Module 2

SENSORS AND THEIR APPLICATIONS

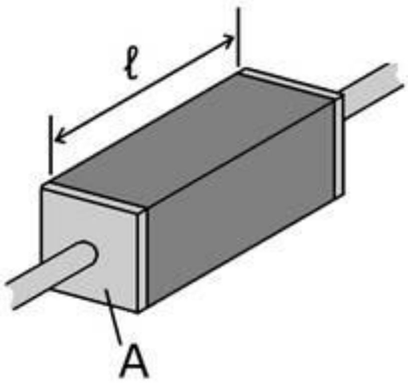
TRANSDUCERS BASED ON CHANGE IN RESISTANCE

The electrical measurements are used for measurement of electrical quantities but its use in measurement of non electrical quantities is growing. In the measurement of non electrical quantities a detector is used which usually converts the physical quantity in displacement. The displacement actuates an electric transducer, gives an output which is electrical in nature. The electrical quantity so produced is measured by standard methods used for electrical measurements. The resultant electrical output gives the magnitude of the physical quantity being measured.

The electrical signal could be a voltage, current or frequency. The production of these signals is based upon the resistive, inductive or capacitive effects. These phenomena may be combined with appropriate primary sensing elements / detectors to produce different types of transducers

Resistive Transducers

The resistive transducers or resistive sensors are also called as variable resistance transducers. The variable resistance transducers are one of the most commonly used types of transducers. They can be used for measuring various physical quantities, such as, temperature, pressure, displacement, force, vibrations etc. These transducers are usually used as the secondary transducers, where the output from the primary mechanical transducer acts as the input for the variable resistance transducer. The output obtained from it is calibrated against the input quantity and it directly gives the value of the input.
The variable resistance transducer elements work on the principle that the resistance of the conductor is directly proportional to the length of the conductor and inversely proportional to the area of the conductor.

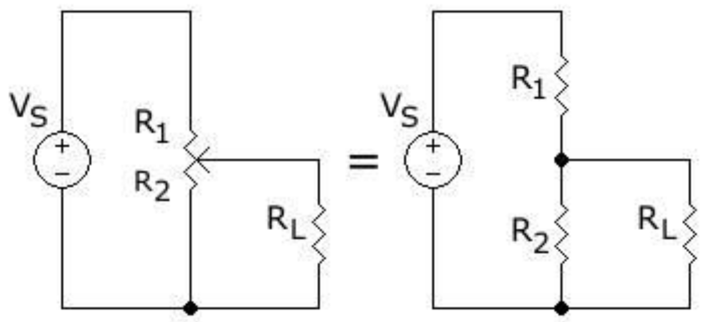


Thus, if L is the length of the conductor (m) and A is its area (m^2) as shown in Fig., then its resistance R(ohms) is given by:

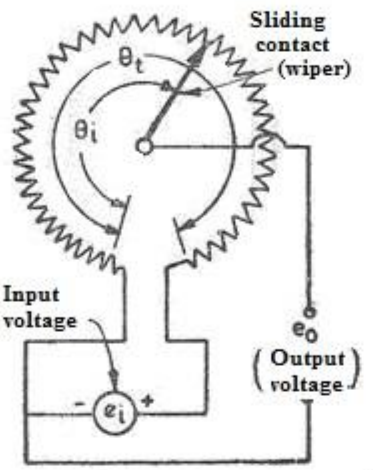
$$R = \rho L/A$$

Sliding contact devices

In the sliding contact type of variable resistance transducers, there is a long conductor whose effective length is variable. One end of the conductor is fixed, while the position of the other end is decided by the slider or the brush that can move along the whole length of the conductor. The slider is connected to the body whose displacement is to be measured. When the body moves the slider also moves along the conductor so its effective length changes, due to which it resistance also changes. The effective resistance is measured as the resistance between the fixed position of the conductor and the position of the sliding contact as shown in Fig. The value of the resistance is calibrated against the input quantity, whose value can be measured directly. One of most popular sliding contact type of variable resistance transducer is the potentiometer. These devices can be used to measured translational as well as angular displacement and are shown in Figs.



Sliding contact type of variable resistance element



Rotational potentiometer

Resistive Sensor

These sensors based on change in resistance. Both AC and DC currents can be applied to cause change in resistance.

The resistance of metal conductor is expressed as

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

where R=Resistance in Ω

l= length of the conductor in m

A= Cross section area of the conductor in m^2

There are many ways to get change in resistance with the change in physical parameter.

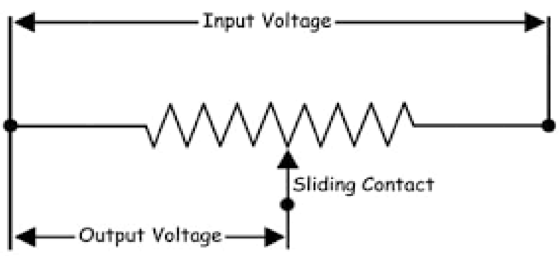
• Potentiometers

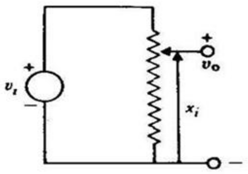
• Strain gauges

• RTD, Thermistor

Potentiometers

Simply POT. It is a Zero-order system. Consists of a Resistive Element with a sliding contact. Sliding contact is called Wiper. Motion of Sliding contact will be Translational or Rotational. Helipots: Multi-turn Rotational devices used for either translational or rotational

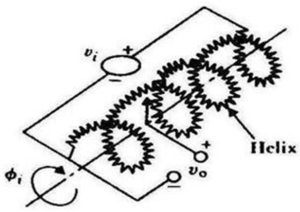


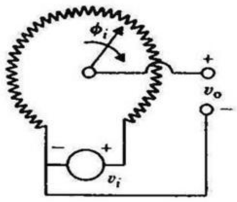


Translational

$$v_0 = \frac{R_i}{R} v_s = \frac{x_i}{l} v_s$$

Helical





Single turn

Let

e_i & e_o = input and output voltages

x_t = total length of potentiometer

x_i = displacement of wiper from its zero position

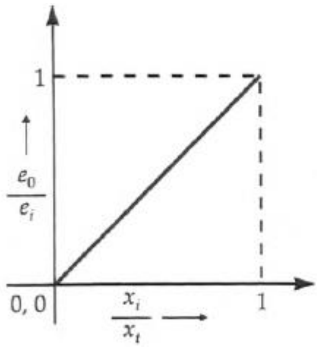
R_p= total resistance of the potentiometer

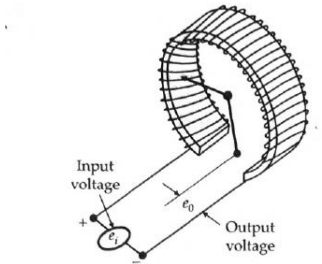
Resistance per unit length = R_p/x_t

The output voltage under ideal condition is

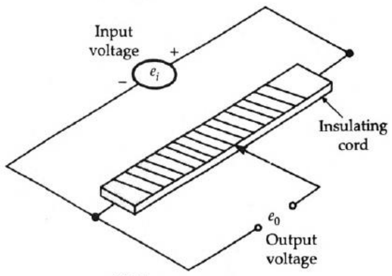
e_o= (Resistance at the output terminals/Resistance at the input terminals) x e_i

$e_o = [R_p(x_i/x_t)]/R_p = (x_i/x_t)e_i$

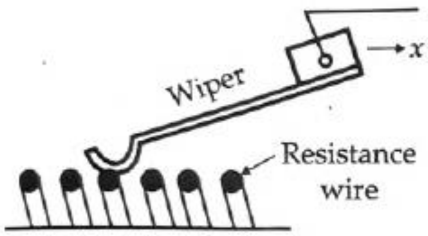


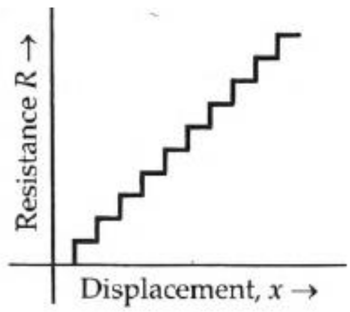


(*b*) Circular (Rotational) potentiometer.



(*a*) Linear potentiometer.





Wire Wound Potentiometers:

Materials: Platinum, nickel chromium, nickel copper.

Non-Wire Potentiometers:

Materials: Cermet, Hot moudled carbon, Carbon film, Thin metal film

Advantages:

- They don't cost much.
- easy to use
- used to quantify displacements with huge amplitudes
- Extremely high electrical efficiency means no amplification is needed.
- The resolution for Metal Film and Cermet is unlimited.

Disadvantages:

The sliding contacts (wipers) of linear pots require a lot of force to move. They can also become dirty, wear down, and produce noise.

Strain Gauges

The resistance fluctuation of a wire or semiconductor under mechanical stress is the basis for s train gauges.
Given a wire with length l, resistivity ρ, and cross section A, its electric resistance is

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

When the wire is stressed longitudinally, R undergoes a change given by

$$\frac{dR}{R} = \frac{d\rho}{\rho} + \frac{dl}{l} - \frac{dA}{A}$$

by Hooke's law,

$$\sigma = \frac{F}{A} = E\varepsilon = E\frac{dl}{l}$$

Where E is Young's Modulus, σ is the mechanical stress, and ε is the strain

$$\frac{dA}{A} = 2\frac{dt}{t}$$

Consider a wire that in addition to a length l has a transverse dimension t. A longitudinal stress changes both l and t.

Poisson's law

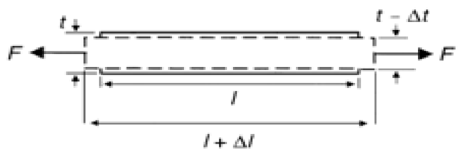
$$\nu = -\frac{d\,t/t}{d\,l/l}$$

Gauge factor,

$$G_f = \frac{d\,R/R}{d\,l/l}$$

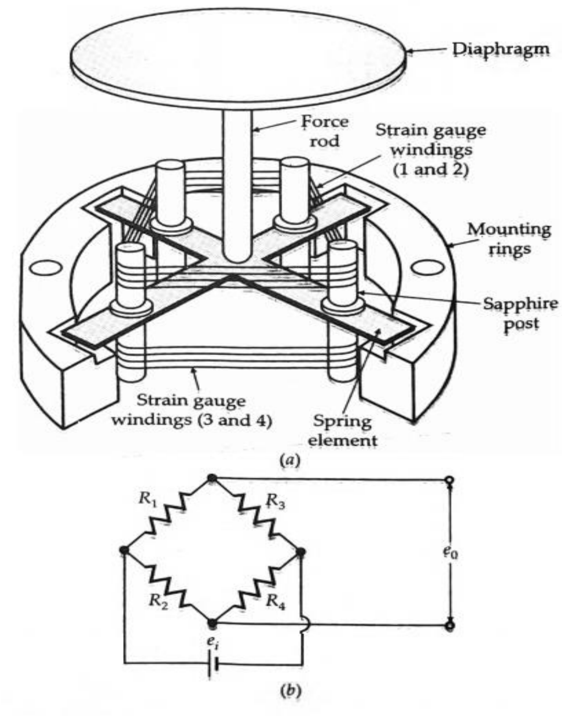
$$\frac{dR}{R} = G_f\varepsilon$$

$$\frac{dR}{R} = 1 + 2\nu + \frac{d\,\rho/\rho}{d\,l/l}$$



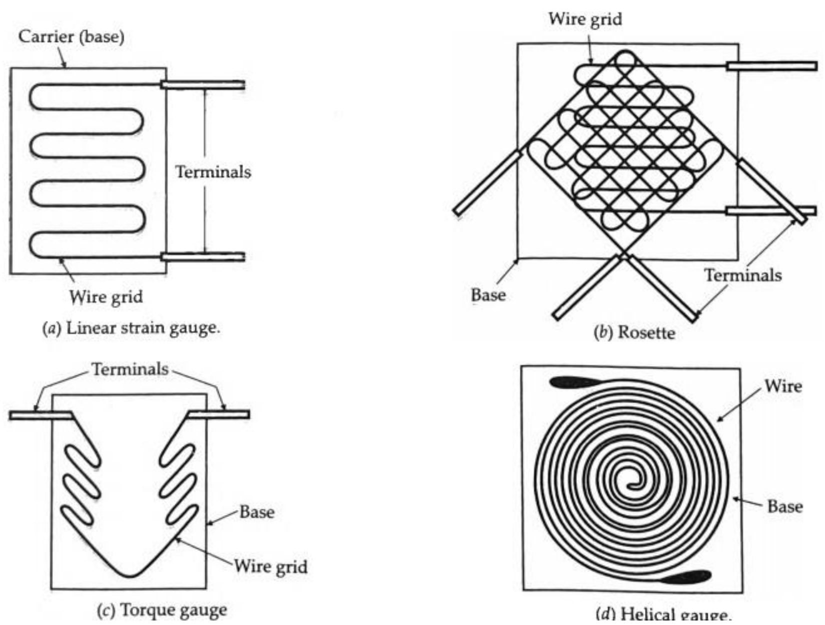
Unbonded Strain gauge

An insulating substance, such air, is used to stretch a wire between two points to provide this gauge. Different alloys of copper, nickel, chrome, or nickel iron may be used to make the wires. They have a gauge factor of 2 to 4, a diameter of around 0.003 mm, and can withstand a force of 2 mN. The wire is no longer than 25 mm. Applying pressure results in a tiny displacement of roughly 0.004 mm (full scale), which raises tension in two wires and lowers it in the other two. This increases the resistance of the two wires that are under stress while lowering the resistance of the other two wires. This throws the bridge out of balance, resulting in an output voltage that is proportionate to pressure



Bonded wire strain gauge

A resistance wire strain gauge is made out of a tiny resistance wire grid with a diameter of no more than 0.025 mm. The carrier (base), which could be a thin sheet of teflon, bakelite, or paper, is glued to the grid. A thin sheet of material is placed on top of the wire to shield it from mechanical harm. Stress can be distributed uniformly throughout the grid thanks to the wire spreading. An adhesive substance is used to fuse the carrier to the specimen being examined. This enables a good strain transmission from the carrier to the wire grid.



The following qualities are ideal for good and repeatable results: • High value of gauge factor

The metal has strong resistance, a low resistance temperature coefficient, no hysteresis effects, and linear properties.

• Resonant frequency response

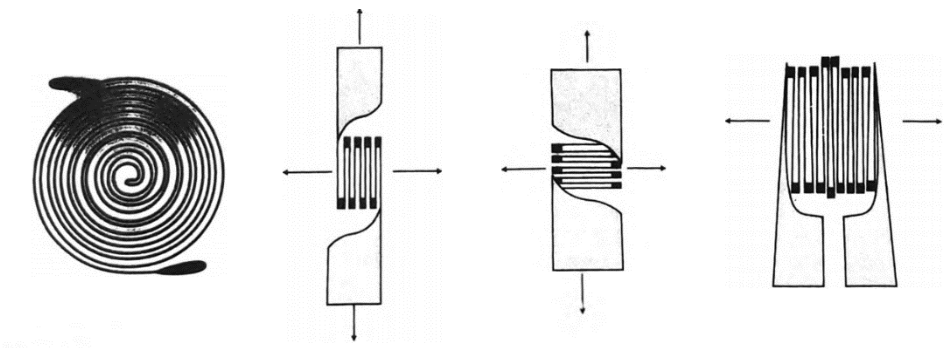
Base (Carrier): The materials that support the wires are referred to as bases or carriers. Impregnated paper, cellulose from bakelite, and epoxy

Adhesives

Adhesives are materials used for bonding. There are four types of cement: bakelite, epoxy, nitrocellucose, and ethylene glycol.

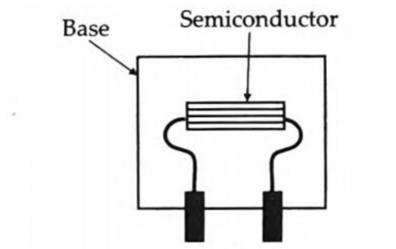
Bonded Metal Foil Strain Gauges

An expansion of the metal strain gauges with joined wires. Gauges made of foil have a far higher capacity to dissipate heat. Large surface area compared to wire strain gauge, better bonding, and same volume

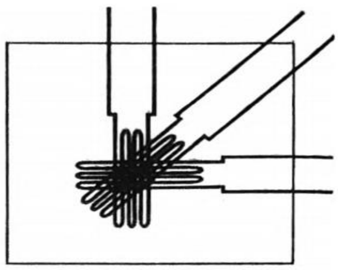


Semi-conductor Strain Gauge

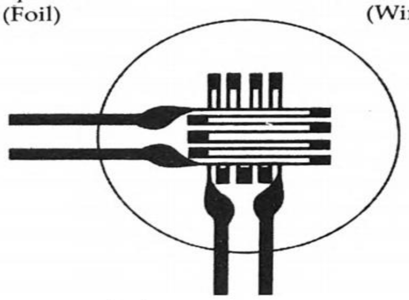
the variation in resistance value brought forth by resistivity changes. elevated sensitivity as a result of a high gauge factor. These gauges are made using typical semi-conductor technology, which involves attaching semi-conducting wafers or filaments with a thickness of 0.05 mm on appropriate insulating substrates like teflon.



3-element rosette
60° planar
(Foil)



3-element rosette
45° stacked
(Wire)

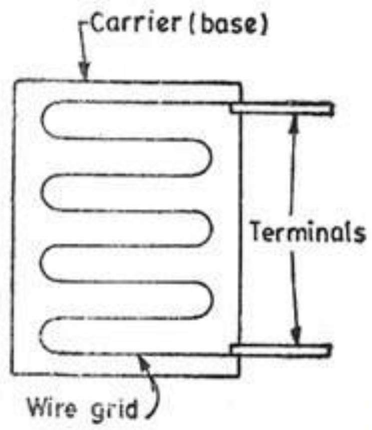


2-element rosette
90° stacked
(Foil)

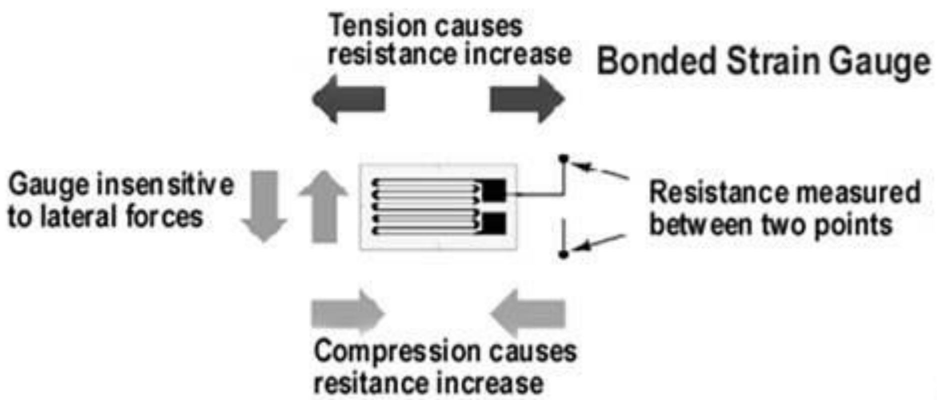
A combination of strain gauges called "Rosettes".

Wire resistance strain gauge

When mechanically stressed, a fine wire—the strain gauge—changes its electric resistance. An electrical conductor will get longer and narrower when it is stretched within its elasticity's bounds without breaking or irreversibly deforming; these changes raise the conductor's electrical resistance from end to end. In contrast, a conductor will expand and contract in size to reduce its electrical resistance end-to-end when it is pressured so that it does not buckle. As illustrated in Fig., a standard strain gauge sets up a long, thin conductive strip in a zigzag pattern of parallel lines so that a little amount of stress in the direction of the parallel lines' orientation results in a multiplicatively larger strain along the effective length



(a)



(b)

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Working principle of strain gauge

The sensitivity of the strain gauge to strain is one of its key parameters. It has a quantitative expression known as the gauge factor (GF). According to its definition, gauge factor is the ratio of the fractional change in electrical resistance to the fractional change in length (or strain).

$$GF = \frac{\Delta R / R_G}{\varepsilon}$$

Generally, metallic strain gauges have a gauge factor of approximately 2.

Where: ΔR = change in resistance caused by strain

R_G = resistance of the undeformed gauge

ε = strain

The bulk of strain gauges are foil kinds, which come in a variety of sizes and shapes to fit a range of applications. They are made up of a backing material placed atop a resistive foil pattern. Their working idea is that the foil's resistance alters in a predictable way when it undergoes stress. The active regions of foil gauges are usually between 2 and 10 mm^2. Strains up to a minimum of 10% can be measured with proper installation, the right gauge, and the right adhesive. Utilised for many years, the strain gauge serves as the basic sensing component for numerous sensor kinds, including as position, torque, load, pressure, and more. **Bonded Strain Gauges** These gauges are directly bonded (that is pasted) on the surface of the structure under study. Hence they are termed as bonded strain gauges. The three types of bonded strain gauges are

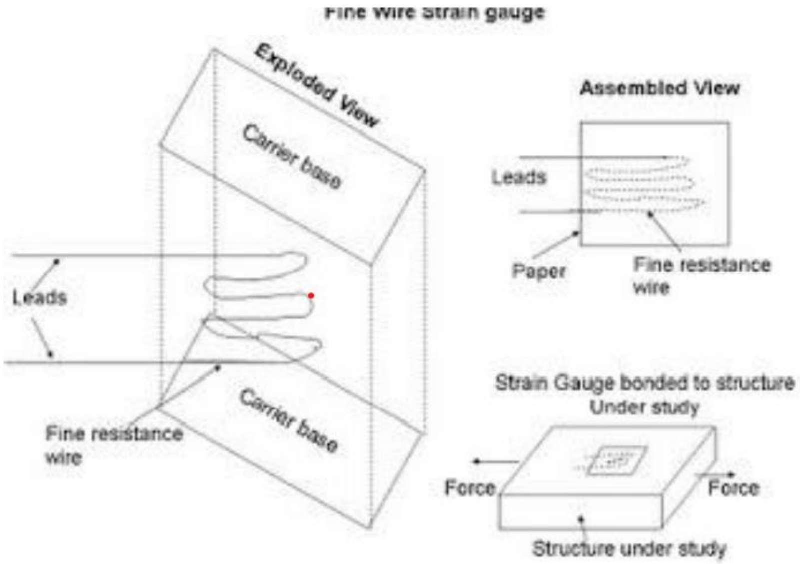
1. Fine wire strain gauge
2. Metal foil strain gauge
3. Semi-conductor gauge

1. Fine wire strain gauge

This is the first type of Bonded Strain Gauges.

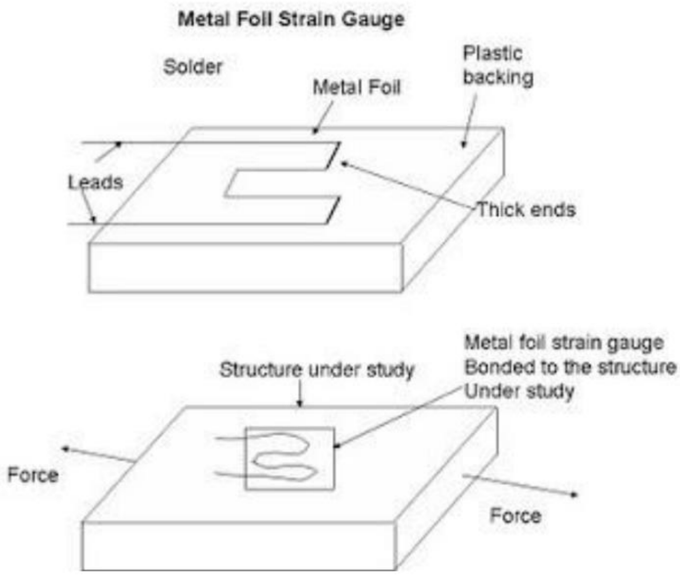
Description

The following components make up the arrangement: A fine, 0.025-mm resistance wire is bent repeatedly, as depicted in the diagram. This is done to extend the wire's length and provide a consistent distribution of stress. Between the two carrier bases (paper, Bakelite, or Teflon) that are glued to one another lies this resistance wire. Damage to the gauge is prevented by the carrier base. The strain gauge can be electrically connected to a measurement device (such as a Wheatstone bridge) using the provided leads.



Metal Foil Strain Gauge

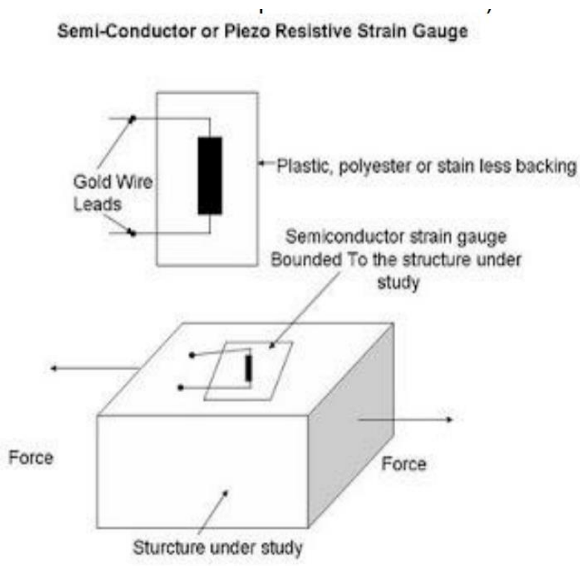
The Metal Foil Strain Gauge: An Overview The following makes up the arrangement: Using the printed circuit process, 0.02 mm thick metal foil is created. One side of the plastic backing is used to make this metal foil. In order to electrically link the strain gauge to a measurement device (heat stone bridge), leads are soldered to the metal foil.



Semi – conductor or Piezo Resistive Strain Gauge Partially-conductive or Piezo Resistive Strain Measurement The Piezo Resistive Strain Gauge: An explanation. This is how a semi-conductor strain gauge is configured: Rectangular filaments constructed from silicon or geranium crystals are used as the sensing element's wafer. To give these crystals the desired qualities, boron is added; this process is known as doping, and the resulting crystals are known as doped crystals. The plastic or stainless steel backing of this sensing element is attached to it. To electrically link the strain gauge to a measurement device (heat stone bridge), lead wires made of gold are extracted from the sensing element. Sensing elements come in two varieties, specifically:

• Negative or n-type, where the resistance decreases as the tensile strain increases.

• Positive, or P-type, resistance that rises in proportion to tensile



O**peration** The strain gauge is glued or adhered to the structure being studied with the use of adhesive material. A force (compressive or tensile) is now applied to the structure. The force will cause the structure to alter in dimension. Both the length and cross-section of the stain gauge will alter as the strain gauge bonds to the structure—that is, is stressed. A change in resistivity of the semiconductor strain gauge's sensing element (crystal) causes the strain gauge's resistance to fluctuate. Using a wheat stone bridge, the strain gauge's resistance change is measured. The strain gauge's change in resistance serves as a metric for how much the structure is deformed.

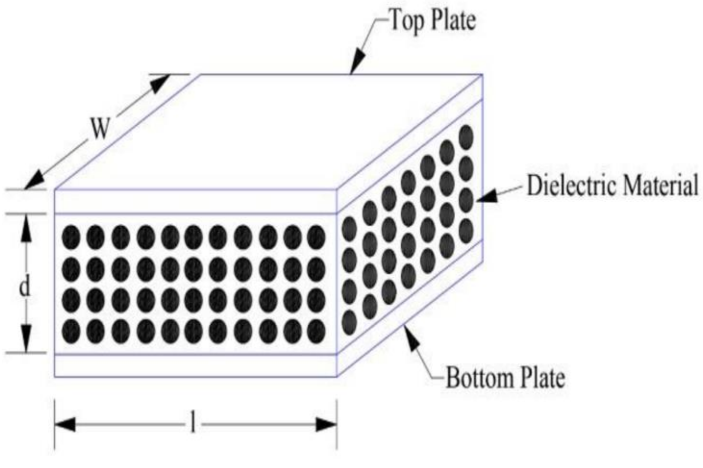
Capacitive Sensors:

A capacitive transducer is a tool that modifies its capacitance in response to variations in the physical phenomena that has to be monitored. As a passive transducer, it needed an outside power source to operate. A capacitor, which might be angular, cylindrical, or parallel plate in shape, serves as the transduction element of a capacitive transducer. It is frequently employed in linear displacement measurement.

The capacitance of the parallel plate capacitor serves as the foundation for the operation of the capacitive transducer. Given a parallel plate capacitor with plate area A separated by distance d, the capacitance (C) is as follows.

$C = (\varepsilon_o \varepsilon_r A) / d$

Where ε_o and ε_r are the permittivity of free space and the relative permittivity of the dielectric material of capacitor.



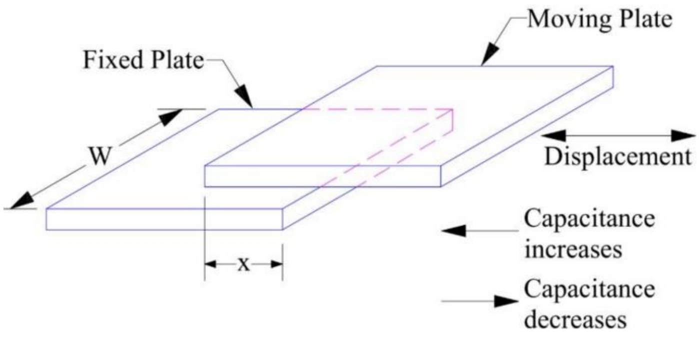
The theory behind how the capacitive transducer functions is that the following can be changed to change the capacitance:

Plate area; plate separation; and altering the dielectric material in between the plates.

Physical factors like linear displacement, angular displacement, force, pressure, and liquid level are what create the alterations mentioned above in a capacitive transducer.

Overlapping Area:

Capacitance of parallel plate capacitor is directly proportional to the area of plate



Let us assume that

The width of plate is W

The length at any time t is X.

Thus,

the area of plates of parallel plate capacitor so formed at time t will be (WX).

Therefore, the capacitance at any time t is given as below.

$C = \varepsilon_o \varepsilon_r A / d$

$C = [\varepsilon_o \varepsilon_r (WX) / d]$

it is clear that the displacement X is directly proportional to capacitance C. Hence, measurement of capacitance will directly tell us the magnitude of displacement. Thus, physical quantity displacement is converted into electrical quantity capacitance which is the required function of a transducer.

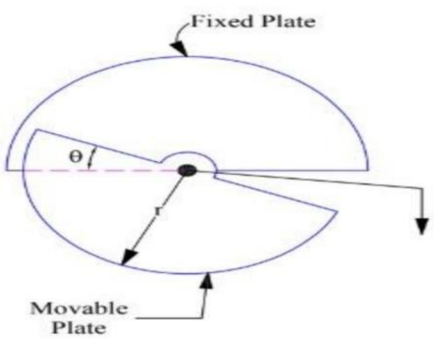
Sensitivity of a device is the rate of change of output with respect to input. Thus, the sensitivity of capacitive transducer will be the rate of change of capacitance (C) with respect to displacement (X).

Sensitivity $(S) = dC / dx$

$= \varepsilon_o \varepsilon_r W / d$

it may be stated that the sensitivity of a capacitive transducer is constant and depends on the width & separation between the plates. This is a great feature of capacitive transducer and exploited for measurement of linear displacement ranging from 1 mm to 10 mm. The accuracy is as high as 0.005%.

The principle of change of capacitance with change in area is also employed for the measurement of angular displacement.



The angular displacement changes the effective area between the plates and hence, a corresponding change in capacitance.

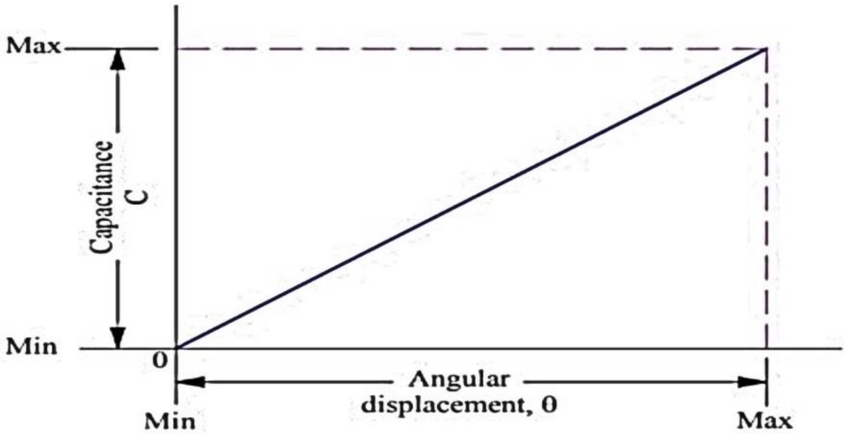
Let, at any time t, the angular overlapping position is Θ. Since the area of entire plate is (πr^2

/2) for angular overlapping of π radian, therefore, the area (A) of plate for angular overlapping of Θ radian will be

$A = (\pi r^2/2\pi)\Theta = \Theta r^2/2$

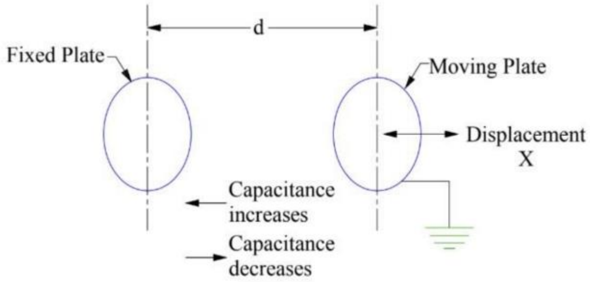
Capacitance = $[\varepsilon_o \varepsilon_r \Theta r^2/(2d)]$

it is obvious that the capacitance is directly proportional to the angular movement. Hence, measurement of capacitance is a direct indication of angular movement. The graph between the capacitance and angular position is a straight line and shown below



Distance between the Plate:

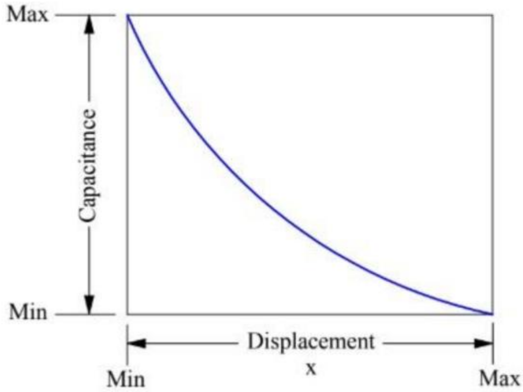
One of the capacitor's plates can be fastened to the moving object while the other plate remains fixed to enable a capacitive transducer to react to linear displacement. The capacitance changes as a result of the object moving and altering the distance between the plates. The distance between the plates has an inverse relationship with the variation of capacitance with separation. The following graphic depicts a basic schematic of a capacitive transducer that makes use of the idea of change in capacitance with change in distance between the plates.



The separation between the plate is x at any time t. Hence, capacitance is given as

$C = \varepsilon A/x$

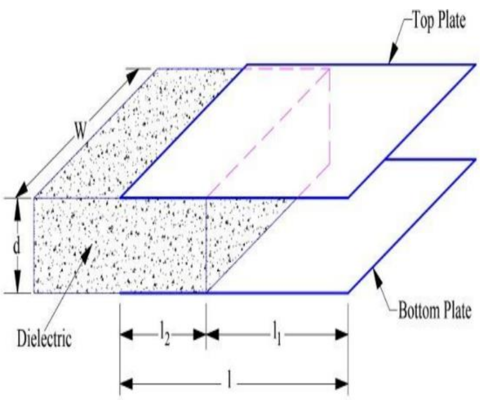
The characteristics of this transducer is, thus, non-linear. Actually, it is hyperbolic as shown below



This transducer's sensitivity fluctuates according to how far apart the plates are from one another. The sensitivity really increases with decreasing distance x. This implies that the gadget will react to a smaller displacement value. If the displacement value is higher, it won't react. For applications requiring the measurement of incredibly little displacement, this kind of capacitive transducer is employed. It is a drawback.

Dielectric Constant:

That isn't the case, though. Just take a look at the capacitive transducer's sensitivity using the changes in area and distance between the plates. For the former, the sensitivity is constant, but for very minor displacement, it increases. Thus, in order to measure extremely little displacement, a transducer that uses



Capacitor plates cannot be removed. On the other hand, a moving object with a dielectric constant

The plate is being moved inside by €r. Our goal is to quantify the object's displacement. Allow the object to be inside the plates by the l2 length at any intermediate point. As a result, the capacitor is filled with dielectric up to l2 length, with a dielectric constant of \r, whereas l1 length is filled with air. You may find the capacitance in this combination as indicated below.

$$C = \frac{\varepsilon_0 W}{d}[l_1 + \varepsilon_r l_2]$$

it is clear that, as the object moves into the capacitor, the value of l_2 increases and hence the capacitance C increases. By measuring this capacitance, the linear displacement can be predicted.

Advantage:

- The major advantages of capacitive transducer are:
- Because it requires extremely little force to function, this transducer is used in small systems.
- They are quite perceptive. Up to 0.005% accuracy is achieved.
- This transducer's high input impedance results in a little loading impact.
- These transducers make it simple to reach a resolution on the order of 2.5×10-3.
- A capacitive transducer is not impacted by stray magnetic fields, whereas an inductive transducer's measurement is.
- Capacitive transducers take less electricity to function since they require less force.Disadvantage:

The disadvantages of a capacitive transducer are:

- The metallic components of a capacitive transducer must be isolated from one another. The capacitance value will drop to zero if they get short. Above all, this transducer's frame needs to be earthed in order to prevent the measurement from being impacted by stray capacitance.
- The action of edges can occasionally lead the capacitive transducer to behave nonlinearly. Guard rings take care of this effect.
- Another potential source of mistake when measuring minute physical changes is the cable that connects to the transducer. The source of loading that causes sensitivity loss could be the cable. Additionally, loading deteriorates the low frequency response.
- Dust, moisture, and other factors may alter the capacitance.
- Because of their sensitivity to temperature, they are negatively impacted by any changes in performance.
- Because of the lower capacitance value, the capacitive transducer's output impedance (1/2πfC) is relatively large, and the instrumentation circuitry utilised with it is fairly sophisticated. The loading effect results from this. The frequency of the signal used to assess capacitance determines the output impedance. The frequency utilised must provide an output impedance in the range of 1 kΩ to 10 MΩ for capacitances between 10 and 500 pF. Because of the high output impedance, it is necessary to maintain a high insulation resistance to prevent excessive capacitance shunting and sensitivity reduction.

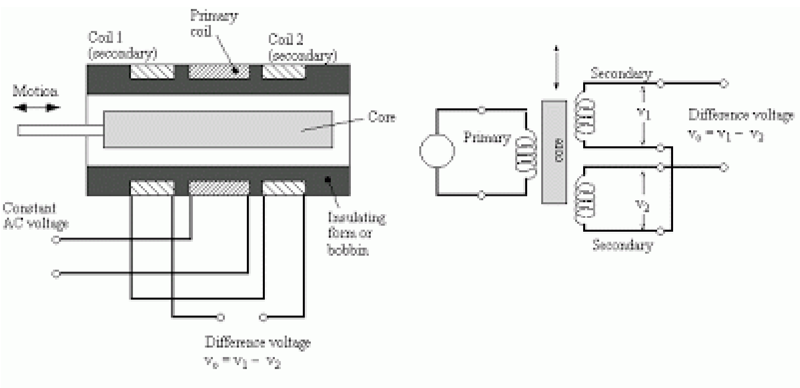
Inductive Sensors

Linear Variable Displacement Transducer (LVDT):

Principle of LVDT:

With the help of the mutual induction principle, LVDTs can convert non-electric displacement energy into electrical energy.

Construction of LVDT:



(a) (b)

The one primary winding is located in the center of the cylindrical former, and there are two secondary windings on either side of the former to complete the LVDT. Due to the fact that the two secondary windings have the same number of turns but are oriented in opposite directions—that is, if the left secondary winding is turning clockwise, the right secondary winding will be turning counterclockwise—the net output voltages will be the difference in voltages between the two secondary coils. S1 and S2 are the symbols for the two secondary coils. As seen in the figure, an esteem iron core is positioned in the center of a cylindrical former that can move back and forth. 50 to 400 Hz is the operating frequency, and the AC excitation voltage is 5 to 12 V.

Working of LVDT:

Based on the location of the iron core within the insulated former, there are three scenarios.

Situation 1: If the core remains motionless in the null position when an external force, such as displacement, is applied, the voltage induced in both secondary windings is equal, resulting in zero net output, or Esec1-Esec2=0.

Situation 2:

In comparison to the induced emf in secondary coil 2, the induced emf voltage in the secondary coil is larger when an external force is applied and the steel iron core tends to move in a leftward direction. Esec1-Esec2 will be the net output as a result.

Situation 3: The induced voltage of the induced emf in secondary coil 2 is higher than that of secondary coil 1 when an external force is applied and the steel iron core moves in a rightward direction. thus Esec2-Esec1 will be the net output voltage.

The LVDT has the following benefits:

- It has infinite resolution
- It has a high output
- It provides Good linearity, ruggedness, low hysteresis, low friction, high sensitivity, and low power consumption are all advantages of LVDT.

The low voltage differential transformer (LVDT) has certain drawbacks.

- Firstly, it requires a very high displacement to generate high voltages.
- Secondly, because it is sensitive to magnetic fields, shielding is necessary.
- Thirdly, vibrations can affect the transducer's performance.
- Lastly, Temperature variations have a significant impact on it.

Utilizing LVDT in Applications:

- The displacement between a fraction of a millimeter and a centimeter can be measured using an LGDT.

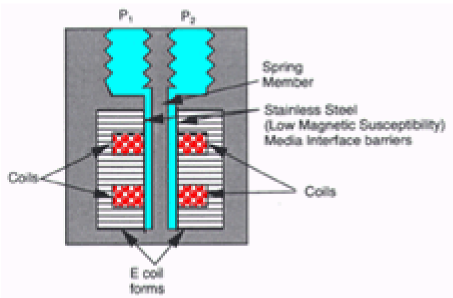
- Force, weight, pressure, and other quantities can be measured with an LVDT, which functions as a secondary transducer.

Variable Reluctance Sensor:

Depending on pressure, force, or acceleration, the parameter input of the strain-based variable reluctance sensor creates a magnetic circuit and causes the spring member to mechanically deflect.

The oscillator and demodulator system for variable reluctance sensors must internally limit the operating temperature range of -40 C to +120 C in order to provide a static output capability. Positioned centrally between two coils, as depicted, the spring member is made of a magnetic material with a high permeability.

Variable Reluctance Differential Pressure Sensor



Nonmagnetic stainless steel barriers are welded to keep the coils isolated from the measurand. The differential pressure transducer causes the two coils' inductance (L) to modulate because of the pressure differential between them. This distortion occurs towards the magnetic pole piece on the low-pressure side of the spring member.

The variable reluctance sensor is powered by an alternating voltage source operating in the 1 KHz to 10 KHz range, forming an inductive half-bridge electrical configuration. The spring member positioned in the center creates an inductive push-pull arrangement in which the deflection of the spring member causes a difference in coil impedance by decreasing the inductance of one coil and increasing the inductance of the other.
As a function of the parameter input, the effective inductance modulation is generated by changes in the magnetic reluctance.

Eddy current sensor

Eddy current sensors uses the principle of eddy current formation to sense displacement. These sensors measure shaft displacement in rotating machinery and have been around for many years as they offer manufacturers high-linearity, high-speed measurements, and high resolution.

Operating Principle:

Electromagnetic Induction:

In order to create an alternating current (AC) magnetic field, the sensor is made up of one or more coils.

A conductive substance experiences eddy currents when this magnetic field interacts with it.

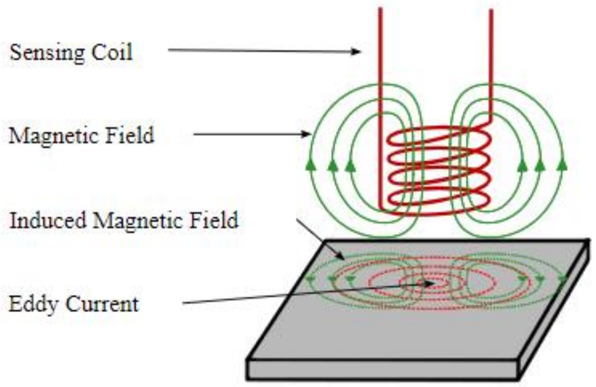


Fig. A coil inducing an eddy current in a conductive plate

Eddy currents are formed when a moving or changing magnetic field intersects a conductor or vice versa.

The relative motion causes a circulating flow of electrons, or currents, within the conductor. These circulating eddies of current create electromagnets with magnet fields that oppose the effect of applied magnetic field. The stronger the applied magnetic field, or greater the electrical conductivity of the conductor, or greater the relative velocity of motion, the greater the currents developed and greater the opposing field. Eddy current probes senses this formation of secondary fields to find out the distance between the probe and target material.

Eddy Currents Interaction:

The induced eddy currents in the conductive material produce counteracting magnetic fields to the original magnetic field's change.

The impedance of the sensor coil or coils varies as a result of this opposition.

Detection and Measurement:

Because eddy currents are present and have certain characteristics, the sensor detects changes in the induced AC signal's impedance, phase, or amplitude.
A material's conductivity, permeability, thickness, and defect presence can all be determined by varying these parameters.

Hall Effect Sensor

It is in 1879 that Edwin Hall discovers hall voltage. The way current flows through a conductor causes the Hall Effect. This theory of Hall Effect was applied to many inventions. Additional applications of this theory include pressure, fluid flow, and current sensors. A device that has been developed to measure magnetic field is the Hall Effect sensor.

Hall Effect Sensor Definition

In order to determine the strength of the magnetic field, linear transducers called Hall-effect sensors are employed. These sensors measure the magnetic flux density by producing a Hall voltage in response to the presence of a magnetic field. This process is based on the Hall Effect.

The Hall Effect Sensor's Operation

A fundamental working principle of the Hall Effect sensor is the concept of Hall voltage. Applying electricity causes electrons on a thin strip of a conductor to flow in a straight line. Electron motion is perpendicular to the magnetic field, and this charged conductor deflects the electrons when it comes into contact with it.

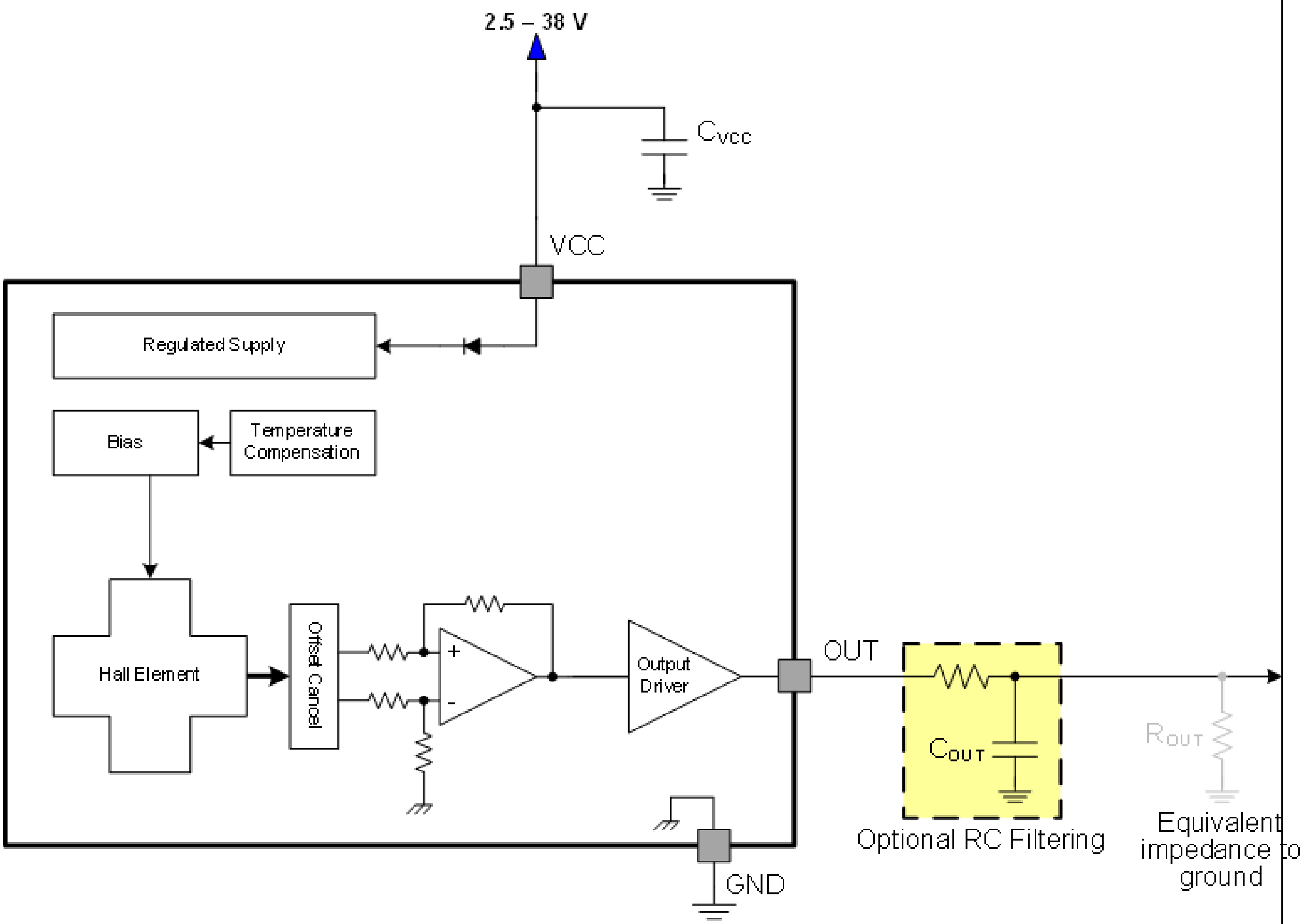
On one side, some electrons gather, and on the other, on the other. As a result, one conductor plane exhibits negative charging behavior while the other displays positive charging behavior. Voltage is produced when this produces a potential difference. The Hall voltage is the name given to this charge.

Once a balance is reached between the force acting on charged particles as a result of an electric field and the force causing the magnetic flux that caused this change, the electrons will continue to move from one side of the plane to the other. The magnetic flux density can be measured at the moment the separation stops by calculating the hall voltage.

Two types of Hall Effect sensors exist based on the relationship between magnetic flux density and hall voltage. The output voltage and magnetic flux density in the linear sensor are related linearly. Every magnetic flux density will cause the threshold sensor's output voltage to drop sharply.

Utilizing Hall Effect Sensors

- Together with threshold detection, they function as a switch.
- Keyboards and other applications requiring extremely high reliability employ these.
- Wheels and shafts are timed by means of Hall Effect sensors.
- In brushless electric DC motors, these are employed to locate the permanent magnet.
- Digital electronic devices incorporate Hall Effect sensors in addition to linear transducers.
- In industrial applications, detecting the existence of a magnetic field.
- Use this on your smartphone to see if the flip cover accessory is closed.
- The Hall Effect sensor is used to measure DC current in current transformers without making contact.
- This serves as a sensor to identify the fuel level in cars.



Piezoelectric Transducer
Physical quantities such as temperature, pressure, and mechanical stress applied on metal must be measured in a variety of situations that arise in daily life.To measure these unknown quantities in units and calibrations that we are familiar with is necessary for all of these applications. The TRANSDUCER is one such gadget that is very helpful to us. Any physical quantity can be converted into a proportionate electrical quantity, such as voltage or electrical current, using a transducer, which is an electrical device.

A piezoelectric transducer is an electrical transducer that operates by converting any kind of physical quantity into a measurable electrical signal. Piezoelectric transducers are electrical devices that convert physical quantities into electrical signals by utilizing the properties of piezoelectric materials.

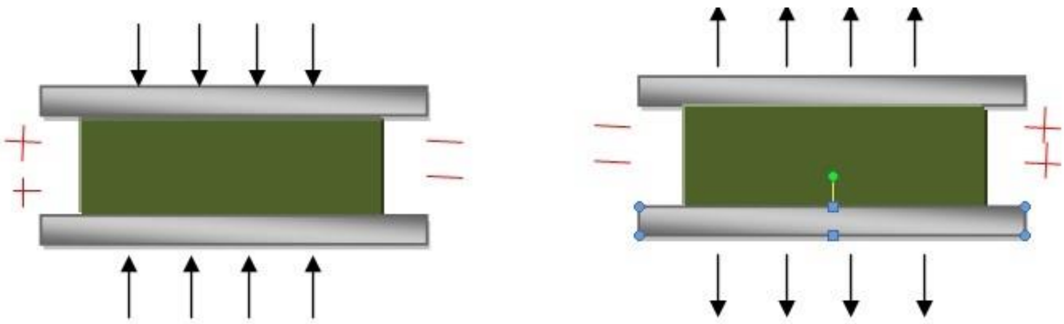
When any type of physical quantity is converted into a measurable electrical signal, an electrical transducer known as a piezoelectric transducer works. Piezoelectric transducers are electrical devices that use the characteristics of piezoelectric materials to transform physical quantities into electrical signals.
Classification of Piezoelectric Substances
Piezoelectric materials come in a variety of forms.

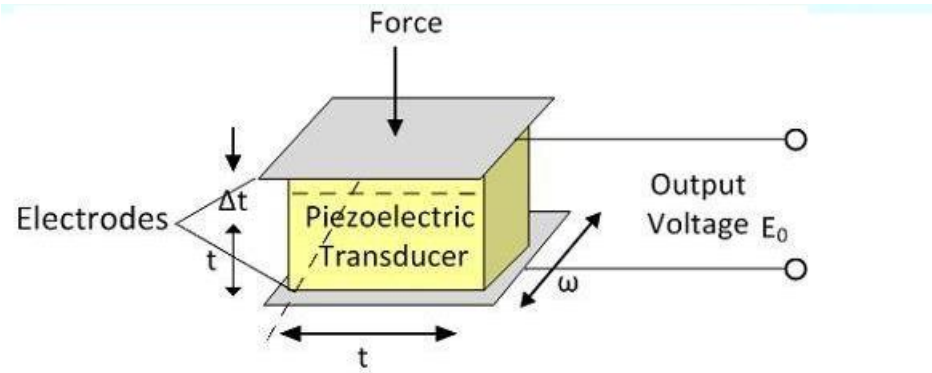
Minerals found in nature: Tourmaline-group minerals, quartz, Rochelle salt, topaz, and certain organic materials like silk, wood, enamel, bone, hair, rubber, and dentin. Potassium niobate, Lithium niobate, Lithium tantalate, Barium titanate, Lead titanate, Lead zirconate titanate (PZT), Polyvinylidene difluoride, PVDF or PVF2, and other lead-free piezoelectric ceramics are examples of artificially manufactured piezoelectric materials.

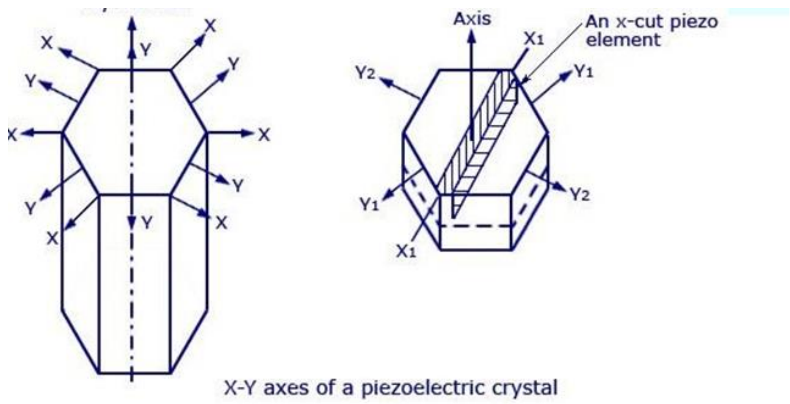
Piezoelectric transducers are not compatible with all types of piezoelectric materials. For piezoelectric materials to be used as transducers, they must meet specific requirements. The materials used for measurement should be flexible enough to be manufactured into different shapes without affecting their properties, have high output values, be insensitive to extremes of temperature and humidity, and have frequency stability. Regretfully, no piezoelectric material exists that possesses all of these characteristics. Despite having low output levels, quartz is a very stable crystal that is found naturally. Quartz is a useful tool for measuring parameters that vary slowly. Although Rochelle salt has the highest output values, it cannot be used above 1150F due to its sensitivity to environmental factors.

Functioning of Pizezoelectric Transducer

The principle of piezoelectricity is used by piezoelectric transducers. Silver or some other thin conducting material is applied to the faces of piezoelectric material, which is typically quartz. When a material is under stress, its ions migrate away from one conducting surface and towards the other. Charge is created as a consequence of this. Stress calibration is done with this charge. The direction in which the stress is applied determines which way the generated charge is polarized. As demonstrated below, stress can be applied in two different ways: compressively and tensilely.

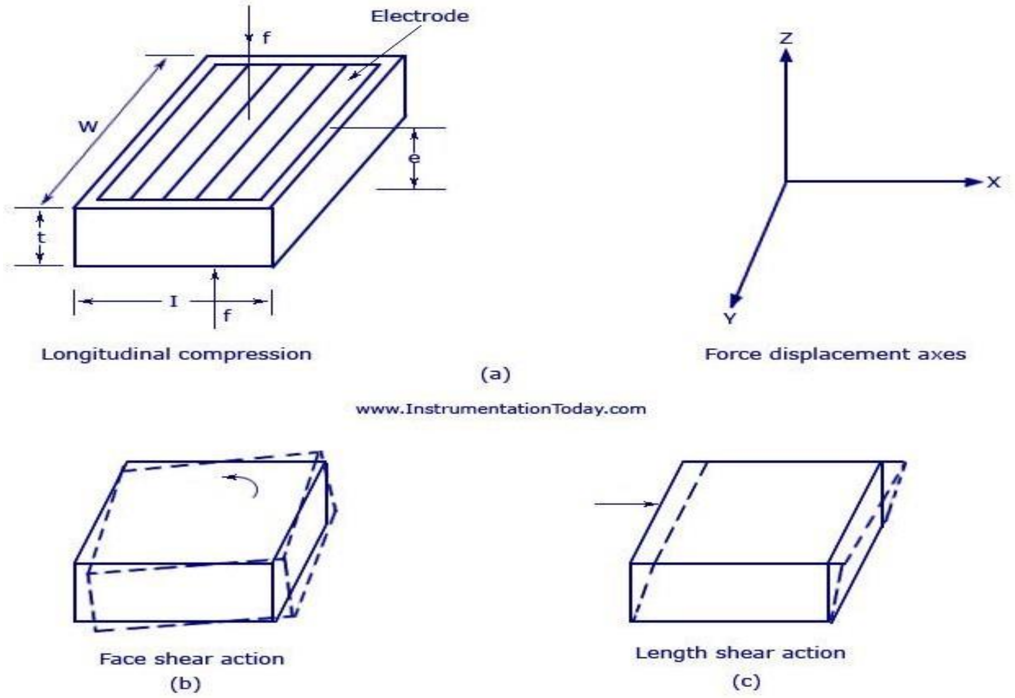




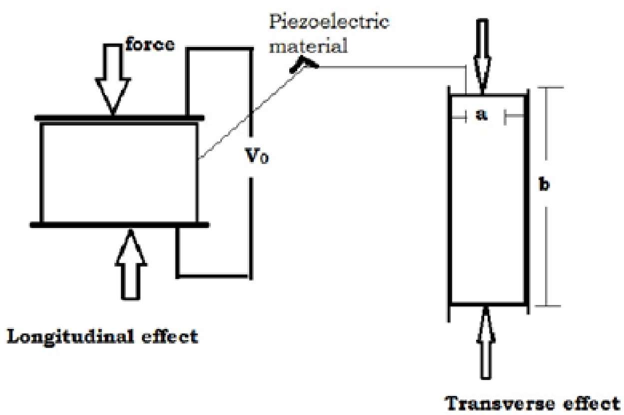


X-Y axes of a piezoelectric crystal

Modes of Operations



The formula for a piezoelectric transformer
The crystal's orientation has an impact on the voltage produced as well. A transducer's crystal may be positioned transversely or longitudinally.

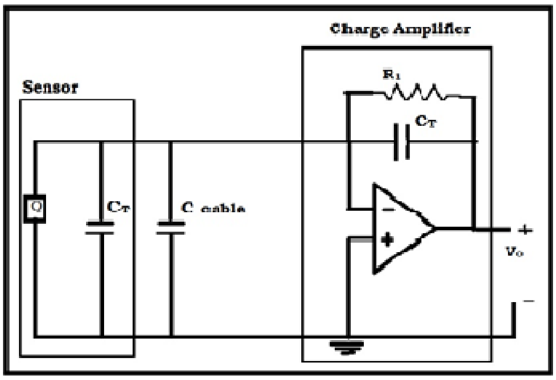


Longitudinal and Transverse Effect
The charge generated in the longitudinal effect is given by Q = F * d.
where F is the applied force and d is the crystal's piezoelectric coefficient.
Quartz crystals have a piezoelectric coefficient of d of about 2.3 * 10-12 C/N.

The charge produced by the transverse effect is expressed as Q = F * d * (b/a).
The amount of charge produced by transverse arrangement will exceed that produced by longitudinal arrangement when the ratio b/a is greater than 1.

Network of Piezoelectric Transducers

The following figure illustrates how a simple piezoelectric transducer operates.



Piezoelectric Transducer Circuit

As stress is applied to this silver-coated quartz crystal, it functions as a sensor to produce a voltage. Measurement of the generated charge without dissipation is done using a charge amplifier. With a high resistance R1, very little current can be drawn. The lead wire capacitance that links the piezoelectric sensor and transducer has an impact on the calibration as well. Thus, it is common practice to position the charge amplifier very close to the sensor.
To calibrate applied stress, a charge amplifier is used to enhance the proportionate electric voltage that a piezoelectric transducer generates when mechanical stress is applied.

Potential Uses of Piezoelectric Transducers

- The main applications of piezoelectric materials are in vibration pickup, accelerometers, and surface roughness measurement because they are not able to measure static values.
- To detect vibrations in rockets, seismographs employ them.
- For the purpose of measuring force, stress, vibrations, etc., strain gauges
- Engine detonation is measured by the automotive industry using this tool.
- In medical applications, these are employed for ultrasonic imaging.

Benefits and Drawbacks of Piezoelectric Transducers

Piezoelectric transducers have the following benefits and drawbacks.

Benefits

These transducers are active, meaning they don't need external power to function and can generate their own energy. Their high-frequency response makes them a good option for a variety of applications.
Limitations: the transducer can only measure changing pressure; therefore, it is useless for measuring static parameters. Temperature and environmental conditions can also affect the transducer's behavior.

Ultrasonic Transducer

The amount of signals or waves that can appear in a given amount of time is known as frequency. There are Hertz (Hz) units for frequency. In accordance with the frequency values, these frequencies are separated into multiple ranges. The frequencies that they correspond to are Extremely High Frequencies (EHF), Ultra-High Frequencies (UHF), Super High Frequencies (SHF), Medium Frequencies (MF), High Frequencies (HF), Very High Frequencies (VHF), Low Frequencies (LF), and Medium Frequencies (MF). The frequency range may vary depending on the type of frequencies. The frequency range of VLF is 3–30 kHz. LF operates in the frequency range of 30 kHz to 300 kHz. MF operates between 300 and 3000 kHz in frequency. HF operates in a frequency range of 3 MHz to 30 MHz. UHF frequencies span from 300 MHz to 3000 MHz. SHF operates between 3 GHz and 30 GHz in frequency. The EHF frequency spectrum spans from 30 GHz to 300 GHz.

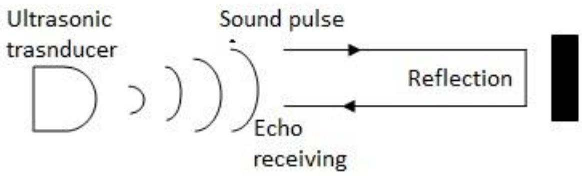
One kind of sensor that is related to sound is the ultrasonic transducer. These transducers transfer electrical signals to the target, whereupon the signal returns to the transducer. During this procedure, the transducer gauges the object's distance rather than its sound intensity. These transducers measure a few parameters using ultrasonic waves. It is widely applicable in many

different fields. Ultrasonic waves have frequencies that are higher than 20 kHz. The primary applications for these are in distance measurement.
.

These transducers are characterized as transducers that convert one form of energy into an ultrasonic vibration. This transducer determines the object's distance using these ultrasonic vibrations. They come in two varieties: active and passive.

Operational Framework

This transducer produces a sound wave when an electrical signal is applied, causing it to vibrate within a certain frequency range. When an obstruction arises, the sound waves travel and reflect the transducer's echo information. Additionally, this echo transforms into an electrical signal at the transducer's end. Here, the transducer determines how long it takes for the sound wave to be sent and for the echo signal to be received. At 40 kHz, the ultrasonic sensor generates an ultrasonic pulse that travels through the atmosphere. These transducers are superior to infrared sensors because they are impervious to substances like smoke and dark materials. When it comes to reducing background interference, ultrasonic sensors excel.



The primary application of ultrasonic transducers is the use of ultrasonic waves to measure distance. Use the following formula to calculate the distance.
D equals ½ * T * C.
D in this case denotes the distance.
T is the amount of time that passes between sending and receiving ultrasonic waves.
The sonic speed is represented by C.

Applications

Numerous fields, including industrial and medical, can benefit from the use of these transducers. Thanks to ultrasonic waves, these are finding greater uses. The use of ultrasonic transducers is beneficial in locating targets, measuring object distances from targets, determining object positions, and calculating levels.
Ultrasonic transducers are useful in the medical field for various purposes such as internal organ testing, cardiovascular disease, uterine and eye exams, cancer treatment, and diagnostic testing.

Ultrasonic transducers have limited significant applications in the industrial field. These transducers are useful for a variety of tasks, including wire break detection, liquid level control, production line management, vehicle detection, people counting, and many more. They can also be used to measure an object's distance in order to prevent a collision.

The benefits and drawbacks

Benefits

It is possible to measure in any kind of material with these ultrasonic transducers. All kinds of materials are sensed by them.

Dust, water, or any other element has no effect on the ultrasonic transducers.

The ultrasonic transducers demonstrate good performance in all types of environments.

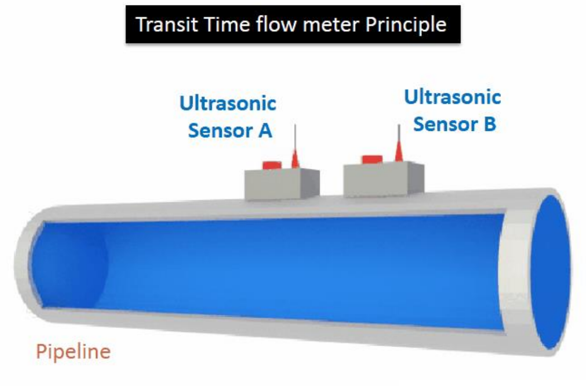
High sensing distances can also be measured by it.

Drawbacks:

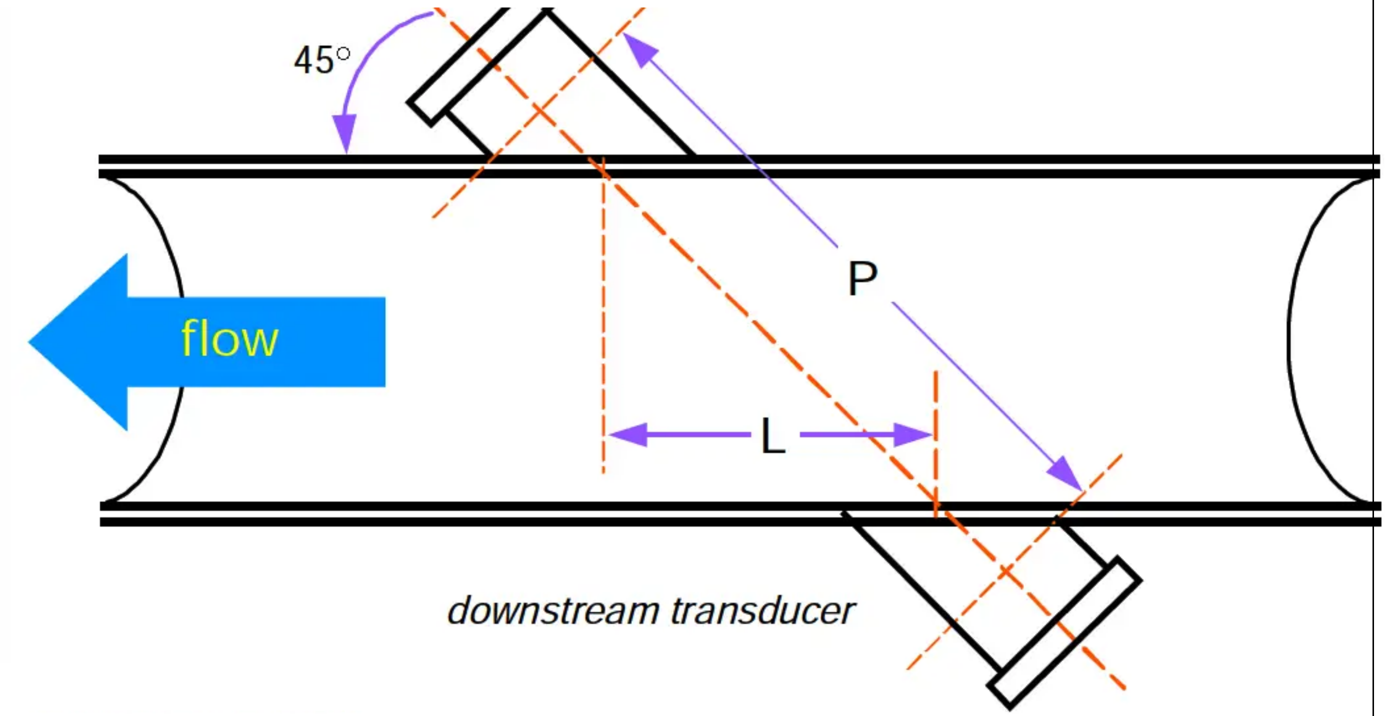
Temperature variations can affect ultrasonic transducers. The ultrasonic reaction could be altered by this temperature variation. It will also have trouble reading reflections from thin, soft, and small objects.

Ultrasonic Flow meter

An ultrasonic signal sent from one transducer to another, across a pipe, and back is measured in time by a transit time flow meter. We compare time measurements upstream and downstream. Both directions would have the same transit time in the absence of flow. Sound travels more quickly in the flow's direction and more slowly in the opposite direction.



Although extremely precise timing circuits are necessary, 1% accuracy is generally acceptable when the transducers are installed on a section of pipe with uniform flow.The fluid should not have a high concentration of solids or bubbles (less than 2%), as the ultrasonic signal needs to travel through the pipe to reach a transducer for reception.Should the high frequency sound be allowed to pass through the pipe unaltered, it will become too weak.Water/glycol solutions, hydraulic oil, fuel oils, chemicals, and drinkable water are a few examples of applications.Radio frequencies in the range of 1-2 MHz are usually used by transit time transducers. Generally, smaller pipes use higher frequency designs, while larger pipes with a diameter of several meters use lower frequencies.



Transducers installed on uniformly flowing sections of pipe can typically tolerate 1% accuracy, even with the requirement for extremely precise timing circuits.It is important that the fluid contain less than 2% of solids or bubbles because the ultrasonic signal must pass through the pipe to be received by a transducer.It will grow too weak if the high frequency sound is permitted to travel through the pipe unchanged.Some examples of applications are fuel oils, chemicals, drinkable water, hydraulic oil, and water/glycol solutions.Transit time transducers typically use radio frequencies between one and two megahertz. More than a few meters in diameter, larger pipes typically use lower frequencies, while smaller pipes typically use higher frequency designs.

$$v = \frac{KP^2}{2L}\left(\frac{1}{t_d} - \frac{1}{t_u}\right)$$

where, v = *measured velocity,*
L = *distance btw transducers*
P = *fluid path length diagonally from transducers*
t_u = *transit time upstream*
t_d = *transit time downstream*
K = *meter factor*

Single traverse Ultrasonic Flow meter
When two transducers are positioned across from one another on a pipe, the signal they transmit only once at a 45-degree angle through the fluid (figure 1). This is known as a single-traverse configuration.

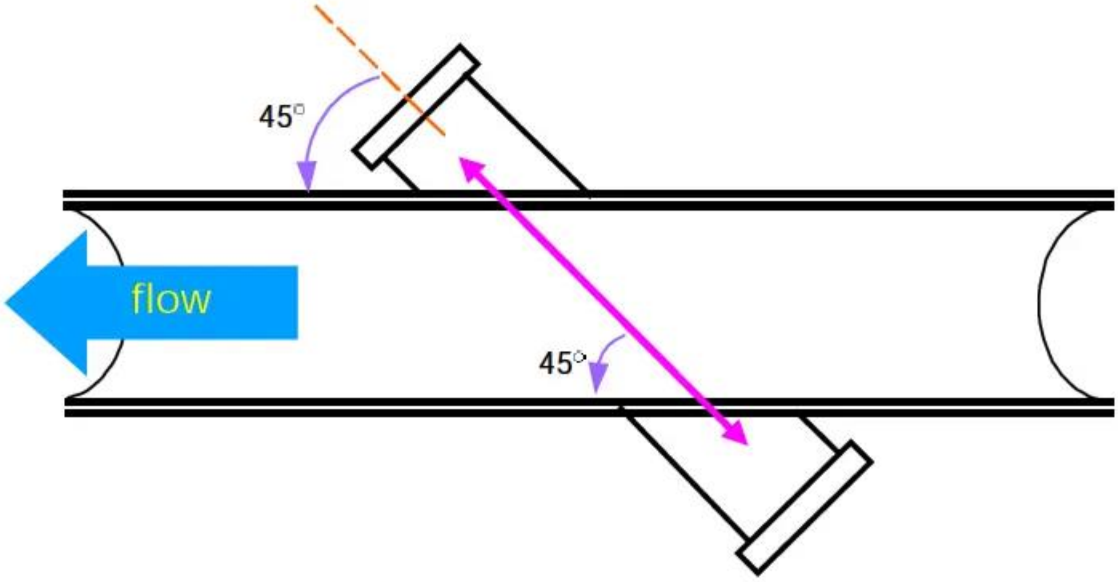
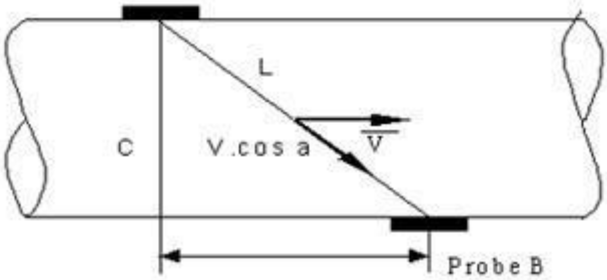


Figure 1 : Single-traverse Flowcell : L = pipe ID

The time interval between the emission and reception of a signal burst is measured by ultrasonic level sensors to determine the distance from the transducer to an impedance discontinuity.

The operating principle is: For measuring flow, the basic hardware needed is a flow meter, two probes, and an interconnection cable.



Probes A and B both function as "Trans-Receivers." The event is memorized when the electronic unit pulses probe A during the first cycle. Probe B acknowledges the acoustic beam's return to velocity and generates the "ECHO" signal. An electronic device memorizes time upon receiving the ECHO. The time of flight, or TAB (Time Taken to Travel from Probe A to Probe B), is calculated by an electronic device. The event is memorized when the electronic unit pulses Probe

B during the second cycle. Probe A recognizes the sound beam that enters against the direction of motion. The time of flight (TBA) is computed by an electronic device (Time taken to travel from Probe B to Probe A). The flow is calculated by an electronic device in the following way.

$$T_{AB} = \frac{L}{C + V\cos a}$$

$$T_{BA} = \frac{L}{C - V\cos a}$$

$$\frac{1}{T_{AB}} - \frac{1}{T_{BA}} = \frac{2V\cos a}{L} = \frac{2VD}{L^2}$$

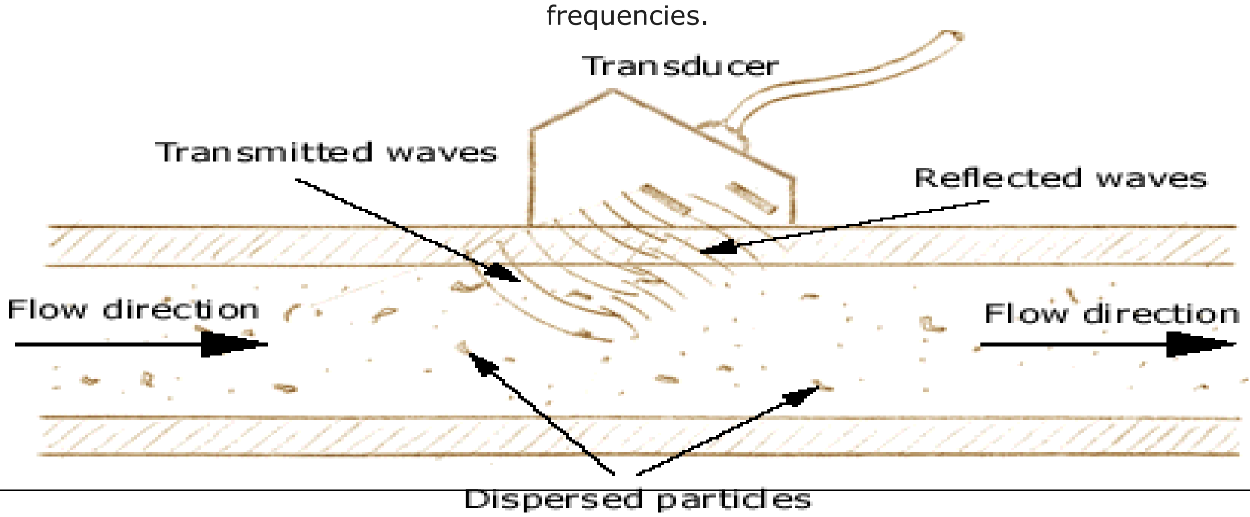
$$V = \frac{L^2}{2D}\left(\frac{1}{T_{AB}} - \frac{1}{T_{BA}}\right)$$

$$V = \frac{L^2}{2D}\left(\frac{\Delta T}{T_{AB} \times T_{BA}}\right)$$

The projected velocity V cos should be used in place of the velocity V because the transducer's input signal forms an angle with the direction of flow. The observed frequencies will be present in the acoustic waves moving upstream and downstream.

$$\begin{cases} f_u = \dfrac{f}{1 - \dfrac{V\cos\theta}{c}} \\ f_d = \dfrac{f}{1 + \dfrac{V\cos\theta}{c}} \end{cases}$$

Doppler ultrasonic flowmeters use the Doppler effect to connect the flow velocity to the frequency shifts of acoustic waves. In most cases, some particles in the flow are necessary for the signals to be reflected. As a general rule, for transducers operating at 1 MHz or higher, 25 PPM suspended solid or bubbles with a diameter of 30 microns or greater is recommended. Filter conditions may need to be "dirtier" for transducers operating at lower frequencies.



When an object moves toward an observer at a velocity V, the Doppler formula for that object is

$$f_{ref} = \frac{f}{1 - \frac{V}{c}}$$

$$\Delta f = f_u - f_d = \frac{2f\,\frac{V\cos\theta}{c}}{1 - \left(\frac{V\cos\theta}{c}\right)^2}$$

$$\approx 2f\,\frac{V\cos\theta}{c}$$

$$V = \frac{c\Delta f}{2f\cos\theta}$$

Temperature Sensors:

Temperature Indicators:

Temperature: A numerical representation of heat or cold. It can be detected by particle velocity, kinetic energy, heat radiation, or by observing how a thermometric material behaves in bulk.

Degrees Celsius (oC), Fahrenheit (oF), and Kelvin (oK) are the units of measure.

Unit of absolute Celsius is kelvin.

Use: Process Industries: Viscosity, level, flow, pressure, etc.

Ideal gas relations used to measure temperature.

$Pv = nRT$

P = Pressure
v = specific volume
n = amount of substance (No of moles)
R = Ideal or universal gas constant
T = temperature

$Q_{n+1}/Q_n = T_{n+1}/T_n$

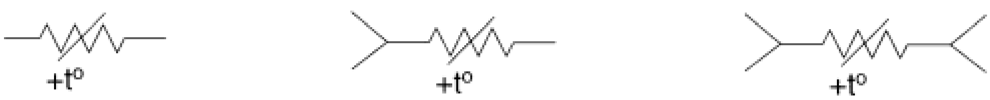
Q = heat
T = isotherm temperature

Based on range 4 instruments are recommended.

1) Gas thermometer
2) Platinum resistance thermometer
3) Platinum/Platinum-rhodium thermocouple
4) Radiation pyrometer.

Resistance temperature detector (RTD):

In essence, an etched grid on a substrate or a long, small diameter metal wire wound in a coil make up a resistance temperature detector, or RTD for short.
The most common metal used in RTDs is platinum.
The resistor is shown to change linearly by the straight line that crosses it diagonally.
The change is induced by temperature and has a positive coefficient, according to the label next to that line.



Connecting lead measurement errors are minimized by using three- and four-wire resistors (b, c diagrams).
The operation of RTDs is dependent upon the resistance of a conductor having a positive temperature coefficient.
Temperature has little effect on the quantity of electrons that can conduct electricity in a conductor.
However, as the temperature rises, the amplitude of the atoms' vibrations around their equilibrium positions increases.
The electrons become more dispersed as a result, which lowers their average speed.
As a result, resistance rises with rising temperatures. One way to express this relationship is as

$$R = R_0[1 + \alpha_1(T - T_0) + \alpha_2(T - T_0)^2 + \cdots + \alpha_n(T - T_0)^n]$$

where R_0 is the resistance at the reference temperature T_0.
At fixed-point temperatures, resistance measurements can be used to calculate the coefficients.
In the respective linear range of metals utilized as RTD probes, (1)and reduces to

$$R = R_0[1 + \alpha(T - T_0)]$$

Where α, or temperature coefficient of resistance, is represented by α, which is derived from resistance measurements made at two reference temperatures, such as 100 ^{0}C and 0 ^{0}C:

$$\alpha = \frac{R_{100} - R_0}{(100\,^\circ\mathrm{C})R_0}$$

α is sometimes termed relative sensitivity

Construction of RTD:

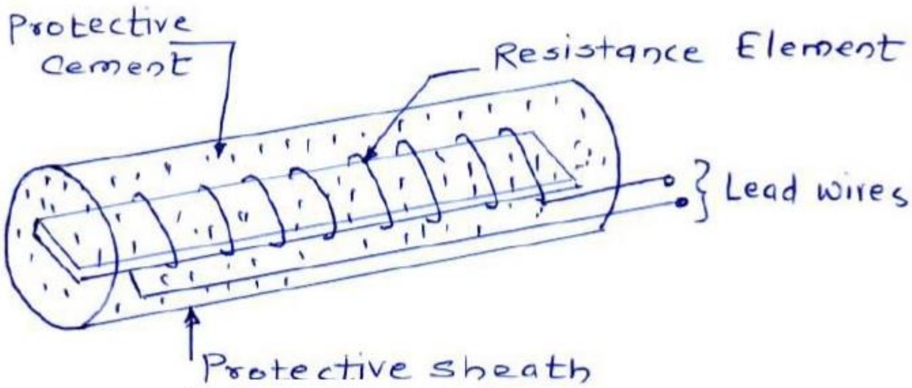


Fig: - RTD

Using resistance measurement, RTD functions as an electrical transducer, translating temperature changes into voltage signals.
Since they have low resistivities, gold and silver are rarely used to construct RTDs.
While it is suitable for high temperature applications, tungsten has a relatively high resistivity.
Occasional RTD element uses include copper. Although its low linearity and low cost make it an affordable alternative, its low resistivity forces the element to be longer than the platinum element. Approximately 120°C is its maximum temperature.
Brass, copper, and platinum are frequently found materials in RTD sensors.

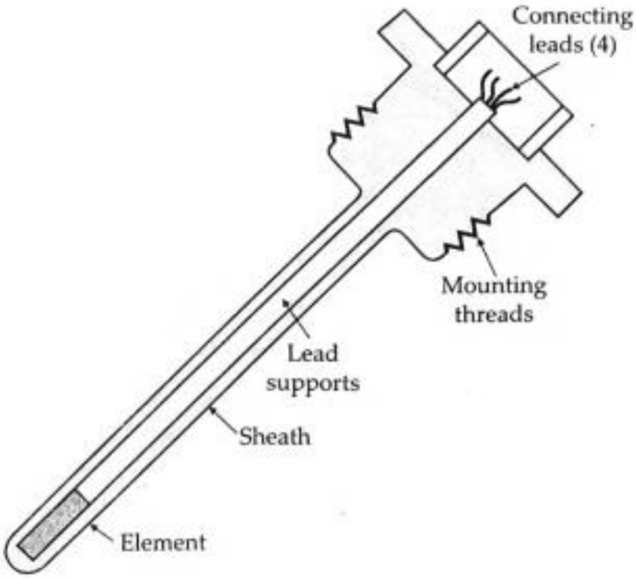
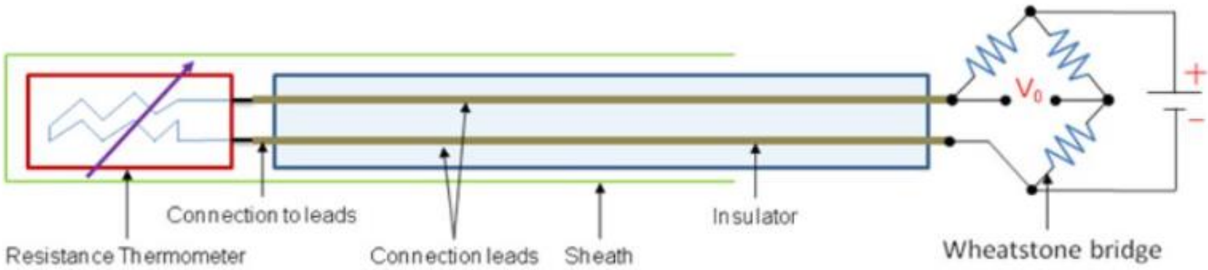


Fig. Industrial platinum resistance thermometer



The bridge's ratio arms are resistors R1 and R2. They use the ratio of the two variable resistances to calculate the ammeter's current flow. R3, sometimes referred to as the standard arm, is a variable resistor that can be tuned to match the unknown resistor.
The current flowing through the bridge circuit can be seen visually with the sensing ammeter. An examination of the circuit reveals that when R3 is set to zero current on the ammeter, the resistance of the bridge circuit's two arms is equal.

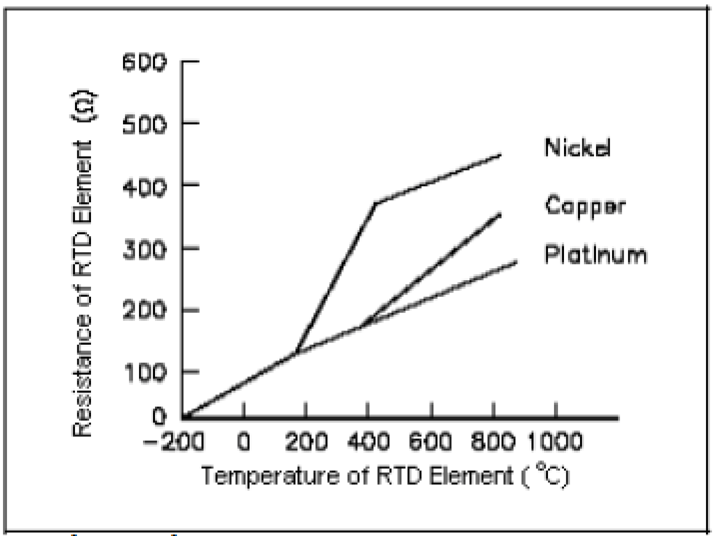
The resistance relationship between the bridge's two arms can be stated as $\frac{R_1}{R_3} = \frac{R_2}{R_x}$

Resistors R1 and R2 of the bridge are its ratio arms. To determine the ammeter's current flow, they use the ratio of the two variable resistances. R3 is a variable resistor that can be adjusted to match the unknown resistor. It is also known as the standard arm.
The detecting ammeter allows one to visually see the current flowing through the bridge circuit. Examining the circuit shows that the resistance of the two arms of the bridge circuit is equal when R3 is set to zero current on the ammeter.

The bridge's two arms' resistance relationship can be expressed as

$$R_x = \frac{R_2 R_3}{R_1}$$

Plotting the properties of different materials used to make resistance thermometers is what defines the characteristics of RTD.



Electrical Resistance-Temperature Curves

Advantages:

1. There is great accuracy in the measurement.
Moreover, controllers, recorders, and indicators can be used.
The same indicating/recording device can be equipped with multiple resistance elements.
4. Installation and replacement of the temperature-sensitive resistance element are simple tasks.
5. The measuring circuit's accuracy can be quickly verified by replacing the resistive element with a standard resistor.
6. It is possible to measure differential temperature using resistive elements.
7. Resistance thermometers can measure temperatures between −200°C and +650°C and have a broad working range without losing accuracy.
8. It takes between two to ten seconds for the resistive element to respond.
9. The resistive element can have dimensions of between 6 and 12 mm in diameter and 12 and 75 mm in length.
10. Highly precise temperature monitoring.
11. Performance stability over extended durations.

The Resistant Limits Temperature Measurement

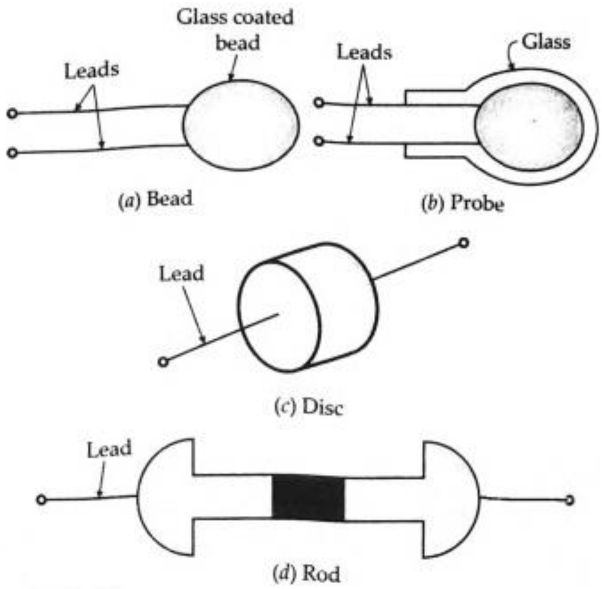
1. Expensive price
2. Requirement for power source and bridge circuit
3. The ability to heat oneself
4. Larger than a thermocouple bulb size

Thermistor:

A resistor whose electrical resistance fluctuates in response to temperature variations is called a thermistor, also known as a thermal resistor. As a passive transducer, thermoswitches function. When the temperature rises, the resistance of most thermistors decreases, exhibiting a negative coefficient of temperature resistance. These make temperature measurements reliable, affordable, and accurate. For every 1°C increase in temperature, the resistance of a thermistor at room temperature can drop by as much as 5%. Applications involving measurements between - 60°C and 15°C frequently use thermocouples. A thermocouple's resistance can be anywhere between 0.5 and 0.75 MΩ. One very sensitive device is the thermocouple.

Construction of Thermistor:

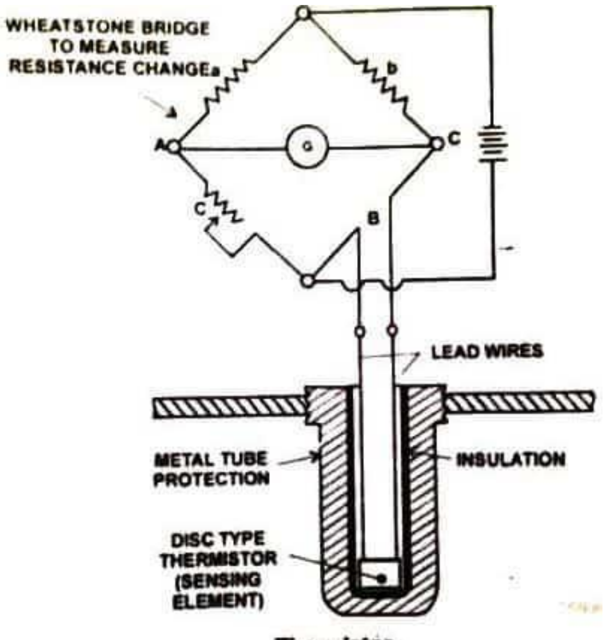
Thermistor oxides are composed of metals like copper, uranium, nickel, manganese, and cobalt. It comes in a range of sizes and shapes. Rod type, Bead type, and Disk type are frequently used configurations.



When more power dissipation is needed, the rod type and disc type thermistors are utilized. A high power handling capacity is possessed by the rod type thermistor. Bead type thermistors are the smallest thermistors in these configurations. It only has a 0.15 mm diameter. Usually, a glass probe contains the measurement element. Glass probes come in a range of lengths from 6 to 50 mm, with a diameter of roughly 2.5 mm. It is frequently employed to determine the temperature of liquids. Solid glass rods can be sealed with beads to create probes that might be simpler to mount than beads alone. Materials with diameters ranging from 2.5 mm to 25 mm are compressed under intense pressure into cylindrical, flat forms to create discs.

Fundamental Thermistors Operation:

Thermistors operate on the straightforward theory that a temperature change will alter their resistance. As the temperature of these thermistors varies, their resistance will also change. This means that the applied temperature can be found by measuring the change in resistance value. The thermistor begins to self-heat its components when the outside temperature changes. By using a Wheatstone bridge circuit, one can determine how temperature variations affect resistance. It is possible to determine temperature by measuring the resistance value because resistance varies in response to temperature changes. Utilizing a wheat stone bridge, the initial resistance of the thermistor sensing element is measured after a known constant current is run through it. The medium whose temperature needs to be measured now has a thermistor added to it. The temperature changes (declines) and causes a change in the sensing element. Assume the temperature change is positive. Keep in mind that during the measurement process, the sensing element receives the same steady current. Nowadays, the wheat stone bridge is used to measure this change in the thermistor's sensing element's resistance. With calibration, this variation in resistance turns into a temperature indicator.



Thermistor

Resistance-Temperature Characteristics of Thermistors:

The following is the formula that describes the relationship between a thermistor's resistance and its absolute temperature:

$$R_{T1} = R_{T2} \exp\left[\beta\left(\frac{1}{T_1} - \frac{1}{T_2}\right)\right]$$

where the thermistor's resistance at absolute temperature T1; °K is represented by RT1. The constant β depends on the thermistor material and ranges from 3500 to 4500 °K. RT2 denotes the thermistor's resistance at absolute temperature T2 in °K.

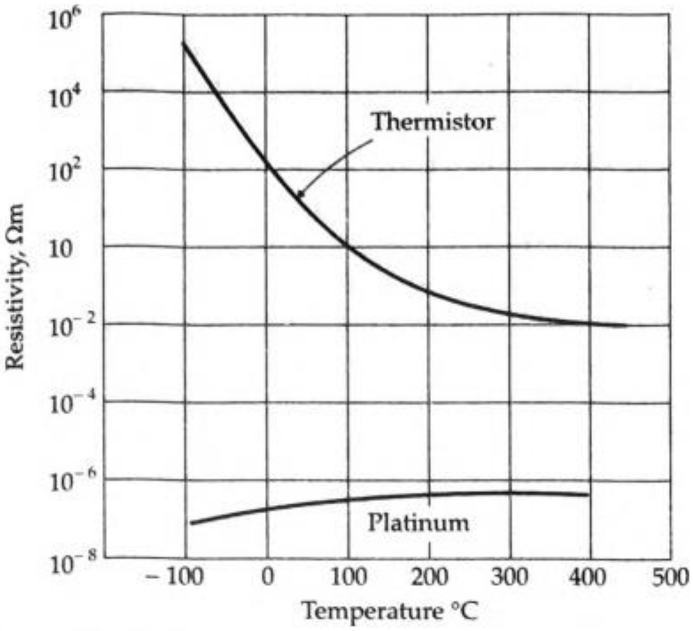


Fig. Resistance-temperature characteristics of a typical thermistor and platinum

Thermistor Types:

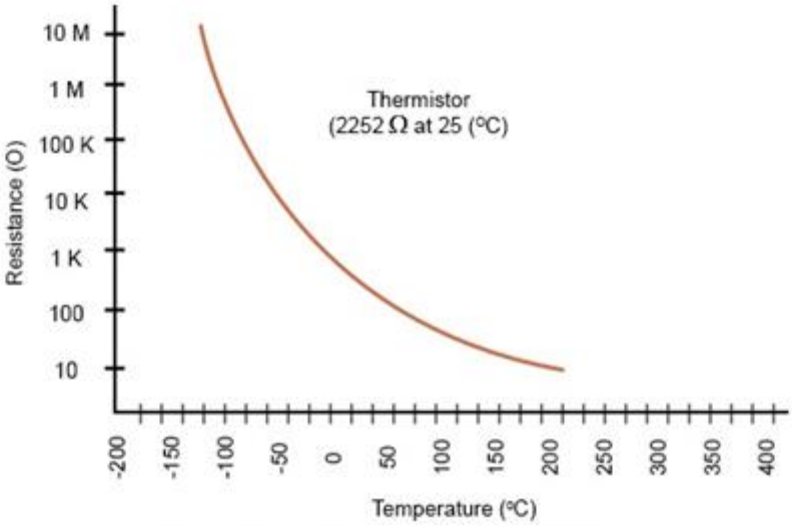
• A temperature increase causes the resistance to increase if the temperature coefficient of resistance (k) has a positive value.

Positive Temperature Coefficient Thermistor, or Posistor, is another name for this kind of device (PTC).

• The term "negative temperature coefficient resistor" (NTC) refers to a device in which a rise in temperature results in a decrease in the resistance value since the value of k is negative.

NTC Thermistor

• Resistance falls in an NTC thermistor as temperature rises. Resistance also rises with a drop in temperature. Temperature and resistance are therefore inversely proportional in an NTC thermistor. The most prevalent kind of thermistor is this one.



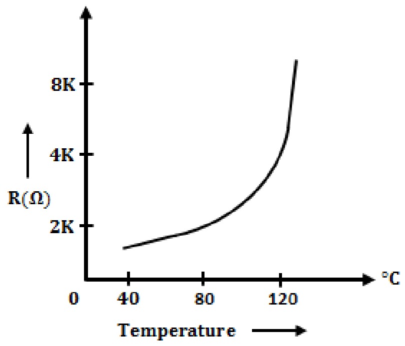
Thermistor Characteristic NTC Curve

Where temperature resistance is represented by RT. T. (K)
Resistance at temperature is denoted by R0. T0 (K)
T0 is the standard temperature, which is typically 25 oC.
β is a constant, and the properties of the material determine its value. We take 4000 as the nominal value.

• The temperature range between -55°C and 200°C is where an NTC thermistor typically provides the most accurate readings. On the other hand, some specifically made NTC thermistors are used at -273.15°C, or absolute zero, and some can be used above that temperature.

Positive Temperature Coefficient or PTC Thermistor:

• This kind of thermistors responds better to heat; that is, they have a positive temperature coefficient. The illustration below depicts it.



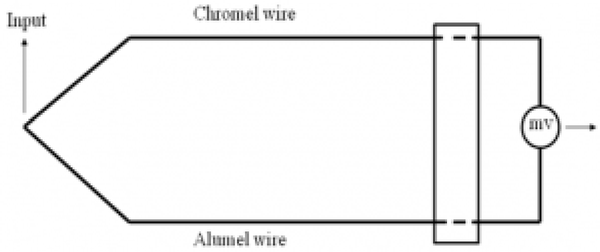
Resistance Temperature Characteristics of PTC Thermistor

PTC thermistors are primarily used as protective elements in electric machinery for the protection of windings in transformers, motors, and other electrical equipment. They are typically made of titanates of barium, lead, and strontium.
The PTC thermistor resistance increases sharply when an electrical apparatus overheats, and they are used as a device to prevent overheating in various types of apparatus. The equipment is unplugged from the supply and the relay coil is de-energized.

Thermistors' benefits

• Cheaper.
• Sensitiver than alternative sensors.
• Quick reaction.
• Tiny in dimensions.

Thermistors' shortcomings
• Strict temperature tolerance.
• There is nonlinear correlation between resistance and temperature ratio.
• The self-heating effect could result in an inaccurate measurement.
• Easily damaged.
Utilizations
• Temperature readings are taken using NTC thermistors, typically over small temperature ranges.
• The gadget has the ability to restrict the abrupt overcurrent that flows through supply circuits.
• The temperature of incubators is measured with this apparatus.
• While batteries are being stored for charging, NTC thermistors are used to measure and monitor them.
• They are employed to monitor the coolant and oil temperatures inside automobile engines.
Thermocouples:
Any type of temperature sensor that measures the temperature at a single point in the form of an electric current or electromagnetic field is known as a thermocouple. Two distinct metal wires are connected at a single junction to form this sensor. This junction allows for the measurement of temperature, and voltages are stimulated by changes in the metal wire's temperature.



Very sensitive devices must be used to calculate the amount of electromagnetic field (EMF) produced in the circuit because the amount generated in the device is extremely small (millivolts). Common tools for determining the e.m.f. are the standard galvanometer and the voltage balancing potentiometer. A mechanical or physical balancing potentiometer is made from these two.

Principle of Thermocouple Operation

The three effects—Seebeck, Peltier, and Thompson—are the primary foundation of the thermocouple principle.

Refer to the Beck effect

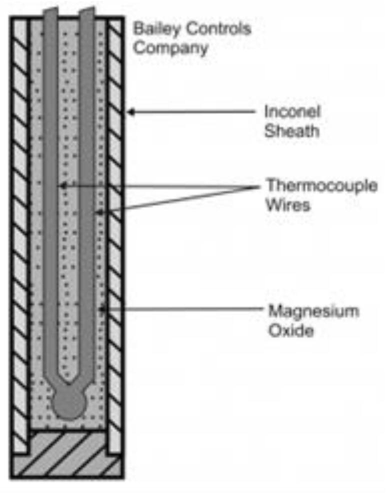
This kind of effect happens between two different metals. The flow of electrons from hot to cold metal wire occurs when heat is applied to any one of the metal wires. Direct current thus stimulates the circuit.

In contrast to the Seebeck effect is the Peltier effect. This phenomenon indicates that any two dissimilar conductors can develop a temperature difference by introducing a potential variation between them.

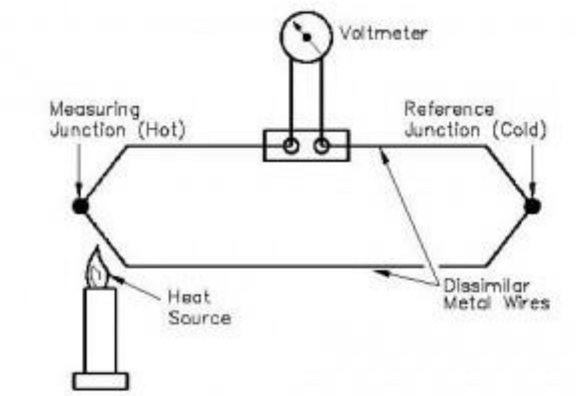
Thompson effect

According to this effect, the voltage causes the entire conductor's length because of the temperature gradient as two different metals fix together and, if they form two joints. The rate and direction of temperature change at a specific location are shown physically by this word.
Construction of Thermocouple:

The construction of the device is shown below. It comprises two different metal wires and that are connected together at the junction end. The junction thinks as the measuring end. The end of the junction is classified into three type's namely ungrounded, grounded, and exposed junction.



Working of thermocouple:
The device's construction is displayed below. It is made up of two distinct metal wires that are joined at the junction end. The junction serves as the endpoint for measurement. There are three types of junction ends: exposed, grounded, and ungrounded.



There will be no current flow through the circuit if the temperature at the junction end becomes equivalent. This will result in the production of both the equivalent and reverse electromagnetic force. The circuit experiences a potential variation when the temperature at the junction end becomes unbalanced.

Which kind of material is used to make the thermocouple affects how much of an electromagnetic force is induced in the circuit. The measurement tools calculate the total current flow across the circuit. Equation (1) computes the electromagnetic force induced in the circuit.

E is equal to a (Δ) + b (Δ).Two

If a and b are constants, then Δ is the temperature difference between the hot thermocouple junction end and the reference thermocouple junction end.

Kinds of Thermocouples

Form K: Another name for this kind of thermocouple is Nickel-Chromium/Nickel-Alumel. It's the type that's most commonly used. It can function over a wider temperature range and has the qualities of improved precision, affordability, and dependability.

These are the temperature ranges:

Thermocouple grade wire: -2700C to 12600C (-454F to 2300F)

Wire extension (00C to 2000C)

The accuracy level of this K-type is

Normal limits are +/- 2.2C, or +/-0.75%, and exceptional limits are +/- 1.1C, or 0.4%.

Type J: This is an iron/constantan mixture. This kind of thermocouple is also the most popular. Its qualities include increased precision, affordability, and dependability. When used in a wide range of temperatures, this device has a limited operating temperature range and a short lifespan.

These are the temperature ranges:

-346F to 1400F (-2100C to 7600C) is the thermocouple grade wire.

Wire extension (00C to 2000C)

The accuracy level of this J-type is Standard +/- 2.2C, or +/-0.75%, and the special limits are +/- 1.1C, or 0.4%.

Type T: A mixture of copper and constantan. The T type thermocouple is more stable and is typically used in lower temperature applications, such as cryogenics and ultra-low temperature freezers.

These are the temperature ranges:

-454F to 700F (-2700C to 3700C) is the thermocouple grade wire.

Wire extension (00C to 2000C)

The accuracy level of this T-type is Standard +/- 1.0C, or +/-0.75%, with special limits of +/- 0.5C, or 0.4%.

Type E: This is a nickel-chromium/constantan mixture. Operating at ≤ 1000F, it exhibits superior signal ability and accuracy over Type K and J thermocouples as well.

These are the temperature ranges:

Thermocouple grade wire: -2700C to 8700C (-454F to 1600F).

Wire extension (00C to 2000C)

Standard +/- 1.7C or +/-0.5% is the accuracy level for this T-type, and the special limits are +/- 1.0C or 0.4%.

Type N: This thermocouple is also referred to as a Nisil thermocouple. Type N is comparable to type K in terms of temperature and precision levels. However, type K is less expensive than this type.

These are the temperature ranges:

-454F to 2300F (-2700C to 3920C) is the thermocouple grade wire.

Wire extension (00C to 2000C)

The accuracy level of this T-type is Standard +/- 2.2C, or +/-0.75%, and the special limits are +/- 1.1C, or 0.4%.

Type S: This type of thermocouple is classified as 10%/Platinum or Platinum/Rhodium. High-temperature range applications, like those found in biotech and pharmacy companies, heavily utilize the S type of thermocouple. Its greater precision and stability even lead to its use in applications with a smaller temperature range.

Those are the temperature ranges:
Wire of thermocouple grade: -58°F to 2700°F (-500°C to 14800°C).
00C to 2000C extension wire
Special limits are +/- 0.6C or 0.1%, and the accuracy level for this T-type is Standard +/- 1.5C or +/-0.25%.

The Type R thermocouple is classified as either platinum/rhodium or 13%/platinum. Applications involving a high temperature range make extensive use of the S type thermocouple. Compared to Type S, this type has more rhodium, which increases the device's cost. Type R and S perform and have features that are almost identical. Since it is more accurate and stable, it is even utilized for applications with a smaller temperature range.

These are the temperature ranges:

-58F to 2700F (-500C to 14800C) is the thermocouple grade wire.
Wire extension (00C to 2000C)
Standard +/- 1.5C, or +/-0.25%, is the accuracy level for this T-type; special limits are +/- 0.6C, or 0.1%.

Type B – The percentage of Platinum Rhodium thermocouple that it makes up is either 30% or 60%. The higher temperature range of applications makes extensive use of this. Type B is the one with the highest temperature limit among all the types mentioned above. The type B thermocouple will exhibit greater accuracy and stability at the raised temperature levels.

Those are the temperature ranges:

32°F to 3100°F (00°C to 17000°C) is the thermocouple grade wire.
00C to 1000C extension wire
An accuracy level of Standard +/- 0.5% is maintained by this type T.
Noble metal thermocouples fall into three categories: S, R, and B. Their long lifespan and excellent accuracy make them the preferred option, even at high temperatures.