Sensing Elements

Definition : **Any device that receives a signal or stimulus (as heat or pressure or light or motion etc.) and responds to it in a distinctive manner**.

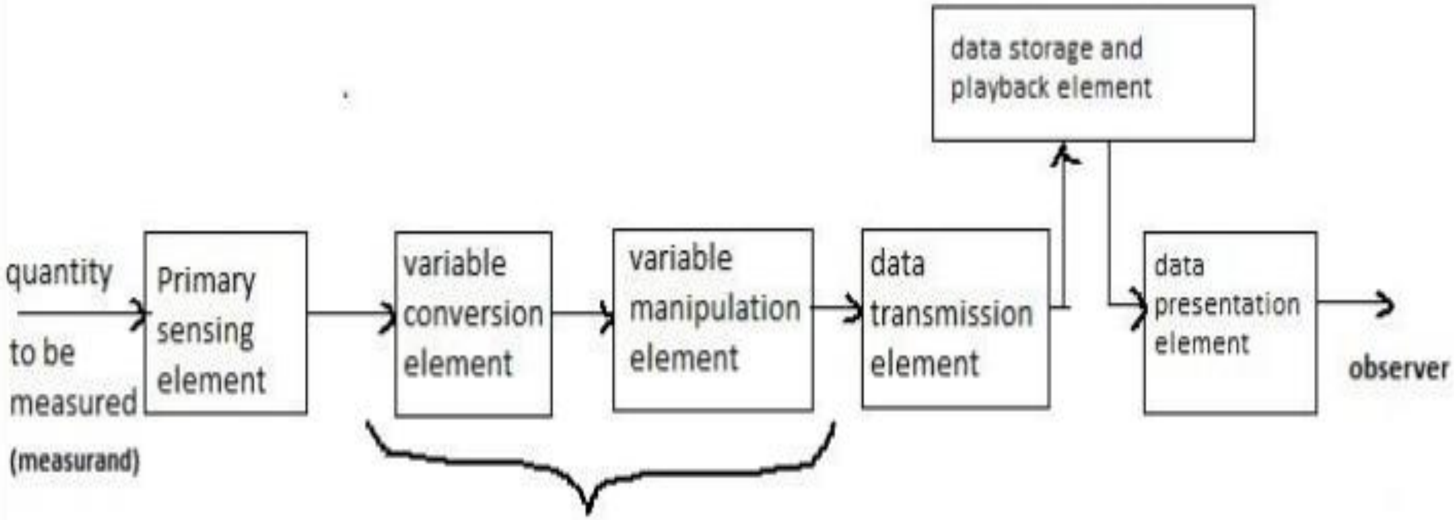
Sensing element used for : Sensors are the device that **detects physical or chemical changes which may include pressure, force or any electrical quantity**. In other words, sensors are the devices which help to sense the signal from an object or human. After detection, the signals are sent to the processor.

Sensing device means **a device capable of acquiring data from its surroundings**. Sensing devices include, but are not limited to, cameras, microphones, thermal detectors, chemical detectors, radiation gauges, and wireless receivers in any frequency (including cellular, WiFi, or other data frequencies).

Force Sensing

Elastic Sensing:	$F = k \cdot x$
Strain Sensing:	$F = \sigma \cdot A$
Pressure Sensing:	$F = P \cdot A$
Acceleration Sensing:	$F = m \cdot a$

Functional elements of an Instrument



Sensing Elements

Sensors are the device that detects physical or chemical changes which may include pressure, force or any electrical quantity. In other words, sensors are the devices which help to sense the signal from an object or human. After detection, the signals are sent to the processor. Finally the sensor produces an output signal that corresponds to the input signal.

A transducer is a device / instrument that convert one form of energy into another. Generally, it produces electrical output only. It is classified into different types of transducers namely resistive, inductive, capacitive, ultrasonic, piezoelectric, pressure transducers, etc.

Types of Resistive Sensors & Transducers

- Resistive Transducers
- Potentiometers
- Strain Gauges

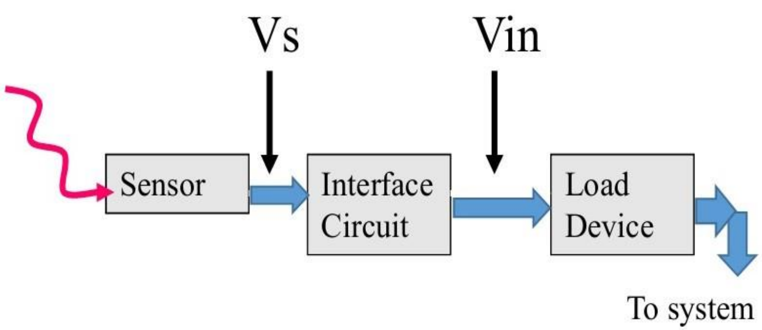
➢The most commonly used type of transducer is variable **resistance transducer.** It is otherwise called as **resistive sensors**. It measures **temperature, pressure, displacement, force, vibrations, etc**

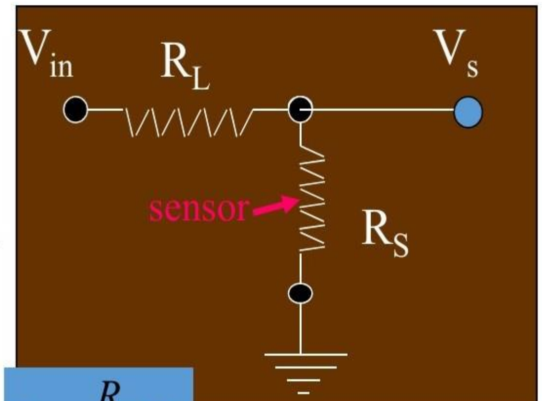
Resistive Sensor Circuits

Resistive device obeys Ohm's law which means that voltage difference across the resistance is proportional to the current.

So one way to measure resistance is to make current flow through it.

That means one needs to make a current source which can be built from a voltage source and a resistance whose value is much larger than sensor resistance.





$$V_s = \frac{R_s}{R_s + R_L} V_{in}$$ If $R_L >> R_S \Rightarrow$ $$V_s = \frac{R_s}{R_L} V_{in}$$

Is that your response function?

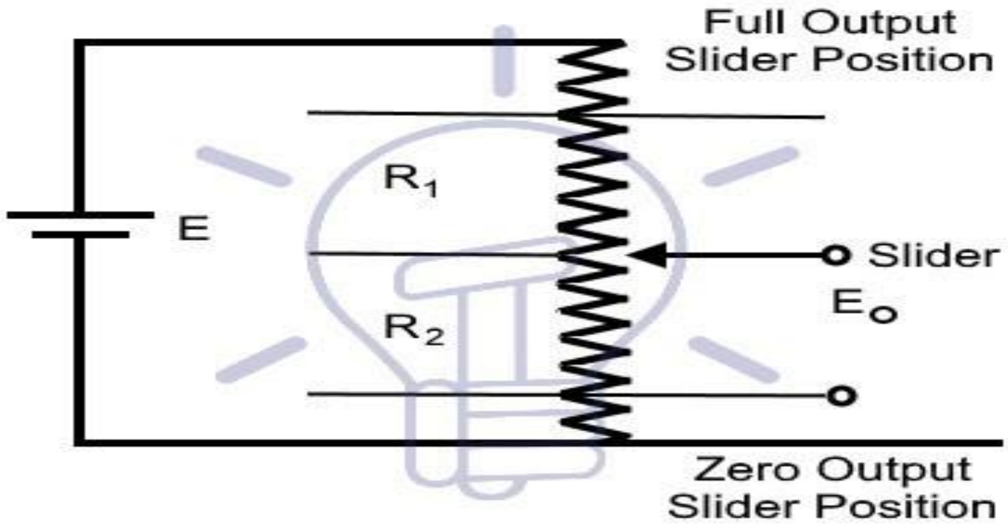
Working Principal of Resistive Sensor:

to understand the working principle, consider a conductor rod. Resistive sensors works on the principle that, **the conductor length is directly proportional to resistance of the conductor and it is inversely related with area of the conductor**. Therefore, L is denominated for conductor length, A for area of the conductor and R for resistance of conductor. **ρ is the resistivity** and it is constant for all the materials used for conductor construction.

$$R = \frac{\rho L}{A}$$

- The resistance of the transducer varies due to external environmental factors and physical properties of the conductor.
- AC or DC devices are used to measure the resistance change. **This transducer acts as both primary and secondary transducer.**
- As a primary transducer, it converts physical quantity into mechanical signal.
- As a secondary transducer, the obtained mechanical signal is converted into electrical signal.

Sliding Contact Devices: Every sliding contact type of resistance transducer consists of a long conductor whose length can be varied. One end of the conductor will be fixed while other end of the conductor is connected to a slider or a brush which moves along the full length of the conductor.



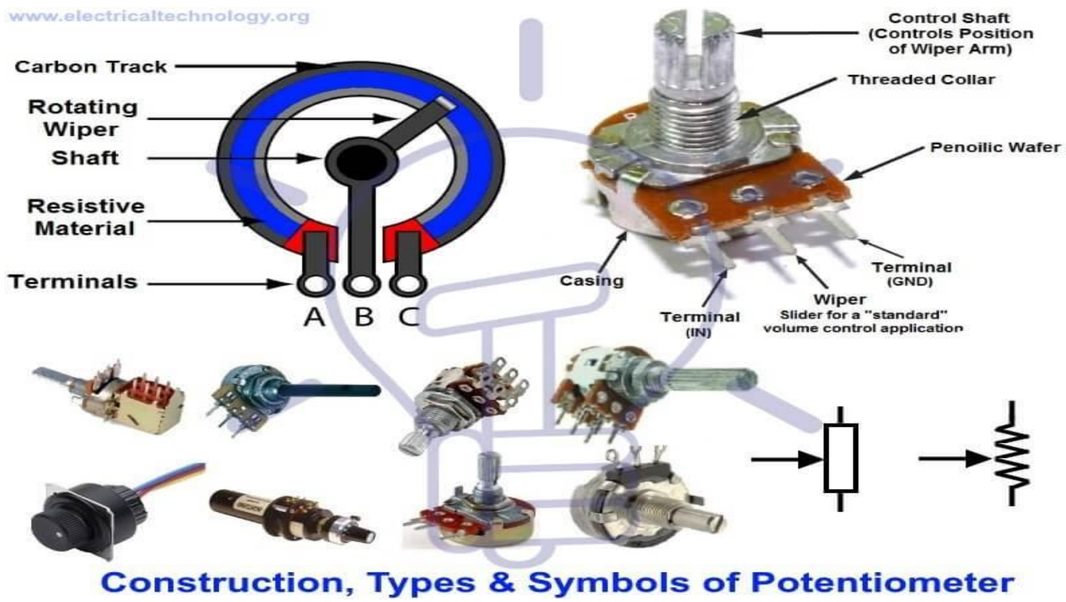
Sliding Resistive Transducer

- The slider is connected to the object whose displacement has to be measured.
- When a force is applied to the object to move them from its initial position, the slider also travels all along the length of the conductor.
- Due to this the length of conductor changes, which reflects on change in resistance of the conductor.
- Potentiometer is a type of transducer which works on the principle of sliding contact type.
- Potentiometers are used to measure linear and angular displacement.

Potentiometers:

What is a Potentiometer?

A potentiometer is also called as pot. It is variable resistor that has 3 terminals. Two fixed terminals and one variable terminal. In this device the current flow is controlled by varying the resistance manually. Potentiometer does the function of an adjustable voltage divider.



Working of Potentiometer:

- Potentiometer is a passive component that works on moving the slider across the full length of the conductor.
- The input supply voltage is applied to the entire length of the resistor.
- The output voltage is measured as voltage drop between fixed and movable contact as seen in the figure below.
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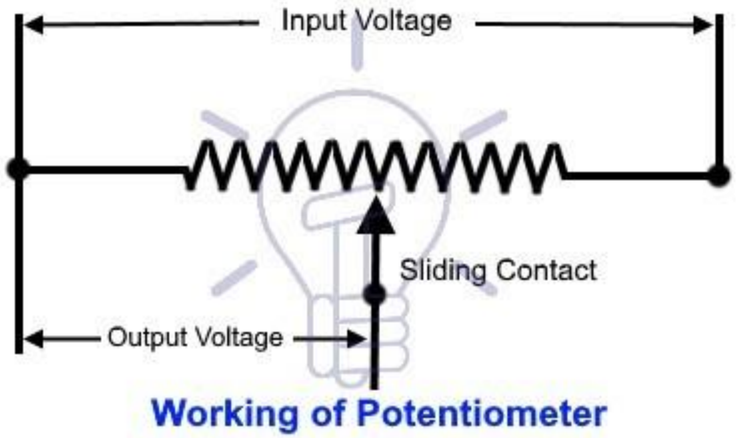


- The slider is adjusted manually over the resistive strip to change the resistance value from zero to a higher value.
- When the resistance changes, the current flowing through circuit changes. Hence according to Ohm's law, the resistive material also changes.
- Assume that two batteries are connected in parallel through galvanometer.
- Negative ends of both batteries are connected together and similarly both positive ends are connected together.
- Since ***both batteries carry same electric potential, there will be no current flowing through galvanometer and its does not show deflection.*** The pot also works on the same phenomenon.

Types of Potentiometers:

- Linear Potentiometer
- Rotary Potentiometer

Rotary Potentiometer: Adjustable supply voltage can be obtained using rotary potentiometer. A familiar **example is volume controller of a radio transistor,** in which the amplifier supply is supported by the rotary knob of the pot. The other applications are it is used when the end user needs smooth voltage control.

Linear Potentiometer: It works same as the rotary potentiometer but the only difference is slider moves linearly on the resistor. The resistor ends are connected across the supply voltage. The two ends of the output circuit are connected to the sliding terminal and resistor terminal

Applications of Potentiometers:

- Potentiometer as a Voltage Divider:
- Audio Control
- Television
- Transducers
- Pots as measuring devices:
- Pots as tuners and calibrators
- To compare the emf of a battery cell with a standard cell
- To measure the internal resistance of a battery cell
- To measure the voltage across a branch of a given circuit

Strain Gauges

What is stress & strain?

- When a force is applied on a material, internal pressure of the material is measured and that is called ***stress***. Due to the internal pressure, there will be deformation of shape. Stress is given as change in force per unit area.
- ***Strain*** occurs due to stress. Due to the stress applied, the material will be elongated or compressed. So, strain is defined as ratio of change in length produced due to force to the original length of the material.
- It is most common used for force measurements used in **Robotics.**

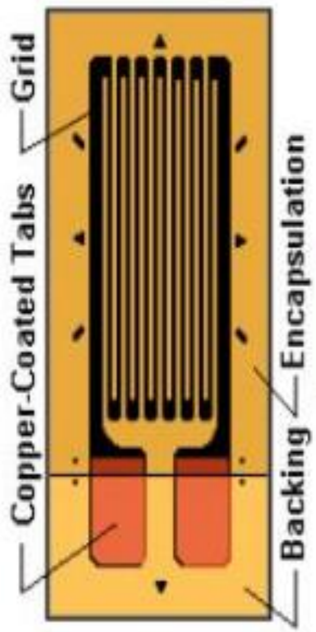
Working Principle of a Strain Gauge:

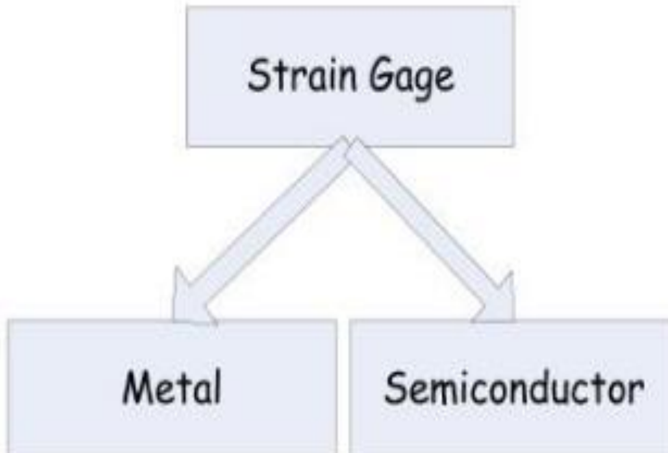
- A strain gauge is a sensor, ***which results in change of resistance due to the applied force.***
- The parameters like force, pressure, etc. are converted into measureable electrical resistance.
- To a stationary object, when external forces are applied, it results in stress and strain. So here,. If L_1 is ***stress*** **is defined as internal resistance of the object and** ***strain*** **is given as displacement and deformation**
- the initial length of the conductor L_1 and L_2 is the length of the conductor after application of force.

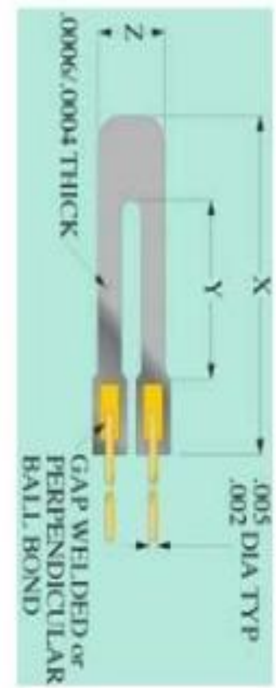
$$\varepsilon = (L_2 - L_1) / L_1$$

- When a stress is applied to the conductor, length and area of the conductor changes, due to which resistance also changes.
- Another parameter which is changed is the **resistivity of the conductor**. So there is a property called as **Piezo-resistive Effect**, which tells about change in electrical resistivity due to the applied strain. Hence strain gauges are also called as **piezo-resistive gauges**.

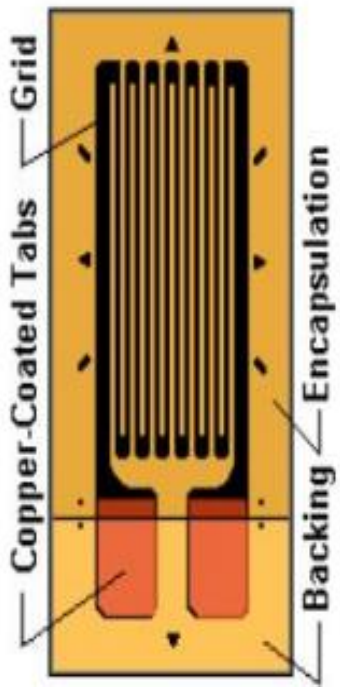
Strain Gages





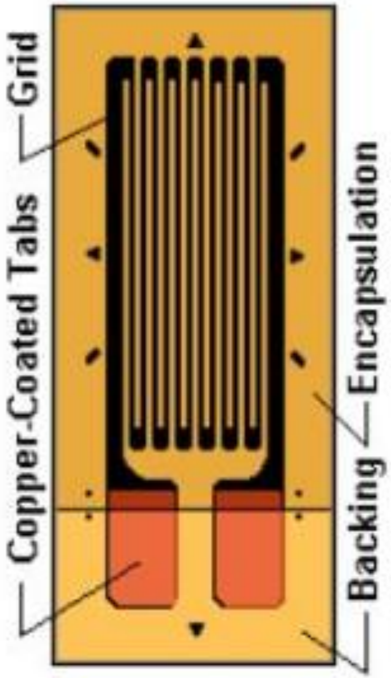


Metal Strain Gages



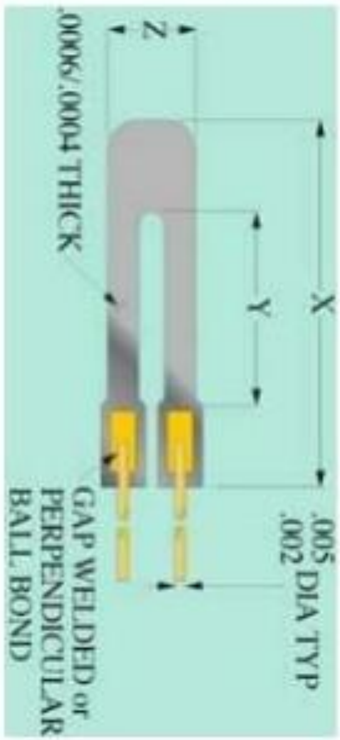
- The able to measure up to 30000με for gage lengths under 3mm, up to 50000 με for gage lengths of 3mm and over
- Nonlinearity = 0.02%
- Small and light
- Able to response to high frequency signals
- Gage factor of 2-4

Metal Strain Gages



- Low in cost
- Low resistance and gage factor to temperature coefficients
- Easy compensation
- Temperature Range -80 °C to +200 °C
- Fatigue Life of 10^4 cycles at ±2000με
- Come in different patterns

Semiconductor Strain Gages



- Operating strain ± 2000με
- Maximum strain up to ± 5000με
- Subminiature size
- Wide range of frequency response
- Linearity
  - Better than 0.25% for up to ± 600με
  - Better than 1.5% for up to ± 1000 με
- Gage factor of 100-180
- High resistance/temperature and gage factor/temperature coefficients
- More difficult temperature compensation

Semiconductor vs Metal

Low tension output and extended range

- The larger signal output from silicon gages allows measurement of very low tensions.
- Transducers with metal gages have difficulty with low tensions because the nominal output is so low that it can be lost in the ambient electronic noise present in the electrical system

Strain Gauges Principle of Operation

- **Piezoresistive effect in metal strain gages**

The resistance change effect of metal gage sensors is only due to the change of the sensor geometry resulting from applied mechanical stress.

$$GF = \frac{dR/R}{dL/L} = 1 + 2\upsilon$$

- **Piezoresistive effect in emiconductor strain gages** The resistance of silicon gages changes not only due to the stress dependent change of geometry, but also due to the stress dependent resistivity of the material. This results in larger gauge factors than those observed in metals.

$$GF = \frac{dR/R}{dL/L} = 1 + 2\upsilon + \frac{d\rho / \rho}{dL / L}$$

Poisson's ratio

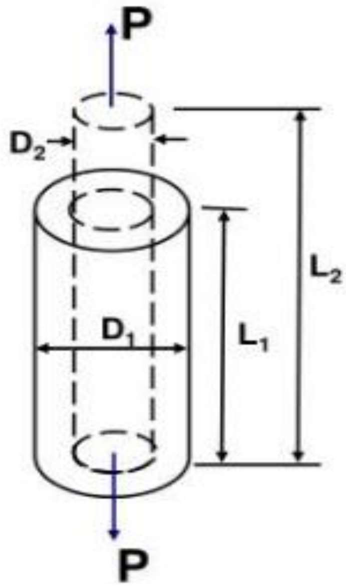
Definition

- Poisson's ratio is a measure of the simultaneous change in elongation and in cross-sectional area within the elastic range during a tensile or compressive test.
- During a tensile test, the reduction in cross-sectional area is proportional to the increase in length in the elastic range by a dimensionless factor, the Poisson's ratio

$$\varepsilon_A = \frac{L_2 - L_1}{L_1} = \frac{\sigma_a}{E} = \text{Uniaxial Strain}$$

$$\varepsilon_L = \frac{D_2 - D_1}{D_1} = \text{Lateral Strain}$$

$$\upsilon = -\frac{\varepsilon_L}{\varepsilon_A} = \text{Poisson's Ratio}$$



$$GF = \frac{dR/R}{dL/L} = \frac{dR/R}{\varepsilon_L}$$

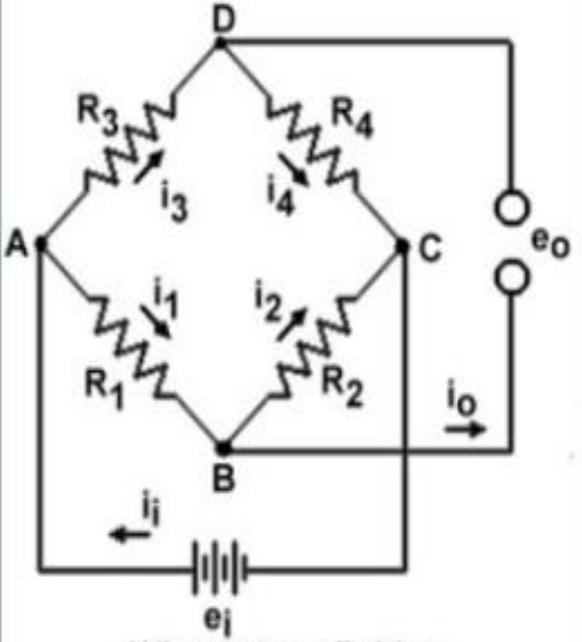
$$\varepsilon = \frac{1}{GF}\frac{dR}{R}$$

- GF and R are known, by measuring dR the strain ε can be determined
- By knowing the sensing geometry and material properties the force can be obtained

Measurement of dR

- The resolution limit of most strain gauge measurements is 'about' (1 με).
- A typical metal gage has a resistance of 120 ohms and a gage factor of 2.0, this implies that we have to be able to resolve a change in resistance of dR = 120x2.0x10-6 = 0.00024 ohms

Measurement of dR

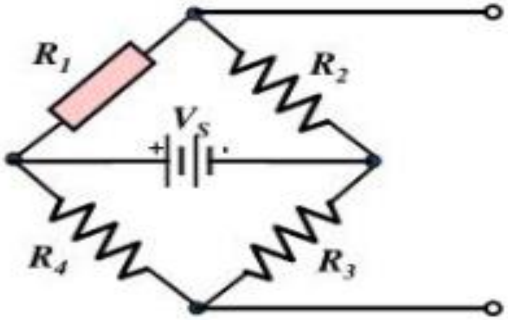


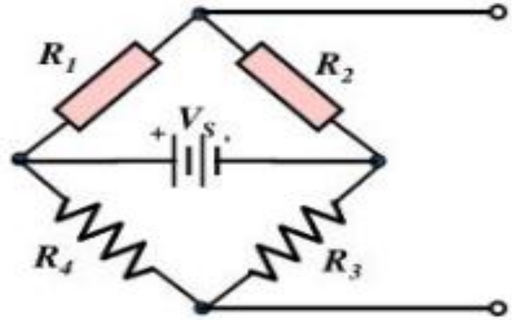
Wheatstone Bridge

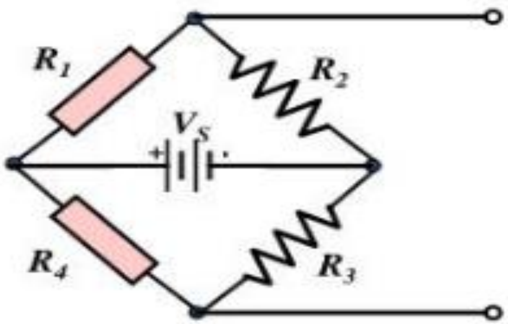
Wheatstone bridge is typically used

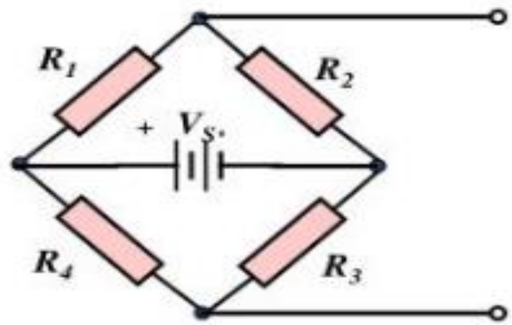
Sensitive instrumentation is required to measure the small changes in resistance produced by strain gauges.

Common Strain Gage/Bridge Arrangements









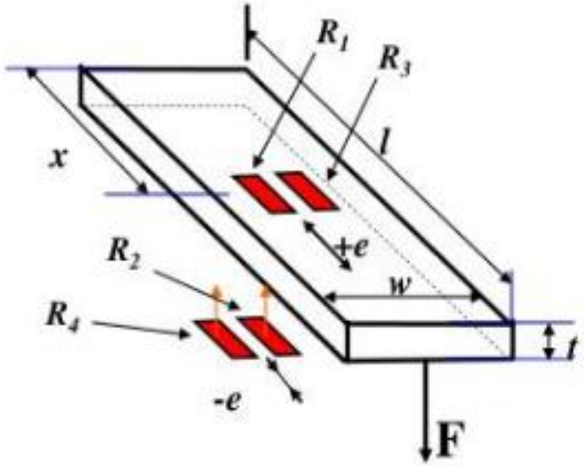
Sensing Geometries

For the sensing geometry it must be possible for an applied load to relate the load to the stresses and strains in the object.

- Given the value of the strain (given by one or more strain gauges), the applied load can be found.
- Cantilever beams, Pillar cells, and Tubes, are ideal elements for their simple geometry.

Application of Strain Gages

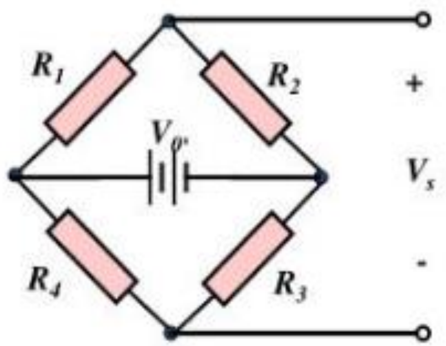
Single Axis Sensing Cantilever cells



Strain gages are used in cantilever type load cells

$$e = \frac{6(l-x)}{wt^2E}F$$

$$V_0 = \frac{V_s R_2 R_3}{(R_2+R_3)^2}\left[\frac{\Delta R_3}{R_3} + \frac{\Delta R_1}{R_1} - \frac{\Delta R_2}{R_2} - \frac{\Delta R_4}{R_4}\right]$$



Force Sensing

- Metal foil strain-gage based (load cell)
  - Good in low frequency response
  - High load rating
  - Resolution lower than piezoelectricity-based
  - Rugged, typically big size, heavy weight

Courtesy of Davidson Measurement

Pressure sensors-Fluids

Download

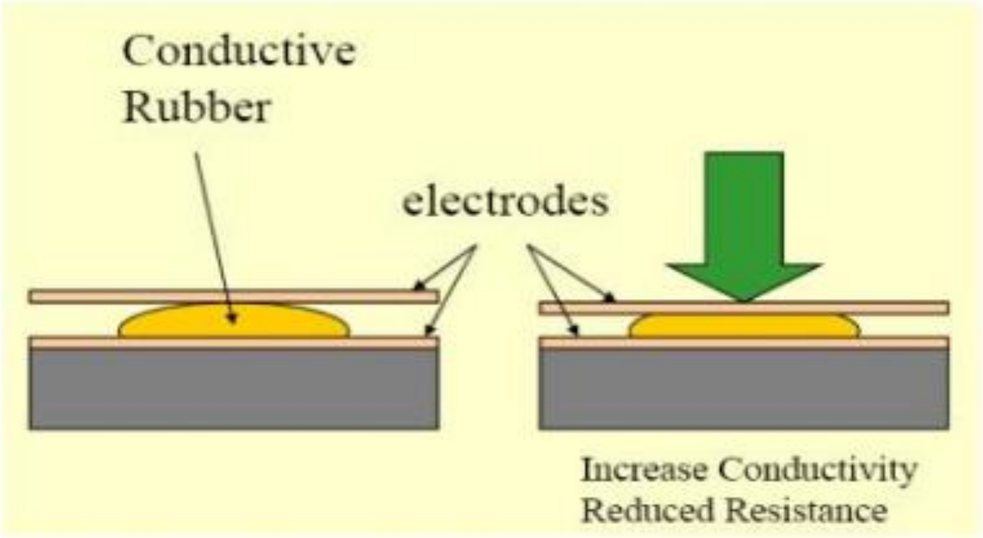
- A **pressure sensor** measures pressure, typically of gases or liquids
- **Absolute pressure sensor**
- This sensor measures the pressure relative to perfect vacuum pressure
- **Gauge pressure sensor**
- Measures the pressure relative to a given atmospheric pressure at a given location.
- **Vacuum pressure sensor**
- Measures pressure less than the atmospheric pressure
- **Differential pressure sensor**
- Measures the difference between two or more pressures introduced as inputs to the sensing unit

Sensing Principle

- ***Piezoresistive Strain Gage***
  - Uses the piezoresistive effect of bonded or formed strain gages to detect strain due to applied pressure.
- ***Capacitive***
  - Uses a diaphragm and pressure cavity to create a variable capacitor to detect strain due to applied pressure.
- ***Electromagnetic***
  - Measures the displacement of a diaphragm by means of changes in inductance
- ***Piezoelectric***
  - Uses the piezoelectric effect in certain materials such as quartz to measure the strain upon the sensing mechanism due to pressure
- ***Optical***
  - Uses the physical change of an optical fiber to detect strain due to applied pressure. A

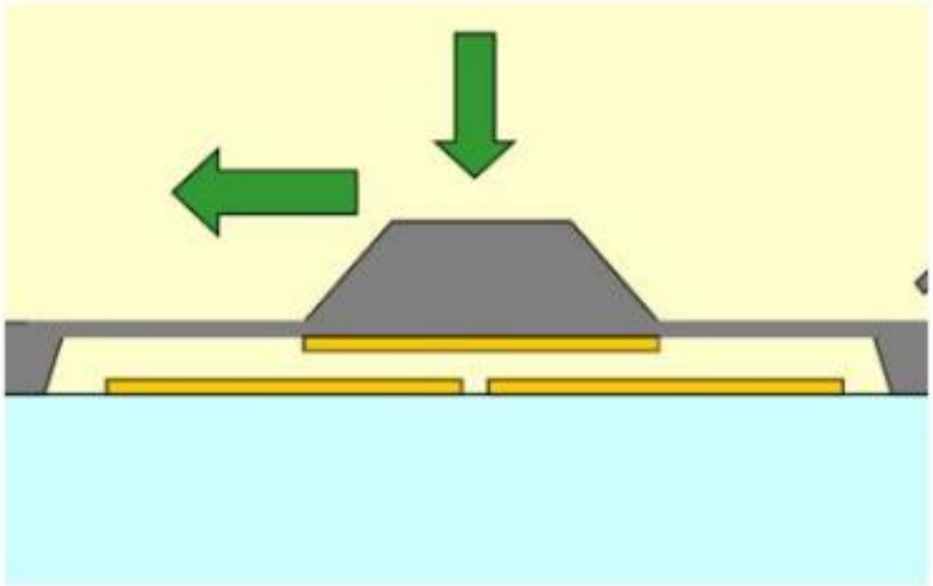
Pressure-Tactile Sensor

- Resistive



Pressure-Tactile Sensor

- Capacitive



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