UNIT – 1

SCIENCE OF MEASUREMENT AND TRANSDUCERS

Transducer

- A transducer is defined as a device that receive energy from one system and transmits it to other, often in a different form
- The energy transmitted by these systems may be electrical, mechanical, optical, or acoustical
- Basically, there are two types of transducers:

(a) Electrical Transducer (b) Mechanical Transducer

(Manometer, Turbines, Spring, Diaphragm, etc.)

Electrical Transducer:

- The transducer may be thought of consisting of two parts:

(i) Sensing Element, (ii) Transduction Element

- **Sensing Element** responds to a physical phenomenon or a change in physical phenomenon
- **Transduction Element** transforms the output of a sensing element to an electrical output

Electrical Transducer (-contd.)

- In other words, an electrical transducer is a sensing device by which the physical, mechanical, or optical quantity to be measured be transformed directly by a suitable mechanism into an electrical voltage/current proportional to the input measured
- The output may be analog, digital, or frequency modulated

- The important parameters relating to an electrical transducer are as follow:

(a) Linearity: The relationship between a physical quantity and the resulting electrical signal must be linear.

(b) Sensitivity: Sensitivity is defined as the electrical output per unit change in the physical quantity (e.g. v/^{o}c for a temperature sensor). High sensitivity is generally desirable for a transducer.

(c) Dynamic range: The operating range of the transducer should be wide enough to permit its use under a wide range of measurement conditions.

Advantages of Electrical Transducer

(d) Repeatability: The input/output relationship for a transducer should be predictable over a long period of time. This ensures reliability of operation.

(e) Physical size: The transducer must have minimal weight and volume, so that its presence in the measurement system does not disturb the existing conditions.

<u>Advantages of Electrical Transducers</u>:

- The main advantages of electrical transducers (conversion of physical quantity into electrical quantities) are as follow:

(i) Electrical amplification and attenuation can be easily done

(ii) Mass inertia effects are minimized

(iii) Effects of friction are minimized

(iv) The output can be indicated and recorded remotely at a distance from the sensing medium

Classification of Transducers

(v) The output can be modified (pulse conversion/frequency conversion, modulated, or amplified) to meet the requirements of the indicating or controlling units

(vi) The signal can be conditioned or mixed to obtain any combination with outputs of similar transducers or control signals

(vii) The electrical or electronic signal can be controlled with a very small power level

(viii) The electrical output can be easily used, transmitted, and processed for purpose of measurement

<u>Classification of Transducers</u>:

- The transducers may be classified:

  (i) On the basis of transduction principle (ii) As primary and secondary transducers (iii) As passive and active transducers (iv) As analog and digital transducers (v) As transducer and inverse transducers

Classification of Transducers (-contd.)

On the Basis of Transduction Principle:

- Depending upon how they convert the input quantity into resistance, inductance, or capacitance; the transducers are called resistive, inductive, or capacitive respectively
- They may also be classified as piezoelectric, thermoelectric, magnetorestrictive, electrokinetic, & optical, etc.

Primary and Secondary Transducers:

- In most of the measurement systems, there is a suitable working combination wherein a mechanical device acts as a primary detector (transducer) and the electrical device acts as the secondary transducer with mechanical displacement serving as the intermediate signal

Passive and Active Transducers:

- Passive transducers derive the power required for transduction from an auxiliary power source
- They also derive part of the power required for conversion from the physical quantity under measurement

Classification of Transducers (-contd.)

- In the absence of external power, the transducers can not work and hence are called passive (externally powered) transducers, e.g. resistive, inductive, and capacitive transducers
- On the other hand, active transducers are those which do not require an auxiliary power source to produce their output
- They are also known as self generating type since they develop their own voltage or current output
- The energy required for production of output signal is obtained from the physical quantity being measured, e.g., thermocouples, photovoltaic cells, and piezoelectric crystals etc.

Analog and Digital Transducers:

- Analog transducers convert the input physical quantity into analog output which is a continuous function of time, e.g., a strain gauge, an LVDT, a thermocouple, or a thermistor etc.
- On the other hand, the digital transducers convert the input quantity into an electrical output which is in the form of pulses, e.g., photocell

Classification of Transducers (-contd.)

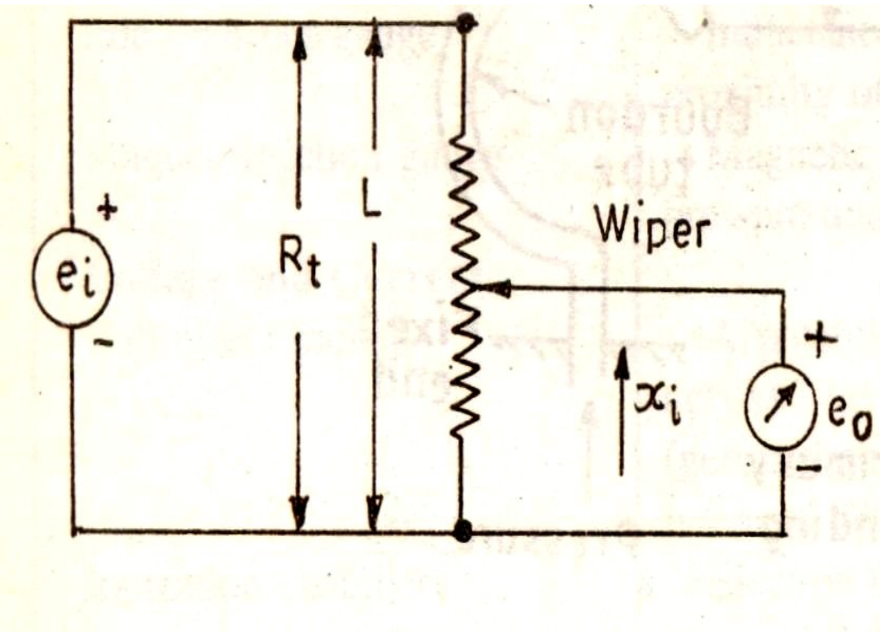


Fig. 25.28. Linear potentiometer (POT), a passive transducer

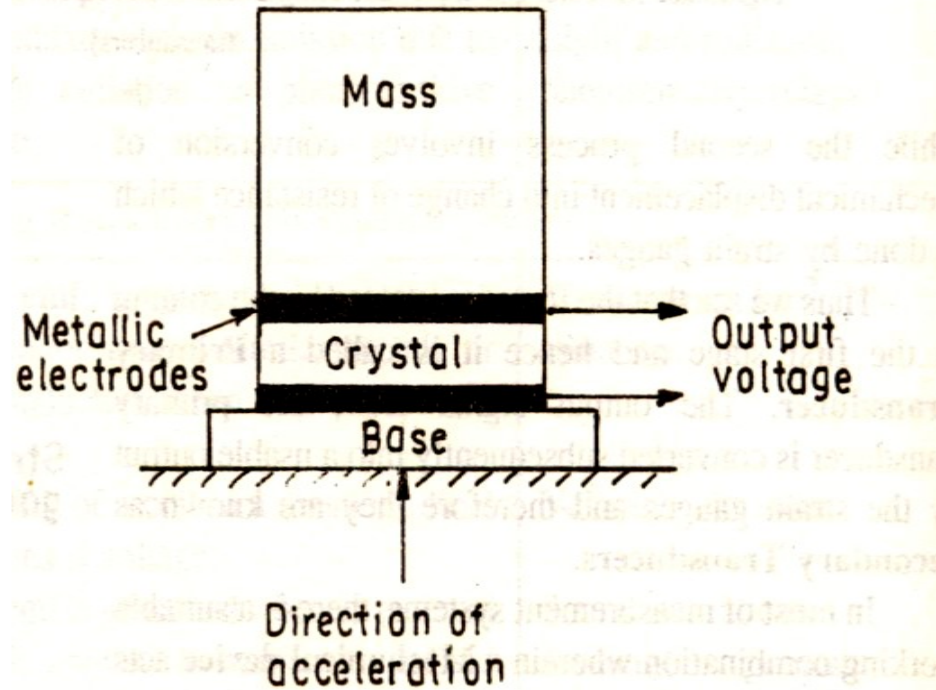


Fig. 25.29. Piezo-electric crystal measuring acceleration—an active transducer

Selection of Transducer

Transducers and Inverse Transducers:

The transducers may be broadly defined as the devices which convert a non-electrical quantity into an electrical quantity and the inverse transducers are defined as the devices which convert an electrical quantity into a non-electrical quantity

Selecting a Transducer:

- The transducer has to be physically compatible with its intended application. The following features should be considered while selecting a transducer:

(i) Operating Range – chosen to maintain range requirement and good resolution

(ii) Sensitivity – chosen to allow sufficient output

(iii) Frequency Response and Resonant Frequency – flat over the entire desired frequency range

Selection of Transducer (-contd.)

(iv) Accuracy – repeatability and calibration error as well as errors due to sensitivity to other stimuli should be minimum

(v) Electrical Parameters – length and type of cable required, SNR when combined with amplifiers etc.

(vi) Usage and Ruggedness – Ruggedness both of mechanical and electrical intensities versus size and weight

(vii) Environmental Compatibility – temperature range, pressure, corrosive fluids, shocks, size, interaction and mounting restrictions

(viii) Loading Effects – transducer should have a high input impedance and a low output impedance to avoid loading effects

Force Measurement: Piezoelectric Transducers

- A piezoelectric material is one in which an electric potential appears across certain surfaces of a crystal if the dimensions of the crystal are changed by the application of a mechanical force
- This potential is generated by the displacement of charges. The effect in reversible, i.e. conversely, if a varying potential is applied to the proper axis of the crystal, it will change the dimensions of the crystal thereby deforming it
- This effect is known as piezoelectric effect
- Common piezoelectric materials include Rochelle salts, quartz, barium titanate (Ceramics A & B), ammonium dihydrogen phosphate, lithium sulphate, etc.
- The ceramics A & B do not have piezoelectric properties in their original state but these properties are produced by special polarizing treatment

Piezoelectric Transducers (-contd.)

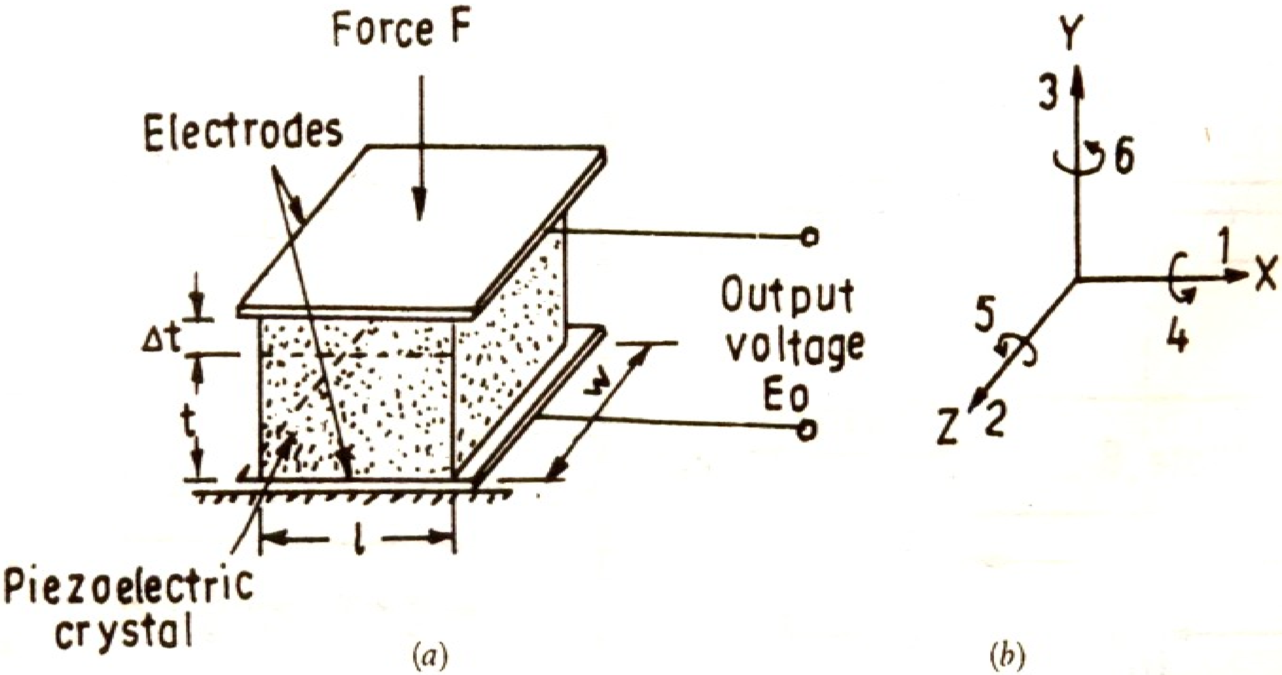
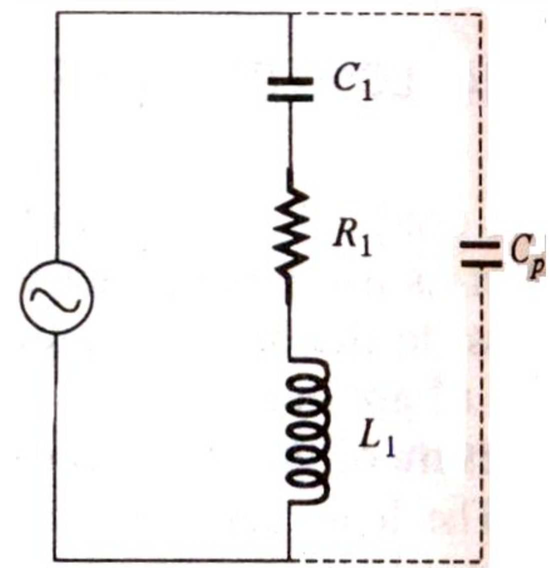


Fig. 25.121. (a) Piezo-electric crystal used for measurement of force.
(b) Axis numbering system for the crystal.



Equivalent Circuit of Crystal

Piezoelectric Transducers (-contd.)

- The piezoelectric effect can be made to respond to (or cause) mechanical deformations of the material in different modes: thickness expansion, transverse expansion, thickness shear, & face shear
- The mode of operation depends on the shape of the body relative to the crystal axis and location of the electrodes
- A piezoelectric element used for converting mechanical motion to electrical signals may be thought as charge generator & a capacitor
- Mechanical deformation generates a charge and which appears as a voltage across the electrodes, i.e.

Piezoelectric Transducers (-contd.)

- The piezoelectric effect can be made to respond to (or cause) mechanical deformations of the material in different modes: thickness expansion, transverse expansion, thickness shear, & face shear
- The mode of operation depends on the shape of the body relative to the crystal axis and location of the electrodes
- A piezoelectric element used for converting mechanical motion to electrical signals may be thought as charge generator & a capacitor
- Mechanical deformation generates a charge and which appears as a voltage across the electrodes, i.e.

$$\text{Voltage}\ E_0 = \frac{Q}{C_p} = \frac{Q}{\varepsilon_r \varepsilon_0 A/t} \qquad ..(1)$$

$$\left(C_p : \text{Capacitance between electrodes} = \frac{\varepsilon A}{t} = \frac{\varepsilon_r \varepsilon_0 A}{t} \right)$$

Piezoelectric Transducers (-contd.)

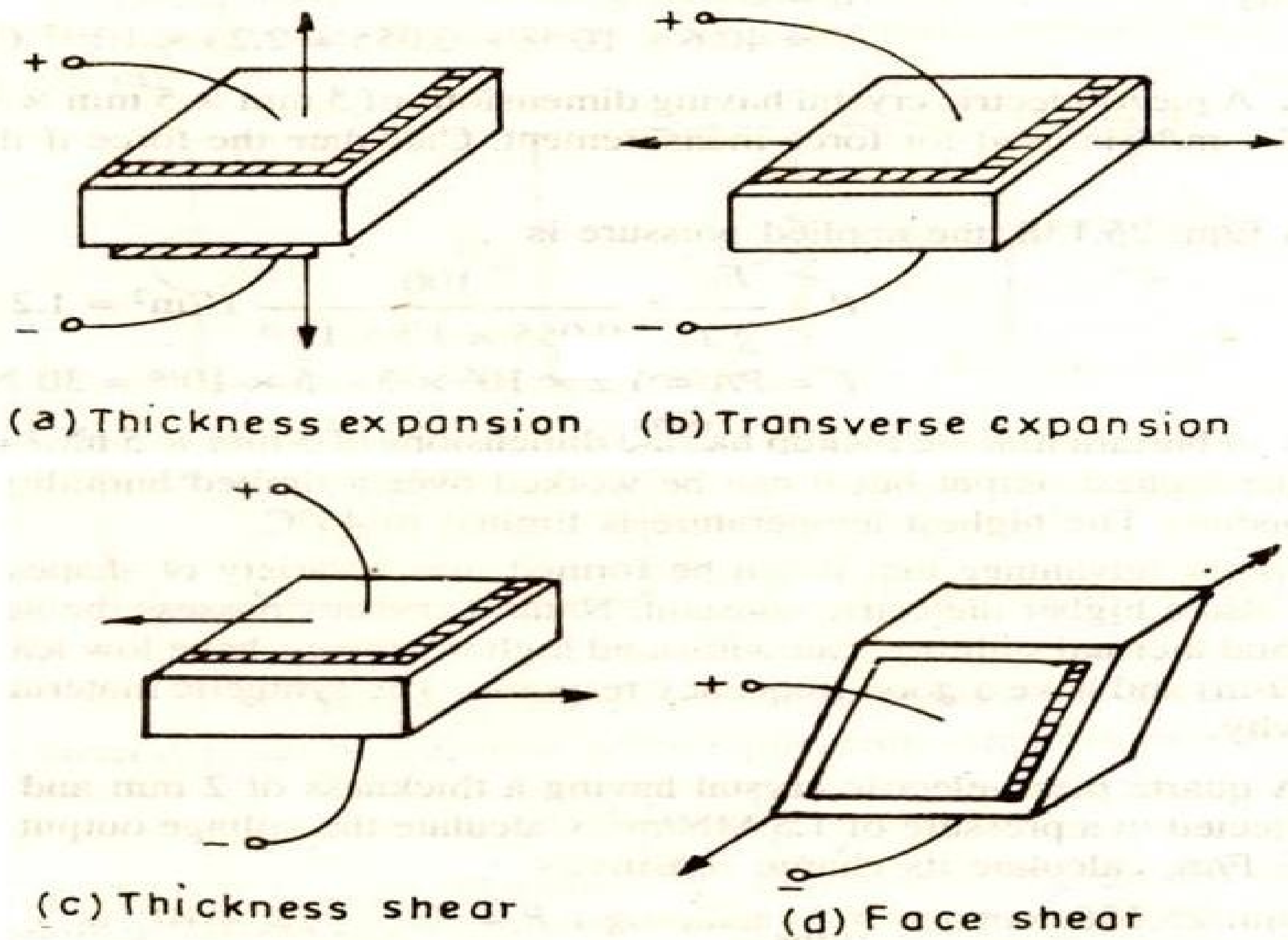


Fig. 25.122. Modes of operation of piezo-electric crystals.

Piezoelectric Transducers (-contd.)

- The piezoelectric effect is direction sensitive, a tensile force produces a voltage of one polarity while a compressive force produces a voltage of opposite polarity
- The magnitude and polarity of the induced surface charges are proportional to the magnitude and direction of the applied force (F)
- The induced charge is given by

$$Q = d \times F \qquad \ldots (2)$$

where, d is charge sensitivity of the crystal (constant for a given crystal)

- If the force (F) causes a change (Δt) in thickness (t) of the crystal, then

$$F = \frac{AE}{t}.\Delta t \qquad \ldots (3)$$

where, A: area of the crystal, $E: \text{Young modulus} = \frac{\text{Stress}}{\text{Strain}} = \frac{F/A}{\Delta t/t}$

- From eqns. (2) & (3), we have $Q = dAE\left(\frac{\Delta t}{t}\right) \qquad \ldots (4)$

Piezoelectric Transducers (-contd.)

- From eqns. (1) & (2), we get

$$E_0 = \frac{dF}{\varepsilon_r \varepsilon_0 A/t} = \left(\frac{d}{\varepsilon_r \varepsilon_0}\right) . t . \frac{F}{A}$$

$$\Rightarrow \quad E_0 = g \times t \times P \quad \ldots(5)$$

$$where, g = \frac{d}{\varepsilon_r \varepsilon_0} : voltage\ sensitivity\ of\ crystal\ (Vm/N), P: Stress$$

- We can write eqn. (5) as: $g = \frac{E_0/t}{P} = \frac{Electric\ Field}{Stress}$

Table 25.8. Properties of Barium Titanate and Quartz

Material	*Voltage Sensitivity g Vm/N*	*Permittivity, ∈ F/m*	*Charge Sensitivity, d pC/N*
Barium titanate	12×10^{-3}	12.5×10^{-9}	150
Quartz	50×10^{-3}	40.6×10^{-12}	2

Piezoelectric Transducers (-contd.)

- The piezoelectric transducer is cut from a large crystal in the direction of any of the electrical or mechanical axis perpendicular to the optical or crystal axis
- The values of 'd' and 'g' are not necessarily the same but are dependent upon the axis of cut

Properties of Piezoelectric Crystals:

- The desirable properties of piezoelectric materials are stability, high output, insensitivity to temperature and humidity and the ability to be formed into most desirable shape
- Quartz is the most stable piezoelectric material, however, its output is quite small
- On the other hand, Rochelle salt provides the highest output but it can be worked over a limited humidity range and has to be protected against moisture. Its highest temperature is limited to 45^0C

Piezoelectric Transducers (-contd.)

- Barium titrate has the advantage that it can be formed into a variety of shapes and sizes since it is polycrystalline. It also has a higher dielectric constant
- Natural crystals possess the advantages that they have higher mechanical and thermal stability, can withstand higher stresses, have low leakage (resistivity is of the order of 10^{16} Ω/m) and have a good frequency response
- The synthetic materials, in general, have a higher voltage sensitivity

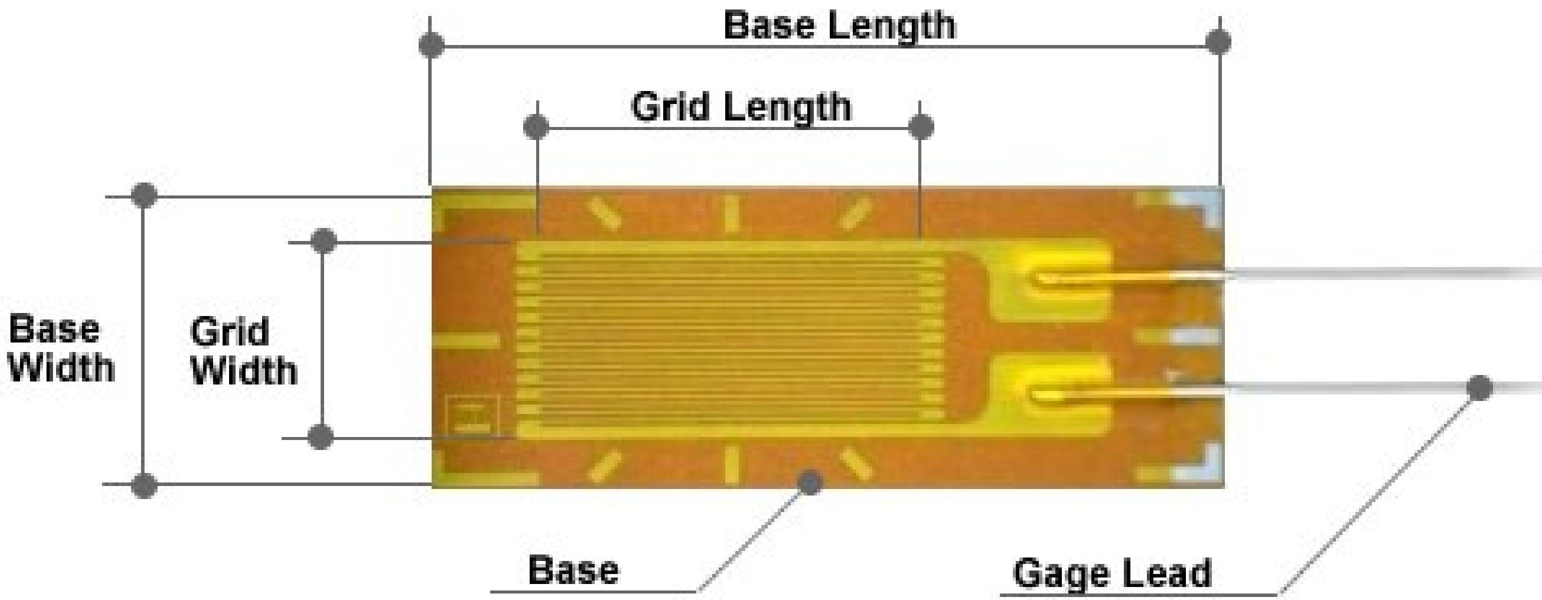
<u>Uses of Piezoelectric Material and Transducers</u>:

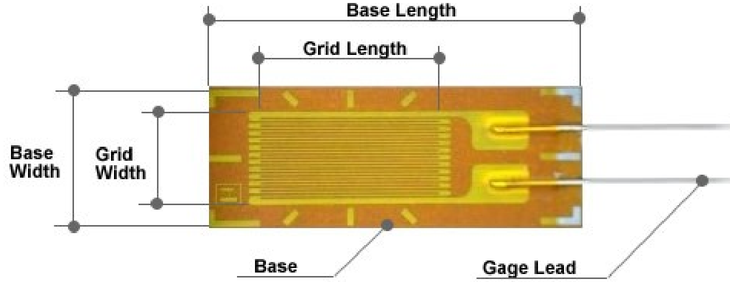
(1) Because of its stability, quartz is commonly used for stabilizing **electronic oscillators**. The crystal is ground to proper shape and is connected in an appropriate electronic cut whose frequency is controlled by it.

Piezoelectric Transducers (-contd.)

(2) The use of piezoelectric transducer elements is confined primarily to dynamic measurements. The voltage developed by application of strain is not held under static condition. Hence the elements are primarily used in the measurement of such quantities as surface **roughness, in accelerometers** and **vibration pickups**

(3) **Ultrasonic generator elements** also use barium titrate, a piezoelectric material and theses ultrasonic generator elements are used in industrial cleansing apparatus and also in underwater detection system (known as sonar)

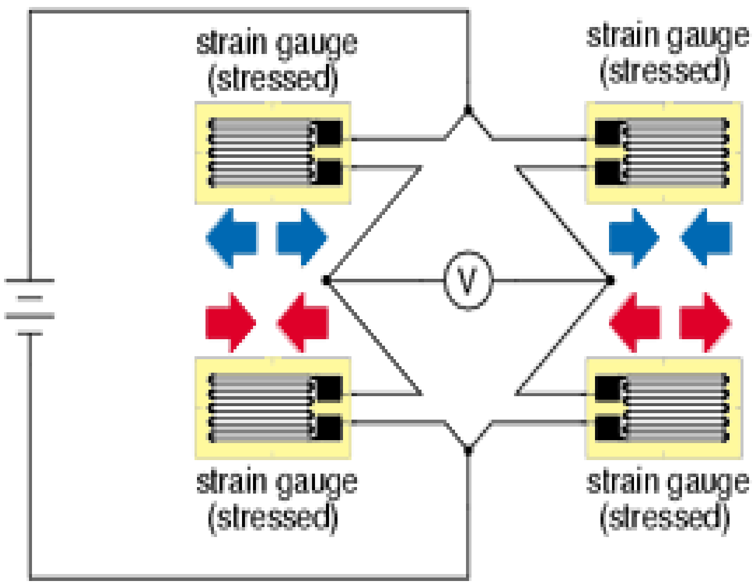

Base Length
Grid Length
Base Width
Grid Width
Base
Gage Lead



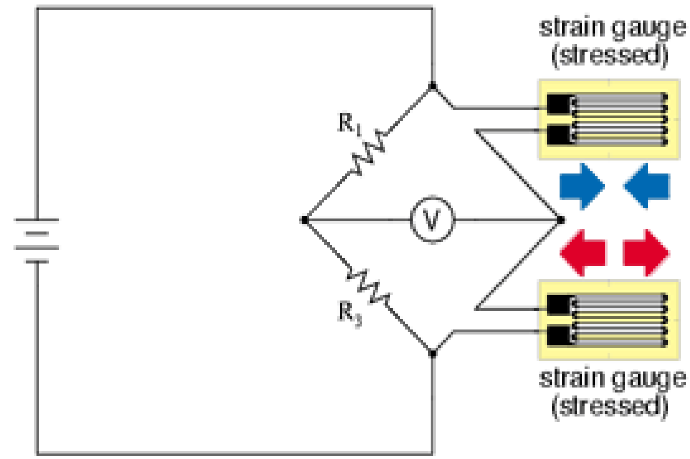
Specification	FA series	MA series	Unit and Note
Gage Length	0.3mm to 60mm	0.3mm to 60mm	standard
Gage Resistance	Within ±0.3% of the nominal resistance	Within ±0.3% of the nominal resistance	120Ω to 1000Ω
Foil Material	A : Cu-Ni Alloy	A : Cu-Ni Alloy	
Base Material	Polyester	Polyimide	
Gage Factor	2.00 (Nominal)	2.00 (Nominal)	1.90 to 2.10
Measurable Strain	2 to 4% maximum	2 to 4% maximum	Up to 10% with yielding strain
Temperature Range	-30°C to +80°C	-30 to +180°C	
Thermal Output	±2μst/°C(RT to +80°C)	±2μst/°C(RT to +160°C) ±5μst/°C(+160°C to higher)	Compensated temperature range
Gage Factor Change with Temperature	±0.015%/°C	±0.015%/°C	Refer to "Tech Information"
Fatigue Life	More than 1×10^5 reversals	More than 1×10^5 reversals	at $\pm1000\times10^6$ strain
Applicable Linear Expansion Coefficient	Common steel Stainless steel Aluminum alloy	Common steel Stainless steel Aluminum alloy	10.8ppm/°C 16.2ppm/°C 23.4ppm/°C

The strain gauge is connected into a Wheatstone Bridge circuit with a combination of :

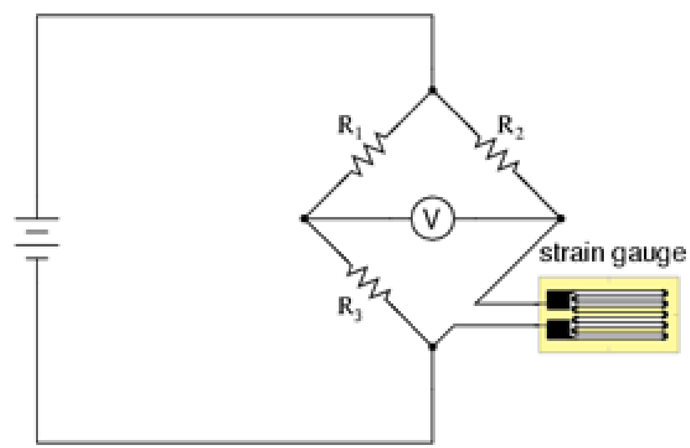
Full-bridge strain gauge circuit



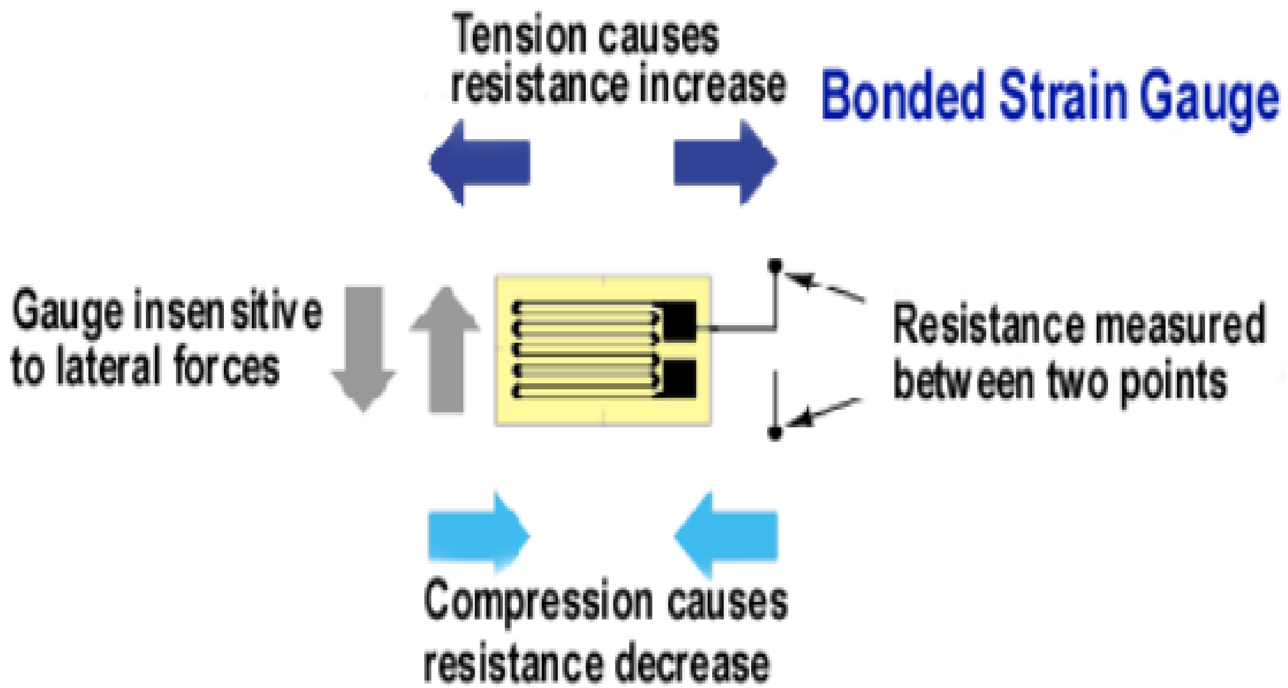
Half-bridge strain gauge circuit



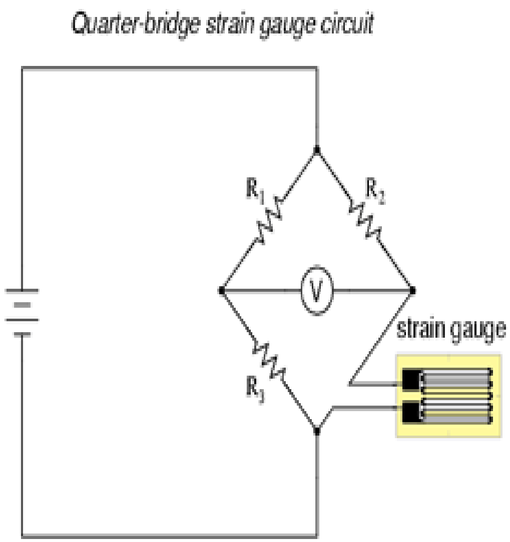
Quarter-bridge strain gauge circuit



The name "bonded gauge" is given to strain gauges that are glued to a larger structure under stress (called the test specimen)



Typical strain gauge resistances range from 30 Ohms to 3 kOhms (unstressed)



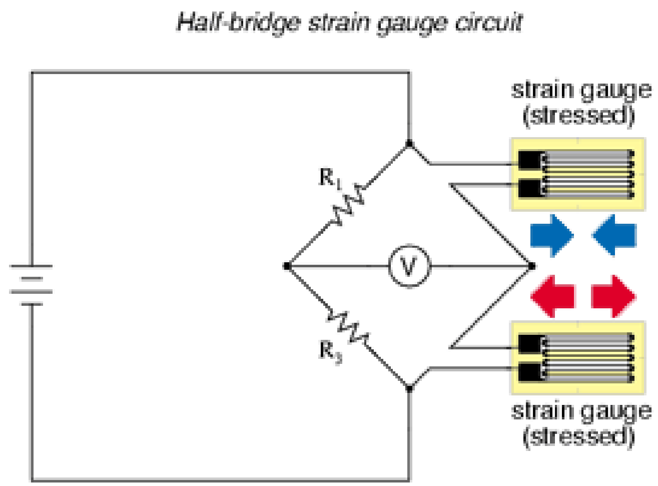
Typically, the rheostat arm of the bridge (R2 in the diagram) is set at a value equal to the strain gauge resistance with no force applied.

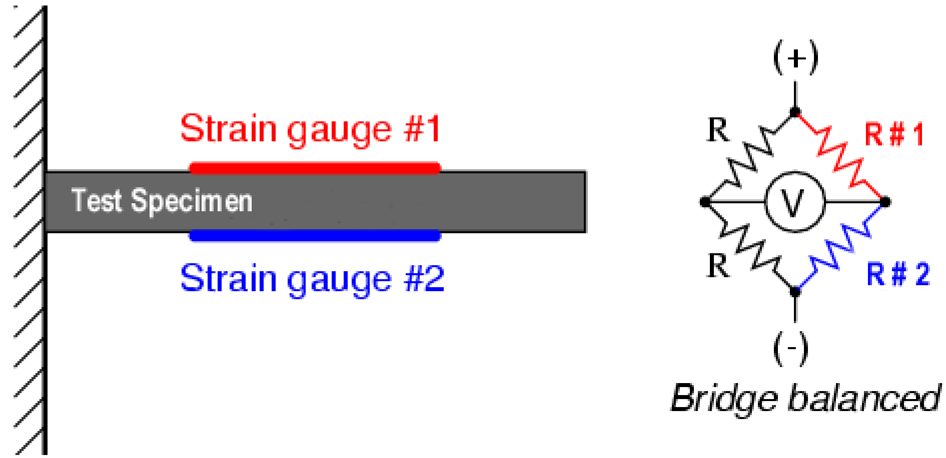
The two ratio arms of the bridge (R1 and R3) are set equal to each other.

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.

As the strain gauge is either compressed or tensed, its resistance will decrease or increase, respectively, thus unbalancing the bridge and producing an indication at the voltmeter.

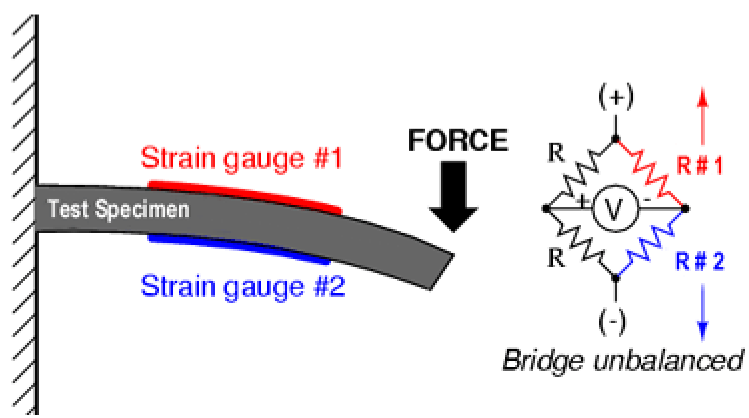
This arrangement, with a single element of the bridge changing resistance in response to the measured variable (mechanical force), is known as a quarter-bridge circuit.





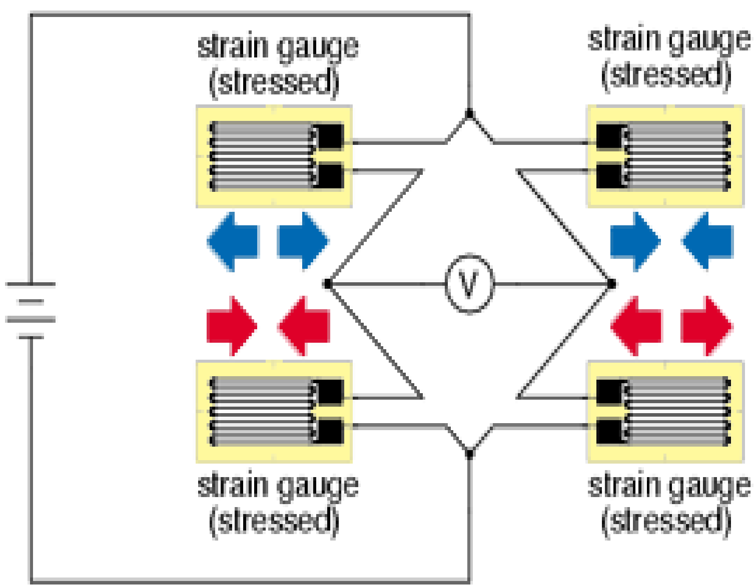
With no force applied to the test specimen, both strain gauges have equal resistance and the bridge circuit is balanced.

However, when a downward force is applied to the free end of the specimen, it will bend downward, stretching gauge #1 and compressing gauge #2 at the same time:



In applications where such complementary pairs of strain gauges can be bonded to the test specimen, it may be advantageous to make all four elements of the bridge "active" for even greater sensitivity. This is called a full-bridge circuit:

Full-bridge strain gauge circuit



Strain Gages Applications

They are often used in medical instruments like kidney dialysis machines and syringe pumps to help monitor fluid flow rates.

•Strain gages are also used in patient weighing and patient lift systems.

•Wireless strain gages can be found in CT scanners and mammography machines.

•Patient positioning systems used during radiation treatments

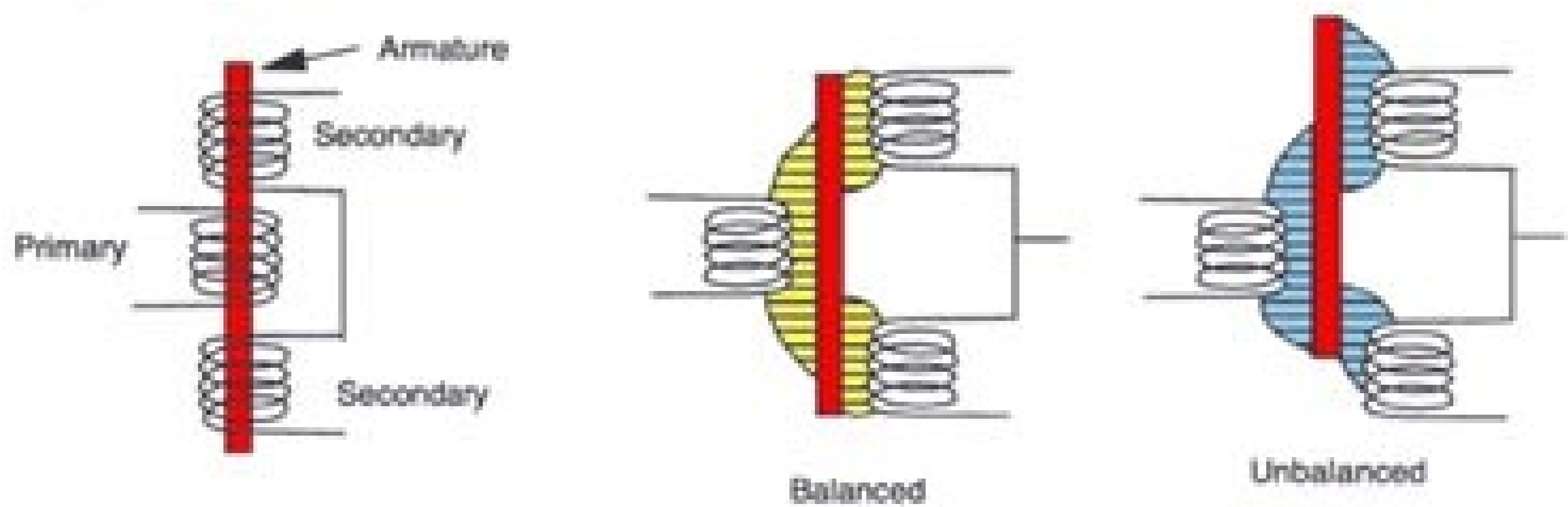
•In physical therapy applications, strain gage-based force sensors are used to measure forces on joints (shoulders, hips, knees, et al).

•Force feedback crutches aid patients undergoing orthopaedic therapy by detecting the amount of weight is being borne by the crutch

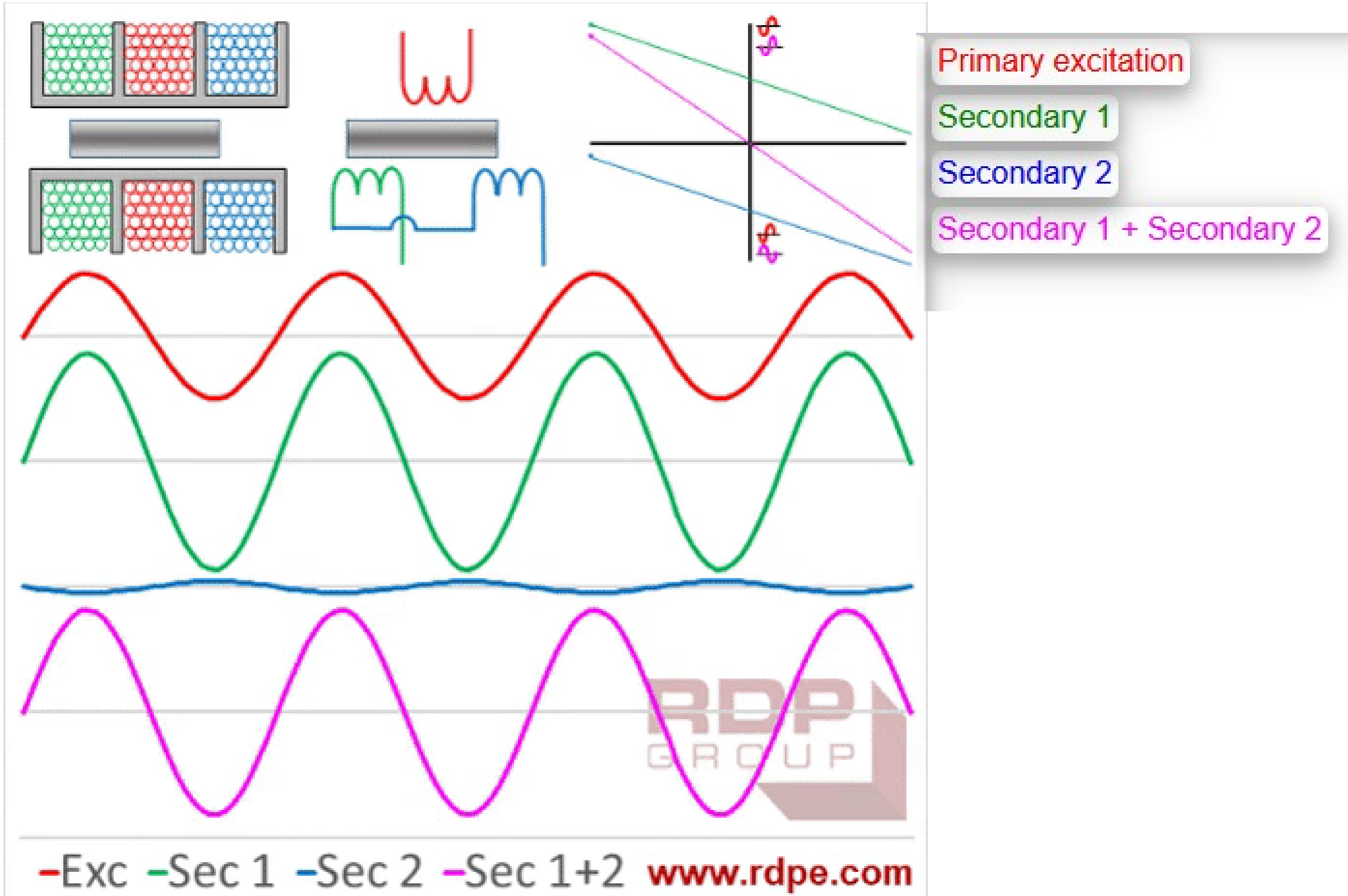
THE LINEAR VARIABLE DIFFERENTIAL TRANSFORMER (LVDT)

The Linear Variable Differential Transformer (LVDT) is a displacement measuring instrument and is not a strain-based sensor.

Two components comprise the LVDT: the mobile armature and the outer transformer windings. The secondary coils are series-opposed; wound in series but in opposite directions.



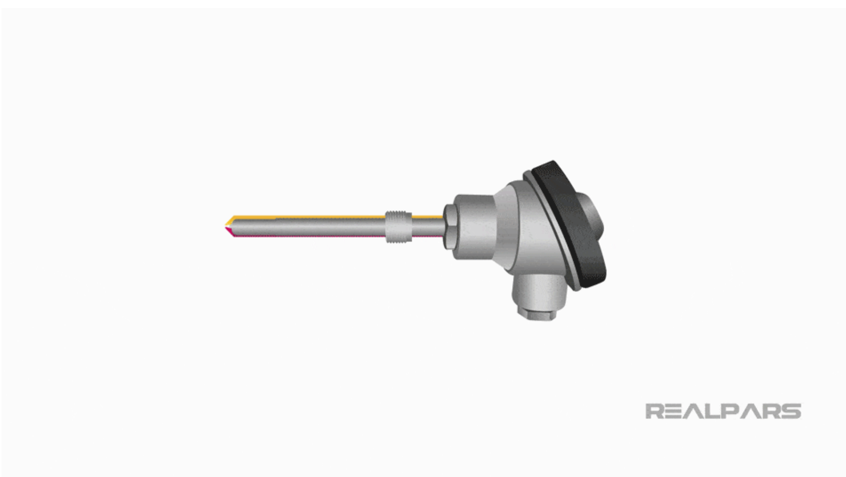
LVDT How it Works

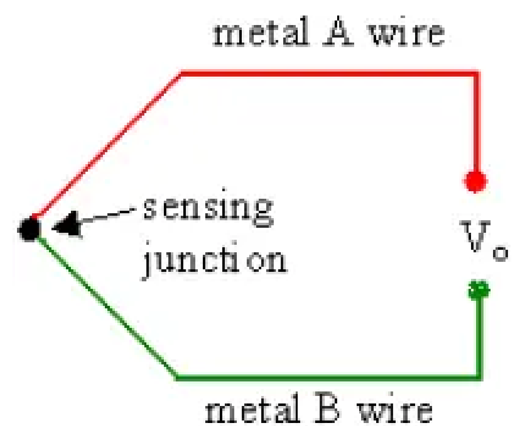


An LVDT Displacement Transducer comprises 3 coils;
a primary and two secondaries

Thermocouple Working Principle

A thermocouple is made up of two dissimilar metals, joined together at one end, that produce a voltage (expressed in millivolts) with a change in temperature. The junction of the two metals, called the sensing junction, is connected to extension wires. Any two dissimilar metals may be used to make a thermocouple.

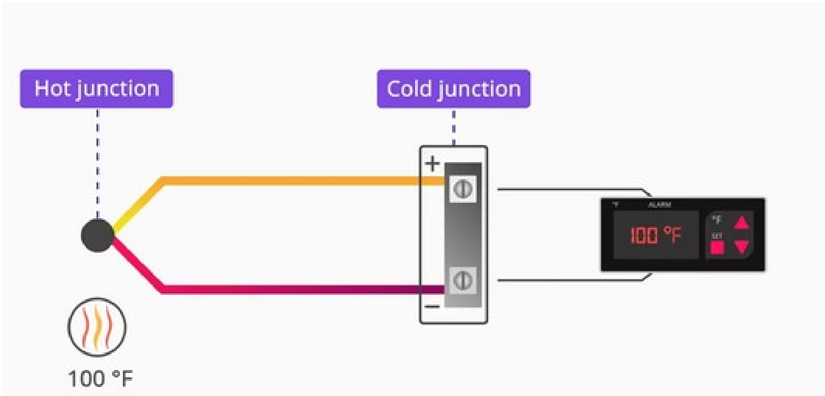


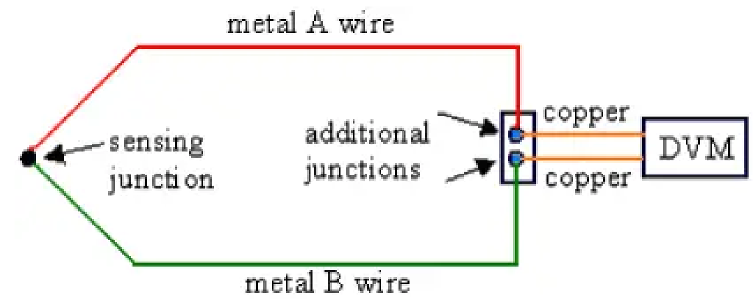


When two dissimilar metals are connected together, a small voltage called a *thermo-junction voltage* is generated at the junction. This is called the ***Peltier effect***.

If the temperature of the junction changes, it causes voltage to change too, which can be measured by the input circuits of an electronic controller.
The output is a voltage proportional to the temperature difference between the junction and the free ends. This is called the ***Thompson effect***.

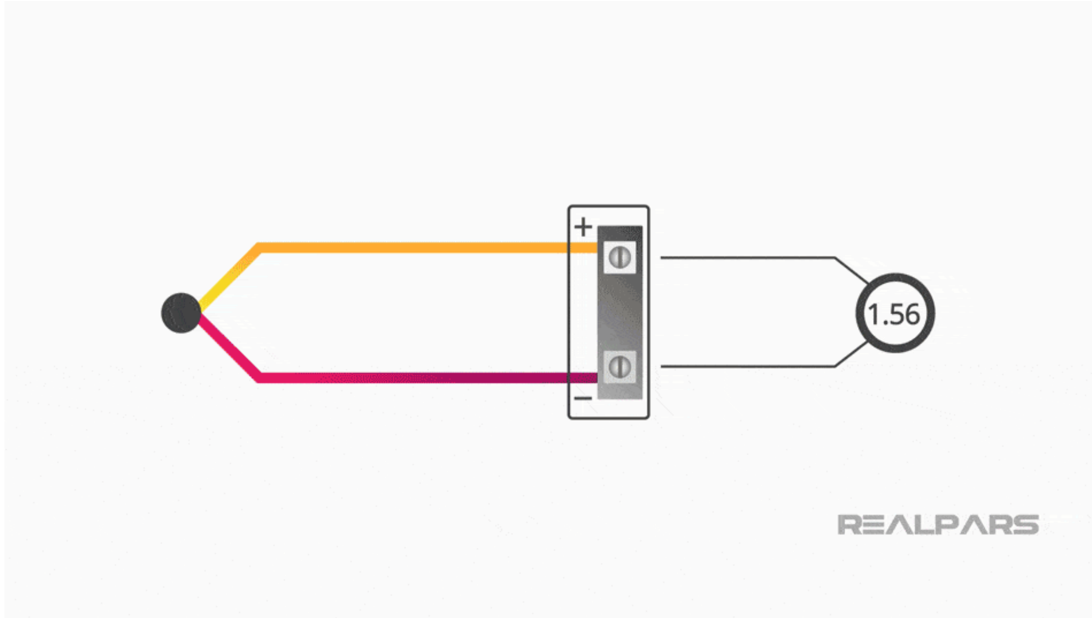
Both of these effects can be combined to measure temperature. By holding one junction at a known temperature (reference junction) and measuring the voltage, the temperature at the sensing junction can be deduced. The voltage generated is directly proportional to the temperature difference. The combined effect is known as the *thermo-junction effect* or the ***Seebeck effect***.

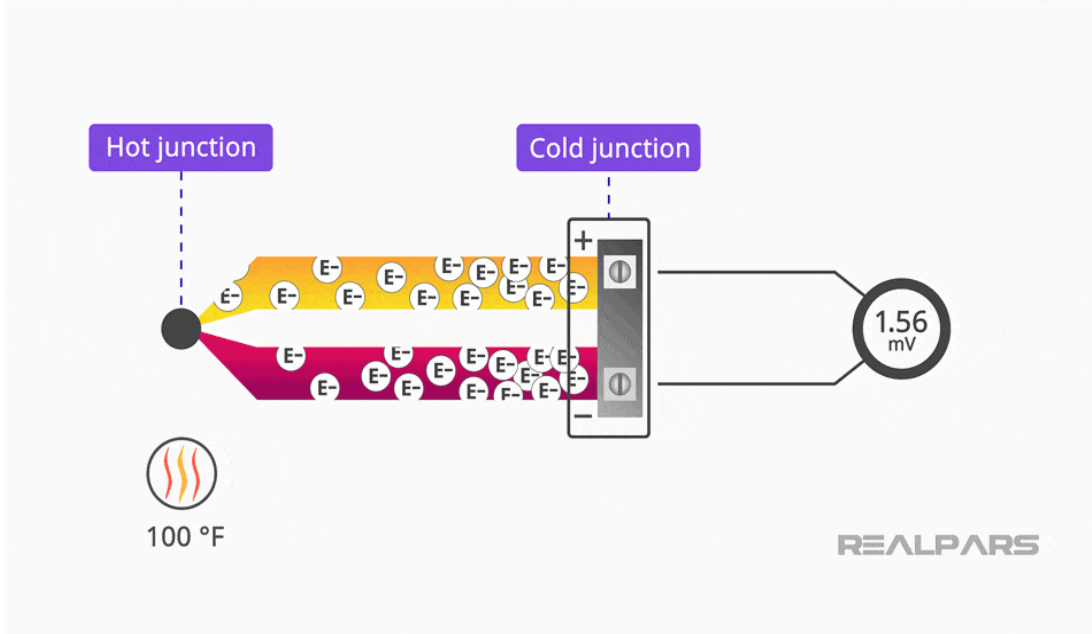




Hot Junction, Measurement Junction, Sensing Point, or Sensing Junction

The wiring terminals on the measuring instrument are most often called the **Cold Junction**.


1.56


Hot junction
Cold junction
1.56
mV
100 °F

A ***type K*** thermocouple has the color *yellow*, and uses *chromel – alumel,* which are the trade names of the Ni-Cr and Ni-Al wire alloys.

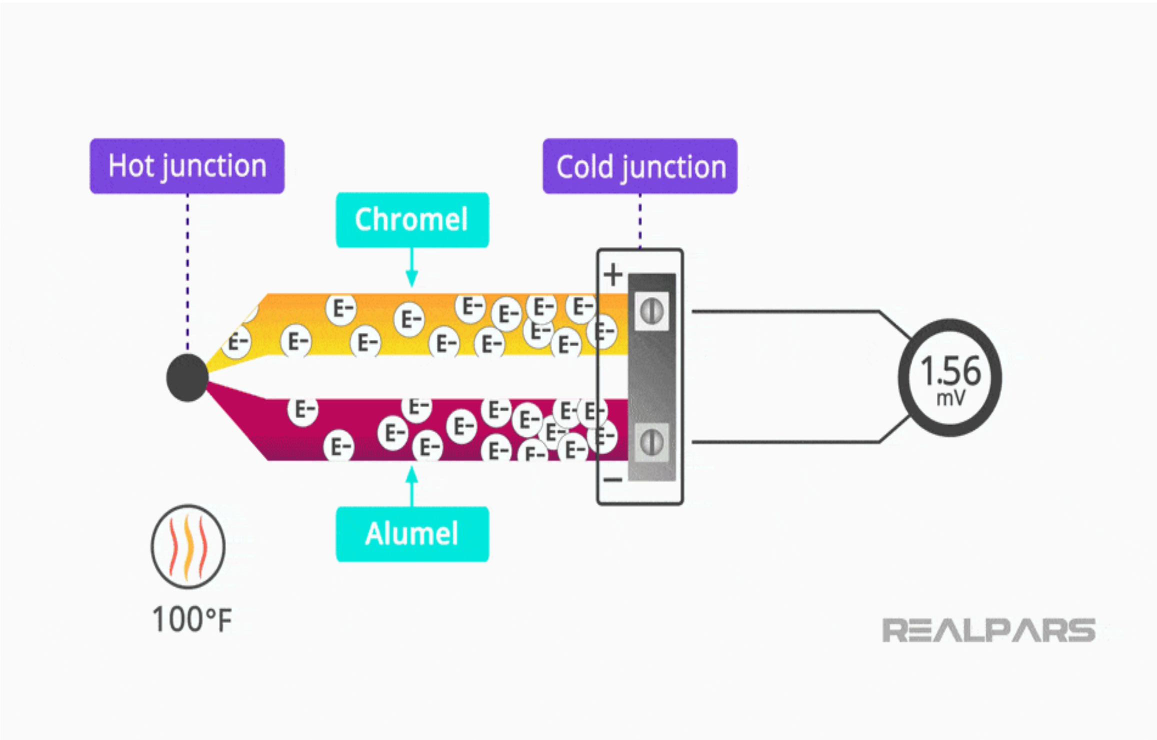
A ***type J*** thermocouple has the color *black*, and uses *iron* and *constantan* as its component metals. **(Constantan is an alloy of nickel and copper.)**

A ***type T*** thermocouple has the color *blue*, and uses *copper* and *constantan* as its component metals.

A **type S** thermocouple uses Pt/Rh-Pt

A **type E** thermocouple uses Ni/Cr-Con

*A **type N** thermocouple uses Ni/Cr/Si-Ni/Si*



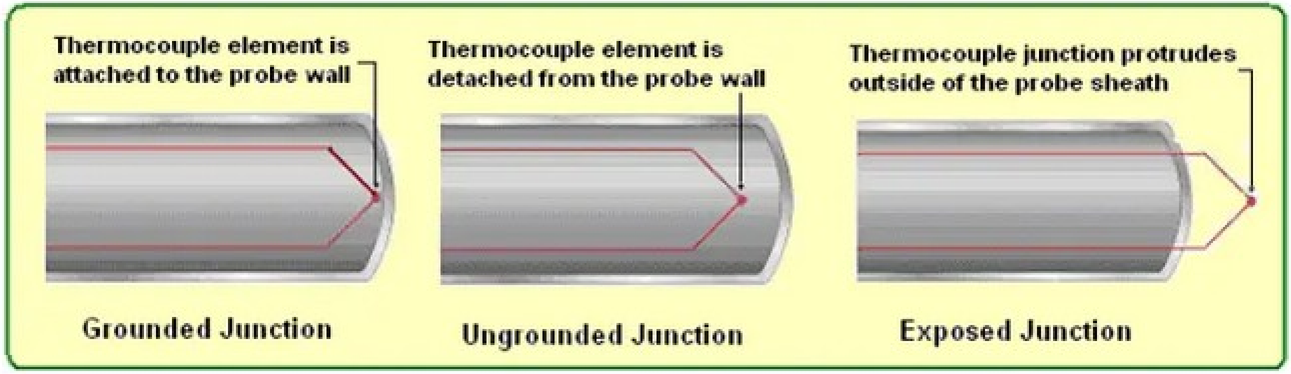
Temperature V/s Voltage Reference Table for Type J

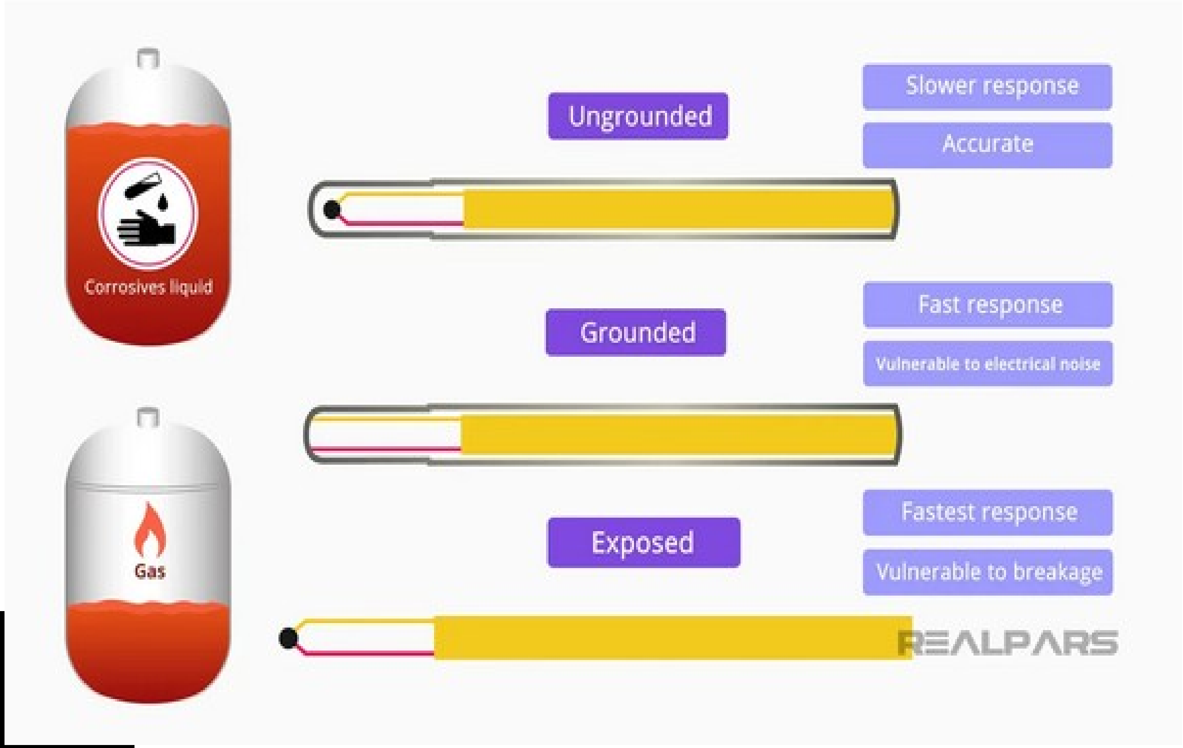
Temperature (°C)	voltage (mV)
0.0	0.000
10.0	0.507
20.0	1.019
30.0	1.537
40.0	2.059
50.0	2.585
60.0	3.116

The following criteria are used in selecting a thermocouple:

- ✓Temperature range.
- ✓Chemical resistance of the thermocouple or sheath material.
- ✓Abrasion and vibration resistance.
- ✓Installation requirements

(may need to be compatible with existing equipment; existing holes may determine probe diameter).


Thermocouple element is attached to the probe wall
Thermocouple element is detached from the probe wall
Thermocouple junction protrudes outside of the probe sheath
Grounded Junction
Ungrounded Junction
Exposed Junction


Ungrounded
Slower response
Accurate
Corrosives liquid
Grounded
Fast response
Vulnerable to electrical noise
Exposed
Fastest response
Vulnerable to breakage
Gas
REALPARS

Linear Variable Differential Transducer/Transformer (LVDT)

- The differential transformer is a passive inductive transformer (known as LVDT) is used to measure displacement directly
- The transformer consists of a single primary winding P1 and two secondary windings S1 and S2 wound on a hollow cylindrical former (as shown in fig. 13.19)
- The secondary windings have an equal number of turns and are identical placed on either side of the primary windings
- The primary winding is connected to an ac source (50 Hz to 20 kHz)
- A movable soft iron core slides within the hollow former and therefore affects the magnetic coupling between the primary and the two secondaries
- The displacement to be measured is applied to an arm attached to the soft iron core (the core is made up of a nickel iron alloy which is slotted longitudinally to reduce eddy current losses)
- Assume the output voltages of secondary windings S1 and S2 are E_{s1} and E_{s2}

Linear Variable Differential Transducer/Transformer (LVDT)

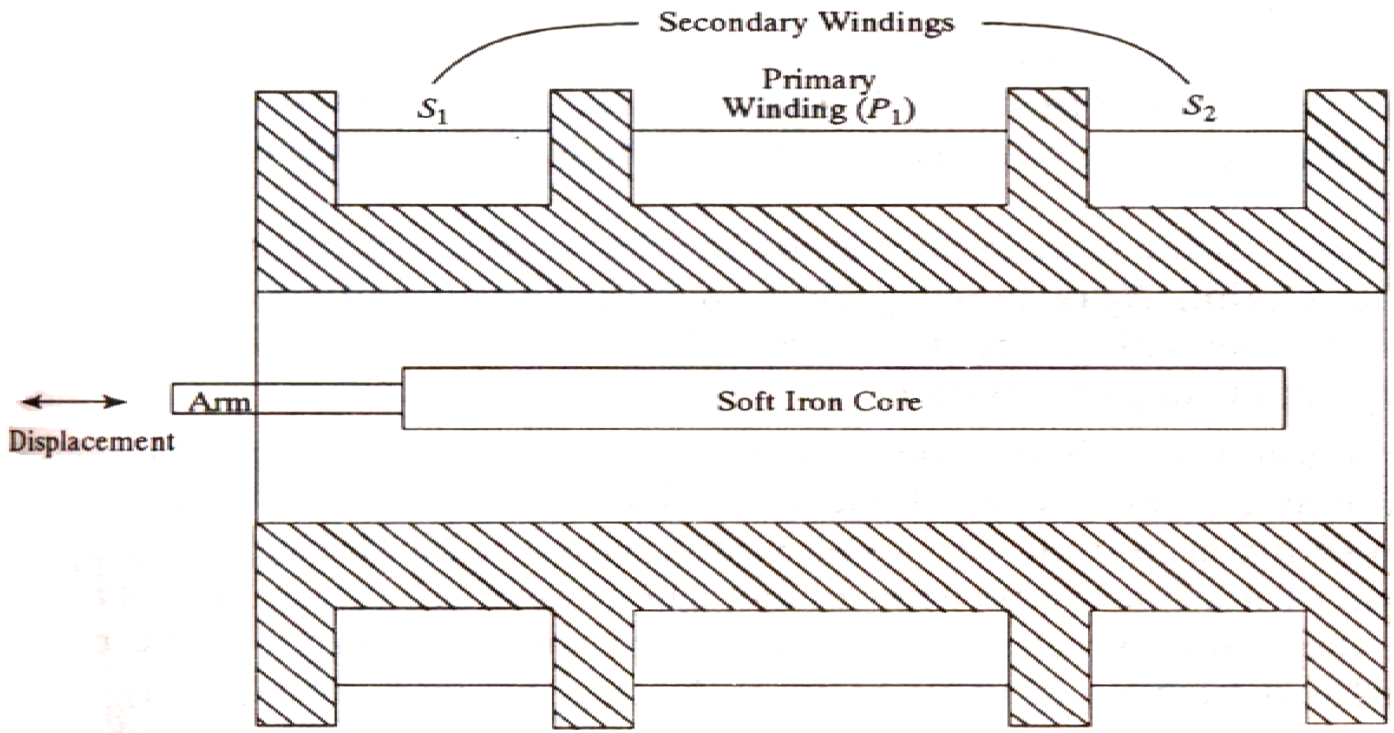
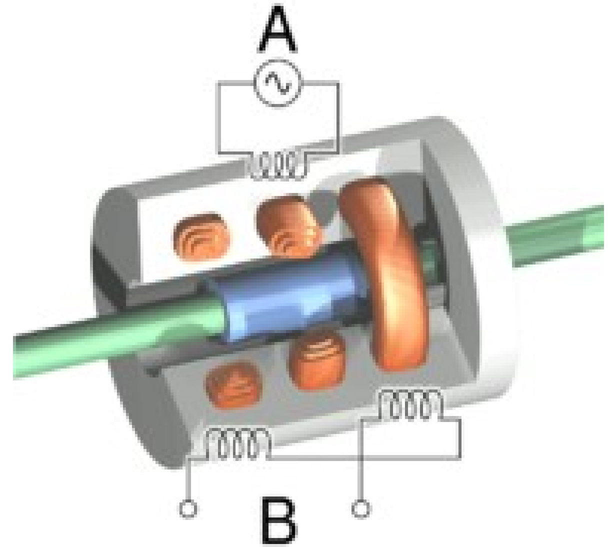


Fig. 13.19 Construction of a Linear Variable Differential Transducer (LVDT)

Linear Variable Differential Transducer/Transformer (LVDT)



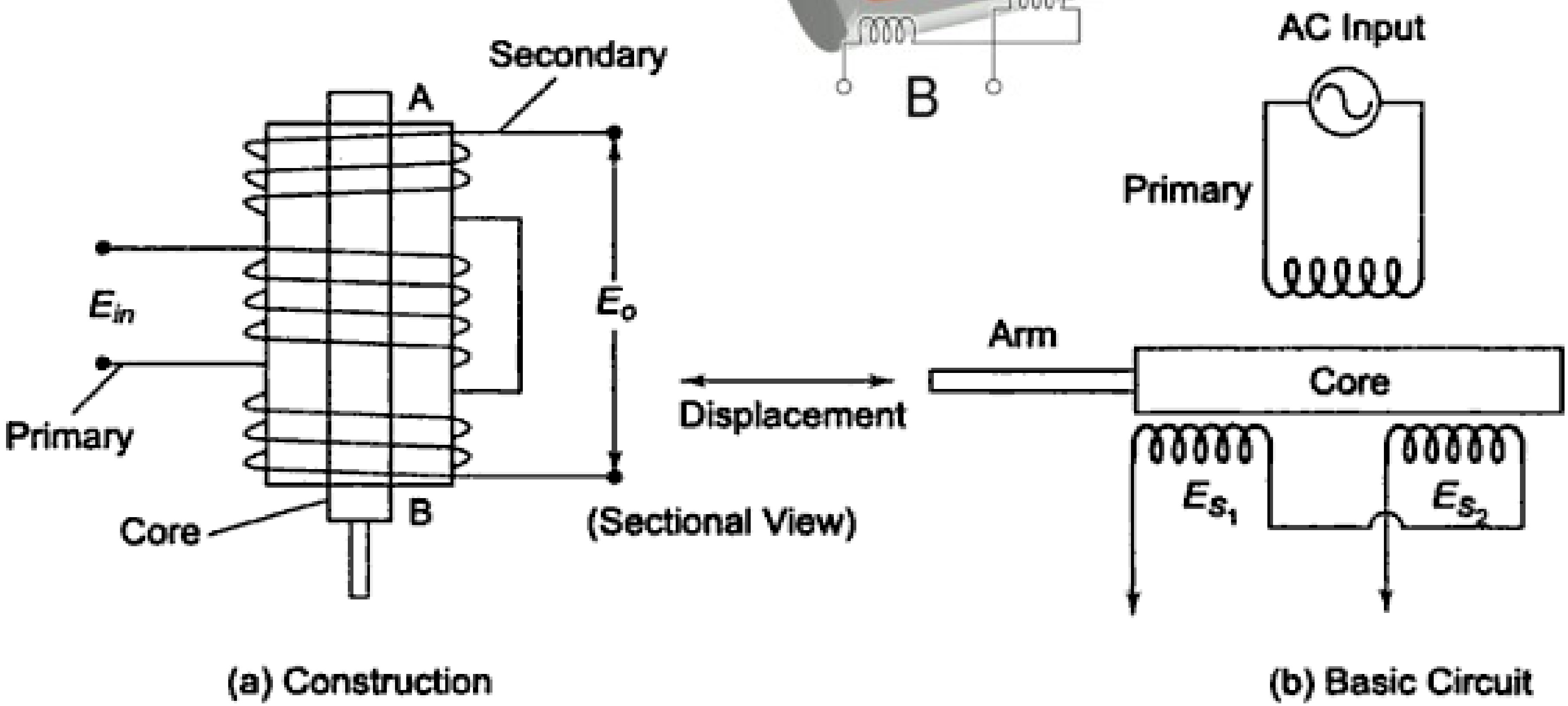


Fig. 13.20 Secondary Winding Connected for Differential Output

Linear Variable Differential Transducer/Transformer (LVDT)

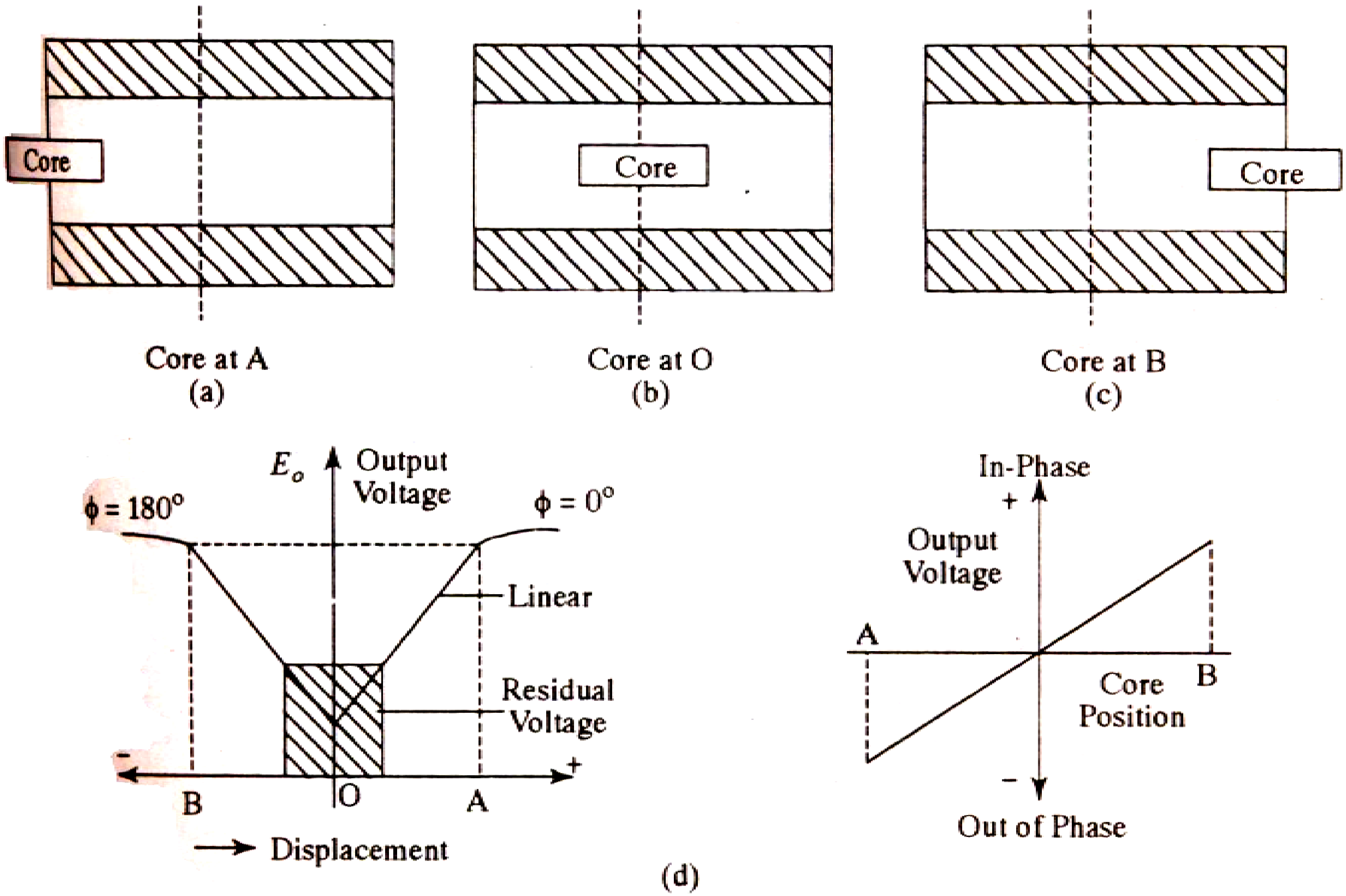


Fig.13.21 (a),(b),(c) Various Core Position of LVDT (d) Variation of Output Voltage vs Displacement

Linear Variable Differential Transducer/Transformer (LVDT)

- In order to convert the output from S1 to S2 into a single voltage signal, the two secondaries S1 and S2 are connected in series opposition (as shown in fig. 13.20)
- And hence, the differential output voltage $E_0 = E_{s1} – E_{s2}$
- When the core is at its normal position, the flux linking with both secondaries is equal and equal emfs are induced in them
- Hence, at null position $E_{s1} = E_{s2}$ and this results $E_0 = 0$ (fig. 13.21b)
- Now, if the core is moved to left of null position, more flux links with winding S1 and less with winding S2
- Hence, output voltage E_{s1} of the secondary winding S1 is greater than E_{s2}, which results E_0 in phase with E_{s1} (also with E_{in})
- Similarly, if the core is moved to the right of null position, the flux linking with S2 becomes greater than that linked with S1 and this results in E_{s2} becoming larger than E_{s1}
- The output voltage E_0, in this case, is out of phase with E_{s1}

Linear Variable Differential Transducer/Transformer (LVDT)

- The amount of voltage change in either secondary winding is proportional to the amount of movement of the core
- Hence we have an indication of the amount of linear motion
- By noting which output is increasing or decreasing, the direction of motion can be determined
- The output ac voltage inverts as the core passes the centre (null) position
- The farther the core moves from the centre, the greater the difference between E_{s1} and E_{s2} and consequently the greater the value of E_0
- Hence, the amplitude of E_0 is the function of displacement of the core and the polarity or phase of E_0 indicates the direction of motion
- Output signal may also be applied to a recorder or to a controller that can restore the moving system to its normal position
- The output voltage of an LVDT is a linear function of core displacement within a limited range of motion (approximately 5mm from the null position) and beyond this range, the curve starts to deviate

Linear Variable Differential Transducer/Transformer (LVDT)

- Ideally, the output voltage at the null position should be zero but in actual practice there exists a small voltage (residual voltage) at the null position
- This may be on account of presence of harmonics in the input supply voltage and also due to the harmonics produced in the output voltage due to the use of iron core
- There may be either an incomplete magnetic or electrical imbalance or both which result in a finite output voltage (generally less than 1% of maximum output voltage in linear region) at the null position
- Other causes of residual voltage are stray magnetic fields and temperature effects
- However, with improved technological methods and with the use of better ac sources the residual voltage can be reduced to negligible value
- Mostly, the LVDTs produce higher output voltage for small changes in core position
- Several commercial models that produce 50 mV/mm to 300 mV/mm are available

Linear Variable Differential Transducer/Transformer (LVDT)

- LVDTs are available with ranges as low as ±0.05” to as high as ±25” and are sensitive enough to be used to measure displacements of well below 0.001”
- They can operate at temperatures as low as -265^{0}C and as high as 600^{0}C and are also available in radiation resistance designs for nuclear operations

Advantages of LVDT:

(1) **Linearity**: The output voltage of this transducer is practically linear for displacements up to 5 mm.

(2) **Infinite Resolution**: The change in output voltage is stepless. The effective resolution depends more on the test equipment than on the transducer.

(3) **High Output**: It gives a high output. Therefore, there is frequently no need for intermediate amplification devices.

(4) **High Sensitivity**: The transducer possess a sensitivity as high as 40 V/mm.

Linear Variable Differential Transducer/Transformer (LVDT)

(5) Ruggedness: These transducers can usually tolerate a high degree of vibration and shock.

(6) Less Friction: There are no sliding contacts.

(7) Low Power Consumption: Most LVDTs consume less than 1 W of power.

Disadvantages of LVDT:

(1) Large displacements are required for appreciable differential output

(2) They are sensitive to stray magnetic fields (but shielding is possible)

(3) The receiving instrument must be selected to operate on ac signals, or a demodulator network must be used if a dc output is required

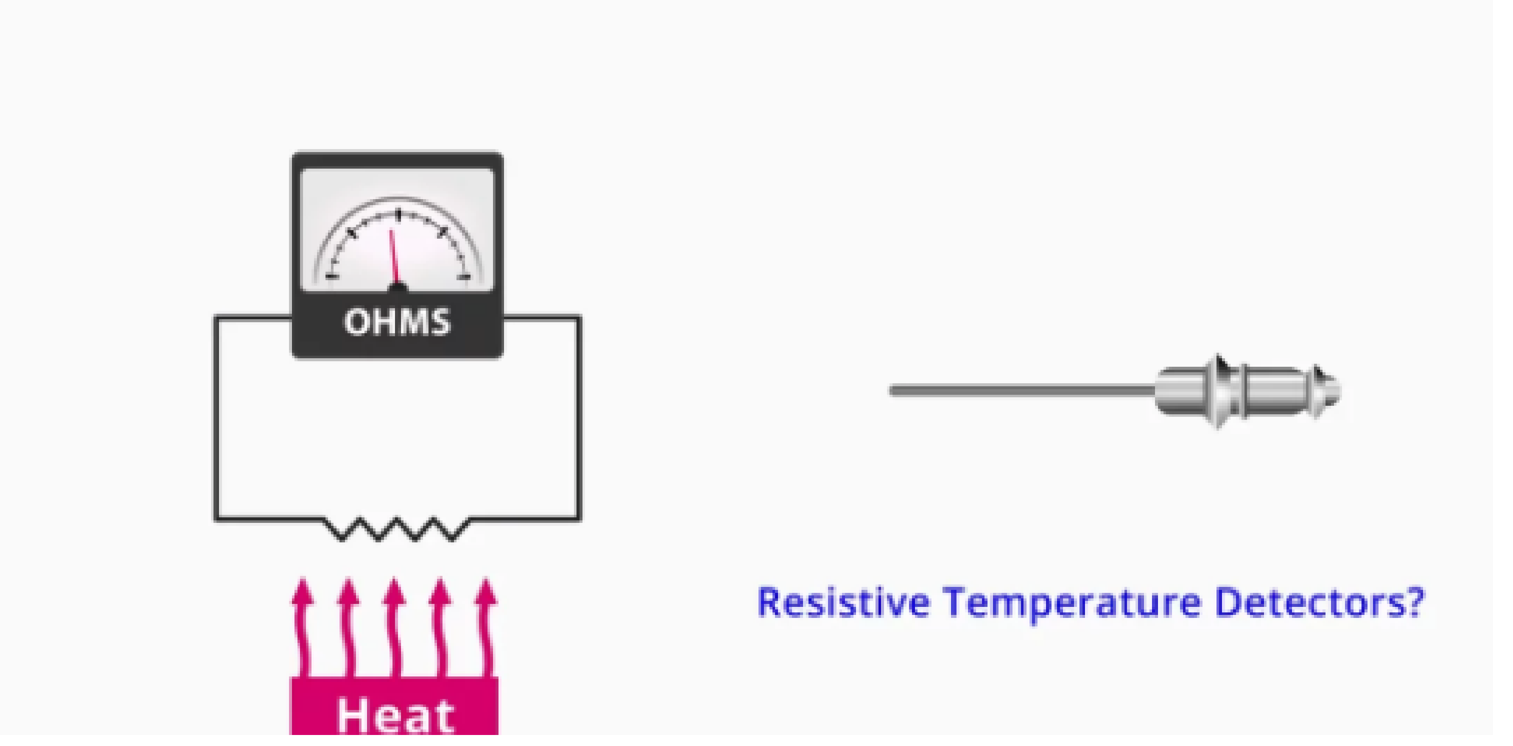
(4) The dynamic response is limited mechanically by the mass of the core and electrically by the applied voltage

(5) Temperature affects the transducer

Thermoelectric Transducers

- Generally used thermoelectric transducers are:

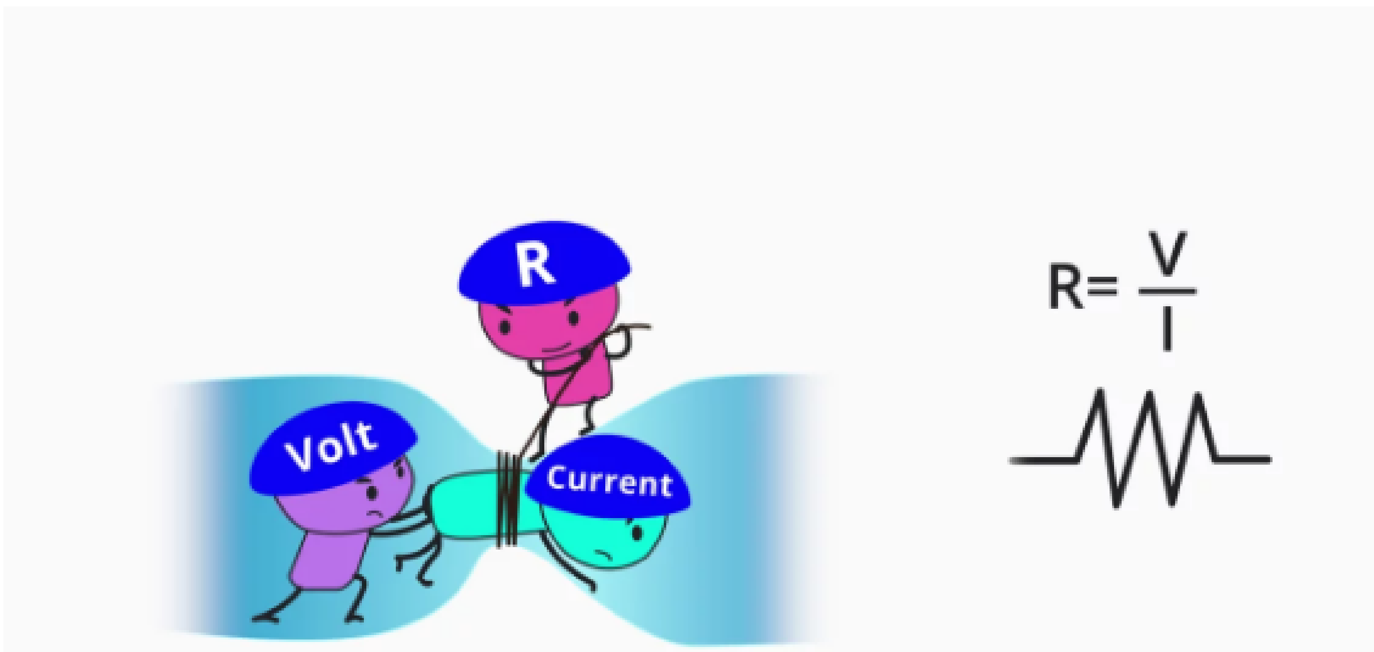
(a) Resistance Thermometer (Resistance Temperature Detector, RTD)



what electrical resistance and specific electrical resistance are ?

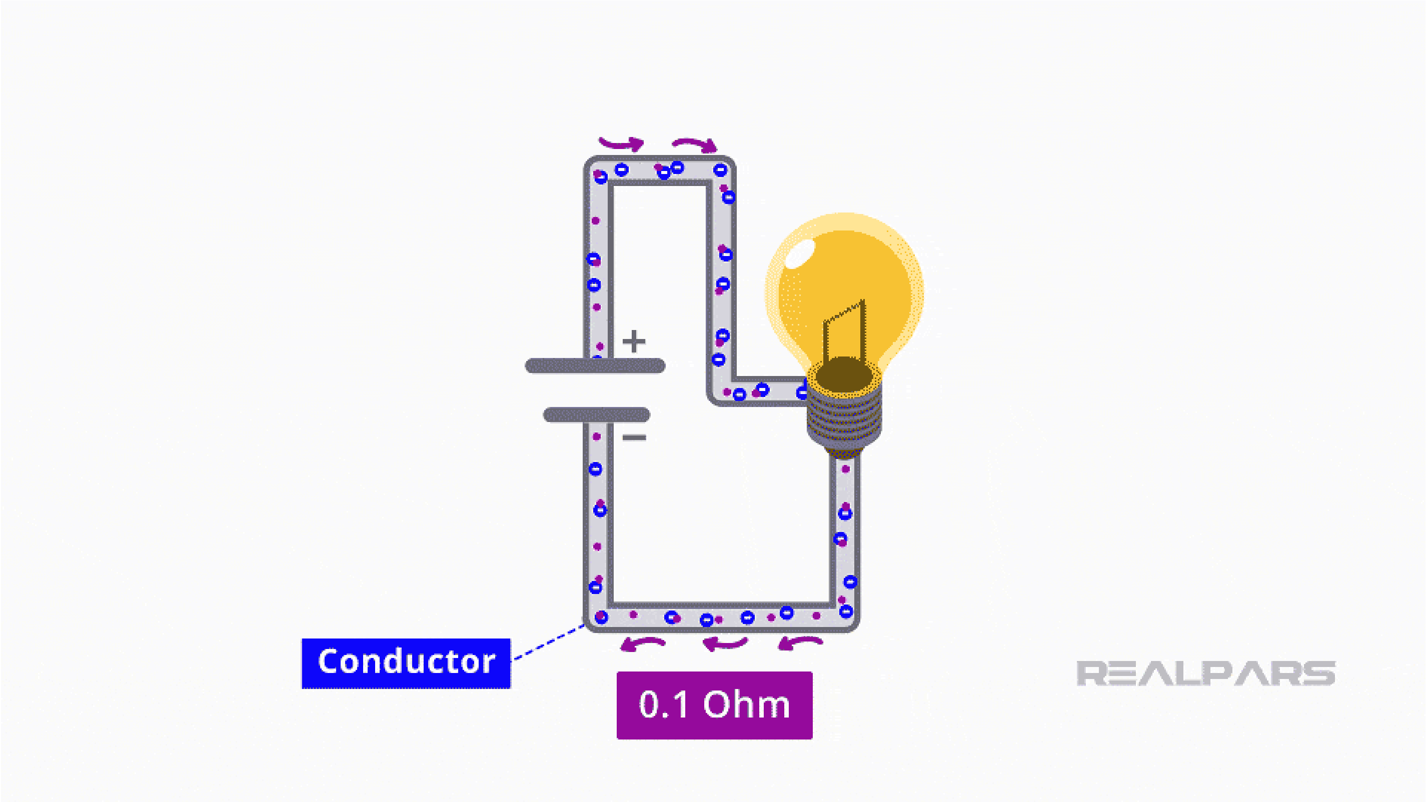
Electrical resistance

Electrical resistance is defined as the ability of a body to oppose the flow of electric current.

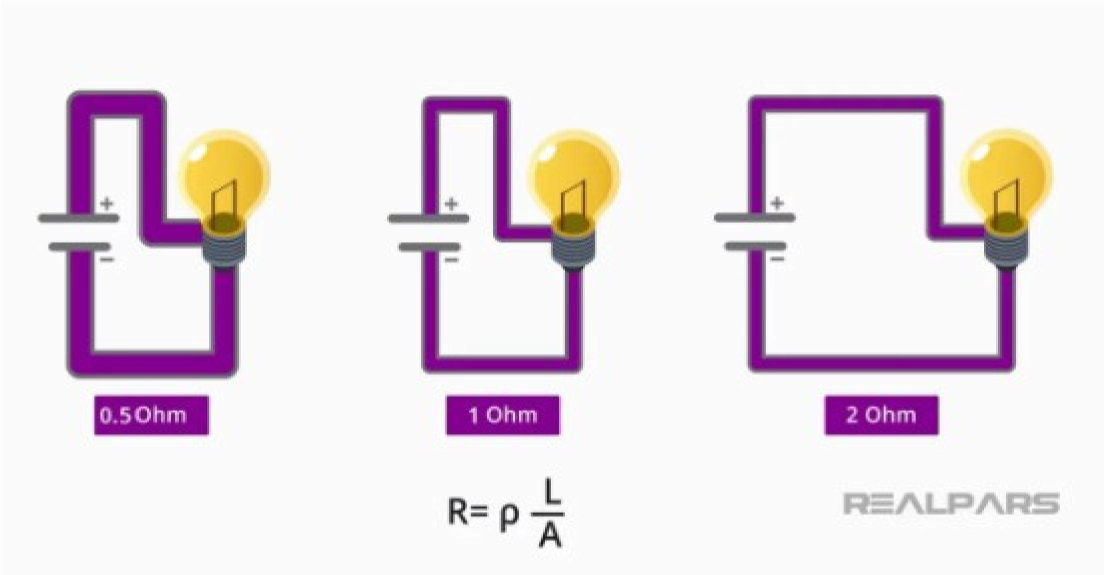


Resistance Temperature Detector

- A substance that has free electrons and where the charge can move relatively freely is called a conductor.



Effective factors



Electrical resistance varies depending on the **length**, **width**, and **nature of the conductor material**, as well as the **temperature** to which it is subjected.

Resistance is directly proportional to the length of the conductor, that is, the longer the length, the greater the resistance.

It is also inversely proportional to the area of the conductor, since the larger the area, the easier the passage of electrons and, consequently, the lower the resistance of the material.

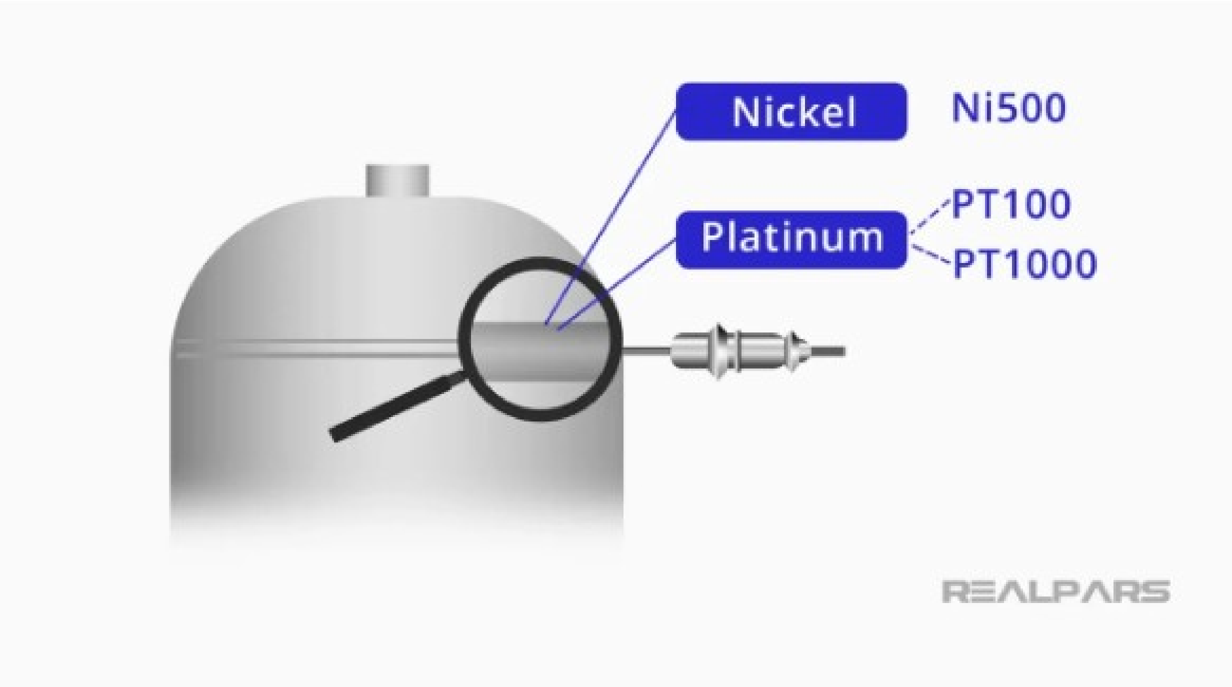
How does an RTD work?

- Specific electrical resistance is also known as electric resistivity is a property of material defining **how strongly can the material oppose** the flow of electric current

- When the **conductor is heated**, its atoms absorb this heat energy, resulting in an increase in vibration.

- Now, when the electric current is crossing the conductor, the number of collisions between electrons and atoms increases, making it harder for the current to flow throw it.

- RTD sensors use this variation in electrical resistance to measure the change in temperature.



resistance at zero degrees Celsius

RTD components

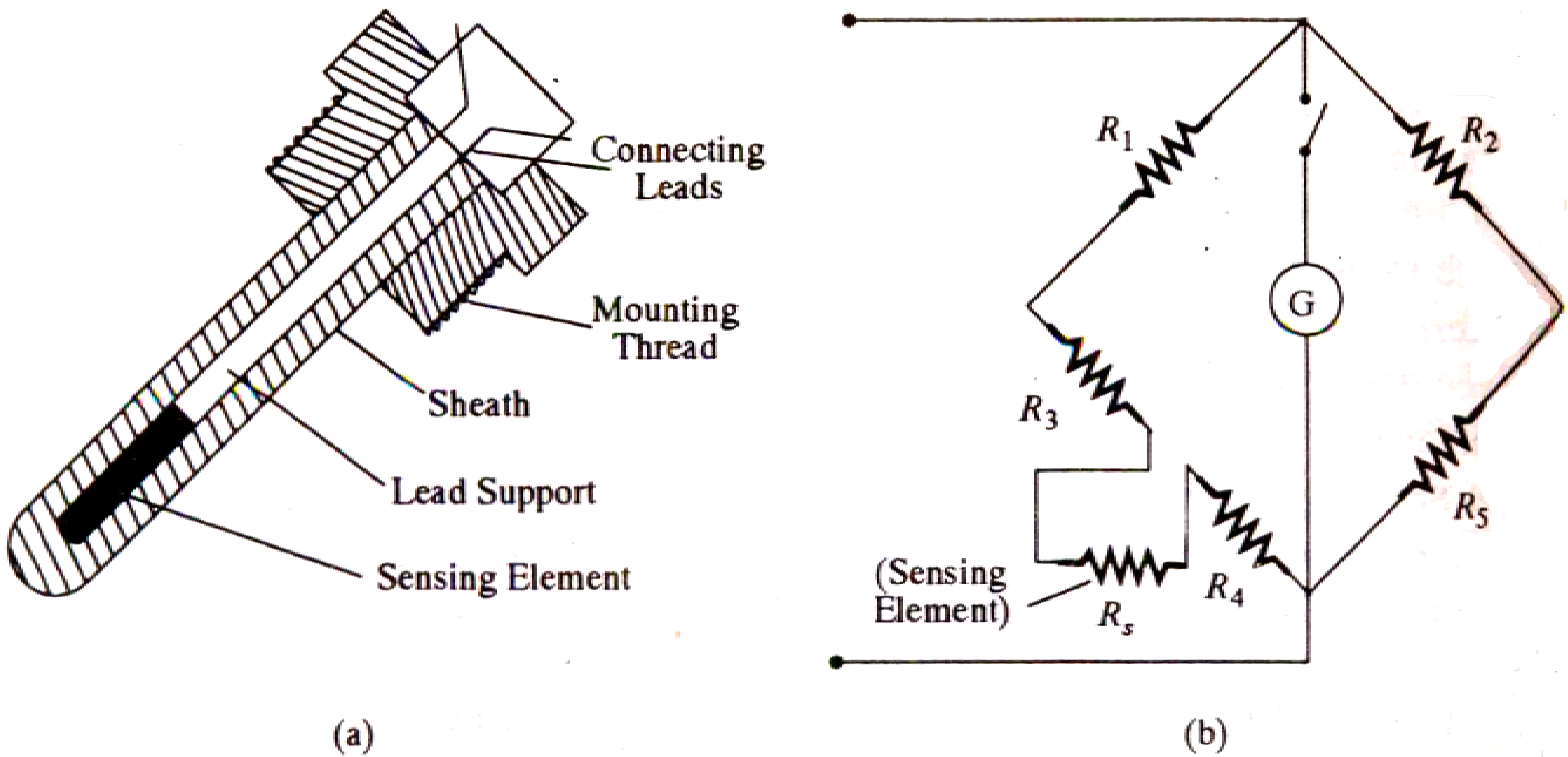
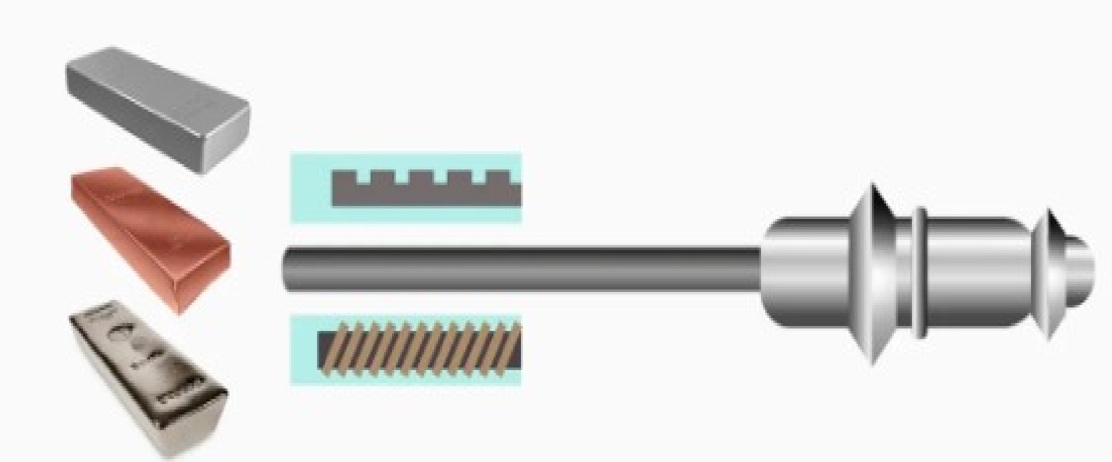
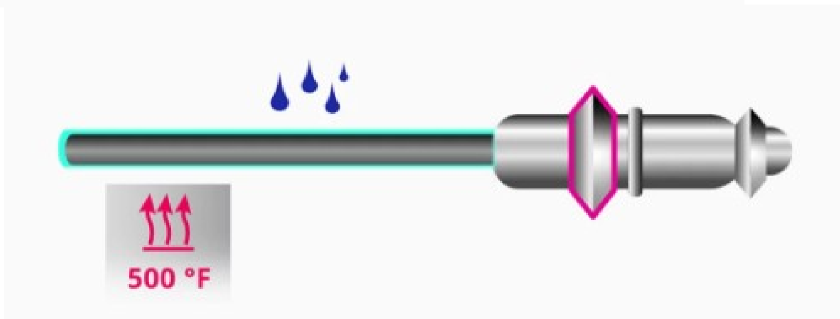
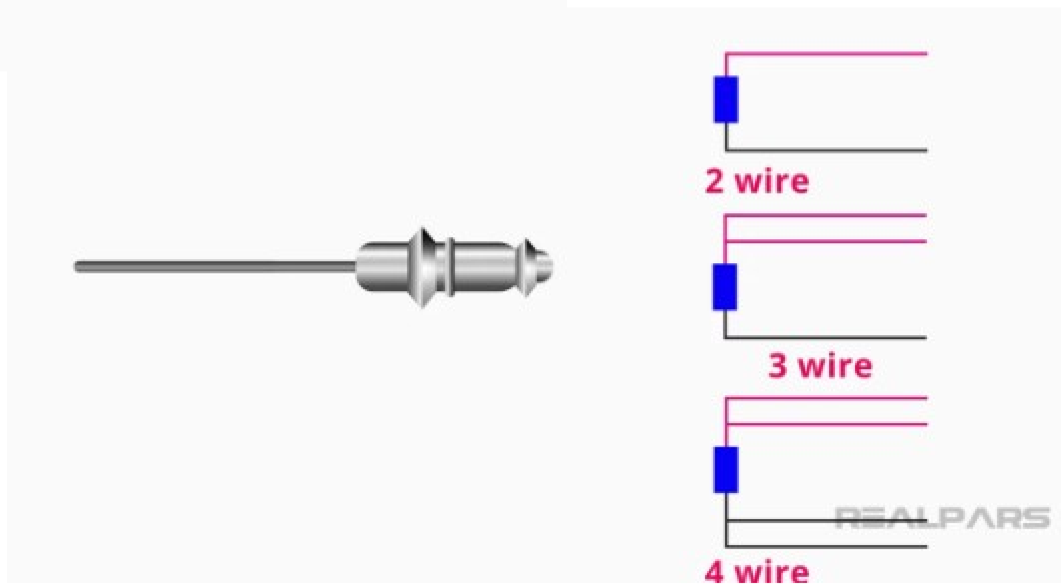
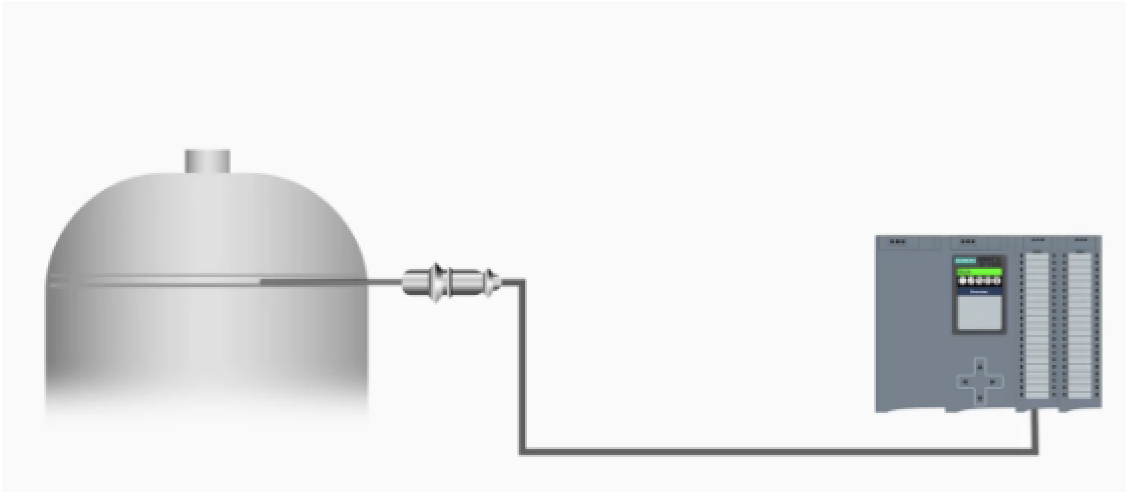


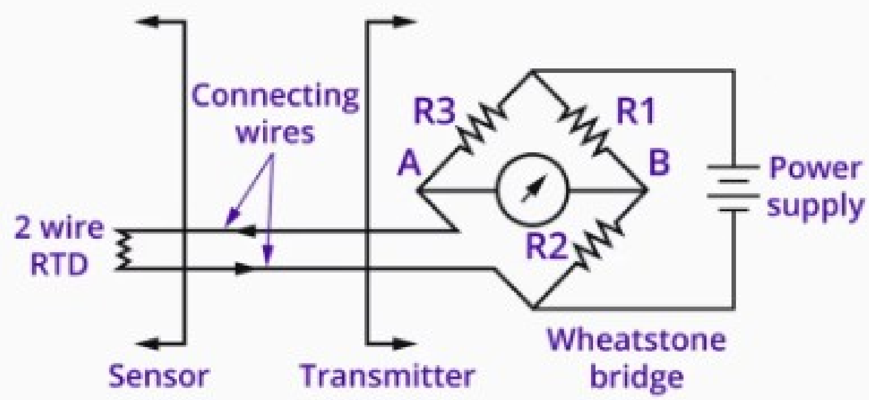
Fig. 13.11 (a) Industrial Platinum Resistance Thermometer (b) Bridge Circuit




500 °F

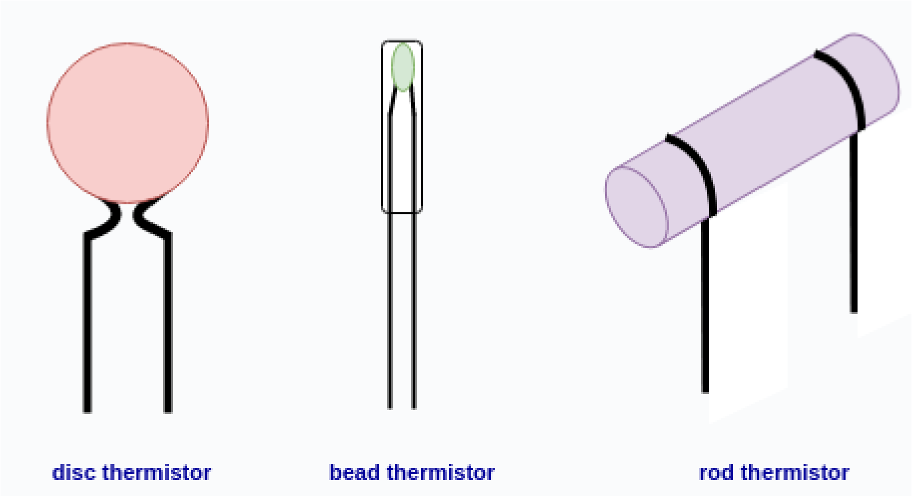

2 wire
3 wire
4 wire
REALPARS




Connecting
wires
R3
R1
A
B
Power
supply
2 wire
RTD
R2
Sensor
Transmitter
Wheatstone
bridge

Thermistor

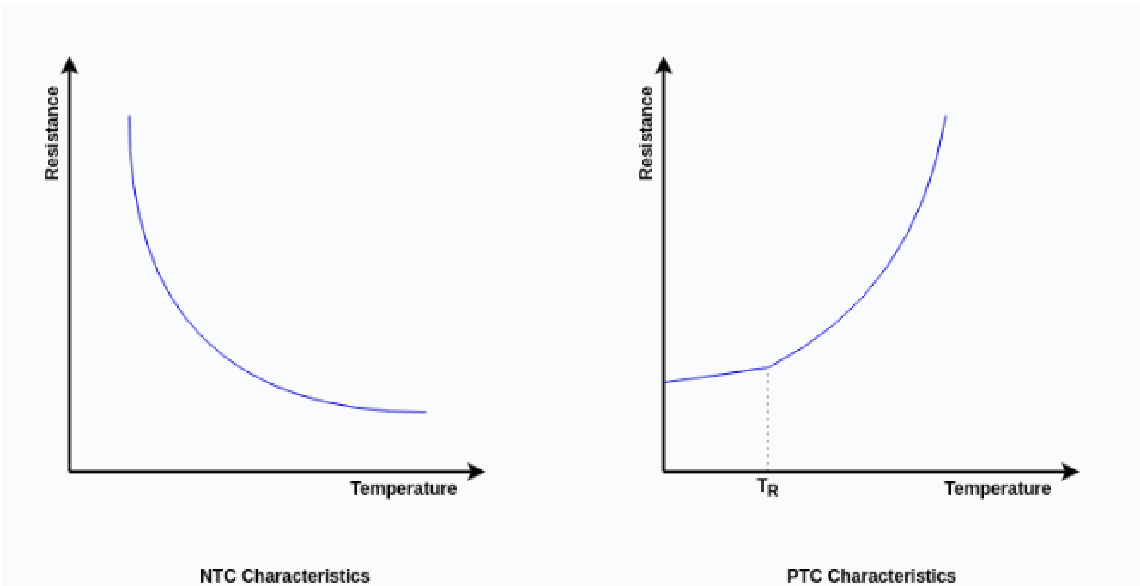
- The Thermistor or simply Thermally Sensitive Resistor is a temperature sensor that works on the principle of varying resistance with temperature. They are made of semiconducting materials. The circuit symbol of the thermistor is shown in the figure.

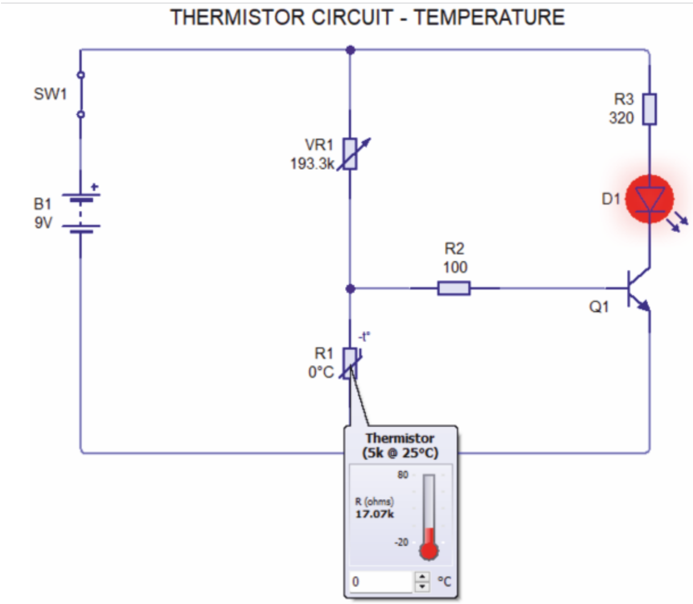


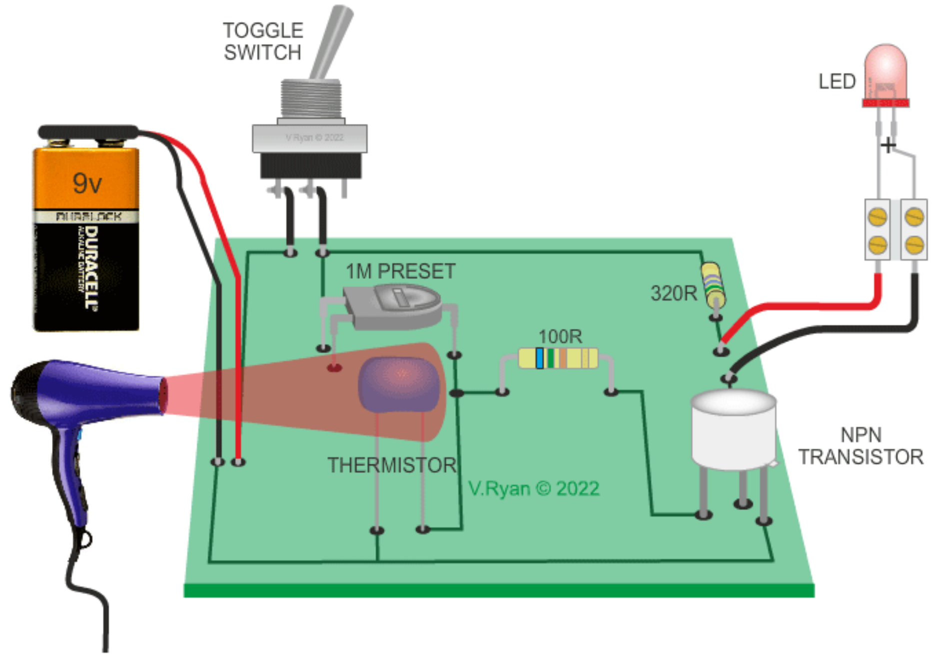
Types of Thermistors

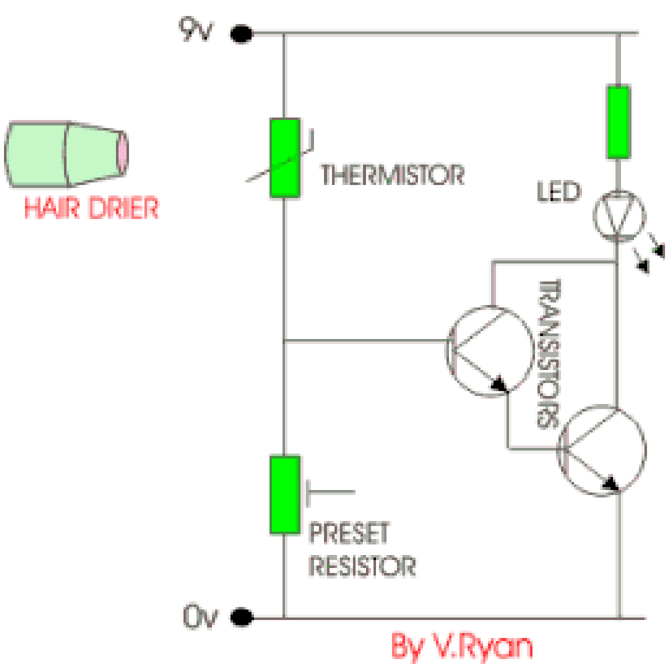
- The two basic types of thermistors available are the NTC and PTC types.

Circuit symbols of NTC and PTC thermistors are shown in the following figure.



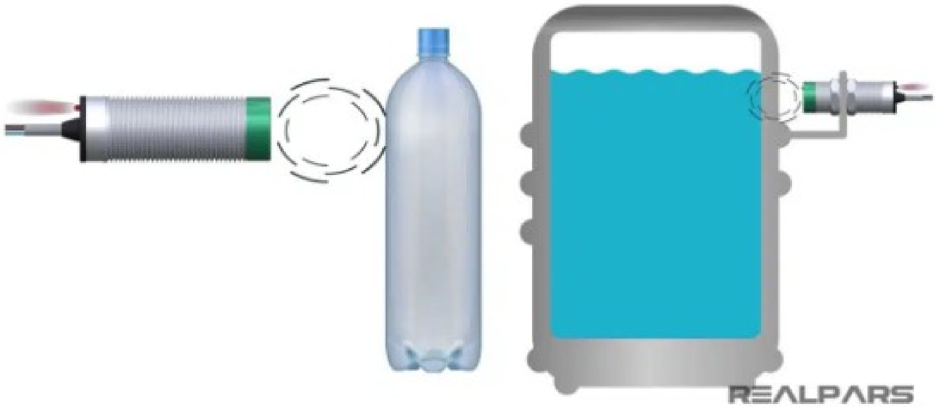

THERMISTOR CIRCUIT - TEMPERATURE
SW1
B1
9V
VR1
193.3k
R3
320
D1
R2
100
Q1
R1
0°C
Thermistor
(5k @ 25°C)
80
R (ohms)
17.07k
-20
0
°C


TOGGLE SWITCH
LED
9v
DURACELL
1M PRESET
320R
100R
THERMISTOR
V.Ryan © 2022
NPN TRANSISTOR


9v
THERMISTOR
LED
HAIR DRIER
TRANSISTORS
PRESET RESISTOR
0v
By V.Ryan

What is a capacitive sensor?

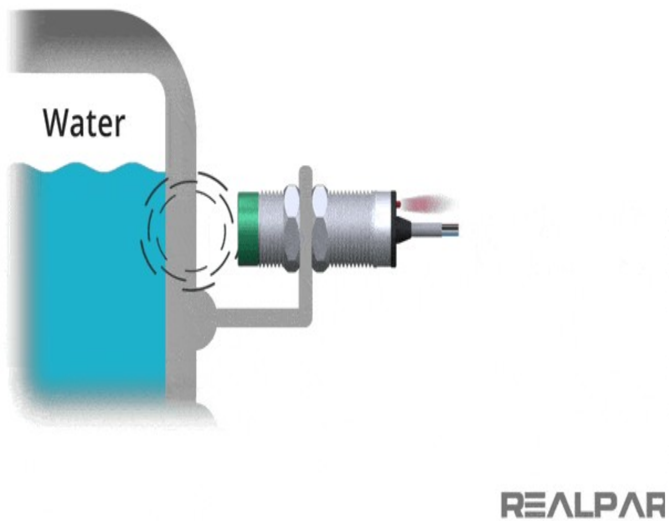
- A capacitive sensor is an electronic device that can detect solid or liquid targets without physical contact.

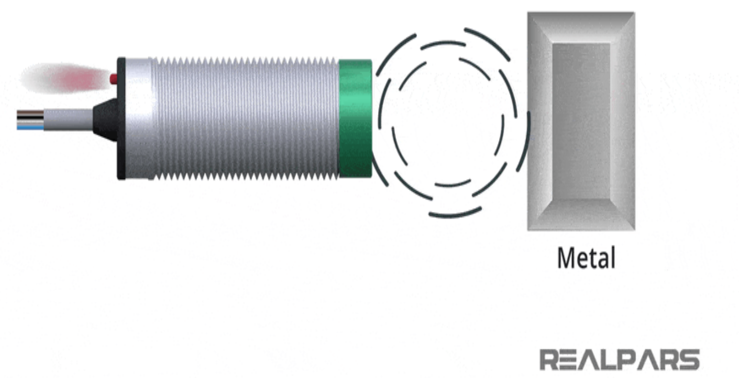


To detect these targets, capacitive sensors emit an electrical field from the sensing end of the sensor.

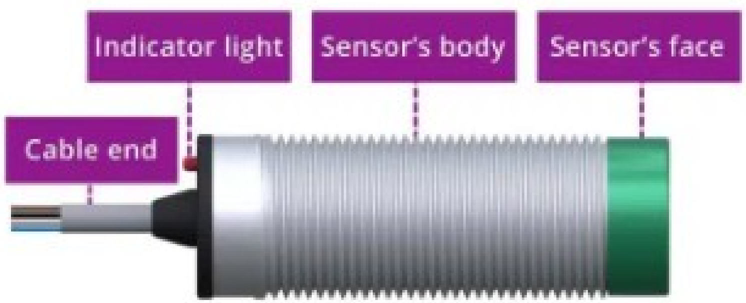
Any target that can disrupt this electrical field can be detected by a capacitive sensor.

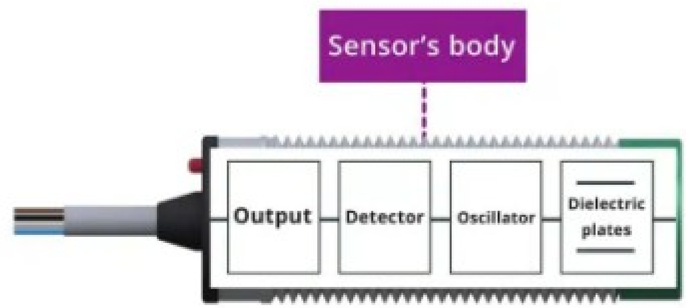
Types of materials capacitive sensors can detect

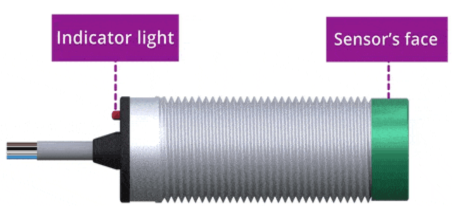


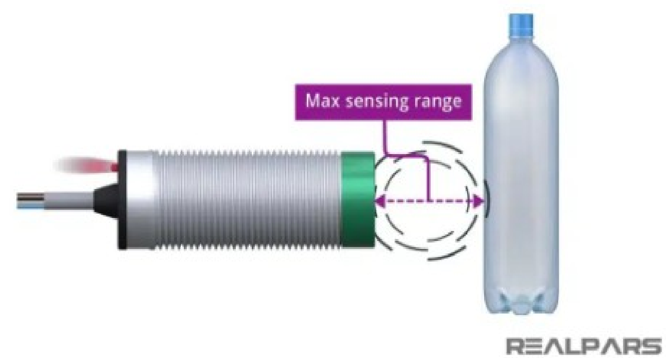


Capacitive sensor main parts

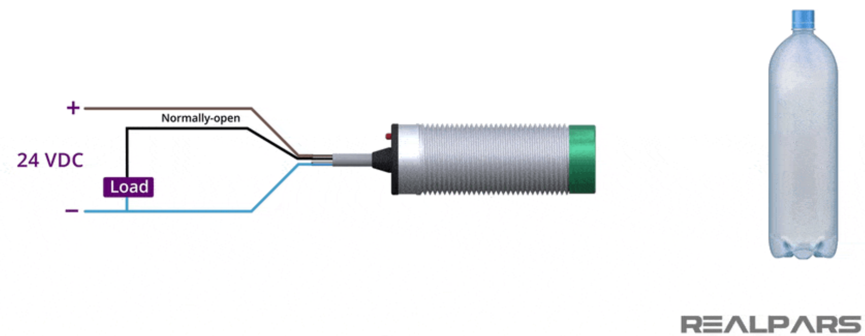


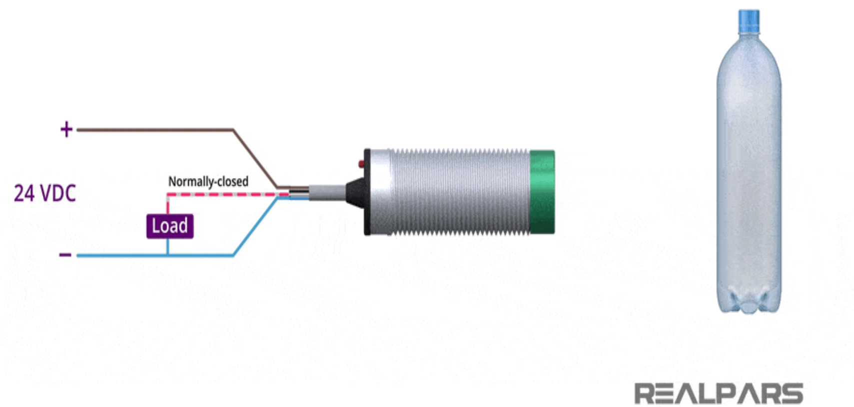




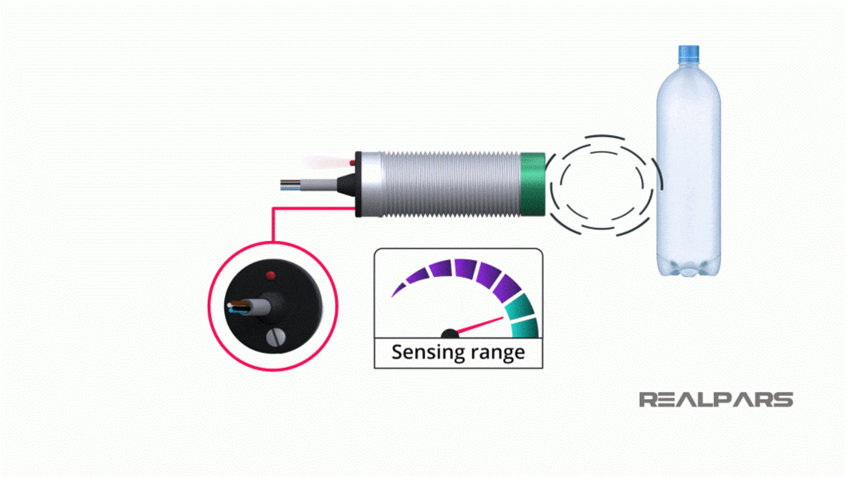


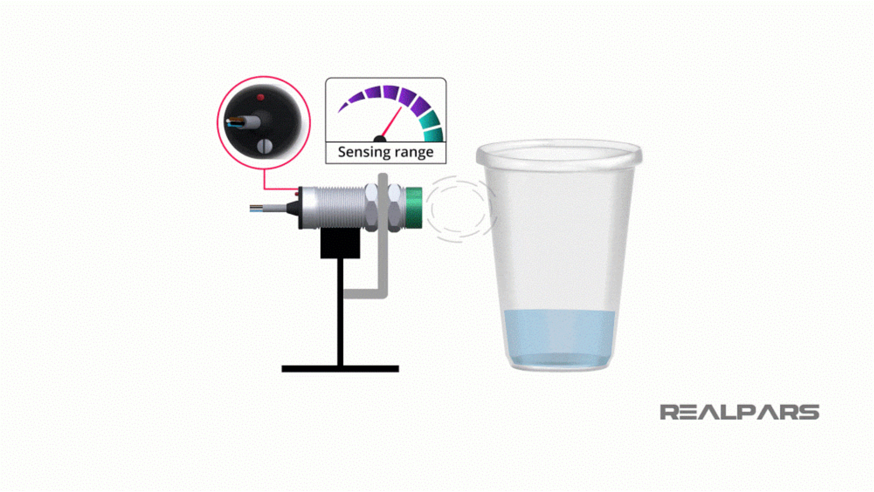
Sensor connection

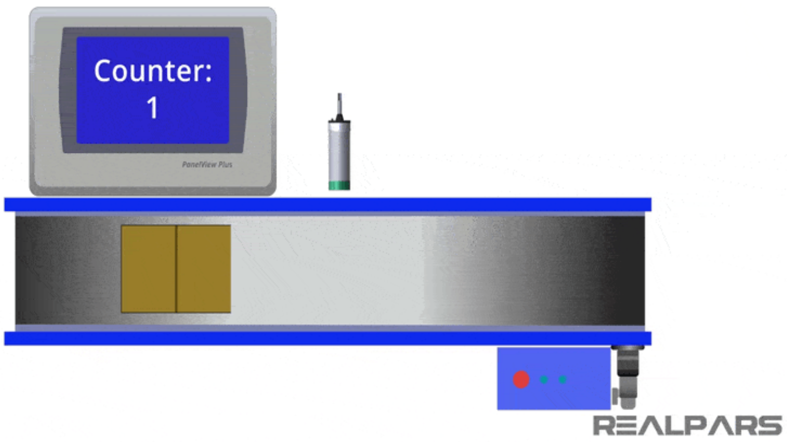


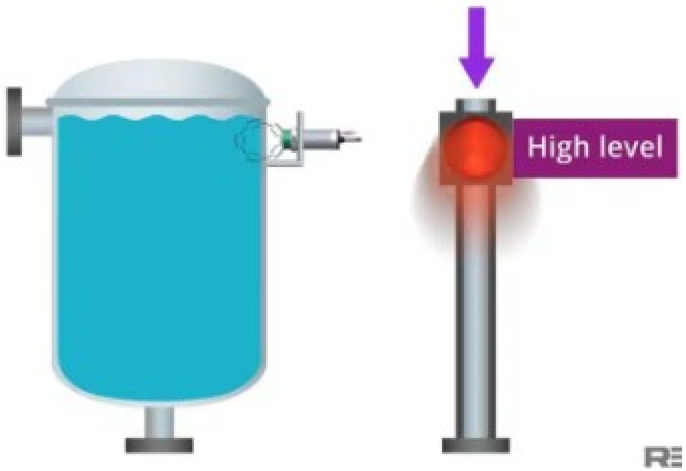


Applications









Thermoelectric Transducers

- Generally used thermoelectric transducers are:

(a) Resistance Thermometer (Resistance Temperature Detector, RTD)

(b) Thermistor (Thermally Sensitive Resistor)

(a) <u>Resistance Thermometer (RTD)</u>:

- The resistance of a conductor changes when its temperature is changed; this property is utilized for the measurement of temperature
- The resistance thermometer is an instrument used to measure electrical resistance in terms of temperature, i.e., it uses the change in the electrical resistance of the conductor (sensing element) to determine the temperature
- The characteristics of the sensing element determines the sensitivity and operating temperature range of the instrument
- The sensing element may be any material that exhibits a relatively large resistance change with change in temperature
- Also the material used should be stable in its characteristics, i.e., neither its resistance nor temperature coefficient of resistance should undergo permanent change with use or age

Resistance Thermometer (-contd.)

- Another desirable characteristic for a sensing element is a linear change in resistance with change in temperature
- The speed with which a resistive element responds to changes in temperature is important when the measured temperature is subjected to rapid variations
- Smaller the given sensing element, the less heat required to raise its temperature and the faster its response
- **Platinum, Nickel, & Copper** are the metals most commonly used to measure temperature
- The resistance of platinum tends to increase less rapidly at higher temperatures than for other metals, hence it is commonly used material for resistance thermometers
- The temperature range over which platinum has stability is -260^0 C to 1100^0C
- The changes in resistance caused by changes in temperature are detected by a Wheatstone bridge as shown in fig. (13.11b)

Resistance Thermometer (-contd.)

- The temperature sensing element (platinum, nickel or copper) contained in a bulb along with the balancing bridge, forms the essential components of a temperature measuring system
- The sensing element R_s is made of a material having a high temperature coefficient and R_1, R_2 and R_5 are made of resistances that are practically constant under normal temperature changes. As the sensing element is away from the indicator and its leads have a resistance R_3 and R_4
- Therefore, under balanced condition

$$\frac{R_1}{R_2} = \frac{R_3 + R_s + R_4}{R_5}$$

- Now, if resistance R_s changes, balance can not be maintained and the galvanometer shows a deflection which can be calibrated to give a suitable temperature scale

Resistance Thermometer (-contd.)

Advantages of Resistance Thermometer:

- The measurement is very accurate
- It has a lot of flexibility with regard to choice of measuring equipment
- The temperature sensitive resistance element can be easily installed and replaced
- Resistive elements can be used to measure differential temperature
- Resistance thermometers have a wide working range without loss of accuracy
- They are best suited for remote indication
- The resistive element response time is of the order of 2 to 10 seconds
- The limits of error of a resistive element are ±0.25% of the scale reading
- Stability of performance over long periods of time

Limitations of Resistance Thermometer:

- High cost
- Need for bridge circuit and power device
- Possibility of self heating
- Large bulb size compared to a thermocouple

Thermistor

- The electrical resistance of most materials changes with temperature
- By selecting materials that are very temperature sensitive, devices can be made that are useful in temperature control circuits and for temperature measurement
- Thermistors (Thermally Sensitive Resistors) are non-metallic (semiconductor material) resistors made by sintering mixtures of **metallic oxides** such as **Mn, Ni, Co, Cu, & U**
- Thermistors have a negative temperature coefficient (NTC), i.e., resistance decreases as temperature rises as shown in fig. (13.12)
- The resistance at room temperature (25^0C) for a typical commercial thermistor ranges from 100 Ω to 10 MΩ
- They are suitable for use only up to about 800^0C
- In some cases the resistance of a thermistor at room temperature may decrease by 5% for each 1^0C rise in temperature
- This high sensitivity to temperature changes makes the thermistor extremely useful for precision temperature measurements, control and compensation

Thermistor (-contd.)

- Thermistors can be made in the form of disc, rod, washer and bead etc.
- The smallest thermistors are made in the form beads (~ 0.15 mm in diameter)
- These may come in a glass coating or sealed in the tip of solid glass probes having a diameter of 2.5mm and length of 6-50mm
- The probes (100 Ω to 10 MΩ) are used for measuring the temperature of liquids
- When greater power dissipation is required the disc rod or washer thermistors are used
- Disc thermistors (diameter of about 1.25 mm - 25 mm, thickness of 0.25 – 0.75 mm) are mainly used for temperature control and have a resistance values from 1 Ω to 1 MΩ
- These are sintered and coated with silver on two flat surfaces
- Washer thermistors are made like disc thermistors, except that a hole is formed in the centre in order to make them suitable for mounting on a bolt

Thermistor (-contd.)

- Rod thermistors are extruded through dies to make long cylindrical units of having a diameter of 1.25, 2.75 or 4.25mm and a length of 12.5- 50mm connecting leads are attached to the end of the rods
- Their resistance varies from 1 - 50 kΩ
- The advantage of rod thermistors over other configurations is the ability to produce high resistance units with moderately high power handling capability
- Thermistors can be connected in series/parallel combinations for applications requiring increased power handling capability
- Thermistors are chemically stable and can be used in nuclear environments
- Their wide range of characteristics also permits them to be used in limiting and regulation circuits as time delays, for integration of pulses, as memory units
- A thermistor in one arm of a Wheatstone bridge provides precise temperature information
- Accuracy is limited only by the readout devices

Thermistor (-contd.)

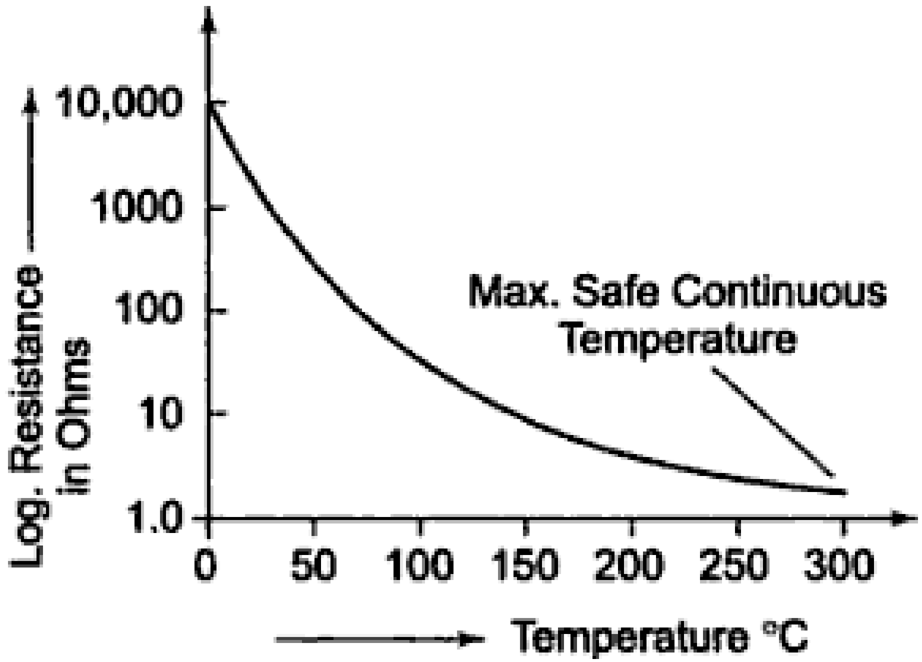


Fig. (13.12) Resistance vs Temperature Graph of Thermistor

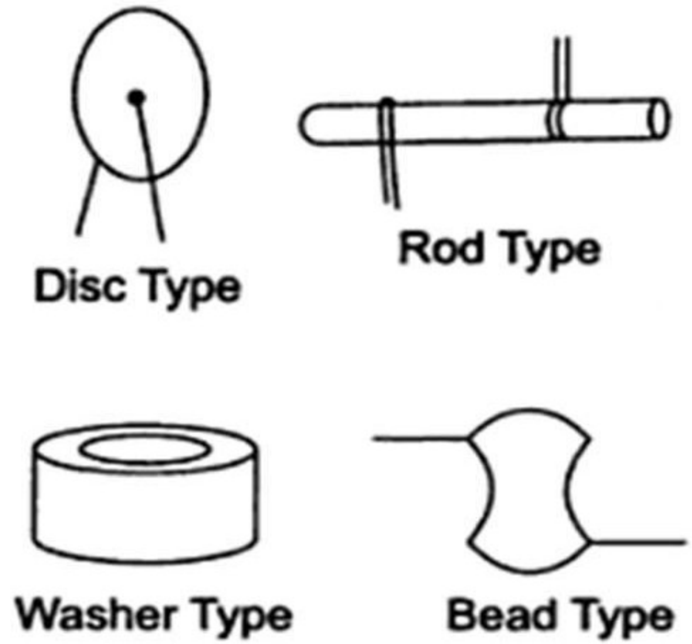


Fig. (13.13) Various Configurations of Thermistor

Thermistor (-contd.)

Advantages:

- Small size and low cost
- Fast response over narrow temperature
- Good sensitivity
- Contact and lead resistance problems not encountered due to large value of R

Limitations:

- Non-linearity in resistance versus temperature characteristics
- Unsuitable for wide temperature range
- Very low excitation current to avoid self-heating
- Need for shielded power lines, filters, etc. due to high resistance