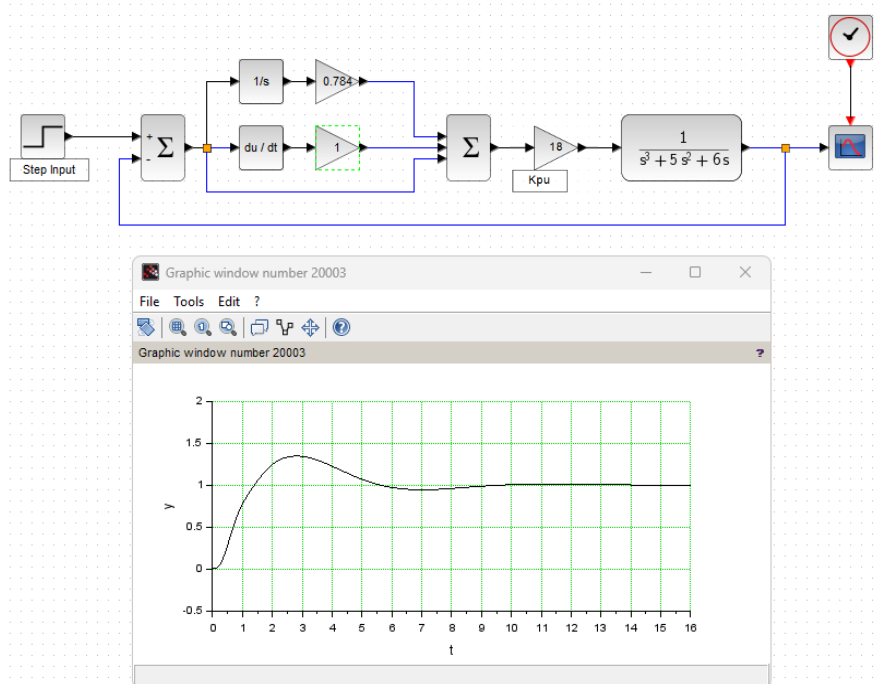


Figure 24 - Increased T_D to 1

Figures 23 and 24 show how the response of the system changes by adjusting the Derivative value between 0 and 1. Figure 23 shows that lowering the derivative value sends the system into full oscillation whereas Figure 24 shows that increasing the derivative value, decreases the oscillation and maximum percentage overshoot but increases the settling time compared to the original response. It can also be seen that the rise time and peak time are increased.

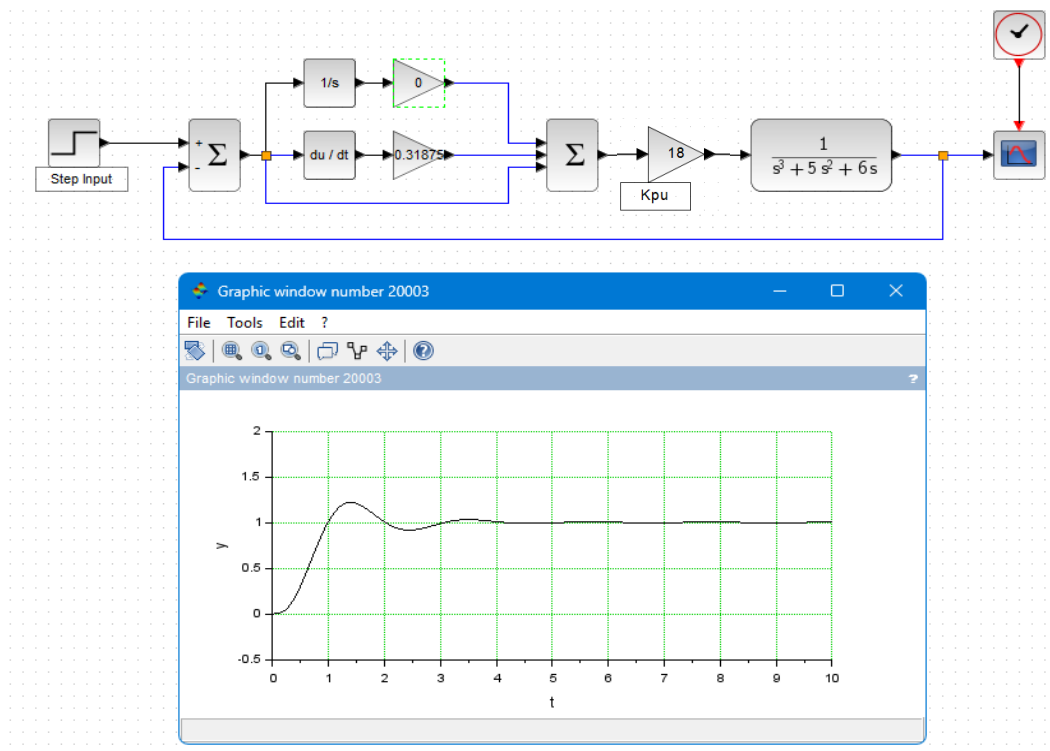


Figure 25 - Decreased T_I to 0

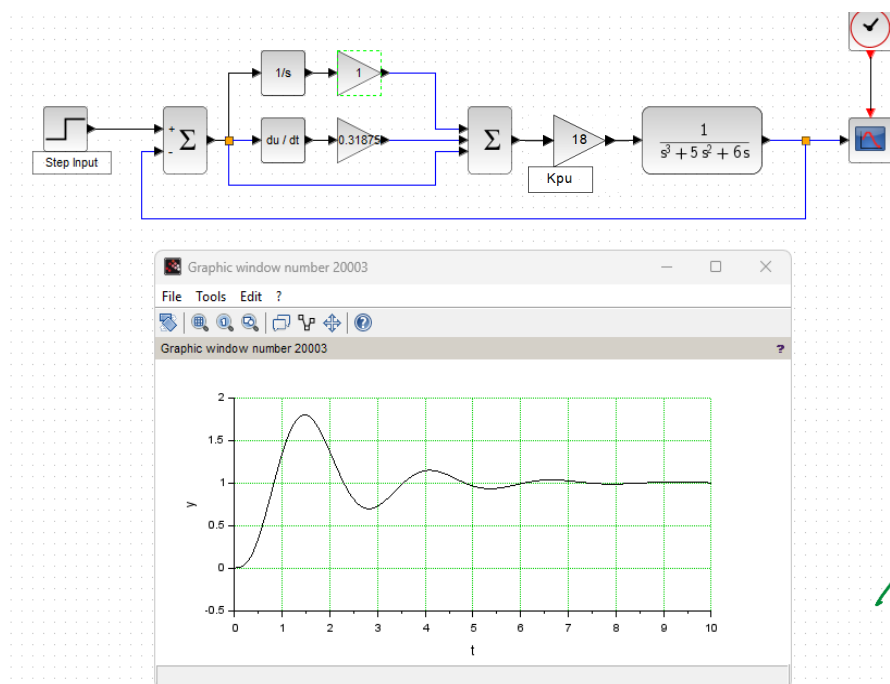


Figure 26 - Increased T_I to 1

Figures 25 and 26 shows how the response changes as the Integral value is adjusted. Figure 25 shows as the Integral value is changed to 0. The response here is much better as the undershoot and overshoot is far less with a much lower maximum percentage overshoot. However, it can be seen that the settling time is far greater as the system never seems to completely settle. ✓

Figure 26 shows as the Integral value is adjusted to 1. This again gives the system more overshoot and undershoot and seems to take longer to settle.

As shown, modifying the PID controller values has a significant effect on the response of the system. By carefully modifying these values, an ideal response can be created with a fast peak and rise time, little to no overshoot or undershoot, a fast-settling time and a small maximum percentage overshoot. 

Task 4 – Computerised Control Systems

All modern engineering sites rely on computerised control systems for safe and efficient operation. These systems are responsible for controlling a number of different processes such as reactors, compressors, HVAC, utility systems, and distillation columns. Some of the types of control systems in these environments are Programmable Logic Controllers (PLC), Direct Digital Control (DDC), and Distributed Control Systems (DCS).

PLCs are industrial digital computers used for process automation. They are common for stand-alone systems and the control of machines. PLCs are known for fast processing and I/O handling which makes them suitable for time-critical systems. PLCs are programmed simply using ladder logic or function block diagrams. PLCs are normally modular in design which allows for flexible configurations with digital and analogue inputs, power supplies, outputs, and communications. They can also be built to withstand harsh industrial environments with extreme temperatures, dust, and vibrations.

Direct Digital Control (DDC) is not as common in main process operations but is commonly used in non-process areas like labs, control buildings and utility buildings. They are used to control environmental conditions such as heating and HVAC, automate building and utility management systems using microcontrollers.

In a DDC there is a centralised control logic where the controller processes all of the sensor data. In a building management system, the DDC communicates with a number of sensors measuring temperature, humidity, CO₂, and pressure. All of this information is fed back into the controller to operate things such as dampers, fans, and valves in HVAC systems. DDCs can also operate on time-based schedules for automated lighting, HVAC, and equipment control (Erickson, 2025).

A Distributed Control System (DCS) is a control system which is used to automate large, complex, and continuous industrial processes. On a refinery, DCS is used for the majority of the process control, managing and monitoring a number of systems. DCS is designed in a way that makes it highly reliable, stable, and safe. Like the name suggests, DCS distributes control functions across a number of local controllers which are each responsible for a section of plant. Human-Machine-Interfaces (HMI) and control panels are used for real time graphical feedback and control of the plant (Frost, 2024).

In conclusion, PLCs are excellent for machinery control and safety systems due to their fast control, flexible configuration, and reliability in harsh environments but are not as suitable as DCS for a large-scale continuous process control. DDCs are suited well to building control and HVAC

systems but have severely limited process logic handling capabilities which make them not viable for process control. DCS are designed for continuous operation handling hundreds of I/O points across multiple process units and integrating control, monitoring, and safety functions but have a much higher cost compared to PLCs and require trained personnel for maintenance. ✓

References

Bolton, W., 2004. *Instrumentation and Control Systems*. 1st ed. s.l.:Elsevier.

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