



In conjunction with



ELEC50367 CONTROL TECHNOLOGY

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Please revert to Appendix 1 in the electronic copy of this assignment for the Matlab work.

Section 1.

A first order system has a transfer function $G(s) = \frac{K}{\tau s + 1}$ where K is the gain of the system and τ is the system time constant.

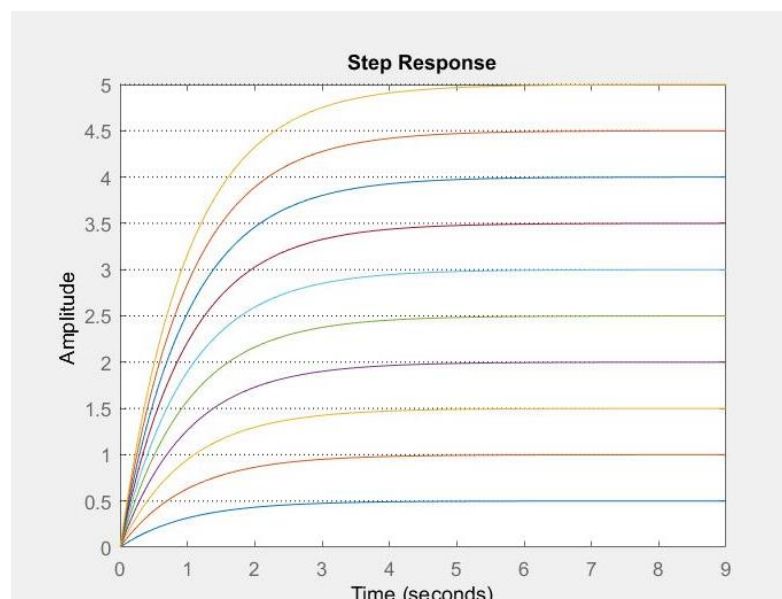
Section 2.

Load the Matlab software and simulate the unit step response for gains (values of K) between 0.5 and 5 in even steps and compare the response with each other using the hold command.

The following script was entered into Matlab with increasing aspects of gain:-

```
1- clc
2- %A first order system transfer function (values of K)
3- K1 = tf (0.5, [1, 1])
4- K2 = tf (1, [1, 1])
5- K3 = tf (1.5, [1, 1])
6- K4 = tf (2, [1, 1])
7- K5 = tf (2.5, [1, 1])
8- K6 = tf (3, [1, 1])
9- K7 = tf (3.5, [1, 1])
10- K8 = tf (4, [1, 1])
11- K9 = tf (4.5, [1, 1])
12- K10 = tf (5, [1, 1])
13- %use of hold command to compare results
14- hold on; grid on;
15- step(K1)
16- step(K2)
17- step(K3)
18- step(K4)
19- step(K5)
20- step(K6)
21- step(K7)
22- step(K8)
23- step(K9)
24- step(K10)
```

When this was run through the software the following results are shown below



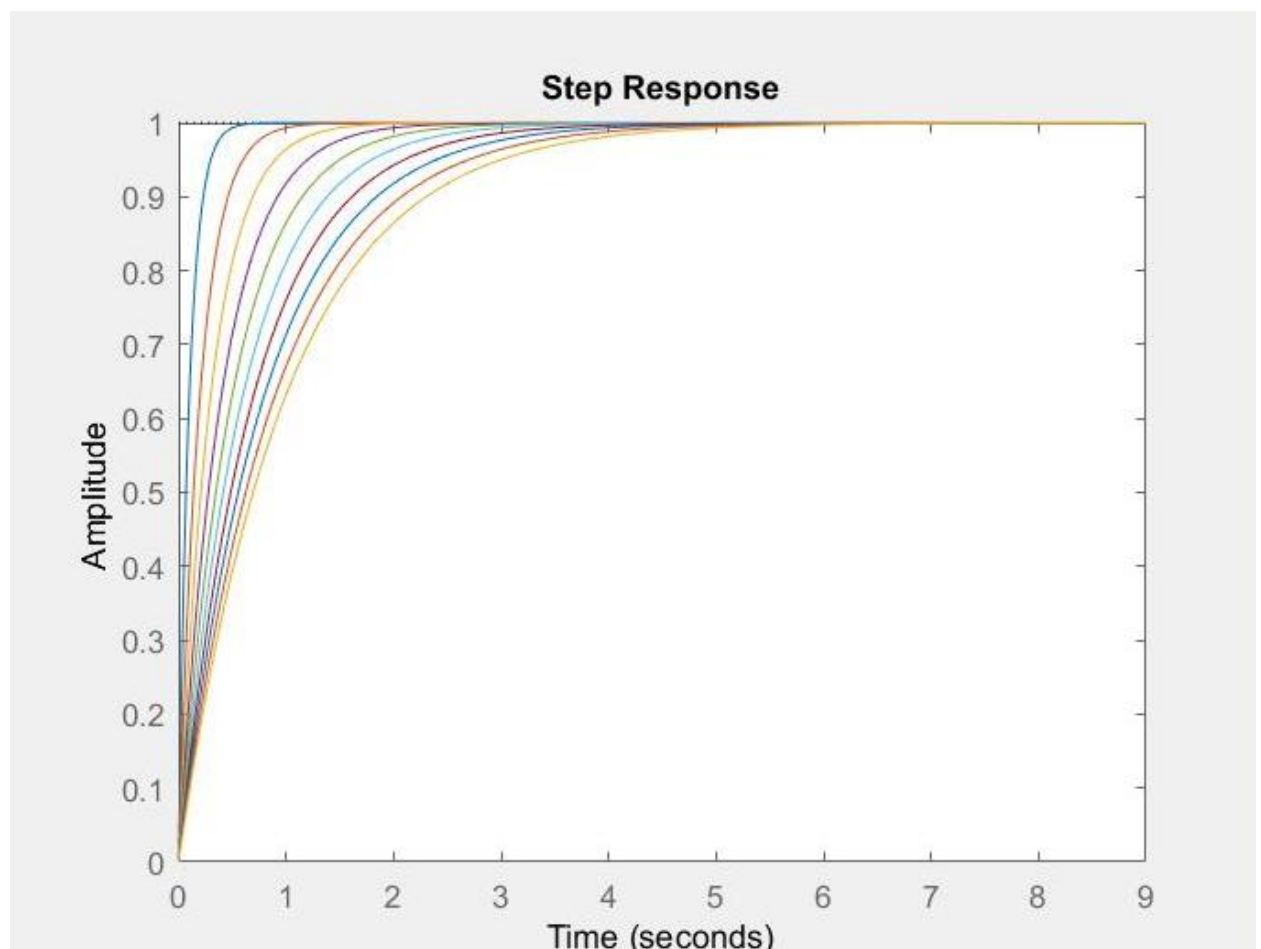
Section 3.

Now change the time constant (τ) in even steps from 0.1 to 1 and compare the responses with each other using the hold command.

The following script was entered into Matlab with increasing aspects of time constant:-

```
1- clc
2- %A first order system transfer function (values of K)
3- K1 = tf (0.5, [1, 1])
4- K2 = tf (1, [1, 1])
5- K3 = tf (1.5, [1, 1])
6- K4 = tf (2, [1, 1])
7- K5 = tf (2.5, [1, 1])
8- K6 = tf (3, [1, 1])
9- K7 = tf (3.5, [1, 1])
10- K8 = tf (4, [1, 1])
11- K9 = tf (4.5, [1, 1])
12- K10 = tf (5, [1, 1])
13- %use of hold command to compare results
14- hold on; grid on;
15- step(K1)
16- step(K2)
17- step(K3)
18- step(K4)
19- step(K5)
20- step(K6)
21- step(K7)
22- step(K8)
23- step(K9)
24- step(K10)
```

When this was run through the software the following results are shown below



Section 4.

Comment on the effect on final value and settle time of changing the time constant and gain of the system.

The first order system transfer function is written in the form of a differential equation shown below.

$$T \frac{dy(t)}{dt} + y(t) = Ku(t)$$

The response of the system when excited with a unit step input is illustrated as below.

$$u(t) = \begin{cases} 1, & t \geq 0 \\ 0, & t < 0 \end{cases}$$

The Laplace transform of the ordinary differential equation with a 0 initial condition

$y(0) = 0$, is

$$TsY(s) + Y(s) = \frac{K}{s}$$

The Laplace transform of a unit step function obtained from Laplace transform table is as follows.

$$U(s) = \frac{1}{s}$$

Solving for $Y(s)$.

$$Y(s) = \frac{K}{s(Ts + 1)}$$

$$Y(s) = \frac{K}{s} - \frac{K}{s+1/T}$$

So, the output response of the system is:

$$y(t) = K(1 - e^{-(\frac{1}{T})t})$$

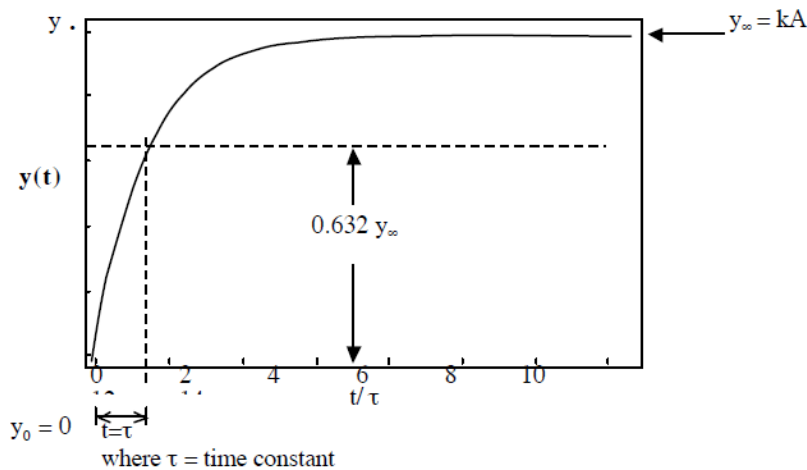
The effect of time constant (τ) on the time response is as follows when we let $K=1$, so the output response is:

$$y(t) = 1 - e^{-(\frac{1}{\tau})t}$$

If the three first order systems with the time constants of $\tau_1=1$, $\tau_2=2$, and $\tau_3=3$ seconds and t , is equal to the time constant (τ) the output is:

$$y(\tau) = 1 - e^{-\left(\frac{1}{\tau}\right)\tau} = 0.632$$

The output responses for these three systems are 0.632. When the outputs reach the value of 0.632, the time, shown as (t) is equal to the time constants. Therefore, when the time constant is greater, the output response is slower.



The gain (K) of the system can be understood by considering three first order systems with the same value of time constant (τ), equal to one but having three different values of gains, $K_1=0.5$, $K_2=1$, and $K_3=2$. If the speed of response of each in this system is the same as shown earlier, then the time constants of these systems must be the same. The output response is shown below:

$$y(t) = K(1 - e^{-t})$$

The gain (K) has the effect of amplification or attenuation and the output responses of these systems are shown in exercises 2. If the value of the gain increases, the greater is the steady-state value of the output response.

Section 5.

A second order system has a transfer function $G(s) = \frac{K \omega_n^2}{s^2 + 2\zeta \omega_n s + \omega_n^2}$

K is the system gain

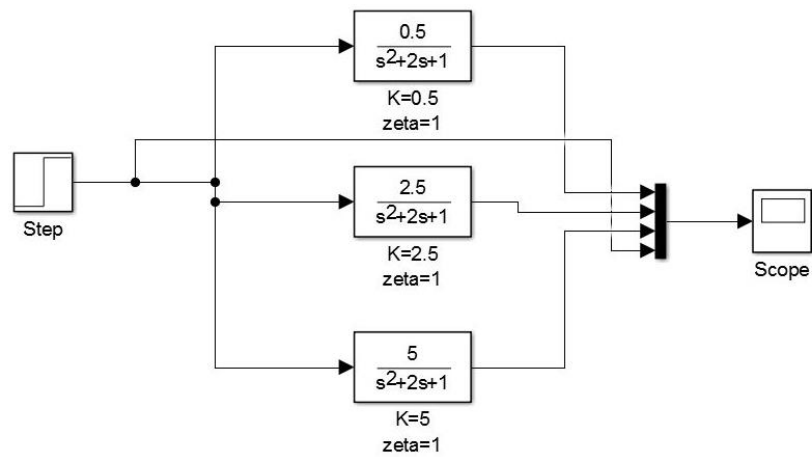
ζ is the damping factor

ω_n is the undamped natural frequency in radians/second

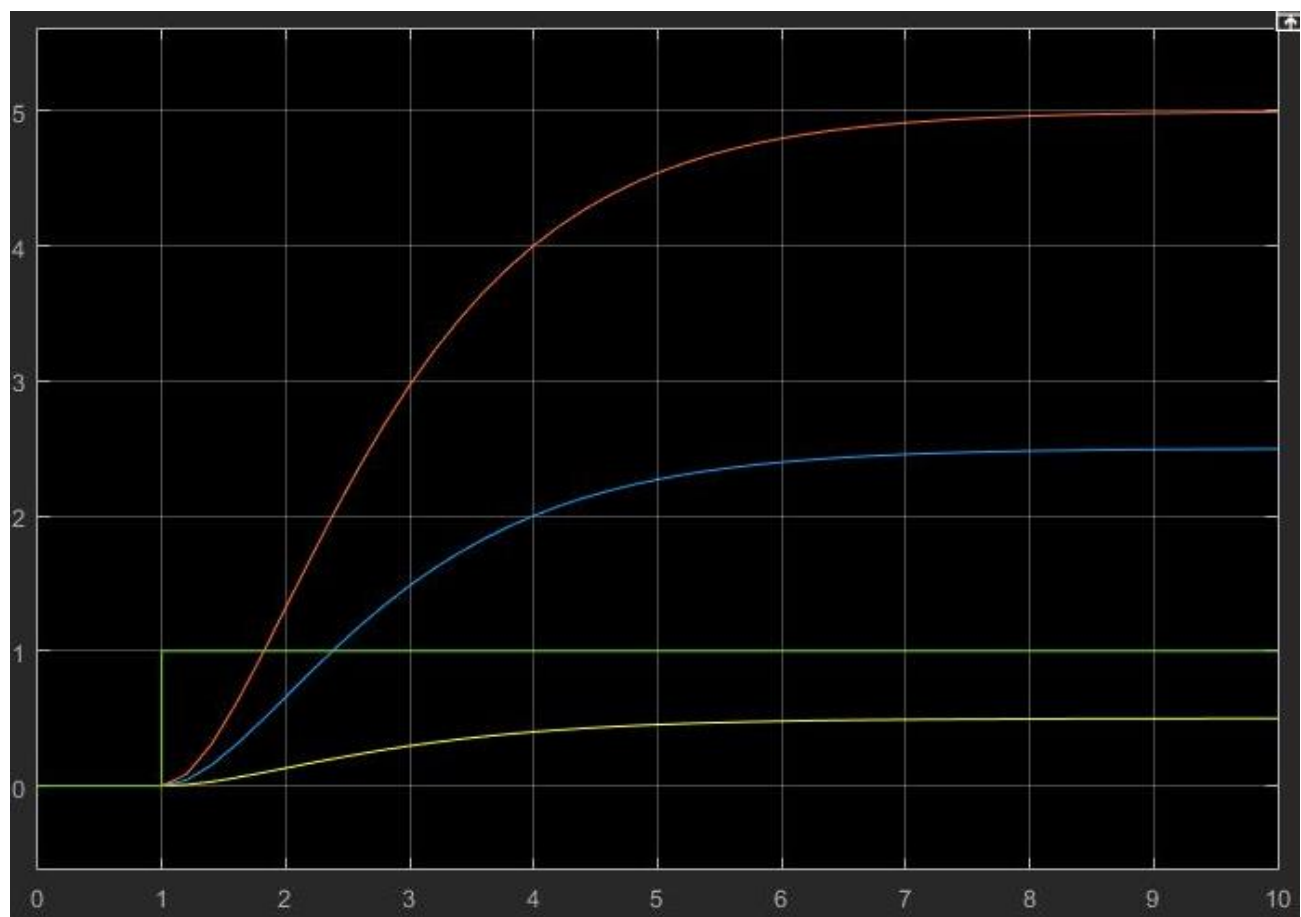
Section 6.

Simulate the transfer function of the second order system for a unit step response and altering the gain from 0.5 to 5 and compare the results with each other.

See below for the Matlab/Simulink layout.

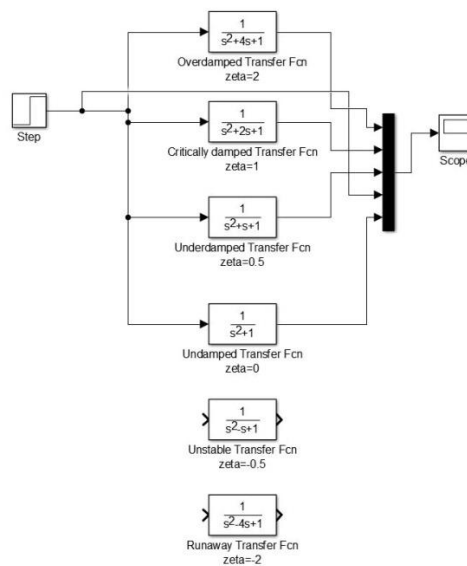


The results of experiment can be seen below to show the effect of gain on the output response.

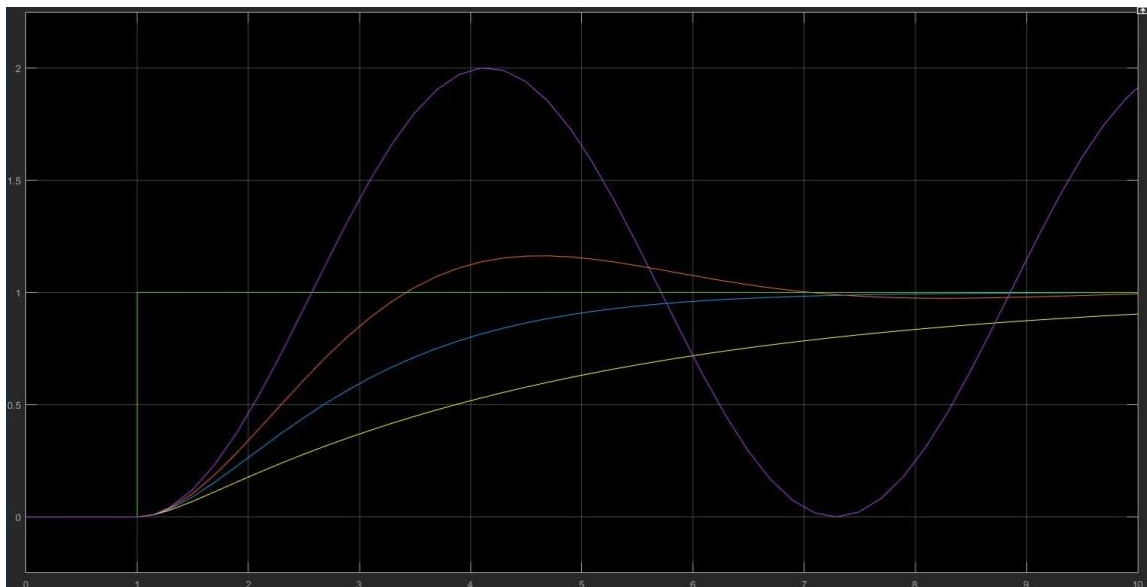


Section 7.

Keeping the gain constant change the value of the damping factor and compare the response with the natural frequency.



The results of experiment can be seen below to show the effect of damping factor on the output response.

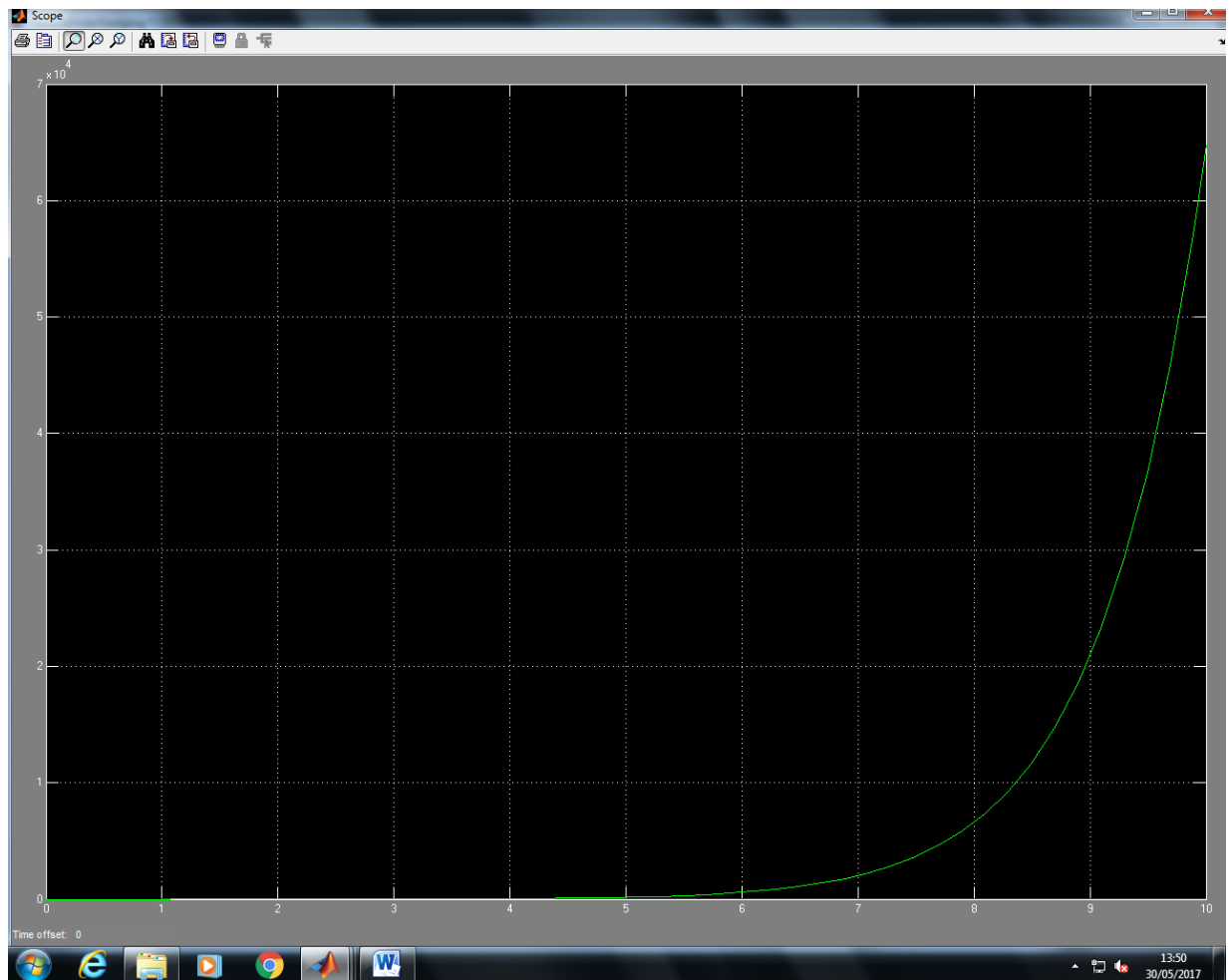


KEY

1. Yellow is where Zeta = 2 resulting in an overdamped transfer function.
2. Blue is where Zeta = 1 resulting in a critically damped transfer function.
3. Orange is where Zeta = 0.5 resulting in an underdamped transfer function.
4. Purple is where Zeta = 0 resulting in an undamped transfer function.

Section 8.

Set negative damping factor and observe the effect on the output.



You will see from the above that the transfer function is unstable.

Section 9.

Comment on the importance of the damping in a second order system with particular regard to overshoot and settle time.

$$G(s) = \frac{K\omega_n^2}{s^2 + 2\zeta\omega_n s + \omega_n^2}$$

Where, ω_n is the undamped natural frequency ζ is the damping ratio, and K is the gain of the system. These are 3 parameters that form the response of the system. The system can show 3 types of responses that depend on the value of the damping ratio. They are undamped response if $\zeta = 0$, overdamped response if $\zeta > 1$, and underdamped response if $0 < \zeta < 1$.

This type of response can also be indicated based on the values of poles of the system. The poles are the roots of characteristic equation. The characteristic equation of a second order system is:

$$s^2 + 2\zeta\omega_n s + \omega_n^2 = 0$$

The poles are given by:

$$s = \frac{-2\zeta\omega_n \pm \sqrt{(2\zeta\omega_n)^2 - 4\omega_n^2}}{2}$$

If $\zeta = 0$, the poles are:

$$s = \pm\omega_n j$$

For example two poles with only imaginary parts. Therefore, if any pair of the poles is only imaginary part, the system will be undamped.

When $\zeta > 1$, the term under the square root is positive. There will be two real number poles. Therefore, if all poles of the system are real numbers, then the output response is overdamped.

When $0 < \zeta < 1$, the term under the square root is negative. Square root of a negative number is a complex number leading to a pair of complex conjugate poles. Therefore if the poles of a system are complex conjugate, the output response is underdamped.

Now assume a second order system with unit step input and all initial conditions are zero. In general, the unit step response of a general second order system is shown in figure 1

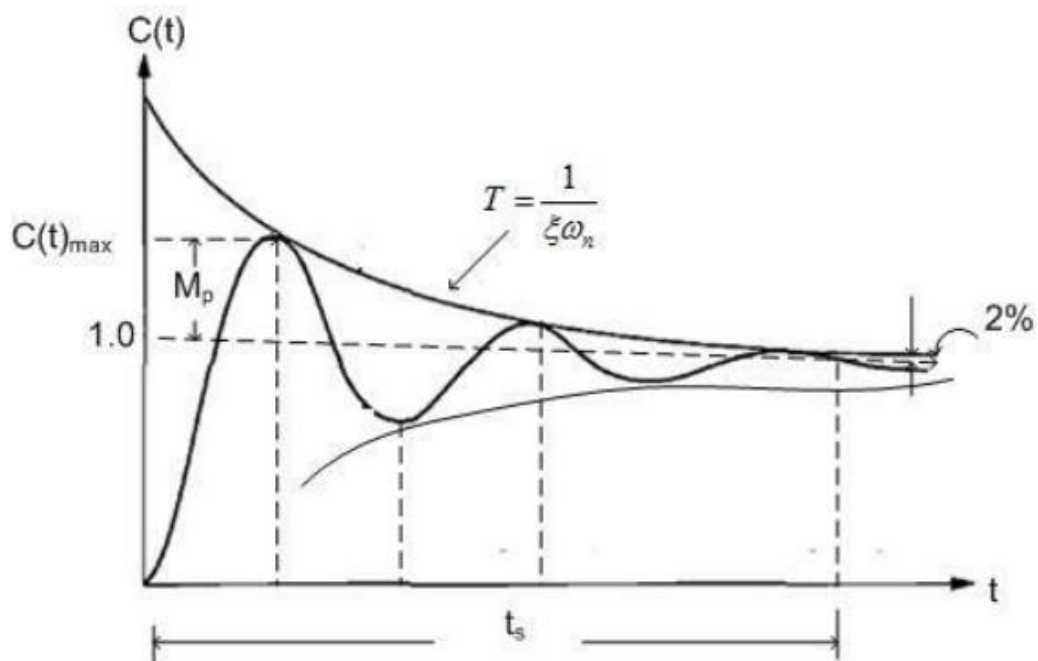


Figure 1. An underdamped response of a second order system

The following information from the output response will enable control engineers to obtain the values of the gain of the system, the damping ratio, and the natural frequency. This can be shown by:

The first peak occurs at time t_1 , shown by:

$$\omega_n t_1 = \frac{\pi}{\sqrt{1 - \zeta^2}} \text{rad}$$

The second peak occurs at time t_2 , shown by:

$$\omega_n t_2 = \frac{3\pi}{\sqrt{1 - \zeta^2}} \text{rad}$$

Settling time t_s is when the time the output response is identified by when it reaches its steady-state value and if it is assumed that a 2% error of the steady-state value, then

$$t_s = \frac{4}{\zeta \omega_n}$$

Maximum overshoot M_p , is

$$M_p = e^{-\frac{\zeta \pi}{\sqrt{1 - \zeta^2}}}$$

Section 10, Part (a)

A copy of my flow diagram for the PLC Ladder program can be found under the Appendix Section - (2). A rough copy of my ladder diagram is written out and is in the hard copy of Appendix under number (3) both of which will form part of my log book.

I am making the assumption that

- Tank 1 is the only tank that is full prior to pressing start.
- The sequence is Tank 1 will fill Tank 2, Tank 2 will then fill Tank 3 and finally Tank 3 will fill Tank 1. This equates to 1 cycle. At the end of each pump cycle a main counter will incrementally count 3 times.
- There are 2 timers in the flashing light sequence and a counter to finalise the flashing sequence.
- The Emergency Stop will cease all activity and continue once it is released.
- When the green start button is pressed the lamp counter and main counter will be reset.

My program has been slightly altered from my handwritten attempt and is now complete and functional; this can be found in Appendix (4)

Section 10, Part (b)

In terms of alternative methods, the chosen method would be to use a standard computer system with a small addition to control the system entirely.

Requirements

A Windows based personal computer

A small I/O controller – National Instruments USB-6501 [1]

Window programming interface NIDAQ supplied FOC with above

External circuitry

External circuitry

As per enclosed diagram (See Appendix 5)

The controller is compatible with 5v TTL signals [2]

The external circuitry can basically be split into two areas, input and output.

The inputs are the green and red switch and each of the tanks top and bottom level sensors, 8 in total

The outputs are the indicator lamp and pump for each tank, 6 in total.

We therefore need two 8 bit digital I/O ports for complete control. These are provided on the USB6501

Inputs

As all inputs are switches of one type or another, these can be wired such that they switch +5v from a power supply to one of the I/O pins on the controller

As the controller is a relatively fast and sensitive device we may need to deal with the problem of switch bounce using appropriate capacitors at each switch [3]

If the test rig is in an area of ‘signal noise’ [4] then we may need to use various forms of signal conditioning to ‘clean up’ the inputs. (See Appendix 6)

Outputs

The controller outputs 5v TTL and the lamps and pumps are ‘relatively’ higher power devices by comparison

We therefore need an interface circuit to join the controller and the devices.

It makes good sense to also use relays in the output control circuit as this provides a degree of isolation from the external system and provides the chance of using a larger range of

devices in the future should a current model become unavailable. It also means that current and voltage considerations are negated.

The ideal device is a small integrated circuit ULN2003A [5] which is ideal as it conveniently allows control of relay coils from 5v TTL signals and includes the freewheeling diodes [6]. A single unit can control 8 outputs.

Positives

Relatively low cost

On screen control using universal interface

Greater scope for monitoring/ logging

Future proof

Easy network remote control / monitoring

Supported by many different programming languages.

Negatives

Specialise program needed.

Requires active computer

References

[1] Anon, (2017). [Online] Available at: <http://www.ni.com/pdf/manuals/375268b.pdf> [Accessed 16 May 2017]

[2] Anon, (2017). [Online] Available at: <https://www.allaboutcircuits.com/textbook/digital/chpt-3/logic-signal-voltage-levels/> [Accessed 16 May 2017]

[3] Anon, (2017). [Online] Available at: <https://www.allaboutcircuits.com/textbook/digital/chpt-4/contact-bounce/> [Accessed 16 May 2017]

[4] Anon, (2017). [Online] Available at: <https://www.manufacturing.net/article/2013/11/7-ways-signal-noise-can-impact-your-electrical-equipment> [Accessed 16 May 2017]

[5] Anon, (2017). [Online] Available at: <https://www.diodes.com/assets/Datasheets/ULN200xA.pdf> [Accessed 16 May 2017]

[6] Anon, (2017). [Online] Available at: <https://www.elprocus.com/freewheeling-or-flyback-diode-circuit-working-functions/> [Accessed 16 May 2017]

Appendices

Please revert to the attachments in this assignment.

Jamie Roberts. June 2017