Unit-2



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Unit-I (CO-I):

Different Sensors & Transducers: Resistive, Inductive & Capacitive Transducers. Potentiometer, strain gauge, LVDT, piezoelectric transducer, Temperature Sensors, Motion Sensors, Pressure sensors, Flow sensors, pH measurement.

By: Ms. Swati C. Hadke

What are Sensor and Transducer?

A transducer is a device that converts a non-electrical signal into an electrical signal. Transducers are referred to as energy converters. Transducers are of different types; input transducers and output transducers.

Example of transducers are:

•Thermocouple

•Microphones

A sensor is a device used to measure the physical changes in the surroundings, like temperature, light, etc., and convert them into a readable signal.

Examples of sensors are:

•Barometer

•Accelerometer

The transducer consists of a sensor and signals conditioning circuits and finds application in communication systems to convert the electricity to electromagnetic waves.

Difference Between Transducer and Sensor	
Transducer	**Sensor**
It helps in converting one form of energy into another form.	It senses physical quantities and converts them into signals read by an instrument.
It converts electricity to electromagnetic waves.	It senses physical quantity and converts it into analog quantity.
The antenna is one type of transducer. Microphones and loudspeakers are also of one type.	One type of Sensor is LED. Sensors are used in automobiles to detect touch and activate the siren.
It converts the measured quantity into a standard electrical signal like -10 to +10V DC	It measures voltage, capacitance, inductance, and ohmic resistance.
Examples: Strain gauge, piezoelectric transducer, linear transducer, and microphone.	Examples: Temperature sensor, thermistor, proximity sensor, and pressure switch.

Introduction to transducers

- A transducer is a device that converts one form of energy to other form. It converts the measurand to a usable electrical signal.
- In other word it is a device that is capable of converting the physical quantity into a proportional electrical quantity such as voltage or current.
- The physical quantity may be mechanical, chemical, optical or thermal.
- Transducers are classified based on,
    - Application.
    - Method of energy conversion.
    - Nature of output signal.

Classification of transducers

- Electrical transducers
  1) voltage, current, frequency.
  2) R, C, I component and its effects.
- Non-electrical transducers
  1) Detector (sensor): Physical quantity is obtained which is converted to electrical quantity.
- Displacement transducers
  Capacitive, oscillation, potentiometric, photoelectric, piezoelectric (Force Summing Devices).
- Opto-electronic transducers

Converts light energy into electrical energy. Photoconductive cell, photovoltaic cell, solar cell, photo tube, photo multiplier, etc.

Classification of transducers

The transducers can be classified as:

I. Active and passive transducers.

II. Analog and digital transducers.

III. On the basis of transduction principle used.

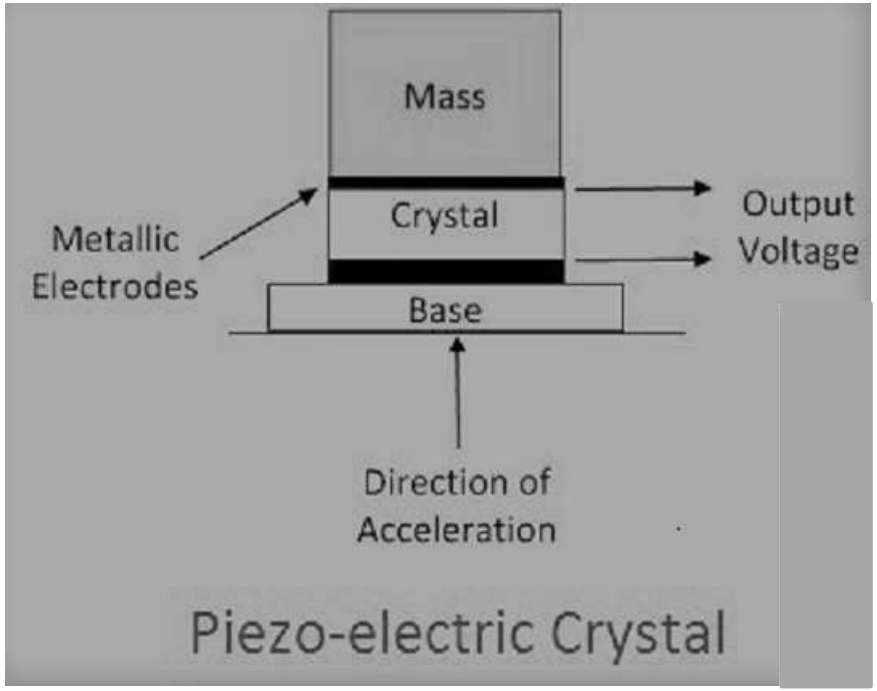
IV. Primary and secondary transducer

V. Transducers and inverse transducers.

Active Transducers

Active transducers are one which develop their output in the form of electrical voltage or current without any auxiliary source. They are also called self-generating transducers. Active transducers draw energy from the system under measurement and such transducers normally give very small output. Thermocouples used for the measurement of temperature, tacho-generators used for the measurement of angular velocity comes under this category.

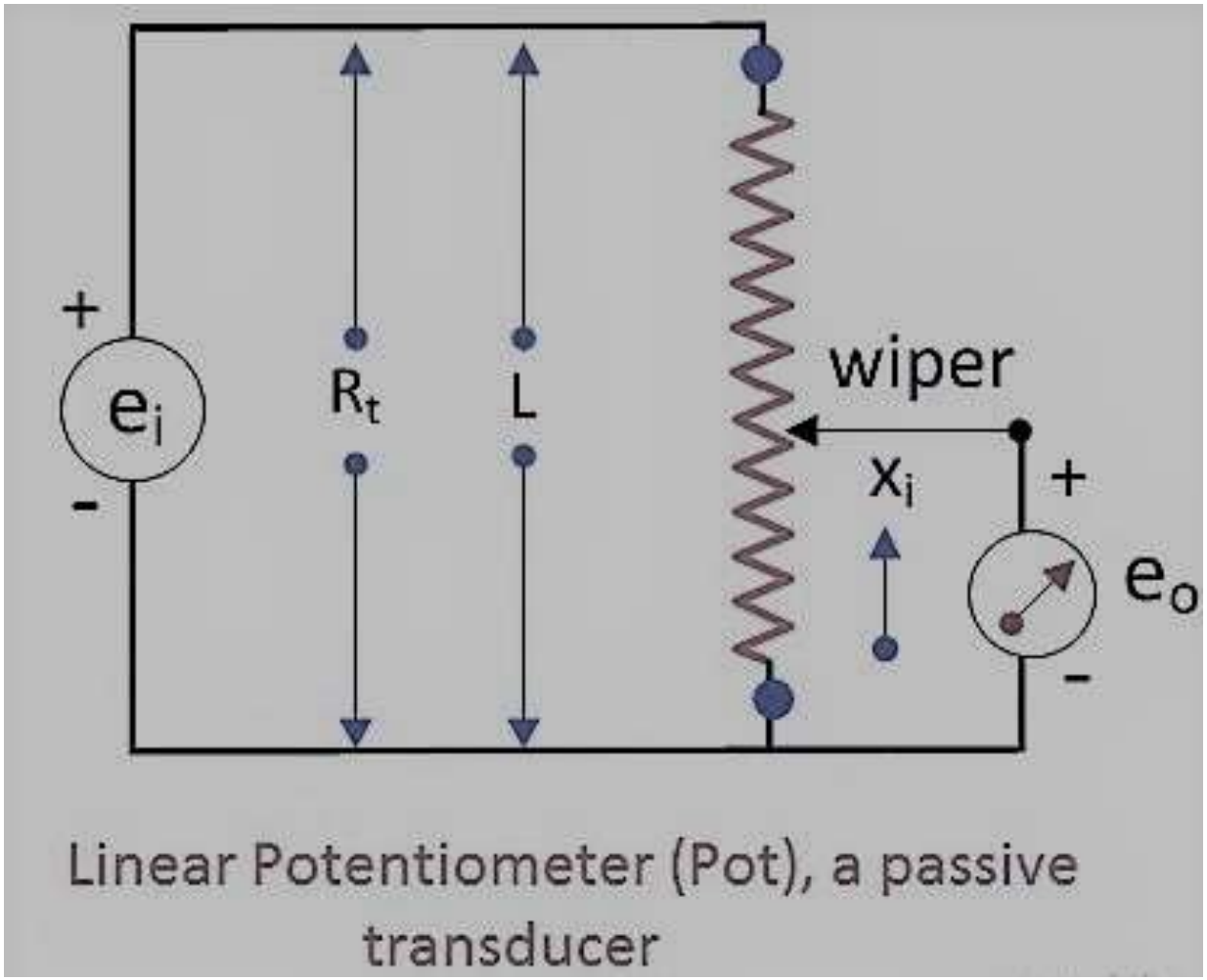
Active Transducers



In the example shown above, the crystal is sandwiched between 2 metallic electrodes, and the entire sandwich is fastened to a base which may be the floor of a rocket. On the top of the sandwich a fixed mass is placed which exerts a certain force due to acceleration on the crystal due to which a voltage is generated. The voltage output is proportional force and hence is proportional to acceleration. The property of piezo -electric crystal is that when a force is applied to them, they produce an output voltage.

Passive Transducers

Passive transducers are one which require external power source for energy conversion. In passive transducers electrical parameters like resistance, inductance, capacitance causes a change in voltage, current or frequency of external source. Resistive, inductive and capacitive transducers fall in this category.



Linear Potentiometer (Pot), a passive transducer

This is an example for passive transducer. A linear potentiometer is a resistive transducer powered by a source voltage ei and is used for the measurement of linear displacement xi.

Active and Passive transducers

Active Transducers	Passive Transducers
•Self-generating type. •Energy for generating output is obtained from physical phenomenon. •Thermocouple •Piezoelectric transducer •Photovoltaic cell •Photoelectric (photoemission) cell	•Externally powered. •Resistance type •Strain gauge •Potentiometric device •Thermistor •Inductive type •LVDT •Capacitive type •Hall effect transducer

Analog and Digital transducer

Transducers, on the basis of nature of output can be classified as analog and digital.

- **Analog transducers**: These type of transducers which convert input signal into output in the form of a continuous function of time such as thermistor, LVDT, thermocouple etc.

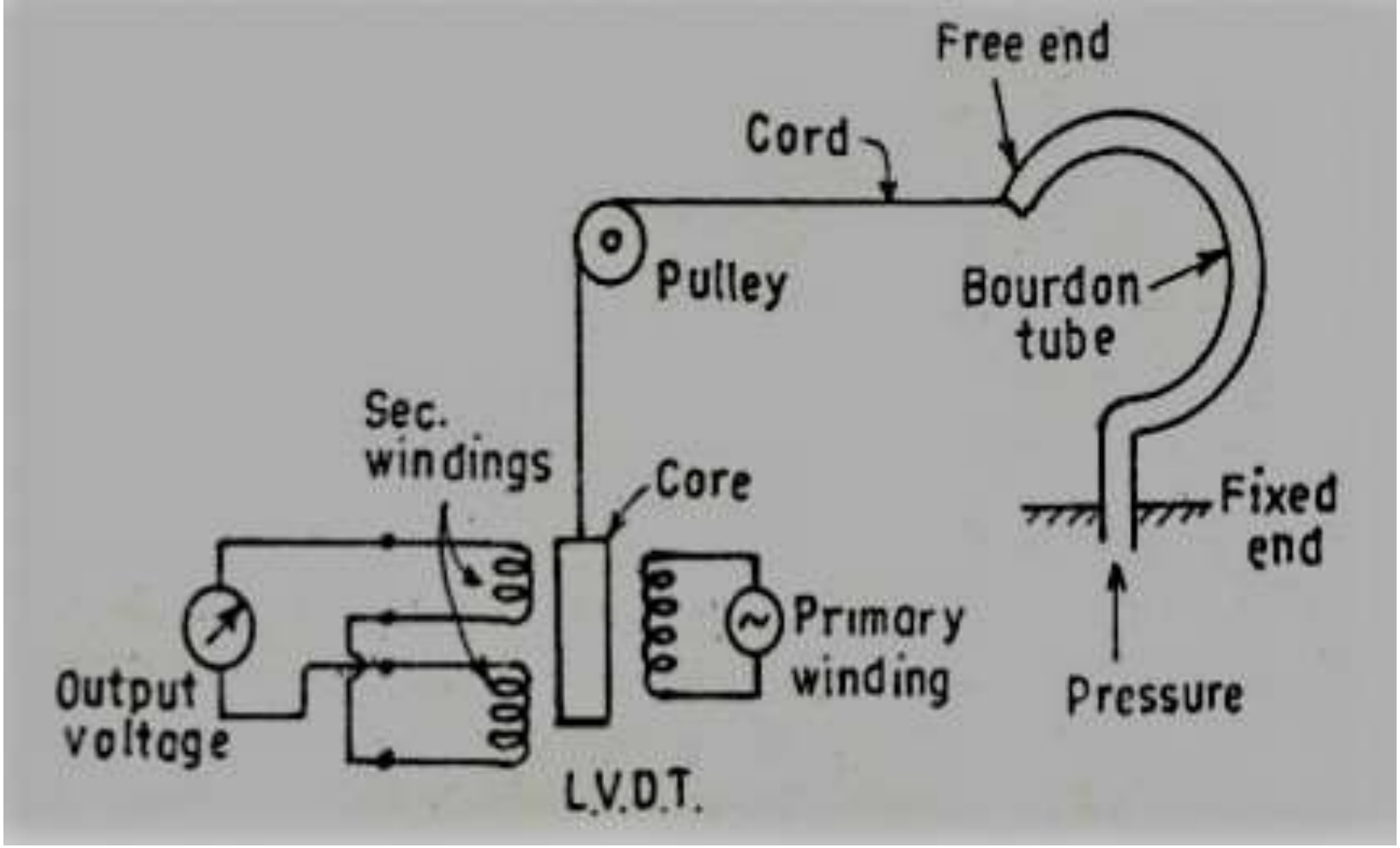
- **Digital transducers**: These type of transducers which convert input signal into output in the form of pulses. The examples of digital transducers are linear displacement transducers using conducting and non-conducting contacts, opaque and translucent segments and shaft encoders. It can be easily represented by opaque and transparent areas on a *glass scale* or non-conducting and conducting areas as the binary system uses only two symbols 0 and 1.

Classification based on the principle of transduction form used:

This classification is based on the principle of transduction as resistive, inductive, capacitive etc. depending upon their conversion into resistance, inductance or capacitance respectively. They can be classified as thermoelectric, piezoelectric, electrokinetic, optical and magnetorestrictive.

Classification as primary and secondary transducers

Primary transducer senses the input directly and physical phenomenon is converted into the electrical form directly. While in secondary transducer, initially input is being sensed by some detector or sensor and then its output in some form other than input signal is given to transducer to convert into electrical signal. Mechanical device acts as a primary detector transducer and the electrical device acts as the secondary transducer in most of the measurement systems with mechanical displacement serving as the intermediate signal.



As shown in the figure, the bourdon tube which senses the pressure and converts it into displacement of its free end and hence acts as primary transducer. The core of LVDT (linear variable differential transformer) is moved due to this displacement. Hence the LVDT produces output voltage proportional to that displacement of the free end of bourdon tube. Bourdon tube, which acts as primary transducer and LVDT acts as secondary transducer.

Transducers and Inverse transducers

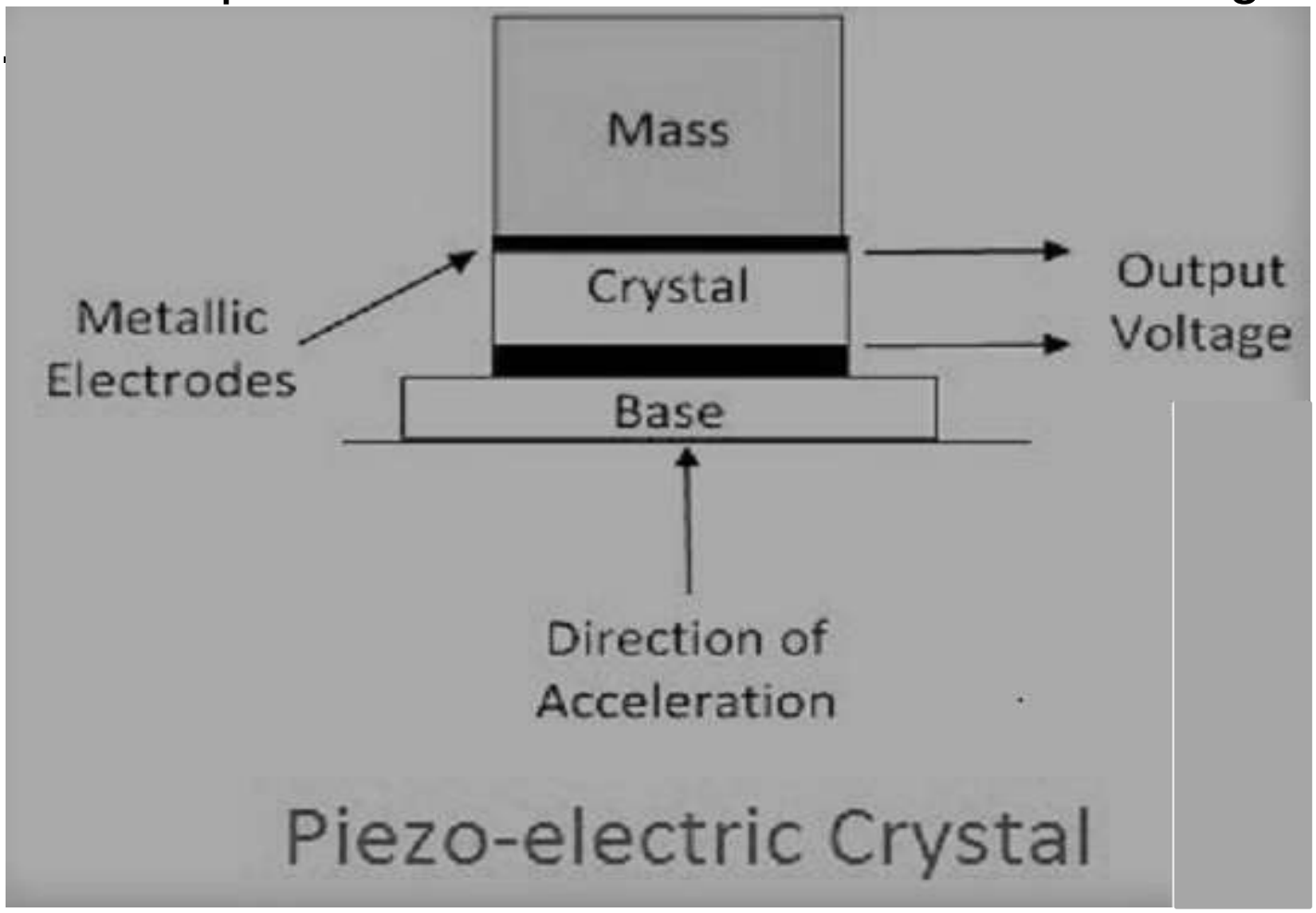
The basic requirement for control of physical quantities such as position, speed, temperature pressure and flow rate in an industrial plant is the ability to measure these quantities. The control action is only possible if the physical quantity can be measured.

Transducers as early mentioned converts a non-eletrical quantity into electrical whereas inverse transducers converts an electrical quantity into some other forms.

An example is a current carrying coil moving in a magnetic field is an inverse transducer as the current carried by it is converted into a force which causes a rotational or translational displacement. A large number of data indicating and recording devices are inverse transducers. Such devices which include instruments like pen recorders, oscilloscopes that convert electrical into mechanical movement are placed at the output stage are called as output transducers.

Transducers and Inverse transducers

The below diagram shows a piezo -electric crystal acts as an inverse transducer. When a voltage is applied across its surfaces, a mechanical displacement is caused as it changes its dimensions.



Basic requirements of a transducer

- **Linearity** –characteristics between input and output.
- ***Ruggedness*** **–**ability to withstand overload and protection measures.
- ***Repeatability*** **–**ability to produce same output for same input at different times and environment.
- ***High stability & reliability*** **–**output should not be affected by temperature, vibration, other environmental conditions, with minimal error.
- ***Good dynamic response*** **–**ability to change output quickly for dynamic variation in input with respect to time.
- ***Convenient instrumentation*** **–**high analog output, high SNR, direct measurement or after amplification.
- ***Good mechanical characteristics*** **–**ability to withstand deformation and deterioration in performance caused by various mechanical strains.

Potentiometer Displacement Sensors

Potentiometer displacement sensor is a primary sensor which converts the linear motion or the angular motion of a shat into changes in resistance.

It is a type of resistive displacement sensor. Linear potentiometers are sensors that produce a resistance output proportional to the linear displacement or position.

Linear potentiometers are essentially variable resistors whose resistance is varied by the movement of a slide over a resistance element.

Rotary potentiometer are sensors that produce resistance output proportional to the angular displacement or position. They can be either wire wound or conductive plastic, and either rectangular or cylindrical.

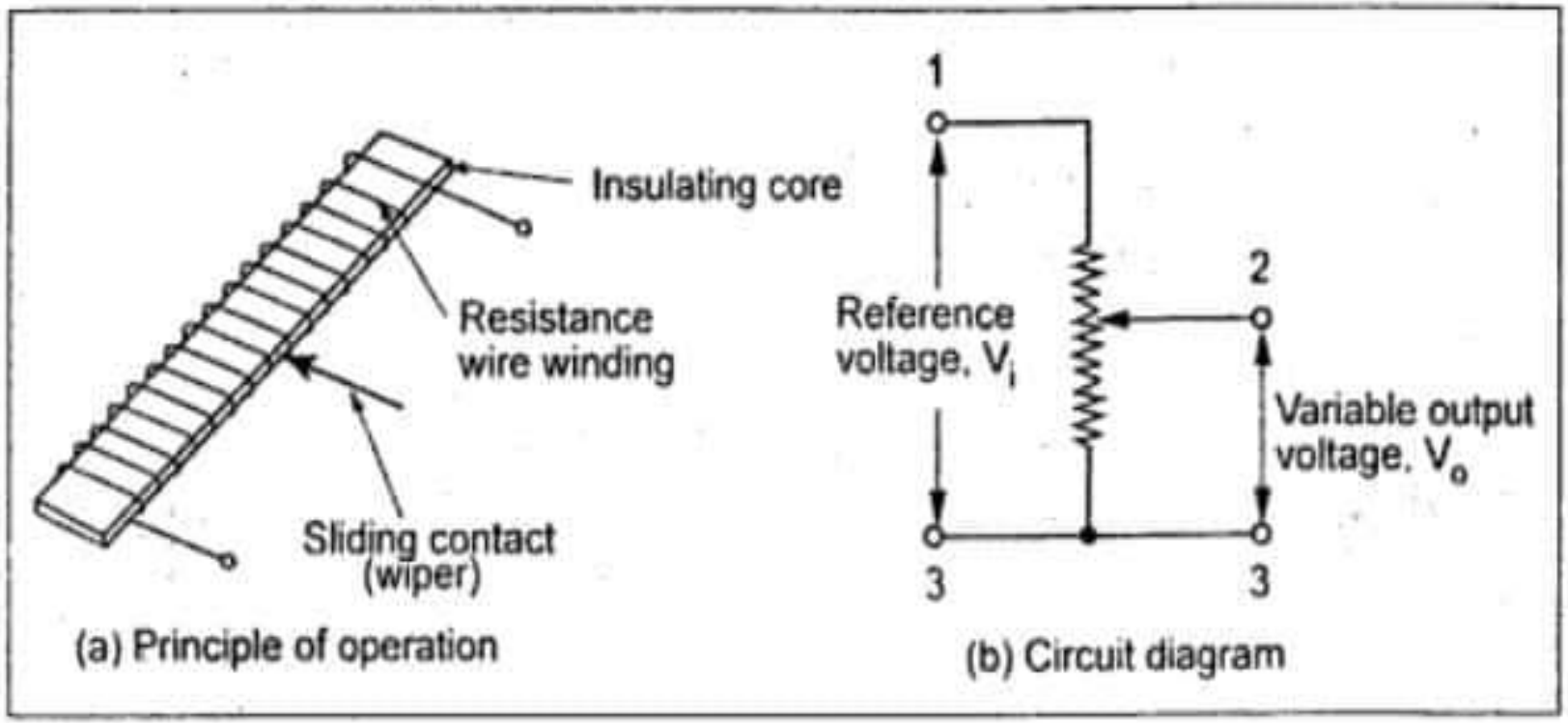


Figure 1.23 Linear potentiometer

Figure above illustrates the basic principle of a linear potentiometer.

The linear potentiometer employs an electrically conductive linear slide member (also called wiper) connected to a variable wire wound resistor (winding) that changes resistance to be equated to the linear position of the device that is monitored.

As the sliding contact moves along the winding, the resistance changes in linear relationship with the distance from one end of the potentiometer.

To measure displacement, a potentiometer is typically wired as a ‘voltage divider’ so that the output voltage is proportional to the distance traveled by the wiper. A known voltage is applied to the resistor ends.

The contact is attached to the moving object of interest. The output voltage at the contact is proportional to the displacement.

The resolution is defined by the number of turns per unit distance, and loading effects of the voltage divider circuit should be considered.

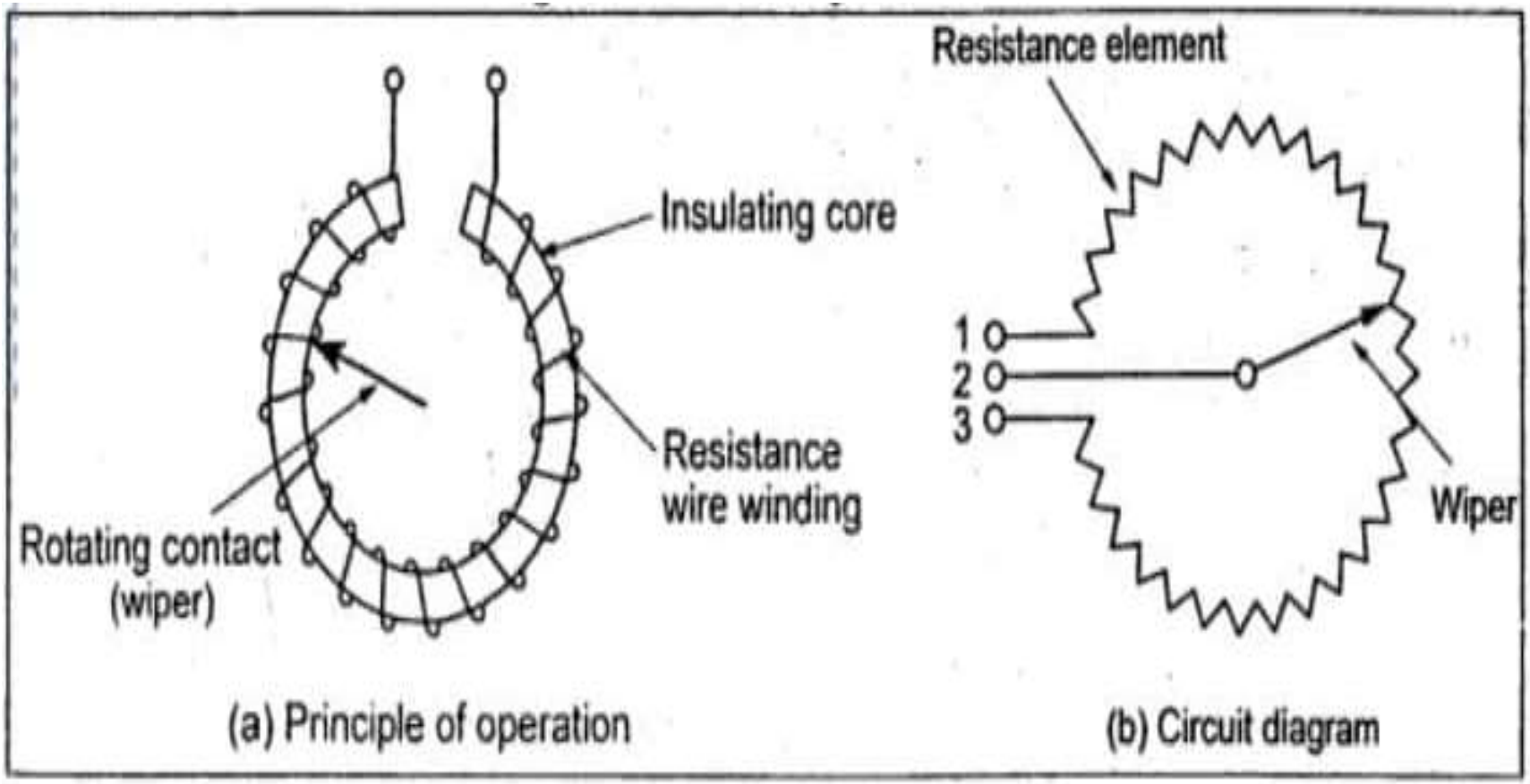


Figure 1.24 Rotary potentiometer

A rotary potentiometer employs a rotary slide member connected to a variable wire wound resistor that changes resistance to be equated to the angular position of the device that is monitored.

Other principles of operations are same as that of linear potentiometer.

The potentiometer can be used as a voltage divider to obtain a manually adjustable output voltage at the slider (wiper) from a fixed input voltage applied across the two ends of the resistance wire winding.

Advantages and Disadvantages of Potentiometers

Advantages:

- Easy to use
- Low cost
- High-amplitude output signal
- Proven technology
- Rugged construction
- Very high electrical efficiency
- Availability in different forms, ranges and sizes

Disadvantages

- ♦Limited bang width
- ♦Frictional loading
- ♦Inertial loading
- ♦Limited life due to wear

Linear Variable Differential Transformer (LVDT)

The term LVDT stands for the Linear Variable Differential Transformer. It is the most widely used inductive transducer that converts the linear motion into the electrical signal. The output across secondary of this transformer is the differential thus it is called so. It is very accurate inductive transducer as compared to other inductive transducers.

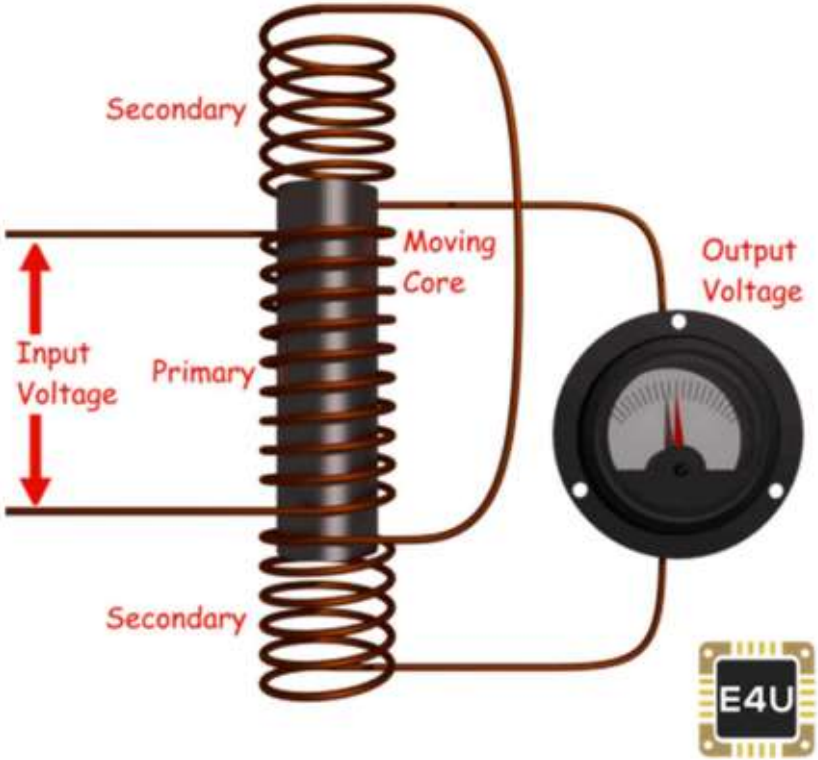
Construction of LVDT

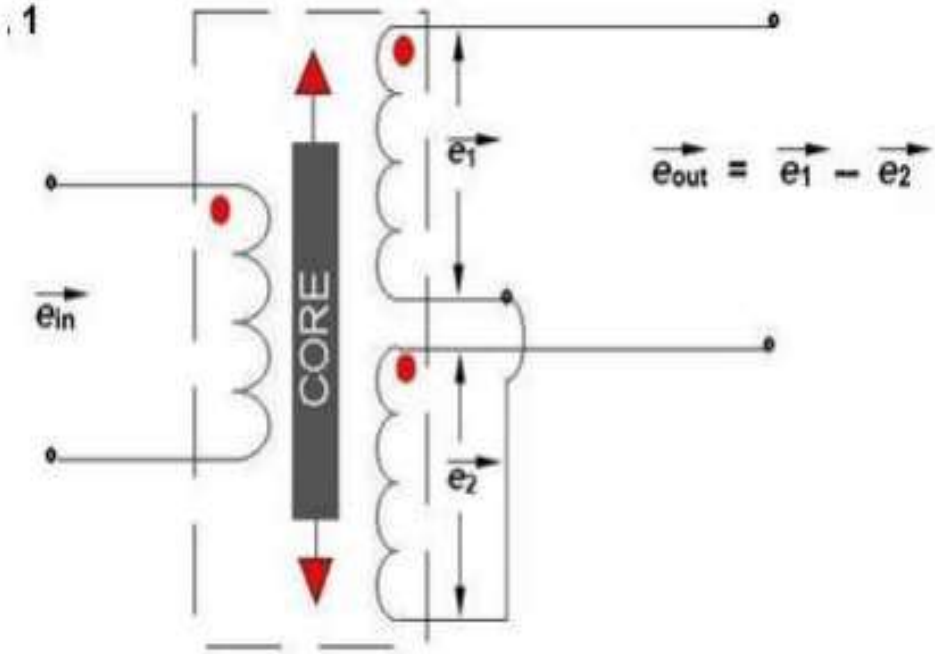
Main Features of Construction

- The transformer consists of a primary winding P and two secondary windings S1 and S2 wound on a cylindrical former (which is hollow in nature and contains the core).
- Both the secondary windings have an equal number of turns, and we place them on either side of primary winding
- The primary winding is connected to an AC source which produces a flux in the air gap and voltages are induced in secondary windings.

Construction of LVDT

- A movable soft iron core is placed inside the former and displacement to be measured is connected to the iron core.
- The iron core is generally of high permeability which helps in reducing harmonics and high sensitivity of LVDT.
- The LVDT is placed inside a stainless steel housing because it will provide electrostatic and electromagnetic shielding.
- The both the secondary windings are connected in such a way that resulted output is the difference between the voltages of two windings.


Secondary
Moving
Core
Output
Voltage
Input
Voltage
Primary
Secondary
E4U


1
CORE
$\vec{e}_{in}$
$\vec{e}_1$
$\vec{e}_2$
$\vec{e}_{out} = \vec{e}_1 - \vec{e}_2$

Principle of Operation and Working

As the primary is connected to an AC source so alternating current and voltages are produced in the secondary of the LVDT. The output in secondary S1 is e1 and in the secondary S2 is e2. So the differential output is,

$$e_{out} = e_1 - e_2$$

This equation explains the principle of Operation of LVDT.

Now three cases arise according to the locations of core which explains the working of LVDT are discussed below as,

CASE I When the core is at null position (for no displacement) When the core is at null position then the flux linking with both the secondary windings is equal so the induced emf is equal in both the windings. So for no displacement the value of output eout is zero as e1 and e2 both are equal. So it shows that no displacement took place.

CASE II When the core is moved to upward of null position (For displacement to the upward of reference point) In the this case the flux linking with secondary winding S1 is more as compared to flux linking with S2. Due to this e1 will be more as that of e2. Due to this output voltage eout is positive.

CASE III When the core is moved to downward of Null position (for displacement to the downward of the reference point). In this case magnitude of e2 will be more as that of e1. Due to this output eout will be negative and shows the output to downward of the reference point. Output VS Core Displacement A linear curve shows that output voltage varies linearly with displacement of core.

Strain Gauge

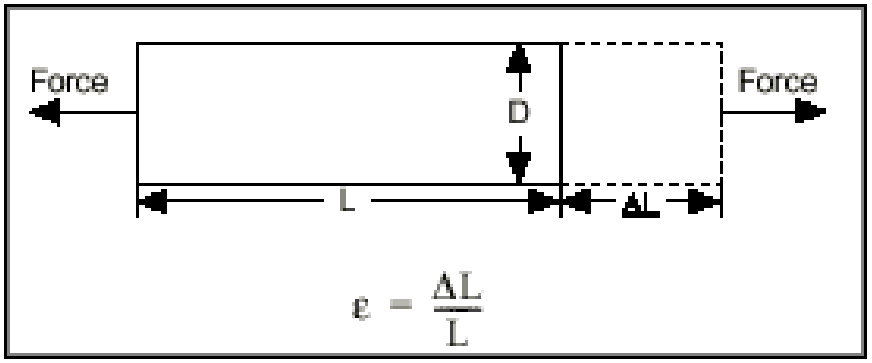
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What is strain

Strain is the amount of deformation due to an applied force. More specifically strain is defined as the **fractional change in length**.

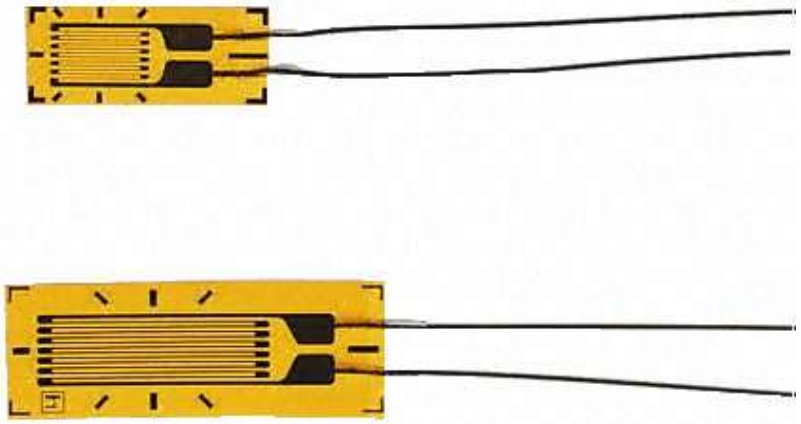
Strain can be negative (compressive) or positive (tensile) whereas dimensionless strain is sometime expressed in units such as in/in or mm/mm.

In practice magnitude of strain is very small therefore it is expressed as microstrain.



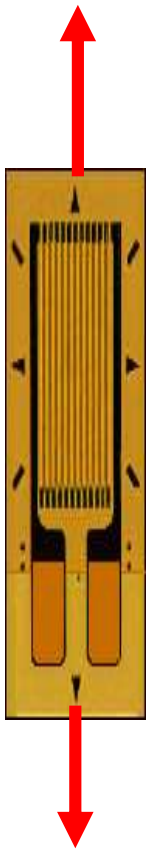
Strain Gauge

- A **strain gauge** is a device used to measure strain on an object. It is also termed as Load cell
- Invented by Edward E. Simmons and Arthur C. Ruge in 1938
- The most common type of strain gauge consists of an insulating flexible backing which supports a metallic foil pattern.



Strain Gauge

Tension



$l \uparrow$

$R \uparrow$



$$R = \rho \frac{l}{A} \quad \Rightarrow \quad R \propto l$$

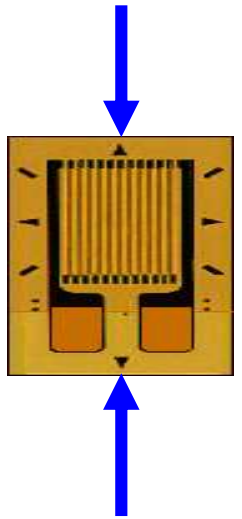
$R =$ Resistance

$\rho =$ Property of material

$l =$ Length of wire

$A =$ Effective cross sectional area of wire

Compression



$l \downarrow$

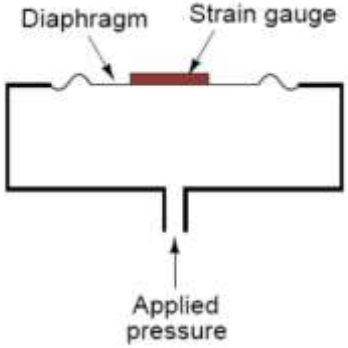
$R \downarrow$

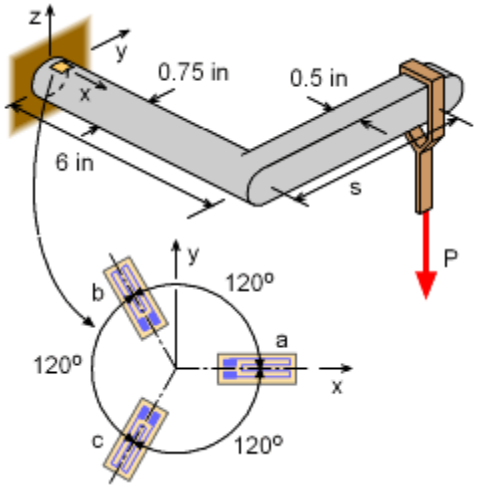
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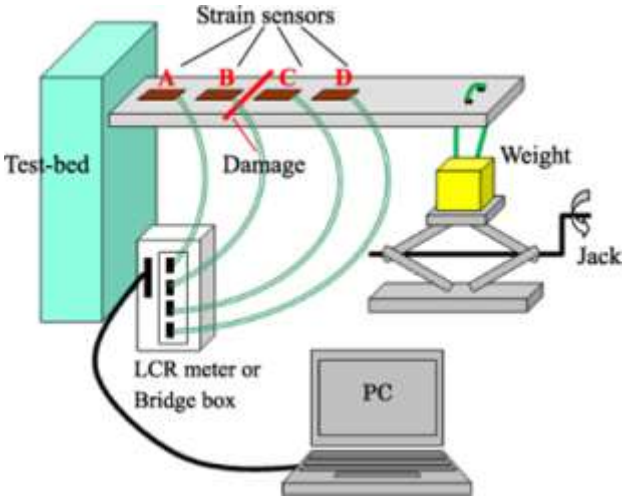
Strain Gauge Applications

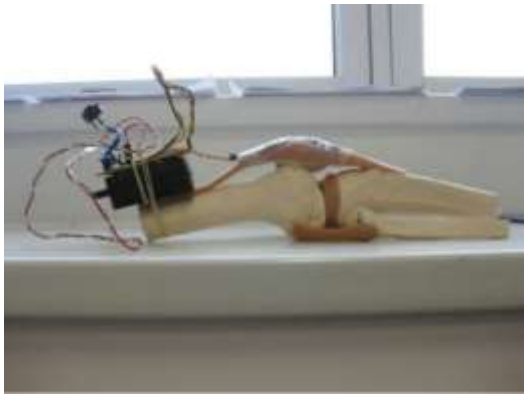
- Measurement of pressure
- Measurement of force
- Measurement of small displacement
- Measurement of Torque
- Measurement of Load etc.







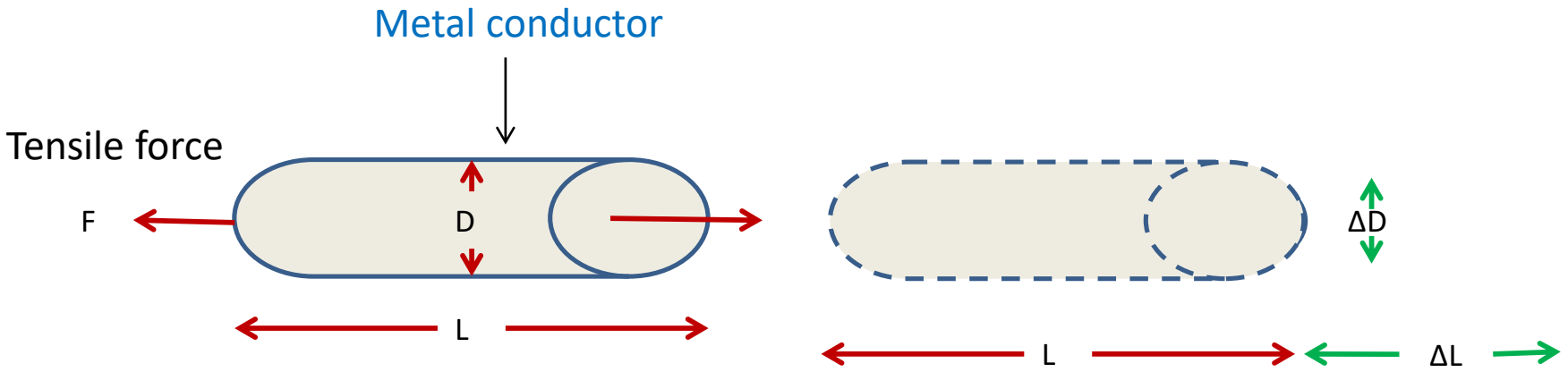




Principle

If a metal conductor is stretched or compressed, its resistance changes on account of the fact that both length and diameter of the conductor changes.

$R=\rho\frac{L}{A}$ is a resistance of unstrained conductor



$R=\rho\frac{L}{A}$ (1)

Let the tensile stress ***'s'*** applied to the wire . With result change in length **ΔL**, Change in area **ΔA**, change in diameter **ΔD.**

In order to find ΔR ; R is differentiated w.r.t. stress 's'

$$\frac{dR}{ds}=\frac{\rho}{A}\frac{\partial L}{\partial s}-\frac{\rho L}{A^2}\frac{\partial A}{\partial s}+\frac{L}{A}\frac{\partial \rho}{\partial s} \quad (2)$$

Dividing equation (2) throughout with $R=\rho\frac{L}{A}$

$$\frac{1}{R}\frac{dR}{ds}=\frac{1}{L}\frac{\partial L}{\partial s}-\frac{1}{A}\frac{\partial A}{\partial s}+\frac{1}{\rho}\frac{\partial \rho}{\partial s} \quad (3)$$

In equation (3) per unit change in resistance is due to (a) per unit change in length ΔL/L (b) per unit change in area ΔA/A and (c) per unit change in resistivity $\Delta\partial/\partial$

$$A=\frac{\pi}{4}D^2 \quad \therefore \quad \frac{\partial A}{\partial s} = 2.\frac{\pi}{4}D.\frac{\partial D}{\partial s} \qquad (4)$$

Dividing both sides by A

$$\frac{1}{A}\frac{dA}{ds} = \frac{\left(2\frac{\pi}{4}\right)D}{\left(\frac{\pi}{4}\right)D^2}\frac{\partial D}{\partial s} = \frac{2}{D}\frac{\partial D}{\partial s} \qquad (5)$$

$$\frac{1}{R}\frac{dR}{ds} = \frac{1}{L}\frac{\partial L}{\partial s} - \frac{1}{A}\frac{\partial A}{\partial s} + \frac{1}{\rho}\frac{\partial \rho}{\partial s}$$

$$\frac{1}{R}\frac{dR}{ds} = \frac{1}{L}\frac{\partial L}{\partial s} - \frac{2}{D}\frac{\partial D}{\partial s} + \frac{1}{\rho}\frac{\partial \rho}{\partial s} \qquad (6)$$

Now Poisson's ratio $\nu = \frac{Lateral\ strain}{Longitudnal\ stress} = -\frac{\partial D/D}{\partial L/L}$ (7)

$$\frac{\partial D}{D} = -\nu \times \frac{\partial L}{L}$$

Putting equation (7) in equation (6)

$$\frac{1}{R}\frac{dR}{ds} = \frac{1}{L}\frac{\partial L}{\partial s} + \nu\frac{2}{L}\frac{\partial L}{\partial s} + \frac{1}{\rho}\frac{\partial \rho}{\partial s}$$

For small variation above can be written as

$$\frac{\Delta R}{R} = \frac{\Delta L}{L} + 2\nu\frac{\Delta L}{L} + \frac{\Delta \rho}{\rho}$$

Gauge factor (G_f) is defined as the ratio of per unit change in resistance to per unit change in length $G_f = \frac{\Delta R/R}{\Delta L/L}$ $\in = strain = \frac{\Delta L}{L}$

$$\frac{\Delta R}{R} = G_f \frac{\Delta L}{L} = G_f \in$$

Gauge factor= $1 + 2\nu + \frac{\Delta\rho/\rho}{\in}$ or $= 1 + 2\nu + \frac{\Delta\rho/\rho}{\Delta L/L}$

Gauge factor= $1 + 2\nu$ as the strain is in the term of microstrain

Gauge factor= 1 + 2ν is valid only when Piezoresistive effect *i.e.* change in resistivity due to strain is almost negligible

For metals Poisson's ratio is between 0-0.5

Material	Gauge factor
Nickel	-12.1
Manganin	+0.47
Nichrome	+2.0
Constantan	+2.1
Soft Iron	+4.2
Platinum	+4.8
carbon	+20

Problem

A resistance wire strain gauge uses a soft iron wire of small diameter. The gauge factor is +4.2. Neglecting the Piezoresistive effect, calculate the Poisson's ratio.

Gauge factor = $1 + 2v + \frac{\Delta\rho/\rho}{\in}$

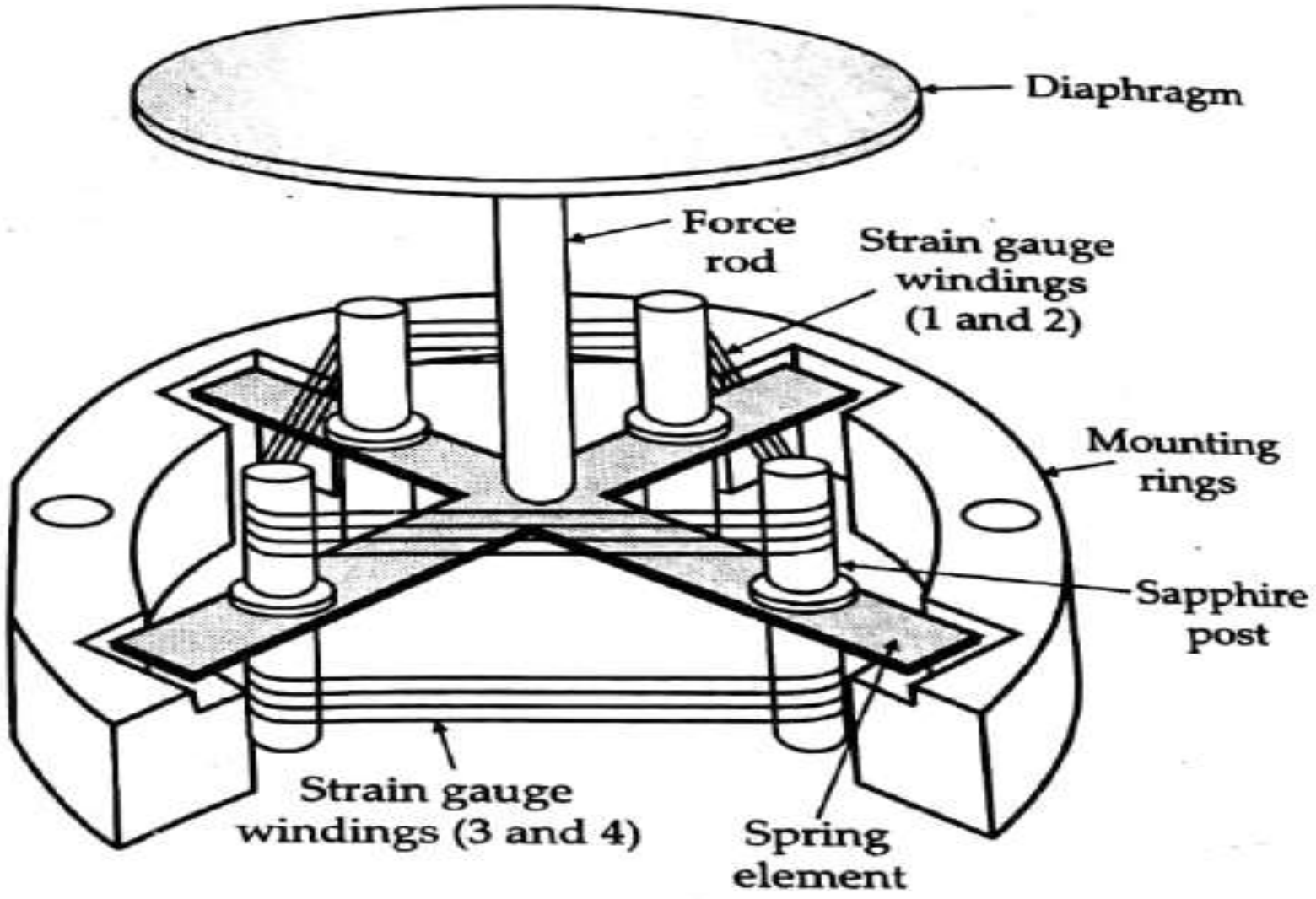
Gauge factor= $1 + 2v$ (neglecting Piezoresistive effect)

$\therefore Poisson's\ ratio$ v=(4.2-1)/2 = 1.6

Types of Strain gauge

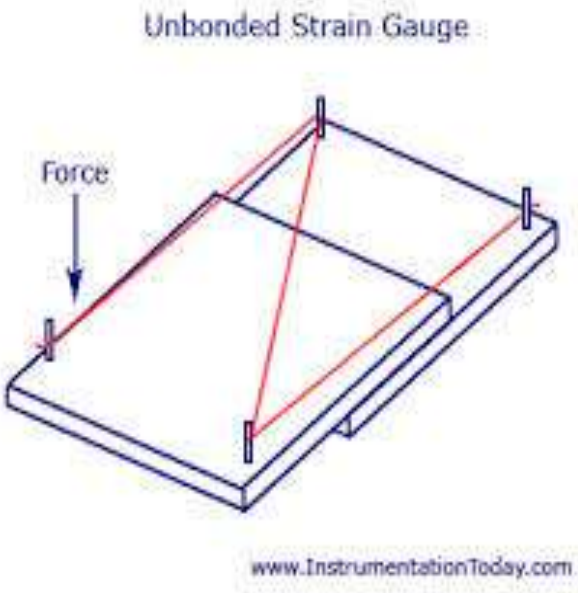
- **Unbounded Strain Gauge**
- **Bonded wire Strain Gauge**
- **Bonded Metal Foil Strain gauge**
- **Vacuum Deposit Strain Gauge**
- **Semiconductor strain gauge**
- **Diffused metal strain gauge**

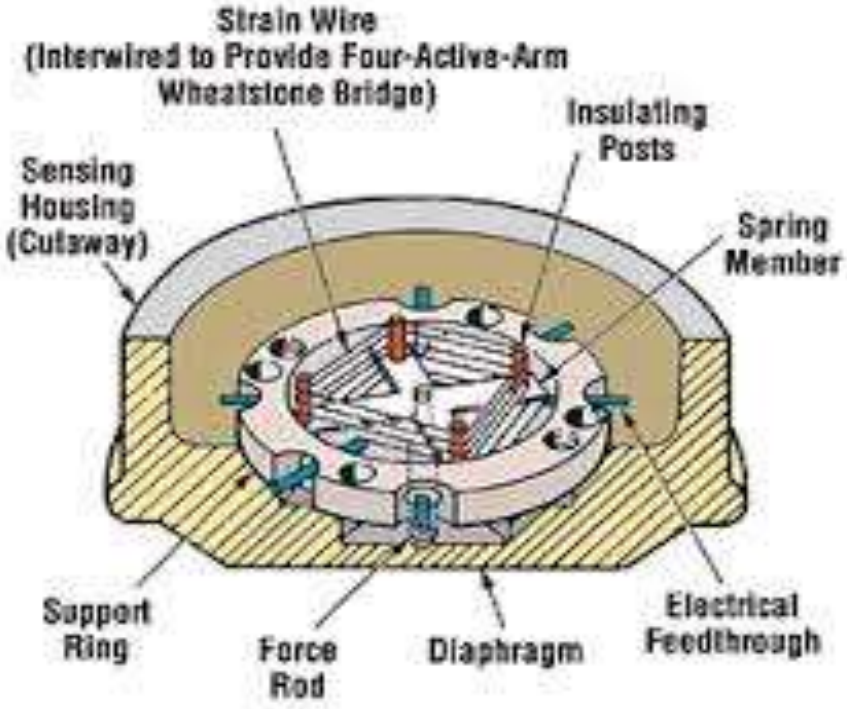
Unbonded strain gauge



Unbonded strain gauge

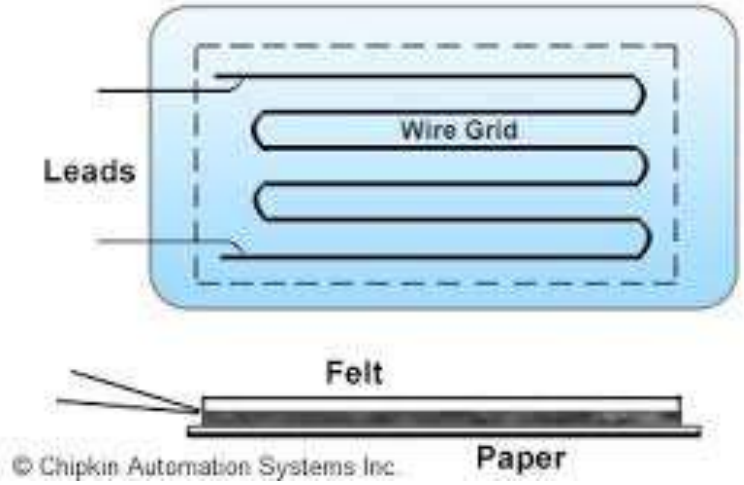
- Wire Diameter 0.003mm
- Length of wire 25mm
- Resistance of each arm 120-1000 ohms
- Input Voltage 5-10V DC





Bonded Wire Strain Gauge

- Fine wire with diameter about .025 mm
- Grid of wire is cemented to the carrier (Base)- sheet of paper, thin sheet of Bakelite or Teflon
- Small as 3X3mm, larger 25X12.5mm



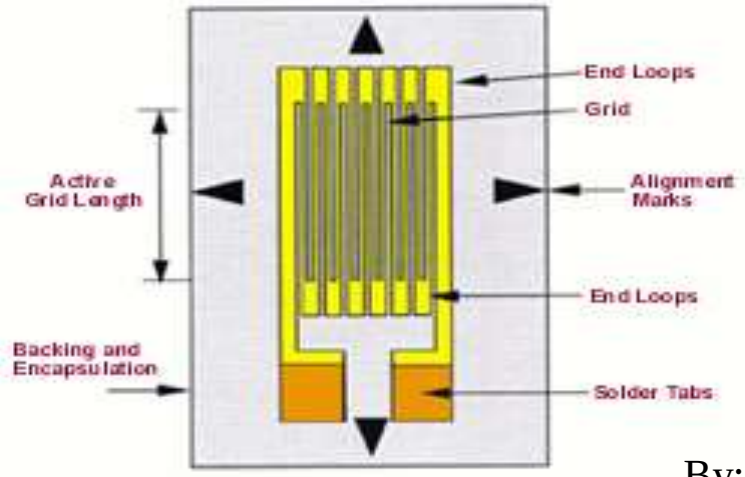
Materials used for wire Strain Gauge

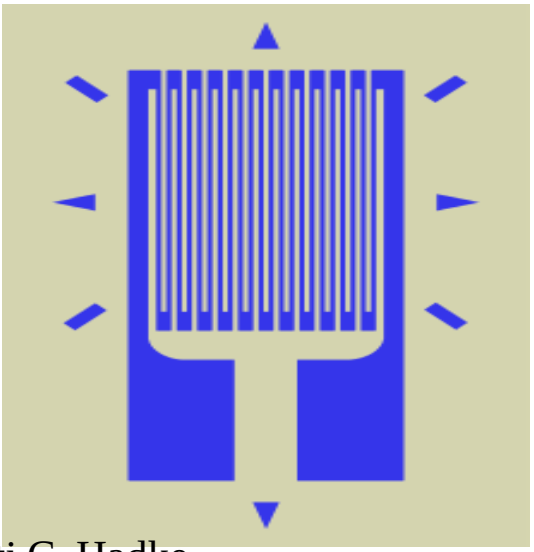
Materials	Composition	Gauge Factor	Resistivity ohm m
Nichrome	Ni: 80% Cr:20%	2.5	$100 X10^{-8}$
Constantan	Ni:45% Cu:55%	2.1	$48 X10^{-8}$
Isoelastic	Ni:36% Cr:8% Mo:05%	3.6	$105 X10^{-8}$
Nickel	-	-12	$6.5 X10^{-8}$
Platinum	-	4.8	$10 X10^{-8}$

By: Ms. Swati C. Hadke

Bonded metal foil strain gauge

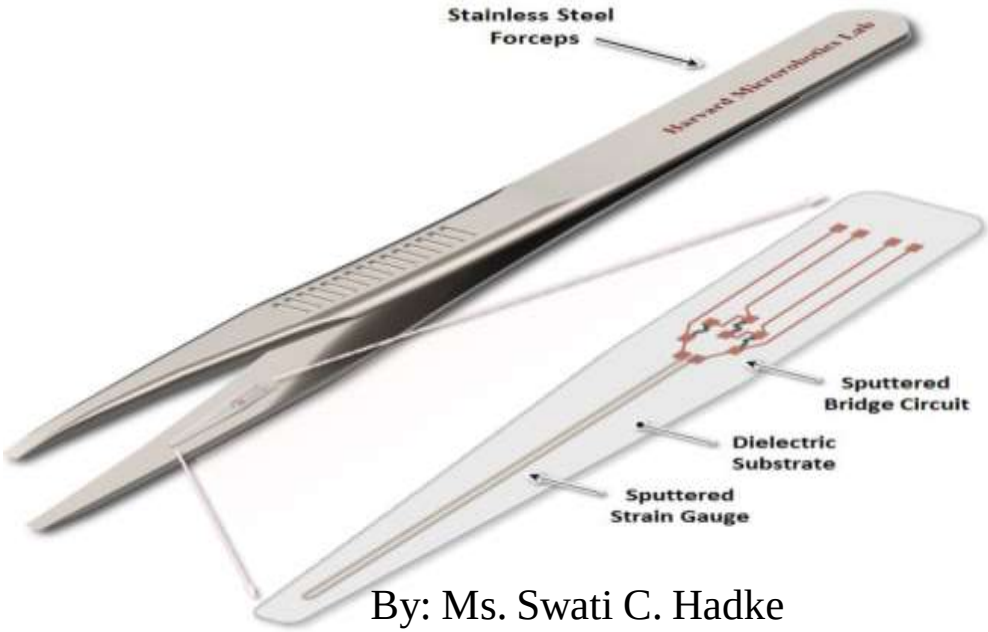
- Grater heat dissipating capacity
- Formed from a sheet of metal less than 0.005mm thick by photo-etching process
- Easy manufacturing process
- Can be apply in curved surface
- 10 million cycles at +- 1500 micro-strain can be applied to foil gauge





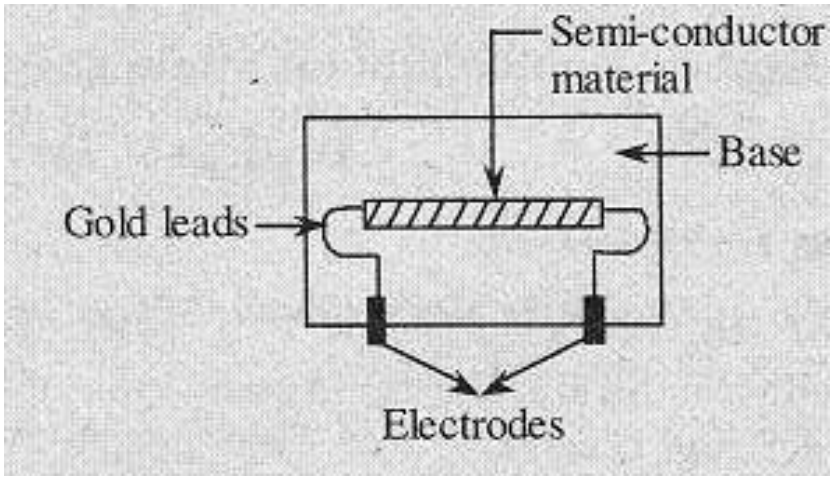
Vacuum Deposit Strain Gauge

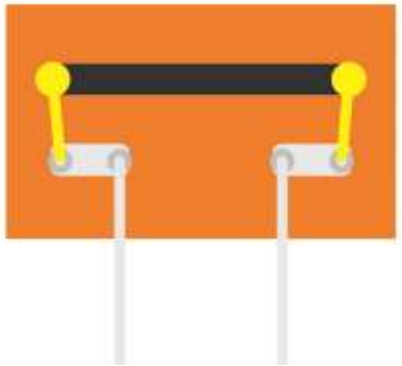
- Thin film vacuum deposition process to bond strain gauges directly to stainless steel etc for 30 years.
- The process begins by preparing the surface with remove all surface pinholes and cracks.
- The next step is the deposition of an oxide layer to insulate the circuit from the metal substrate. Following this, a thin film resistive alloy is sputtered over the oxide layer. This film is laser trimmed under power to produce the four resistors of the Wheatstone bridge



Semiconductor Strain gauge

- semiconducting wafers or filaments of length varying from 2 mm to 10 mm and thickness of 0.05 mm are bonded on suitable insulating substrates (for example Teflon).
- The gold leads are usually employed for making electrical contacts.
- The electrodes are formed by vapour deposition.
- The assembly is placed in a protective box



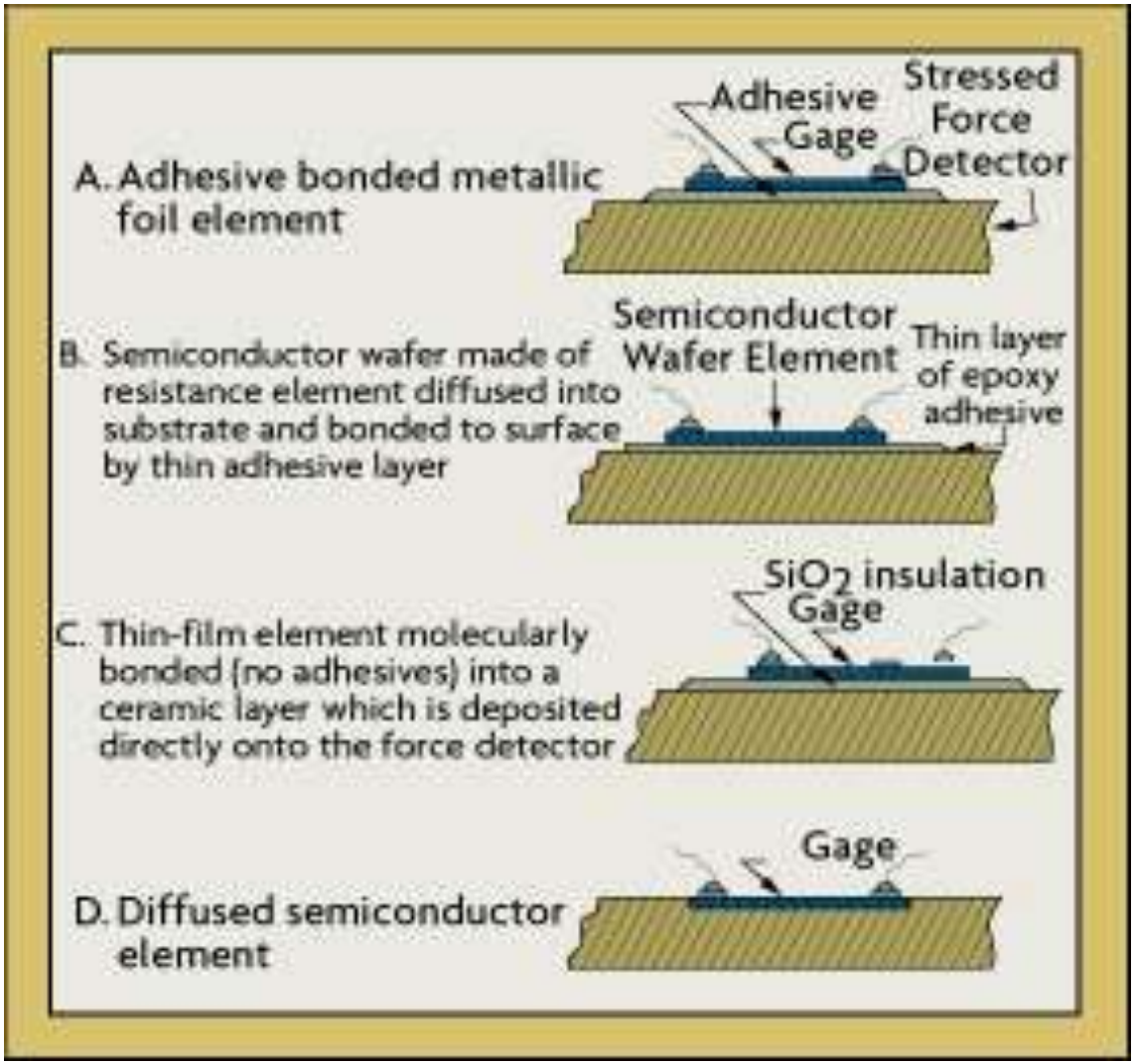


Advantages of Semiconductor Strain Gauge

- The gauge factor of semiconductor strain gauge is very high, about ±130.
- Semiconductor strain gauge exhibits very low hysteresis i.e., less than 0.05%.
- They are useful in measurement of very small strains of the order of 0.01 micron
- The semiconductor strain gauge has much higher output, but it is as stable as metallic strain gauge.
- It has a large fatigue life i.e., 10×10^6 operations can be performed.
- It possesses a high frequency response of 1012 Hz.
- can be manufactured in very small sizes, their lengths ranging from 0.7 to 7.0 mm.

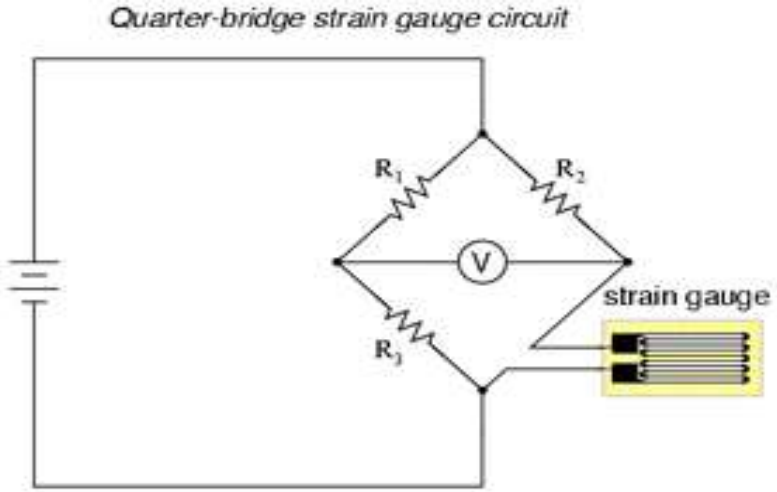
Diffused semiconductor Strain gauge

Thin film element molecularly bounded (no adhesive) into a ceramic layer which is deposited directly onto the force detector



Quarter Bridge Strain Gauge

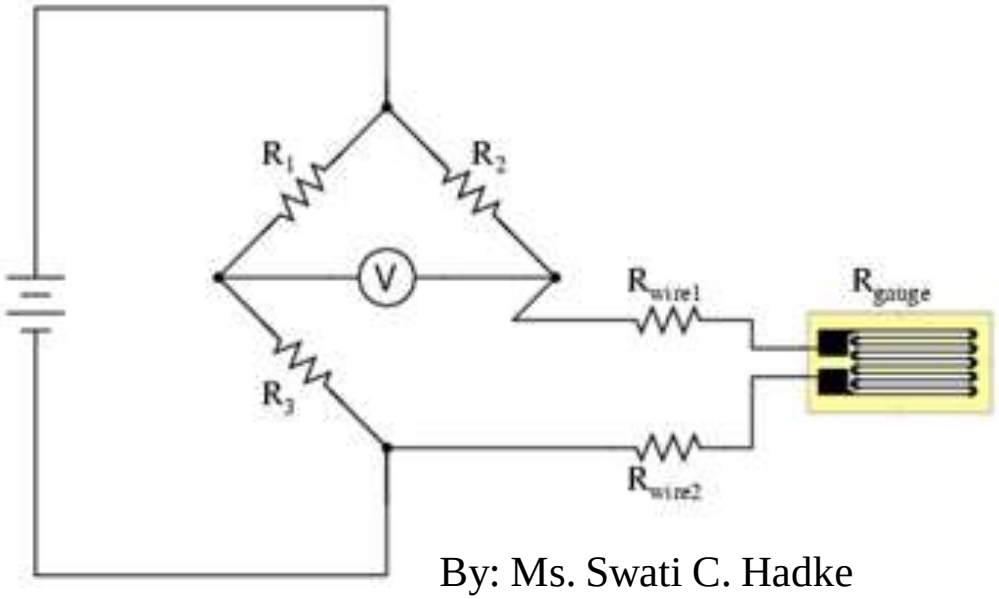
- R2 is set at a value equal to the strain gauge resistance with no force applied.
- The two ratio arms of the bridge (R1 and R3) are set equal to each other.
- Thus, with no force applied to the strain gauge, the bridge will be symmetrically balanced and the voltmeter will indicate zero volts, representing zero force on the strain gauge.
- This arrangement, with a single element of the bridge changing resistance in response to the measured variable (mechanical force), is known as a quarter-bridge circuit.



Wire resistance

The strain gauge's resistance (Rgauge) is not the only the resistance being measured:

The wire resistances Rwire1 and Rwire2, being in series with Rgauge, also contribute to the resistance of the lower half of the arm of the bridge, and consequently contribute to the voltmeter's indication.

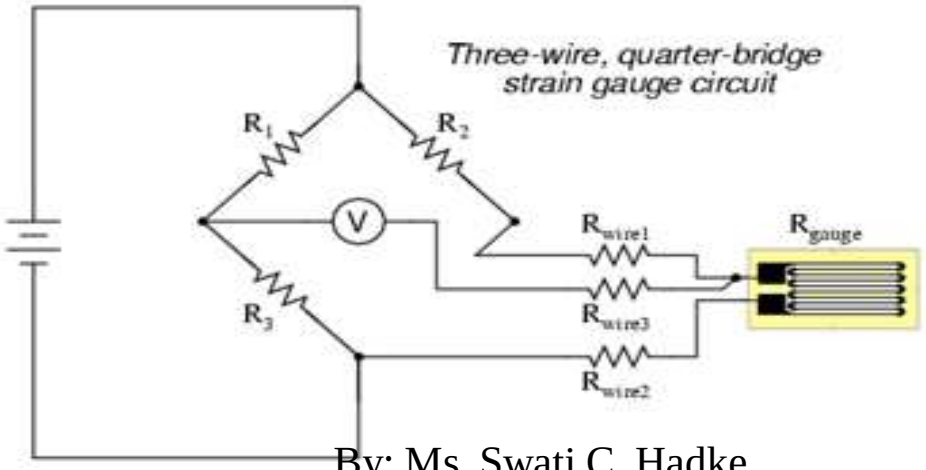


Three wire configuration

Because the third wire carries practically no current (due to the voltmeter's extremely high internal resistance), its resistance will not drop any substantial amount of voltage.

the resistance of the top wire (Rwire1) has been "bypassed" now that the voltmeter connects directly to the top terminal of the strain gauge, leaving only the lower wire's resistance (Rwire2) to contribute any stray resistance in series with the gauge.

There is a way, however, to reduce wire resistance error far beyond the method just described, and also help mitigate another kind of measurement error due to temperature.

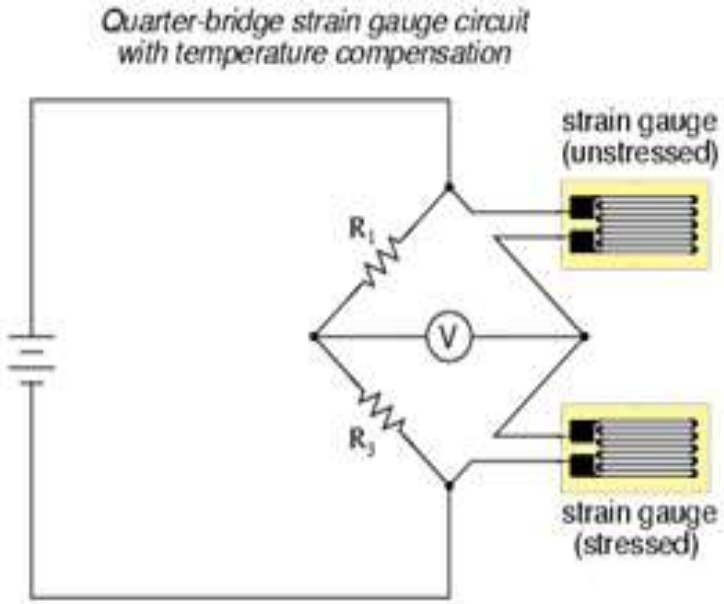


Dummy Strain Gauge

In strain gauges the resistance change with changes in temperature causing errors.

Thus, quarter-bridge circuit as shown can used to reduce the errors

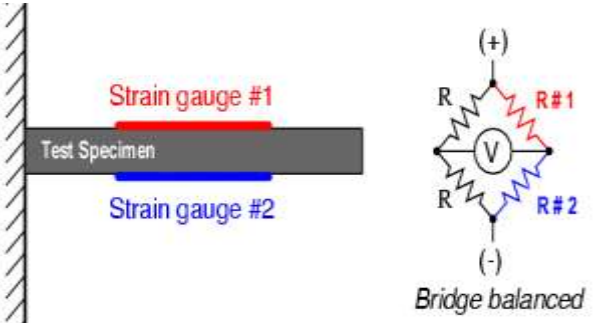
By using a **"dummy"** strain gauge in place of R2, the change in resistance is in the same proportion when temperature changes, thus canceling the effects of temperature change:

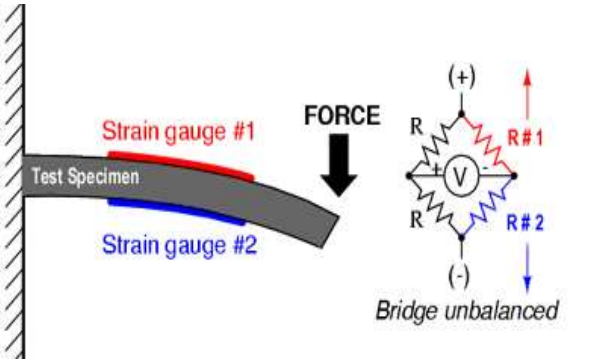


Half Bridge

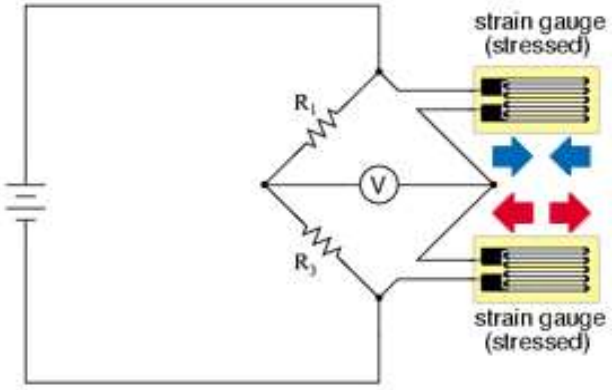
In half bridge the upper strain gauge position is so that it is exposed to the opposite force: as the lower gauge is compressed, the upper gauge will be stretched, and visa-versa

Both gauges responding to strain, and the bridge will be more responsive to applied force.
This utilization is known as a half-bridge. Since both strain gauges will either increase or decrease resistance by the same proportion in response to changes in temperature, the effects of temperature change remain canceled and the circuit will suffer minimal temperature-induced measurement error:





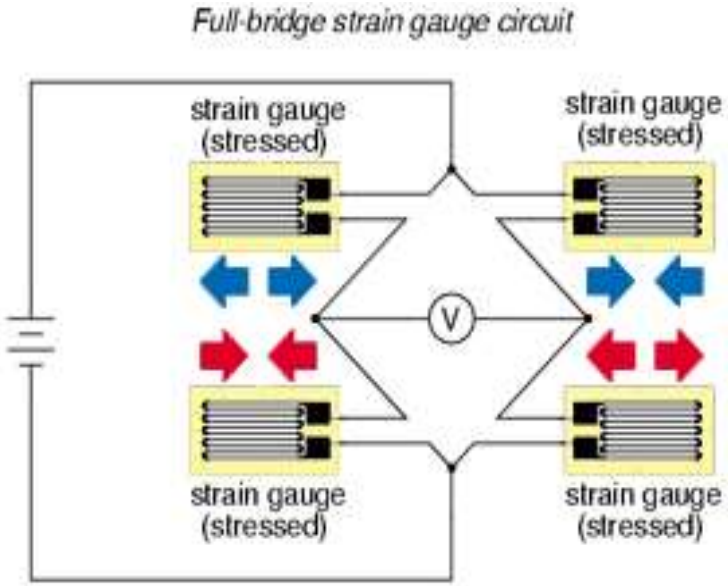
Half-bridge strain gauge circuit

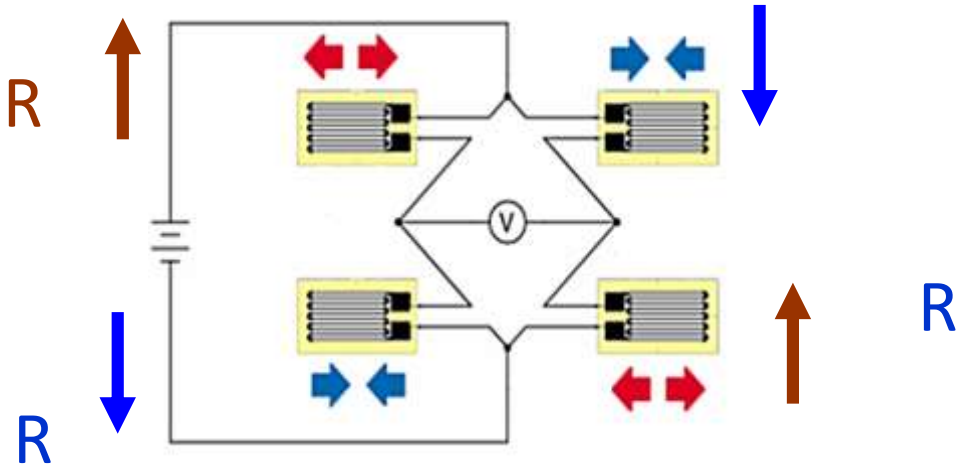


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Full-bridge circuit:

In few applications where complementary pairs of strain gauges is are bonded to the test specimen is called a full-bridge circuit,
It may be advantageous to make all four elements of the bridge "active" for greater sensitivity.





Strain Guage

Example 25.18 *A resistance, wire strain gauge with a gauge factor of 2 is bonded to a steel structural member subjected to a stress of 100 MN/m^2. The modulus of elasticity of steel is 200 GN/m^2. Calculate the percentage change in the value of the gauge resistance due to the applied stress. Comment upon the results.*

Solution.

Strain $$\varepsilon = \frac{s}{E} = \frac{100 \times 10^6}{200 \times 10^9}$$

$$= 500 \times 10^{-6} \text{ (500 microstrain)}$$

We have, $$\frac{\Delta R}{R} = G_f \varepsilon = 2 \times 500 \times 10^{-6} = 0.001 = 0.1\%$$

$\therefore$ The change in resistance is only 0.1%.

Strain Gauge

Example 25.19 *A single strain gauge having resistance of 120 Ω is mounted on a steel cantilever beam at a distance of 0.15 m from the free end. An unknown force F applied at the free end produces a deflection of 12.7 mm of the free end. The change in gauge resistance is found to be 0.152 Ω. The beam is 0.25 m long with a width of 20 mm and a depth of 3 mm. The Young's modulus for steel is 200 GN/m^2. Calculate the gauge factor.*

Solution. Moment of inertia of beam,

$$I = 1/12\,(bd^3) = 1/12 \times 0.02 \times (0.003)^3$$

$$= 45 \times 10^{-12}\ \mathrm{m}^4$$

Strain Guage

Deflection $x = \frac{Fl^3}{3EI}$

$\therefore$ Force $F = \frac{3EIx}{l^3}$

$$= \frac{3 \times 200 \times 10^9 \times 45 \times 10^{-12} \times 12.7 \times 10^{-3}}{(0.25)^3}$$

$$= 22 \text{ N}$$

Bending moment at 0.15 m from free end

$$M = Fx = 22 \times 0.15 = 3.3 \text{ Nm}$$

Stress at 0.15 m from free end

$$s = \frac{M}{I} \cdot \frac{t}{2} = \frac{3.3}{45 \times 10^{-12}} \times \frac{0.003}{2} = 110 \text{ MN/m}^2$$

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

$$= \frac{s}{E} = \frac{110 \times 10^6}{200 \times 10^9} = 0.55 \times 10^{-3}$$

$\therefore$ Gauge factor

$$= \frac{\Delta R / R}{\Delta L / L} = \frac{0.152 \times 120}{0.55 \times 10^{-3}} = 23$$

Strain Guage

Example 25.20 A strain gauge is bonded to a beam 0.1 m long and has a cross-sectional area 4 cm^2. Young's modulus for. steel is 207 GN/m^2. The strain gauge has an unstrained resistance of 240 Ω and a gauge factor of 2.2. When a load is applied, the resistance of gauge changes by 0.013 Ω. Calculate the change in length of the steel beam and the amount of force applied to the beam.

Strain Gauge

Solution. We have gauge factor

$$G_f = \frac{\Delta R / R}{\Delta L / L}$$

and therefore change in length

$$\Delta L = \frac{\Delta R / R . L}{G_f}$$

$$= \frac{(0.013 / 240)}{2.2} \times 0.1 = 2.46 \times 10^{-6} \text{ m}$$

Stress $s = E\varepsilon$

$$= \frac{207 \times 10^9 \times 2.46 \times 10^{-6}}{0.1}$$

$$= 5.092 \times 10^6 \text{ N} / \text{m}^2$$

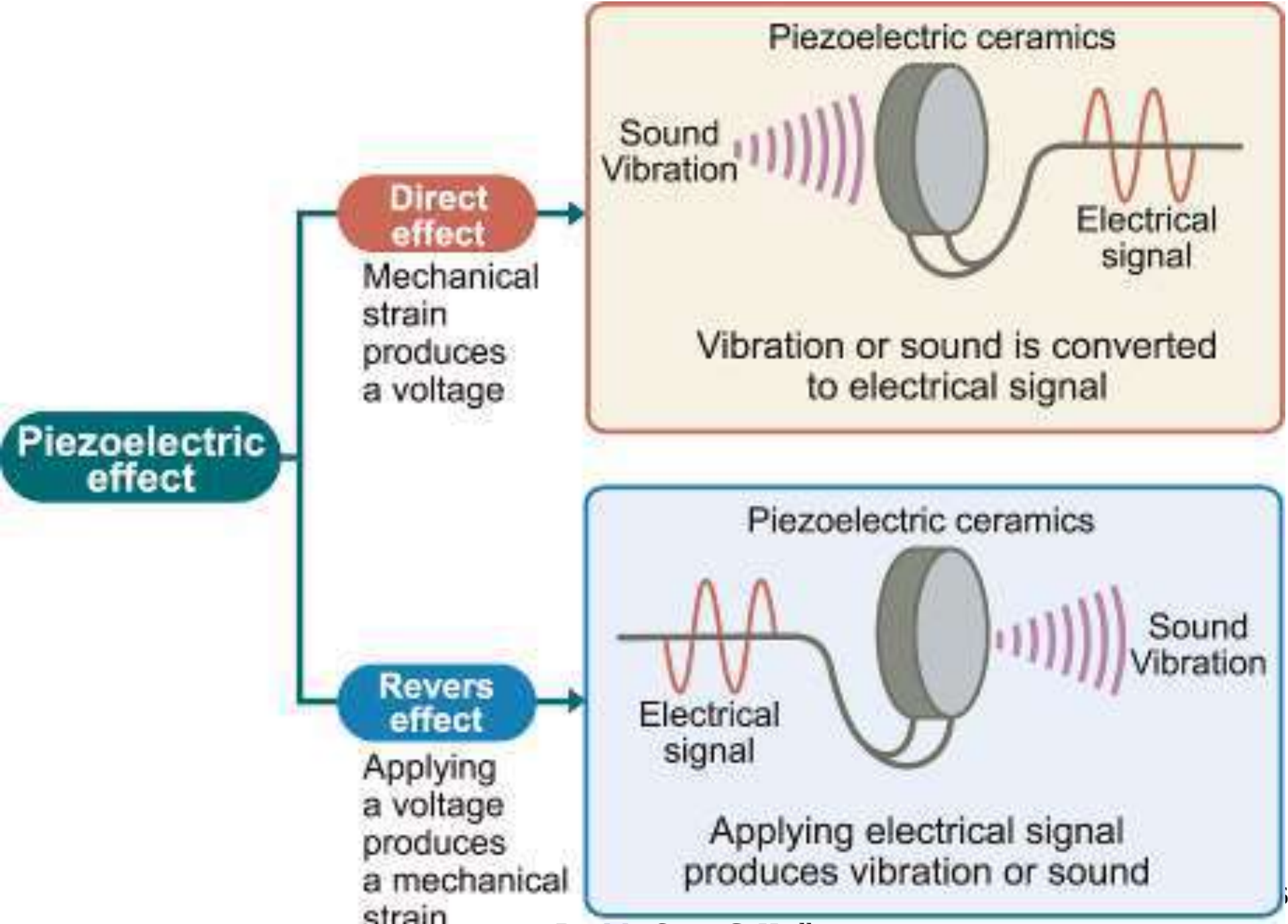
Force $F = sA$

$$= 5.092 \times 10^6 \times 4 \times 10^{-4} = 2.037 \times 10^3 \text{ N}$$

PIEZOELECTRIC EFFECT

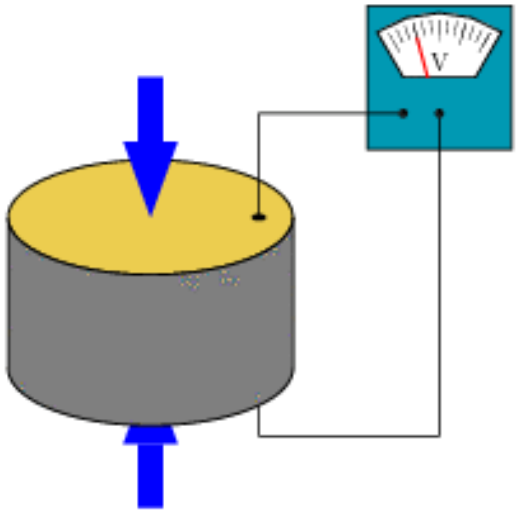
There are certain materials that generate electric potential or voltage when mechanical strain is applied to them or conversely when the voltage is applied to them, they tend to change the dimensions along certain plane. This effect is called as the PIEZOELECTRIC EFFECT.




Piezoelectric effect
Direct effect
Mechanical strain produces a voltage
Piezoelectric ceramics
Sound Vibration
Electrical signal
Vibration or sound is converted to electrical signal
Revers effect
Applying a voltage produces a mechanical strain
Piezoelectric ceramics
Electrical signal
Sound Vibration
Applying electrical signal produces vibration or sound

Piezoelectric Transducer

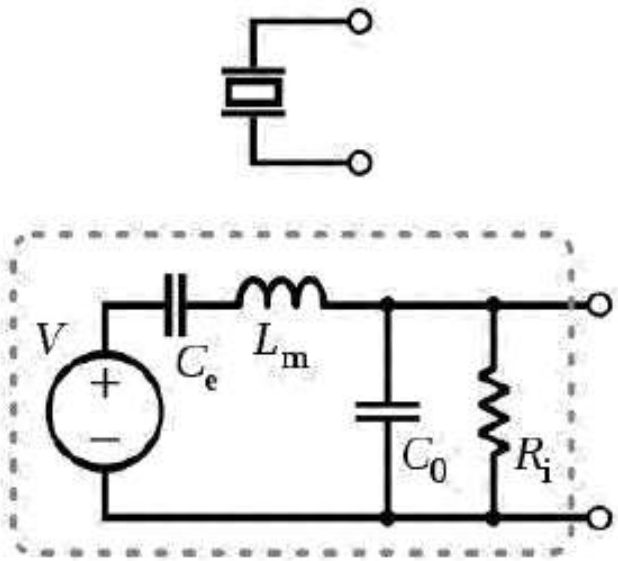
The piezoelectric transducers work on the principle of PIEZOELECTRIC EFFECT. When mechanical stress or forces are applied to some materials along certain planes, they produce electric voltage. This electric voltage can be measured easily by the voltage measuring instruments, which can be used to measure the stress or force.



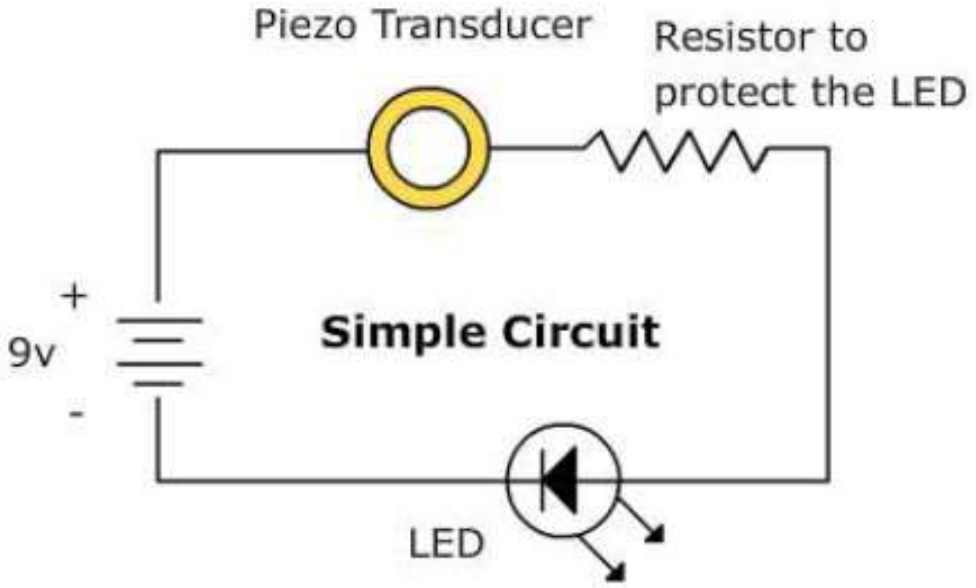
A piezoelectric disk generates a voltage when deformed (change in shape is greatly exaggerated)



The voltage output obtained from the materials due to piezoelectric effect is very small and it has high impedance. To measure the output some amplifiers, auxiliary circuit and the connecting cables are required.



symbol



Materials used for the Piezoelectric Transducers

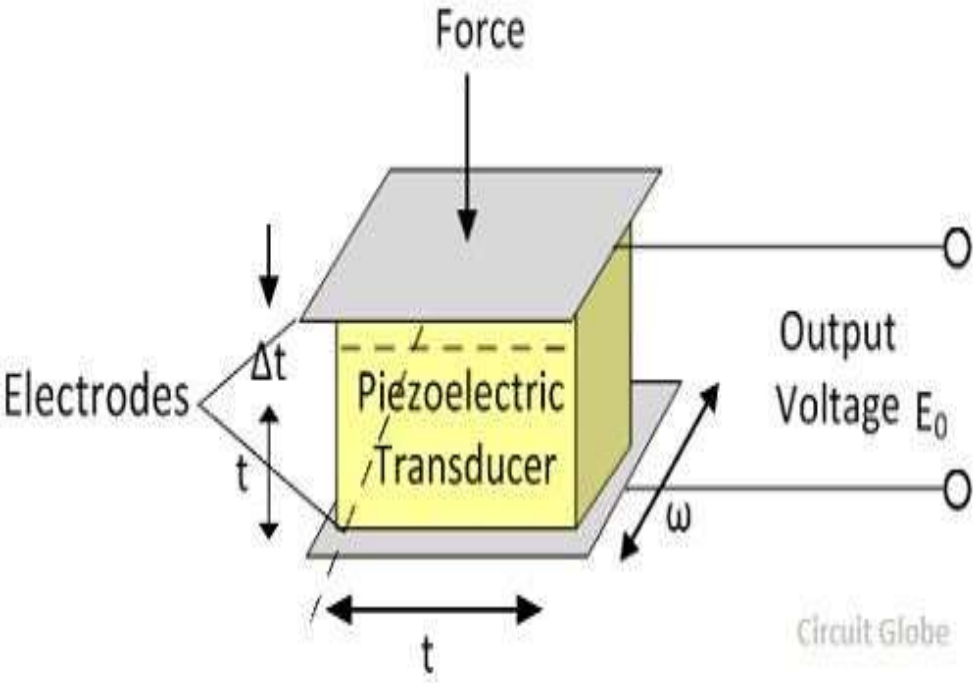
There are various materials that exhibit piezoelectric effect. The materials used for the measurement purpose should posses desirable properties like

- stability,
- high output,
- insensitive to the extreme temperature and humidity and
- ability to be formed or machined into any shape.
- But none of the materials exhibiting piezoelectric effect possesses all the properties.

Examples of Piezoelectric Material

The materials are :

- Barium Titanate.
- Lead zirconate titanate (PZT).
- Rochelle salt.
- Quartz



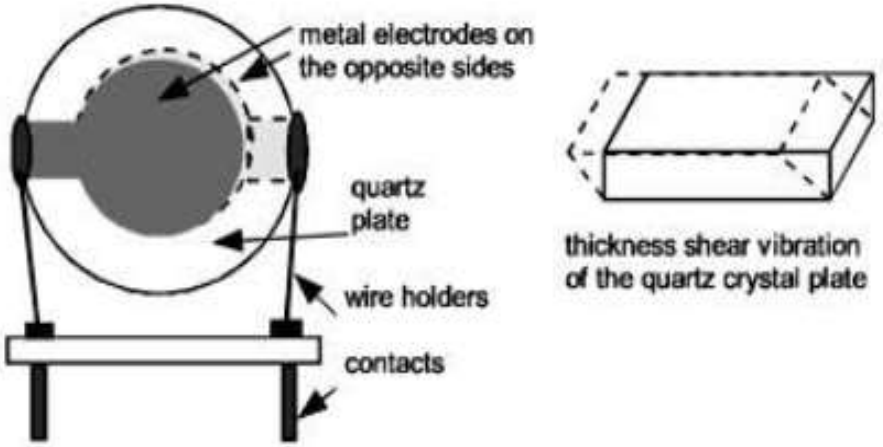
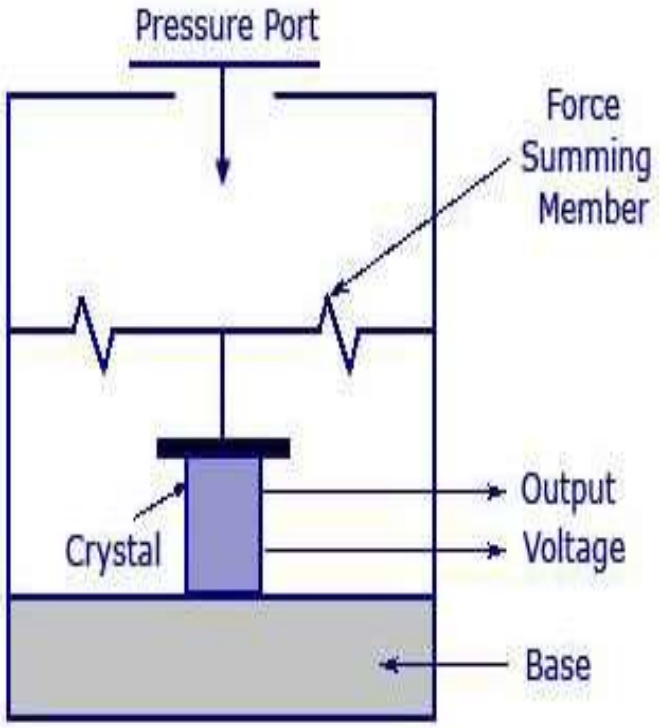


Figure 1. Piezoelectric quartz crystal microbalance and scheme of vibrations.

CONSTRUCTION and WORKING

- The figure shows a conventional piezoelectric transducer with a piezoelectric crystal inserted between a solid base and the force summing member.
- If a force is applied on the pressure port, the same force will fall on the force summing member.
- Thus a potential difference will be generated on the crystal due to its property. The voltage produced will be proportional to the magnitude of the applied force.



Piezo-Electric Transducer

Advantages of Piezoelectric Transducers

- **High frequency response:** They offer very high frequency response that means the parameter changing at very high speeds can be sensed easily.
- **High transient response:** The piezoelectric transducers can detect the events of microseconds and also give the linear output.
- The piezoelectric transducers are **small in size** and have rugged construction.

Limitations of Piezoelectric Transducers

- **Low Output**: The output obtained from the piezoelectric transducers is low, so external electronic circuit has to be connected.
- **High impedance**: The piezoelectric crystals have high impedance so they have to be connected to the amplifier and the auxiliary circuit, which have the potential to cause errors in measurement. To reduce these errors amplifiers high input impedance and long cables should be used.
- **Forming into shape:** It is very difficult to give the desired shape to the crystals with sufficient strength.

Applications of the Piezoelectric Transducers

- 1) The piezoelectric transducers are more useful for the dynamic measurements, i.e. the parameters that are changing at the fast rate. This is because the potential developed under the static conditions is not held by the instrument. Thus piezoelectric crystals are primarily used measurement of quantities like surface roughness, and also in accelerometers and vibration pickups.
- 2) For the same reasons they can be used for studying high speed phenomenon like explosions and blast waves

3)Used along with the strain gauges for measurement of force, stress, vibrations, etc.

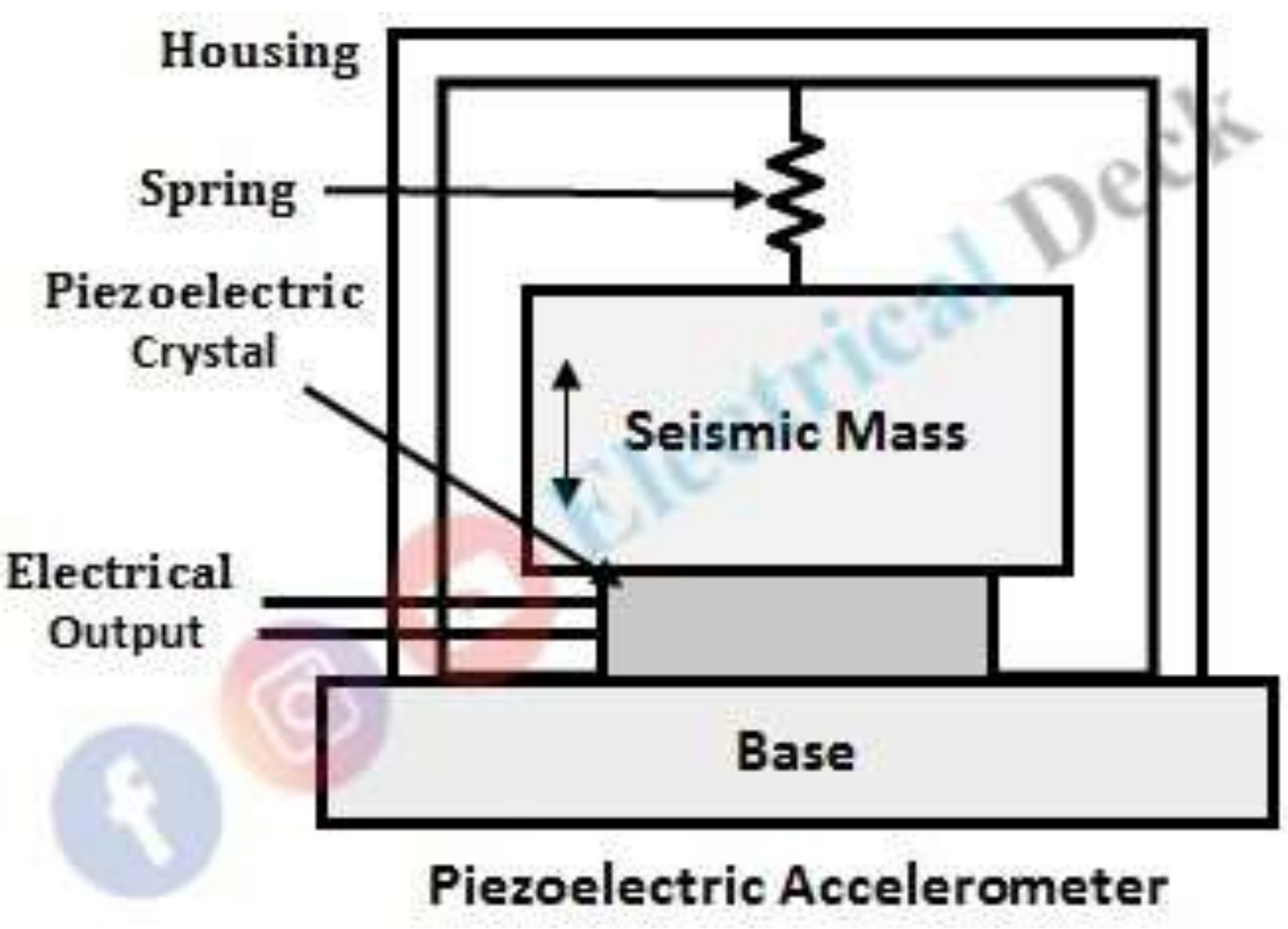
4) The automotive companies used piezoelectric transducers to detect detonations in the engine blocks.

5)Used in medical treatment and industrial processing equipment's for monitoring the power.

6)Used in Inkjet printers

7)Used in smartphone screens.

8)Used in lighters.



Piezoelectric Accelerometer

- Temperature Sensors,
- Motion Sensors,
- Pressure sensors,
- Flow sensors,
- pH measurement.

Temperature Sensors

DESIRED CHARACTERISTICS

- High sensitivity
- Large temperature range
- Accuracy
- Repeatability
- Relationship between measured quantity and temperature
  - Nonlinear
  - Linear
- Easy calibration
- Fast response

Types of Temperature sensors

1. Thermistor
2. Resistive Temperature Device (RTD)
3. Thermocouple
4. Integrated Silicon Linear Sensor

Choosing a Temperature Sensor

Q1: What is the desired temperature range?

Q2: What is the tolerable limit to the error in measurement?

Q3: What are the conditions under which the measurement is to be performed?

Q4: Are there any performance and cost constraint?

1. THERMISTOR

- High sensitivity*
- Inexpensive
- Reasonably accurate
- Lead resistance ignored
- Glass bead, disk or chip thermistor
- Typically Negative Temperature Coefficient (NTC), PTC also possible
- R-T mode (zero-power mode): nonlinear relationship between R and T



2. RESISTANCE TEMPERATURE DEVICE (RTD)



- Very Accurate and stable
- Reasonably wide temperature range
- More expensive (platinum)
- Positive Temperature Constant, and rather constant



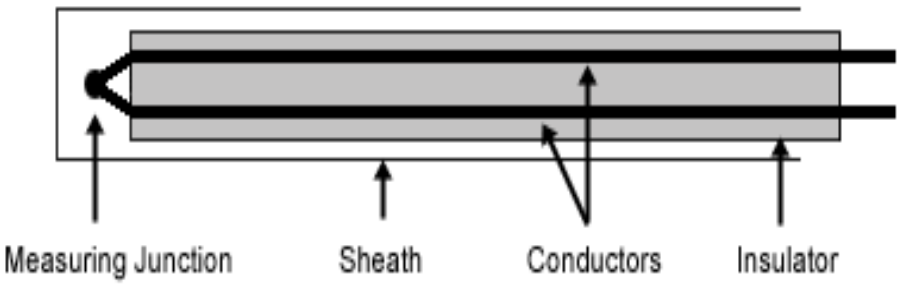
- Requires current excitation
- Smaller Resistance range



- Self-heating is a concern
- Lead resistance is a concern

3. THERMOCOUPLE

- High temperature range
- Inexpensive
- Stand tough environment
- Made from Platinum or Platinum-Rhodium
- Requires reference junction
- Fast response
- Output signal is usually small



The principle: If two conductors of different materials are joined at one point, an EMF is created between the open ends which is dependent upon the temperature of the junction. As T1 increases, so does V. The EMF also depends on the temperature of the open ends T2.