

LEVEL 4 ASSESSMENT SPECIFICATION

Student name:	Harry Myers	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	11.6
Engagement with an appropriate range of literature, including sources retrieved independently. Referencing may show minor inaccuracies or inconsistencies.		
2. Knowledge and Understanding Skills	40	26.2
Task 1 - 62%. Task 2 - 70%. Task 3 - 62%. Task 4 - 68%. 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	5.5
Good evaluation of the underlying concepts and principles for tasks 2 and 3.		
4. Practical Application Skills	20	16.4
Task 1 - 82%. 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	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%

PCEE4005 – INSTRUMENTATION, AUTOMATION AND CONTROL

ASSIGNMENT 2 – CONTROL SYSTEMS

SUBMISSION DEADLINE 15/05/25

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Task 1 – Control Types

a) Open Loop Systems

Open loop control systems are systems of control whereby there is no feedback between elements. For example, when you turn on an oven, it will stay on until you turn it off; there is no feedback from the oven which determines whether the food inside it is cooked or not and it will keep running until it is switched off manually. ✓

An open-loop circuit diagram is shown below in figure 1.

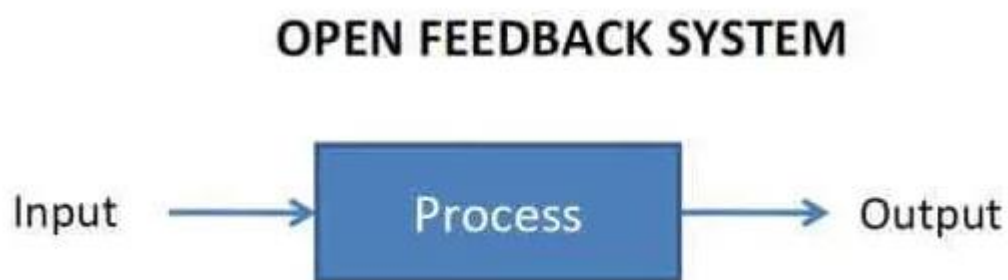


Figure 1 - Open Loop System (Instrumentation Tools, 2023)

Open loop systems are easy to operate and do not require technical expertise, but their lack of feedback can cause issues. In the oven analogy, if it is forgotten about, and not turned off before leaving the house, and there is no internal feedback which tells it to turn it off after a certain amount of time, it could burn the food inside, or worse, cause a fire. ✓

b) Closed Loop System

A closed loop system involves the addition of a feedback element which will alter the output of the controller based on a given setpoint. A block diagram of a closed loop system is shown below in figure 2.

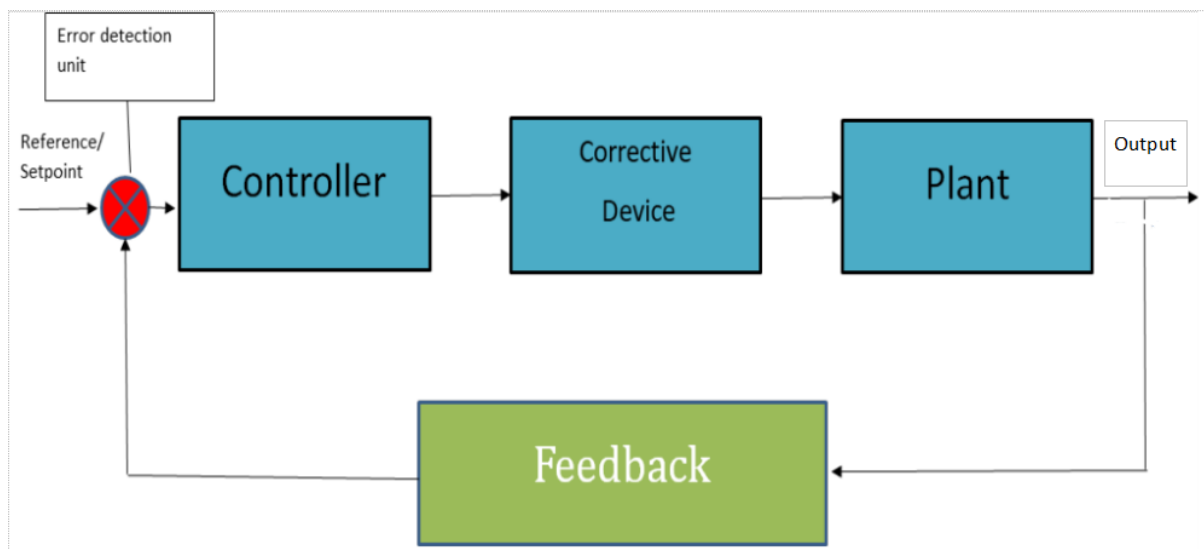


Figure 2 - Closed Loop System Block Diagram (Myers, 2025)

A description of each element is provided below.

Reference/setpoint: This is the desired value which is trying to be achieved in the system.

Controller: This sends a control signal to the corrective device to either increase its output, decrease it, or stay the same.

Corrective device: This could be for example an actuator. It responds to the signals given by the controller, e.g. the controller sends it a signal to open by one defined increment.

Plant: This is the process which is being controlled by the closed loop system for example a tank which needs to keep a consistent level.

Output: This is the actual feedback, for example the level in the tank, and is continuously measured.

Feedback: This relays the output information to the error detection unit.

Error detection unit: This compares the actual feedback (output) with the desired feedback (setpoint) and sends this signal to the controller.

A mathematical model for a closed-loop system can be derived and used for simulation/practical applications. The formula for a closed-loop system is detailed below in figure 3.

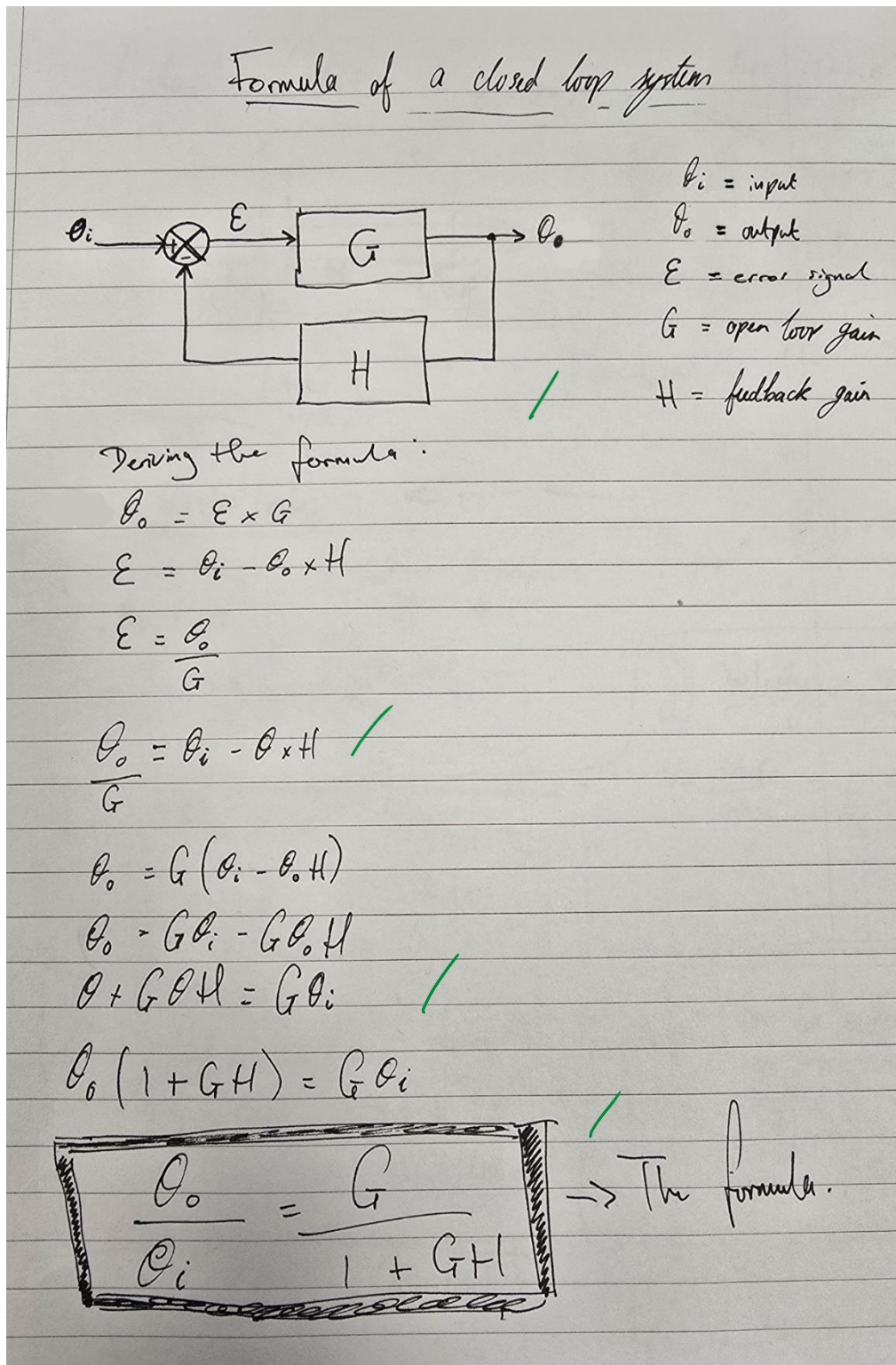


Figure 3 - Formula for a Closed-Loop System (Myers, 2025)

Very untidy next time try doing this on word.

c) Three Term Controllers

Three terms controllers are referred to as PID controllers (proportional, integral and derivative) and are used in the context of a closed loop system. A description of each element is provided below.

Proportional – This can be considered as the ‘present’ value and depends on the ‘error’ when comparing the current setpoint with the actual value of the process variable. The proportional gain will determine the magnitude of output response based on this error. For example if there is an error of 10, and the proportional gain is set to 3, the proportional controller will produce an output of $3 \times 10 = 30$ units. /

Integral – This can be considered as the ‘past’ values, as it uses integration to sum the error term based on past values. This value will continue to increase until the error value reaches zero, which is known as steady state. /

Derivative – This can be considered as the ‘future’ values, as it uses differentiation to calculate the rate of change of the response curve. This predicts the future values of the system which can help to smooth out the response curve by ramping the response up or down, based on the steepness of the response curve. /

Task 2 – Simulation

a) Position Control Servomechanism Calculations

The photograph below shows the second order calculations used to determine the values of B and the natural frequency.

Position Control Servomechanism

Transfer function:

$$\frac{\theta_o(s)}{\theta_i(s)} = \frac{\left(\frac{k_p k_A k_F}{I} \right)}{s^2 + \left(\frac{B}{I} \right) s + \left(\frac{k_p k_A k_F}{I} \right)}$$

Second Order System Standard Equation:

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

$$\begin{aligned} k_A &= 1 \\ k_p &= 5 \text{ V r}^{-1} \\ k_F &= 6 \text{ mA V}^{-1} \\ I &= 1.5 \times 10^{-4} \text{ kg m}^2 \end{aligned}$$

$\Rightarrow$ Substitute values into formula to find B values:

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

$$\Rightarrow = \frac{200}{s^2 + 666.67 B s + 200}$$

$\therefore \omega_n^2 = 200$
 $2\zeta\omega_n = 666.67 B$

natural frequency $\omega_n = \sqrt{200} = 14.142 \text{ rad/sec}$

Try using
Equation Editor.

Figure 4 - Position Control Servomechanism Second Order Calculations - (Myers, 2025)

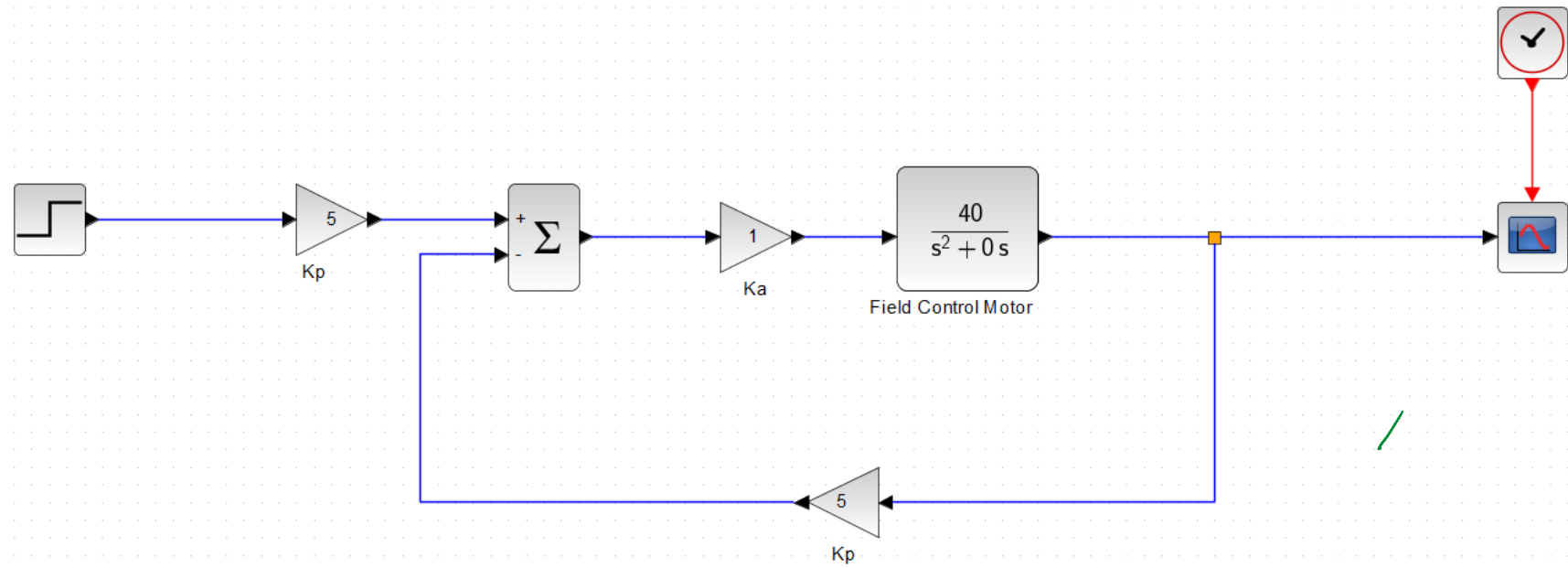
From here the following damping ratios are applied to find the B values at different damping conditions.

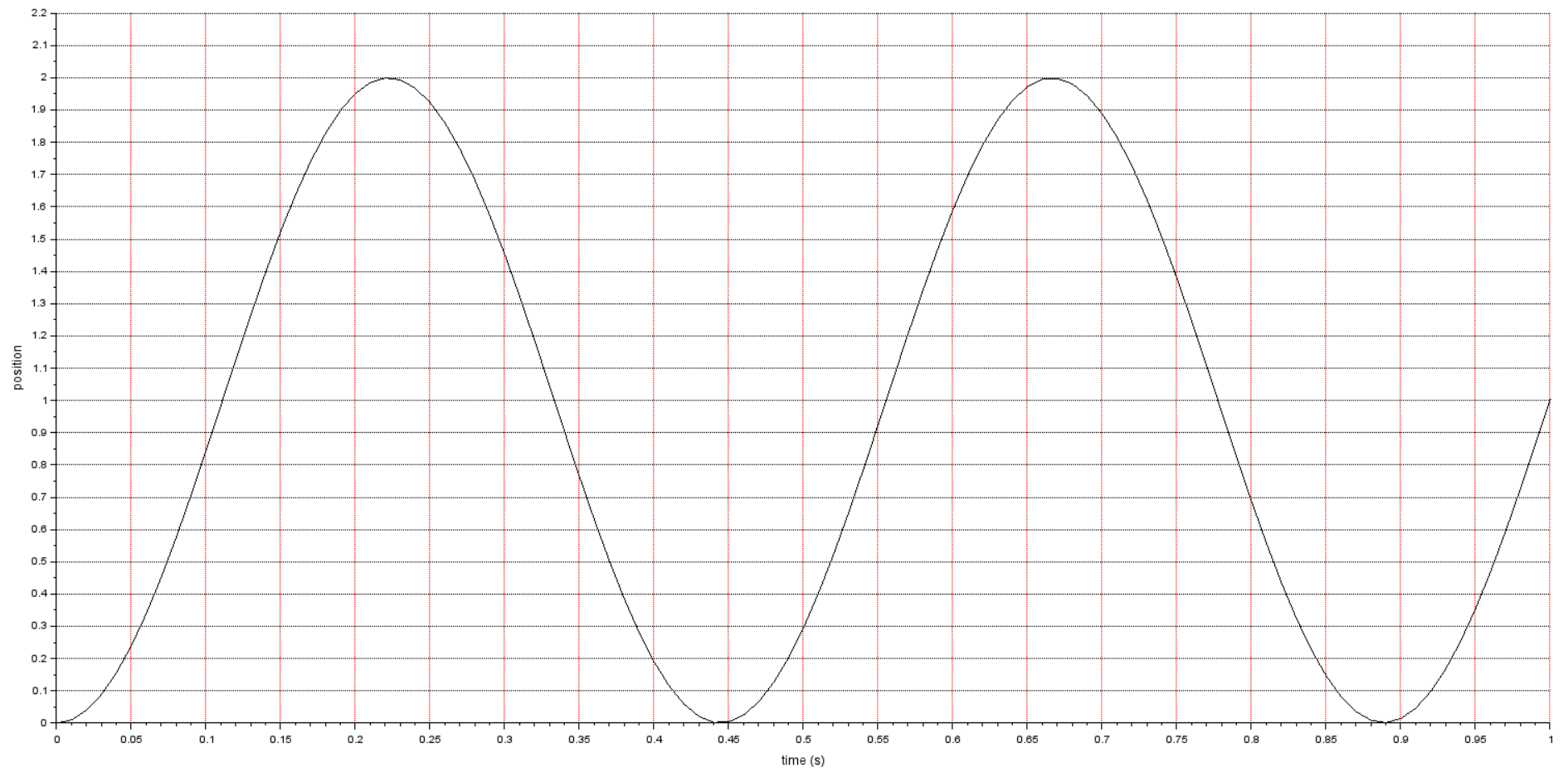
Values used for different damping conditions:

Damping Conditions		B	B/I
No Damping	$\zeta = 0$	0	0
Under Damped	$\zeta = 0.43$	0.00182	12.162
Critical Damped	$\zeta = 1$	0.00424	28.284
Over Damped	$\zeta = 1.65$	0.007	46.669

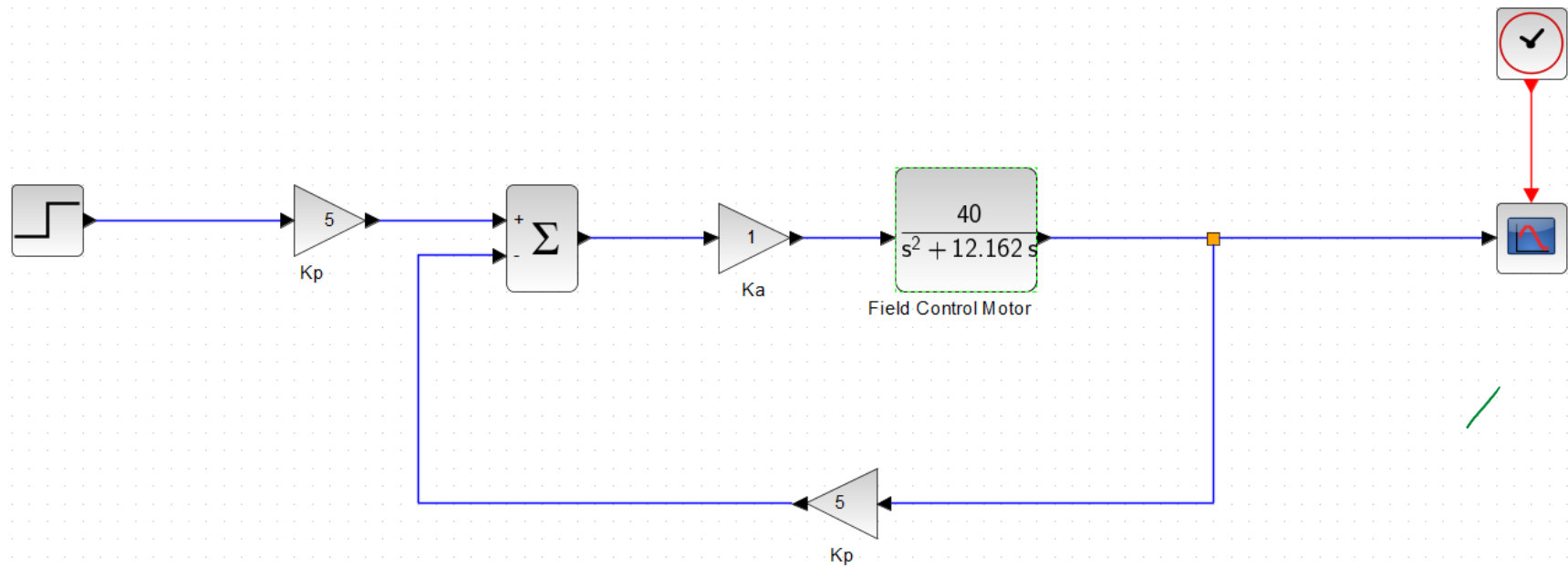
The following diagrams were produced on xcos in the Scilab software using the calculations derived in figure 4. They show the different responses curves of the damping conditions detailed above as well as the mathematical models created in xcos on the Scilab software.

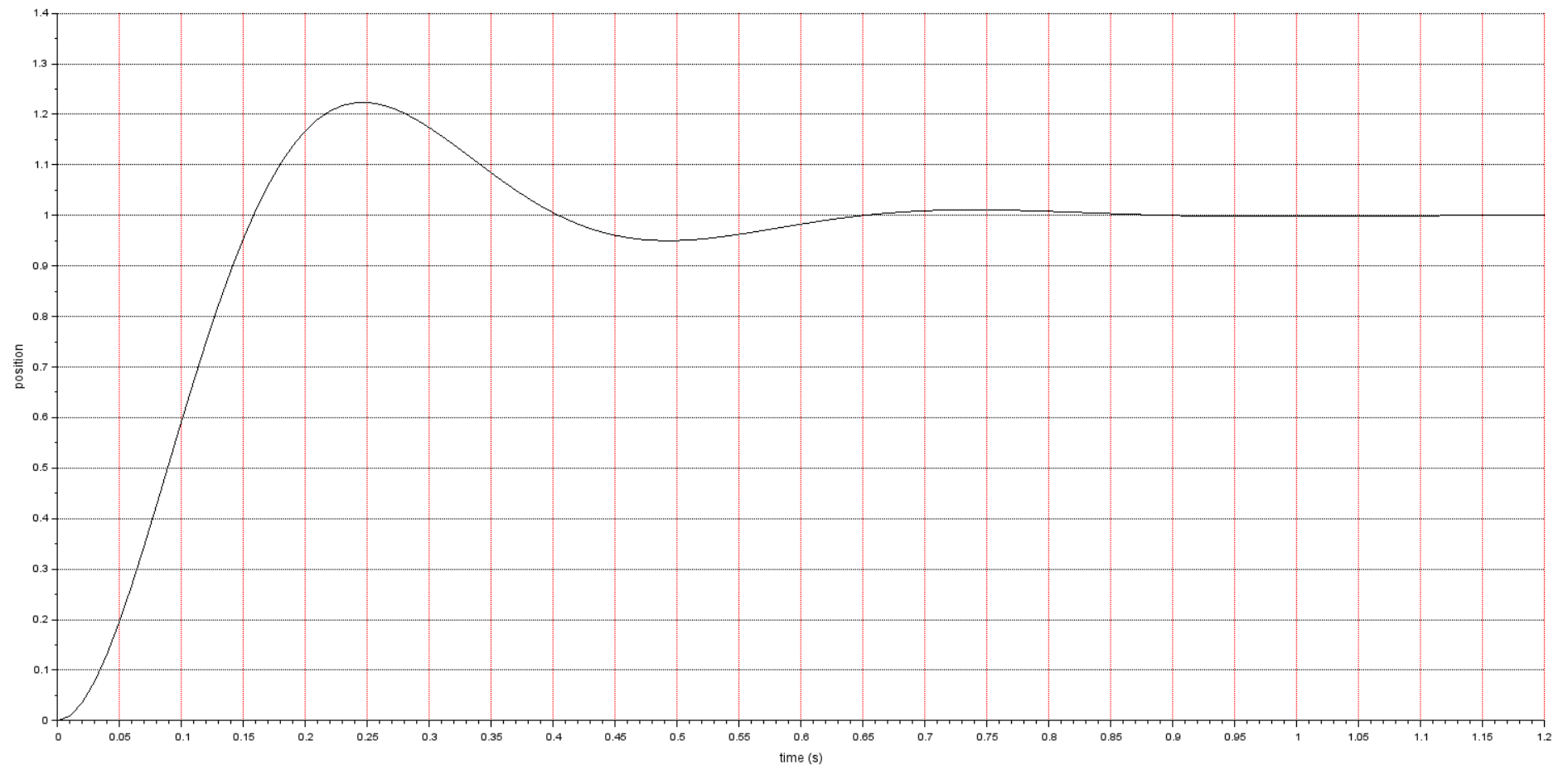
No damping $\zeta = 0$



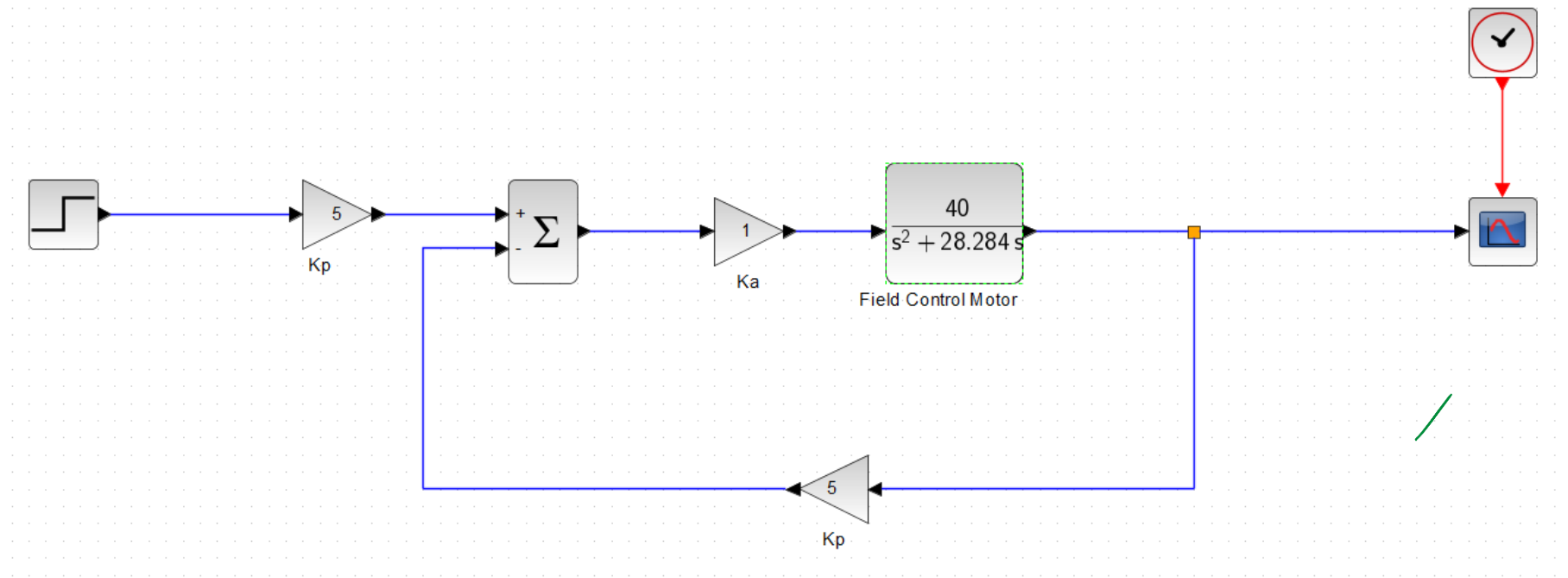


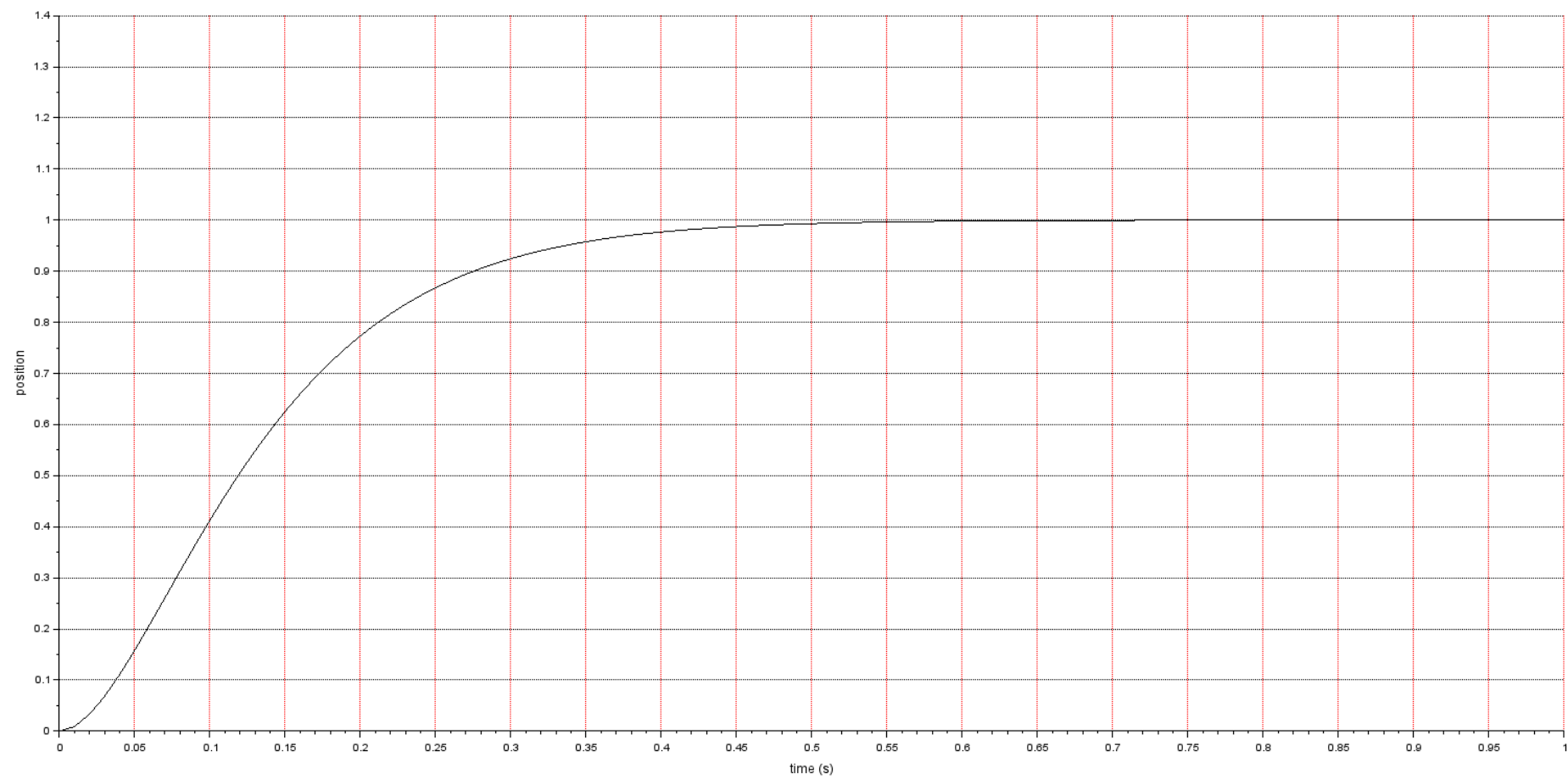
Under damping $\zeta = 0.43$



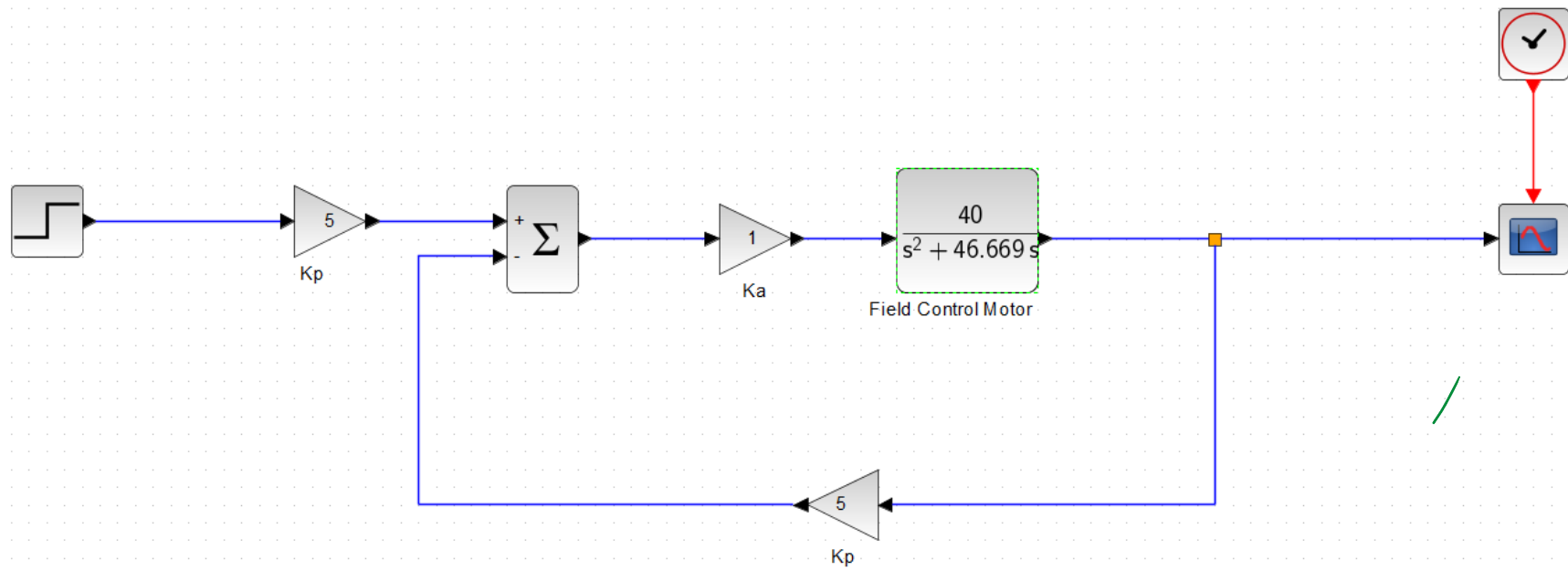


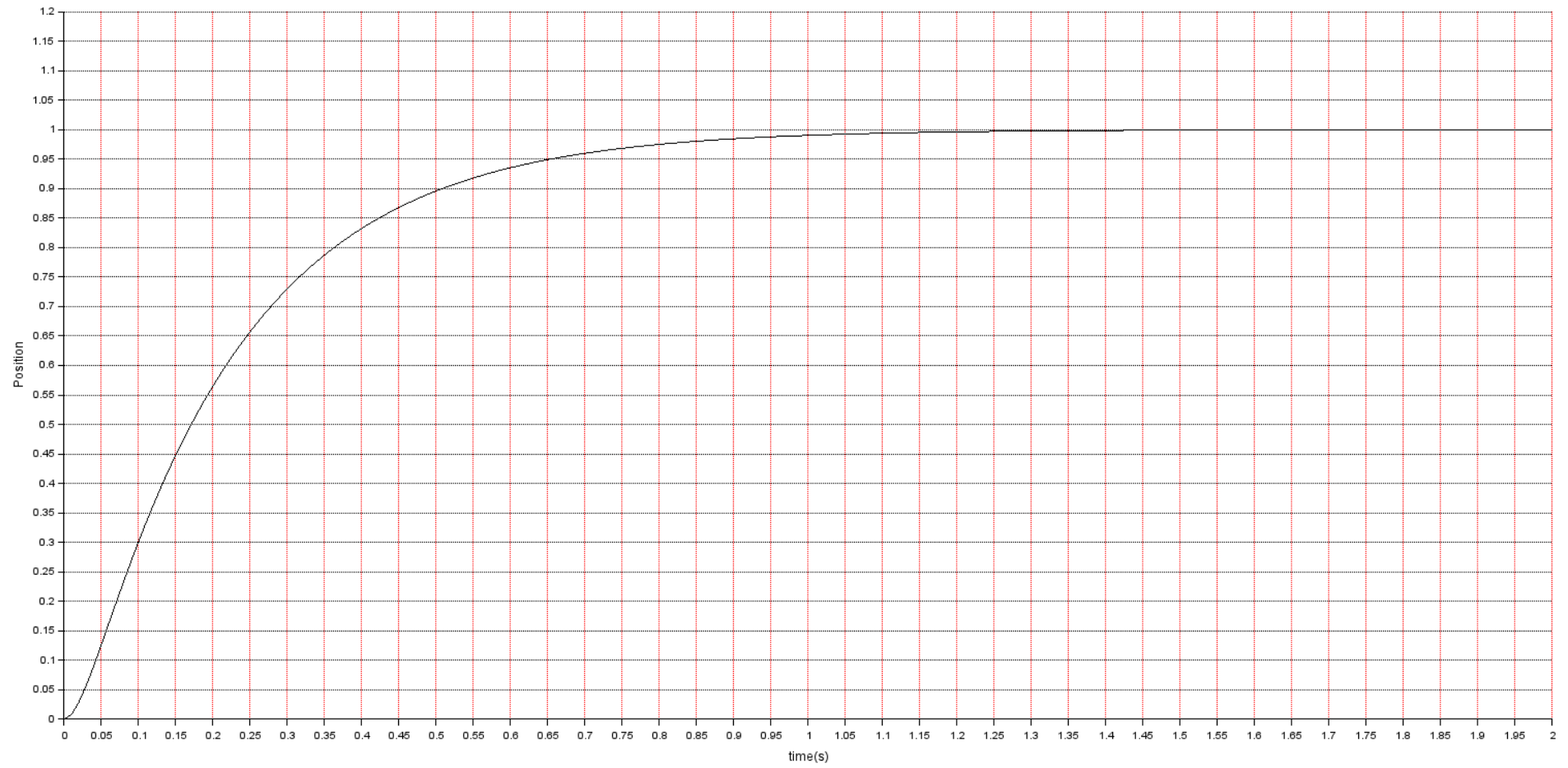
Critically damped $\zeta = 1$





Over damped $\zeta = 1.65$





b) Characteristics of an under-damped system

The characteristics of an under-damped system can be quantified using the terms outlined in the image below

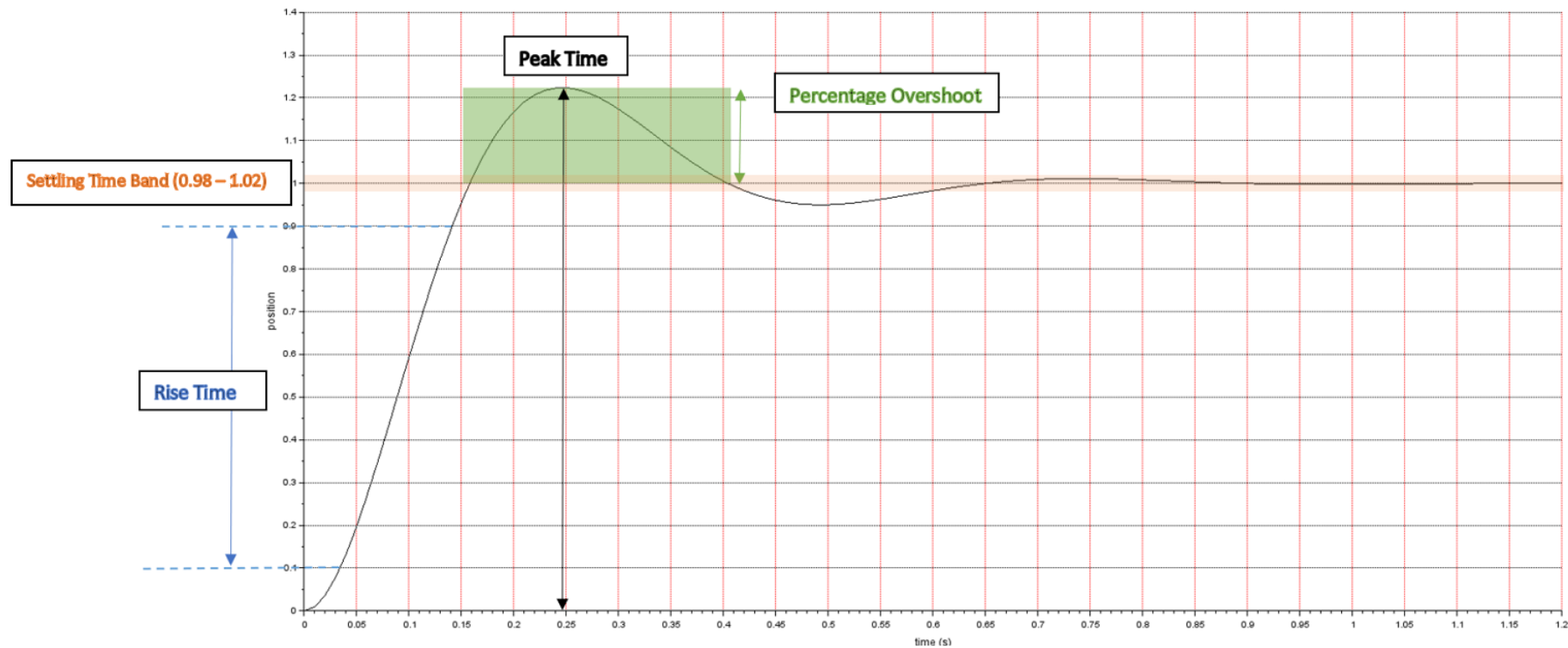


Figure 5 - Characteristics of an Under-Damped System (Myers, 2025)

Rise time: This refers to the time taken for the response to go from 10% to 90% of its final steady state value (Zhang, 2012). For figure 5, the rise time is $0.14 - 0.03 = 0.11\text{s}$. ✓

Peak time: This refers to the time taken for the response to achieve its maximum value. For figure 5 this is 0.247s. ✓

Percentage maximum overshoot: This refers to the difference between the maximum value and the final steady state value. For figure 5 this is;

$$((1.22 - 1)/1) \times 100 = 22\% \quad ✓$$

Settling time: This refers to the time taken for the response to remain within 2% of its final steady state value. A zoomed in image of the settling time band shown in figure 5 is shown below to see the settling time value. ✓

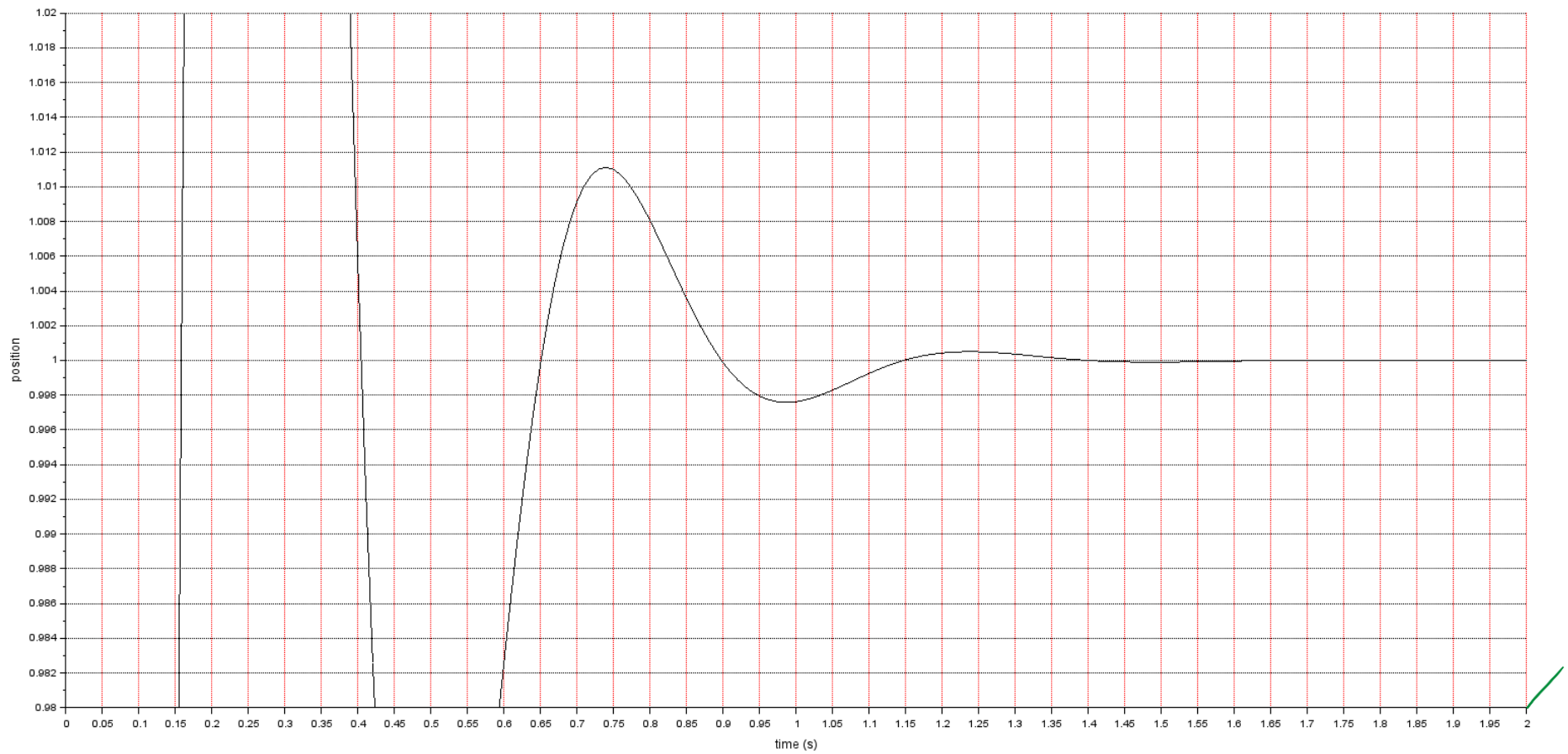


Figure 6 - Figure 5 Zoomed in to Work out Settling Time

As seen in figure 6, the response stays within 2% of its steady state value of 1 at 0.59 seconds, therefore the settling time is 0.59s.

Evaluating different under-damped conditions

$\zeta = 0.85$

As seen below, the closer the damping ratio is to 1; the peak time and rise time is slower, whilst percentage overshoot and settling time is reduced. This means a smoother response curve with a small amount of overshoot and no oscillations.

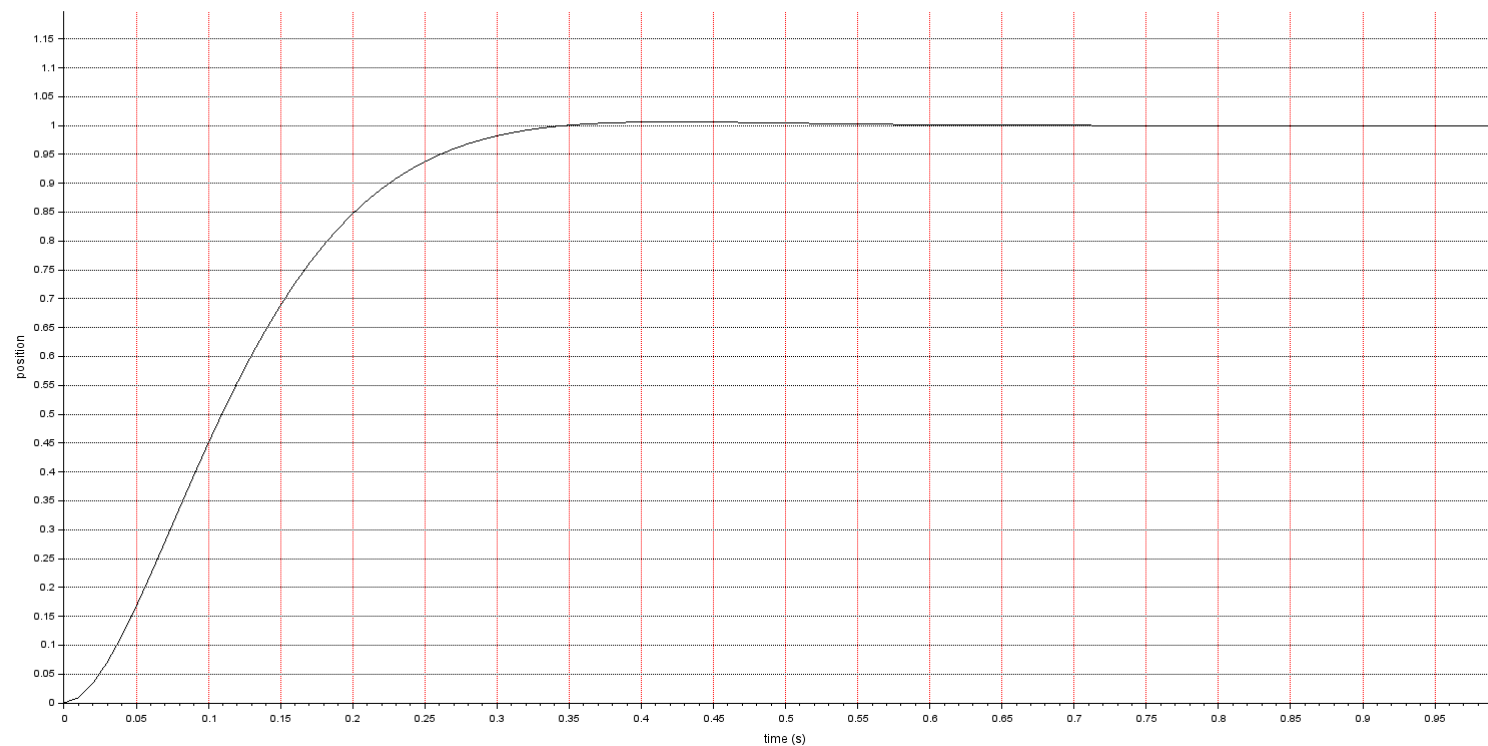


Figure 7 - Under Damped System where $\zeta = 0.85$

$\zeta = 0.20$

As seen below, the closer to damping ratio is to 0; the peak time and rise time is quicker, whilst percentage overshoot and settling time is greatly increased.

This leads to an erratic response with multiple oscillations which takes a long time to settle.

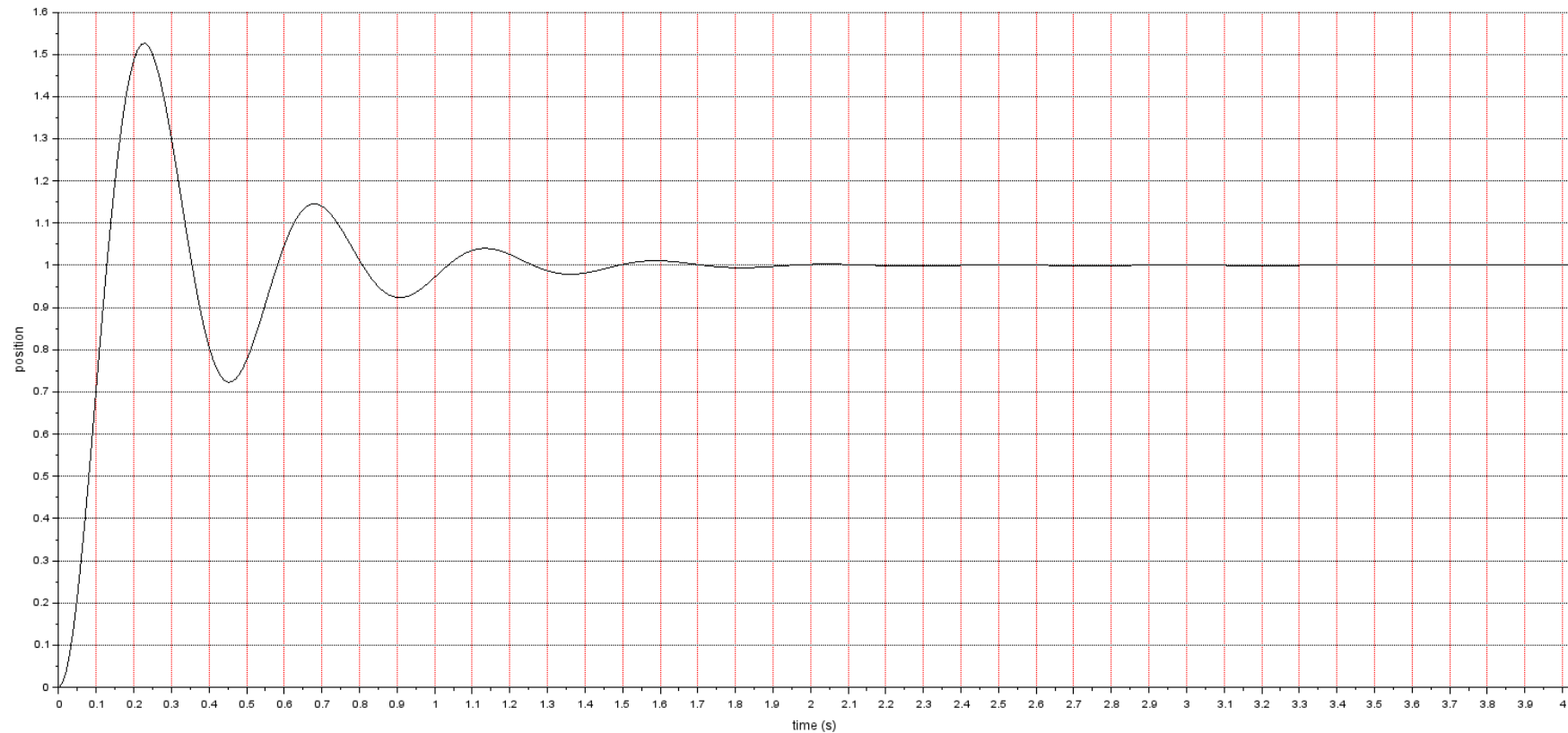


Figure 8 - Under Damped System where $\zeta = 0.20$

Task 3

a) Ziegler-Nichols Tuning Methods for PID Controllers

Tuning a PID controller is essential in creating a response that is optimal to the process. The two methods of tuning which will be discussed were both developed by Ziegler and Nichols and are known as process reaction tuning and ultimate cycle tuning.

Process Reaction Tuning Method

This is an open-loop method of PID tuning as the feedback element within the closed loop system is ignored and so no corrective action is performed.

A unit step input is applied to the system which will produce a reaction in the feedback curve (figure 9). A tangent to the process reaction curve is then drawn from the inflection point (the point at which the curve direction) to the points to the origin and the maximum value of the curve on the y-axis as shown in the figure.

You do not just apply a unit step.

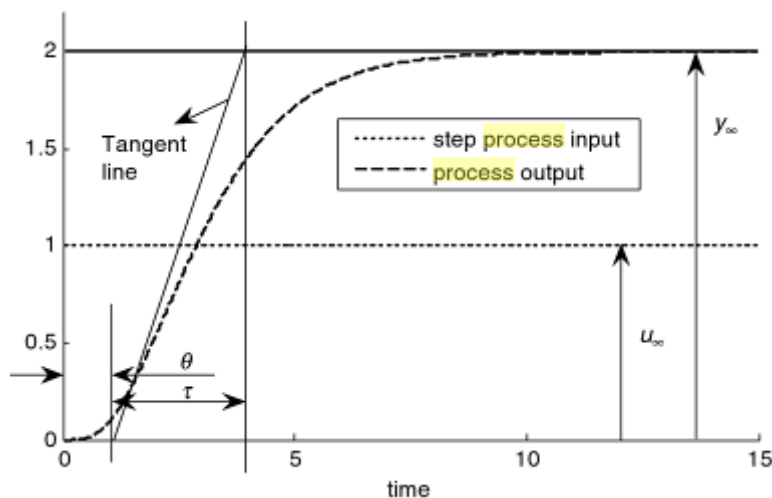


Figure 9 - Process Reaction Curve (Bennett, et al., 2025)

As can be seen in the figure, the following measurements can then be made:

θ – The distance horizontally from the origin to the point where the tangent meets the x-axis.

τ – The distance horizontally from each end of the tangent line (used to calculate gradient).

M – The gradient of the tangent (change in y/change in x)

P – The value of the unit step input measured in % change.

Once these measurements have been made, the values of ' θ ' and ' τ ' can be inputted into the following table depending on which type of controller is being used (P, PI, or PID) to produce values for:

K_p – Proportional Constant

T_i – Integral Time Constant

T_D – Derivative Time Constant

CONTROLLER TYPE	K_p	T_i	T_D
P	$P/M\theta$	∞	0
PI	$0.9P/M\theta$	3.3θ	0
PID	$1.2P/M\theta$	2θ	0.5θ

Table 1 - Process Reaction Tuning PID Calculations

Using the values derived from the table, the following calculations can then be made and inputted in the PID controller.

$$K_i \text{ (Integral Constant)} = K_p / T_i$$

$$K_D \text{ (Derivative Constant)} = K_p T_D$$

This method is typically used first when setting up a PID controller as it does not require the system to be put into full oscillation, which could cause damage to the process and equipment which it is controlling. If this fails to work, the 'ultimate cycle tuning method' may be used.

Ultimate Cycle Tuning Method

The ultimate cycle tuning method utilises a closed loop control system which is tuned 'live' as the process must be running normally to set the initial values in the PID controller.

The values of K_I and K_D are initially set to infinity, (or zero), and zero respectively (their minimum values).

The value of K_P will then be set to its minimum value, and slowly increased until it reaches $K_{critical}$ – this refers to the point when the system is in full oscillation, thereby is constantly oscillating but it's amplitude and time period remains constant. An example of this is shown below in figure which was created using SciLab.

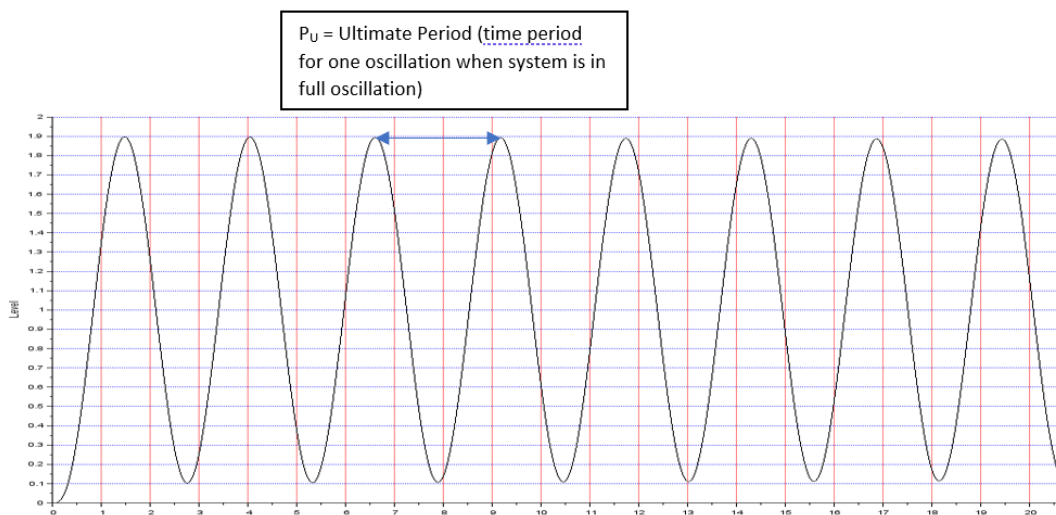


Figure 10 - Control System in Full Oscillation

From here, as with process reaction tuning, there is a preset table (shown below) defined by Ziegler and Nichols, of which the values can now be substituted to calculate the PID controller values. Table 2 shows the table of values for a quarter-decay ratio, whereby the amplitude of each oscillation is reduced by a quarter each time period. The following abbreviations are defined below;

K_P – Proportional Constant

K_{PU} – Ultimate Gain

T_i – Integral Time Constant

T_D – Derivative Time Constant

P_U – Ultimate Period

CONTROLLER TYPE	K_P	T_I	T_D
P	$K_{PU}/2$	∞	0
PI	$K_{PU}/2.2$	$P_U/1.2$	0
PID	$K_{PU}/1.7$	$P_U/2$	$P_U/8$

Table 2 – Ultimate Cycle Tuning PID Calculations

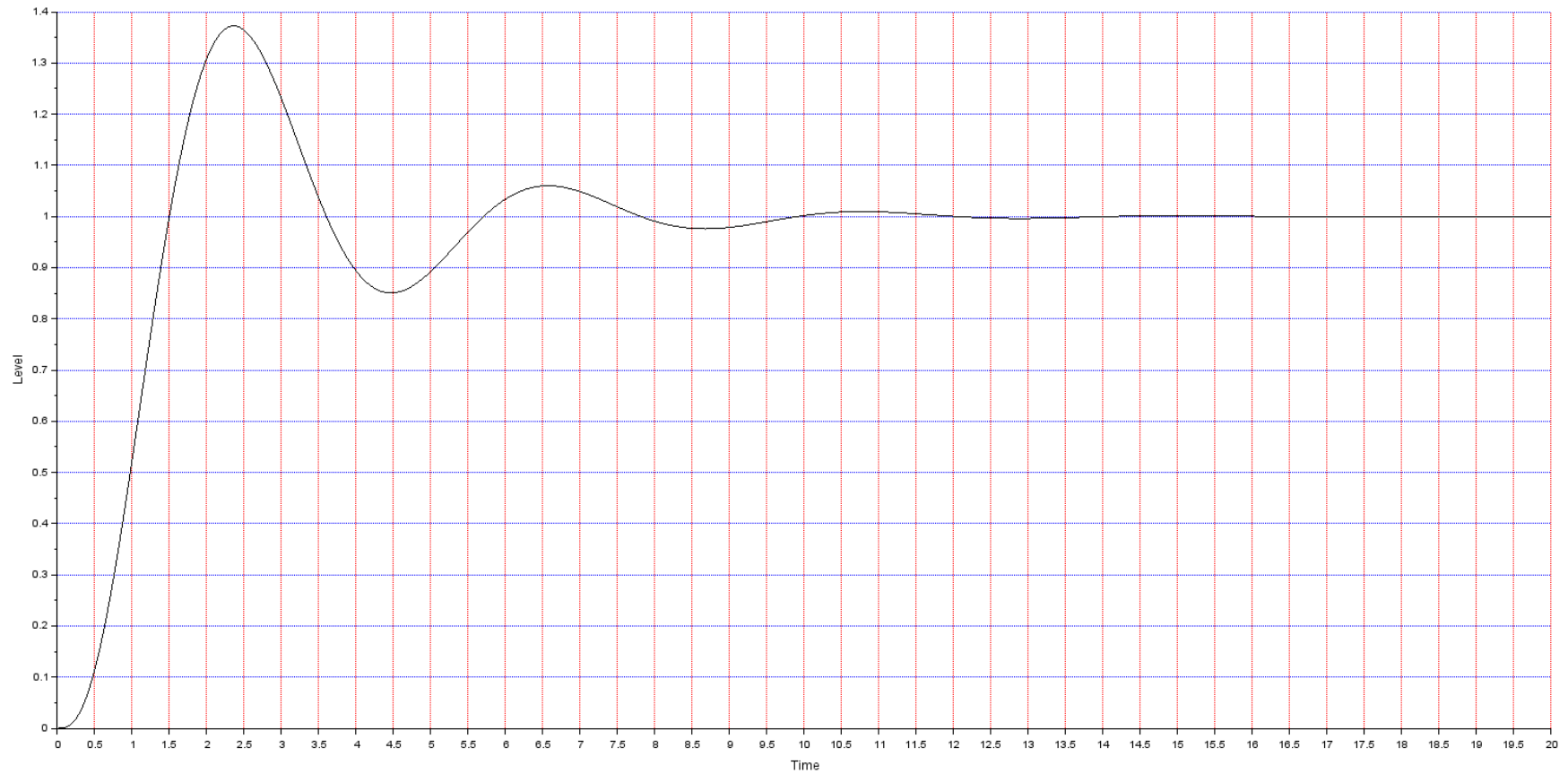
This method is simple to implement, but due to the initial setting up of the system into full oscillation, it means that there is an element of trial and error when using this method. If time periods between oscillations are excessively long, it can become extremely difficult to setup a controller this way as it may take hours or days depending on the time period.

b) Setting up a PID Controller using the Ultimate Cycle Tuning Method.

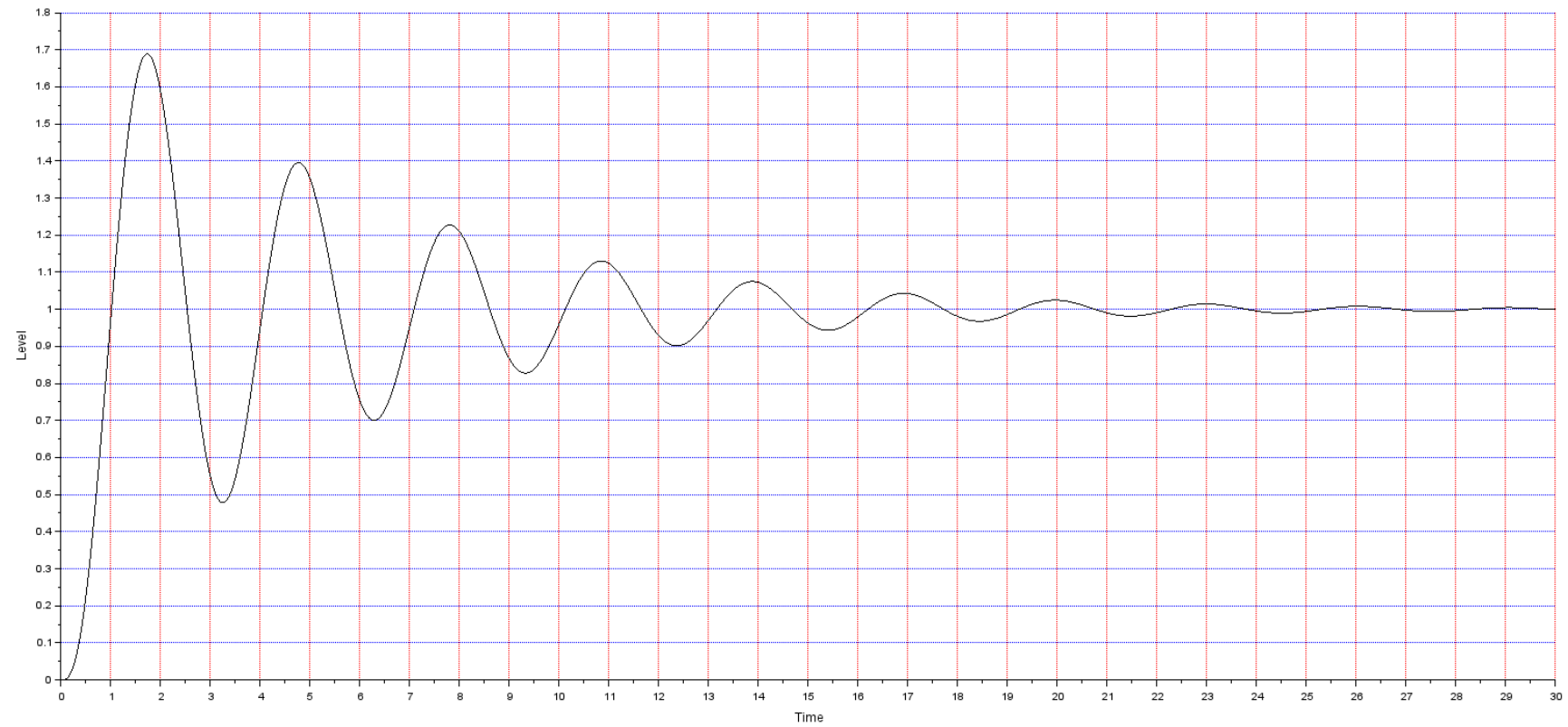
The following images are from simulations in the SciLab software.

First of all the values of K_I and K_D are set to their minimum values, whilst K_C is set to a low value and increased gradually.

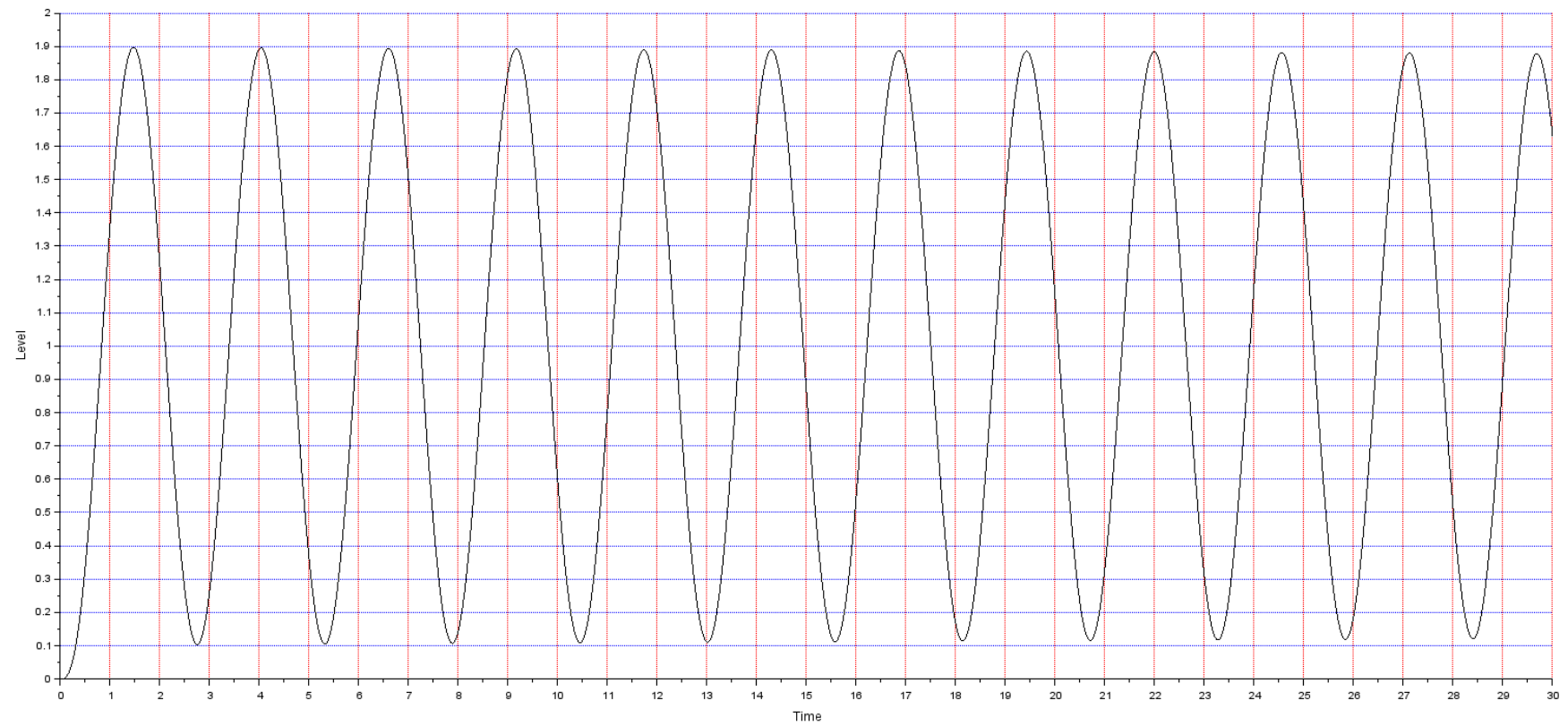
This graph shows when K_c (gain) = 10



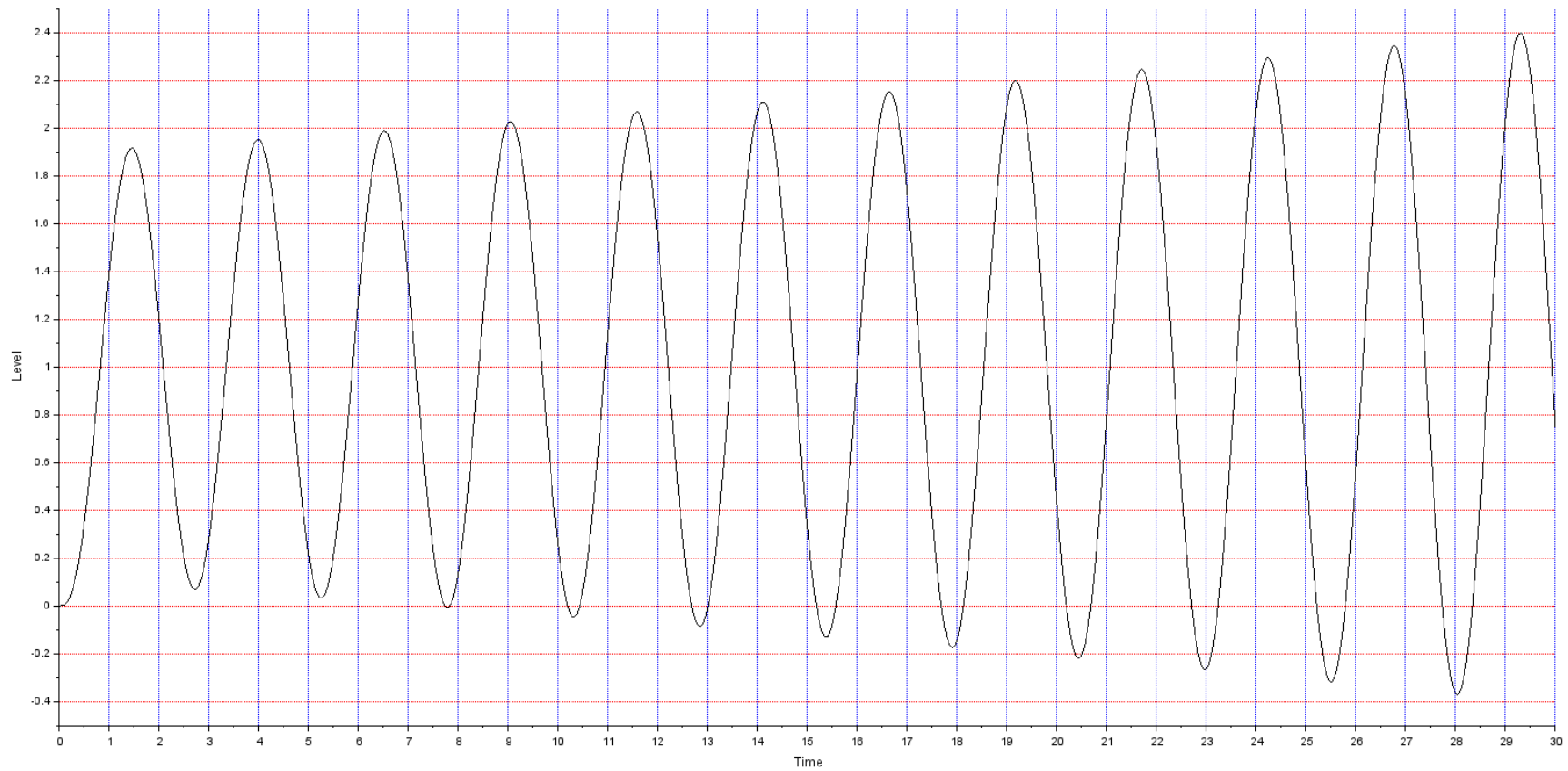
The gain is increased, this graph shows when $K_c = 20$.



This graph shows when $K_c = 30$. As can be seen in the graph, the system has been sent into an acceptable level of full oscillation.

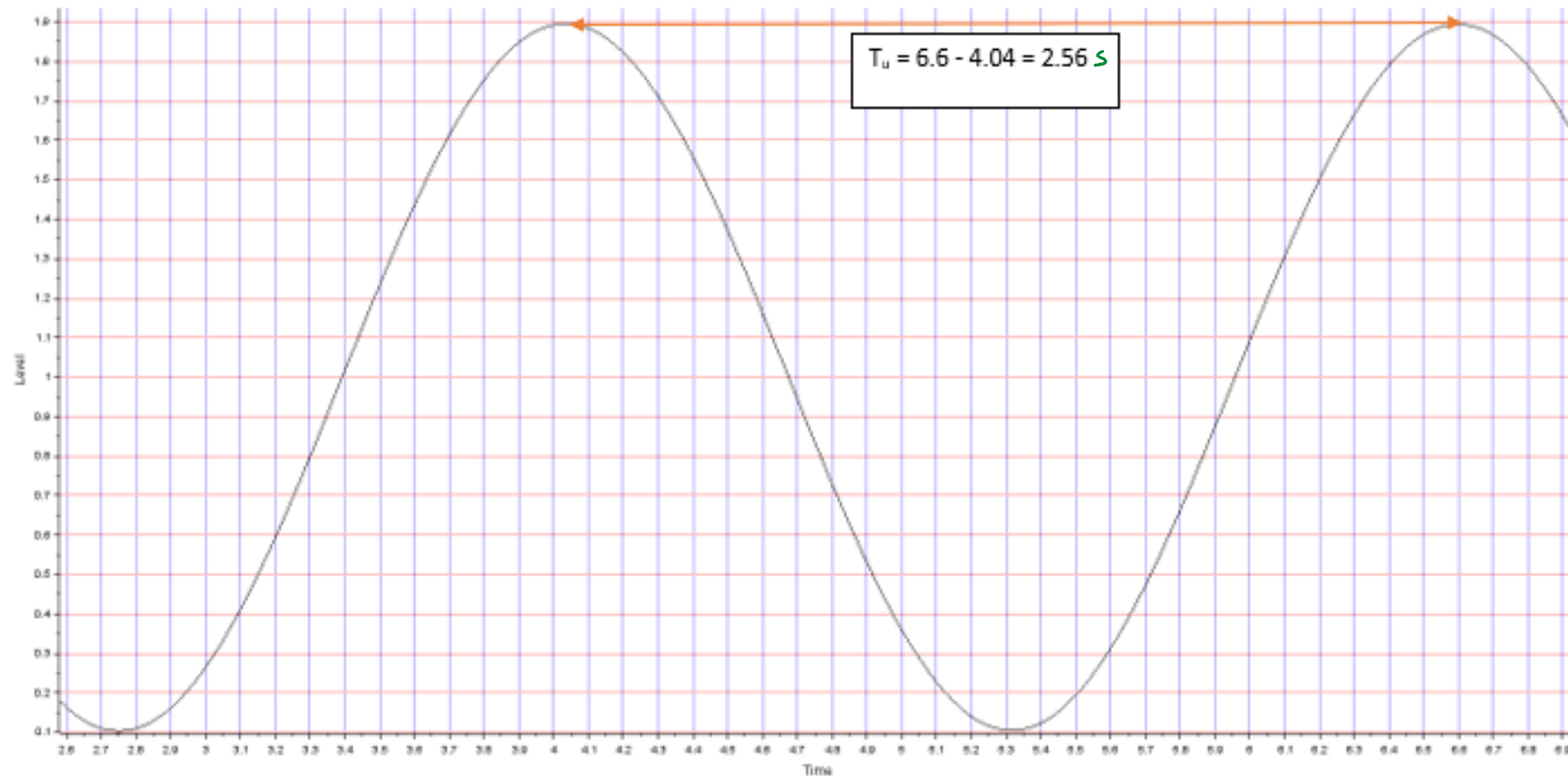


This graph shows when K_c is set too high, at 31. As can be seen, the amplitudes of the oscillations are increasing too rapidly.



The response curve using a value of $K_c = 30$ is then used to calculate the time period between oscillations.

The graph below shows a zoomed in image of the response curve at $K_c = 30$.



These values are then used in the following calculations to determine the values for the PID controller.

$$K_C = K_{PU}$$

$$K_{pu} = 30$$

$$\text{(time period)} T_u = 6.6 - 4.04 = 2.56$$

$$K_p = 0.6 \times K_{pu} = 0.6 \times 30 = 18$$
 Proportional constant at even oscillation (neither rising not decaying)

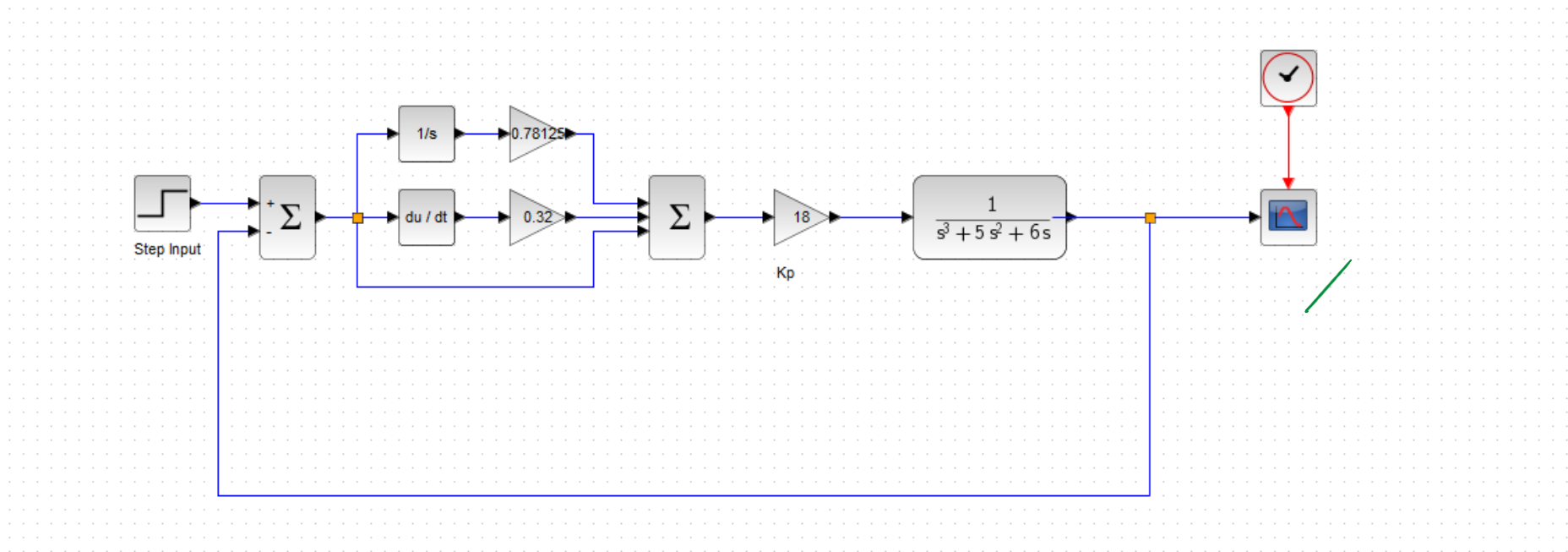
$$T_i = T_u / 2 = 2.56/2 = 1.28$$
 Integral time constant

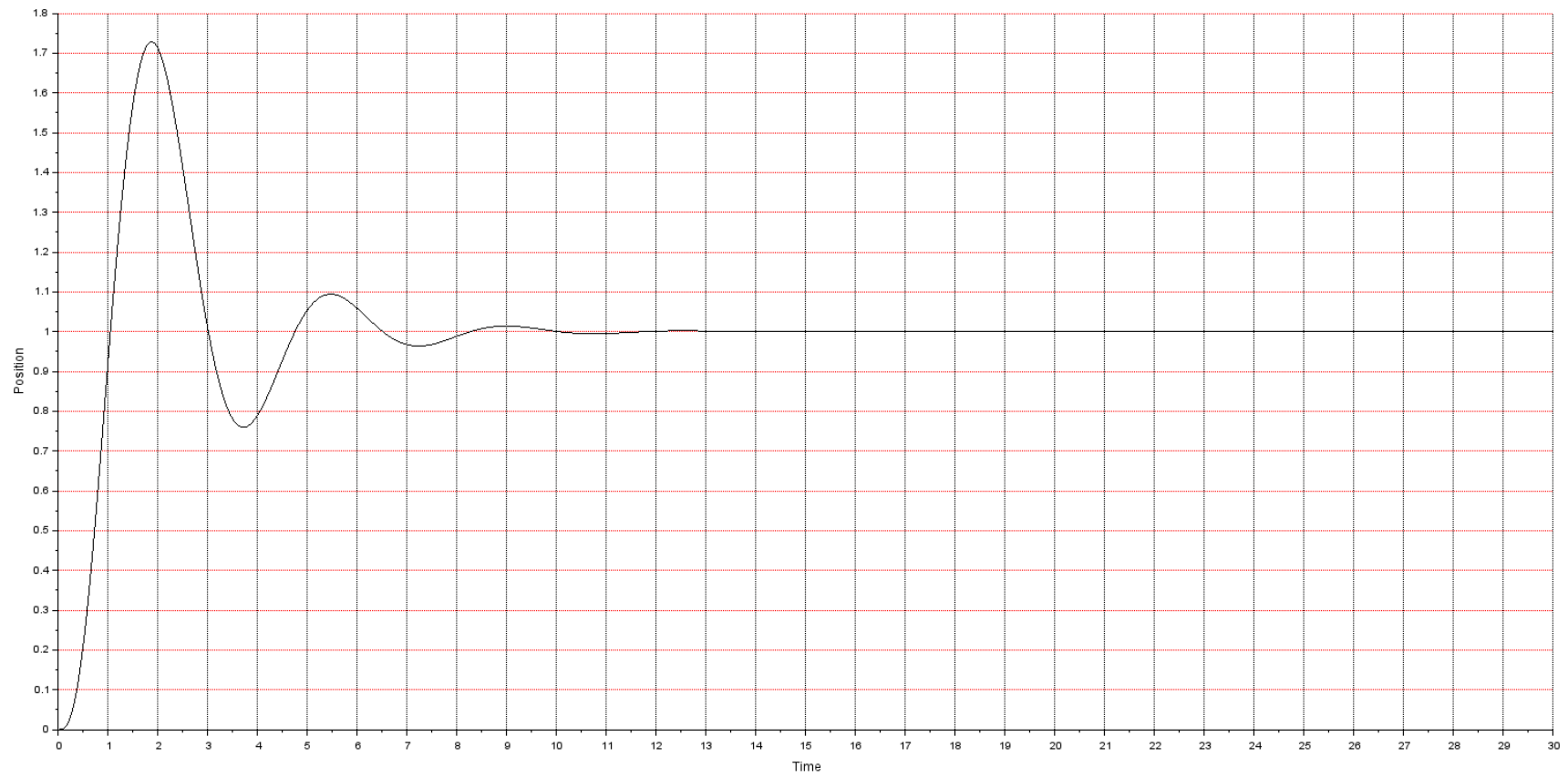
$$T_D = T_u/8 = 2.56/8 = 0.32$$
 Derivative time constant

$$1/T_i = 1/1.28 = 0.78125$$

Once calculated, the values were then put into a PID controller created in SciLab which can then be tuned further.

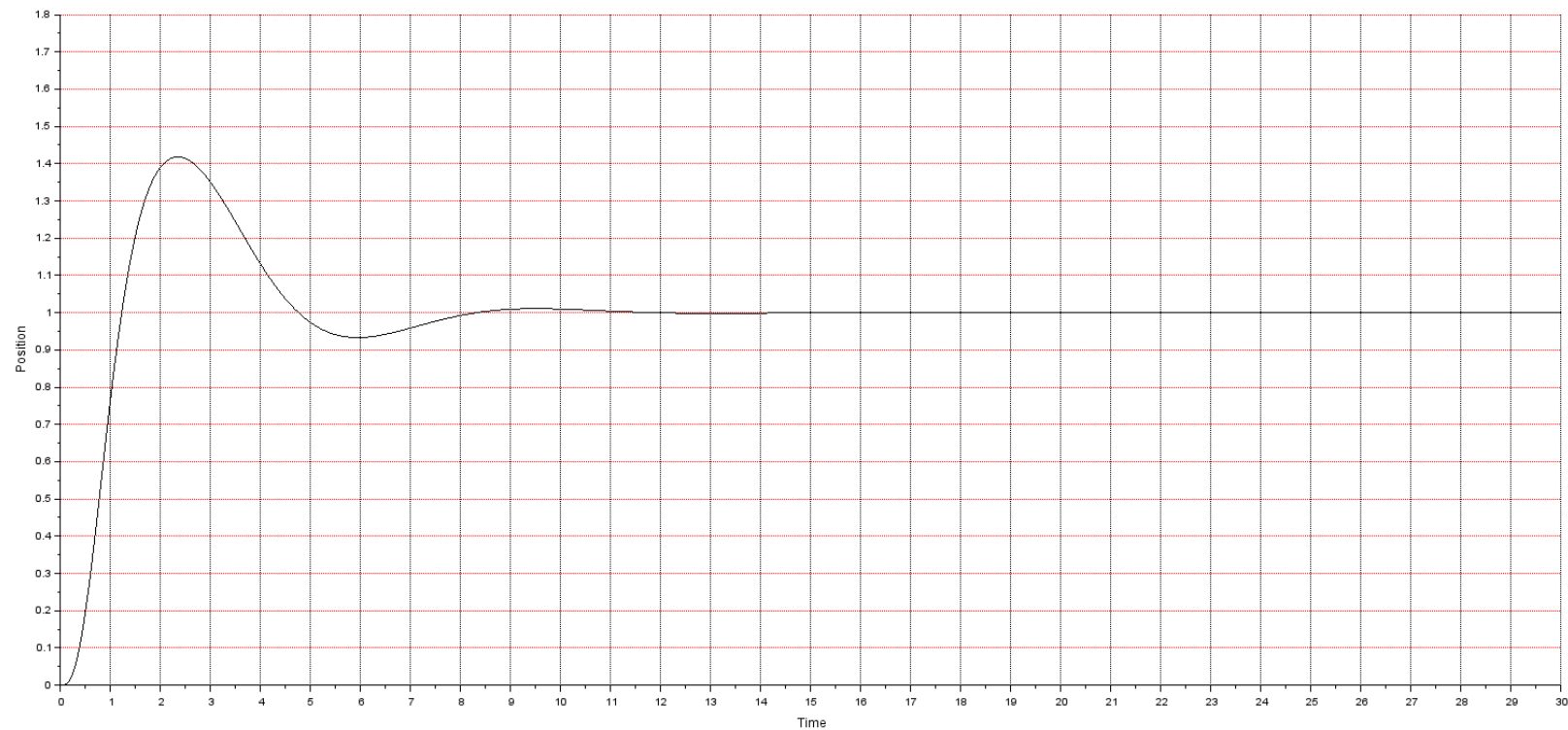
The two images below show the initial values put into the PID controller and the response curve produced from this.



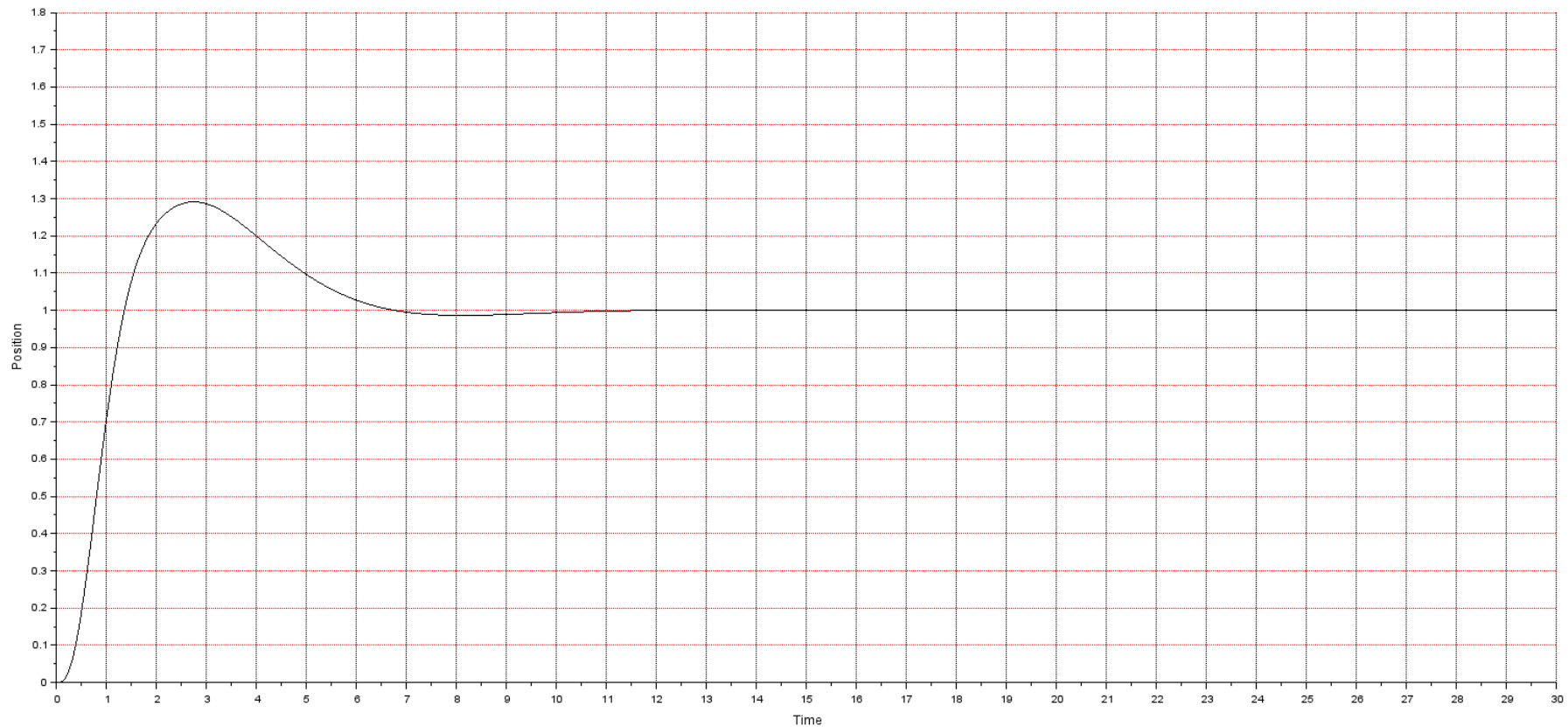


Further Tuning

From here it is a case of using trial and error to produce the desired response curve by altering the values of T_I and T_D . Initially the value of T_D was increased to 0.70 whilst T_I remained at 0.78125. This produced a slightly slower settling time but drastically reduced the number of oscillations, shown in the graph below.



From this point, the value of T_I was reduced to 0.50, whilst the value of T_D remained at 0.70. Shown in the graph below, this reduced the settling time and the maximum overshoot whilst reducing the number of oscillations. Further trial and error could be applied to reduce these values even more, but this is an acceptable response.



Task 4 – Computerised Control Systems

Introduction

Computerised control systems are an integral part of industrial automation processes. The three types of control system being discussed in this report are;

PLC – Programmable Logic Controller

DDC – Direct Digital Control

DCS - Distributed Control System

Each system has their own benefits and drawbacks which will determine which is best suited to a company or individual's specific requirements.

Programmable Logic Controllers

Functions and Features

PLCs are ruggedised computers whose function is to automate industrial processes, primarily using ladder logic and function blocks. When they were invented in 1968 by Dick Morley, they were used to programme one singular process, but as technology has advanced, they can now be linked and programmed in conjunction with one and other to act more like a DCS. The architecture of a typical PLC network is shown below in figure 11.

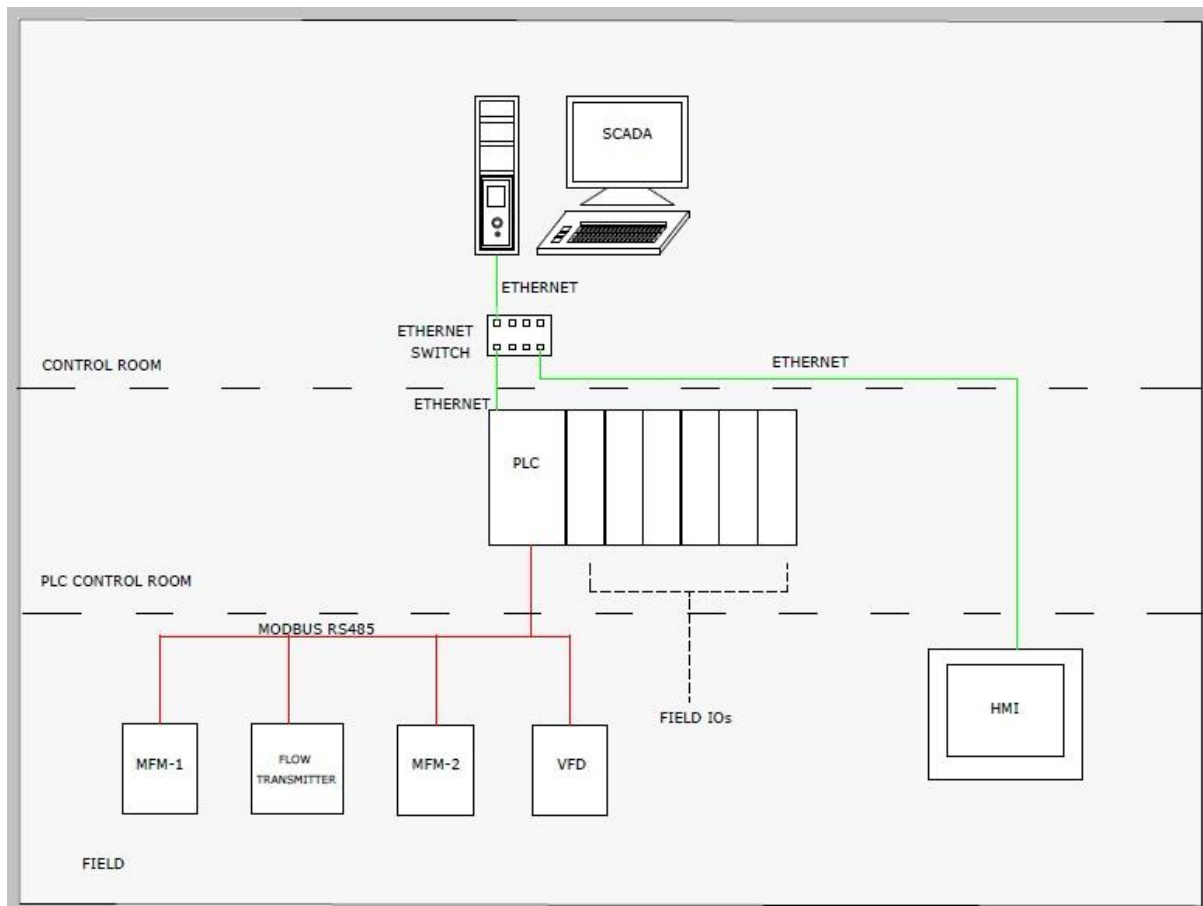


Figure 11 - PLC Network Topology (See It How, 2019)

As shown in figure 11 there are essentially 3 layers to the network. The field devices connect to the PLC, which connects to the SCADA system and any HMIs (human-machine-interfaces) on its network. This provides two-way communication between field devices, their controllers and the SCADA/HMIs which allows for centralised control of the site processes.

Advantages

- Requires more general programming knowledge of ladder logic, therefore it is easier to find a software engineer who can assist in programming/fault finding.
- Fast response time (10ms).
- Addition of SCADA system allows for centralised control for ease of use by operators.

Disadvantages

- PLCs require a SCADA system to be networked to allow for control and monitoring by an operator.

- Can be more costly due to the addition of a SCADA network and HMIs required to control the plant.

Distributed Control Systems

Functions and Features

DCSs are also ruggedised computers used in industrial automation, primarily using function block programming. They utilise multiple autonomous controllers which control different parts of an automated process, for example in a cake factory; one of the controllers may be used to control the batching of the icing whilst another controller would oversee the baking process etc. This means if one controller fails, only that part of the process is impacted which prevents total shutdown of the factory. When they were invented in the mid 1970's, they had the advantage of being able to control whole processes and production lines, but with the technological advancements in communications networks, PLCs can now perform the same functions.

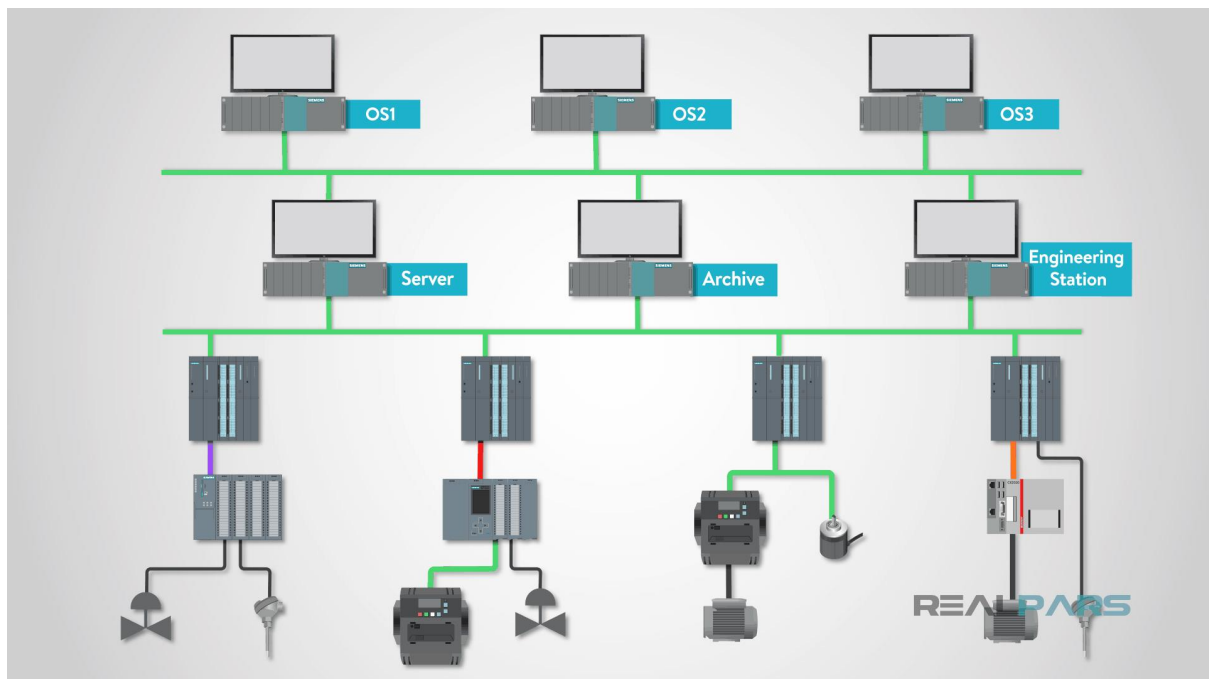


Figure 12 - DCS Network Topology (RealPars, 2019)

As shown in figure 12, there is virtually no difference between a PLC network and a DCS network apart from the integration of separate servers and archives, rather than being integrated into a SCADA network.

Advantages

- DCS are typically cheaper to install as the controllers can be close in proximity to the plant equipment, saving costs on running I/O wire to a centralised location.
- They feature a built-in monitoring and control system, therefore don't require a separate SCADA system to be networked for interaction between the operator and their plant.

Disadvantages

- Requires more specialist knowledge to programme so may be more costly and difficult to find a software engineer to assist in programming.
- They are programmed exclusively using function blocks
- Slower response times (30ms) compared to PLCs (10ms).

Direct Digital Control Systems

Functions and Features

DDC systems are used in BMS (building management systems) and BAS (building automation systems) to control and/or automate entire building processes such as lighting, security and most commonly, HVAC (heating, ventilation and air conditioning) systems. In such systems, both software and hardware components (e.g. sensors and mechanical/electrical devices such as fans and fridges) are designed specifically for DDC systems. This means they use their own bespoke programming language, not logic gates and function blocks as with DCS and PLCs. Shown figure 13 below is a simplified diagram of the architecture of a DDC system. The concept is the same as in DCS and PLCs as there are devices which provide analogue/digital data which is sent via an RTU (remote terminal unit). These are microcontrollers which feed back to the master station such as a SCADA so that field devices around the whole of the building can be monitored and controlled remotely. DDCs also feature data-logging and historical trending to monitor the performances of field devices/HVAC equipment, useful for fault finding and wear and tear monitoring.

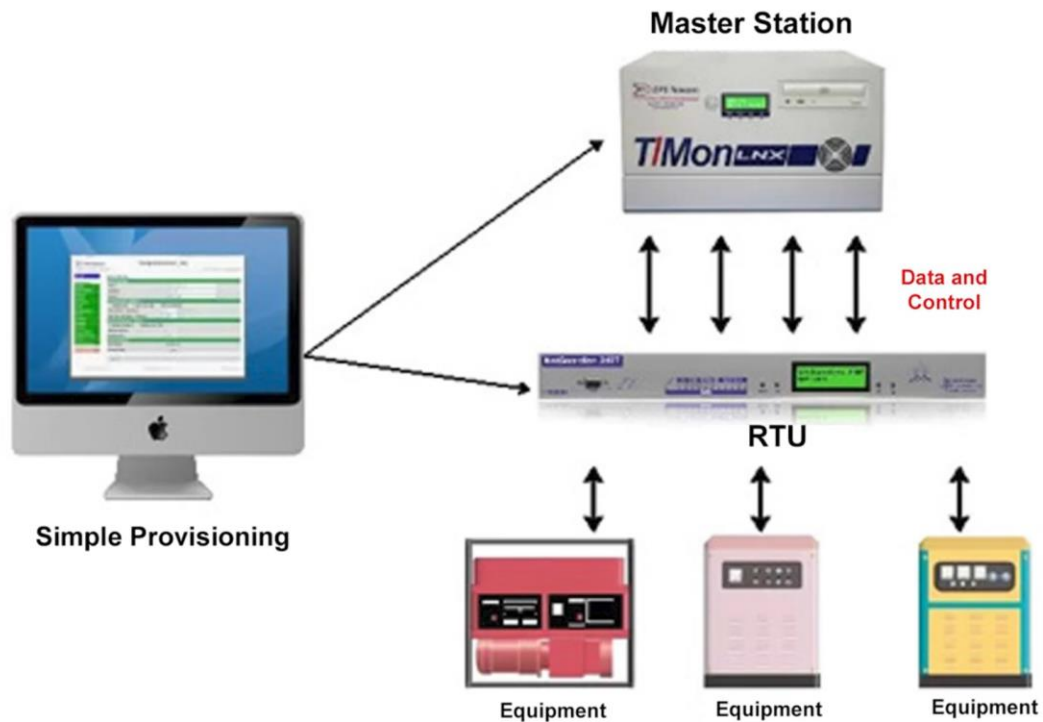


Figure 13 - DDC Network Topology (Erickson, 2025)

Advantages

- Provides real-time data for efficient and timely fault diagnosis.
- Increased energy efficient and therefore reduced overall running cost of building equipment.
- Reduces workload to building staff as processes are automated.
- Can alert maintenance staff when maintenance is necessary.

Disadvantages

- Bespoke programming language requires specific set of skills for installation, commissioning and maintenance of the system as a whole, meaning initial cost and maintenance contracts can be very high in price.
- Less versatile than PLCs and DCS due to their specialisation in BMS/BAS systems.

Conclusion/Overview of PLCs, DCS and DDCs.

All three systems work off the same principle of having a field device which is connected via analogue/digital signals to a microcontroller which is fed back to a master station e.g. SCADA which offers centralised control of an automated system. Historically, PLCs and DCS differed in that PLCs were generally used to automate one specific device whilst DCS was used to bring together a group of devices which could communicate and be controlled centrally. Nowadays there is not much difference between DCS and PLCs as they both offer 2-way communication between field devices and their controllers and can be used to control the automation of entire industrial sites. DDCs offer specificity with BAS and BMS and are commonly associated with HVAC systems. When comparing them to PLCs and DCS they offer less versatility as PLCs and DCSs could be implemented in place of DDCs, but not vice versa. PLCs offer the most versatility and highest reliability as they are rugged, have fast response times and can be programmed using a variety of programming languages.



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