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Dynamics Control and Instrumentation

The Use and Application of Instrumentation

Results = 36
Structure = 42

78%

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Introduction

The assignment given consists of three tasks all with separate objectives. The tasks will be completed one at a time with separate research, if required, solutions and conclusions. The assignment will then have a conclusion looking at the effectiveness of the overall layout of the assignment.

Objectives

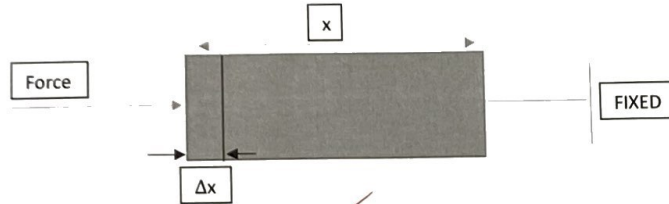
In this assignment, there are three separate tasks to complete:

- Task 1 requires the use of instrumentation to determine the strain in a strut created by two forces. Stress and strain must also be explained in the context of applied forces. The instrumentation will also have to be applied theoretically while calculating the strain of the strut with the given values.
- Task 2 is about kinematic particles moving in a straight line. The objective of this task is to calculate the acceleration, time and net displacement at various different stages of the particle on its path. The task also requires a graph of the particle at times in-between the values of $t = 0$ to $t = 5$.
- Task 3 is about open and closed loop systems and the key differences in the output for these two systems. In this task mason's gain rule is included. It is required to explain the terms and to provide a diagram to demonstrate the terms.

Task 1

(Task 1a) Stress and Strain

Below is a diagram showing stress and strain in terms of an applied force:



x = original dimension

Δx = change in dimension

$$\text{Strain } (\epsilon) = \frac{\Delta x}{x}$$

As seen from the diagram the force applied onto the object is condensing the object. This force creates a change in dimension (Δx). This change in dimension divided by the original dimension is called the strain measured in epsilon (ϵ).

To measure stress, the area of the surface that the force is being applied to is taken into account. The formula for stress is as follows:

$$\text{Stress } (\sigma) = \frac{\text{Force}}{\text{Area}}$$

(Task 1a) Research

In the objective given in this task, a suitable method of measuring and calculating strain caused by two forces applied to a strut is required. The method found is a strain gauge. The strain gauge is a sensor which will be fitted to the strut and then the gauges resistances will vary with applied forces. It will convert force, pressure, tension and weight into a change of resistance. This can then be measured.¹ There are various types of strain gauges available to choose from:

- General Purpose Precision Strain Gauges
- Transducer Quality Strain Gauges
- Karma Strain Gauges
- Bonded Metallic Strain Gauges

The strain gauge selected for this assignment is going to be the bonded foil strain gauge. The bonded foil strain gauge has a higher accuracy when measuring the strain vertically and is

¹ Introduction to Strain Gauges by Omega [online] Available from: <https://www.omega.com/en-us/resources/strain-gauges#:~:text=A%20strain%20gauge%20is%20a, and%20strain%20are%20the%20result.> [Accessed 02/05/2023]

most commonly used with struts. The strain gauge is most typically placed in the formation seen in Appendix 1.²

(Task 1b) Calculations

In task 1, the specifications of the strut and modulus of elasticity is given. The strut is made of steel to the dimensions given in figure 1 of the task 1. The modulus of elasticity (E) is equal to 210Gpa. There are two separate loads applied to the strut, of which are 1.5MN and 2.5MN. The task will be to calculate the stress, strain and change in dimensions to the strut and the effectiveness of the strain gauge.

Load 1.5MN Calculations

To calculate the stress in the system the following formula is applied:

$$\text{Stress} = \frac{\text{Force}}{\text{Area}}$$

Area – The surface area of which the force is being applied too.

$$\text{Area} = 100\text{mm} \times 50\text{mm}$$

$$\text{Area} = 5000\text{mm}^2$$

Now that the area has been calculated, the stress formula can be applied:

$$\text{Stress} = \frac{1.5\text{MN}}{5000\text{mm}^2}$$

$$\text{Stress} = 300\text{Mpa}$$

Once stress is calculated, the modulus of elasticity formula can be applied to calculate strain:

$$\text{Modulus of Elasticity } (E) = \frac{\text{Stress}}{\text{Strain}}$$

$$210\text{Gpa} = \frac{300\text{Mpa}}{\text{Strain}}$$

$$\text{Strain} = \frac{300\text{Mpa}}{210\text{Gpa}}$$

$$\text{Strain} = 0.00143$$

² Temperature Correction and Strut Loads in Central Artery Excavations by Youssef M. A. Hashash Published June 2003 [online] Available from: https://www.researchgate.net/figure/Typical-strut-section-and-strain-gauge-arrangement_fig5_245294116 [Accessed 02/05/2023]

With strain calculated, the change in dimension can be calculated using the following formula:

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

Δx – Change in dimension

x – Original dimension

$$0.00143 = \frac{\Delta x}{2m}$$

$$\Delta x = 0.00143 \times 2m$$

$$\Delta x = 2.86 \times 10^{-3}m$$

$$\Delta x = 2.86mm$$

Load 2.5MN Calculations

The process for calculating the stress, strain and change in dimension are the same as previously shown.

The area of the strut where the load is applied is the same as previously calculated.

$$\text{Area} = 100mm \times 50mm$$

$$\text{Area} = 5000mm^2$$

The stress formula is now applied using the new 2.5MN load:

$$\text{Stress} = \frac{2.5MN}{5000mm^2}$$

$$\text{Stress} = 500Mpa$$

With the stress calculated, the values can be applied to the following to calculate strain:

$$\text{Modulus of Elasticity (E)} = \frac{\text{Stress}}{\text{Strain}}$$

$$210Gpa = \frac{500Mpa}{\text{Strain}}$$

$$\text{Strain} = \frac{500Mpa}{210Gpa}$$

$$\text{Strain} = 0.00238$$

With strain calculated, the change in dimension can now be calculated using the following formula:

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

Δx – Change in dimension

x – Original dimension

$$0.00238 = \frac{\Delta x}{2m}$$

$$\Delta x = 0.00143 \times 2m$$

$$\Delta x = 4.76 \times 10^{-3}m$$

$$\Delta x = 4.76mm$$

As seen above, the calculations have been completed and showing the necessary values to see if the strain gauge selected is suitable for the strut.

The strain gauge selected is suitable to the task as they are typically applied to struts in industrial and construction environments.

APPLY TO BRIDGE !
(8)

Task 2

(Task 2a) Displacement, Velocity, Acceleration

Displacement, velocity and acceleration are all vector quantities. Vector quantities all have, both magnitude and direction. This differs to scalar quantities which only have a magnitude or size.

Displacement is the net distance in which an object is moved or forced from its fixed starting position to its final position in a specific direction.

Velocity is the rate of change of displacement in an object and can be determined by

$$\text{Velocity} = \frac{\text{Change in Displacement}}{\text{Time}} \text{ or } v = \frac{\Delta s}{\Delta t}$$

Acceleration is the rate of change of velocity in an object and can be determined by

$$\text{Acceleration} = \frac{\text{Change in Velocity}}{\text{Time}} \text{ or } a = \frac{\Delta v}{\Delta t}$$

(Task 2b) Calculations

Task 2b requires calculations to work out the displacement, velocity and acceleration of a particle. The particle is confined to move in a straight line and is represented by $s = 3t^3 - 24t + 6$. For the particle the following must be calculated:

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

The solutions area as follows:

- To calculate the time required for the particle to reach 60m/s, the line needs to equal velocity. The relationship between displacement and velocity is as follows:
 $v = \frac{ds}{dt}$ So, $s = 3t^3 - 24t + 6$ then, $v = 9t^2 - 24$. To calculate the time, substitute 60m/s into velocity giving the equation, $60 = 9t^2 - 24$. To solve this make t the subject of the equation; $t = \sqrt{\frac{(60+24)}{9}}$, $t = 3.055 \dots$, $t = 3.06\text{s}$.

- To calculate the acceleration at the point where velocity is equal to 35m/s you need to substitute 35m/s into the equation; $v = 9t^2 - 24$. So $35 = 9t^2 - 24$ making $t = 2.569 \dots$, $t = 2.57\text{s}$. The relationship of acceleration and velocity is as follows; $a = \frac{dv}{dt} = v$. So, $v = 9t^2 - 24$ then, $a = 18t$. Substitute the time at which 35m/s is met into the new equation, as shown; $a = 18(2.57)$ then, $a = 46.26\text{m/s}^2$.
- To calculate the net displacement between $t=2\text{s}$ and $t=4\text{s}$, substitute the values into the equation; $s = 3t^3 - 24t + 6$. So, $s = 3(2)^3 - 24(2) + 6$ and $s = 3(4)^3 - 24(4) + 6$. The solutions are as follows respectively; $s = -18\text{m}$ and $s = 102\text{m}$. To calculate the net displacement, subtract the values, $s = 102\text{m} - (-18\text{m})$ then, $s = 120\text{m}$.

- To calculate the distances between the times of $t=0\text{s}$ and $t=5\text{s}$, the values of 0 to 5 seconds will be substituted into the formula $s = 3t^3 - 24t + 6$.

$$s = 3(0)^3 - 24(0) + 6$$

$$s = 6\text{m}$$

$$s = 3(1)^3 - 24(1) + 6$$

$$s = -15\text{m}$$

$$s = 3(2)^3 - 24(2) + 6$$

$$s = -18\text{m}$$

$$s = 3(3)^3 - 24(3) + 6$$

$$s = 15\text{m}$$

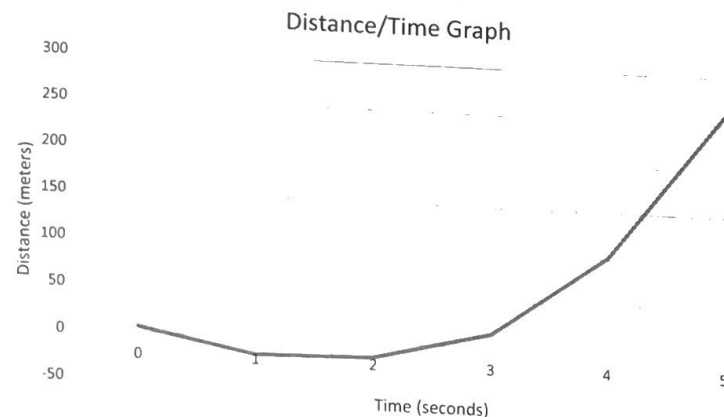
$$s = 3(4)^3 - 24(4) + 6$$

$$s = 102\text{m}$$

$$s = 3(5)^3 - 24(5) + 6$$

$$s = 261\text{m}$$

The values will now be plotted in a distance/time graph. This is seen below:

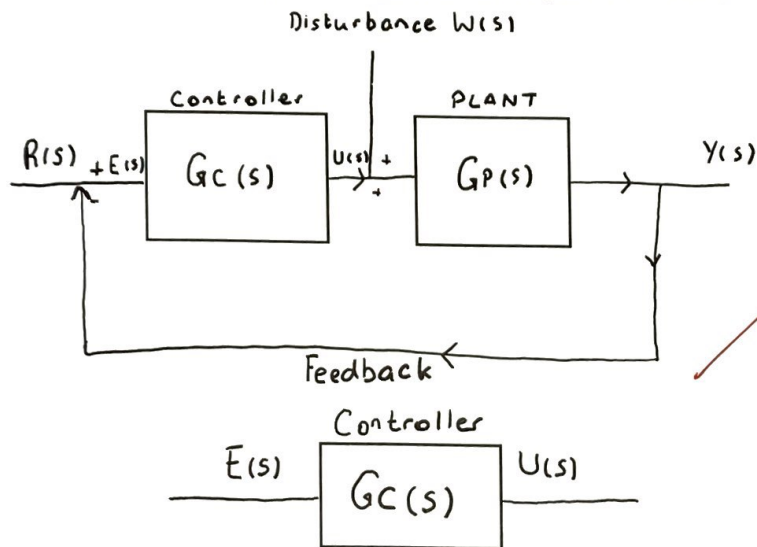


Task 3

Open and Closed Loop Systems

One of the key differences between open and closed loop systems is that closed loop systems have feedback built in the circuit allowing for the ability of self-correction while the open loop system does not have this feature. Open loop systems are useful in systems and situations where the output does not typically change and where the output is more predictable and constant. A closed loop system is able to take advantage in circuits with automatic corrections to the sequence and the output. This will allow the final output to keep to a set value. A negative of an open loop system is that the output can drift, as there is no auto correcting sequences.

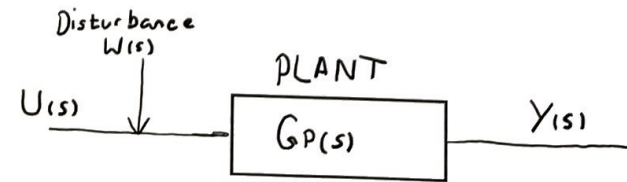
An example of a closed loop system having an effect on a output is as seen below:



This shows the input effected by the feedback feeding into the controller gain and the following output.

$$1) U(s) = E(s) \cdot G_c(s)$$

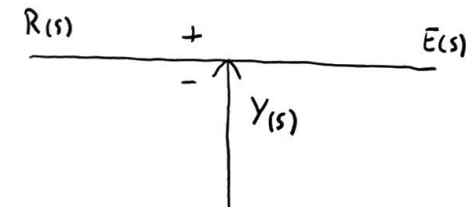
The following demonstrates the output of the controller being effected by the incoming disturbance and feeding into the PLANTs gain. $Y(s)$ is the output affected by the PLANTs gain and disturbance:



$$2) Y(s) = (U(s) + W(s)) \cdot G_p(s)$$

$$3) Y(s) = ((E(s) \cdot G_c(s)) + W(s)) \cdot G_p(s)$$

Below is the feedback effecting the input giving the value $E(s)$:



$$4) E(s) = R(s) - Y(s)$$

The above formula labelled 4 is substituted into the formula labelled 3:

$$5) Y(s) = (((R(s) - Y(s)) \cdot G_c(s)) + W(s)) \cdot G_p(s)$$

The formula is then simplified and to the final output seen in formula labelled 8.

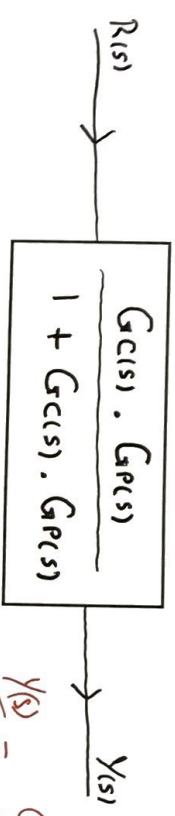
$$6) G_p(s) \cdot R(s) \cdot G_c(s) + W(s) = Y(s) \cdot (1 + G_c(s) \cdot G_p(s))$$

$$7) Y(s) = R(s) \cdot \left(\frac{G_c(s) \cdot G_p(s)}{1 + G_c(s) \cdot G_p(s)} \right) + W(s) \cdot \left(\frac{G_p(s)}{1 + G_c(s) \cdot G_p(s)} \right)$$

⁴ Know when to use open- or closed-loop control by Lee Payne August 17, 2017 [online] Available from: <https://www.controleng.com/articles/know-when-to-use-open-or-closed-loop-control/#:~:text=Feedback%20is%20the%20key%20difference,and%20the%20process%20is%20erratic.> [Accessed 17/05/2023]

DISTURBANCE
NEXT

8) $Y(s) = R(s) \cdot \left(\frac{G_c(s) \cdot G_p(s)}{1 + G_c(s) \cdot G_p(s)} \right)$



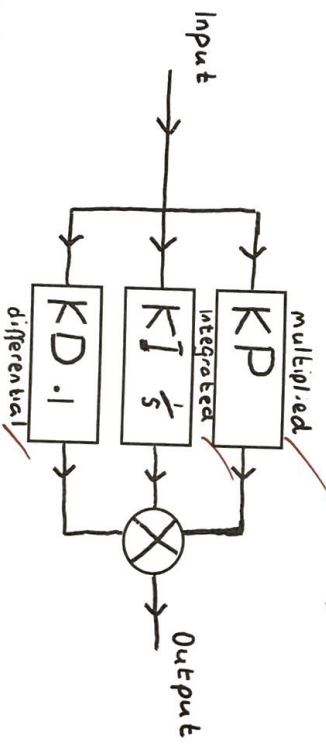
This is the simplified closed loop system showing the output and how it is affected by the components typically seen in a closed loop control system. The block labelled PLANT is the part of the system that takes in the control signal and from the controller and as an input and outputs a variable being controlled.⁵

$\frac{Y(s)}{R(s)} = \frac{G_s}{1 + G_s H_s}$

Task 3c

The following terms can be best described and represented by a transient response graph (seen in Appendix 2):

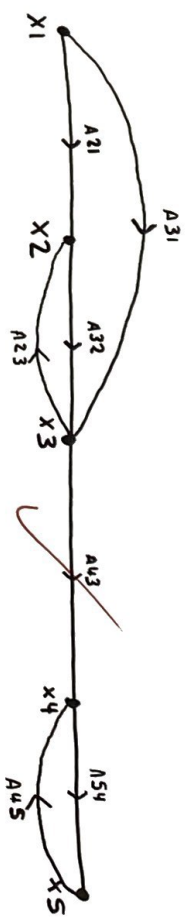
- **Overshoot** – The max overshoot is how far the response goes over the unit step input.
- **Settling Time (ts)** – This is the time taken for the response to settle between 1.05 and 0.95 of the time.
- **Steady State Error** – When the response has settled, the difference between the response and the unit step input.
- **The proportional integral differential (PID) controllers** use a control closed loop feedback systems to control process variables and are the most accurate and stable controller to keep an output stable and at a set target.⁶



⁵ Block Diagrams, Feedback and Transient Response Specifications by G.F. Franklin [online] Available from: https://www.maplesoft.com/content/EngineeringFundamentals/1/1/MapleDocument_11/Block%20Diagrams,%20Feedback%20and%20Transient%20Response%20Specifications.pdf [accessed 22/05/2023]
⁶ What is a PID Controller? By Omega [online] Available from: <https://www.omega.co.uk/product/pid-controllers.html#:~:text=PID%20proportional%20integral%20derivative%20controllers,a%20target%20position%20or%20level.> [accessed 22/05/2023]

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The PID controller has improvements in both the transient response and steady state error response. It also gives stability to the closed loop system. The term non-touching loops can be best represented and described through Masons Rule. Two loops are non-touching if they do not share any nodes nor branches. The signal flow graph below shows nodes: X1, X2, X3, X4, X5 with the input being X1 and the output being X5.



An example of non-touching loops is displayed on this signal flow graph, and are represented by the following:

- $NTL1 = X4, X5, X4 \text{ and } X2, X3, X2$
- $NTL2 = X4, X5, X4 \text{ and } X1, X2, X3, X1$

Conclusion

In conclusion to this assignment, all briefs have been met and the overall layout and design of the assignment has gone to plan. The first task undertaken was achieved through research on stress and strain and strain gauges. Followed by applying formulas to the strut and demonstrating where the strain gauge can be applied to the strut. The calculations were done separately with the 1.5MN and 2.5MN loads. This then gave the values needed to analyse the strain gauge system. The

Task 2 was accomplished by calculating the velocity, displacement and acceleration of a kinematic particle. These were done in a good, structured order giving the desired solutions. The distance/time graph was created and plotted word with clear labels of the axis and graph.

Task 3 was accomplished through structured answers and details from my own work as well as research and labelled drawings.

Overall, all tasks were met in this assignment with a clear structured approach.

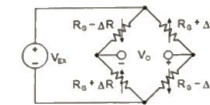
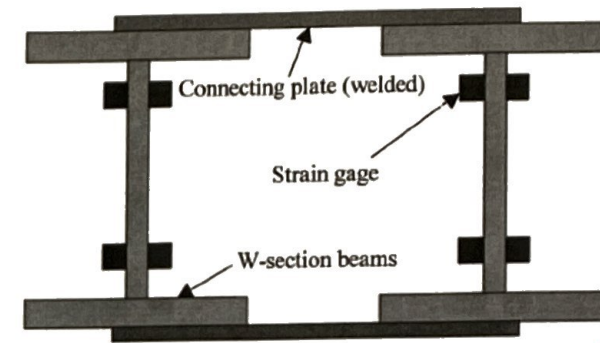
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- 3) 2.1.1 Displacement, Velocity & Acceleration by Katie [online] Available from: <https://www.savemyexams.co.uk/a-level/physics/cie/22/revision-notes/2-kinematics/2-1-equations-of-motion/2-1-1-displacement-velocity--acceleration/#:~:text=Displacement%3A%20the%20distance%20of%20an,of%20velocity%20of%20an%20object> [Accessed 09/05/2023]
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Appendix

Appendix 1 Typical Architecture and Layout of Struts and Beams with Strain Gauges Attached and Full-Bridge Circuit



$$\frac{V_0}{V_{EX}} = -GF \cdot \epsilon$$

Figure 7. Full-Bridge Circuit

Appendix 2 Transient Response Graph Example (Labelled)

