

Weaver

Dynamics control and instrumentation assignment

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$$\begin{array}{rcl} R & = & 27 \\ S & = & 25 \\ \hline & & 52\% \end{array}$$

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Introduction

In this assignment I must "propose a measurement system to determine the strain experienced by the strut. Explain Stress and Strain in the context of a force applied directly to the strut. Explain any special arrangements to maximize the accuracy of and hence confidence in the measurements." For task 1(b), I will demonstrate the performance of my system when a load of 1.5MN and 2.5MN are applied, whilst assuming the strut is made out of steel to the dimensions that are shown in the figure below and with a Modulus of Elasticity (E) of 210Gpa.

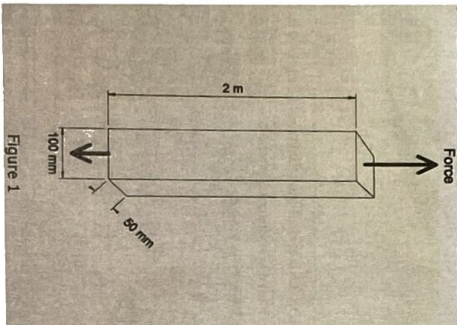


Figure 1

For task 2(A), I have to provide a definition for the terms Displacement, Velocity and Acceleration.

Which I then must support my answers with mathematical expressions along with what relation they have to one another. For task 2(B), I will use the equation given to me to determine what the questions are asking for. Finally, task 3(a,b) will be focusing on open and closed loops. I must explain the key differences between the two along with a mathematical analysis. In task 3(c), I will explain the following terms along with an example:

- Overshoot
- Non-touching loops
- Plant

- Settling Time
- Steady state error
- PID

Task 1

(a)

What is Stress?

There are 2 types of stress, one is normal stress. Normal stress is when a force is acting perpendicular to the objects surface. It then exerts normal stress. The other is shear stress, and this is when a force is acting parallel to the objects surface. This lets off shear stress. So, in this case as the stress looks to be perpendicular, the stress type is normal. Stress is measured in N/m^2 (SI). SI is referred to as Pascals (Pa).

What is Strain?

Strain is the amount of deformation there is once stress has been applied. For example, if 2 forces were pulling on a piece of rope, depending on the force they are pulling at, would determine the amount of strain that is being produced. So, if we were to calculate the strain of the diagram above, we would use this formula:

$$\text{Strain} = \frac{\text{Elongation}}{\text{Original Length}}$$

Elongation is the amount of which the object has been stretched from its original size.

(b)

Convert the current measurement (mm) to metres.

$$\frac{100}{1000} = 0.1m$$

$$\frac{50}{1000} = 0.05m$$

Multiply the two measurements to get the CSA (Cross Sectional Area).

$$CSA = 0.05 \times 0.1$$

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$$0.0005 \text{ m}^2 = 5000 \text{ mm}^2$$

Convert the current force (MN) to newtons.

$$1.5 \times 1,000,000 = 1.5 \times 10^6 \text{ N}$$

To work out the stress, we must divide our new force with our CSA.

$$\text{Stress}(1.5 \text{ MN}) = \frac{1.5 \times 10^6}{0.005} = 300 \text{ MPa}$$

$$\text{Stress}(1.5 \text{ MN}) = 3 \times 10^8 \text{ Pa}$$

Apply the same to the 2.5MN value.

$$\text{Stress}(2.5 \text{ MN}) = \frac{2.5 \times 10^6}{0.005}$$

$$\text{Stress}(2.5 \text{ MN}) = 5 \times 10^8 \text{ Pa}$$

Now we must work out the strain. So, we are going to need length change value of the strut. To get this we will use this formula.

$$\text{Length Change} = \frac{\text{Stress}}{\text{Elasticity}}$$

We must first convert the GPa to Pa.

$$210 \times 100,000,000 = 2.1 \times 10^{11} \text{ Pa}$$

$$\text{Length Change}(1.5 \text{ MN}) = \frac{3 \times 10^8}{2.1 \times 10^{11}}$$

$$\text{Length Change}(1.5 \text{ MN}) = 1.4 \times 10^{-3} \text{ m}$$

Do the same with the other stress value.

$$\text{Length Change}(2.5 \text{ MN}) = \frac{5 \times 10^8}{2.1 \times 10^{11}}$$

$$\text{Length Change}(2.5 \text{ MN}) = 2.4 \times 10^{-3} \text{ m}$$

Finally, we can use the strain formula from question (a) to work out the strain with our calculated values.

$$\text{Strain}(1.5 \text{ MN}) = \frac{1.4 \times 10^{-3}}{2}$$

$$\text{Strain}(2.5 \text{ MN}) = \frac{2.4 \times 10^{-3}}{2}$$

$$E = \frac{\text{Stress}}{\text{Strain}}$$

$$\text{Strain} = \frac{\Delta L}{L}$$

$$0.0014 = \frac{0.0014 \times 2000}{2000}$$

$$= 2.86 \text{ mm}$$

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Task 2

A. Provide a definition of the following terms:

- Displacement
- Velocity
- Acceleration.

Support your answer by figures and mathematical expressions. What is the relationship among them?

(6 Marks)

What is Displacement?

"Displacement is the change in an object's position relative to a reference frame. For example, when a player strikes a billiards ball, the ball moves from one position to another. It is said to be displaced. Displacement is a vector quantity that has both magnitude and direction" (ScienceFacts.net, n.d.).

Displacement is distance, so it is measured in meters, miles, yards, feet, etc. When calculating displacement, it is calculated as:

$$S = ut + \frac{1}{2}at^2$$

- S = displacement
- u = initial velocity
- a = acceleration
- t = time

Displacements (S) is equal to initial velocity (u) multiplied by time (t) plus half of acceleration (a) multiplied by time (t) squared.

What is Velocity?

Velocity is the constant speed of which an object is moving. For example, if a car was to maintain the speed of 60mph, it would be moving at a velocity of 60mph. When measuring velocity, we would use the unit's m/s (metres per second). When working out velocity, we need the measurements of Displacement (S) and Time (t):

$$v = \frac{S}{t}$$

- S = displacement
- v = velocity
- t = time

Velocity (v) is equal to Displacement (S) divided by Time (t).

There is also initial velocity (u) which is "the velocity at time interval t = 0. It is the velocity at which the motion starts" (BYJU'S, n.d.). The formula for initial velocity (u) is:

2.5

$$u = v - at$$

- v = velocity
- u = initial velocity
- a = acceleration
- t = time

Initial velocity (u) is equal to velocity minus acceleration (a) multiplied by time (t).

What is Acceleration?

Acceleration is the rate of which velocity changes when the speed is increased. For example, when you're driving and you speed up from 10 – 20 mph, that is known as acceleration as the speed (velocity) has been increased. As the speed is increasing and not at a constant speed, the unit of measurement we would use is (metres per seconds squared). The formula for acceleration is:

$$a = \frac{v - u}{t}$$

- v = velocity
- u = initial velocity
- a = acceleration
- t = time

Acceleration (a) is equal to velocity (v) minus initial velocity (u) divided by time

- B. The position coordinate of a particle which is confined to move along a straight line is given by $s = 3t^3 - 24t + 6$, where s measured in meters from a convenient origin and t is the time in seconds.

Determine:

- The time required for the particle to reach a velocity of 60 m/s from its initial condition at $t=0$.
- The acceleration of the particle when $v = 35$ m/s.
- The net displacement of the particle during the interval from $t=2$ s to $t=4$ s.
- Draw the path of the particle between $0 < t < 5$ s.

(8 Marks)

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- We have to derive the equation so that we can get the particles velocity.

We know have to make this the equivalent of 60m/s.

$$9t^2 - 24 = 60$$

Then we rearrange the equation so that 24 is adding to 60, leaving $9t^2$ on its own.

$$9t^2 = 60 + 24$$

$$9t^2 = 84$$

Know we move the 9 over so that we have t^2 on its own and 84 divided by 9.

$$t^2 = \frac{84}{9}$$

$$t^2 = 9.33$$

Finally, we can get the total of time by throwing the squared over to 9.33 making it a square root. We also give the total the unit of seconds (s) as that is what time is measured in.

$$t = \sqrt{9.33}$$

$$t = 3.1s$$

- To find the acceleration we first have to find the time. So, we repeat the method we did for question (a), but replace 60m/s with 35m/s.

$$9t^2 - 24 = 35$$

$$9t^2 = 35 + 24$$

$$9t^2 = 59$$

$$t^2 = \frac{59}{9}$$

$$t^2 = 6.56$$

$$t = \sqrt{6.56}$$

$$t = 2.6s$$

Once we have the time, we can input that into the Suvat ($a = \frac{v-u}{t}$) equation to try and work out the acceleration. We already have a final velocity (v) of 35m/s and we have to assume that the initial velocity (u) is 0m/s as we don't have the acceleration to work it out. We also have a time (t) of 2.6s which gives us what we need to work out acceleration.

$$a = \frac{35 - 0}{2.6}$$

$$a = 18t = 18(2.6) = 46.26 \text{ m/s}^2$$

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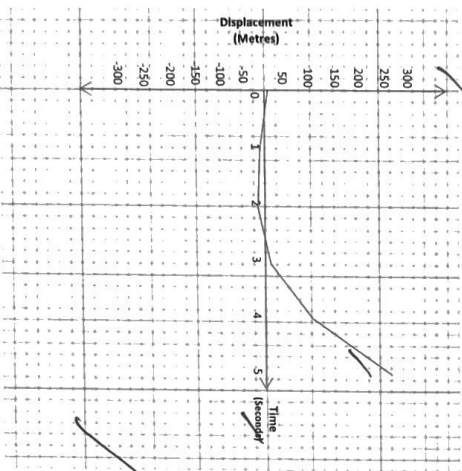
- (c) We know want to find the displacement (S) of the particle during the interval from $t=2$ s to $t=4$ s. To do this we have to replace t with 4 and then subtract that equation with the same equation that has t replaced with 2.

$$(3(4)^3 - 24(4) + 6) - (3(2)^3 - 24(2) + 6) = 120m$$

$S = 144m$

- (d) To draw the path of the particles between $0s < t < 5s$, we must replace t in the displacement equation with numbers $0 - 5$ and then use our answers to plot the values on a time and displacement graph.

$$\begin{aligned} 3(0)^3 - 24(0) + 6 &= 6m \\ 3(1)^3 - 24(1) + 6 &= -15m \\ 3(2)^3 - 24(2) + 6 &= -18m \\ 3(3)^3 - 24(3) + 6 &= 15m \\ 3(4)^3 - 24(4) + 6 &= 102m \\ 3(5)^3 - 24(5) + 6 &= 261m \end{aligned}$$



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3.5

Task 3

Control systems are often characterised as being Open loop or Closed loop.

- Explain the key differences between these two terms.
- Compare the key operational differences between open and closed loop systems. This should include a mathematical analysis of the impact to the system output due to component variation and disturbances.
- Provide an explanation of the following terms (illustrate with suitable examples):-
 - Overshoot
 - Non-touching loops
 - Plant
 - Settling Time
 - Steady state error
 - PID

(18 Marks)

- (a) "The main difference between an open-loop system and a closed-loop system is that the closed-loop system has the ability to self-correct while the open-loop system does not. Consequently, closed-loop systems are often called feedback control systems while open-loop systems are also known as non-feedback controls." (Yalcin, 2017). An open loop system is usually used for jobs where an output doesn't change often and the process is unpredictable. An example of a closed loop being used is in a thermostat as closed loop allows the output to have an impact on the input keeping the desired value.

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(b) The differences between Open loops and Closed loops operating systems:

- "One of the significant differences between the open loop and closed loop control system is that in an open loop system the desired output does not depend on the control action. While in the closed loop system the desired output depends on the control action of the system."
- "The open loop system means the output of the system is free from their input. In the closed-loop system, the desired output depends on their input."
- "The open loop system is called the non-feedback system while the closed loop is the feedback system."
- "The control and controlled process are the two components of the open loop system. The closed loop requires some components like an amplifier, controller, controlled process, feedback system etc." (CIRCUIT GLOBE, n.d.)

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(c) Overshoot – the maximum amount the response value overshoots the steady-state value. This creates a large peak in the graph.

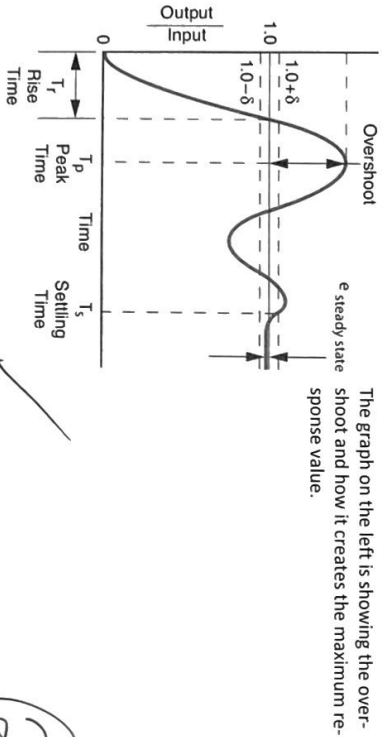
Non-touching loops – When certain loops aren't sharing any of the same nodes in a signal flow graph. This means they wouldn't be making any contact with other loops.

Plant – is also known as a transfer function. It could be anything that has an input and gives an output.

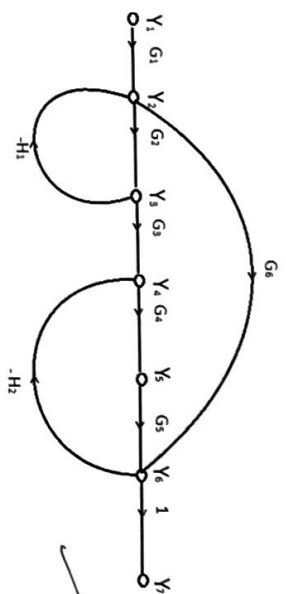
Settling Time – is the time that is required for the output to reach its steady state and remain in the error band $\pm\delta$.

Steady state error – "the difference between the input and output of a system in the limit as time goes to infinity i.e. when the response has reached the steady state)." (LJO, 1996)

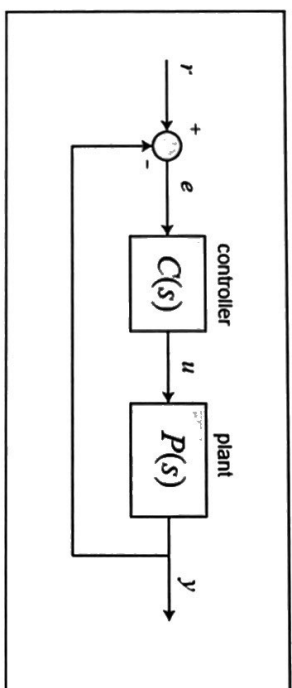
PID – "Proportional-Integral-Derivative controller is a control loop feedback mechanism widely used in industrial control systems and other applications requiring continuously modulated control." (APMonitor, n.d.)



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The picture above shows a Signal Flow graph where there are 3 loops. Only 2 of the loops are Non-touching loops as they don't share the same nodes. Loops – (G2H1) and –(G4G5H2).



The closed loop above shows a PID controller and a plant. PID is receiving values from the plants output and changing any values that need changing.

4

4

References

What is Displacement?

<https://www.sciencefacts.net/displacement.html>

(ScienceFacts.net, n.d.)

Initial Velocity

<https://byjus.com/initial-velocity-formula/#:~:text=Initial%20Velocity%20is%20the%20velocity,at%20which%20the%20motion%20starts,>

(BYJU'S, n.d.)

The differences between Open loops and Closed loops operating systems

<https://circuitglobe.com/difference-between-open-loop-and-closed-loop-system.html>
(CIRCUIT GLOBE, n.d.)

Difference between Open loop and Closed loop terms

<https://www.admet.com/blog/open-loop-vs-closed-loop-systems-materials-testing-industry/#:~:text=The%20main%20difference%20between%20an,known%20as%20non%20feedback%20controls.>

(Yalcin, 2017)

Steady state error

<https://www3.diism.unisi.it/~control/ctm/extras/ess/ess.html#:~:text=Steady%20state%20error%20is%20defined,%20C%20I%20or%20r%20I.>

(UO, 1996)

PID

<https://apmonitor.com/pdc/index.php/Main/ProportionalIntegralDerivative#:~:text=A%20PID%20Proportional%20Integral%20,applications%20requiring%20continuously%20modulated%20control.>
(APMonitor, n.d.)