

LEVEL 4 ASSESSMENT SPECIFICATION

Student name:	Robert Day	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	12.8
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	27.3
Task 1 - 53%. Task 2 - 72%. Task 3 - 72%. Task 4 - 76%. Generally excellent knowledge and understanding of the basic underlying concepts and principles for each task but there were elements of knowledge lacking in task 1.		
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	16.9
Task 1 - 84%. Task 2 - 85%. 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
Work is coherent, very fluent and is presented professionally. Excellent layout making the assignment easy to read.		

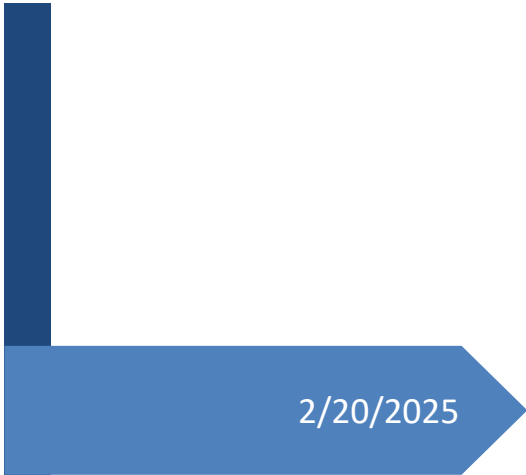
Assessment Mark (Assessment marks are subject to ratification at the Exam Board. These comments and marks are to give feedback on module work and are for guidance only until they are confirmed.)

Late Submission Penalties (tick if appropriate)

Up to 1 week late (40% Max)

Over 1 week late (0%)

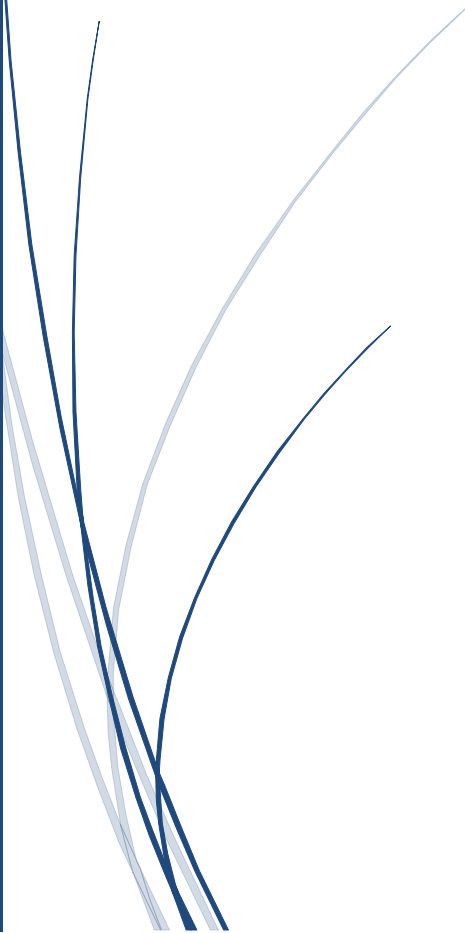
70%



2/20/2025

Instrumentation, Automation & Control

PCEE4011



Student Name: Robert Day
Student ID: 51404
Lecturer Name: Jason Pointer

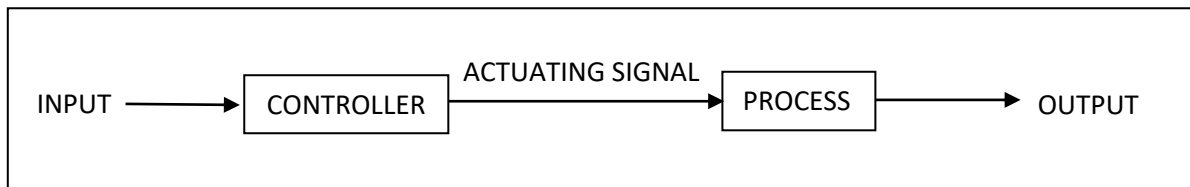
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Task 1 – Control types

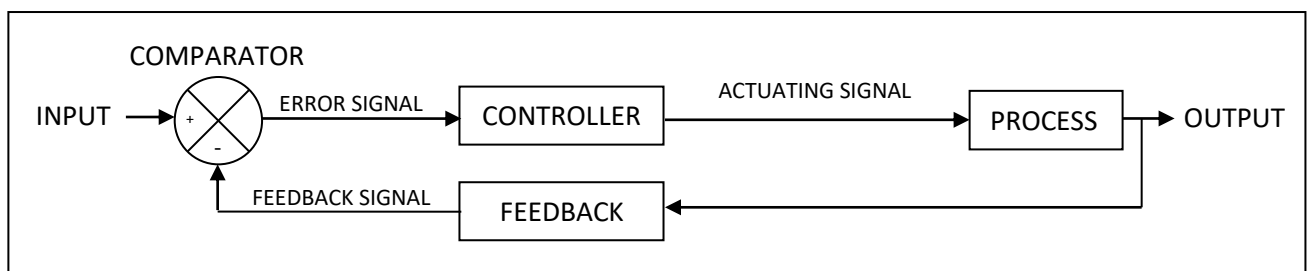
Question a)

Open loop control systems are extremely common, and feature in many pieces of equipment we use every day. For example, a toaster or light switch - both begin their functions by way of pressing a button (input), they perform the task according to preset instructions, and the end result (toasted bread or light) is the output. In an open loop system, the output is not monitored, so there is no guarantee that the desired output has actually happened. This basic form of control system cannot compensate for inaccuracies or external factors and is generally less accurate than a closed loop system. However, they are cheap to produce, easy to design, and have fast response times. The block diagram below shows the basic operation principle. ✓



Question b)

In contrast to the open loop system, feedback is used to compare the actual output of the control system with the desired output. This is highlighted in the block diagram below. ✓



An example of a common closed loop system would be a heating system with a thermostat. The desired temperature is determined by the user, and this becomes the setpoint. The temperature is monitored continuously by the thermostat and fed back to the comparator. It compares the current temperature against the setpoint and if there is a difference between the two, the “error signal” is sent to the controller so that it can take action. The action will either be to turn the heating off if it is too hot, or turn the heater on if it is too cold. This continuous operation ensures the temperature of the room is maintained at the required temperature. ✓

Need a bit information of the operation and features of the closed loop system.

Have not shown how the equation is derived.

Question c)

“Three term” is a control system that uses three different control types in one – namely Proportional, Integral and Derivative. The three of these combined creates a robust system that is accurate, stable, and benefits from automatic error correction.

According to (Omega, 2019) *“The first evolution of the PID controller was developed in 1911 by Elmer Sperry. However, it wasn’t until 1933 that the Taylor Instrumental Company (TIC) introduced the first pneumatic controller with a fully tuneable proportional controller. A few years later, control engineers went eliminate the steady state error found in proportional controllers by resetting the point to some artificial value as long as the error wasn’t zero. This resetting “integrated” the error and became known as the proportional-Integral controller. Then, in 1940, TIC developed the first PID pneumatic controller with a derivative action, which reduced overshooting issues. However, it wasn’t until 1942, when Ziegler and Nichols tuning rules were introduced that engineers were able to find and set the appropriate parameters of PID controllers. By the mid-1950’s, automatic PID controllers were widely adopted for industrial use.*

The proportional control element is responsible for comparing the real time output with the desired input or setpoint. The Integral control element is responsible comparing the accumulated errors over time. The derivative control element is used to monitor the rate of change in the error. Put simply, these three combined observe the past, present and future in order to provide an output that offers responsiveness and stability. This type of controller is commonly called “PID” (Proportional, Integral, and Derivative). A PID controller provides automatic error correction, which means it eliminates any offset or drifting errors, whilst also being able to provide a smooth system response which eliminates any overshoot problems.

A real-life example of a PID controller would be a cruise control system in a car

Cruise Control:

A cruise control system is designed to maintain a constant speed, set by the driver of the vehicle. However, there are various factors such as wind, hills and quality of road surface that affect keeping the speed constant. A PID controller can help in this situation. The proportional control element adjusts the accelerator for the real time speed “error”. The Integral controller will allow for the uphill or downhill gradients and/or the effect of wind. The derivative controller reacts to the changes in the road surface quality. These three controllers combined allow the cruise control system to maintain an almost constant speed.

Thermostatically controlled oven:

A PID controller is used in an oven to adjust the heating and cooling based on the real-time temperature reading from the Thermistor or RTD, eliminate temperature drift and prevent any temperature overshoot in the heating up phase.

Task 2 – Position control servo

Question a)

Variables:

$$K_A = 1$$

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

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

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

B = To be determined

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

Therefore...

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

Compare to the standard equation:

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

Then:

$$\omega_n^2 = 200$$

So, the steady state value = $k = 1$

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

$$B = 2\zeta\omega_n I \text{ therefore } B = 2 \times 14.14 \times 1.5 \times 10^{-4} \times \zeta = 0.004242641 \times \zeta$$

Where ' ζ ' =	0 (no damping)	$B = 0$
	0.36786 (under damped)	$B = 0.001560698$
	1 (critically damped)	$B = 0.004242641$
	1.92 (over damped)	$B = 0.00814587$

Damping ratio ' ζ ' = $\frac{B}{I}$ therefore for:

$$\text{no damping} = \frac{0}{1.5 \times 10^{-4}} = 0$$

$$\text{under damped} = \frac{0.001560698}{1.5 \times 10^{-4}} = 10.405$$

$$\text{critically damped} = \frac{0.004242641}{1.5 \times 10^{-4}} = 28.284$$

$$\text{over damped} = \frac{0.00814587}{1.5 \times 10^{-4}} = 54.3058$$

XCOS simulations and outputs from SciLab:

Figure 1 below shows the model created in SciLab which can be used to simulate the controller. In this instance no damping has been applied.

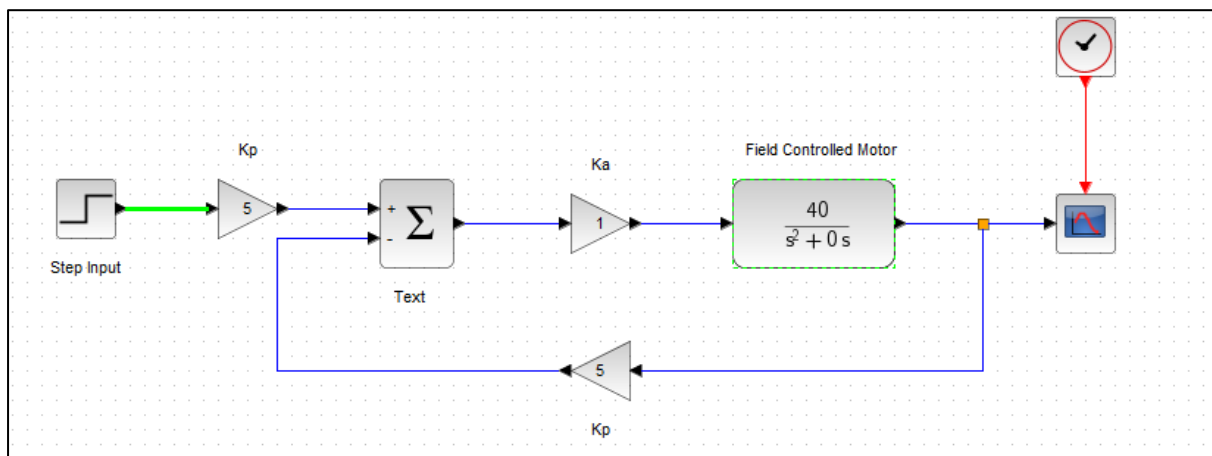


Figure 1 – no damping – full oscillation

The output below shows the system in full oscillation due to no damping being applied.

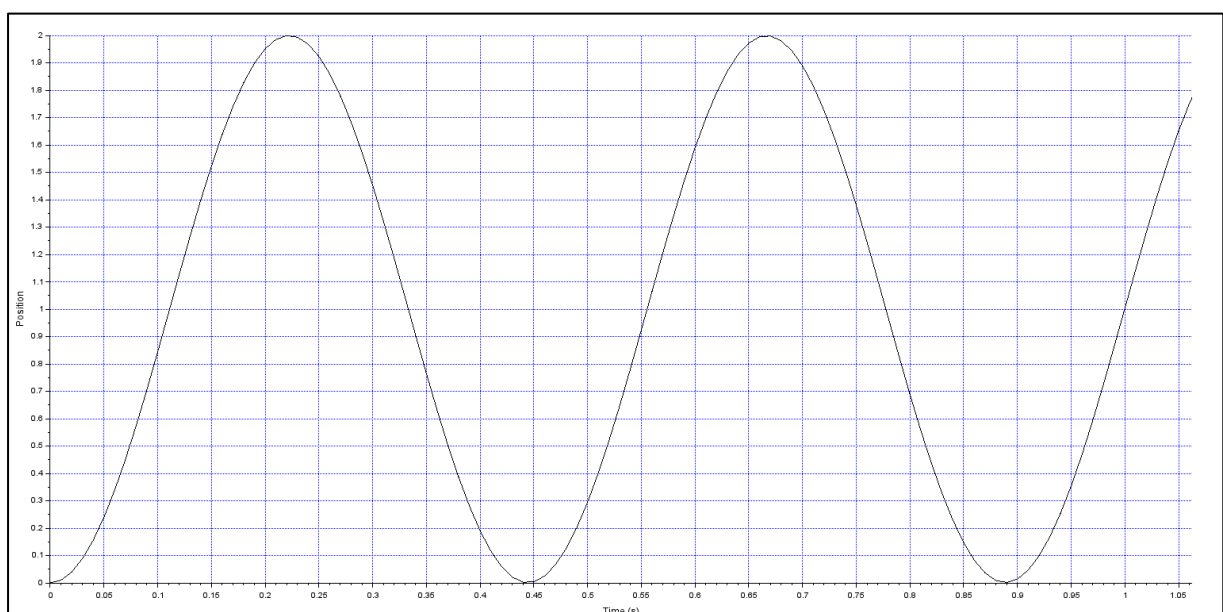


Figure 2 - No Damping

Figure 3 below show the underdamped model using 10.405.

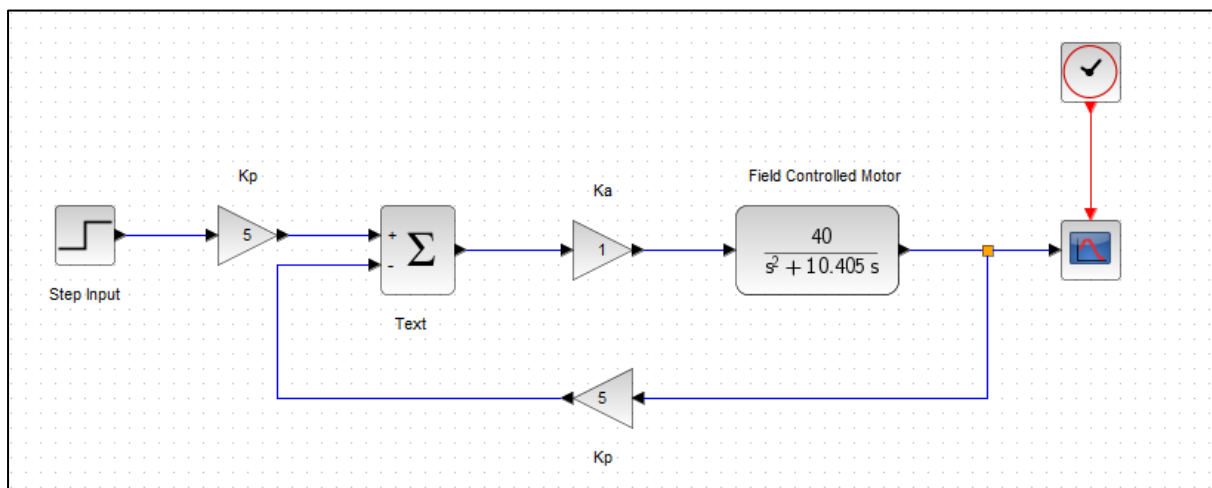


Figure 3 under damped 10.405s

The output below shows an under damped system as shown by the overshoot and undershoot, however after 1.1 seconds it does start getting close to settling.

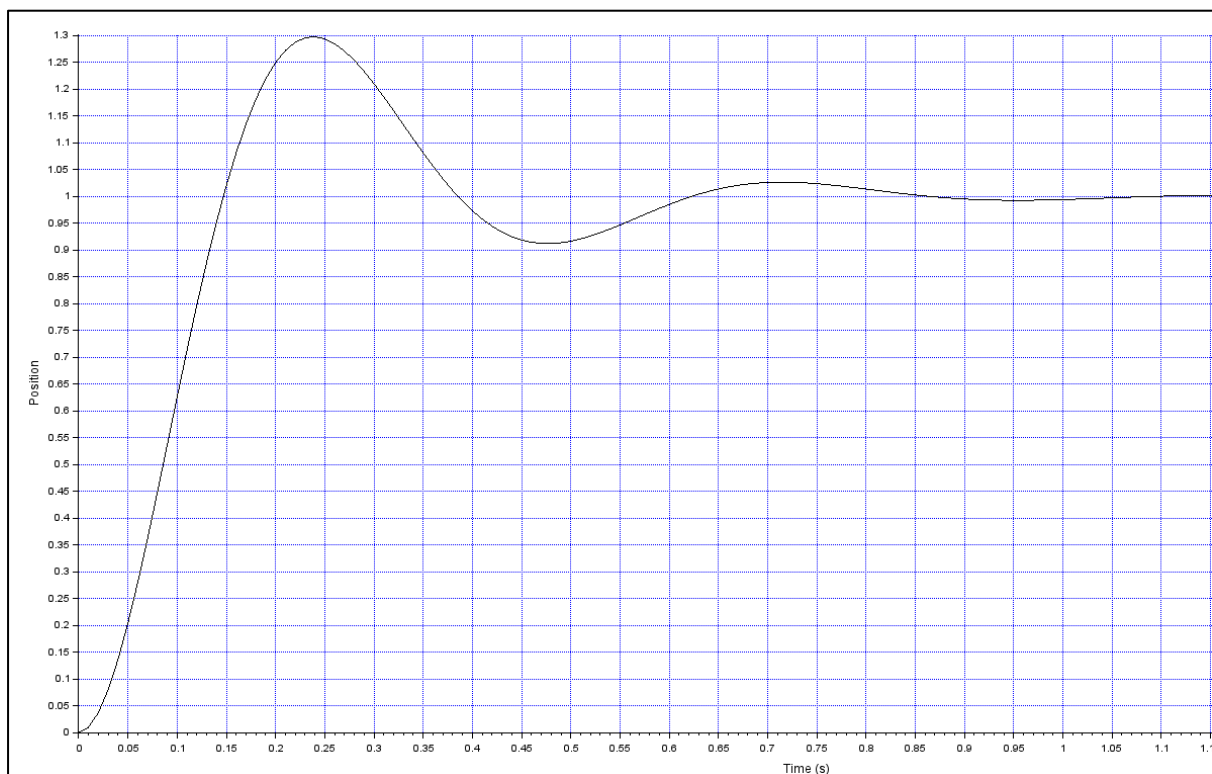


Figure 4 - Under damped 10.405s

Figure 5 below shows the critically damped model using 28.284.

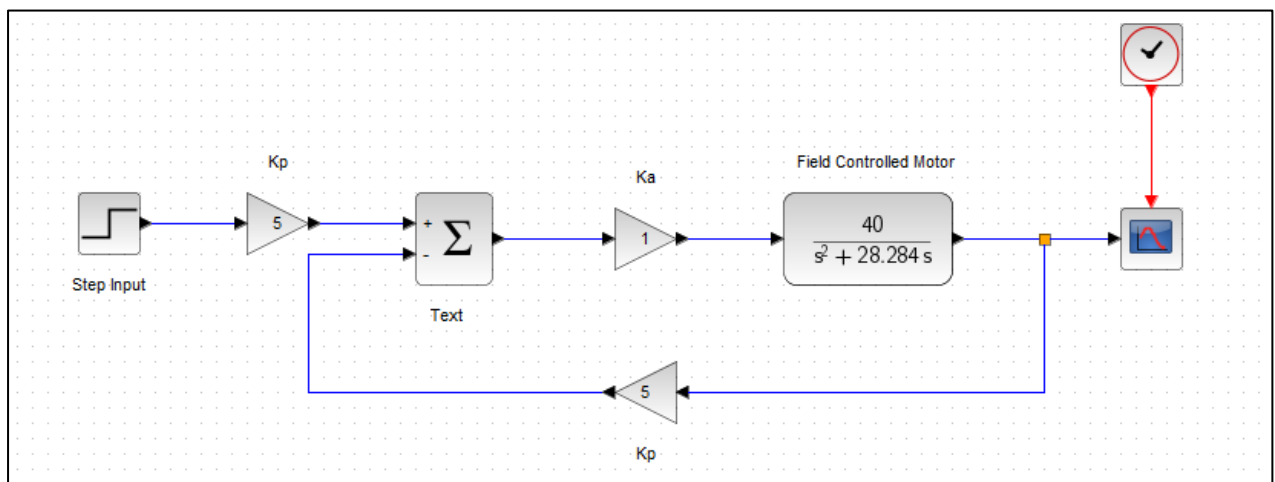


Figure 5 - critically damped

The output below shows a critically damped system. This is the 'sweet spot' between an under damped and over damped system where no overshoot or undershoot occurs (oscillations). This is the fastest time in which a steady state can be achieved, in this instance approximately 0.65 (s).

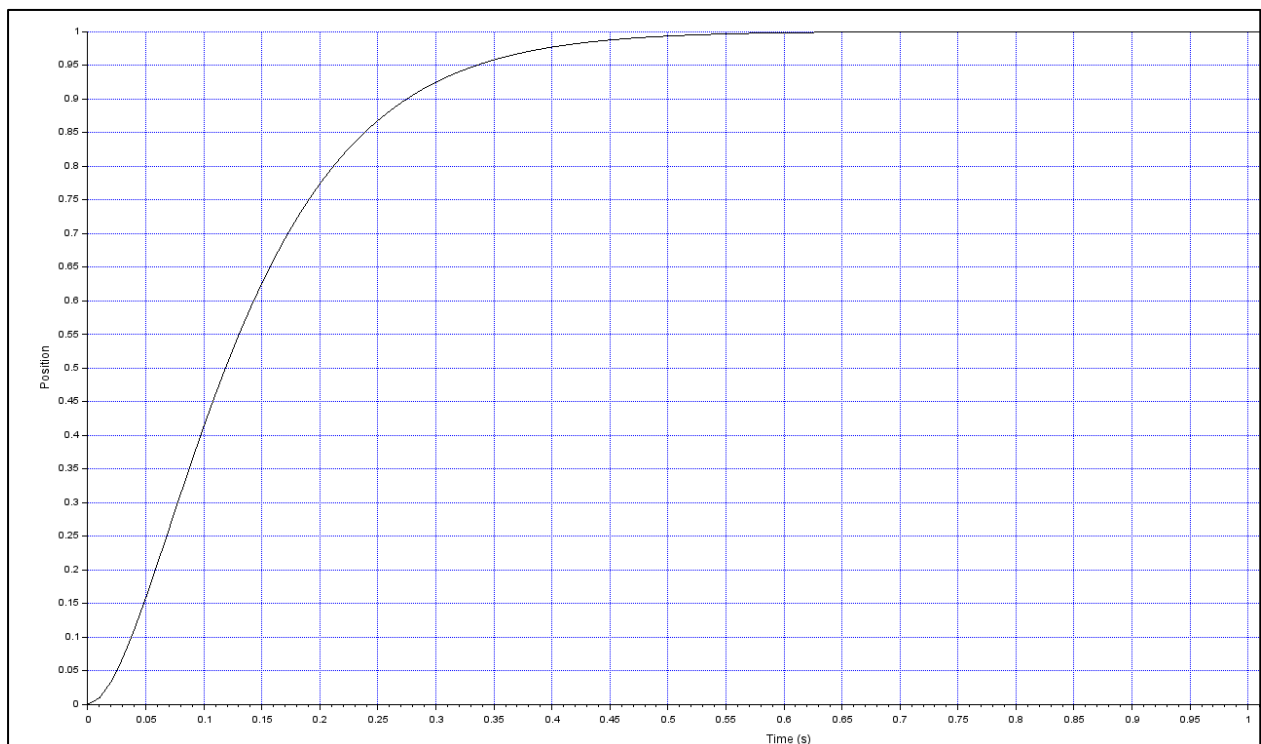


Figure 6 - Critically damped

Figure 7 below shows an overdamped model using 54.306.

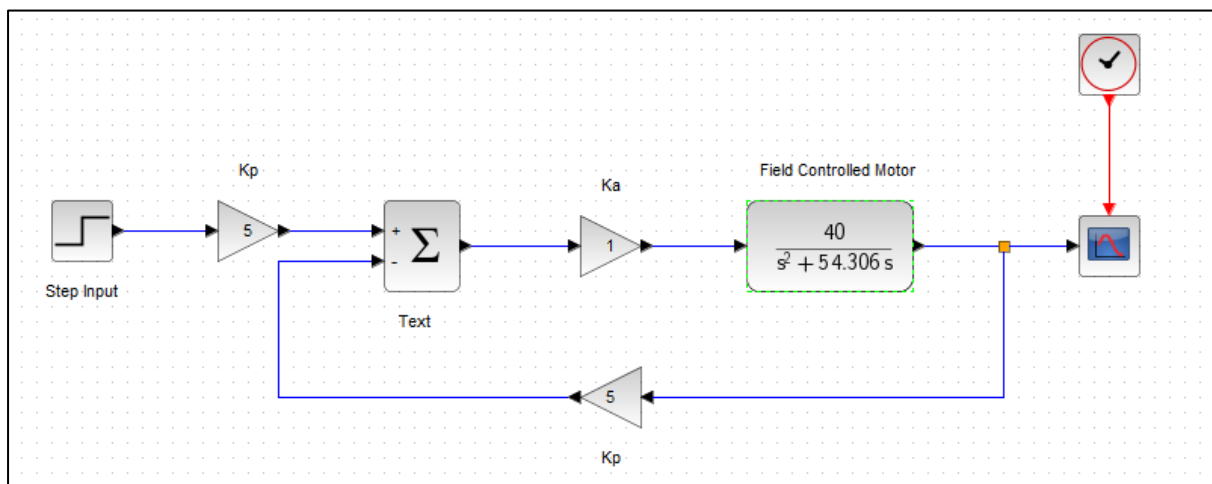


Figure 7 - over damped

The output below shows an over damped system. The damping effect means that there is no overshoot, or undershoot, however it is so strong that it takes significantly more time to reach the steady state. In the example shown steady state is achieved in approximately 1.75 (s).

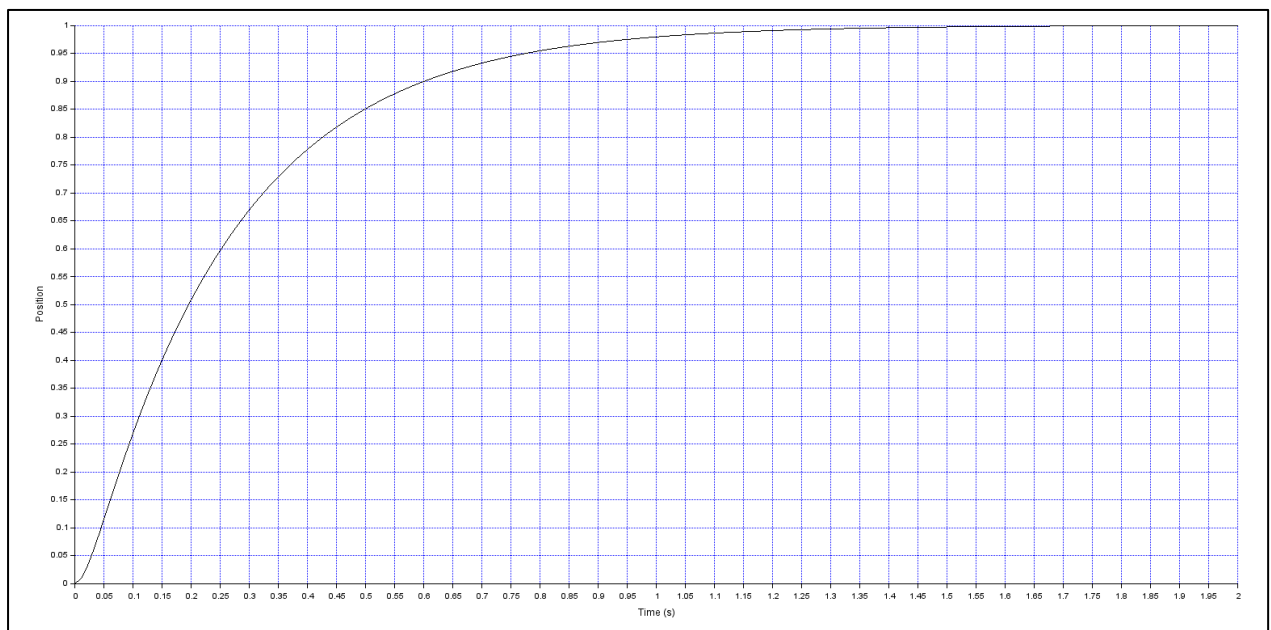


Figure 8 - Over damped

Question b)

For the under damped system below where $B = 10.405$ (s), the following values can be determined.

Settling time = 0.7 seconds (red lines)

Rise time = 0.035(s) to 0.13(s) = 0.095 seconds (green lines) approx.

Percentage overshoot = 30% (orange line) approx.

Peak time = 0.235 seconds (orange line) approx.

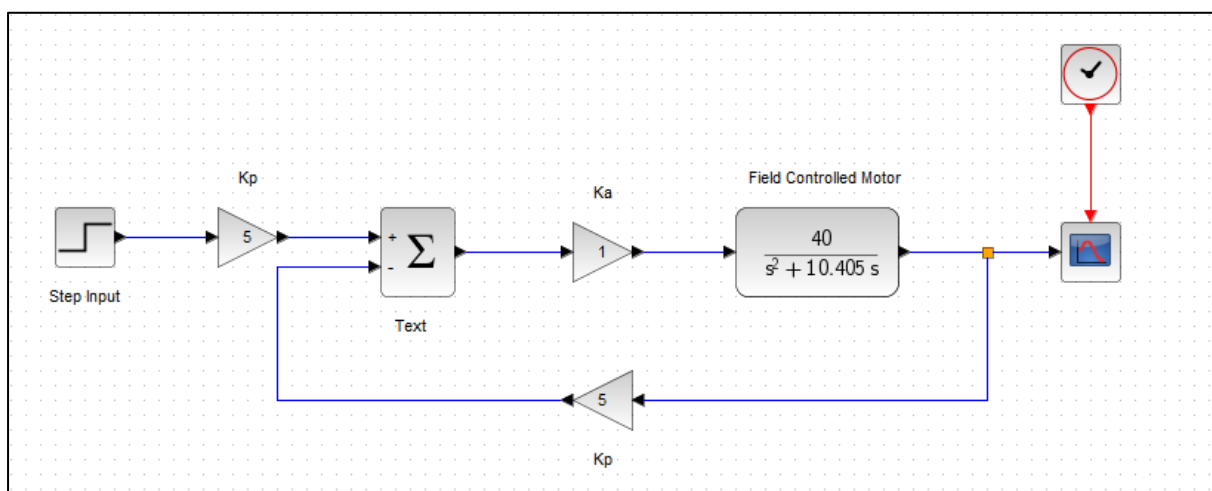


Figure 9 – under damped

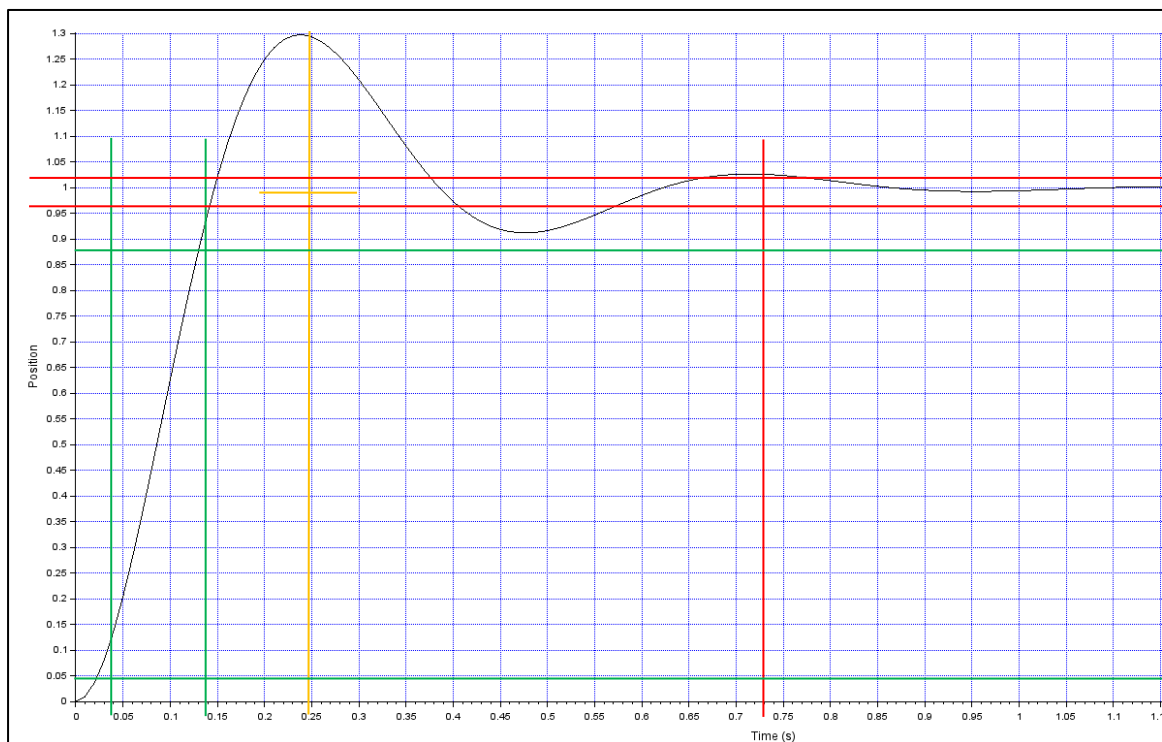


Figure 10 – under damped. The plot has been analysed to determine settling and rise time, peak time and overshoot.

When (B) is decreased to 5 as per the images below, we see a greater number of oscillations. As a result the settling time has increased significantly, but the rise time is quicker.

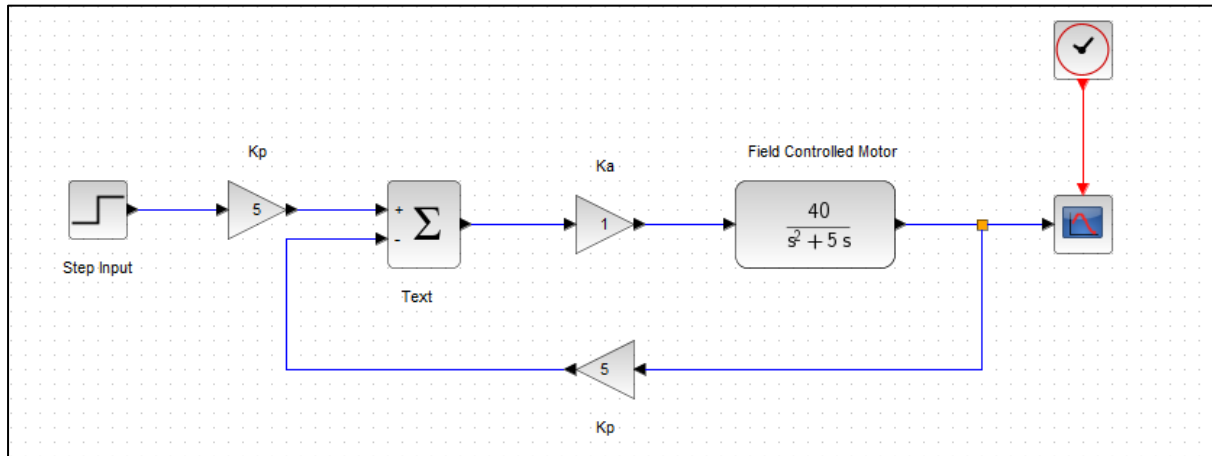


Figure 11 under damped at 5s

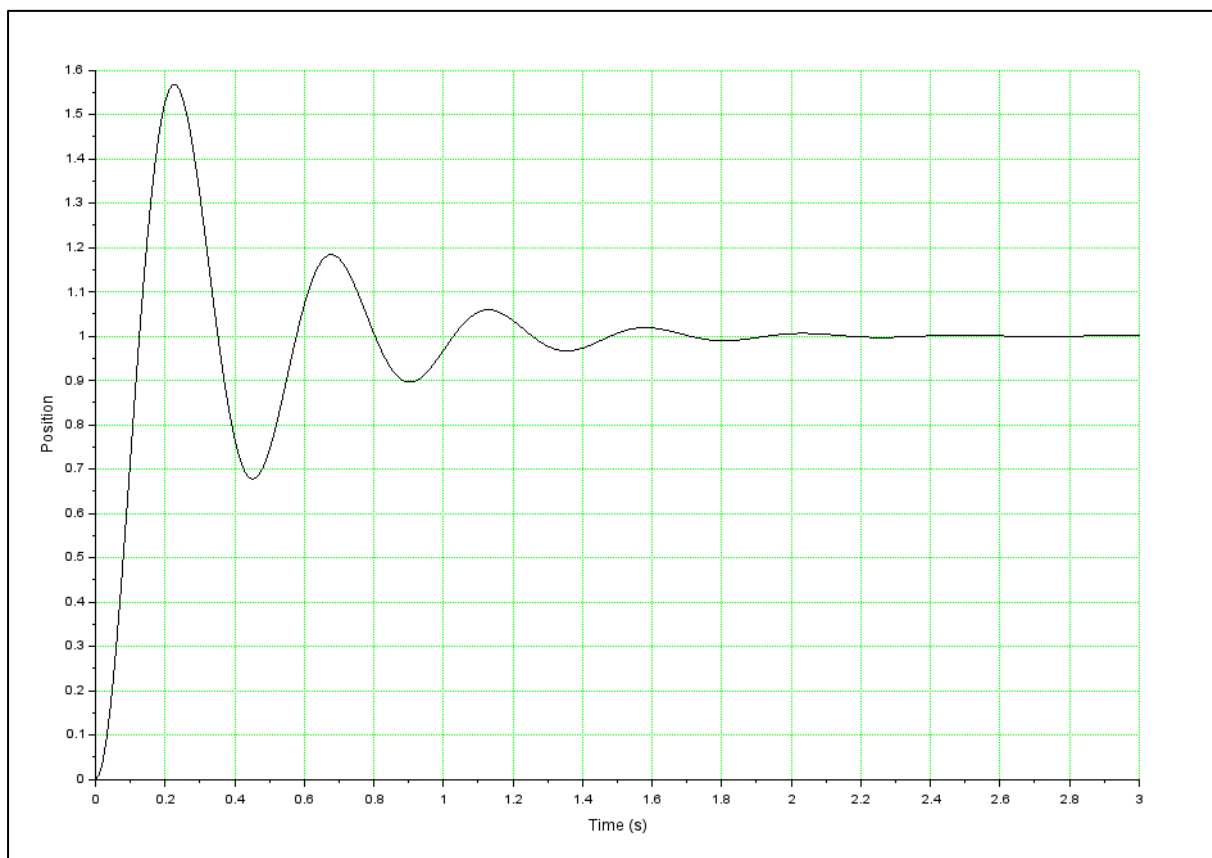


Figure 12 – under damped 5s

When (B) is increased to 15 as per the images below, we see that the number of oscillations has decreased compared to the previous examples where B=10 and B=5. At B=15 we are approaching the critically damped figure of 28.284 and as a result we have a longer rise time, a shorter settling time, and less overshoot and undershoot – as we would expect.

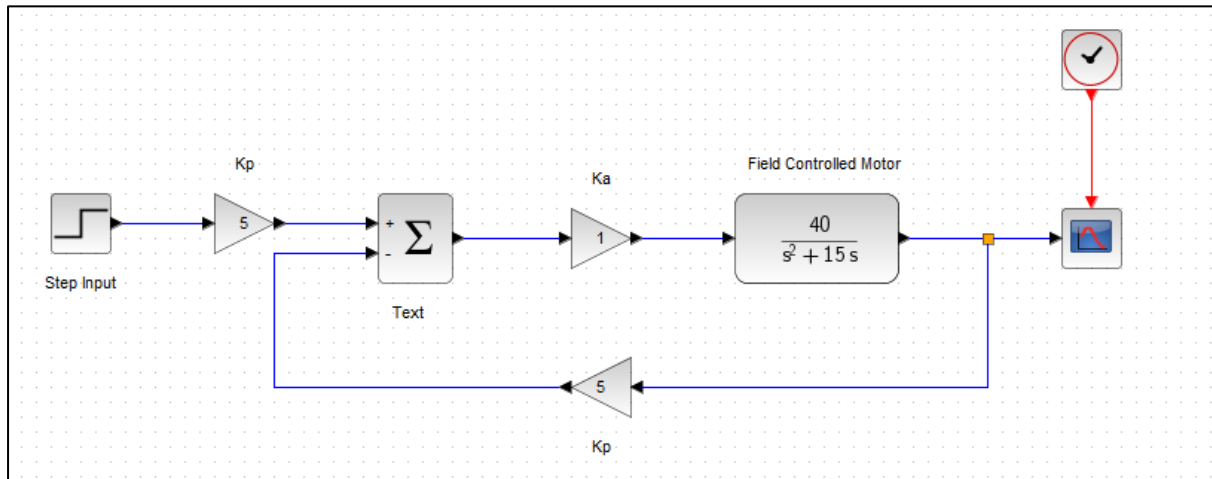


Figure 13 – under damped 15s

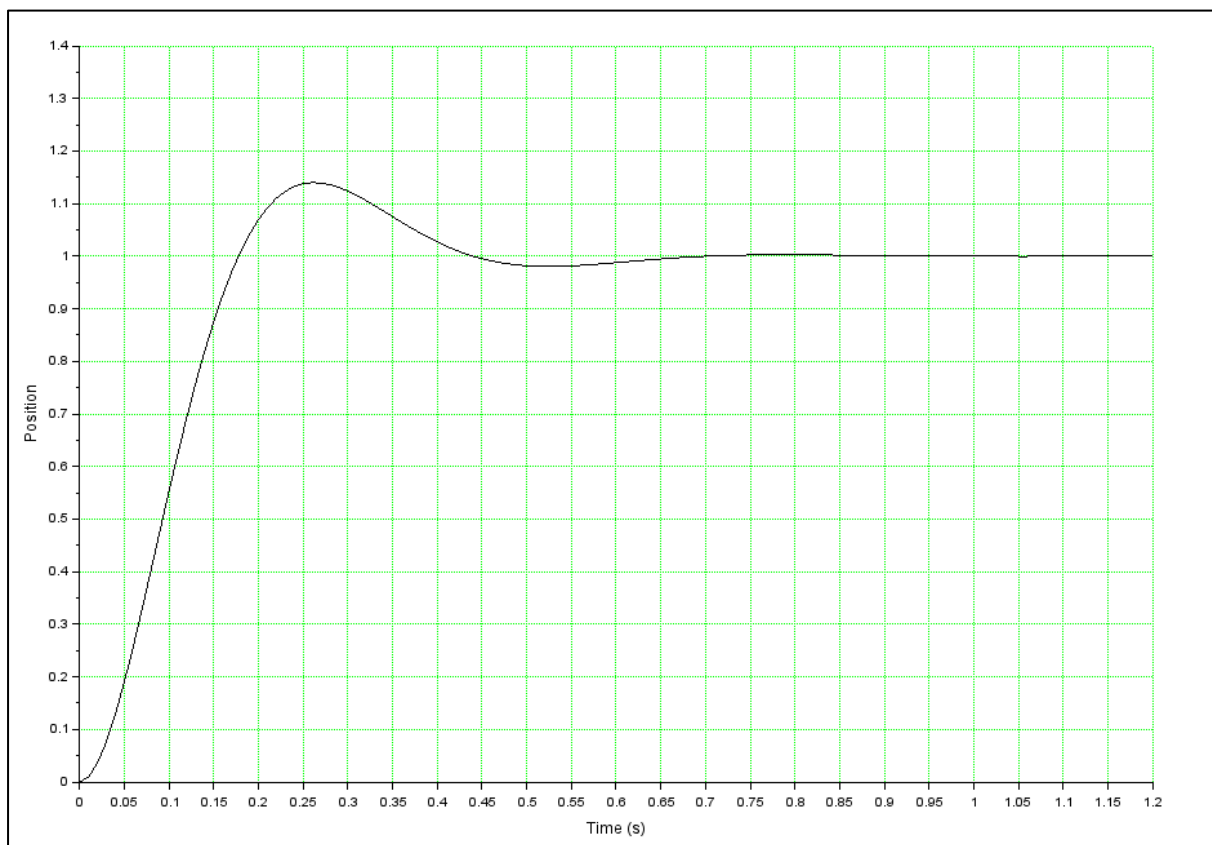


Figure 14 – under damped 15s

Task 3 – Tuning

Question a)

According to (J. Michael Jacob, 1995) *“Selecting the best value for your controller’s constants often appears to be as much black magic as science.”* Thankfully there are several methods for tuning PID controllers, but two of the most commonly used are: Process reactive tuning and Ultimate cycle tuning.

The term tuning refers to making a system perform to its optimum by way of setting the system up using the best settings possible.

The ultimate cycle tuning method was developed by John Ziegler and Nathaniel Nichols, and was published in 1942. They discovered rules on how to determine the proportional (K_p), integral (K_i) and derivative (K_d) gains for a closed loop system, by first establishing the “ultimate gain” and “ultimate period”. This is achieved by increasing the gain of the system until equal, sustained oscillations are observed (no increase or decay in the amplitude – as seen in figure 20). Whatever point this occurs at is the ‘ultimate gain’, and the ‘ultimate’ period can be measured between peak to peak of the oscillation.

The Ziegler Nichols tuning method recommends that the system exhibits a quarter amplitude decay, which means the amplitude of successive oscillations of the system output reduce to a quarter of the previous peak. This will create a damped system that settles quickly, has a balanced response and has an acceptable or little overshoot.

To devise the theoretical preferred Integral time (T_i) setting, the ultimate period is divided by 2 and for the Derivative time (T_d) the ultimate period is divided by 8. The Integral setting acts on a timescale half the length of time of the oscillation period to help reduce any steady-state errors. The derivative setting is for predictive damping, helping to reduce overshoot and provide a quicker response.

The process reaction method is used in open loop tuning. Basically, a step change is introduced into the system and the output is monitored. Analysis of the output can be used to determine the time constant, gain and dead time (the delay between the step change and the output response). According to (J. Michael Jacob, 1995) *“To accomplish process reaction tuning, first assure that the controller output and the process variable are expressed in % full scale output. Monitor each on an appropriate recorder. While in manual mode, step the controller output by 10%. The plot of the process variables response should be “S” shaped. Draw a tangent that runs through the inflection point of this curve, projecting it until it*

intersects both the previous and final values of the process variable.” This graph is called a process reaction curve and from it you can infer the lag time (Reflects how fast the system reacts), the dead time (the latency between the initial input and first noticeable response of the output), and the gain. Figure 15 below shows how the information is extrapolated.

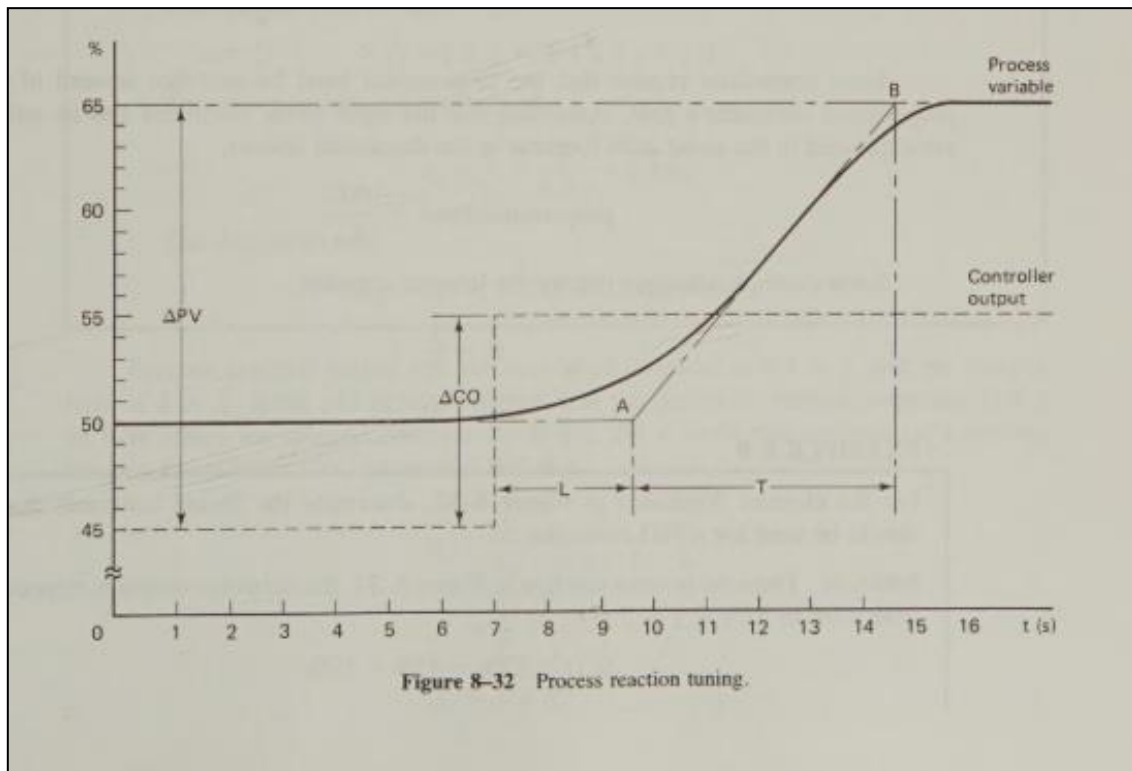


Figure 15 – Process reaction curve – Page 544 – J. Michael Jacob (1995). Industrial Control Electronics

Once these three variables are known, the Ziegler-Nichols tuning can be used to calculate appropriate PID parameters (K_p , K_i , K_d) for the process. Having said all of that, the derived settings from these observations are not always to the most ideal and further fine tuning can be required.

Question b)

Below is the simulation model of a level tank system which requires additional tuning with a PID controller.

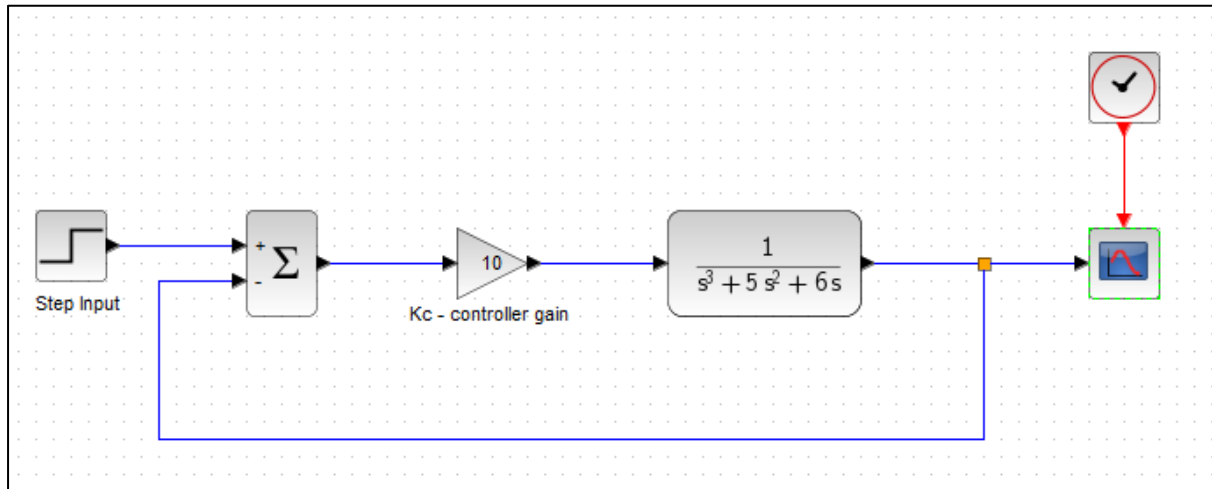


Figure 15 - original state gain

The output below shows the system using its original state gain. The output has a clear and significant overshoot, a fairly slow rise time and long settling period.

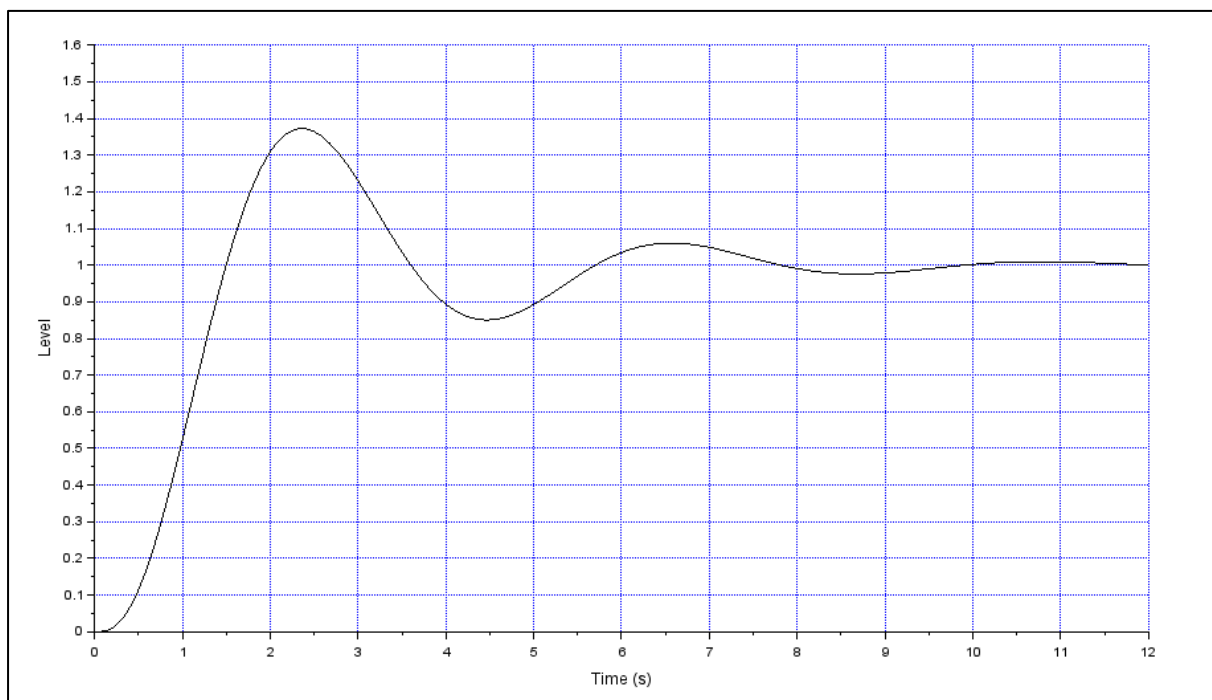


Figure 16 - original state gain graph

Using the ultimate cycle method we shall put the system into full oscillation by increasing the gain so that the periodic time of the oscillations can be measured.

The gain has been increased to 20, and the number of oscillations has increased, but the system is still not in full oscillation.

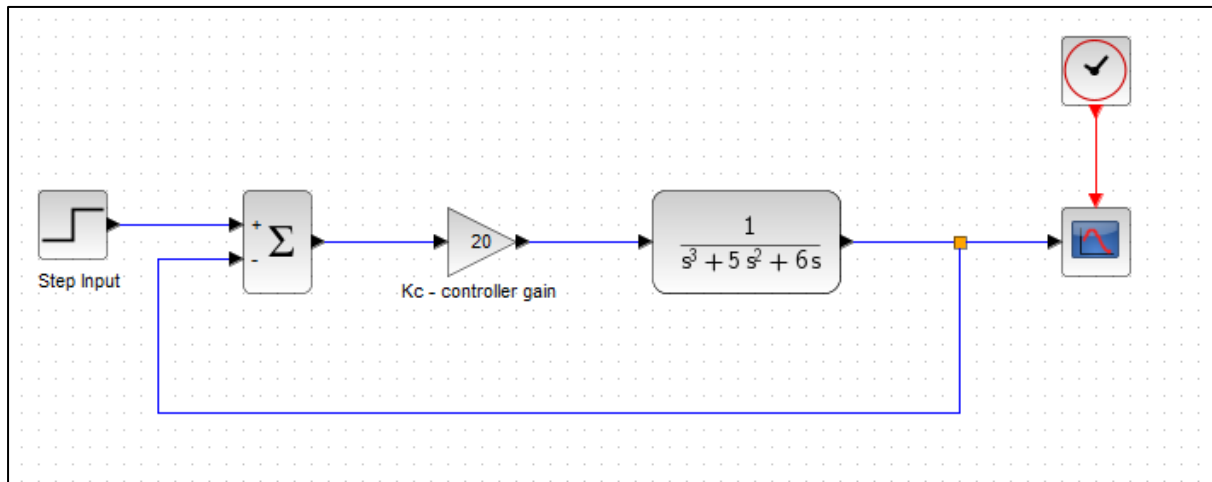


Figure 17 – Increasing the gain until the system reaches full oscillation

The number of oscillations has increased, but the amplitude is still decaying on each cycle.

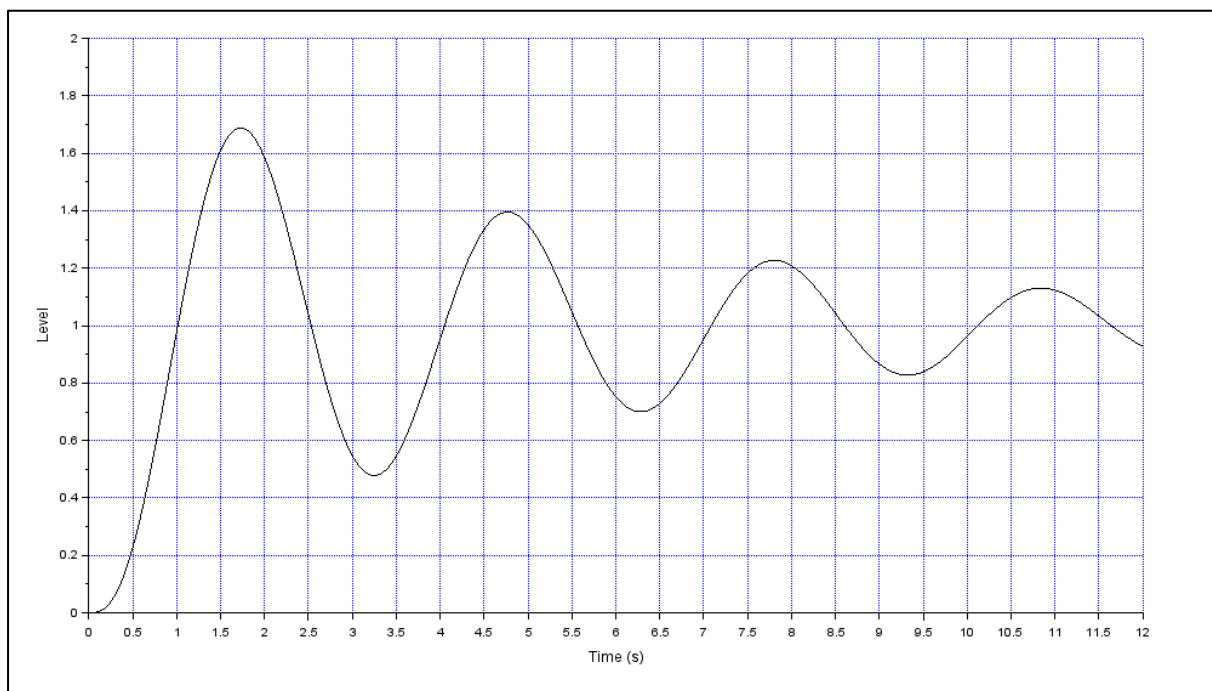


Figure 18 - increased gain, increased oscillations

Now the gain has been increased to 30, and it is clear that the system is in full oscillation. The amplitude of each cycle is the same (no decay). This now offers the opportunity to measure the period time.

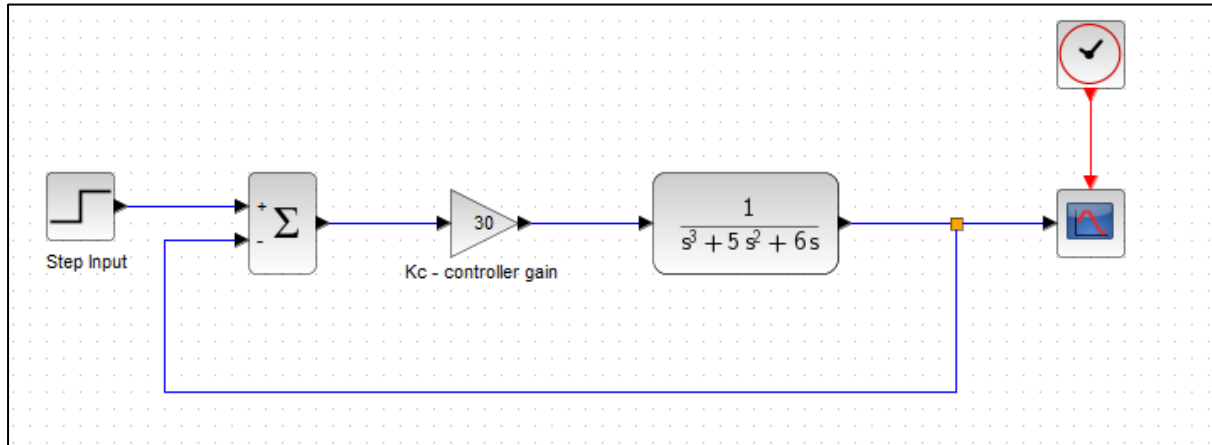


Figure 19 - full oscillation gain

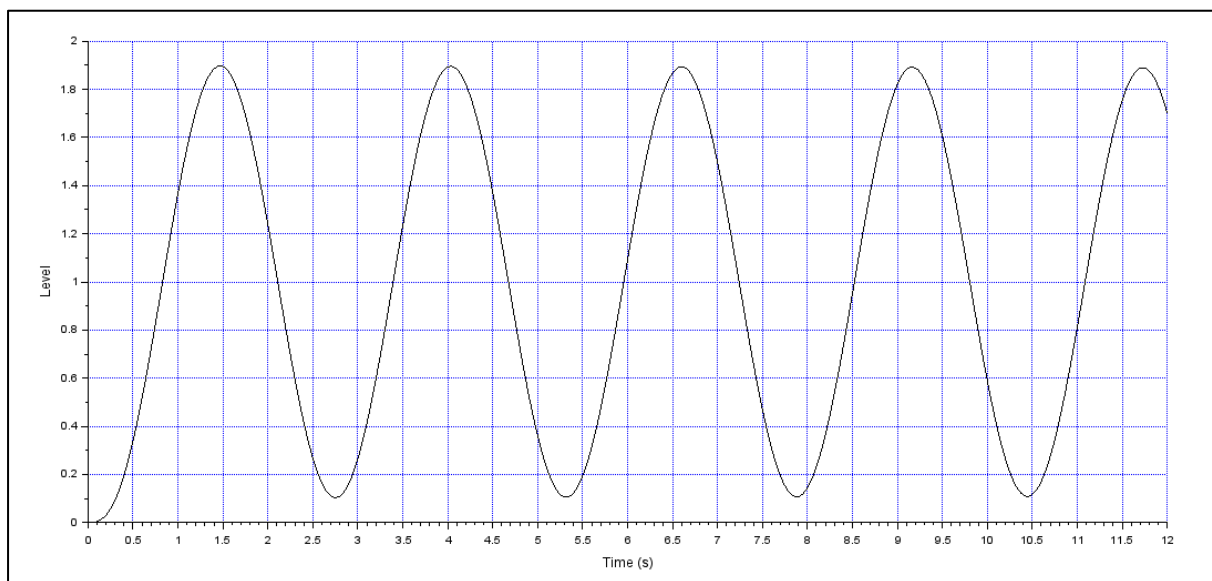


Figure 20 - full gain graph

PID Controller

$K_{pu}=30$

$T_u = 2.7s$ (peak to peak from full oscillation screenshot above)

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

$T_i = T_u/2 = 2.7/2=1.3s$

$T_d = T_u/8 = 2.7/8 = 0.3375s$

Using the calculated values:

The calculated values have been substituted into the model. The integral value of 0.7407 is calculated by dividing 1 by 1.3s = 0.769, the derivative value = 0.3375 and the gain set to 18.

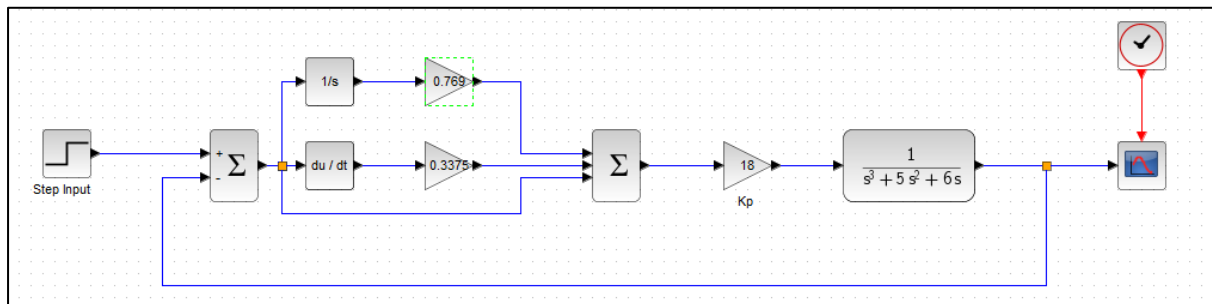


Figure 21 – Model updated with Integral and Derivative control elements.

The output below shows the newly tuned system. Whilst the overshoot is greater than the original system, it has settled quicker. Further adjustments may improve this.

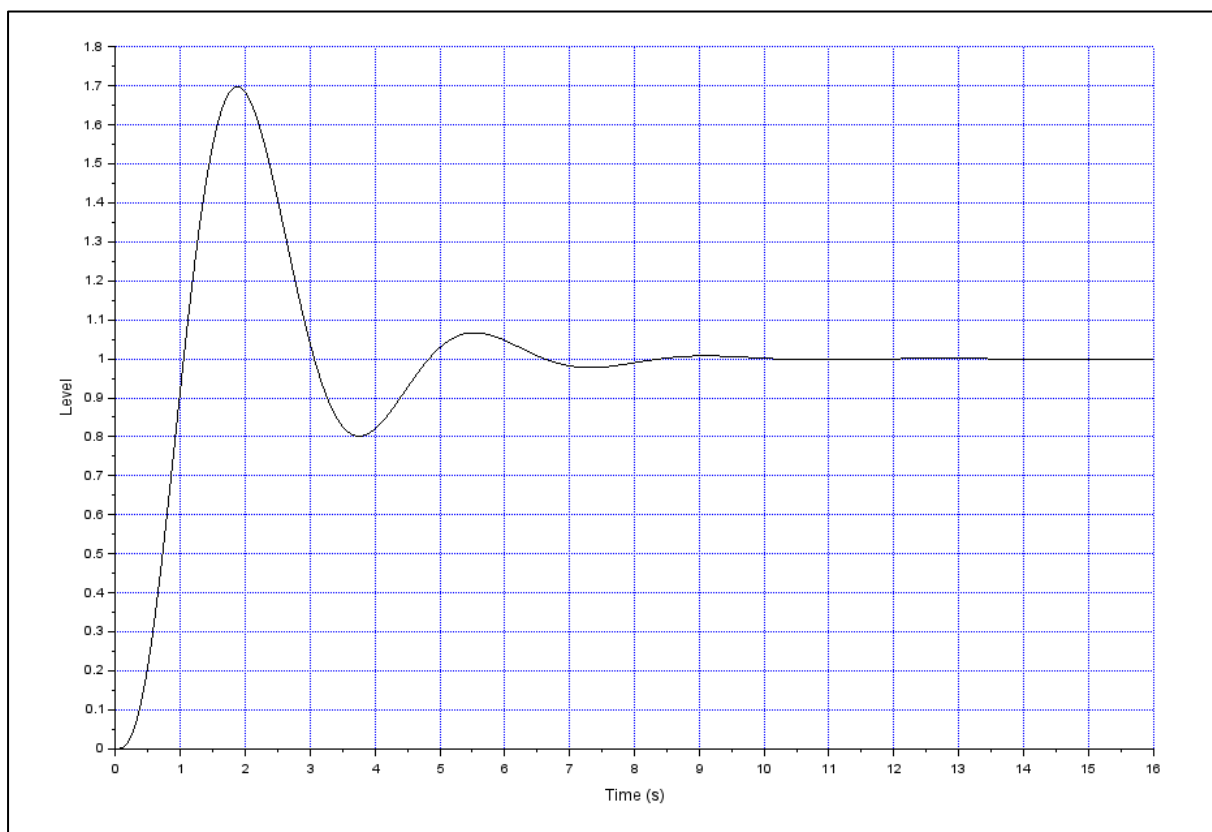


Figure 22 – Tuned using the calculated values.

Adjusting the integral to 0.25.

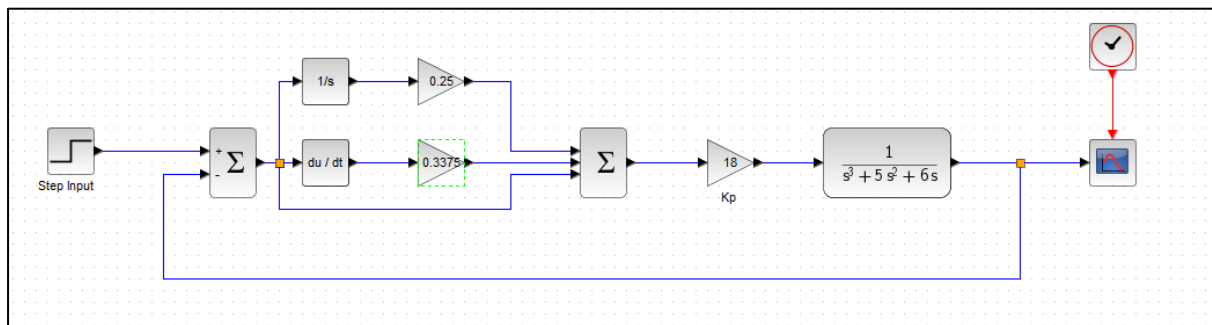


Figure 23 – Adjusting integral setting

The output below shows a drastically reduced overshoot compared with the previous attempt. The settling time is approximately the same.

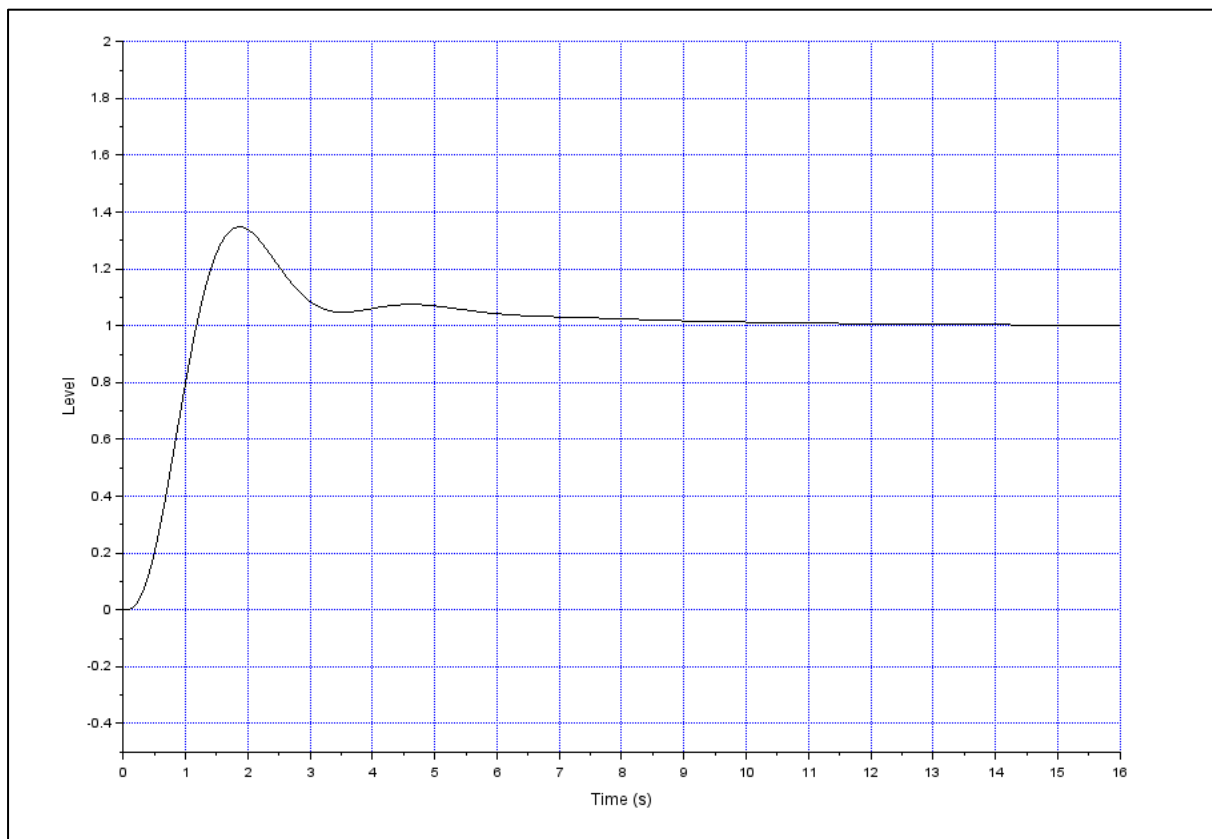


Figure 24 – Tuned further by changing the integral setting.

Below shows the model with adjusted integral and derivative settings. This has given us a damped output with a relatively small overshoot, with no steady state error, and a system that settles in approximately 7 seconds - a significant improvement on the original level tank system. This is the best I have been able to achieve.

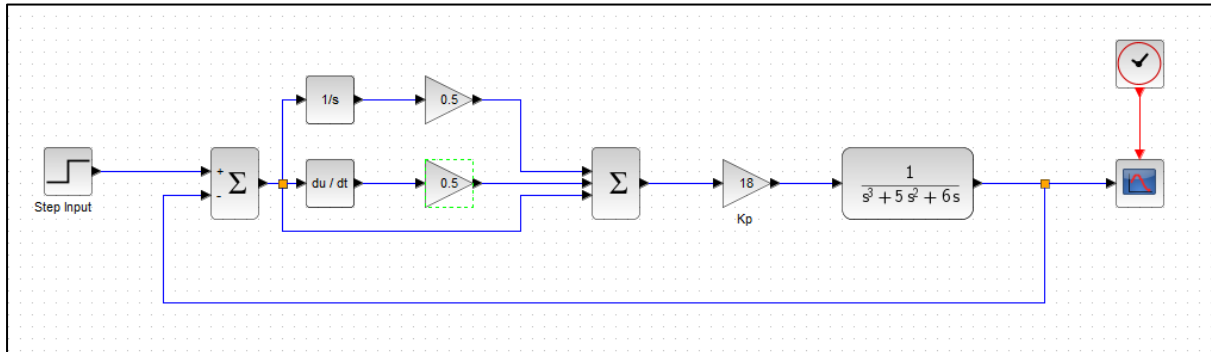


Figure 25 – Tuned further by changing both the integral and derivative settings.

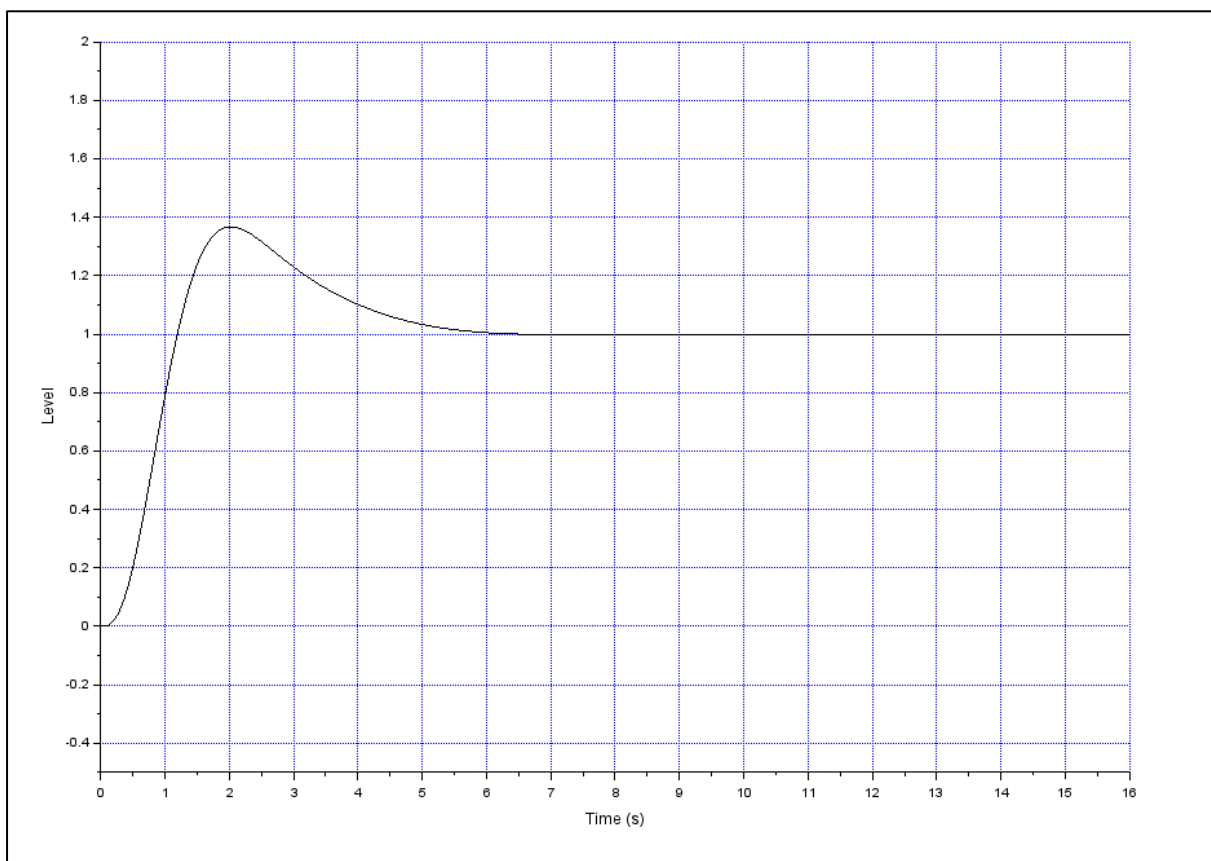


Figure 26 - Tuned further by changing the integral and derivative settings.

Task 4 – Computerised control systems

According to (Kirvan, 2023) *“A control system is a set of mechanical or electronic devices that regulates other devices or systems by way of control loops.”* Most control systems in use today are computerised, i.e., they harness digital computing technologies to automate processes, increase accuracy, safety, and control machines. Among the most common computerised control systems are PLC's (programmable logic controllers, DDC (direct digital control) and DCS (distributed control system). These three control systems are commonplace in industrial and commercial operations, and their specific use normally depends upon the application itself, environmental conditions and scale of the task.

Programmable logic controllers are particularly common in heavy industry because of their rugged specification and compact but scalable profile. PLC's are used to automate control processes based on real time events, for instance: On oil refineries they are used to monitor pressure, temperature, velocity, turbidity, levels and then control heaters, fans, valves, mixers etc. Ladder logic programming is used to create control loops where data is received from field sensors/devices in real-time (inputs), and the output signals are sent to associated electronic/pneumatic/hydraulic equipment, based upon logic program stored in the PLC.

Key features of PLC's:

- Real-time operation
- Modular and scalable hardware
- Ladder logic programming
- Reliable in harsh industrial environments

PLC's do have some limitations which are mainly concerned with the amount of I/O they can handle and the amount of data processing. For larger scale applications a DCS would be more suitable.

According to (Coffin, 1999) *“Direct digital control (DDC) is a control process in which a microprocessor controller constantly updates an internal information database by monitoring information from a controlled environment and continuously produces corrective output commands in response to changing control conditions. This process is similar to the way traditional control systems work, except that digital information processing produces a much faster and more accurate control system response under all conditions at all times.”* A DDC is a continuous measuring, monitoring and control system, which is why they are commonly used for HVAC and building control. For example, it can handle multiple PID control loops for

controlling the heating in hundreds of different rooms. They are similar to PLC's in the way that they are programmable, and scalable but whereas the PLC is modular in its design and rugged, the DDC relies upon a more centralised system architecture. The control parameters are programmed into the system (temperatures for example) and the system continuously measures the temperatures for each room against their setpoints. The programming style for DDC systems is more graphical, relying on GUI's, block diagrams and schedules. As a result, it is a more user friendly, less technical system to install.

Key features of DDC's:

- Graphical User Interface (GUI)
- Easy to integrate with many sensors and actuators
- Use of PID control and setpoints

The DDC's limitations are that they are not particularly robust which is why they do not often feature in industrial applications and they are not suited to larger, more complex control requirements.

A Distributed control system (DCS) is the choice solution for large, complex industrial processes where reliability, scalability and redundancy are important. The term 'distributed' refers to the fact that the architecture is based upon multiple control systems all interacting with each other, as shown in figure 27 below. A DCS system is not a centralised piece of equipment, nor is it an isolated piece of software. It is a combination of hardware and software; it is an environment.

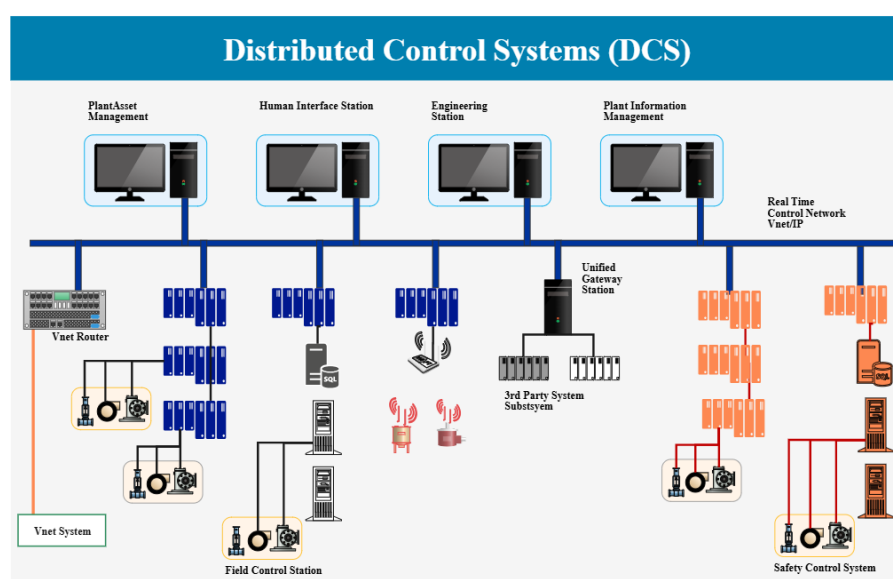


Figure 27 – Available at: <https://www.edrawmax.com/templates/1011829/>

Typically a DCS will use an Ethernet/IP network protocol in which to transfer data, transmit commands and control the functionality. Other protocols such as Modbus, Profibus, HART, and Foundation Fieldbus are also used, not instead of Ethernet/IP but in addition to. A DCS can communicate with all of these protocols, which is why it is so flexible and scalable. /

A DCS can manage thousands, even hundreds of thousands, individual control loops. It can perform logic calculations, store and trend data, manage alarms and co-ordinate a whole host of engineering functions – all in real time.

Key features of DCS:

- High reliability with redundancy /
- Integrate with multiple interfaces and control systems
- Hierarchical control

In industry, you will find a DCS at the heart of the operations. From oil refining, chemical plants, water treatment, power generation, mining, pharmaceutical and manufacturing. Many companies develop an entire DCS environment from hardware to software, for example Emerson has a system called Delta V, Yokogawa have CENTUM VP, and Siemens have SIMATIC PCS 7. /

There are not really any limitations with a DCS, however one of the negatives is the cost associated with implementing a whole new hardware environment coupled with software that needs to be tailored and customised to the client's requirements. /

In conclusion, computerised control systems play a vital role in instrumentation, automation and control. Whilst PLC's offer quick, robust, modular solutions, DDC systems have particular benefits in areas such as HVAC control. Lastly, a DCS is the solution for large, complex industrial processes. Ultimately the choice between these three systems depends on the automation and control needs, the environment and cost implications. /

Well done

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Appendix: