3.2 TYPES OF POTENTIOMETERS:

1. Wire Wound:

- These use nickel chromium, nickel copper, or some other precious resistance elements.
- Wire wound potentiometers can carry relatively large Currents at high temperatures.
- Their temperature coefficient is usually small, is of the order 20 x 10^{-5} Ω/ Ω -°C or less and also they are relatively inexpensive.
- Their resolution is about 0 05 mm and is limited by the number of turns.
- Multiturn potentiometers using 3 to I0 turn units are used when the potentiometer
- is required to have close settings.
- The inter winding capacitance between turns and between winding and arm, housing etc. limits the use of wire wound potentiometers to low frequencies. The response is limited to about 5 Hz.

1. Cermet.

- Cermet uses precious metal particles fused into ceramic base. These fused metal particles act as resistance elementsis shown in Fig 3.2.1.
- The advantages of using Cermet are large power ratings at high temperatures, low cost and moderate temperature coefficients of the order 100 x 10^{-6} to 200 x 10^{-6} Ω/ Ω-°C.
- Cermet is very useful for a.c. applications

Fig 3.2.1 Cermet

[Source: Neubert H.K.P., Instrument Transducers – An Introduction to their Performance and Design, Page: 449]

2. Hot Moulded Carbon

- The resistance element is fabricated by moulding together a mixture of carbon and a thermosetting plastic binder.
- Hot moulded carbon units are useful for a.c. applications.

3. Carbon Film

- A thin film of carbon deposited on a non-conductive base forms the resistance element.
- The advantage of carbon film potentiometers is their low cost. Temperature coefficients are upto 1000 x 10^{-6} Ω/ Ω -°C.

4. Thin Metal Film**.**

- A very thin, vapour deposited layer of metal on glass or ceramic base is used as a resistance element.
- The advantages of this potentiometer are its excellent resistance to

changes in environments and use on a.c.

- The cost is also moderate.

Applications of Potentiometers

1. Potentiometer as a Voltage Divider

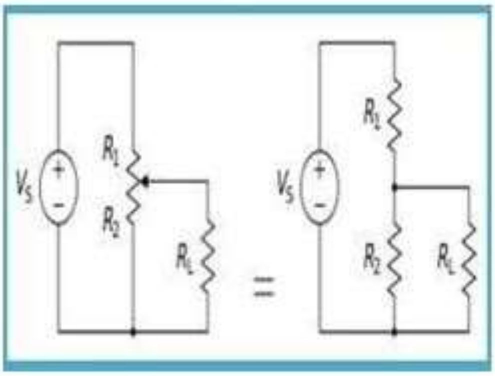


Fig 3.2.2 Voltage divider

[Source: Neubert H.K.P., Instrument Transducers – An Introduction to their Performance and Design, Page: 452]

In Fig 3.2.2, The potentiometer can be worked as a voltage divider to obtain a manually adjustable output voltage at the slider from a fixed input voltage applied across the two ends of the potentiometer. Now the load voltage across RL can be measured as

$$V_L = R_2R_L . V_S/(R_1R_L+R_2R_L+R_1R_2)$$

2. Audio Control

- Sliding potentiometers, one of the most common uses for modern low-power potentiometers are as audio control devices.

- Both sliding pots **(faders)** and rotary potentiometers **(knobs)** are regularly used to frequency attenuation, adjust loudness and for different characteristics of audio signals.

3. Television

- Potentiometers were used to control picture brightness, contrast, and color response.
- A potentiometer was often used to adjust “vertical hold”, which affects the synchronization between the received picture signal and the receiver’s internal sweep circuit (a multi-vibrator)

4. Transducers

- One of the most common applications is measuring displacement.
- To measure the displacement of the body, which is movable, is connected to the sliding element located on the potentiometer.
- As the body moves, the position of the slider also changes accordingly so the resistance between the fixed point and the slider changes. Due to this the voltage across these points also changes.
- The change in resistance or the voltage is proportional to the change in the displacement of the body.

5. Industrial Applications

- It is used in wood processing machine.
- It is used in injection mold machines.

- Potentiometers are widely used as user controls, and may control a very wide variety of equipment functions.
- Motion control: In order to create a closed-loop control, potentiometers are used as position feedback devices known as a servomechanism

Advantages of Potentiometer

(i) They are inexpensive.

(ii) They are simple to operate and are very useful for applications where the

requirements are not particularly severe.

(iii) They are very useful for measurement of large amplitudes of displacement.

(iv) Their electrical efficiency is very high and they provide sufficient output to permit control operations without further amplification.

(v) It should be understood that while the frequency response of wire wound potentiometers is limited, the other types of potentiometers are free from this problem

(vi) In wire wound potentiometers the resolution is limited while in Cermet and metal film potentiometers, the resolution is infinite.

Disadvantages of Potentiometer

(i) The chief disadvantage of using a linear potentiometer is that they require a large force to move their sliding contacts (wipers).

(ii) The other problems with sliding contacts are that they can be contaminated, can wear out, become misaligned and generate noise. So the life of the transducer is limited. However, recent developments have produced a roller contact wiper which, it is claimed, increases the life of the transducer by 40 times.

Strain gauge

Have you ever seen the Birdman Contest, an annual event held at Lake Biwa near Kyoto? Many people in Japan know the event since it is broadcast every year on

TV. Cleverly designed airplanes and gliders fly several hundred meters on human power, teaching us a great deal about well-balanced airframes. However, some airframes have their wings regrettably broken upon flying and crash into the lake. Such crashes provoke laughter and cause no problem since airplane failures are common in the Birdman Contest.

Introduced, the structure is designed to be lighter to attain faster running speed and less fuel consumption. It is possible to design a lighter and more efficient product by selecting lighter materials and making them thinner for use. But the safety of the product is compromised unless the required strength is maintained. By the same token, if only the strength is taken into consideration, the weight of the product increases and the economic feasibility is impaired. Thus, harmony between safety and economics is an extremely important factor in designing a structure. To design a structure which ensures the necessary strength while keeping such harmony, it is significant to know the stress borne by each material part. However, at the present scientific level, there is no technology which enables direct measurement and judgment of stress. So, the strain on the surface is measured in order to know the internal stress. Strain gages are the most common sensing element to measure surface strain. Let's briefly learn about stress and strain and strain gages.

Stress

Stress is the force an object generates inside by responding to an applied external force, P. See Fig.3.2.3. If an object receives an external force from the top, it internally generates a repelling force to maintain the original shape. The repelling force is called internal force and the internal force divided by the cross- sectional area of the object (a column in this example) is called stress, which is expressed as a unit of Pa (Pascal) or N/m2. Suppose that the cross-sectional area of the column is A (m2) and the external force is P (N, Newton). Since external force = internal force, stress, σ (sigma), is:

$$\sigma = P/A \text{ (Pa or N/m2)}$$

Since the direction of the external force is vertical to the cross-sectional area, A, the stress is called vertical stress.

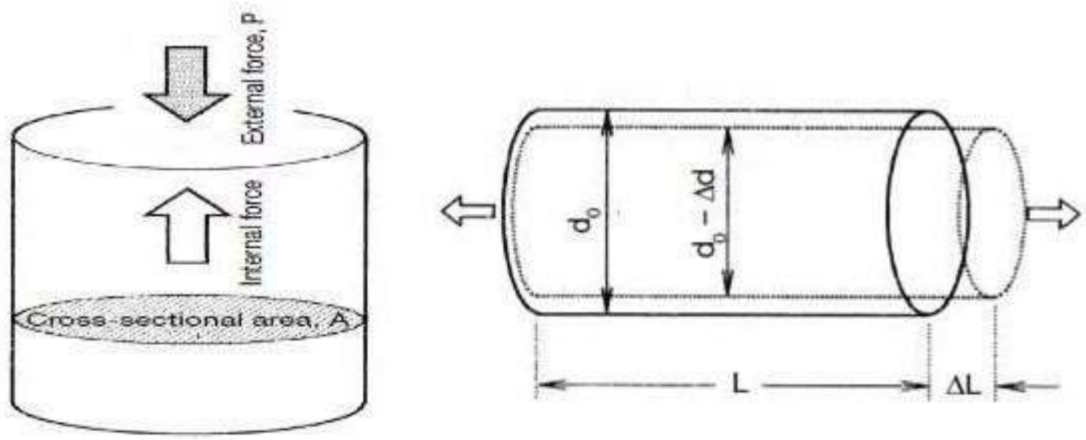


Fig.3.2.3. Stress

[Source: Neubert H.K.P., Instrument Transducers – An Introduction to their Performance and Design, Page: 459]

Strain

When a bar is pulled, it elongates by ΔL, and thus it lengthens to L (original length) + ΔL (change in length). The ratio of this elongation (or contraction), ΔL, to the original length, L

$$\varepsilon 1 = \Delta L \text{ (change in length)}/L \text{ (original length)}$$

Strain in the same tensile (or compressive) direction as the external force is called longitudinal strain. Since strain is an elongation (or contraction) ratio, it is an absolute number having no unit. Usually, the ratio is an extremely small value, and thus a strain value is expressed by suffixing “x10–6(parts per million) strain,” “µm/m” or “µε.”, is called strain, which is expressed in ε (epsilon):

The pulled bar becomes thinner while lengthening. Suppose that the original diameter, d0, is made thinner by Δd. Then, the strain in the diametrical direction is:

$$\varepsilon 2 = -\Delta d/d0$$

Strain in the orthogonal direction to the external force is called lateral strain. Each material has a certain ratio of lateral strain to longitudinal strain, with most materials showing a value around 0.3. This ratio is called Poisson's ratio, which is expressed in ν (nu):

$$\mathbf{v} = \frac{\varepsilon_2}{\varepsilon_1} = \mathbf{0.3}$$

With various materials, the relation between strain and stress has already been obtained experimentally. Fig. 3.2.4 graphs a typical relation between stress and strain on common steel (mild steel). The region where stress and strain have a linear relation is called the proportional limit, which satisfies the Hooke's law.

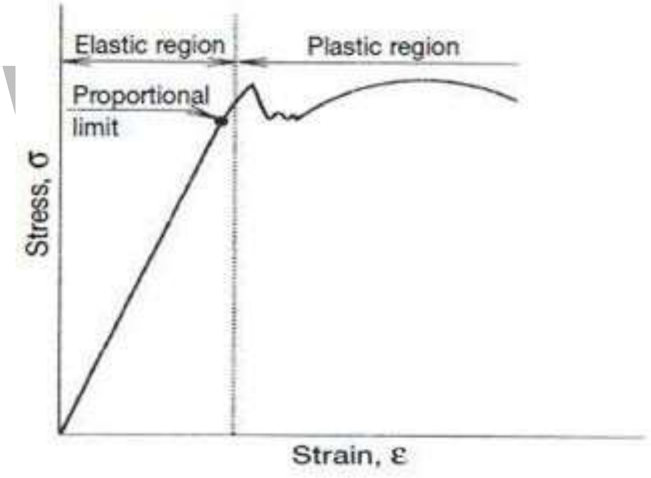


Fig 3.2.4 Relation between stress and strain

[Source: Neubert H.K.P., Instrument Transducers – An Introduction to their Performance and Design, Page: 465]

Definition

Strain Gauge is a device used to measure deformation (strain) of an object. It is also termed as Load cell. Fundamentally, all strain gauges are designed to convert mechanical motion into an electrical signal Invented by Edward E. Simmons and Arthur C. Ruge in 1938. A strain gauge is an example of passive transducer that converts a mechanical displacement into a change of resistance is shown in Fig 2.4.5.

A strain gauge is a thin, wafer-like device that can be attached to a variety of materials to measure applied strain.

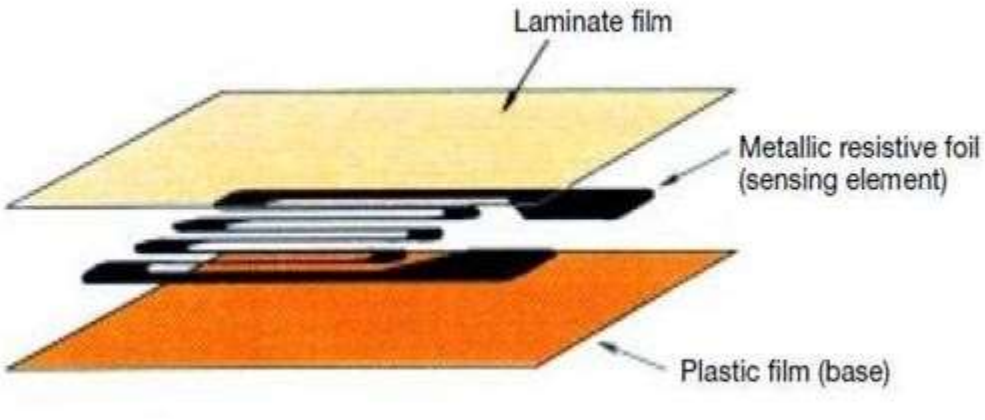


Fig.3.2.5 Strain Gauge

[Source: Neubert H.K.P., Instrument Transducers – An Introduction to their Performance and Design, Page: 470]

Structure of Strain Gauges

There are many types of strain gages. Among them, a universal strain gage has a structure such that a grid-shaped sensing element of thin metallic resistive foil (3 to 6μm thick) is put on a base of thin plastic film (15 to 16μm thick) and is laminated with a thin film.

Principle of Strain Gages

The strain gage is tightly bonded to a measuring object so that the sensing element (metallic resistive foil) may elongate or contract according to the strain borne by the measuring object. When bearing mechanical elongation or contraction, most metals undergo a change in electric resistance. The strain gage applies this principle to strain measurement through the resistance change. Generally, the sensing element of the strain gage is made of a copper-nickel alloy foil. The alloy foil has a rate of resistance change proportional to strain with a certain constant. Let's express the principle as follows:

$$\Delta R/R = K.\varepsilon$$

where,

R: Original resistance of strain gage, Ω (ohm)

ΔR: Elongation- or contraction-initiated resistance change, Ω (ohm)

K: Proportional constant (called gage factor)

ε: Strain

The gage factor, K, differs depending on the metallic materials. The copper-nickel alloy (Advance) provides a gage factor around 2. Thus, a strain gage using this alloy for the sensing element enables conversion of mechanical strain to a corresponding electrical resistance change. However, since strain is an invisible infinitesimal phenomenon, the resistance change caused by strain is extremely small.

For example, let's calculate the resistance change on a strain gage caused by 1000 x10–6 strain. Generally, the resistance of a strain gage is 120Ω, and thus the following equation is established:

$$\Delta R/120 = 2 \times 1000 \times 10^{-6}$$

$$\Delta R = 120 \times 2 \times 1000 \times 10^{-6} = 0.24\Omega$$

The rate of resistance change is:

$$\Delta R/R = 0.24/120 = 0.002 = 0.2\%$$

In fact, it is extremely difficult to accurately measure such a minute resistance change, which cannot be measured with a conventional ohmmeter. Accordingly, minute resistance changes are measured with a dedicated strain amplifier using an electric circuit called a Wheatstone bridge.

Theory of Strain Gauges

If a strip of elastic material is subjected to tension (positively strained), its longitudinal dimension will increase while there will be a reduction in the lateral dimension.

So, when a gauge is subjected to a positive strain, its length increases while, its area of cross-section decreases is shown in Fig 3.2.6.

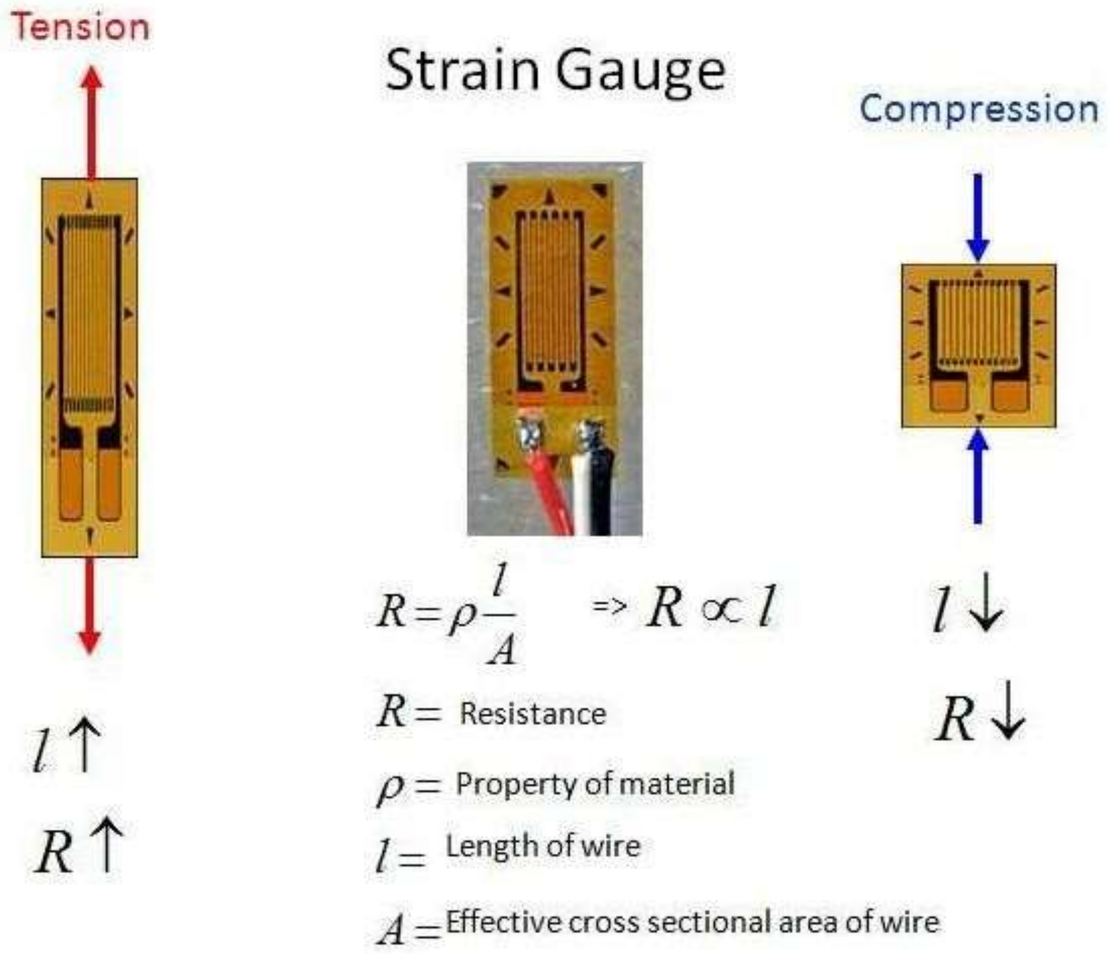


Fig.3.2.6 Compressive and Tensile Strains

[Source: Neubert H.K.P., Instrument Transducers – An Introduction to their Performance and Design, Page: 478]

GENERALISED EXPRESSION FOR THE GAUGE FACTOR OFSTRAIN GAUGE

The strain gage is one of the most widely used strain measurement sensors. %t is a resistive elastic unit whose change in resistance is a function of applied strain in Fig 2.2.7.

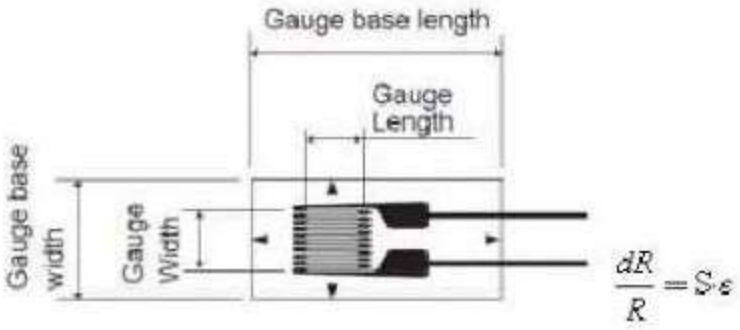


Fig.3.2.7 Gauge Factor

[Source: Neubert H.K.P., Instrument Transducers – An Introduction to their Performance and Design, Page: 485]

Where,

R is the Resistance

ε is the Strain

S is the strain sensitivity factor of the gauge material

When the strain gage is attached and bonded well to the surface of an object, the two are considered to deform together. The strain of the strain gage wire along the longitudinal direction is the same as the strain on the surface in the same direction.

However, its cross-sectional area will also change due to the Poisson's ratio. Suppose that the wire is cylindrical with initial radius *r*. The normal strain along the radial direction. The change rate of cross-section area is twice as the radial strain, when the strain is small.

1. **Metal wire strain gauge**

As in metals change in resistivity is zero is shown in Fig 3.2.8.

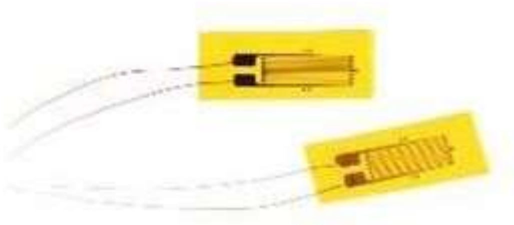


Fig 3. 2.8 Metal wire strain gauge

[Source: Neubert H.K.P., Instrument Transducers – An Introduction to their Performance and Design, Page: 489]

$$S \triangleq \frac{\frac{dR}{R}}{\varepsilon_l} = 1 + 2\upsilon$$

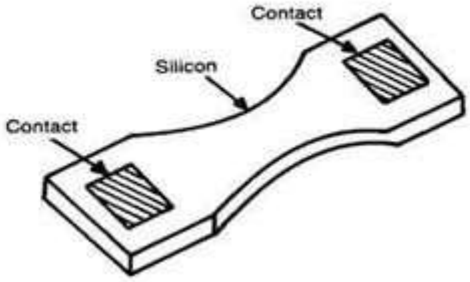


Fig 3.2.9 Semiconductor wire gauge

[Source: Neubert H.K.P., Instrument Transducers – An Introduction to their Performance and Design, Page: 492]

2. Semiconductor wire strain gauge

As in this the change in dimensions are zero. Semiconductor type strain gage is made of a thin wire of silicon, typically 0.005 inch to 0.0005 inch, and length 0.05 inch to 0.5 inch. They can be of two types: *p*-type and *n*-type. In the former the resistance increases with positive strain, while, in the later the resistance decreases with temperature is shown in Fig 2.3.9.

MEMS pressure sensors is now a days becoming increasingly popular for measurement of pressure. It is made of a small silicon diagram with four piezoresistive strain gages mounted on it. It has an in-built signal conditioning circuits and delivers measurable output voltage corresponding to the pressure applied. Low weight and small size of the sensor make it suitable for measurement of pressure in specific applications.

The characteristics of strain gauges are as follows:

- They are highly precise and don't get influenced due to temperature changes. However, if they do get affected by temperature changes, a thermistor is available for temperature corrections.
- They are ideal for long distance communication as the output is an electrical
- signal.
- Strain Gauges require easy maintenance and have a long operating life.
- The production of strain gauges is easy because of the simple operating principle and a small number of components.
- The strain gauges are suitable for long-term installation. However, they require
- certain precautions while installing.
- All the strain gauges produced by Encardio-Rite are hermetically sealed and made up of stainless steel thus, waterproof.

Types of strain gauge:

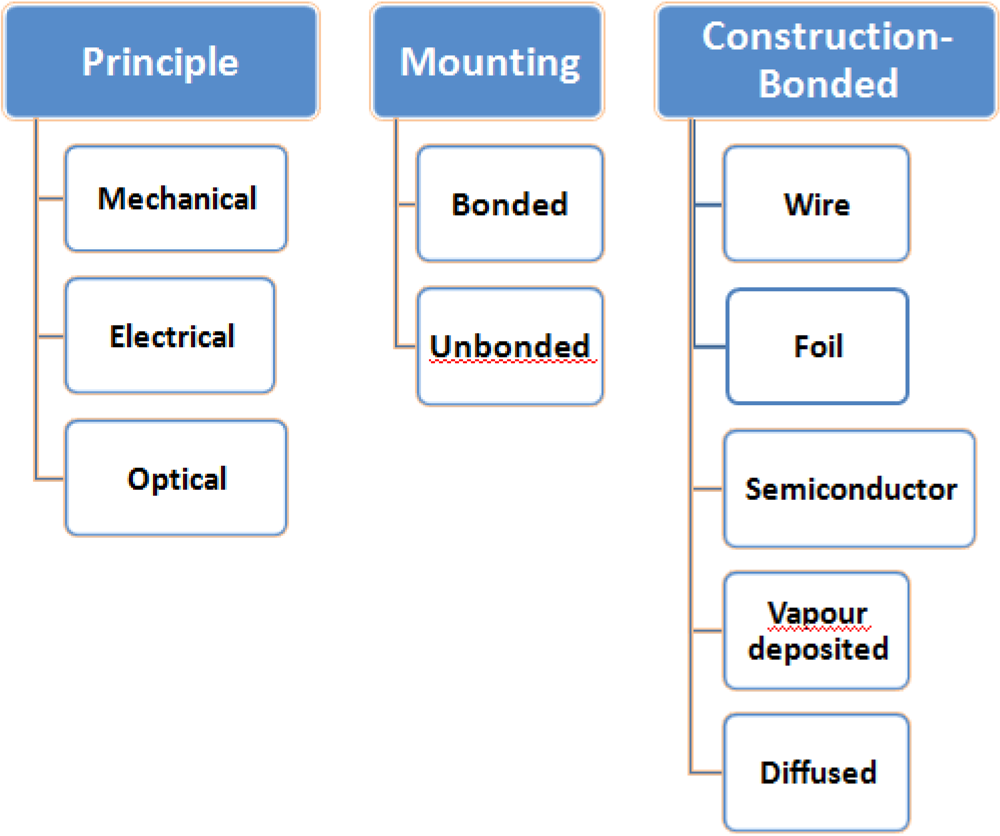


Fig 3. 2.10 Classification of strain gauge

[Source: Neubert H.K.P., Instrument Transducers – An Introduction to their Performance and Design, Page: 495]

1. Unbounded Strain Gauge

The unbounded strain gage consists of a wire stretched between two points in an insulating medium such as air. One end of the wire is fixed and the other end is attached to a movable element in Fig 3.2.10.

Two types:

1. Linear 2. Rotational

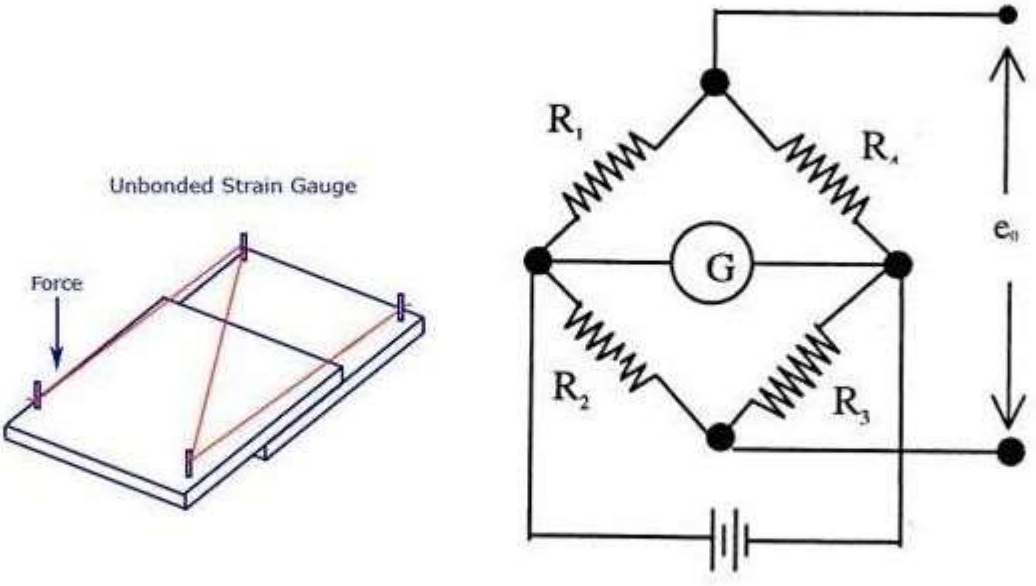


Fig 3. 2.11 Linear Unbounded Strain Gauge

[Source: Neubert H.K.P., Instrument Transducers – An Introduction to their Performance and Design, Page: 498]

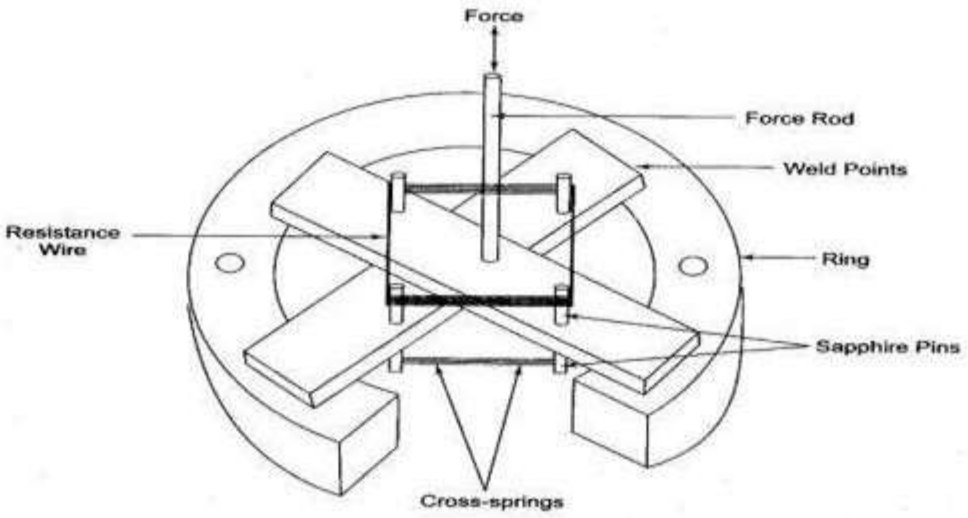


Fig 3.2.12 Rotational Strain gauge

[Source: Neubert H.K.P., Instrument Transducers – An Introduction to their Performance and Design, Page: 502]

- An unbounded metal strain gauge consists of a wire stretched between two points in an insulating medium such as air.
- It is made of various copper nickel chrome nickel or nickel iron alloys. They are about 0.025 mm diameter are fixed with ,some initial tension between two frames which can move relative to each other is shown in Fig 3.2.11.
- This initial tension or preload is necessary, to avoid buckling under , compression or negative displacement and this preloading should be greater than any expected compression or negative displacement in Fig 3.2.12.

2. Bonded Strain Gauges

In case of bonded-filament strain gages, the resistance wire is made into a form of a grid and cemented between two pieces of thin insulating sheet in Fig 3.2.13.

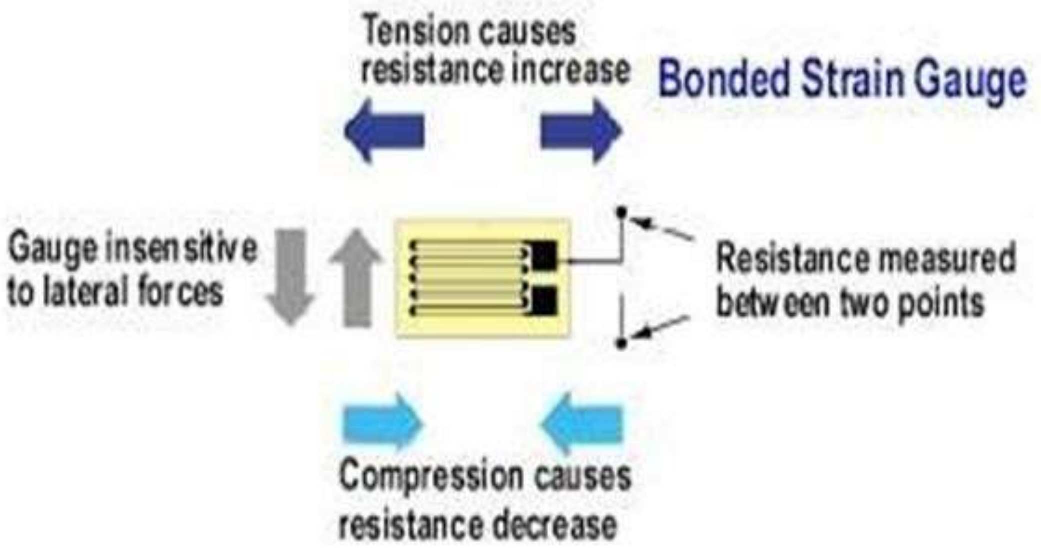


Fig 3.2.13 Bonded Strain Gauge

[Source: Neubert H.K.P., Instrument Transducers – An Introduction to their Performance and Design, Page: 505]

Factors to be Considered

1. Filament construction

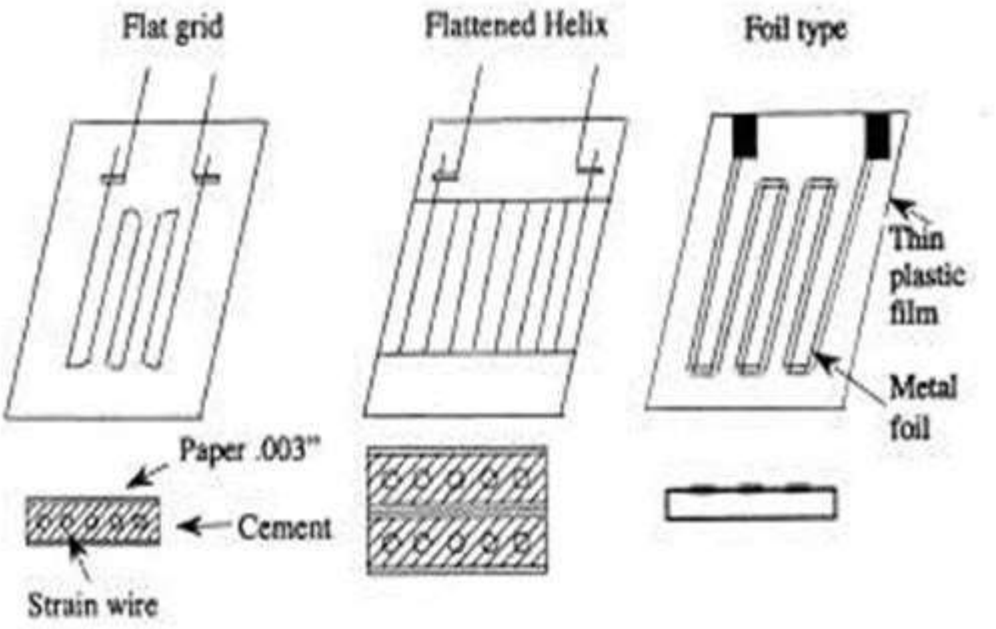


Fig 3.2.14 Filament construction details

[Source: Neubert H.K.P., Instrument Transducers – An Introduction to their Performance and Design, Page: 506]

The filament wire in the bonded type is made in the form of a flat grid or flattened helix or a thin foil etched to give a flat grid pattern as shown the Fig 3.2.14.

In flat grid type the gage lengths were around 2.5cmand wire size 0.025 mm. For shorter gage lengths upto 0.15cmhelical grid type is suitable.

2. Material of the filament wire

The material chosen should have high gage factor. Common materials are Advance, Isoelastic and Nichrome – V. The selection of the grid material is actually a compromise between the following factors :

1. High Gagefactor
2. High resistivity
3. Low temperaturesensitivity

4. High electricalstability
5. High yieldpoint
6. High endurancelimit
7. Good workability
8. Good solderability
9. Low hystersis
10. Low Thermalemf
11. Good corrosionreisistance

3. Base carrier material

- Good adherence to cements used
- High dielectric strength
- High mechanical strength
- Minimum thickness consistent with other factors
- Minimum temperature restrictions.
- Nitrocellulose impregnated paper –For roomtemperature
- Phenolic plastic impregnated cellulose or glass fibres – For higher temperature
- Phenolic- glass – For cryogenic application

4. Strain gagecements

- High mechanical strength
- High creepresistance
- High dielectricconstant
- Good adherence
- Minimum moisture attraction

- Minimum temperature restriction
- Ease of application
- The capacity to dryfast

5. Lead wire connections

- The vulnerable point for failure in the ordinary wire strain gauge is at the discontinuity formed by the junction between the grid and the lead.
- A soldered junction between the fine filament and heavier lead wire or ribbon may be alright forstatic or slowly varying loads.
- But for dynamic strain measurements, resistance welding is necessary to provide a
- fatigue free resistant joint.
- Lead wire materials should have low, stable resistivity, minimum temperature coefficient of resistance.
- This lead wires are to be insulated properly with materials of the same thermal classification as the gauge carrier and bonding cements.

Bonded Wire Strain Gauges

- A resistance wire strain gauge consists of a grid of fine resistance wire of about 0.025 mm in diameter or less.
- The grid is cemented to carrier (base) which may be a thin sheet of bakelite or a sheet of teflon.
- The wire is covered on top with a thin sheet of material so as to prevent it from any mechanical damage.
- The spreading of wire permits a uniform distribution of stress over the grid.
- The carrier is bonded with an adhesive material to the specimen under

study.

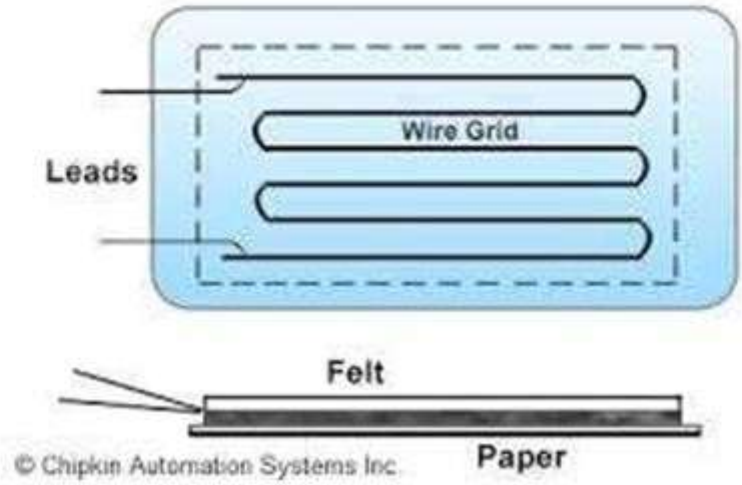
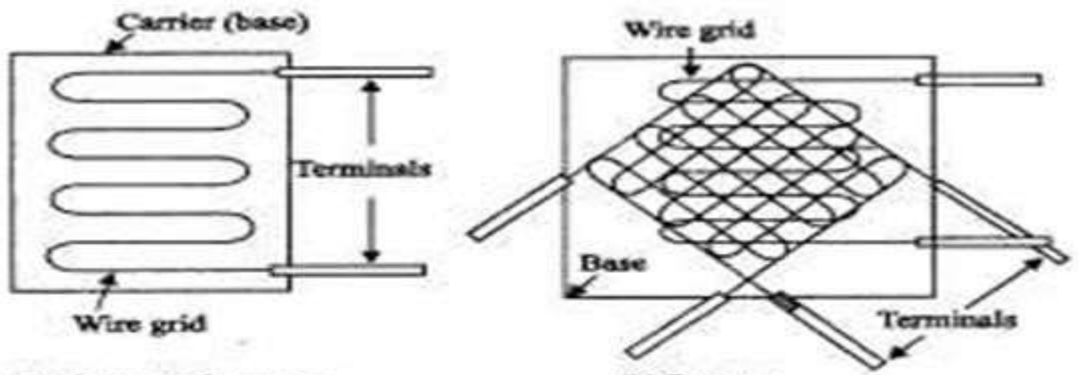


Fig 3. 2.15 Bonded wire Strain gauge

[Source: Neubert H.K.P., Instrument Transducers – An Introduction to their Performance and Design, Page: 510]

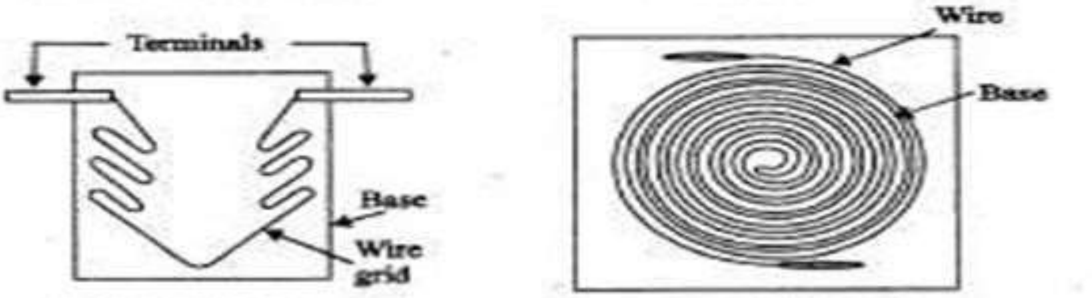
- This permits a good transfer of strain from carrier to grid of wires.
- The wires cannot buckle as they are embedded in a matrix of cement and hence faithfully follow both the tensile and compressive strains of the specimen.
- Since, the materials and the wire sizes used for bonded wire strain gauges are the same as used for unbonded wire strain gauges, the gauge factors and resistances for both are comparable.
- The nominal values of resistance for these gauges range from 40 ohms to 2000
- ohms, but 120, 350 and 1000 are common values.

The most commonly used forms of strain gauges are shown in the Fig.3.2.15.



(a) Linear strain guage

(b) Rosette



(c) Torque guage

(d) Helical gauge

Fig 3.2.16 commonly used forms of strain gauges

[Source: Neubert H.K.P., Instrument Transducers – An Introduction to their Performance and Design, Page: 510]

The nominal values of resistance for these gauges range from 40.,to 2000 ohms, but 120, 350~nd 1000 are common values is shown in Fig 3.2.16.

Adhesives: Ethylcellulose cement, nitrocellulose cement, bakelite cement and epoxy cement are some of the commonly used adhesive materials.

The temperature range upto which they can be used is usually below 175C.

Leads: The leads should be of such materials which have low and stable resistivity and also a low resistance temperature coefficient.

Nylon - 75°C

Vinyl 65°C to 75°C

Polyethylene 75°C to 95°C

Teflon 75°C to 260°C

Bonded Metal foil Strain Gauge

- It is an extension of the bonded metal wire strain gauges.
- The sensing elements of foil gauges are formed from sheets less than 0.005 mm thick by photo-etching processes, which allow greater flexibility with regard to shape.

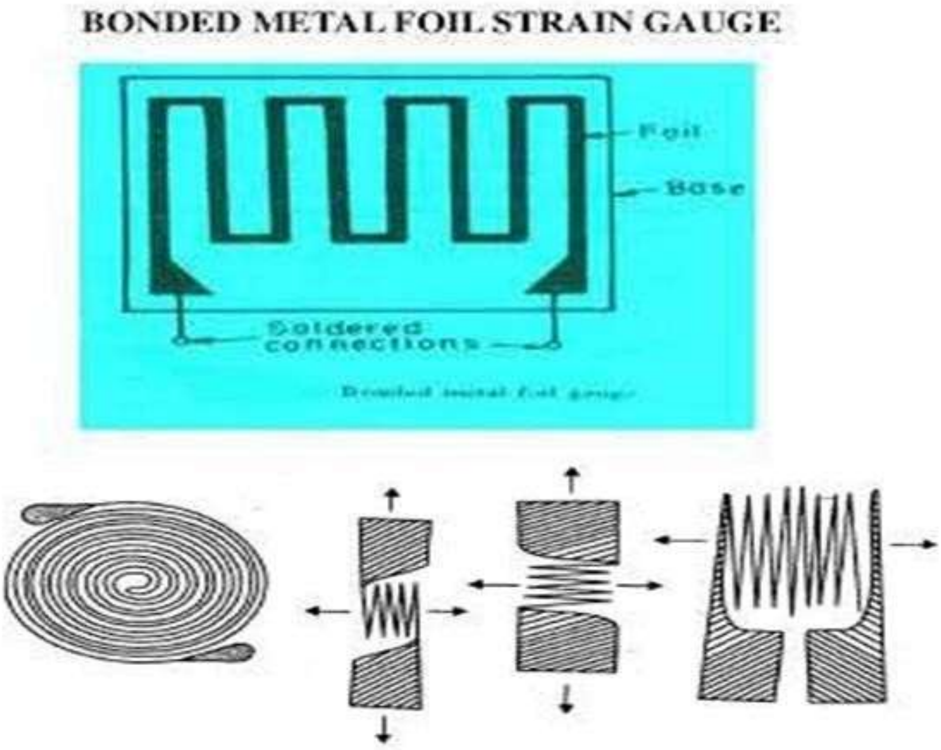


Fig 3.2.17 Bonded Metal foil Strain Gauge

[Source: Neubert H.K.P., Instrument Transducers – An Introduction to their Performance and Design, Page: 513]

For foil type strain gauges, the manufacturing process also easily provides convenient soldering tabs, which are integral to the sensing grid, on all four gauges as shown in Figure 3.2.17

- This local increase in area reduces the transverse sensitivity which is a spurious input since the gauge is designed to measure the strain component along the length of grid elements.

- Foil type of gauges are employed for both stress analysis as well as for construction of transducers.
- Foil type of gauges are mounted on a flexible insulating carrier film about 0.025
- mm thick which is made of polymide, glass phenolic etc.
- Typical gauge resistances are 120, 350 and 1000 ohms with the allowable gauge current of 5 to 40 mA which is determined by the heat dissipation capabilities of the gauge.
- The gauge factors typically range from 2 to 4
- Materials used are Nichrome, Constantan, Isoelastic , Nickel and Platinum.

Vacuum Deposit Strain Gauge

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

Two processes

1. Evaporation process
2. Sputtering process

Evaporation process

- The diaphragm is placed in a vacuum chamber with some Insulating material.
- Heat is applied until the insulating material vaporizes and then condenses, forming a thin dielectric film on the diaphragm.
- Suitably shaped templates are placed over the diaphragm, and the evaporation and condensation processes are repeated with the metallic-gauge material, forming the desired strain gauge pattern on top of the insulating substrate is shown in Fig 3.2.18.

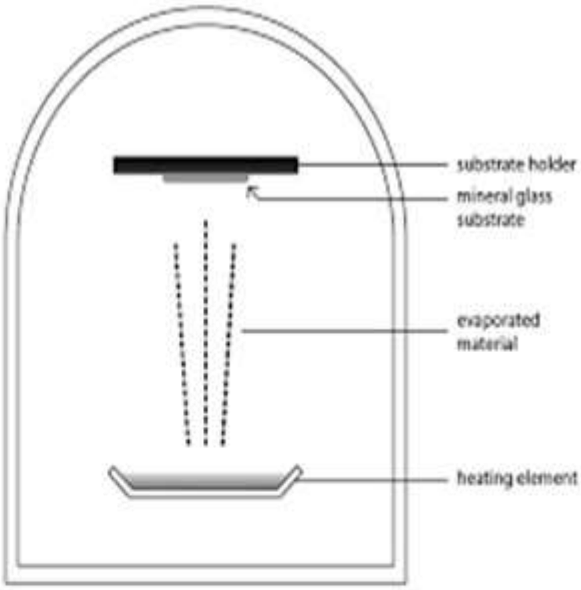


Fig 3.2.18 Evaporation process

[Source: Neubert H.K.P., Instrument Transducers – An Introduction to their Performance and Design, Page: 518]

Sputtering process

- Thin dielectric layer is deposited in vacuum over the entire diaphragm surface.

- The detailed mechanism of deposition is, however, entirely different from the evaporation method.
- The complete layer of metallic gauge is sputtered on the top of the dielectric material.
- The diaphragms are now removed from the vacuum chamber, and micro-imaging techniques using photo masking materials are used to form the gauge pattern I shown in Fig 3.2.19.
- The diaphragms are then returned to the vacuum chamber. Sputter etching techniques are used to remove all unmasked metal layer, leaving behind the desired gauge pattern

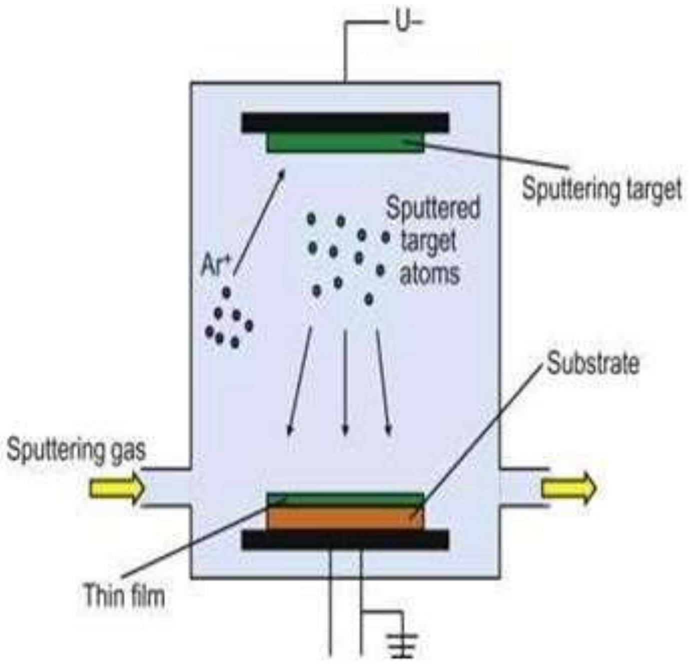


Fig 3.2.19 Sputtering process

[Source: Neubert H.K.P., Instrument Transducers – An Introduction to their Performance and Design, Page: 519]

Semiconductor Strain gauge

Semiconductor strain gauges are used where a very high gauge factor and a small envelope are required. The resistance of the semiconductors changes with change in applied strain. Unlike in the case of metallic gauges where the change in resistance is mainly due to change in dimensions when strained, the semiconductor strain gauge depend for their action upon piezo-resistive effect. Semi conducting materials such as silicon and germanium are used as resistive materials for semiconductor strain gauges is shown in Fig 3.2.20.

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

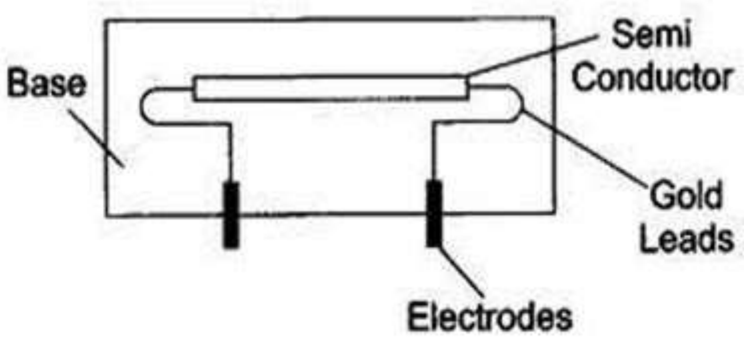


Fig 3.2.20 Semiconductor Strain Gauge

[Source: Neubert H.K.P., Instrument Transducers – An Introduction to their Performance and Design, Page: 521]

Advantages

1. High gauge factor.
2. Hysteresis characteristics are excellent.
3. High fatigue life.
4. Very small in sizeThis type of construction may allow lower

manufacturing costs in some designs, as a large number of diaphragms can be made on a single silicon wafer.

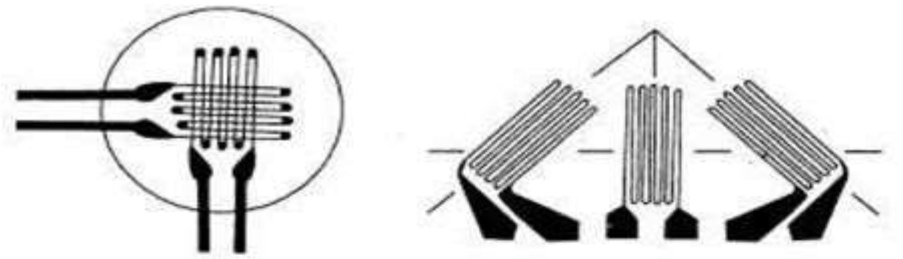
Disadvantages

1. Very sensitive to changes in temperature.
2. Linearity is poor.

Diffused strain gauges

- The Diffusion process used in IC manufacture is employed.
- In pressure transducer, for example, the diaphragm would be of silicon rather than metal and the strain gauge effect would be realized by depositing impurities in the diaphragm to form an intrinsic strain gauge.

1. Rosettes



FABX-50-12SX
2-Element Rosette
90° Stacked
(foil)

3-Element Rosette
45° Stacked
(foil)

2-Element Rosette
90° Planar
(foil)

2-Element Rosette
45° Planar
(foil)

Fig 3.2.21 Rosettes

[**Source: Neubert H.K.P., Instrument Transducers – An Introduction to their Performance and Design, Page: 523]**

- In addition to single element strain gauge, a combination of strain gauge called "Rosettes" are available in many combinations for specific stress analysis (or) transducer application.
- Rosettes are used to measure strain in more than one direction is shown in above Fig 3.2.21.

Strain gauge Circuitry

1. Ballast circuit

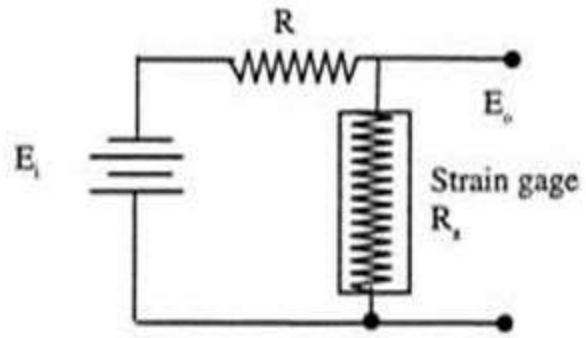


Fig. 4.19b
Ballast circuit

Fig 3.2.22 Ballast circuit

[**Source: Neubert H.K.P., Instrument Transducers – An Introduction to their Performance and Design, Page: 525]**

The value of R is large relative to R_g so that it acts as a ballast resistance to keep the current I constant regardless of gage resistance change. The normal value of R is to fourteen times the magnitude of Rg is shown in Fig 3.2.22.

2. Strain gauge Circuitry-Wheatstone Bridge

For the bridge to be balanced, points ‘b’ and ‘d’ must be at the same potential.

$I_1 R_1 = I_4 R_4$

$I_2 R_2 = I_3 R_3$

Dividing the above 2 equations

$$\frac{I_1 R_1}{I_2 R_2} = \frac{I_4 R_4}{I_3 R_3}$$

In case of no current in the detector

$I_1 = I_2$ and $I_3 = I_4$

$$\frac{R_1}{R_2} = \frac{R_4}{R_3}$$

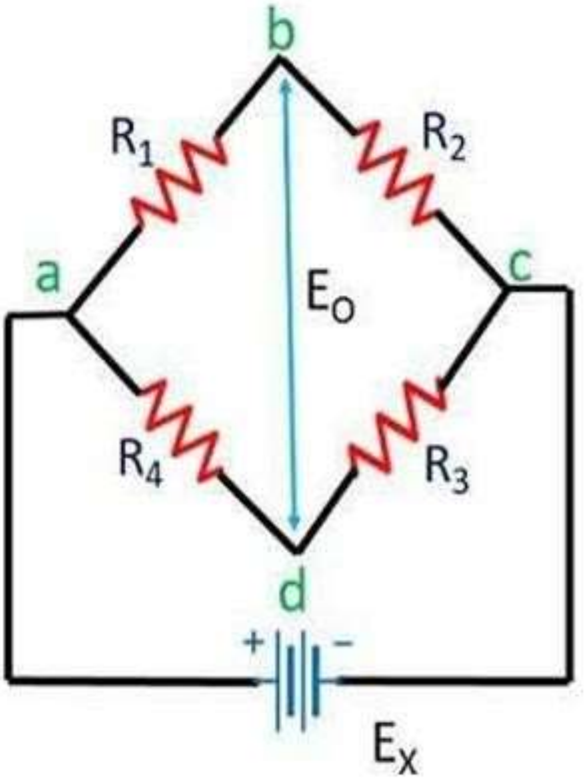


Fig 3.2.23 Wheatstone Bridge

[**Source: Neubert H.K.P., Instrument Transducers – An Introduction to their Performance and Design, Page: 527]**

This simply means that either **R_4** or **R_2** can be used to compensate the temperature. It is sometimes called **ambient temperature compensation**. Wheatstone bridge has **high sensitivity** is shown in above Fig 3.2.23.

3. Wheatstone Bridge with temperature compensation

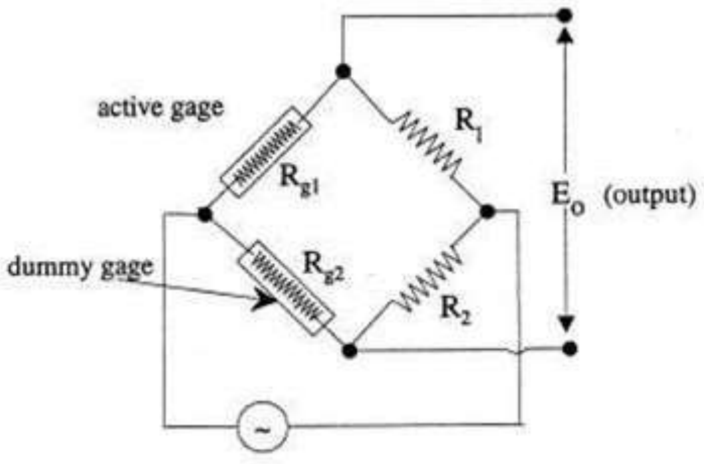


Fig 3.2.24 Wheatstone Bridge

[Source: Neubert H.K.P., Instrument Transducers – An Introduction to their Performance and Design, Page: 527]

A **dummy gauge** is a **strain gage used** in place of a fixed resistor. Temperature compensation is achieved when this **dummy gauge** is mounted on a piece of material similar to the specimen which undergoes the same temperature changes as does the specimen, but which is not exposed to the same **strain** is shown in above Fig 3.2.24.

Applications of Strain Gauge

The exceptional features enable these gauges to be used in the field of geotechnical engineering to monitor structures like dams, tunnels, etc. constantly and to avoid accidents well in advance. Some of the applications of strain gauges include –

- Rail monitoring
- Cable bridges
- Aerospace
- Nuclear power plants
- It is used to determine the stress produced by machinery.

- During component testing, strain gauges are used.
- In the field of **civil engineering**, strain gauges are used to keep rails in good condition.
- A torque on an engine is measured when a strain gauge is attached to a **dyno**.
- Strain gauges are used for measurement of strain and its associated stress in experimental stress analysis

3.5 HOT WIRE ANEMOMETER:

Hot wire anemometers are hot wire resistance transducer which are used for measurement of flow rates of fluids or air. In hot wire anemometers resistive wire is used as a basic sensor, which is heated initially by passing an electric current. This heated resistive wire mounted on a probe is exposed to air flow or wind, which is cooled because of fanning effect. The amount of cooling depends on the velocity of air flow. The resistance of the probe when it is hot is different from that when it is cooled. This difference in resistance, or this variation in resistance is converted into a voltage variation. Broadly hot wire anemometers are commonly used in two different modes.

1. Constant current type 2. Constant temperature type

Construction

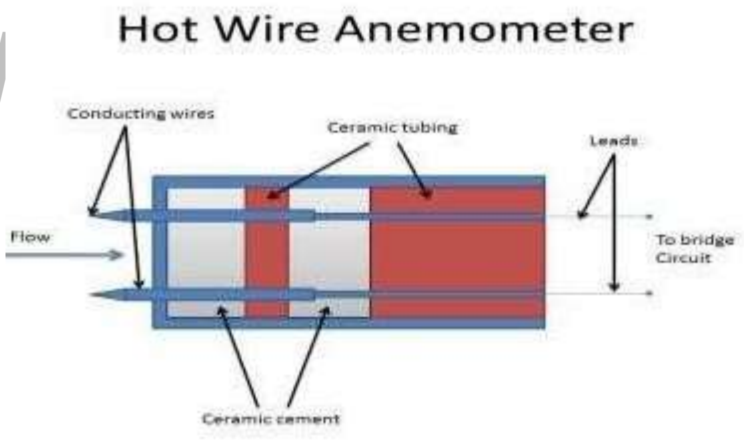


Fig 3.5.1 Wire anemometer

[Source: Neubert H.K.P., Instrument Transducers – An Introduction to their Performance and Design, Page: 602]

The main parts of the arrangement are as follows:

Conducting wires placed in a ceramic body.

Leads are taken from the conducting wires and they are connected to one of the limbs of the wheat stone bridge to enable the measurement of change in resistance of the wire is shown in Fig 3.5.1.

Principle of Operation

1. Constant current mode:

The fine resistance wire carrying a fixed current is exposed to the flow velocity. The flow of current through the wire generates heat on account of i^2R loss. This heat is dissipated from the surface of the wire by convection to the surroundings. (The loss of heat due to conduction and radiation is negligible). The wire attains equilibrium temperature when the heat, generated due to i^2R loss is equal to the heat dissipated due to convective loss. The circuit is so designed that i^2R heat is essentially constant and therefore the wire temperature must adjust itself to change the convective loss until equilibrium is reached.

2. Constant temperature mode:

The current required to maintain the resistance and hence temperature constant, become a measure of flow velocity.

Heat generated = I^2R_W

where I - current through the wire;

R_W – resistance of wire

Heat dissipated due to convection = $hA(\Theta_W - \Theta_f)$

where

h -coefficient of heat transfer; W/ m^2 -°C

A -heat transfer area; m^2

Θ_W- temperature of wire; °C,

Θ_f - temperature of flowing fluid, °C,

For equilibrium conditions, we can write the energy balance for the hot wire as

$$I^2R_W = hA(\Theta_W - \Theta_f)$$

Now from h is a function of flow velocity for a given fluid density. From King's Law, for a range of velocities, this function can be written as,

$$h = C_o + C_1\sqrt{V}$$

where C_O and C_1 are constants and V is the flow velocity of fluid in m/s.

The resistance of the wire depends upon the temperature and the temperature depends the rate of flow. Therefore, the resistance of wire becomes a measure of the flow rate.

1. Contant Temperature Anemometer

The bridge arrangement along with anemometer is shown in the Fig 3.5.2. The anemometer is kept in the flowing gas stream to measure

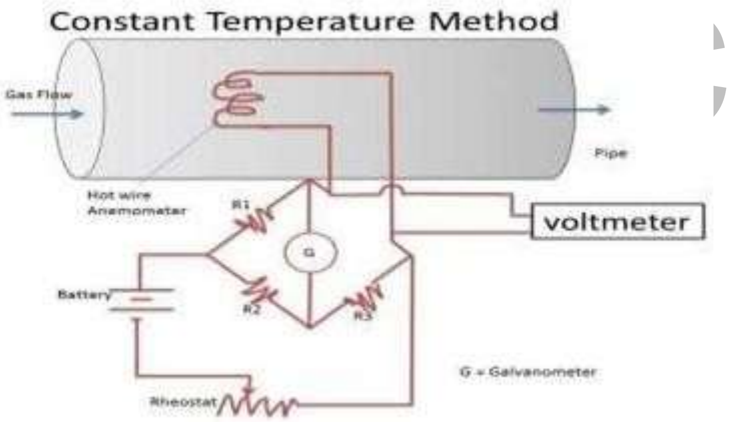


Fig 3.5.2 Constant temperature hotwire anemometer

[Source: Neubert H.K.P., Instrument Transducers – An Introduction to their Performance and Design, Page: 604]

A current is initially passed through the wire. Due to the gas flow, heat transfer takes place from the sensing wire to the flowing gas and this tends to change the temperature and hence the resistance of the wire. The principle in this method is to maintain the temperature and resistance of the sensing wire at a constant level.

Therefore, the current through the sensing wire is increased to bring the sensing wire to have its initial resistance and temperature. The electrical current required in bringing back the resistance and hence the temperature of the wire to its initial condition becomes a measure of flow rate of the gas when calibrated.

2. Constant Current Anemometer

The bridge arrangement along with anemometer is shown in the Fig 3.5.3. The anemometer is kept in the flowing gas stream to measure flow rate.

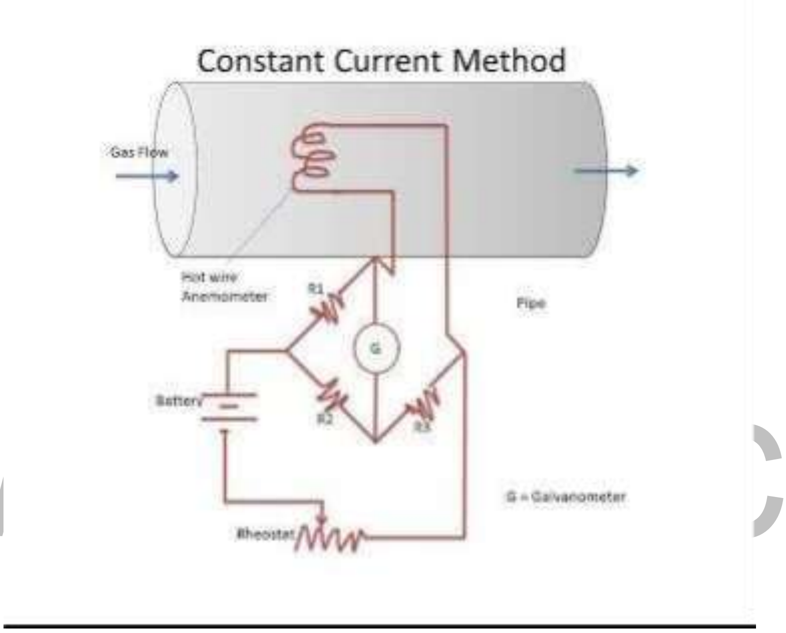


Fig 3.5.3 Constant current hotwire anemometer

[Source: Neubert H.K.P., Instrument Transducers – An Introduction to their Performance and Design, Page: 606]

The anemometer is kept in the flowing gas stream to measure flow rate. A constant current is passed through the sensing wire. That is, the voltage across the bridge circuit is kept constant, that is, not varied. Due to the gas flow, heat transfer takes place from the sensing wire to the flowing gas and hence the temperature of the sensing wire reduces.

Piezoresistive sensors

Piezoresistive sensors (also known as strain-gage sensors) are the most common type of pressure sensor in use today. Piezoresistive effect refers to a change in the electric resistance of a material when stress is applied. Piezoresistive materials can be used to realize strain gages that, when incorporated into diaphragms, are well suited for sensing the induced strains as the diaphragm is deflected by an applied pressure. The sensitivity of a strain gage is expressed by its gage factor, which is defined as the fractional change in resistance, ΔR/R, per unit strain:

Gauge factor $F = \frac{\Delta R / R}{\epsilon}$

where strain ε is defined as ΔL/L, or the extension per unit length

Construction

Strain gauge elements can be made of metal or a semiconducting material. The resistance change in metal strain gauges is mainly due to the change in geometry (length and cross-section area) of the material. In Fig 3.5.4, In some metals, for example platinum alloys, the piezoresistive effect can increase the sensitivity by a factor of two or more. In semiconducting materials, the piezoresistive effect dominates, typically being orders of magnitude larger than the contribution from geometry.

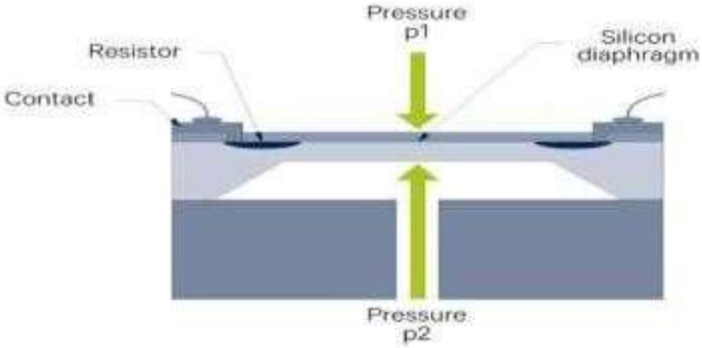


Fig 3.5.4 Piezo resistive sensor

[Source: Neubert H.K.P., Instrument Transducers – An Introduction to their Performance and Design, Page: 608]

Metal sensing elements

One or more strain gauge sensors made from a length of wire can be attached to the surface of a diaphragm. Pressure on the diaphragm will stretch the wires and change the resistance. The sensor elements can be bonded on to the surface with adhesive or the conductor can be directly deposited on the diaphragm by sputtering. The latter method removes potential problems with adhesives failing at high temperatures and also makes it easier to construct small devices. A metal wire sensor can also be made by wrapping a wire between posts that are displaced by changing pressure. This construction can also work at higher temperatures because no adhesive is needed to attach the wire to the posts. Semiconductor sensing elements

Semiconducting materials, most commonly silicon, can also be used to make strain gauge pressure sensors. The characteristics of the sensing element, particularly the size of the piezoresistive effect, can be adjusted by doping; in other words by adding carefully controlled amounts of impurities (dopants) to the semiconductor.

More lightly doped silicon results in a higher resistivity and a higher gauge factor. However, this also increases the thermal sensitivity of both the resistance and gauge factor.

Working

The change in resistance in the sensor is usually measured using a Wheatstone bridge circuit as shown below. This allows small changes in the resistance of the sensor to be converted to an output voltage.

Piezoresistive strain gauge measurements are made using a Wheatstone bridge circuit

An excitation voltage needs to be provided to the bridge. When there is no strain and all the resistors in the bridge are balanced then the output will be zero volts. A change in pressure will cause a change in resistances in the bridge resulting in a corresponding output voltage or current. Performance can be improved by using two or four sensing elements in the bridge, with the elements in each pair being subject to equal and opposite strain. This increases the output signal and can minimize the effects of temperature on the sensor elements is shown in Fig 3.5.5.

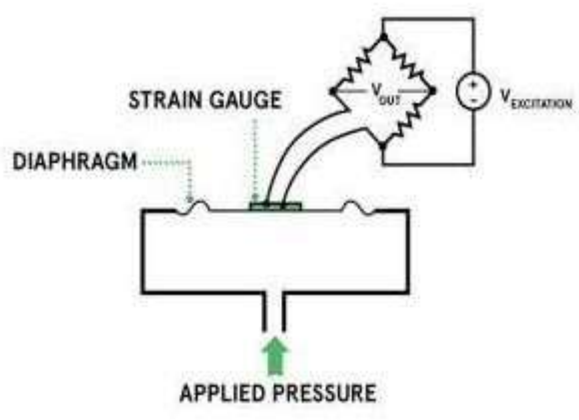


Fig. 3.5.5. Working of Piezoresistive Sensor

[Source: Neubert H.K.P., Instrument Transducers – An Introduction to their Performance and Design, Page: 610]

$$V_o = \left[\frac{R_3}{R_3 + R_4} + \frac{R_2}{R_1 + R_2}\right] V_{ex}$$

Humidity Sensor

Humidity is the measure of water vapour present in a gas. It is usually measured as absolute humidity, relative humidity or dew point temperature. **Absolute humidity** or **Specific humidity** is the mass of water vapour present per unit volume.

$$\emptyset = \frac{m_v}{m_a}$$

Relative Humidity is the ratio of water vapour pressure actually present to water vapour pressure required for saturation at a given temperature. The ratio is expressed in percent. Relative humidity (RH) is always dependent upon temperature**.**

$$\emptyset = \frac{m_v}{m_a} = \frac{p_v}{P_g}$$

p_v = Actual partial pressure

p_g = Saturation pressure of vapour

Construction

A typical resistive hygrometer is shown in Fig 3.5.6.

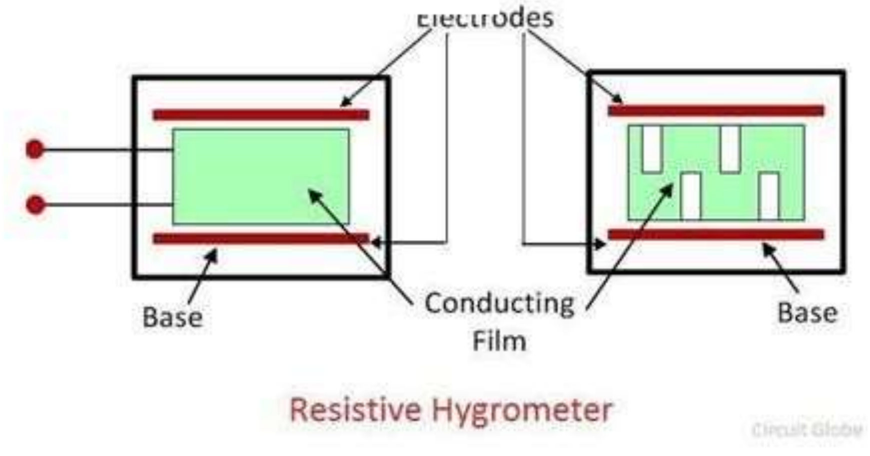


Fig 3.5.6 Hygrometer

[Source: Neubert H.K.P., Instrument Transducers – An Introduction to their Performance and Design, Page: 602]

It shows a mixture of lithium chloride and carbon which acts as conducting film. This is put on an insulating substrate between metal electrodes. A mixture of lithium chloride and carbon exhibits a change in resistivity with humidity. This material with a binder may be coated on wire or an electrodes. Resulting resistance changes over a wide range, e.g. 104 to 109 Ω as the humidity changes from 100 to 0 percent. This makes it impractical to design a single element to operate from 1 to 100 percent relative humidity. Instead several elements are used, each in a narrow range, with provision for switching elements. Resistance is measured either with a Wheatstone bridge or by a combination of current and voltage measurements. Most of these must not be exposed to conditions of 100 percent humidity as the resulting condensation may damage the device. Either they must be operated in a constant temperature environment or temperature corrections must be made. These are accurate to within ± 2.5 percent or ± 1.5 percent in some cases. Response times are typically of the order of few seconds. These are currently the most common electronic hygrometers.

Working Principle

The resistance of the element changes when it is exposed to variations in humidity. The higher the relative humidity, the more moisture the lithium chloride will absorb, and the lower will be its resistance. The resistance of the sensing unit is a measure of the relative humidity, Resistance should be measured by applying a.c to the Wheatstone bridge. D.C voltage is not applied because it tends to breakdown the lithium chloride to its lithium and chloride atoms. The current flow is a measure of the resistance and hence of the relative humidity. Thus hygrometer is called Dunmore type of hygrometer. The resistance/relative humidity relationship is quite non-linear, and generally a single transducer can cover only a small range of the order of 10 percent humidity. Where large ranges, as great as 5 to 99 percent relative humidity, are needed, seven or eight transducers, each designed for a specific part of the total range, are combined in a single package. These transducers are widely used for continuous recording and/or control or relative humidity. Another electrical type of transducer, .the sulfonated polystyrene ion-exchange device called the pope cell exhibits a non-linear change of resistance from a few if Ω at 0 percent to about 1000 Ω at 100 percent relative humidity and a single transducer can cover the entire range. Accuracy is comparable to that of the Dunmore transducer.

3.1 INTRODUCTION:

This unit consists basically transducers with a 'track' having a fixed resistance and a variable contact which can be moved along and make continuous contact with the track. If the track resistance is proportional to the length along the track (i.e. linear track), the output voltage will be proportional to the movement of the variable contact and the unit is suitable for use as a position transducer. Resistive transducers have many and varied applications in the transduction of measurand such as displacements, mechanical strain, pressure, force and load, temperature, and fluid velocity into electrical outputs. The transduction mechanisms are based on the change in resistance brought about by the measurand.

Resistive Transducers:

- Resistive transducers are those transducers in which the resistance change due to the change in some physical phenomenon.
- A resistive sensor is a transducer or electromechanical device that converts a mechanical change such as displacement into an electrical signal that can be monitored after conditioning.
- They are passive devices.
- This transducer works on both as primary & secondary.
- The primary transducer converts the physical quantities to a mechanical signal whereas the secondary transducer converts to an electrical signal directly.
- These transducers are most frequently used for calculating different physical quantities like pressure, vibration, temperature, force, acceleration, humidity, sound level, light intensity and displacement.

Basic Principle of Variable Resistive Transducer

The variable resistance type is of the important group of transducers which are simple and versatile. Most of the system variables like Displacement, Acceleration, vibration, force, pressure, temperature, humidity, sound level, light intensity etc can be analyzed using this category of transducers.

The resistance of a metal conductor is expressed by a simple equation

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

Where,

R = resistance of conductor in Ω

L = length of conductor in m

A = cross sectional area of conductor

in m^2 ρ = resistivity of conductor

material in Ω-m.

Any stimulus or measurand or variable which changes any one of the quantities like l, a or ρ, when the resistance of the wire changes. This change in the resistance is converted to change in the voltage the electric circuitry. Thus a transducer is formed.

Table 3.1.1 Examples of Resistive Transducers

DEVICE	ACTION	APPLICATION
Sliding contact devices	There is a long conductor whose effective length is variable	Potentiometer
Strain gauge	Resistance falls with increased	Sensor in electronic balance

	force	
Thermistor	Resistance fall with increase in temperature	Electronic thermometer
Light Dependent Resistors	Resistance falls with increase light intensity	Light operated switches
Moisture detector	Resistance falls when wet	Damp meter
Flow rate measurement	Change in resistance when a hot wire is cooled	Anemometer

Potentiometer

- Firstly a potentiometer is a resistive wire wound on a former provided with a sliding contact. A resistive potentiometer, or simply a pot consists of a resistance element provided with a sliding contact. This sliding contact is called a **wiper**.
- The motion of sliding contact may be **translatory** or **rotational**.
- Some pots use the combination of the two motions. These potentiometers have their resistive element in the form of helix and thus, are called **helipots**.
- The translational resistive elements are straight devices and have a stroke of about 2 mm to 0.5 m.
- The rotational resistive devices are circular in shape and are used for measurement of angular displacement. They may have a full scale angular

displacement as small as 10° up to 357°

- Multiturn potentiometers may measure up to 3500° of rotation through use of helipots is shown in Fig 3.1.1.

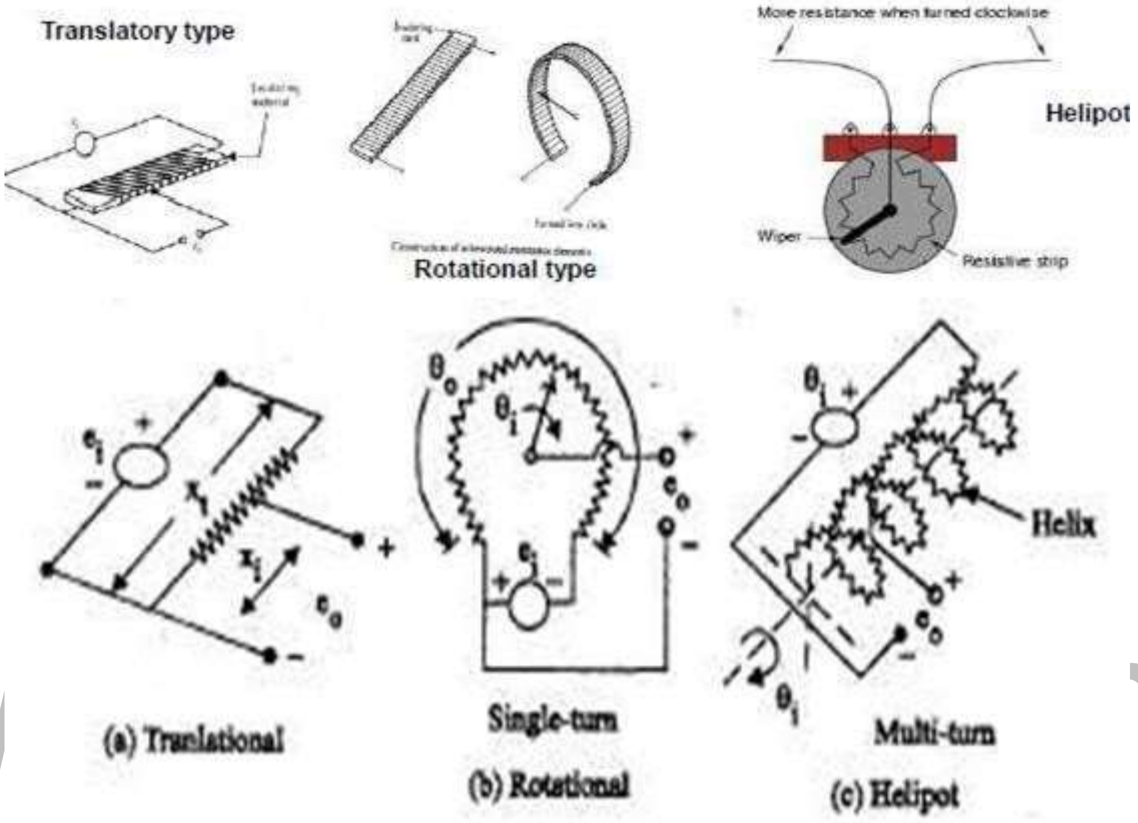


Fig 3.1.1 Potentiometer – Schematic

[Source: Neubert H.K.P., Instrument Transducers – An Introduction to their Performance and Design, Page: 410]

Translatory or Linear Potentiometer

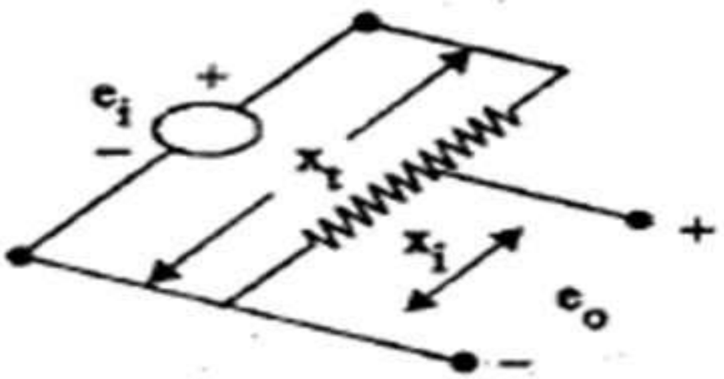


Fig. 3.1.2 Linear Potentiometer

[Source: Neubert H.K.P., Instrument Transducers – An Introduction to their Performance and Design, Page: 415]

Let,

e_i **and** e_o = input and output voltages respectively

X_t = total length of translational pot or stroke length

X_i = displacement of wiper from its zero position

R_p = total resistance of the potentiometer

If the distribution of the resistance with respect to translational movement is linear, the resistance per unit length is $\frac{R_p}{X_t}$

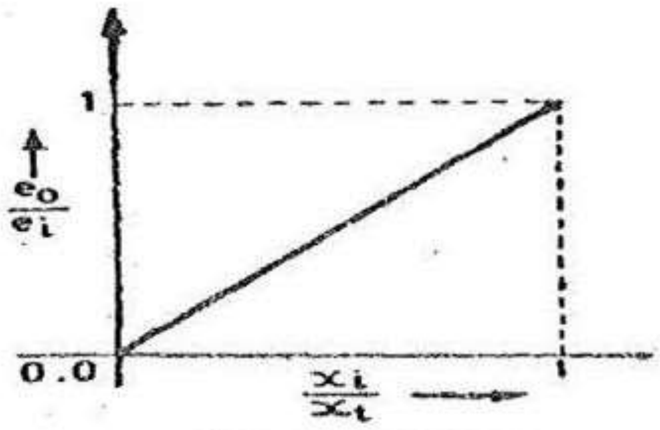
The output voltage under ideal conditions

$$e_o = \frac{Resistance\ at\ the\ output\ terminals}{Resistance\ at\ the\ input\ terminals} \ X\ Input\ voltage$$

$$e_o = \left(\frac{R_p\left(\frac{X_i}{X_t}\right)}{R_p}\right) e_i = \left(\frac{X_i}{X_t}\right) e_i$$

In Fig 3.1.2, Consider the ideal circumstances; the output voltage varies linearly with displacement

Sensitivity S = $\frac{output}{input} = \frac{e_o}{e_i} = \frac{X_i}{X_t}$



(a) Unloaded pot

Fig. 3.1.3 Characteristics of a unloaded pot

[Source: Neubert H.K.P., Instrument Transducers – An Introduction to their Performance and Design, Page: 420]

In Fig 3.1.3, Thus under ideal conditions the sensitivity is constant and the output is faithfully reproduced and has a linear relationship with input.

Rotational Potentiometer

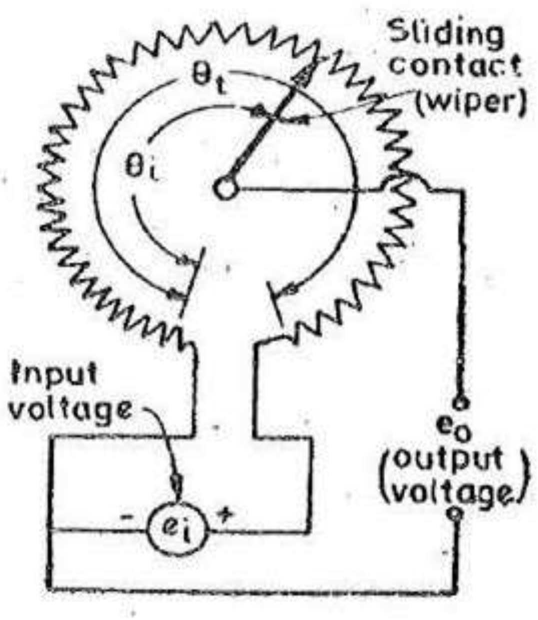


Fig. 3.1.4 Rotational Potentiometer

[Source: Neubert H.K.P., Instrument Transducers – An Introduction to their Performance and Design, Page: 426]

In Fig 3.1.4, Let,

θ_i = Input angular displacement in degrees

θ_t = total travel of the wiper in degrees

θ_t can be 350^0 or 360^0

Output voltage $e_o = \frac{\theta_i}{\theta_t} e_i$

$S = \frac{e_o}{\theta_i} = \frac{e_i}{\theta_t}$

Characteristics of Potentiometer

1. Loading effect in potentiometer

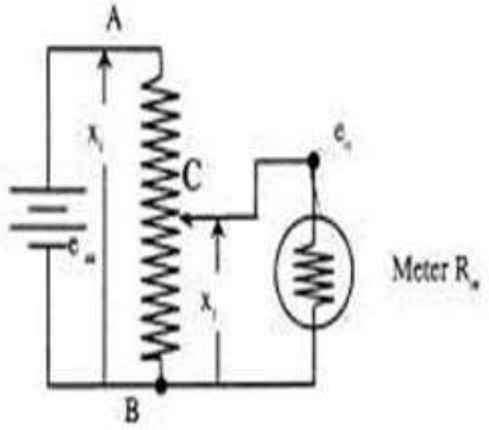


Fig 3.1.5 loading effect

[Source: Neubert H.K.P., Instrument Transducers – An Introduction to their Performance and Design, Page: 431]

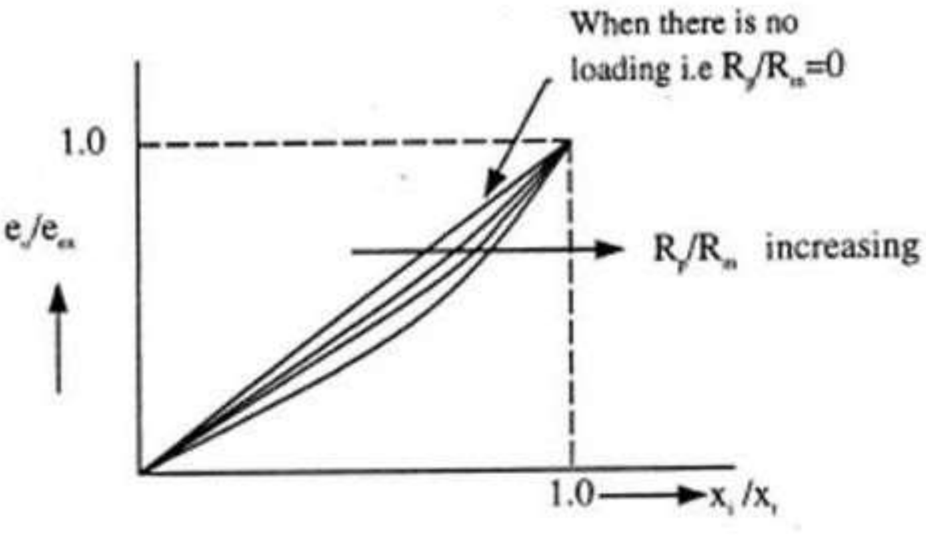


Fig. 3.1.6 Loading Effect Characteristics

[Source: Neubert H.K.P., Instrument Transducers – An Introduction to their Performance and Design, Page: 434]

The output of a potentiometric transducer is normally connected to an amplifier or a recorder or a meter which has definite input impedance and hence a current will be drawn by this meter or amplifier or recorder is shown in Fig 3.1.5.

In Fig 3.1.6, When a meter of input resistance Rm is connected across the potentiometer then the total resistance across points C and B is given by

$$R_o = \frac{R_m R_p \left(\frac{X_i}{X_t}\right)}{R_m + R_p \left(\frac{X_i}{X_t}\right)}$$

$\alpha = \frac{Xi}{X_t}$

$$R_o = \frac{R_m R_p \ \alpha}{R_m + R_p \ \alpha}$$

Then the output voltage across C and B

$$e_o = \frac{e_{ex} R_o}{R_p \ (1 - \alpha) + R_o}$$

Where $R_p \ (1 - \alpha)$ is the resistance between A and C

$$\frac{e_o}{e_{ex}} = \frac{\alpha}{1 + \frac{R_p \ \alpha}{R_m} (1 - \alpha)}$$

Now if $\frac{R_p}{R_m}$ becomes very small, near to zero, the second term in the denominator can be omitted when compared to the first term, then

$$\frac{e_o}{e_{ex}} = \alpha = \frac{X_i}{X_t}$$

This is the condition when there is no loading. In reality R_M is not very large.

Hence e_0 becomes a nonlinear function of displacement xi.

Let us examine the situation when $\frac{R_p}{R_m}$ = 1.0

$$\frac{e_o}{e_{ex}} = \frac{\alpha}{1 + \alpha \ (1 - \alpha)}$$

$$e_o = \frac{\alpha}{1 - \alpha - \alpha^2} e_{ex}$$

Error = (Output voltage under no load - Output voltage under load)/Input voltage

$$\varepsilon = \left(\frac{\alpha e_{ex} - \frac{\alpha e_{ex}}{1 - \alpha - \alpha^2}}{e_{ex}} \right) \text{ x } 100$$

$$= \frac{100\alpha^2(1-\alpha)}{1-\alpha-\alpha^2}$$

When $R_P/R_M = 1$, the Maximum percentage error is

12.14% When $R_P/R_M = 0.1$, the Maximum

percentage error is 1.51%

For values of $R_P/R_M < 0.1$, the maximum error is 15 R_P/R_M percent of Full

scale reading $\alpha = 0$ corresponds to minimum error point

$\alpha = 2/3$ corresponds to maximum error point

2. Linearity, Sensitivity and Power Rating

The error due to loading depends on the ratio of the potentiometer resistance to meter resistance. For a given potentiometer, higher the meter resistance better will be linearity. On the other hand given a meter with a resistance Rm, lower the potentiometer resistance better will be linearity.

But the potentiometer resistance cannot be lowered much for it will reduce the sensitivity of measurement. There can be error in linearity due to loading effect. But there are other factors which give rise to nonlinearity. One of them is the non uniformity in the wire area. Other one is the non uniform winding. Unless specified the potentiometers supplied are nonlinear in nature. Errors in linearity can be corrected by adding fixed resistance in series and or parallel at proper locations on the winding.

Sensitivity is defined as the change in the output for a change in input. Here in the

potentiometer $e_0 = (e_{ex}/x_t)x_i$ $S = e_0/x_i = e_{ex}/x_t$

One may think that sensitivity can be increased by just increasing the excitation voltage. But this is not possible since potentiometers have definite power ratings.

This power ratings depend on the size, material used and the configuration and not on the actual resistance value. Power ratings is actually the heat that can be dissipated away by the potentiometer.

So the power that can be supplied to the potentiometer is fixed depending on the heat dissipation capacity

Power rating will fix the maximum excitation voltage for a given Rp. Let P be the power rating of a potentiometer in watts and Rp be the total resistance of the potentiometer.

$$\text{Max } e_{ex} = \sqrt{PR_P}$$

Therefore for a given meter of resistance Rm, if low Rp is chosen to have a better linearity then the maximum excitation is also low and hence a lower sensitivity.

There can be error in linearity due to loading effect. But there are other factors which give rise to nonlinearity. One of them is the non uniformity in the wire area. Other one is the non uniform winding. Unless specified the potentiometers supplied are nonlinear in nature. Errors in linearity can be corrected by adding fixed resistance in series and or parallel at proper locations on the winding.

3. Resolution:

The resolution of a potentiometer is the smallest change in displacement that can be measured or identified.

- If the excitation is fixed then it is the smallest change in resistance that can be obtained by slidermovement.
- This factor strongly depends on the construction of the resistanceelement.
- To get a high resolution, a single slide-wire can be used as the resistance element of the potentiometer. This will give a continuous step less resistance variation and hence very fine resolution.
- Here the accuracy is limited by other components of the system.

- This type of potentiometers are available but limited to small resistance values because the length of the wire depends on the desired stroke in a translational device and on the space restrictions in rotational devices.
- Resistance of a given length of wire can be increased by decreasing the diameter of the wire. But lesser the diameter less will be the strength and will get worn out quickly.

Resolution Improvement

- To get fairly high resistance values in small space the **wire wound resistance** element is made. The depending on the resistance wire size.

- If a translational device has 100 turns of resistance wire on a card of 1 cm. long, displacement motion changes smaller than 0.01 cm. cannot be detected.

- The practical limit for wire spacing at present times is between 75 to 150 turns per cm.

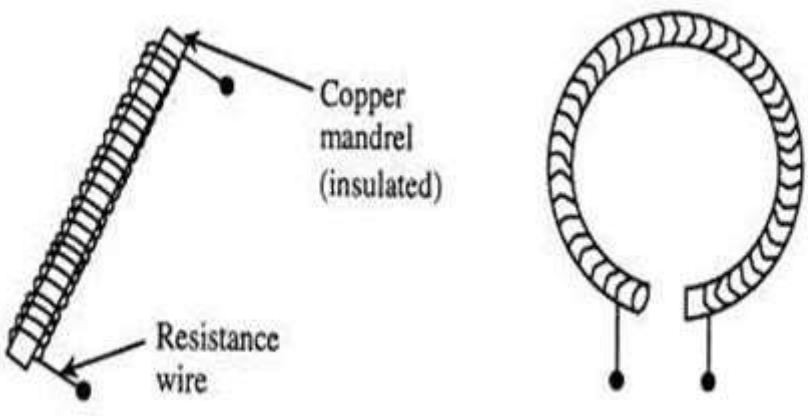


Fig 3.1.7 Wire wound Resistance

[Source: Neubert H.K.P., Instrument Transducers – An Introduction to their Performance and Design, Page: 439]

- Resistance wire is wound on a mandrel or on a card which is then formed into a circle or helix, as shown in Fig 3.1.7.
- Resolution is limited
- So far translational devices, the resolution is limited to 0.001 to 0.002 cm.
- For single turn rotational device with 150 turns per cm., best angular resolution is shown in Fig 3.1.8.

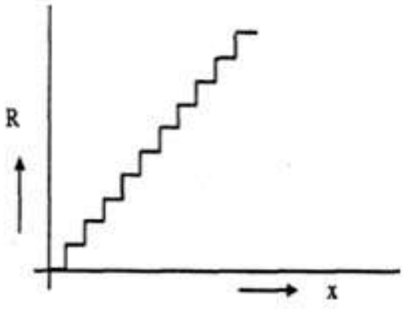


Fig 3.1.8 Resolution

[Source: Neubert H.K.P., Instrument Transducers – An Introduction to their Performance and Design, Page: 445]

- Another way to improve the resolution is to use multi-turn potentiometers.
- Here the resistance element is in the form a of a helix and the wiper travels along a lead screw. It is called as **helipot**. But still the number of wire per cm. is limited.
- The increase in resolution can be obtained with the help of gears. The gears make the potentiometer shaft to go through a number of rotations when the shaft of the measurand goes through one rotation.
- For instant one rotation of the measured shaft can cause the potentiometer shaft to rotate 10 times. In fact multi turn potentiometers are available up to about 60 rotations.
- In a similar way motion amplifying mechanisms can be used for translational devices.

3.3 RESISTANCE THERMOMETER:

It is well known that resistance of metallic conductors increases with temperature, while that of semiconductors generally decreases with temperature. Resistance thermometers employing metallic conductors for temperature measurement are called Resistance Temperature Detector (RTD), and those employing semiconductors are termed as Thermistors. RTDs are more rugged and have more or less linear characteristics over a wide temperature range. On the other hand Thermistors have high temperature sensitivity, but nonlinear characteristics.

Resistance thermometer is a device that is used to determine temperature by the variation in the resistance of a conductor.

It is commonly known as **Resistance Temperature Detector (RTD)**

It is an accurate temperature sensor.

If we want to measure temperature with high accuracy, an **RTD** is the ideal solution, as it has good linear characteristics over a wide range of temperatures.

Resistance Temperature Detector

$R_T = R_0(1 + a_1T + a_2T^2 + \ldots + a_nT^n)$

Resistance thermometers are conductive elements like nickel and copper or tungsten and nickel/iron alloys. The variation of resistance R with temperature T for most metallic materials can be, represented by an equation of the form

where Ro is the resistance at $T = 0^0C$.

The changes in resistance for different metals are given in the form of graph in Fig 3.3.1

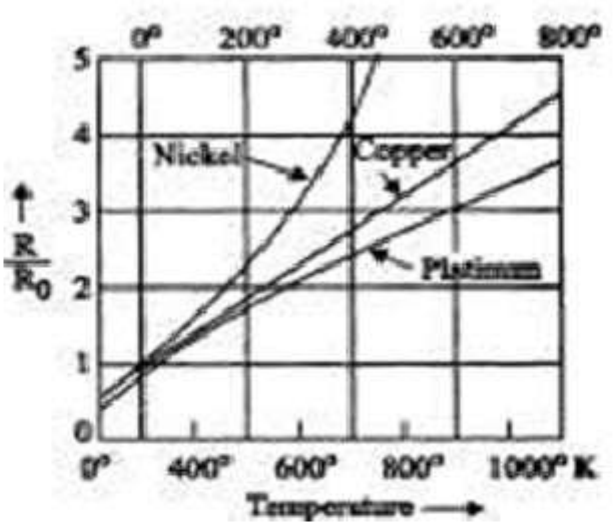


Fig. 3.3.1 Characteristics of materials used for resistance thermometers

[Source: Neubert H.K.P., Instrument Transducers – An Introduction to their Performance and Design, Page: 529]

Working Principle

In Resistance thermometer, the resistance of the conductor depends on the variation in temperature. When the temperature of the metal is increased, there is an increase in the vibration amplitude of the atomic nuclei of the material. This resultantly increases the probability of collision of free electrons with that of the bounded ions. Thus, the interruption in the motion of the electron causes resistance to increase.

Resistance temperature detector is typically made up of **nickel**, **platinum**, **copper** or **tungsten**. However, platinum is used as a primary element in such accurate temperature sensors due to its chemically inert nature. So, that it can be used in the hostile environment to reduce the chances of oxidation.

In a metal, the change in resistance with respect to temperature is given by the following relationship:

$$R_t = R_o (1 + \alpha(t-t_o) + \beta(t-t_o)^2 + \Upsilon(t-t_o)^3 \text{———})$$

R_o = resistance at t^0 C

R_t = resistance at t_o^0 C

α, β, ϒ etc are constants depends on the metals.

This expression is for huge range of temperature. For small range of temperature, the expression can be,

$R_t = R_o [(1 + \alpha(t-t_o)]$

$R_t = R_o [(1 + \alpha\Delta\ t]$

where **α** is the temperature coefficient at t_o and, $\mathbf{R_o}$ is the resistance at t_o

Resistance-Temperature Characteristics

Platinum has the temperature range of 650^{O}C

Copper and Nickel have 120^{O}C and 300^{O}C respectively.

For Platinum, its resistance changes by approximately 0.4 ohms per degree Celsius of temperature is shown in Fig 3.3.2.

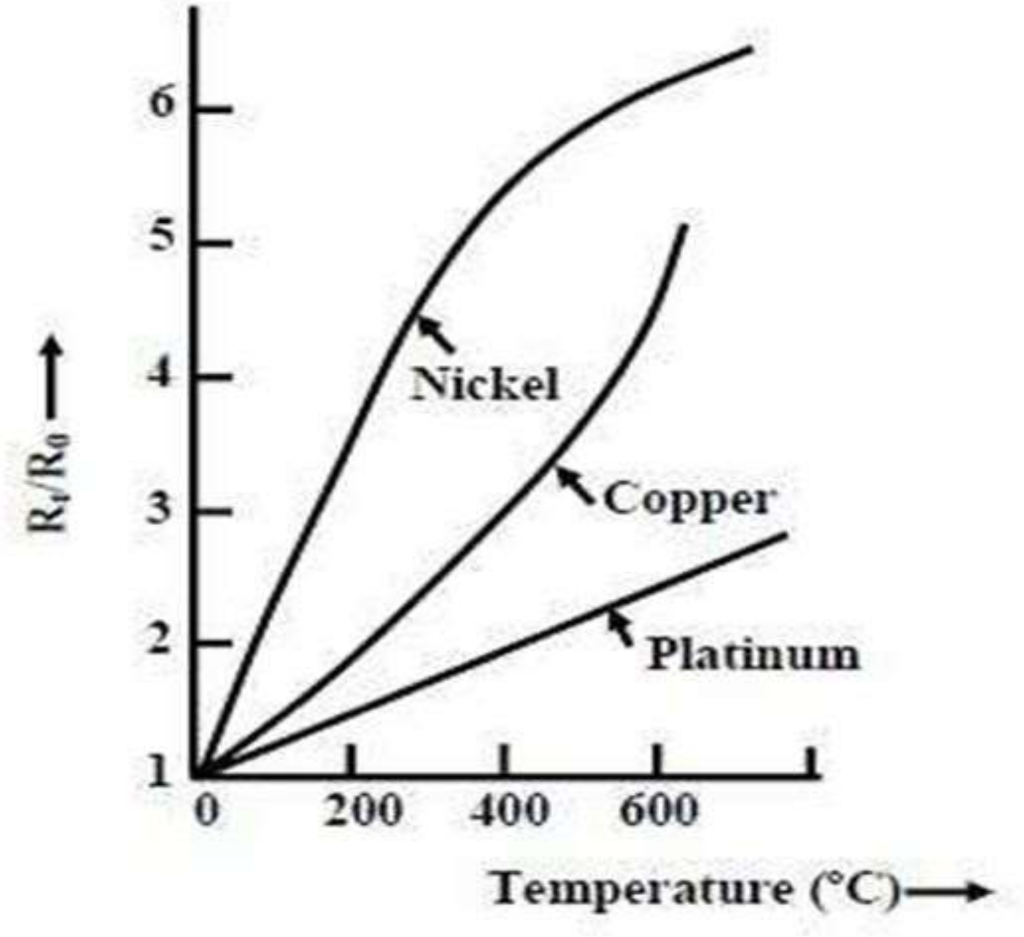


Fig 3.3.2 Resistance-Temperature Characteristics

[Source: Neubert H.K.P., Instrument Transducers – An Introduction to their Performance and Design, Page: 531]

Construction

- It consists of a mica crossed frame, inside which a platinum in coil form is present.
- The whole arrangement is placed in an evacuated tube of a stainless steel.
- The material used must be pure enough to provide proper results.
- The purity of platinum can be checked by the measurement of $\mathbf{R_{100} / R_o}$.
- As for pure platinum material, the value of the ratio should be higher than **1.390**

For industrial use, bare metal wires cannot be used for temperature measurement. They must be protected from mechanical hazards such as material decomposition, tearing and other physical damages. The salient features of construction of an industrial RTD are as follows:

- The resistance wire is often put in a stainless steel well for protection against mechanical hazards. This is also useful from the point of view of maintenance, since a defective sensor can be replaced by a good one while the plant is in operation.
- Heat conducting but electrical insulating materials like mica is placed in between the well and the resistance material.
- The resistance wire should be carefully wound over mica sheet so that no strain is developed due to length expansion of the wire. Fig. 3.3.3 shows the cut away view of an industrial RTD.

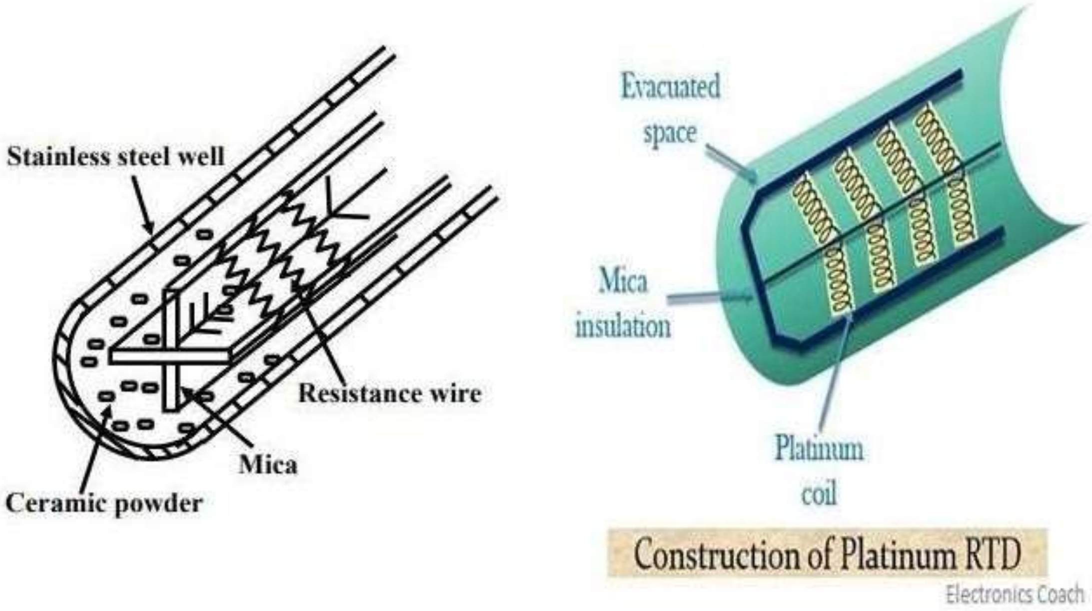


Fig 3.3.3 Industrial RTD

[Source: Neubert H.K.P., Instrument Transducers – An Introduction to their Performance and Design, Page: 533]

Resistance Thermometer Circuit:

The variation in resistance is measured and converted into a voltage signal with the help of a bridge circuit - Bridge circuits employ either deflection mode of operation or the null mode. (manually or automatically balance). Fig 3.3.4 is a bridge for null method of measurement.

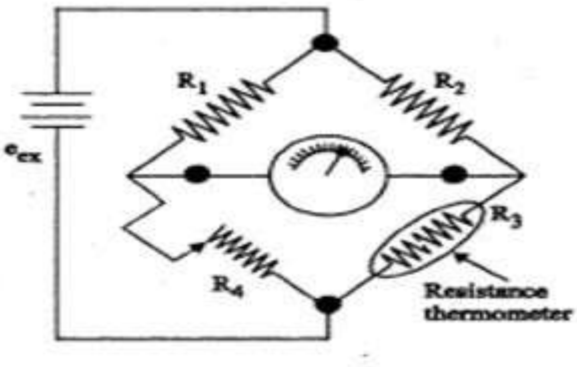


Fig. 3.3.4 Null balance bridge circuit of resistance thermometer

[Source: Neubert H.K.P., Instrument Transducers – An Introduction to their Performance and Design, Page: 534]

R4 is varied until balance is achieved. When better accuracy is required the arrangement shown in Fig 3.3.5 is preferred.

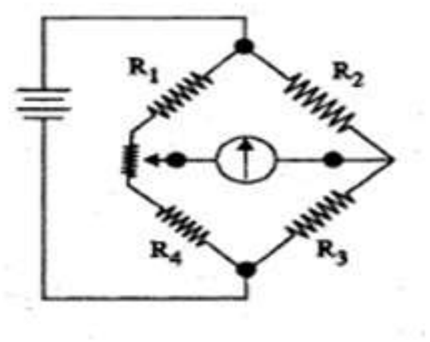


Fig. 3.3.5 Bridge balance circuit for better accuracy

[Source: Neubert H.K.P., Instrument Transducers – An Introduction to their Performance and Design, Page: 534]

In this circuit the contact resistance in the adjustable resistor has no influence on the resistance of the bridge legs. If long lead wires subjected to temperature variations are unavoidable, then three wire resistance thermometer is used with the circuit configuration as shown in Fig 3.3.6.

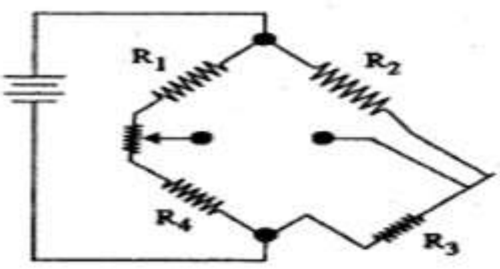


Fig. 3.3.6 Three wire resistance thermometer circuit

[Source: Neubert H.K.P., Instrument Transducers – An Introduction to their Performance and Design, Page: 535]

To get a fairly linear relationship. between the output voltage and the temperature, the values of R1 and R2 of the above circuits are made at least 10 times greater than that of the thermometer.

Circuit designing Considerations

Lead wires of some appropriate length are required to connect the RTD into the circuit. So, if the temperature varies it will consequently vary the resistance in the bridge circuit. So, one must keep a proper distance between the point where RTD must be installed and the measuring point.

The current that flows through RTD, account for the heating effect in the circuit. Thus, the generated heat increases the temperature of the RTD sensor.

This is a **self-heating effect** and we cannot avoid it. The only thing which we can do is a compromise with the sensitivity of the instrument. A reduction in current through RTD will definitely reduce the heat generation rate but, the sensitivity of the device also reduces. However, it can be improved with proper amplification. The increase in temperature of the device due to self-heating effect can be given as:

$$\Delta T = \frac{P}{P_d}$$

ΔT = rise in temperature in ^0C

P = power dissipated in RTD in watts

P_d = Dissipation constant of RTD in W/ ^0C

Signal conditioning

The resistance variation of the RTD can be measured by a bridge, or directly by volt-ampere method. But the major constraint is the contribution of the lead wires in the overall resistance measured. Since the length of the lead wire may vary, this may give a false reading in the temperature to be measured. There must be some method for compensation so that the effect of lead wires is resistance measured is eliminated. This can be achieved by using either a three wire RTD, or a four wire RTD. Both the schemes of measurement are shown in Fig. 3.3.7(a). In three wire method one additional dummy wire taken from the resistance element and connected in a bridge so that the two lead wires are connected to two adjacent arms of the bridge, thus cancelling each other's effect. In Fig. 3.3.7(b) the four wire method of measurement is shown. It is similar to a four terminal resistance and two terminals are used for injecting current, while two others are for measuring voltage.

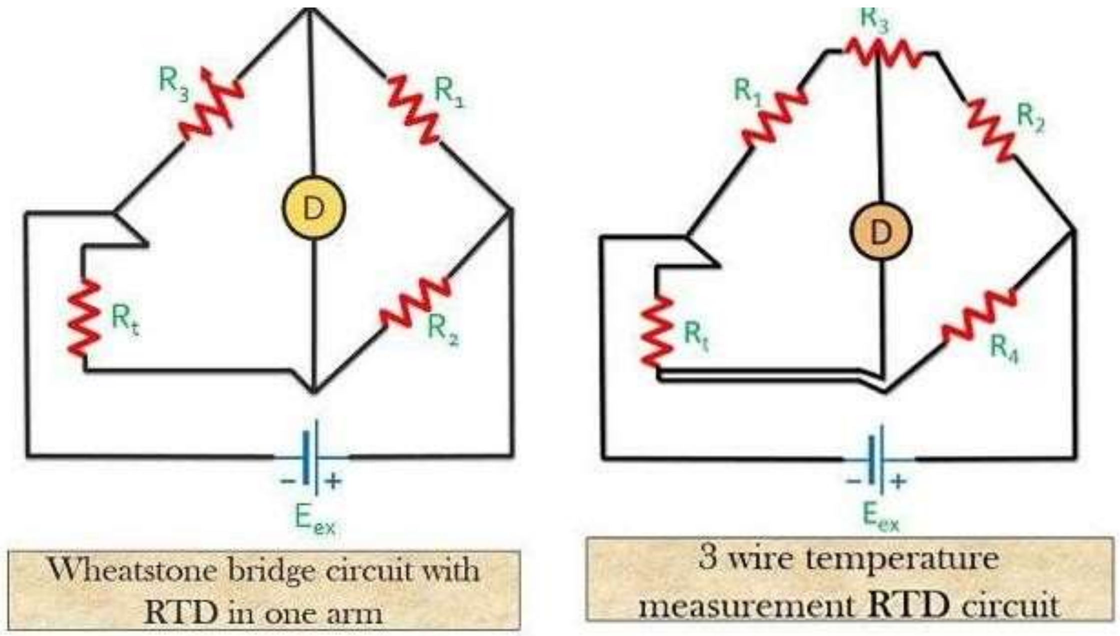


Fig. 3.3.7 (a) Wheatstone bridge with RTD (b) Three wire RTD

[Source: Neubert H.K.P., Instrument Transducers – An Introduction to their Performance and Design, Page: 537]

Advantages & Disadvantages of Resistance Thermometer

Advantages

- It provides highly accurate results.

- RTD provides a vast operating range.
- Good Reproducibility
- Fast in response
- Small in size
- Temperature compensation is not required

Disadvantages

- The sensitivity of platinum RTD is very less for the minor variation in temperature.
- RTD possess slower response time.
- Cost is high
- Excitation needed
- Large bulb size than thermocouple
- Produce mechanical vibration.

3.4 THERMISTOR:

Definition: The thermistor is a kind of resistor whose resistivity depends on surrounding temperature. It is a temperature sensitive device. The word thermistor is derived from the word, thermally sensitive resistor. The thermistor is made of the semiconductor material that means their resistance lies between the conductor and the insulator.

Thermistors are thermal resistors with a high negative temperature.

Coefficient of resistance. Thermistors, are the devices whose resistance changes rapidly with the corresponding change in temperature (Mostly negative temperature coefficient) is shown in Fig 3.4.1.

Thermistor word is composed by the merger of the word thermal and resistor

It is a two terminal solid state semiconductor based metal oxides having metalized connecting leads onto a ceramic disc.

Its resistance lies in between 0.5 to 0.7Ω.

These are widely used in temperature measurement application which ranges from - 60^{o}C to 15^{o}C.

As thermistors are highly temperature sensitive device so it makes them extremely useful for precision temperature measurement and compensation.

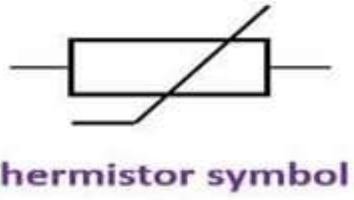


Fig 3.4.1 Thermistor symbol

[Source: Neubert H.K.P., Instrument Transducers – An Introduction to their Performance and Design, Page: 538]

They are made of manganese, nickel, copper, iron, uranium and cobalt oxides which were milled, mixed in proper proportions with binders pressed into the desired shape and sintered.

Types of Thermistor

The thermistor is classified into types. They are the negative temperature coefficient and the positive temperature coefficient thermistor.

Negative Temperature Coefficient Thermistor – In this type of thermistor the temperature increases with the decrease of the resistance. The resistance of the negative temperature coefficient thermistor is very large due to which it detects the small variation in temperature.

Positive Temperature Coefficient Thermistor – The resistance of the thermistor increases with the increases in temperature.

Construction

Two or more semiconductor powder are mixed to form a slurry.

This slurry in the form of small drops is formed over the lead wire after which it is dried and put in a sintering furnace.

During sintering, the metallic oxide shrunk onto lead wires and form electrical connections.

The beads are then sealed by glass coating. This glass coating improves overall stability.

Thermistor can be in the form of discs, beads, rods etc.

The thermistor is made with the sintered mixture of metallic oxides like manganese, cobalt, nickel, cobalt, copper, iron, uranium, etc. It is available in the form of the bead, rod and disc. The different types of the thermistor are shown in the Fig 3.4.2 below.

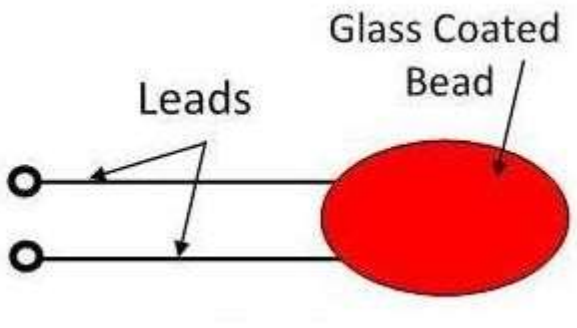


Fig 3.4.2 Bead

[Source: Neubert H.K.P., Instrument Transducers – An Introduction to their Performance and Design, Page: 540]

The bead form of the thermistor is smallest in shape, and it is enclosed inside the solid glass rod to form probes is shown in Fig 3.4.3 below.

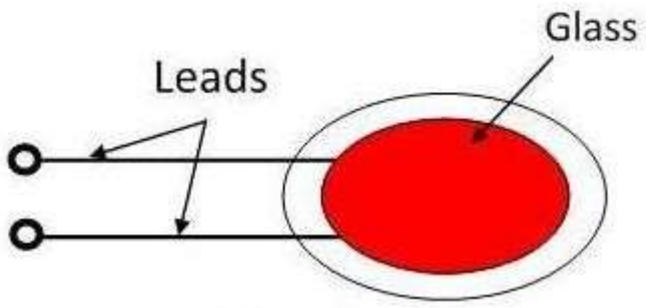


Fig 3.4.3 Probe

[Source: Neubert H.K.P., Instrument Transducers – An Introduction to their Performance and Design, Page: 540]

The disc shape is made by pressing material under high pressure with diameter range from 2.5 mm to 25mm.

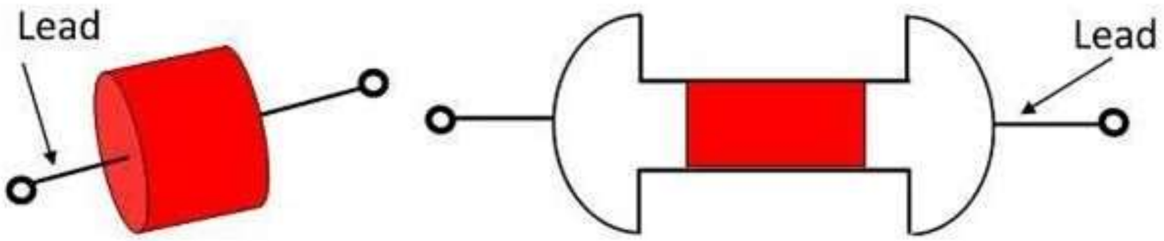


Fig 3.4.4 Disc and Rod

[**Source: Neubert H.K.P., Instrument Transducers – An Introduction to their Performance and Design, Page: 541]**

Thermistor is a contraction of a term thermal resistor. Thermistors are generally composed of semi-conductor materials. Although positive temperature co- efficient of units (which exhibit an increase in the value of resistance with increase in temperature) are available, most thermistors have negative coefficient of temperature resistance i.e. their resistance decreases with increase of temperature. The negative temperature coefficient of resistance can be as large as several percent per degree celsius is shown in above Fig 3.4.4.

In somecases the resistance of thermistor at room temperature may decrease as much as 5 percent for each 1°C rise in temperature. This high sensitivity to temperature changes makes thermistors extremely useful for precision temperature measurements control and compensation

Characteristics of Thermistor

Three important characteristics of thermistor make them extremely useful in measurement and control applications. These are:

(i) the resistance - temperature characteristics

(ii) the voltage current characteristics

(iii) the current-time characteristics

Thermistors have a large negative temperature coefficient and it is highly nonlinear. The resistance at different temperatures can be found out using the following equation.

$$R_T = R_o e^{\beta(\frac{1}{T} - \frac{1}{G_o})}$$

where

R_T - resistance' at temperature T

R_o- resistance at temperature To

f3 - constant characteristic of material

E - base of natural log and T1.To - absolute temperature K,

Due to self heating the resistance decreases and the current increases. As the current is more the heating is also more and hence resistance will decrease. Some kind of chain action takes place here, This process will continue until the thermistor reaches the maximum temperature possible for the amount of power available at which time a. steady state will exist in Fig 3.4.5.

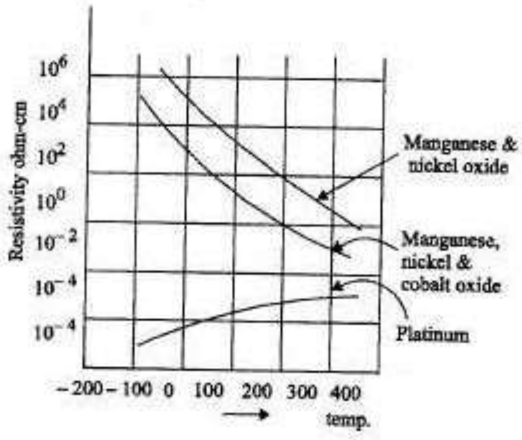


Fig. 3.4.5 Resistive curves for thermistor

[Source: Neubert H.K.P., Instrument Transducers – An Introduction to their Performance and Design, Page: 543]

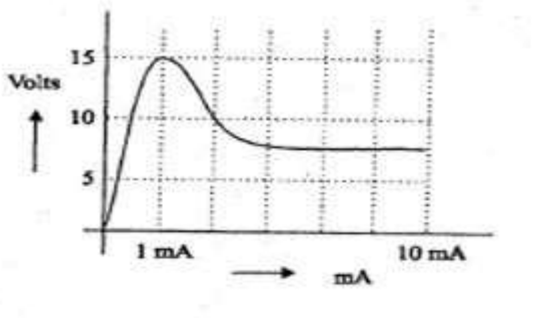


Fig. 3.4.6 V-I characteristics of thermistor

[**Source: Neubert H.K.P., Instrument Transducers – An Introduction to their Performance and Design, Page: 543]**

Fig 3.4.6 show typical current voltage characteristic curves for a semiconductor material. The thermal dissipation constant for typical thermistor ranges from 0.1 m W/ ^{O}C for glass covered beads to 7 mW/^{O}C for relatively large discs. All are measured in still air. Other semiconductor temperature sensors include carbon resistors, silicon and germanium devices.

Carbon resistors are merely the commercial carbon-composition elements commonly used as resistance elements in electronic circuitry. The normal power rating is from 0.1 to 1 watt and the resistance value varies from 2 to 150 ohm. They are also used for cryogenic temperature measurements in the range 1 to 20 K. From about 20 K downward these elements exhibit a large increase in resistance with decrease in temperature given by the relation is the resistance, T is the temperature in Kelvin and A, Band K are constants determined by calibration.

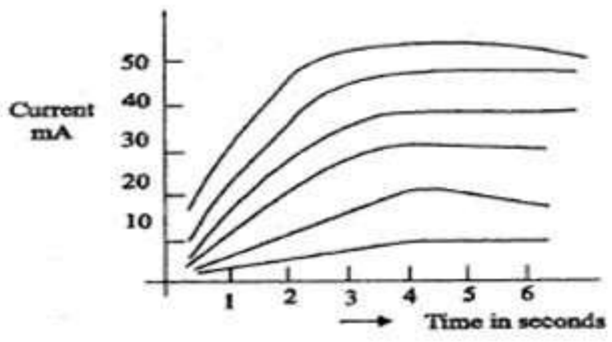


Fig. 3.4.7 Current variation due to self heating in thermistor

[**Source: Neubert H.K.P., Instrument Transducers – An Introduction to their Performance and Design, Page: 544]**

The current through the semiconductor element is time dependent for a constant voltage as the resistance varies due to self heating. Due to self heating the resistance decreases and the current increases. As the current is more the heating is also more and hence resistance will decrease. Some kind of chain action takes place here and this process will continue until the thermistor reaches the maximum temperature possible in the above Fig 3.4.7.

Germanium doped with arsenic and gallium is used for cryogenic temperatures where it exhibits a large decrease in resistance with increase in temperature.

Types of Thermistor

There are mainly two types of thermistors:

1. Negative temperature coefficient thermistor
2. Positive temperature coefficient thermistor

Positive temperature coefficient thermistors

In this type of thermistor, the **resistance rapidly increases** with the respective increase in temperature.

The flow of current reduces as the temperature associated with it increases. The temperature ranges commonly used for switching is from 60°C to 120°C. These are mostly made from doped polycrystalline ceramic.

Negative temperature coefficient thermistors

- It is a category of thermistors in which the **resistance of the thermistor shows decrement with increment in the temperature**.
- Due to their property of causing a significant change in resistance with a small change in temperature, these are widely used for accurate temperature measurement.
- These type of thermistor allows a large flow of current if the temperature associated with it increases. Here, the charge carriers that are responsible for the flow of current are generated by the doping process.
- When we slightly increase the temperature, the charge carriers collide with the electrons at the valence shell of other atoms. These valence electrons then move freely and collision process is further repeated. This simply means more free electron will cause more current.
- Therefore, a small increase in temperature will decrease the resistance of the thermistor due to which large electric current flows. Resistance can vary from a few **ohms to several Kilo-ohms**.

Advantages and Disadvantages of Thermistor

Advantages

- Thermistors are compact.
- It provides good stability.
- These are inexpensive.
- Only a small temperature variation is needed to have a noticeable change in resistance. (Very high sensitivity)
- It can be manufactured in any size or shape.

- Fast in Response

Disadvantages

- It shows non-linear resistance vs temperature characteristics.
- These are not suitable for a wide range of operations.
- In low temperature, sensitivity also low.
- Its upper limit is set by instability

Applications of Thermistor

- It is used to measure thermal conductivity.
- It is used to measure power at high frequency.
- These are widely used in temperature sensing devices.
- These are widely used to measure flow and level of liquids.
- Vacuum measurement
- Measurement of level, flow and pressure of liquids.
- Measurement of composition of gases.