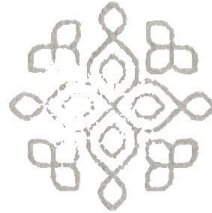


JENKINS



HNC Electrical and Electronic Engineering - Dynamics, Control and Instrumentation Report

University of Wales Trinity Saint David

RESULTS = 38/50
STRUCTURE = 44/50

82%

By Josh Jenkins
(Jen17835588)

Introduction.....	2
Aims and Objectives	2
Stress and Strain	3
Kinematics	7
Control Systems.....	10
Conclusion.....	15
References.....	16

Introduction

The purpose of this report is to lay out the findings of my research and the results of my practical tasks which will help understand some fundamental principles of dynamics, control and instrumentation. In this report, I will cover the three tasks that I had set out to do in great detail which will include research, mathematical equations, and practical examples. The three tasks that were given to me includes:

- Measurement systems to determine strain.
- How the supposed measurement system performs when under load
- Explanations of kinematics used in dynamics and how you work them out using mathematical formulas
- The use of Control Systems

Aims and Objectives

As well as stating how this report is set out, I have set myself several aims and objectives which I hope to achieve which I will discuss at the end of the report in my conclusion. The targets I am aiming for is as follows:

- Explain in detail a measurement system in order to determine strain while it's underload. Also use mathematical expressions to help support my answer in various scenarios.
- Explain Kinematics, and how they are used in different scenarios. Again using mathematical equations to help support my answers
- Provide information on how control systems work, what type of control systems there are and provide detail on how some key terms are used in control systems like these. Throughout this target, there should also be mathematical expressions to help support the findings.



Stress and Strain

Stress is a form of measurement which is used in dynamics. In particular, stress is known as the 'internal resistance, or counterforce, of a material to the distorting effects of an internal force or load'.¹ There are several types of stress which can be considered if a load or force is applied to a material. This includes Residual stress, where stress is caused due to manufacturing processes e.g. from a weld. Structural stress is where different structures are supporting different weights, such as foundations of buildings, and pressure stress which is caused due to pressurized materials in enclosed spaces such as pipes. It is measured in pascals (Pa) which is better described in the following equation where F = Force in Newtons (N) and A = Area in millimeters squared (mm²):

$$\text{Stress} = \frac{F}{A} = Pa$$

When a force is directly applied to a load, it produces strain which is another form of measurement. Strain 'is a unitless measure of how much an object gets bigger or smaller from an applied load'.² In other words, the strain is the deformation of the object which has been pulled by other forces compared to its original length. Some of the types of strain include longitudinal strain, where the body length changes when a force is applied to the material. Lateral strain where the cross sectional area of the object changes due to compressive or tensile stress. And finally shear strain where the surface moves away from its previous position due to tangential stress. Again, stress can be better described in the following equation where S = Strain (mm), ΔL = Change in length (mm) and L = original length (mm).

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

It is important to understand the relationship between stress and strain as it can be crucial for when a load is applied to an object. Each object has a limit to them which is known as ultimate tensile strength which is the maximum amount of stress an object can take while being stretched caused by strain before the object will break. This is why we have to closely monitor the strain of an object so it prevents anything from braking.

¹ https://www.engineersedge.com/material_science/stress_definition.htm#:~:text=Stress%20is%20the%20internal%20resistance,resistance%20is%20known%20as%20stress.

² <https://www.bu.edu/moss/mechanics-of-materials-strain/>

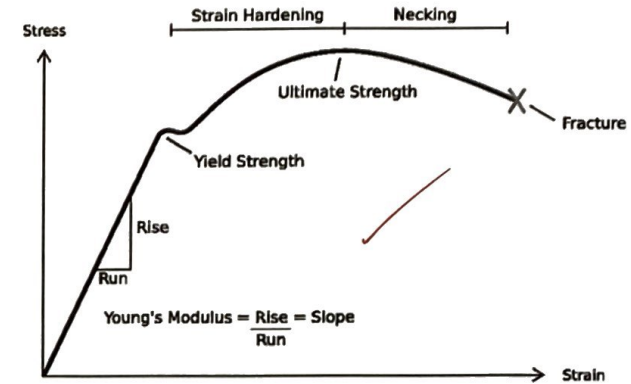
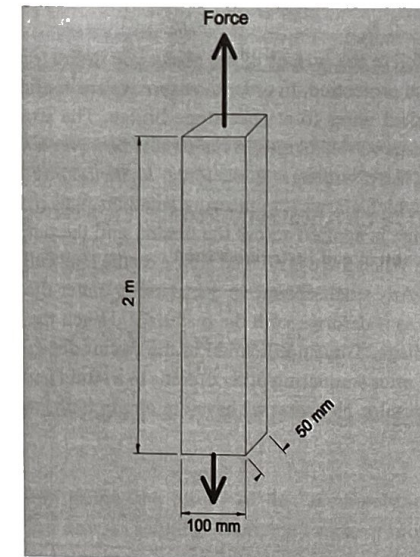


Figure 1 - Graph representing Ultimate tensile strength. After it exceeds its ultimate strength, the object will fracture as shown above³

Now that we have determined what stress and strain is and the relationship between them when a force is applied to an object, we need to propose a measurement system in order to measure the amount of strain that is caused by the strut shown below.



³ <https://www.quora.com/How-can-I-determine-the-ultimate-tensile-strength-of-mild-steel>

Figure 2 - the steel strut we'll be using to calculate strain

After some careful consideration and some research, I found that the best way to measure strain, in this case with the strut above, I believe that a strain gauge is the best course of action. A strain gauge of course measures the strain of an object, but the way it measures strain is unique. This is a sensor, which converts the force that's applied to it into resistance (measured in ohms). The resistance that gives out can then determine the amount of strain that is being applied to the strut. Before applying it to the strut above, we first need to understand how it converts strain into an electrical signal. The strain gauge is made up of several parts which is shown in the diagram below:

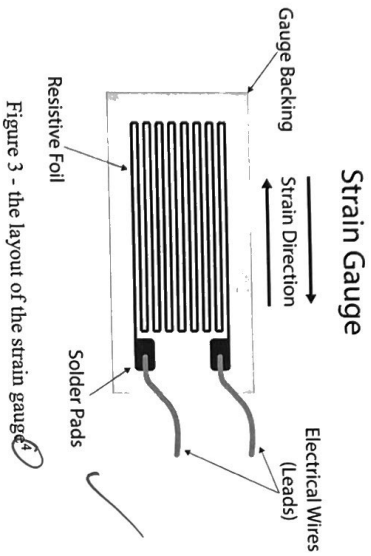


Figure 3 - the layout of the strain gauge

The strain gauge has to be mounted to the surface of the object you desire to measure with gauge tape and cover it with butyl rubber for mechanical protection. In order to ensure we are confident in our results and increase their reliability, we connect the electrical wires to a wheatstone bridge. The strain gauge can be connected to any electrical circuit that is able to respond to changes in resistance, however a wheatstone bridge will improve the accuracy and response time when there's changes to the force. To do this, we'll be using four strain gauges which will be wired in a divider circuit which allows it to measure small changes in resistance. In a Wheatstone bridge configuration, an excitation voltage is applied across the circuit, and the output voltage is measured across two points in the middle of the bridge. When there is no load acting on the load cell, the Wheatstone bridge is balanced and there is zero output voltage. Any small change in the material under the strain gauge results in a change in the resistance of the strain gauge as it deforms with the material. When the bridge becomes out of balance and causes a change in the output voltage. The amplification in the circuit does produce unwanted noise, which can be shown in the signal. However, after comparing other options to a strain gauge, this method I believe is the best one to achieve the most accurate results. Now that we have our circuit built, we can now calculate what we expect our results to be.

⑦

<https://www.michsci.com/what-is-a-strain-gauge/#:~:text=Strain%20gauges%20convert%20the%20applied,is%20gathered%20using%20data%20acquisition.https://www.michsci.com/what-is-a-strain-gauge/#:~:text=Strain%20gauges%20convert%20the%20applied,is%20gathered%20using%20data%20acquisition.>

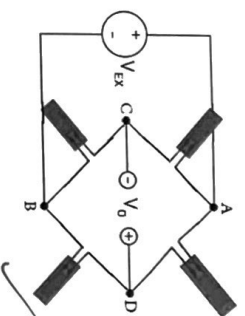


Figure 4 - How a wheatstone bridge is wired using strain gauges

To prove that my system works, I will conduct two mathematical equations that will determine the strain caused when a force is applied to it. We will be using the steel strut as shown in figure two when 1.5MN and 2.5MN of force are applied to it with the modulus of elasticity (E) assumed to be 210GPa. First we will determine the results when 1.5MN is applied to it:

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

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

$$E = \frac{\Delta x}{x} = E \times X = 0.071 \times 2000\text{mm} = 142\text{mm}$$

$$P_a = \frac{1.5 \times 10^6}{100 \times 10^{-6}} = 15\text{GPa} \quad 300\text{MPa} \leq 50 \times 100 = 5000\text{MPa}$$

$$E = \frac{15 \times 10^9}{210 \times 10^9} = 0.071$$

After using these calculations, and comparing them against my strain gauge, I can confirm that these results are correct and that also proves that the strain gauge is working and accurate to my mathematical equations. To prove this again, I shall now apply 2.5MN to the strut:

$$P_a = \frac{2.5 \times 10^6}{100 \times 10^{-6}} = 25\text{GPa} = \frac{2.5 \times 10^6}{5000} = 500\text{MPa}$$

$$E = \frac{25 \times 10^9}{210 \times 10^9} = 0.119$$

$$E = \frac{\Delta x}{X} = E \times X = 0.119 \times 2000\text{mm} = 238\text{mm}$$

Once again, according to my strain gauge, the results of that accurately mirror the results as shown by my calculations, proving once again that a strain gauge is a suitable source of measurement for measuring strain.

APP7 TO BRIDGE

<https://www.docstoc.com.au/blogs/understanding-a-wheatstone-bridge-strain-gauge-circuit/>

⑥

Kinematics

Kinematics is a term used to express objects in motion without taking into account forces that cause the motion in the first place. There are several different properties that are explored in kinematics which help us understand what happens to objects when they are in motion. The following terms are just some of the main terms and criteria that are used and measured in kinematics:

Displacement - This term is used to describe the position change of an object from point A to point B and is measured in meters (m). It is represented using the letter S in mathematical expressions. An example of this would be if a person moved from one side of the room to the other, the displacement would be the change in position from where the person started to where they ended. Displacement can also be described in this mathematical calculation where $\Delta X = \text{Change of position of the object}$, $X_f = \text{Final position}$ and $X_i = \text{initial position}$.

$$\Delta X = X_f - X_i = m$$

This second equation can be used to measure displacement where $S = \text{distance}$, $U = \text{initial velocity}$, $V = \text{final velocity}$ and $t = \text{time}$:

$$S = \left(\frac{U + V}{2} \right) t$$

Velocity - Velocity is a form of measurement which is used find the 'rate at which the displacement is changing'. This includes how fast the object in question would be moving and at what direction it is moving at. Velocity is measured in meters per second (m/s) and is represented using the letter V in mathematical expressions. This unit of measurement can also be better described in mathematical formulas like the one shown below. In this formula, $V = \text{Velocity}$, $U = \text{initial velocity}$, $a = \text{acceleration}$ and $t = \text{time}$.

$$V = U + at$$

Acceleration - Acceleration is the final form of measurement that will be discussed in kinematics, where acceleration is the measurement of the rate of velocity change over a period of time. Acceleration is represented as the letter 'a' in mathematical expressions and is measured in meters per second squared (m/s²). The mathematical expression to best describe acceleration is the same equation as shown by velocity, however it will give a different formula when you rearrange it as shown below:

⁷<https://study.com/academy/lesson/kinematics-displacement-velocity-acceleration.html#:~:text=measured%20in%20meters%20per%20second%20s,Velocity%20is%20the%20rate%20at%20which%20your%20displacement%20is%20changing,or%20meters%20per%20second%20s> (Accessed 20/10/2020)

$$a = \frac{V}{t}$$

What all these units of measurements have in common is that they have relationships among each other. For example, in the relationship between displacement and acceleration, the acceleration of an object is directly proportional to the displacement of the same object in its mean position. As for velocity and displacement, the relationship between these two is that velocity is measured at the rate of which an object is displaced. Finally, the relationship between velocity and acceleration is that 'Acceleration is the rate of change of velocity'.⁸ In order to put these explanations into practice, I will answer the following questions which will hopefully describe how to calculate velocity, acceleration and displacement. The questions are as followed:

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 is measured in meters from a convenient origin and t is the time in seconds. Determine:

- a) The time required for the particle to reach a velocity of 60 m/s from its initial condition at $t=0$.

$$60 \text{ m/s} = 9t^2 - 24 \text{ m/s}$$

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

$$84 = 9t^2$$

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

$$9.33 = t^2$$

$$t = \sqrt{9.33} = + / - 3.05 \text{ s (2 d.p.)}$$

- b) The acceleration of the particle when $V = 35 \text{ m/s}$

$$35 \text{ m/s} = 9t^2 - 24 \text{ m/s}$$

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

$$59 = 9t^2$$

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

$$6.55 = t^2$$

$$t = \sqrt{6.55} = 2.56 \text{ m/s}^2$$

- c) The net displacement of the particle during the interval from $t=2 \text{ s}$ to $t=4 \text{ s}$

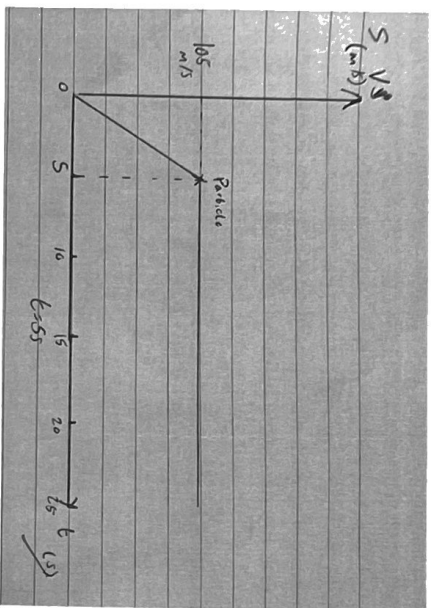
⁸[https://wiki.usask.ca/pages/viewpage.action?pageId=130957313#:~:text=Acceleration%20is%20the%20rate%20of%20V%20eloci ty%20%2F%20Time%20\(Acceleration\)](https://wiki.usask.ca/pages/viewpage.action?pageId=130957313#:~:text=Acceleration%20is%20the%20rate%20of%20V%20eloci ty%20%2F%20Time%20(Acceleration))

$$\Delta s = [3(4^3) - 24(4) + 6] - [3(2^3) - 24(2) + 6] = 120m$$

d) Draw the path of the particle between $0 < t < 5$ s

$$V = 9(5^2) - 24(5) = x = 105 \text{ m/s}$$

$$a = 18(5) - 24 = \hat{x} = 66 \text{ m/s}^2$$



Control Systems

A control system can be described as a system which is used to control several different variables to regulate the behavior of different devices. Control systems are able to command, manage and direct signals in order to achieve a desired output, these are known as control loops. These control loops are heavily used in industry, in which there are two different types. These loops are known as Open loop and closed loop systems. These two looping systems are both unique in their own way, with an open loop described as being a system with no feedback and therefore is referred to as a 'non-feedback control system'.

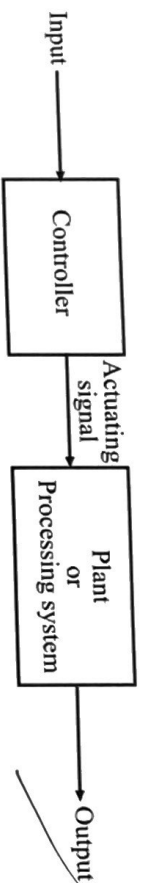


Figure 5 - A diagram of an open loop systems¹⁰

In contrast to an open loop, a closed loop system is able to provide feedback which allows us to have control over variables and we're able to see clearly if we need to change the input in order to achieve the desired output. This does so by using feedback to take away the value sent by the input through a device known as a summing junction. This device provides an error which is sent to the controller and varies conditions in order to get closer to the desired output as set by the input. An open loop doesn't have these components which are shown in the diagrams. Some other differences between these two control systems is that an open loop requires less maintenance compared to a closed loop system due to having less components. Open loops also tend to be cheaper for the same reason, however closed loop systems tend to be more reliable due to the feedback they provide.

⁹<https://www.tutorialspoint.com/difference-between-open-loop-and-closed-loop-control-system#:~:text=An%20open%20loop%20control%20system%20is%20the%20one%20in%20which,control%20action%20of%20the%20system.>

¹⁰<https://www.tutorialspoint.com/difference-between-open-loop-and-closed-loop-control-system#:~:text=An%20open%20loop%20control%20system%20is%20the%20one%20in%20which,control%20action%20of%20the%20system.>

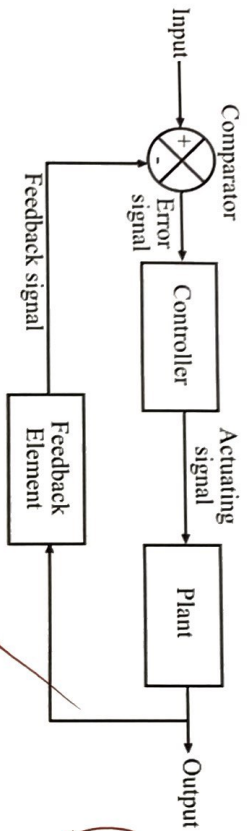
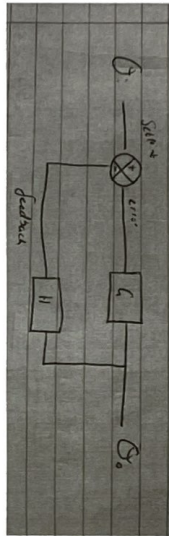


Figure 6 - A diagram of a closed loop system!¹

Open and closed loop systems also differ from each other in mathematical applications. Transfer functions are often used in order to work out what the value of the output is within the system. I will now explain using mathematical equations how the output is achieved, first starting with a closed loop system.



As shown above, σi is the input, the summing junction is the circle with an 'x' going through it, G represents the gain, H represents the feedback element, f represents feedback and σO represents the output. In order to work out the values of each unit using mathematical equations, you will need to use the following equations:

$$\begin{aligned} \text{Error} &= \sigma i - f \\ f &= \sigma O \times H \\ H &= \frac{f}{\sigma O} \\ G &= \frac{\sigma O}{\text{error}} \end{aligned}$$

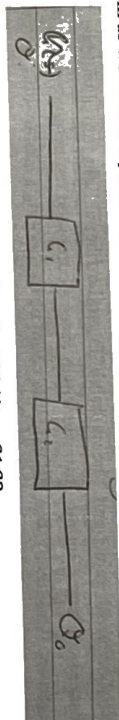
In order to find the output value, we will need to simplify it with the following expressions:

$$\begin{aligned} \sigma O &= G \times \text{Error} \\ \sigma O &= G(\sigma i - f) \\ \sigma O &= G(\sigma i - H\sigma i) \end{aligned}$$

¹<https://www.tutorialspoint.com/difference-between-open-loop-and-closed-loop-control-system/#:~:text=An%20open%20loop%20control%20system%20is%20one%20in%20which,control%20action%20of%20the%20system.>

$$\begin{aligned} \sigma O &= G\sigma i - GH\sigma O \\ \sigma O(1 + GH) &= G\sigma i \\ \sigma O &= \frac{G\sigma i}{(1 + GH)} \\ \frac{\sigma O}{\sigma i} &= \frac{G}{(1 + GH)} \end{aligned}$$

As for an open loop system, it does involve less equations in order to work out the output. Below you will see an open loop system as well as the equations to find the output value, and error value.

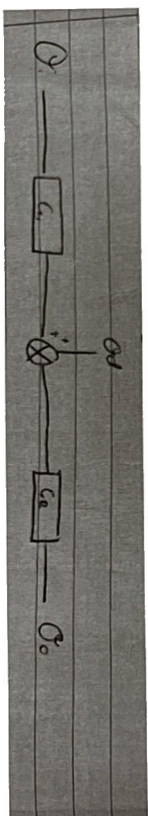


$$\begin{aligned} \text{Total gain } (G(s)) &= G1G2 \\ \frac{\sigma O}{\sigma i} &= G1G2 \\ \text{Error} &= \sigma i(\text{Gain} - 1) \end{aligned}$$

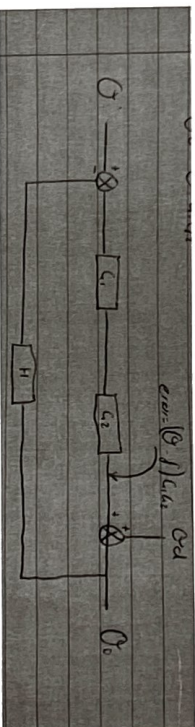
There are also some examples of how to work out the output when the summing junction is placed in different locations in the circuit, with the summing junction sometimes providing positive feedback rather than negative feedback. Three examples are shown below and how to calculate the output of them.



$$\sigma O = \sigma i G1 G2 + \sigma d$$



$$\sigma O = (\sigma i G1 + \sigma d) G2$$

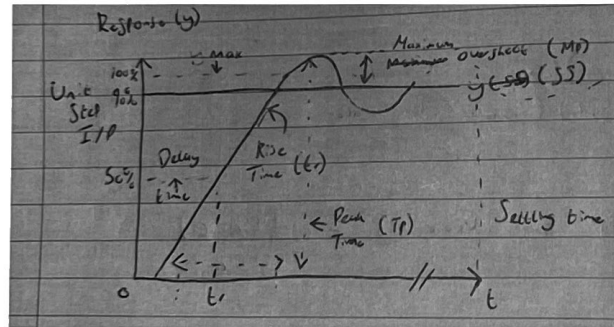


$$\sigma O = \frac{G1G2\sigma i}{1 + G1G2H} + \frac{\sigma d}{1 + G1G2H}$$

4

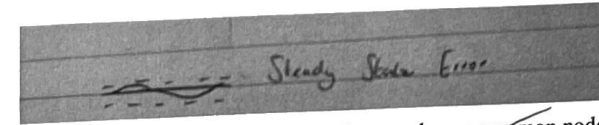
Of course, there are several examples in various scenarios which can be used to help better describe each of these control systems. In order, the first closed loop system can be used as an example for controlling the speed of a DC motor. If you can imagine the gain as the DC motor and H as a tachogenerator, this tacho will provide feedback to the summing junction with the error showing us how out of range in RPM the motor is running at. The open loop system can be used as a clothes dryer, with gain 1 being a timer stating how long they will dry for, and the second gain being a heating element. The next example after that could be a system for measuring a light luminosity in the room, with gain 1 and 2 being lightbulbs and σd being light from a window. The example after that could represent two flames within a furnace which gives a combined temperature rating before moving onto a third flame in gain 2. And finally, the last example could be the cooling system within a freezer where fans are used in gain 1 and gain 2, σO detecting the temperature of the freezer and H calculating if the fans need to accelerate or decelerate depending on the temperature.

c) As well as open and closed loop systems, there are several other factors within control systems that help us maintain and monitor how machines are behaving. One of these being the transient response. This is a technique used to help us understand how current changes in a system due to demand or how a system reacts to changes in load impedance. The diagram below will provide a better explanation.



Here is how the transient response looks, however there are several terms I would like to explain in this. The first one being the overshoot. This is where the signal exceeds the desired result, which in this case was 90% response but made its way past 100% response. An example of this could be the current start up of an AC motor using a DOL (Direct On Line) starter. Next is settling time, where the signal stays around the unit step and does not exceed around +/- 1% or 2% over a period of time. Using the same example of a DOL starter, the current would reach a settling time at a certain amperage where it will stay unless turned off. Finally, I'd like to talk about the steady state error which is shown below. Here we see the difference between the output and the desired output. An example of this could be the error within the summing junction, where you will always get a small error within your closed loop system.

4



Some other control systems out there include non-touching loops, where a common node isn't shared in a signal flow graph. An example for this would be in a closed loop system, you have two loops for two separate gains without touching the path of the two gains. Plant is another important term I'd like to address which is the object you're trying to control in the control system itself. An example for this would be using your gas pedal on your car to achieve a certain speed on your speed monitor. Finally, I would like to describe the term PID (proportional integral derivative) which is used to calculate the error value within a control system. An example for this would be cruise control on a car where the PID will try to calculate your desired speed.

6

6

Conclusion

In conclusion, when looking back at my aims at the start of the report and looking at what I have covered within it, I do believe I have achieved all of my aims. First of all, I proved that I could determine strain using a system that I designed which worked and proved to do so in my mathematical equations which was again shown. Furthermore, I believe I have covered how kinematics works and provided evidence in a way someone can understand and learn from it how to use these units to calculate different questions surrounding particles. And finally I was able to show, with examples, how different control systems work and how they differ from each other. If I could improve this report, I would provide more evidence using real life practicals how each control system worked in real time and I would've provided real life pictures of a strain gauge in action.

References

1. Stress equation definition - strength (mechanics) of materials, Engineers Edge - Engineering, Design and Manufacturing Solutions. Available at: <https://www.bu.edu/moss/mechanics-of-materials-strain/> (Accessed: 30 May 2023) Author not found. Published Date not found
3. Kesavam, O.S. (15/02/2020) How can I determine the ultimate tensile strength of mild steel?, Quora. Available at: <https://www.quora.com/How-can-I-determine-the-ultimate-tensile-strength-of-mild-steel> (Accessed: 30 May 2023).
4. Nachazel, T. (13/08/2020) What is a strain gauge and how does it work?, Michigan Scientific Corporation. Available at: [https://www.michsci.com/what-is-a-strain-gauge/#:~:text=Strain%20gauges%20convert%20the%20applied,is%20gathered%20using%20data%20aquisition.\(Accessed:30May2023\).](https://www.michsci.com/what-is-a-strain-gauge/#:~:text=Strain%20gauges%20convert%20the%20applied,is%20gathered%20using%20data%20aquisition.(Accessed:30May2023).)
5. Nachazel, T. (13/08/2020) What is a strain gauge and how does it work?, Michigan Scientific Corporation. Available at: [https://www.michsci.com/what-is-a-strain-gauge/#:~:text=Strain%20gauges%20convert%20the%20applied,is%20gathered%20using%20data%20aquisition.\(Accessed:30May2023\).](https://www.michsci.com/what-is-a-strain-gauge/#:~:text=Strain%20gauges%20convert%20the%20applied,is%20gathered%20using%20data%20aquisition.(Accessed:30May2023).)
6. Understanding a wheatstone bridge strain gauge circuit, Bestech Australia. Available at: <https://www.bestech.com.au/blogs/understanding-a-wheatstone-bridge-strain-gauge-circuit/> (Accessed: 30 May 2023) Published date not found. Author not found.
7. Wood, D. Kinematics: Displacement, Velocity & Acceleration, Study.com Available at: [https://study.com/academy/lesson/kinematics-displacement-velocity-acceleration.html#:~:text=measured%20in%20meters,-Velocity%20is%20the%20rate%20at%20which%20your%20displacement%20is%20changing,or%20meters%20per%20second%20squared\).\(Accessed:30May2023\).](https://study.com/academy/lesson/kinematics-displacement-velocity-acceleration.html#:~:text=measured%20in%20meters,-Velocity%20is%20the%20rate%20at%20which%20your%20displacement%20is%20changing,or%20meters%20per%20second%20squared).(Accessed:30May2023).)
8. Chatha, A. (12/06/2018) Ph: What is the relationship between displacement, velocity, and acceleration?, Wiki. Available at: [https://wiki.usask.ca/pages/viewpage.action?pageId=1309573135#:~:text=Acceleration%20is%20the%20rate%20of%20D%20velocity%20%20F%20Time%20\(Acceleration\)\(Accessed:30May2023\).](https://wiki.usask.ca/pages/viewpage.action?pageId=1309573135#:~:text=Acceleration%20is%20the%20rate%20of%20D%20velocity%20%20F%20Time%20(Acceleration)(Accessed:30May2023).)
9. Saini, M.K. (03/08/2022) Difference between open loop and closed loop control system, Tutorials Point. Available at: [https://www.tutorialspoint.com/difference-between-open-loop-and-closed-loop-control-system#:~:text=An%20open%20loop%20control%20system%20is%20the%20one%20in%20which,control%20action%20of%20the%20system.\(Accessed:30May2023\).](https://www.tutorialspoint.com/difference-between-open-loop-and-closed-loop-control-system#:~:text=An%20open%20loop%20control%20system%20is%20the%20one%20in%20which,control%20action%20of%20the%20system.(Accessed:30May2023).)
10. Saini, M.K. (03/08/2022) Difference between open loop and closed loop control system, Tutorials Point. Available at: [https://www.tutorialspoint.com/difference-between-open-loop-and-closed-loop-control-system#:~:text=An%20open%20loop%20control%20system%20is%20the%20one%20in%20which,control%20action%20of%20the%20system.\(Accessed:30May2023\).](https://www.tutorialspoint.com/difference-between-open-loop-and-closed-loop-control-system#:~:text=An%20open%20loop%20control%20system%20is%20the%20one%20in%20which,control%20action%20of%20the%20system.(Accessed:30May2023).)

11. Saini, M.K. (03/08/2022) Difference between open loop and closed loop control system, Tutorials Point. Available at: <https://www.tutorialspoint.com/difference-between-open-loop-and-closed-loop-control-system#:~:text=An%20open%20loop%20control%20system%20is%20the%20one%20in%20which,control%20action%20of%20the%20system.> (Accessed: 30 May 2023).