

*HND ELECTRONICS AND ELECTRICAL
ENGINEERING*

*DYNAMICS, CONTROL AND
INSTRUMENTATION
ASSIGNMENT*

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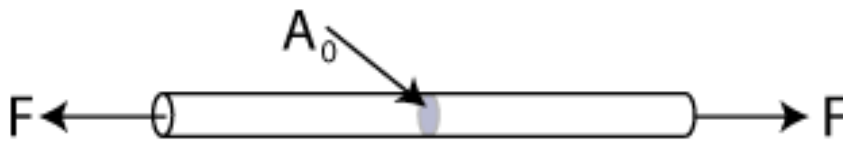
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Task One

Introduction

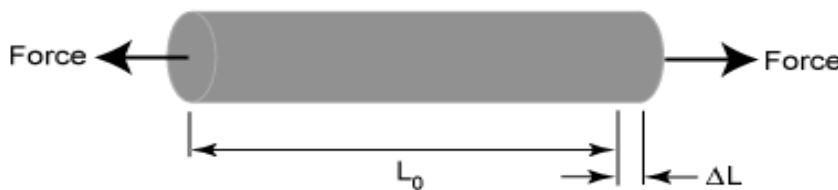
In order to get reliable products, designs must be lighter and stronger, and this by testing. This places the importance of the stress analysis and the different ways of measuring it.

The stress is the amount of force applied to the cross sectional area of object in order to extend or retract it. (NDT Resource centre, 2019)



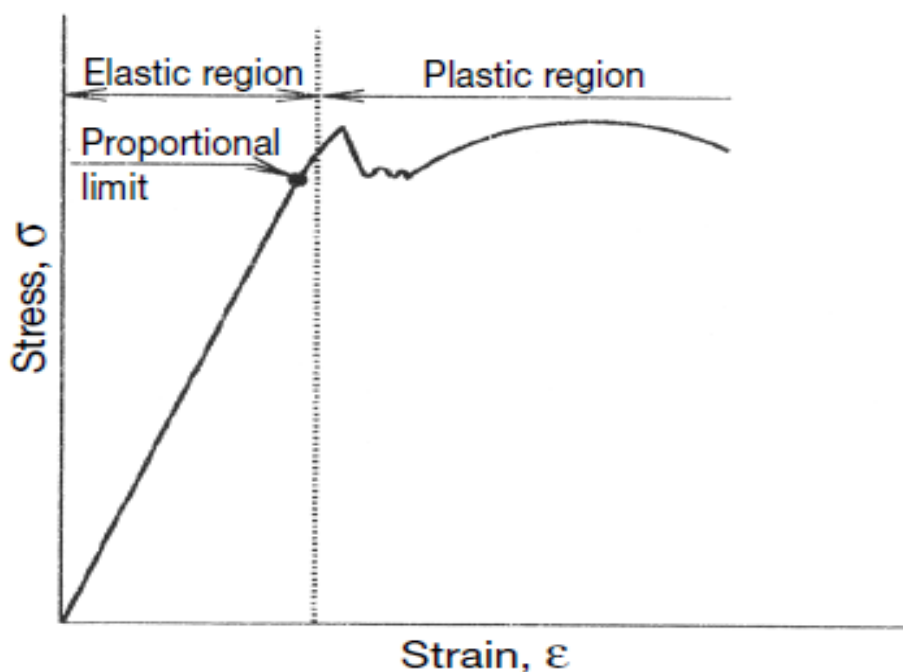
Stress = force / cross sectional area.

The strain is the response of the system to the applied force which is the stress by change in dimensions either extend or retract



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

The modulus is the ratio between the stress to the strain which is the numerical value of a physical property of a material,



Available at
www.kyowa-ei.com

Accessed on
27/02/2019

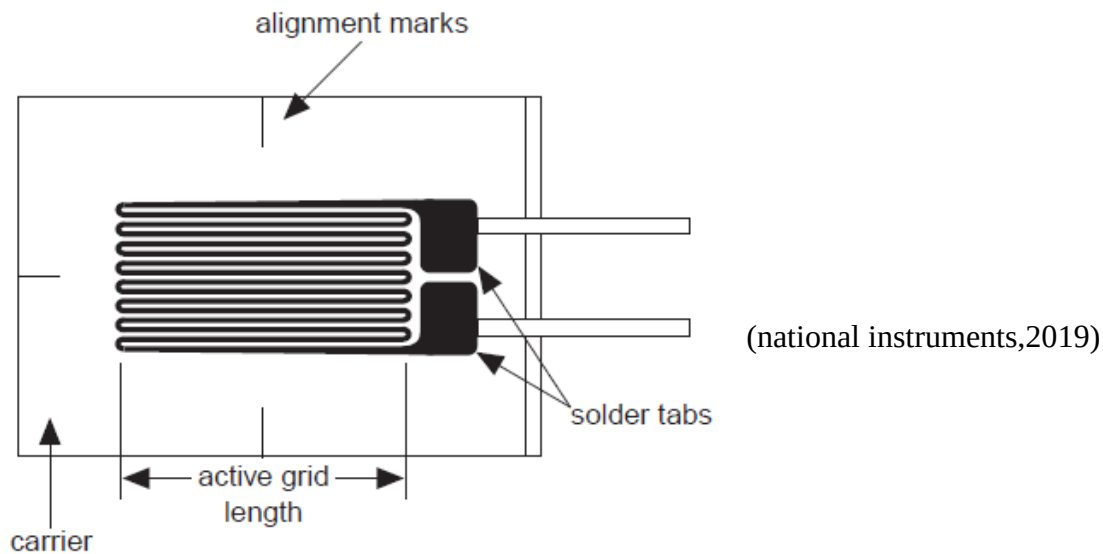
(PhysicsNET, 2019)

$E = \text{stress} / \text{strain}$

$$= \frac{F}{A} / \frac{\Delta L}{L} = FL / A\Delta L$$

How to measure the strain

To measure the strain in load bearing structure, sensors are used to convert a physical phenomenon into a measurable electrical signal, such as, the strain gauges, which is a device has resistance changes according to the force, pressure, tension or weight subjected to it, and it converts this inputs in to voltage through the transducer. As shown below

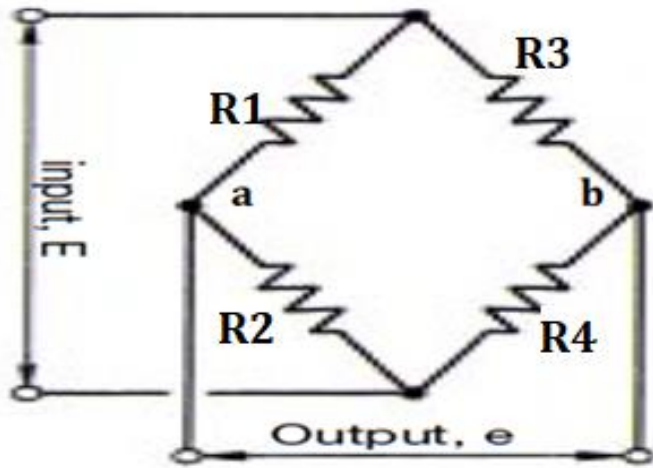


One of the important parameters of the strain gauge is its reactance to the strain, which is the ratio of the change in the resistance to the change in the length, known as the gain factor GF

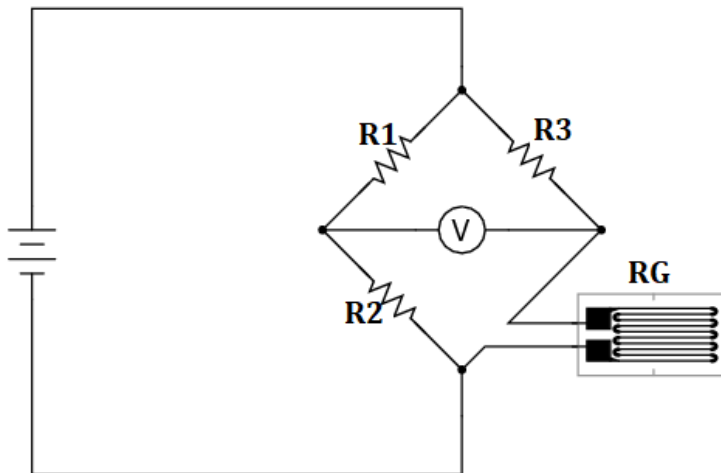
$$GF = \frac{\Delta R}{R} / \frac{\Delta L}{L} = \frac{\Delta R}{R} / \epsilon \quad (\text{national instruments,2019})$$

Wheatstone bridge

In order for the strain gauge to work in the load bearing structure, it needs to be connected to Wheatstone bridge circuit, which is a circuit can measure the change in the minute change in the resistance, that by the circuit as shown in the figure the ratio of resistor R3 to R4 and R1 to R2 is equal which results in the voltage in point a equal (E / 2) and the voltage in point b equals (E / 2). Which makes the bridge circuit stable as the difference between point a and b equals zero ($V_a - V_b = 0$).



But when any of the resistors is replaced with a strain gauge, which is a variable resistor increases according to the acting force or the temperature, as shown below, the circuit will be un stable as there will be voltage difference between point a and b.



Factors affect the measurement of the strain gauge

Excitation

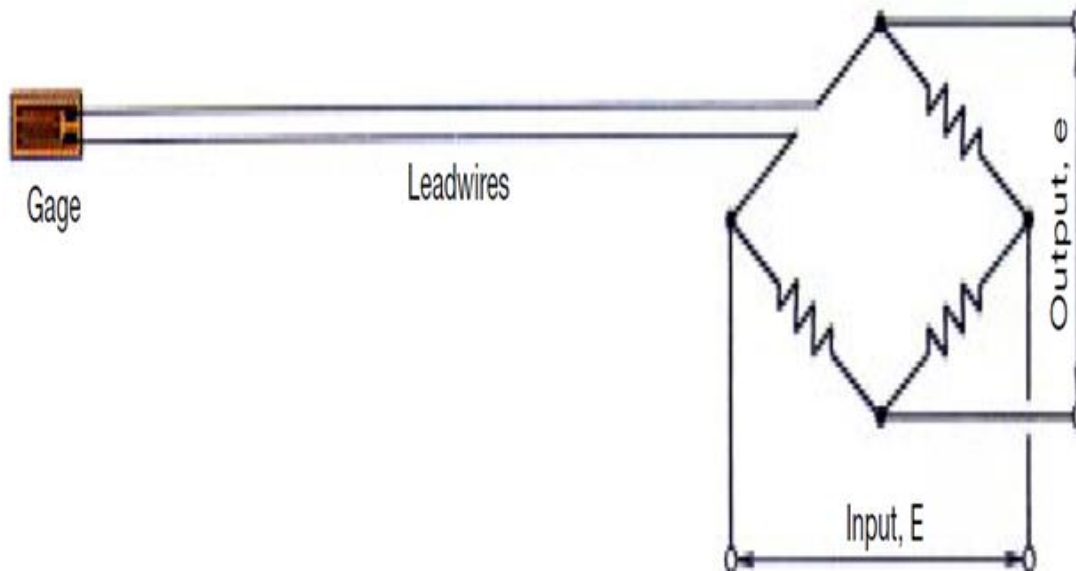
It is important to choose the right excitation voltage which is the input voltage to the bridge circuit, because it is proportional to the amount of noise generated and the also to the heat generated by the strain gauge itself. But commonly the excitation voltage is from 3V to 10V.(national instruments,2019)

The optimum excitation voltage could be decided experimentally, by applying voltage with no load applied to decide the zero-excitation voltage, and then apply voltage in high temperature condition as required to the gauge to operate in and measure the optimum voltage. (national instruments,2019)

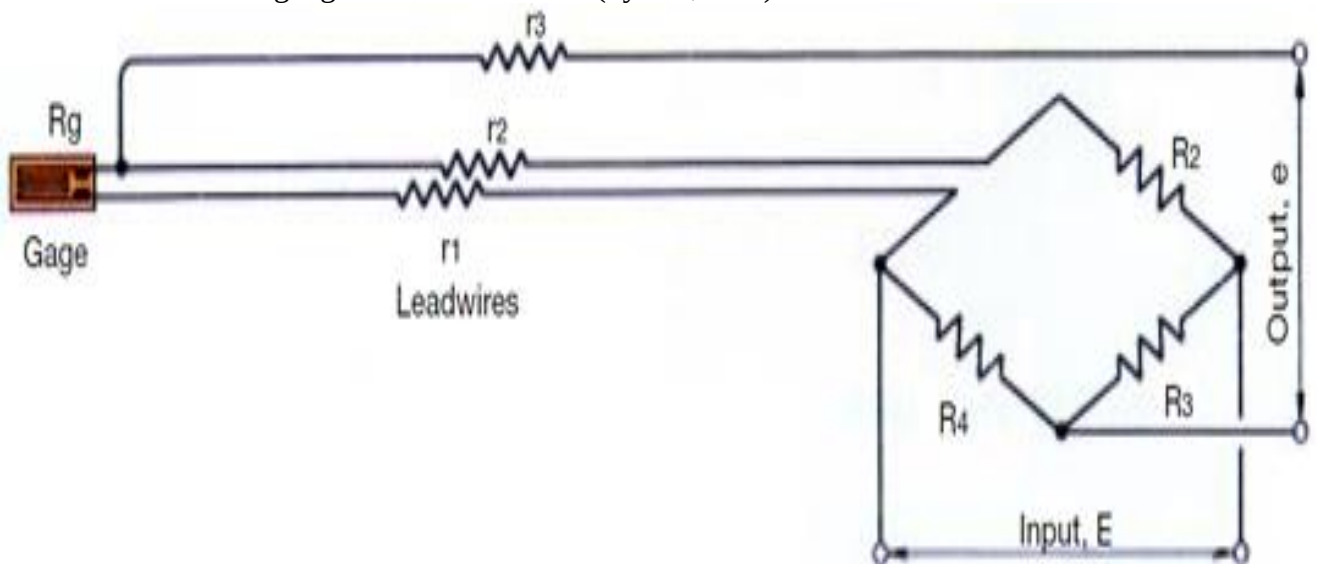
Putting in consideration some factors could help in deciding the optimum excitation voltage such as: using a gauge with bigger surface area and bigger resistance helps reducing the gauge self-heating. Also using high thermal conductivity materials helps as they act as heat sinks for the gauge. (national instruments,2019)

Lead wire resistance

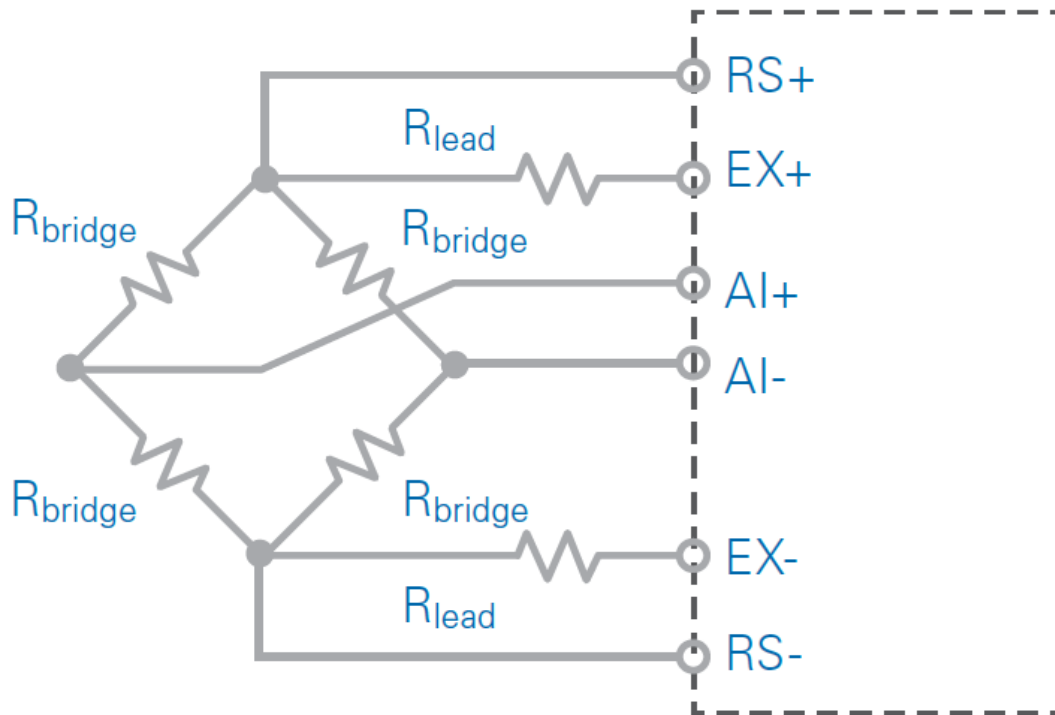
When strain gauge is connected to bridge circuit with short lead wires on each side of the gauge, the resistance of the wires on the sides of the gauge is added to the gauge in series. And as the wires are short, their resistance would not affect the gauge. But if the gauge is connected with long wires, as shown in the figure below, (kyowa,2019)



The resistance of the wires cannot be neglected as the wires are long so the accuracy of the gauge will be affected, so in order to keep the accuracy remain stable, two resistors are added on the long lead wires of the gauge and a third one on the output lead wire which reduces the thermal effect on the gauge. As shown below. (kyowa,2019)



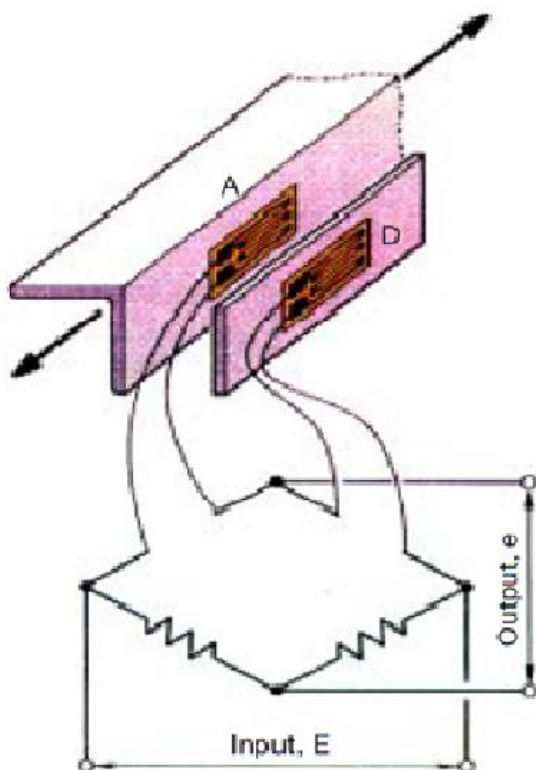
This technique solves the gage accuracy issue, but it generates another problem which is the voltage drop in the excitation voltage caused by the resistors on the long lead wires. This problem could be solved by the remote sensing feature which is a negative feedback amplifier used to regulate the voltage supply to the bridge circuit as intended to be from the excitation voltage source without losses cause by the resistors. As shown below.
. (national instruments,2019)



. (national instruments,2019)

The surrounding temperature thermal effect

As the gauge is sensitive to any change in the affecting load and the surrounding temperature, the gauge measure both of them at the same time which causes in accurate reading, to solve this issue, another a dummy gauge D is used and connected in series with the active gauge A as in the figure below, but not subjected to any load only the surrounding temperature, this makes the output reading from the active gauge A stay the same without any effect by the temperature. (kyowa,2019)



(kyowa,2019)

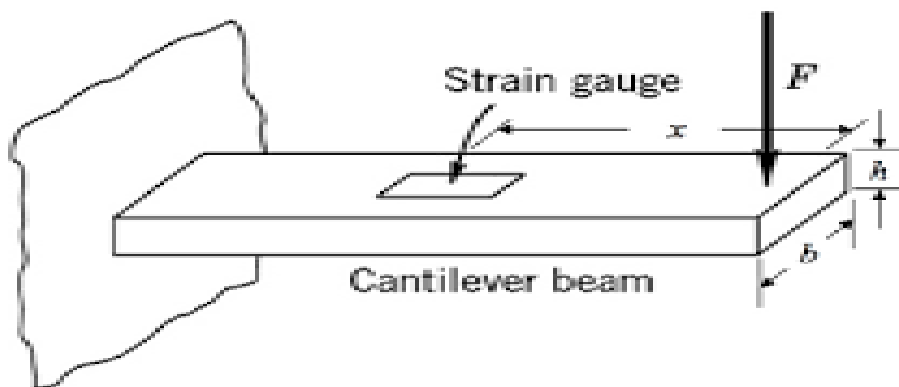
The noise effects

The output signal of the strain measurement is very small, therefore adding noise into it as it is often in noisy environment, just makes it very hard to identify, to reduce its effect on the measurement or improve the signal to noise ratio.

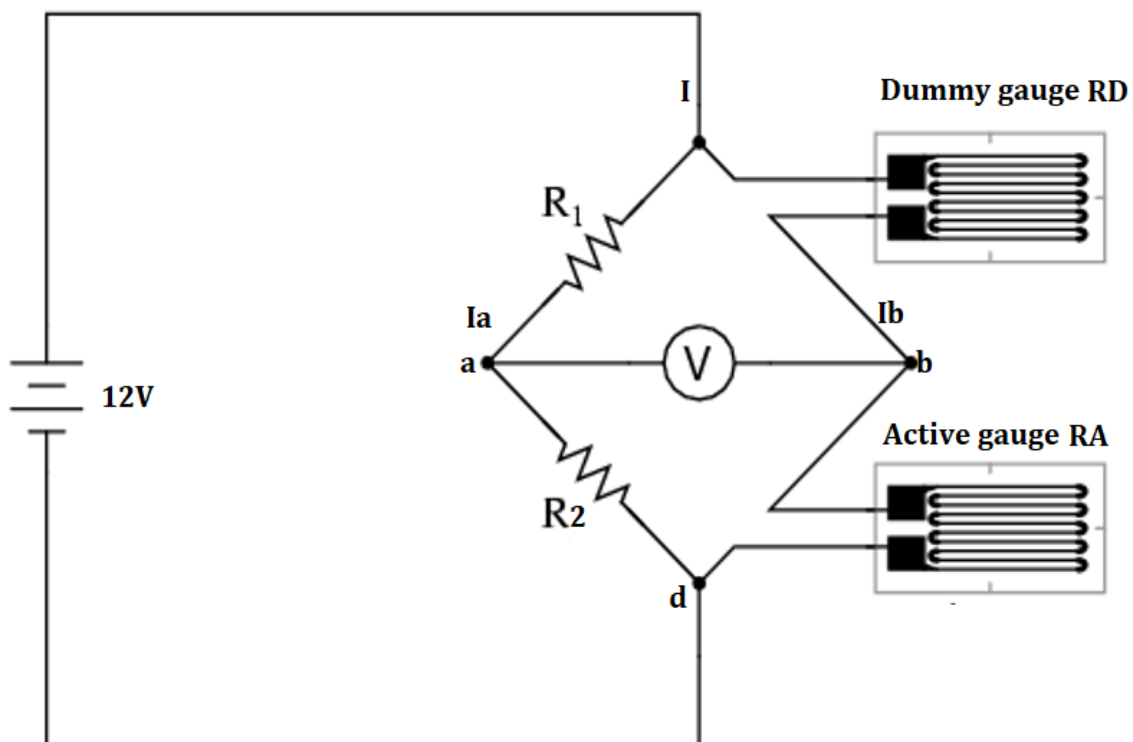
Techniques to eliminate external noise

- Reducing the lead wire length and using twisted pairs
- Increasing the amplitude of the signal before the noise is introduced to it, by using a more sensitive strain gauge or increasing the input excitation voltage.
- Using shielding techniques.

Strain gauge example



In the figure above to measure the strain caused by the force F acting on the cantilever, active strain gauge A and dummy strain gauge D are used as shown below



First measuring the voltage when its not affected by a force

Assumptions

$$R1 = 120\Omega$$

$$R2 = 120\Omega$$

$$RA = 120\Omega$$

$$RD = 120\Omega$$

$$A \text{ (area of the cantilever)} = 4 \text{ m}^2$$

$$E \text{ (steel modulus)} = 200 \text{ Gpa}$$

$$GF \text{ (Gain factor)} = 2$$

$$F \text{ (the force)} = 10\text{KN}$$

$$\text{As } R1 / R2 = GD / GA$$

$$\text{so } V_a = V_b = 6\text{V}$$

to measure the voltage drop between point a and b, I used this formula

$$V = V_{ex} \{ (R2 / R1 + R2) - (RA / RG + RA) \}$$

$$V = 12 \{ (120 / 240) - (120 / 240) \} = 0$$

Second measuring the voltage when it is affected by a force

If the resistance at RA changed due to the change of the acting force, the voltage drop between point a and b will change.

Calculating the strain

$$\text{Stress} = F / A = 10 * 10^3 / 4 = 250 * 10^3 \text{ Pa}$$

$$E = \text{stress} / \text{strain}$$

$$\epsilon = 250 * 10^3 / 200 * 10^9$$

$$\epsilon = 1.25 * 10^{-6}$$

$$\epsilon = \frac{\Delta L}{L}$$

$$\Delta L = 1.25 * 10^{-6} * 2 = 2.5 * 10^{-6} \text{ m}$$

Measuring the change in the resistance

Using the formula of the gain factor

$$GF = = \frac{\Delta R}{R} / \frac{\Delta L}{L} = \frac{\Delta R}{R} / \epsilon$$

$$GF = \frac{\Delta R}{R} / \epsilon$$

$$2 = = \frac{\Delta R}{120} / 1.25 * 10^{-6}$$

$$\Delta R = 3 * 10^{-4} \Omega = 0.3 \text{ m}\Omega$$

Measuring the voltage after the change of RA

$$RA = 120 + 0.0003 = 120.0003 \text{ m}\Omega$$

Assuming that there is no change in the surrounding temperature.

$$V = \{ (120 / 240) - (120 / 240.0003) \} = 6.25 * 10^{-6} \text{ V}$$

Task two

This task is about designing driving system with position control system for a drill connected to a CNC machine part (Y axis), moving vertically up and down on the Z axis to drill holes in PCB boards.

The key requirements of the system design

- In order for the system to be efficient it needs to be accurate.
- The system should overcome the hard-working conditions, as the drilling process include residuals such as dust and dirt.
- The system should have relatively long life
- The system should have a reasonable speed to be efficient.

Challenges and aspects need to be overcome

Accuracy

The accuracy is the difference between the distance which the drill required to move, and the actual distance the drill moved.(Newport,2019)

Absolute accuracy

It is the difference between the output of the motion system which is the distance the drill achieved on either the X axis or the Z axis, to the same distance measured by a measuring device as a ruler. .(Newport,2019)

Resolution

The smallest increment that the motion system can detect by the motion measurement device such as an encoder. .(Newport,2019)

Minimum incremental motion

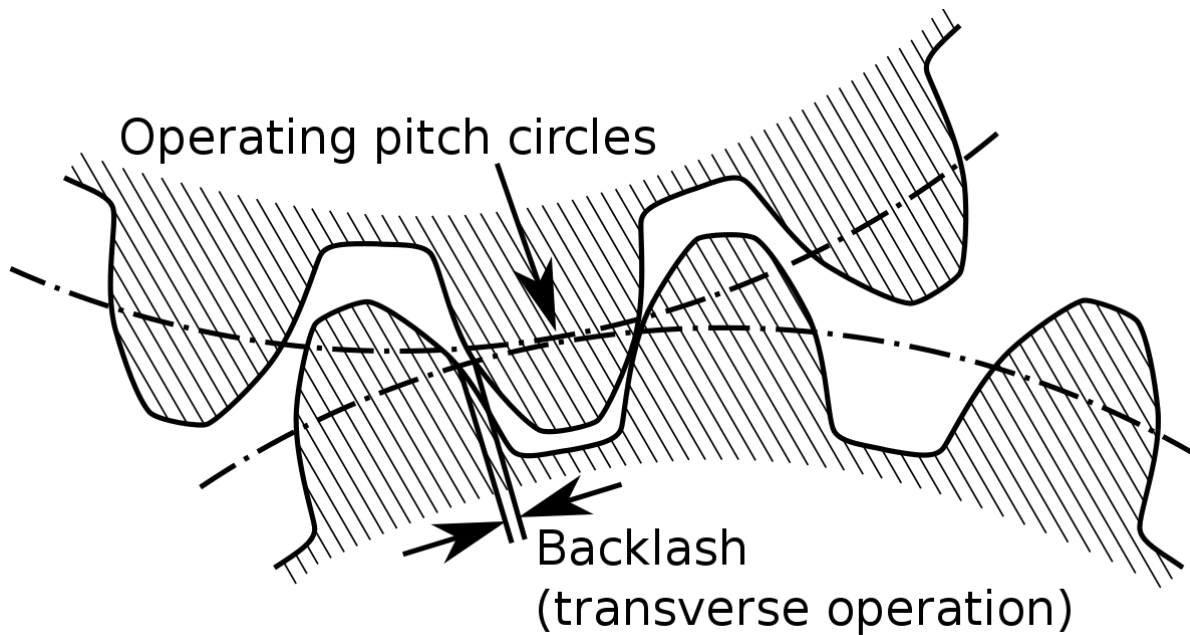
The smallest motion could be achieved by the system reliably. As smaller motion the system can achieve, the better accurate is the system. .(Newport,2019)

Repeatability

The ability of the system of doing the same exact motion by going back to the same position over and over with the same precision and accuracy regardless of the direction from which the position approached. .(Newport,2019)

Backlash

It is the lost motion or delay in motion in the driven gear when the driving gear moves in reverse motion, due to improper meshing or gaps between the teeth, which causes inaccurate output motion of the system. As shown in the figure below. .(Newport,2019)



Available at: www.google.com
 Accessed 08/03/2019

Hysteresis

Is the overall response of the system to a change in direction due to elastic forces such as leadscrew wind up. .(Newport,2019)

Tilt and wobble

It is the deviation between the ideal straight-line motion, and the measured straight-line motion on either X axis or Z axis of the drill. .(Newport,2019)

Play

It is the uncontrolled movement due to the system parts are not connected together tight enough. .(Newport,2019)

Friction

It is the resistance of the contacting surface to the motion of the arm where the drill is connected to, and other elements like drag and lubrication could add to it. .(Newport,2019)

Stiction

It is the static friction when the motion system is at rest which should be overcome to get the system to move. This affects the system as when the applied force on the driving gear increases gradually until it reaches the threshold where it overcomes the static friction, causing the system to overshoot by start moving suddenly. .(Newport,2019)

Inertia

Inertia is the tendency of the body to stay unchanged in its existing state, so the larger inertia of the system, the greater torque required from the motor to drive the system. .(Newport,2019)

Overcoming the challenges

To overcome the design challenges mentioned earlier, I decided to make this system as closed loop feedback system. In order to that, I need to choose the right bearings system, the mechanical drive system options, the drive options and the feedback devices.

First: Bearings system

Bearings provide smooth motion by reducing the friction between the surface and the drill arm, many types of bearings could be used such as:

Ball bearings

Ball bearings reduce friction by converting the sliding motion into rolling motion, they are relatively insensitive to the contamination, because, each ball contact the guide way at only one point allowing debris to be pushed away, also have lower load capacity than crossed roller-bearing.

Cross roller bearings

This type of bearings offers all the features of the ball bearing adding to that more stiffness and more load capacity.

As the drill moves in a linear motion along the X axis and along the Z axis, I decided to use two linear rail ball bearing one on each side of the drill arm to provide the drill arm smooth motion reducing friction and avoid any angular error keeping the drill exactly on the Z axis, avoiding the drill from tilting and wobbling, also elongating and playing, as shown below



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Second: the mechanical drive system options

The most commonly used drive systems for linear motion in CNC machines are: leadscrew, ball screw and rack and pinion.

Leadscrews and ball screws

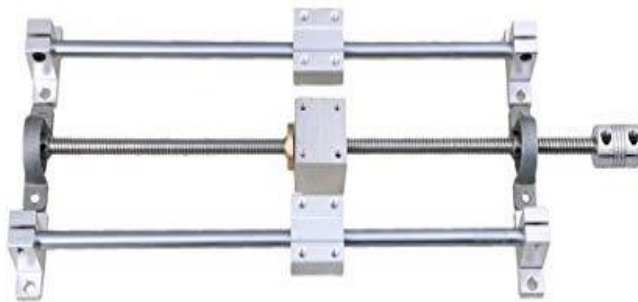
lead screw uses the helix angle of the thread to translate the turning motion into linear motion, it depends on the coefficient of friction between the screw and the nut, providing efficiency range from 20% to 80%. (thomsonlinear,2019).

While ball screw uses the same concept of motion translation but depends on recirculating ball bearings to minimize friction between the screw and the nut which provide efficiency up to 90%. (thomsonlinear,2019).

Rack and pinion

Its another way of translating the turning motion onto linear motion by connecting two gears together, the rack which is driven gear and the pinion which is the drive gear. It is much cheaper than the screw but if the gears are not meshed properly that produces backlash.

Therefore, in this task I could use either screw or rack and pinion system on each dimension, but for more precision and accuracy, also as I am not concerned about the cost, I decided to use ball screw systems on both dimensions, as shown below



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Third: the drive system

There are many types of drives could be used in automated systems such as electrical drives, hydraulic drives and pneumatic drives. But in CNC machines usually electrical drives are used as they are small and easy to control unlike the hydraulic drives which are bulky and hard to maintain, and the pneumatic drives which are noisy and have low power and accuracy.

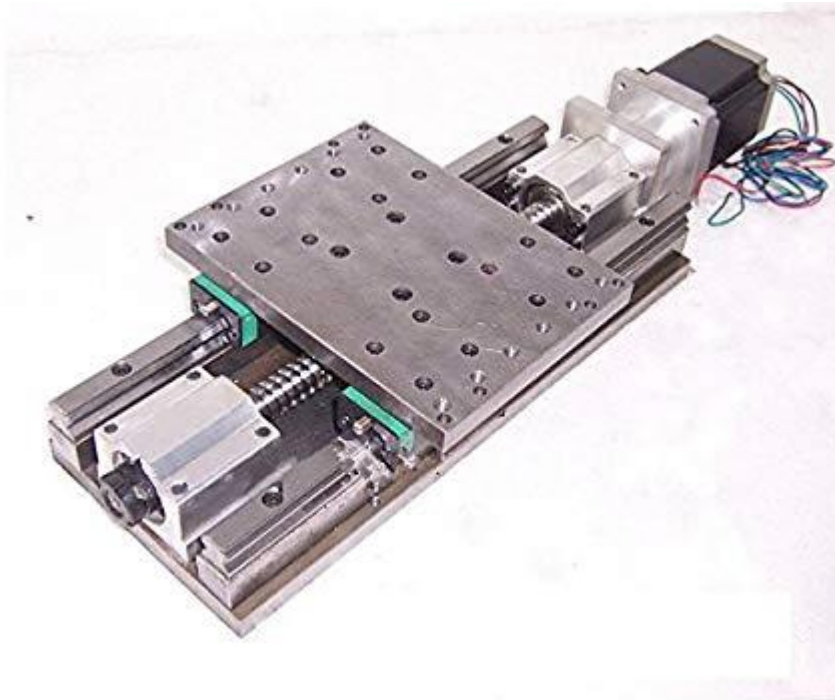
There are many types of AC and DC motors but the most commonly used in CNC are the stepper motor and the servo motor.

I decided to use stepper motor, as it provides more accuracy to the system because of the steps in it so the increment of the system could be very small, and easy to connect it with a feedback system.

Fourth: feedback devices

There are many feedback devices could be used to measure the position such as a potentiometer, the linear variable differential transformer (LVDT), hall effect sensors, magneto resistive element (MRE) incremental optical shaft encoder and the absolute position encoder.

I will be using the absolute encoder as feedback system, which will be included in the stepper motor, and the whole motion and control system for each axis will look as shown below



Available at:
www.google.com
 Accessed on 10/03/2019

Comparison between position measurement devices

Hall effect sensor

Advantages of Hall Effect Sensors

- Hall Effect sensors are not affected by ambient conditions, such as dust, humidity.
- Hall Effect sensors are non-contact sensors so they do wear over time.
- They could work on high speed systems up to 100 KHz
- Hall sensors can measure zero speed.
- They work in high temperature range and measure high currents.

(AZOsensors,2019)

Disadvantages of Hall Effect Sensors

- They cannot measure the current from distance greater than 10 cm.
- Their current measurement changes due to their interface with external magnetic fields as they use the same principle to operate.
- Large offset voltage.

(AZOsensors,2019)

Linear variable deferential sensor (LVDT)

Advantages

- High Range: it can measure displacement from 1.25mm to 250mm
- Friction and Electrical Isolation: as there is no contact between the core and the coil, it has long life as there is no wear.
- High Output: it has high output voltage mostly does not need amplification.
- High Sensitivity: its sensitivity reaches 40V/mm.

- Ruggedness: it can bear shocks and vibrations.
- Low Hysteresis: it has low hysteresis therefore has good repeatability.
- Low Power Consumption: it consumes low power, typically less than 1 W.
(test and measurement world,2019)

Disadvantages

- It is sensitive to the other magnetic fields around.
- Its measurement is affected by the temperature.
- In order to change the output voltage into DC, it needs demodulator circuit

Linear potentiometer

Advantages

- It is cheap
- Good for the application with no extreme accuracy required.
- The output voltage does not need amplification

(electricalvoice,2019)

Disadvantages

- The measurement changes when the contacts of the potentiometer wear out as it is a contact-based technology.
- The measurements are affected by heat, humidity, pressure and vibration
- less accurate than non-contacting technologies
- Poor repeatability with varying temperatures.
- The measurement accuracy decreases because of the drag created by the friction between the potentiometer whipper and the surface.

(cpi.nj, 2019)

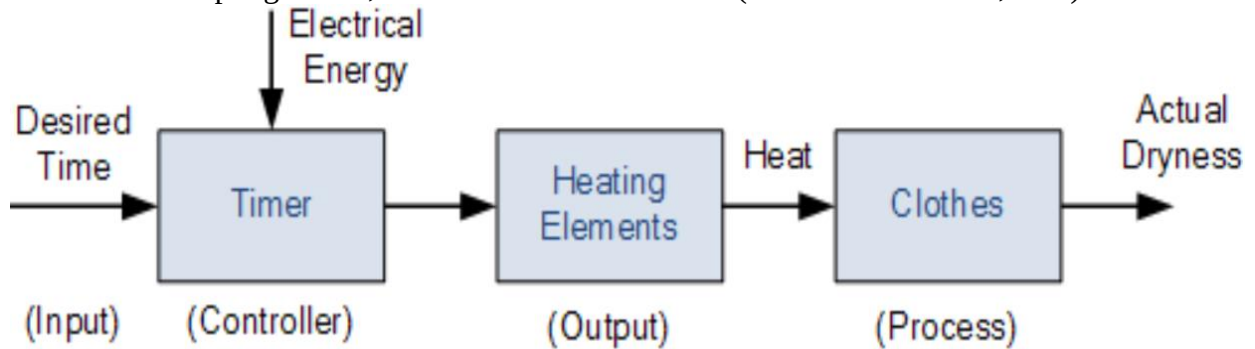
Task three

Comparing open loop to closed loop system

Open loop system

It is a control system designed to strictly follow the input regardless of the final result, as it has no feedback to measure and compare the output of the system to the input.

An example of open loop system, an electrical clothes dryer works with a timer, the user could decide how long to put it on for according to the amount of the clothes and how wet they are, if the user set the timer (controller) for 10 minutes the dryer will start and after 10 minutes will stop regardless, even if the clothes still wet.(electronics tutorials,2019)

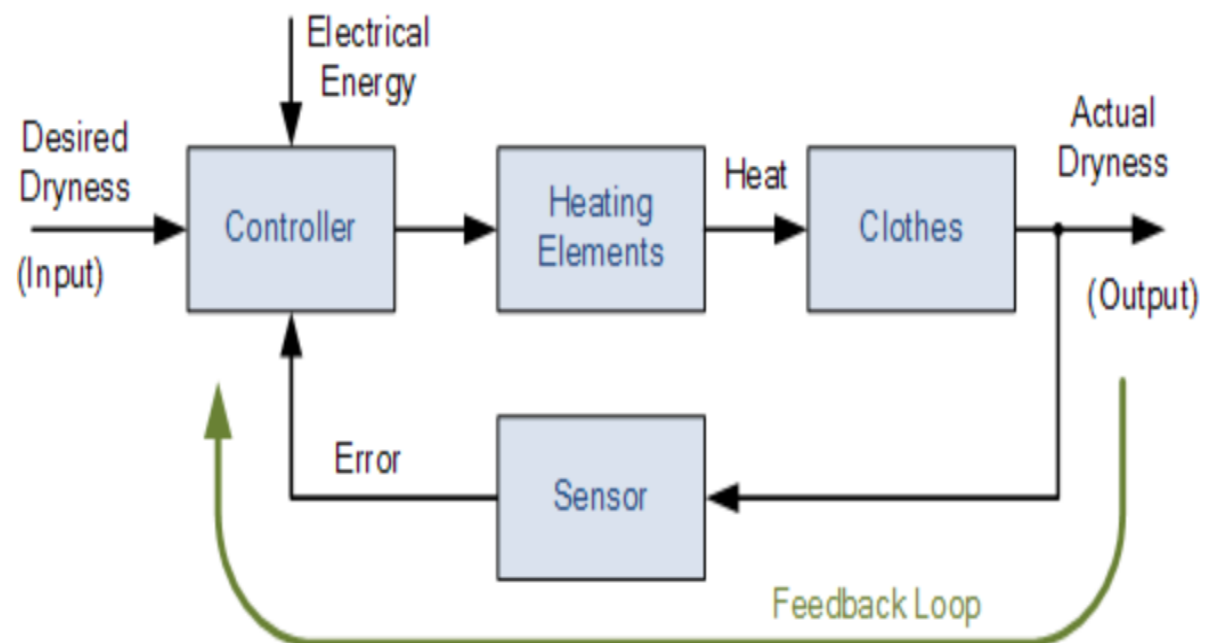


(electronics tutorials,2019)

The closed loop system

It is a fully controlled system designed to keep and maintain the output of the system at the desired condition by measuring and comparing the output to the input of the system which called feedback.

On the figure above suppose there was a sensor measuring the temperature of the clothes and sending this temperature to controller, the controller will set the temperature accordingly to get the clothes dried. This system could be drawn as shown below. .(electronics tutorials,2019)



.(electronics tutorials,2019)

Open loop system characteristics

- There is no comparison between the actual output and the desired output of the system.
- The disturbance or the change of the system set up does not change the output.

(electronics tutorials,2019)

Closed loop system characteristics

- Reduces errors by measuring the output and comparing it to the input.
- Improves the stability of the system.
- Increases the system sensitivity.
- Enhances robustness against external disturbances.
- Produces repeatable action.

(electronics tutorials,2019)

Control terminology

Set point

It is an output value set by the user to get the system maintain the same output despite of the internal and external disturbance, such as the speed cruise control in some cars, where the driver could set speed and the car remains on that speed, and if any disturbance like the driver press the fuel pedal, then the control system restores the speed to the desired one in optimum way.

Process variable

It is the current value of the output of the system, in the previous example suppose the driver of the car pressed the fuel pedal and the speed become 25 Km/h, so the process variable of the cruise control system is 25 Km/h.(wikipedia,2019)

Plant

It is anything to be controlled by means of the controller and the action of the controller is applied to, in the last example the plant is the car.(wikipedia,2019)

Settling time

It is the time taken by the process variables of the system to settle within specific percentage to the desired value, this could be the time the cruise control system takes to retain the speed back to 25 KM/h after disturbance caused by the driver pressing the fuel pedal, or after the start on the engine. (national instruments,2019)

Steady state error

Is the difference between the set point (desired value of the output of the system) and the process variable (current value of the output of the system), this could be the difference between the required speed which is 25 Km/h and the speed at any point after the car settled after the start of the engine, or after disturbance caused by the driver by pressing the fuel pedal.(national instruments,2019)

PID

This stands for proportional integral derivative controller which is an instrument continuously measures and regulates the process variables such as temperature or pressure and sending this value to the controller through the feedback to control it and keep it on the set point.

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