Transducers

A transducer is defined as a device that receives energy from one system and transmits it to another, often in a different form.

Broadly defined, the transducer is a device capable of being actuated by an energising input from one or more transmission media and in turn generating a related signal to one or more transmission systems.

It provides a usable output in response to a specified input measurand, which may be a physical or mechanical quantity, property, or conditions. The energy transmitted by these systems may be electrical, mechanical or acoustical.

The nature of electrical output from the transducer depends on the basic principle involved in the design. The output may be analog, digital or frequency modulated.

Basically, there are two types of transducers, electrical, and mechanical.

Electrical Transducer Definition

An electrical transducer is a sensing device by which the physical, mechanical or optical quantity to be measured is transformed directly by a suitable mechanism into an electrical voltage/current proportional to the input measurand.

An electrical transducer must have the following parameters:

1. **Linearity:** The relationship between a physical parameter and the resulting electrical signal must be linear.
2. **Sensitivity:** This is defined as the electrical output per unit change in the physical parameter (for example V/°C for a temperature sensor). High sensitivity is generally desirable for a transducer.
3. **Dynamic Range:** The operating range of the transducer should be wide, to permit its use under a wide range of measurement conditions.
4. **Repeatability:** The input/output relationship for a transducer should be predictable over a long period of time. This ensures reliability of operation.
5. **Physical Size:** The transducer must have minimal weight and volume, so that its presence in the measurement system does not disturb the existing conditions.

Advantages of Electrical Transducer

The main advantages of electrical transducer (conversion of physical quantity into electrical quantities) are as follows:

1. Electrical amplification and attenuation can be easily done.
2. Mass-inertia effects are minimised.
3. Effects of friction are minimised.
4. The output can be indicated and recorded remotely at a distance from the sensing medium.

5. The output can be modified to meet the requirements of the indicating or controlling units. The signal magnitude can be related in terms of the voltage or current. (The analog signal information can be converted in to pulse or frequency information. Since output can be modified, modulated or amplified at will, the output signal can be easily used for recording on any suitable multichannel recording device.)
6. The signal can be conditioned or mixed to obtain any combination with outputs of similar transducers or control signals.
7. The electrical or electronic system can be controlled with a very small power level.
8. The electrical output can be easily used, transmitted and processed for the purpose of measurement.

Electrical transducer can be broadly classified into two major categories,

(i) Active, (ii) Passive.

An **active transducer** generates an electrical signal directly in response to the physical parameter and does not require an external power source for its operation.

Active transducers are self generating devices, which operate under energy conversion principle and generate an equivalent output signal (for example from pressure to charge or temperature to electrical potential).

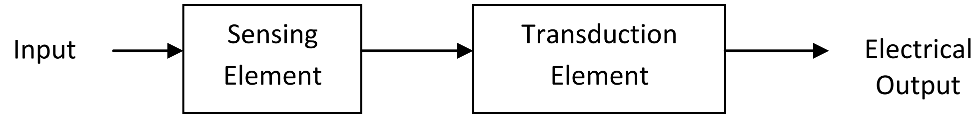
Typical example of active transducers are piezo electric sensors (for generation of charge corresponding to pressure) and photo voltaic cells (for generation of voltage in response to illumination).

Passive transducer operate under energy controlling principles, which makes it necessary to use an external electrical source with them. They depend upon the change in an electrical parameter (R, L and C).

Typical example are strain gauges (for resistance change in response to pressure), and thermistors (for resistance change corresponding to temperature variations).

Electrical transducer are used mostly to measure non-electrical quantities. For this purpose a detector or sensing element is used, which converts the physical quantity into a displacement. This displacement actuates an electric transducer, which acts as a secondary transducer and give an output that is electrical in nature. This electrical quantity is measured by the standard method used for electrical measurement. The electrical signals may be current, voltage, or frequency; their production is based on R, L and C effects.

A transducer which converts a non-electrical quantity into an analog electrical signal may be considered as consisting of two parts, the sensing element, and the transduction element.



Transducer

The sensing or detector element is that part of a transducer which responds to a physical phenomenon or to a change in a physical phenomenon. The response of the sensing element must be closely related to the physical phenomenon.

The transduction element transforms the output of a sensing element to an electrical output. This, in a way, acts as a secondary transducer.

Transducers may be further classified into different categories depending upon the principle employed by their transduction elements to convert physical phenomena into output electrical signals.

The different electrical phenomena employed in the transduction elements of transducers are as follows.

1. Resistive
2. Photo-emissive
3. Inductive
4. Photo-resistive
5. Capacitive
6. Potentiometric
7. Electro magnetic
8. Thermo-electric
9. Piezo-electric
10. Frequency generating

Selecting a Transducer

The transducer or sensor has to be physically compatible with its intended application. The following should be considered while selecting a transducer.

1. **Operating range:** Chosen to maintain range requirements and good
2. **Sensitivity:** Chosen to allow sufficient output.
3. **Frequency response and resonant frequency:** Flat over the entire desired range.
4. **Environmental compatibility:** Temperature range, corrosive fluids, pressure, shocks, interaction, size and mounting restrictions.
5. **Minimum sensitivity:** To expected stimulus, other than the measurand.
6. **Accuracy:** Repeatability and calibration errors as well as errors expected due to sensitivity to other stimuli.
7. **Usage and ruggedness:** Ruggedness, both of mechanical and electrical intensities versus size and weight.
8. **Electrical parameters:** Length and type of cable required, signal to noise ratio when combined with amplifiers, and frequency response limitations.

Resistive Transducer:

Resistive Transducers are those in which the resistance changes due to a change in some physical phenomenon. The change in the value of the resistance with a change in the length of the conductor can be used to measure displacement.

Strain gauges work on the principle that the resistance of a conductor or semiconductor changes when strained. This can be used for the measurement of displacement, force and pressure.

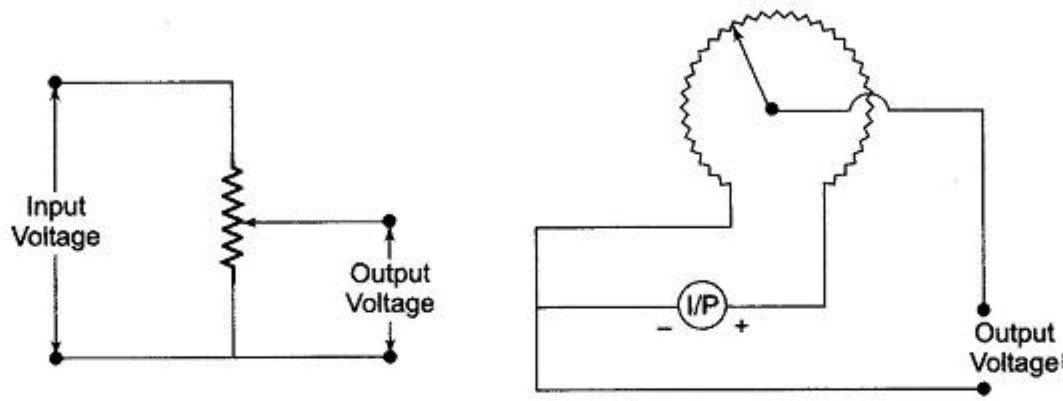
The resistivity of materials changes with changes in temperature. This property can be used for the measurement of temperature.

Potentiometer

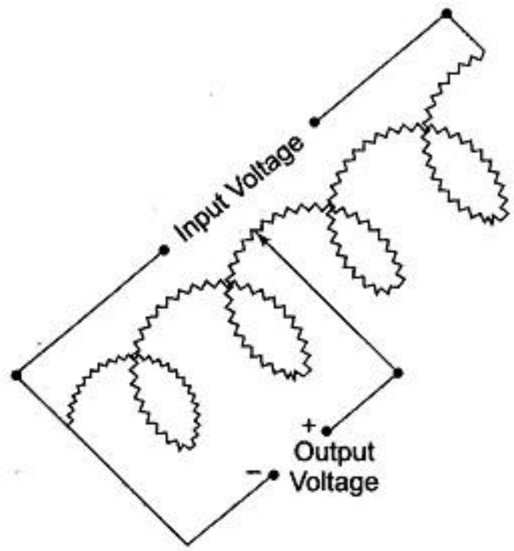
A resistive potentiometer (pot) consists of a resistance element provided with a sliding contact, called a wiper. The motion of the sliding contact may be translatory or rotational. Some have a combination of both, with resistive elements in the form of a helix, as shown in Fig. 13.1(c). They are known as helipots.

Translatory resistive elements, as shown in Fig. 13.1(a), are linear (straight) devices. Rotational resistive devices are circular and are used for the measurement of angular displacement, as shown in Fig. 13.1(b).

Helical resistive elements are multi turn rotational devices which can be used for the measurement of either translatory or rotational motion. A potentiometer is a passive transducer since it requires an external power source for its operation.



(a) (b)



(c)

Fig. 13.1 (a) Translatory Type (b) Rotational Type (c) Helipot (Rotational)

Advantage of Potentiometers

1. They are inexpensive.
2. Simple to operate and are very useful for applications where the requirements are not particularly severe.
3. They are useful for the measurement of large amplitudes of displacement.
4. Electrical efficiency is very high, and they provide sufficient output to allow control operations.

Disadvantages of Potentiometers

1. When using a linear potentiometer, a large force is required to move the sliding contacts.
2. The sliding contacts can wear out, become misaligned and generate noise.

Resistance Pressure Transducer

Measurement in the resistive type of transducer is based on the fact that a change in pressure results in a resistance change in the sensing elements.

Resistance pressure transducers are of two main types.

(1) **Electromechanical resistance transducer**, in which a change of pressure, stress, position, displacement or other mechanical variation is applied to a variable.

(2) **Strain gauge,** where the stress acts directly on the resistance. It is very commonly used for stress and displacement measurement in instrumentation.

In the general case of pressure measurement, the sensitive resistance element may take other forms, depending on the mechanical arrangement on which the pressure is caused to act.

Figure 13.1(d) and (e) show two ways by which the pressure acts to influence the sensitive resistance element, i.e. by which pressure varies the resistance. They are the bellow type, and the diaphragm type (yet another is the Bourdon tube of pressure gauge).

In each of these cases, the element moved by the pressure change is made to cause a change in resistance. This resistance change can be made part of a bridge circuit and then taken as either ac or dc output signal to determine the pressure indication.

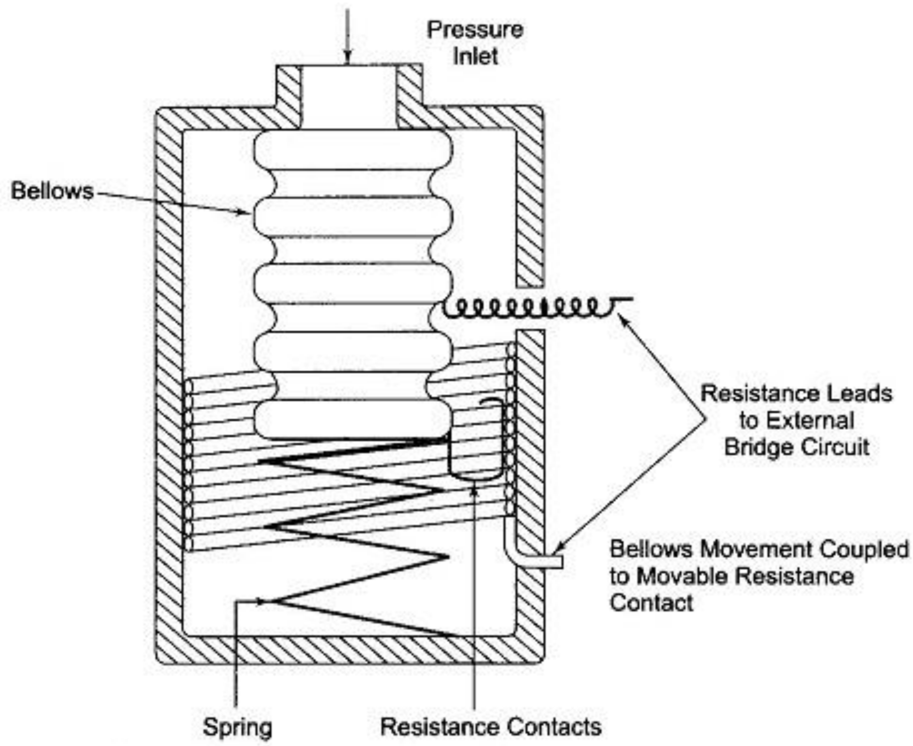


Fig. 13.1(d) Resistance Pressure Transducer

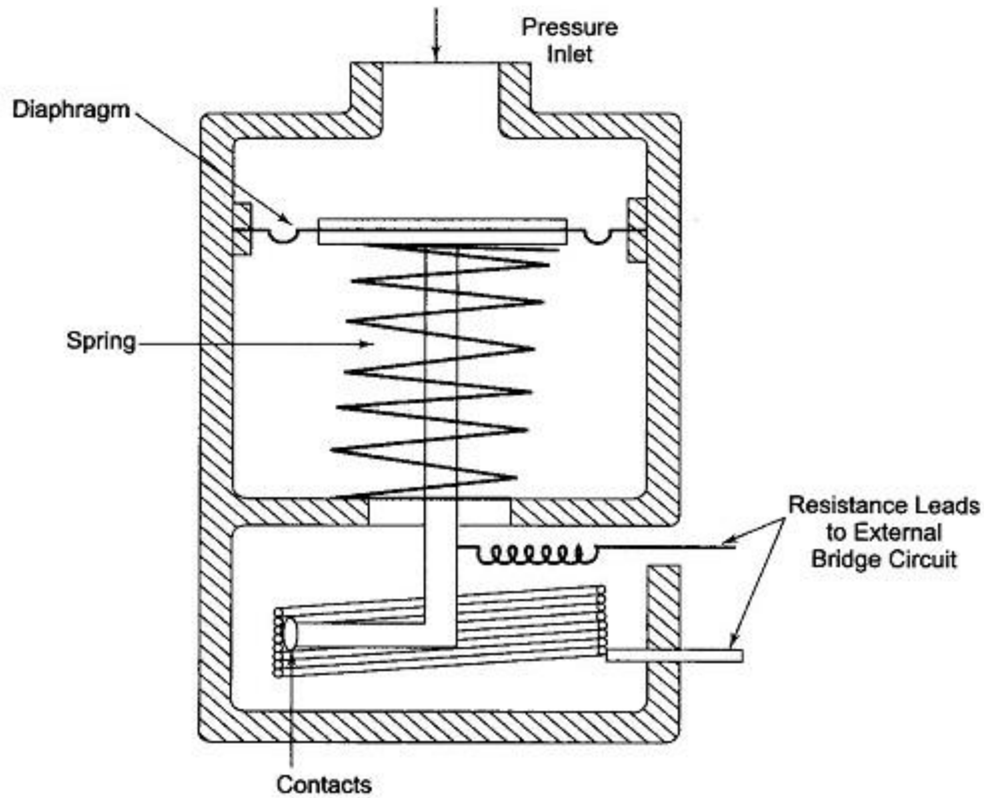


Fig. 13.1(e) Sensitive Diaphragm Moves the Resistance Contact

Resistive Position Transducer:

The principle of the Resistive Position Transducer is that the physical variable under measurement causes a resistance change in the sensing element. (A common requirement in industrial measurement and control work is to be able to sense the position of an object, or the distance it has moved).

One type of displacement transducer uses a resistive element with a sliding contact or wiper linked to the object being monitored or measured. Thus the resistance between the slider and one end of the resistance element depends on the position of the object. Figure 13.2(a) gives the construction of this type of transducer.

Figure 13.2(b) shows a typical method of use. The output voltage depends on the wiper position and is therefore a function of the shaft position. This voltage may be applied to a voltmeter calibrated in cms for visual display.

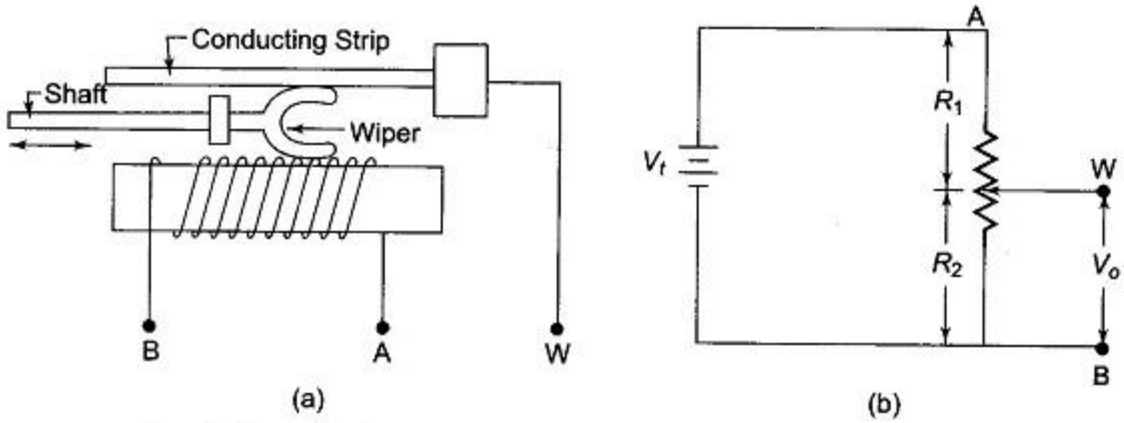


Fig. 13.2 (a) Construction of Resistance Position Transducer
(b) Typical Method

(Typical commercial units provide a choice of maximum shaft strokes, from an inch or less to 5 ft or more.) Deviation from linearity of the resistance versus distance specifications can be as low as 0.1 — 1.0%.

Considering Fig. 13.2(b), if the circuit is unloaded, the output voltage V_o is a certain fraction of $V_{t,}$ depending upon the position of the wiper.

$$\frac{V_o}{V_t} = \frac{R_2}{R_1 + R_2}$$

Therefore,

When applied to resistive position sensors, this equation shows that output voltage is proportional to R_2, i.e. the position of the wiper of the potentiometer. If the resistance of the transducer is distributed uniformly along the length of travel of the wiper, the resistance is perfectly linear.

Problem:

A displacement transducer with a shaft stroke of 3.0 in. is applied with voltage of 5V. The total resistance of the potentiometer is 5K Ω. When the wiper is at 0.9 in. from bottom, what is the value of the output voltage?

Soln:

R2=(0.9/3.0)*5 = 1500 Ω

Output voltage= (1500/5000)*5 = 1.5 V

Strain Gauge:

The Strain Gauge is an example of a passive transducer that uses the variation in electrical resistance in wires to sense the strain produced by a force on the wires.

It is well known that stress (force/unit area) and strain (elongation or compression/unit length) in a member or portion of any object under pressure is directly related to the modulus of elasticity.

Since strain can be measured more easily by using variable resistance transducers, it is a common practice to measure strain instead of stress, to serve as an index of pressure. Such transducers are popularly known as strain gauges.

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

Also, there is a change in the value of the resistivity of the conductor when subjected to strain, a property called the piezo-resistive effect.

Therefore, resistance strain gauges are also known as piezo resistive gauges.

Many detectors and transducers, e.g. load cells, torque meters, pressure gauges, temperature sensors, etc. employ strain gauges as secondary transducers.

When a gauge is subjected to a positive stress, its length increases while its area of cross-section decreases. Since the resistance of a conductor is directly proportional to its length and inversely proportional to its area of cross-section, the resistance of the gauge increases with positive strain. Also the resistance changes due to peizo resisitive effect.

The change in resistance value of a conductor under strain due to piezo resistive effect is more than due to its dimensional changes.

The following types of strain gauges are the most important.

1. Wire strain gauges
2. Foil strain gauges
3. Semiconductor strain gauges

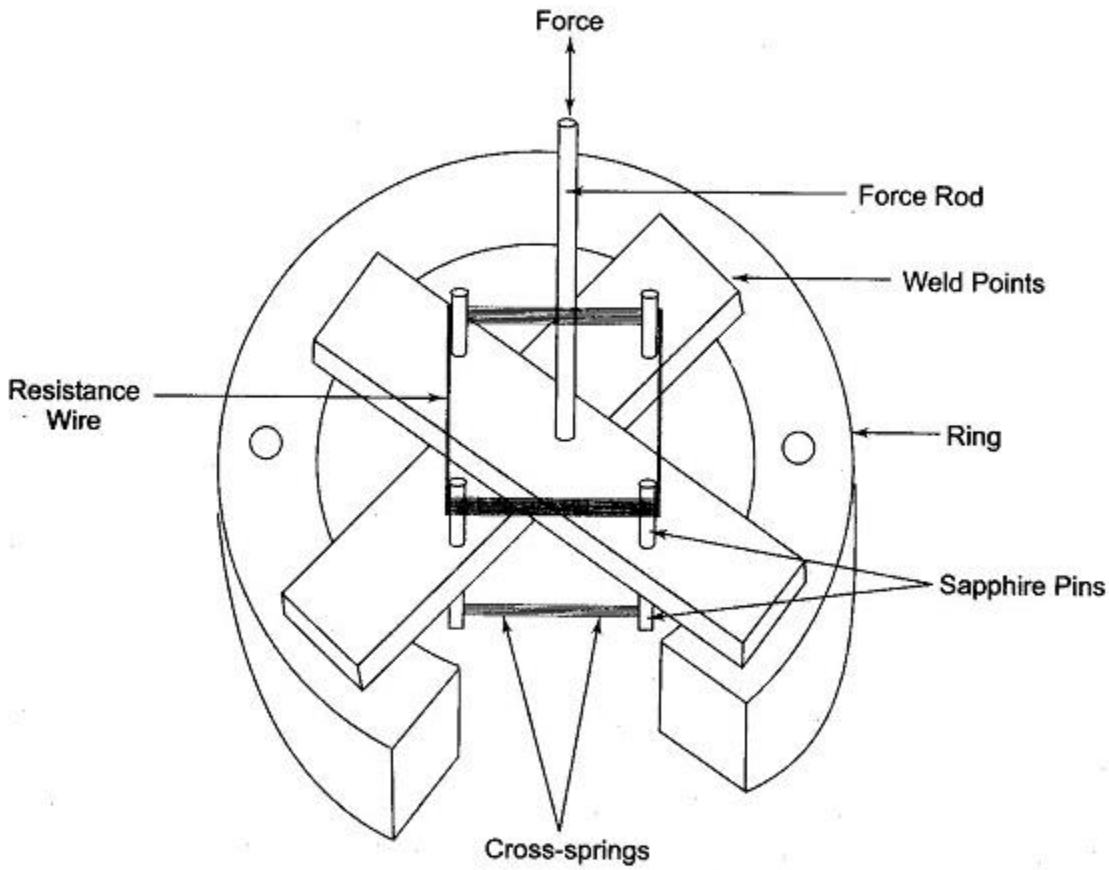
Resistance Wire Gauge

Resistance wire gauges are used in two basic forms, the unbonded type, and the bonded type.

1. Unbonded Resistance Wire Strain Gauge

An unbonded strain gauge consists of a wire stretched between two points in an insulating medium, such as air. The diameter of the wire used is about 25 μm. The wires are kept under tension so that there is no sag and no free vibration. Unbonded Strain Gauges are usually connected in a bridge circuit. The bridge is balanced with no load applied as shown in Fig. 13.3.

When an external load is applied, the resistance of the Strain Gauge changes, causing an unbalance of the bridge circuit resulting in an output voltage. This voltage is proportional to the strain. A displacement of the order of 50μm can be detected with these strain gauges.



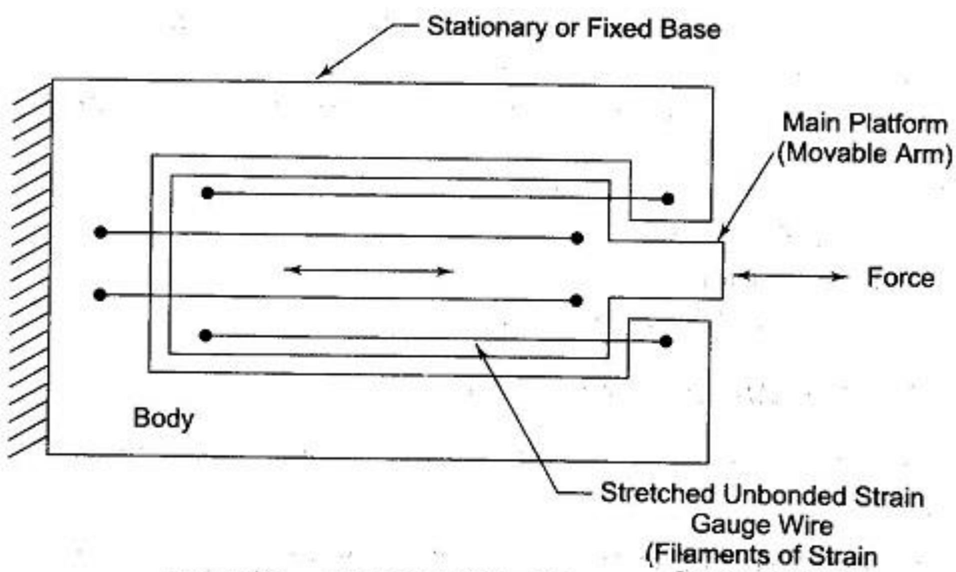


Fig. 13.3 Unbonded Strain Gauge

2. Bonded Resistance Wire Strain Gauges

A metallic bonded Strain Gauge is shown in Fig. 13.4.

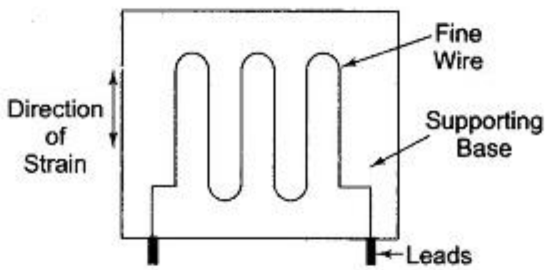


Fig. 13.4 Bonded resistance Wire Strain Gauge

A fine wire element about 25 μm (0.025 in.) or less in diameter is looped back and forth on a carrier (base) or mounting plate, which is usually cemented to the member undergoing stress.

The grid of fine wire is cemented on a carrier which may be a thin sheet of paper, bakelite, or teflon.

The wire is covered on the top with a thin material, so that it is not damaged mechanically. The spreading of the wire permits uniform distribution of stress. The carrier is then bonded or cemented to the member being studied. This permits a good transfer of strain from carrier to wire.

A tensile stress tends to elongate the wire and thereby increase its length and decrease its cross-sectional area. The combined effect is an increase in resistance, as seen from the following equation

$$R = \frac{\rho \times l}{A}$$

where,

ρ = the specific resistance of the material in Ωm.

l = the length of the conductor in m

A = the area of the conductor in m^2

As a result of strain, two physical parameters are of particular interest.

1. The change in gauge resistance.
2. The change in length.

The measurement of the sensitivity of a material to strain is called the gauge factor (GF). It is the ratio of the change in resistance Δ R/R to the change in the length Δl/l

$$GF\ (K) = \frac{\Delta R/R}{\Delta l/l} \qquad (13.1)$$

where,
K= gauge factor
ΔR= the change in the initial resistance in Ω's
R = the initial resistance in Ω (without strain)
Δl= the change in the length in m
l = the initial length in m (without strain)

Since strain is defined as the change in length divided by the original length,

i.e. $$\sigma = \frac{\Delta l}{l}$$

Eq. (13.1) can be written as

$$K = \frac{\Delta R/R}{\sigma} \qquad (13.2)$$

Where, σ is the strain in the Axial direction.

The resistance of a conductor of uniform cross-section is

$$R = \rho \frac{\text{length}}{\text{area}}$$

$$R = \rho \frac{l}{\pi r^2}$$

$$r = \frac{d}{2} \quad \therefore \quad r^2 = \frac{d^2}{4}$$

$$R = \rho \frac{l}{\pi d^2/4} = \rho \frac{l}{\pi/4\, d^2} \qquad (13.3)$$

where,
ρ= specific resistance of the conductor
l = length of conductor
d= diameter of conductor

When the conductor is stressed, due to the strain, the length of the conductor increases by Δl and the simultaneously decreases by Δd in its diameter. Hence, the resistance of the conductor can now be written as

$$R_s = \rho \frac{(l + \Delta l)}{\pi/4(d - \Delta d)^2} = \frac{\rho(l + \Delta l)}{\pi/4\,(d^2 - 2d\,\Delta d + \Delta d^2)}$$

Since Δd is small, Δd^2 can be neglected

$$R_s = \frac{\rho\,(l + \Delta l)}{\pi/4\,(d^2 - 2d\,\Delta d)}$$

$$= \frac{\rho\,(l + \Delta l)}{\pi/4 d^2 \left(1 - \dfrac{2\Delta d}{d}\right)} = \frac{\rho l\,(1 + \Delta l/l)}{\pi/4 d^2 \left(1 - \dfrac{2\Delta d}{d}\right)} \qquad (13.4)$$

Now, Poisson's ratio μ is defined as the ratio of strain in the lateral direction to strain in the axial direction, that is,

$$\mu = \frac{\Delta d/d}{\Delta l/l} \qquad (13.5)$$

$$\frac{\Delta d}{d} = \mu \frac{\Delta l}{l} \qquad (13.6)$$

Substituting for Δd/d from Eq. (13.6) in Eq. (13.4), we have

$$R_s = \frac{\rho l\,(1 + \Delta l/l)}{(\pi/4)\,d^2\,(1 - 2\mu \Delta l/l)}$$

Rationalising, we get

$$R_s = \frac{\rho l\,(1 + \Delta l/l)}{(\pi/4)\,d^2\,(1 - 2\mu \Delta l/l)} \frac{(1 + 2\mu \Delta l/l)}{(1 + 2\mu \Delta l/l)}$$

$$R_s = \frac{\rho l}{(\pi/4)\,d^2} \left[\frac{(1 + \Delta l/l)}{(1 - 2\mu \Delta l/l)} \frac{(1 + 2\mu \Delta l/l)}{(1 + 2\mu \Delta l/l)} \right]$$

$$R_s = \frac{\rho l}{(\pi/4)\,d^2} \left[\frac{1 + 2\mu \Delta l/l + 2\Delta l/l + 2\mu\,\Delta l/l\,\Delta l/l}{1 - 4\mu^2\,(\Delta l/l)^2} \right]$$

$$R_s = \frac{\rho l}{(\pi/4)\,d^2} \left[\frac{1 + 2\mu \Delta l/l + \Delta l/l + 2\mu \Delta l^2/l^2}{1 - 4\mu^2\,\Delta l^2/l^2} \right]$$

Since Δl is small, we can neglect higher powers of Δl.

$$R_s = \frac{\rho l}{(\pi/4)\,d^2}\ [1 + 2\,\mu\,\Delta l/l + \Delta l/l]$$

$$R_s = \frac{\rho l}{(\pi/4)\,d^2}\ [1 + (2\,\mu + 1)\,\Delta l/l]$$

$$R_s = \frac{\rho l}{(\pi/4)\,d^2}\ [1 + (1 + 2\,\mu)\,\Delta l/l]$$

$$R_s = \frac{\rho l}{(\pi/4)\,d^2} + \frac{\rho l}{(\pi/4)\,d^2}\ (\Delta l/l)\,(1 + 2\,\mu)$$

Since from Eq. (13.3),

$$R = \frac{\rho l}{(\pi/4)\,d^2}$$

$$R_s = R + \Delta R \tag{13.7}$$

$$\Delta R = \frac{\rho l}{(\pi/4)\,d^2}\ (\Delta l/l)\,(1 + 2\,\mu)$$

The gauge factor will now be

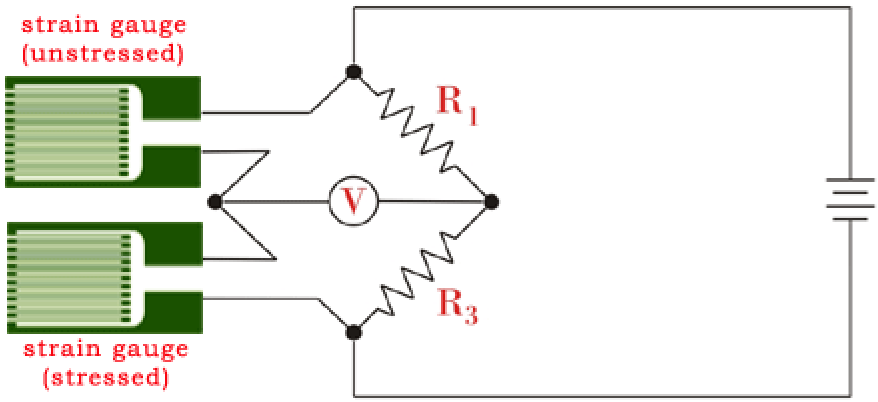
$$K = \frac{\Delta R/R}{\Delta l/l} = \frac{(\Delta l/l)(1+2\mu)}{\Delta l/l}$$

$$= 1 + 2\,\mu$$

$$K = 1 + 2\,\mu \tag{13.8}$$

Strain gauge in Bridge Arrangement:

The strain gauge is normally used in a bridge arrangement in which the gauge forms one arm of the bridge. The bridge may be dc or ac actuated. A simple dc arrangement is shown in the following figure.



Quarter-bridge strain gauge circuit
with temperature compensation

Only one of the gauges is an active element, producing an output proportional to the strain. The other gauge is a dummy gauge which is not strained. It is connected in the bridge for the temperature compensation.

Since the resistance of the fine wire element is sensitive to the temperature as well as stress variation, any change in the temperature will cause a change in the bridge conditions. This effect can cause error in the strain measurement. Hence, when temperature variations are significant or when unusual accuracy is required, some compensation must be used.

The dummy gauge in the above arrangement accomplishes this, because it is placed in the same temperature environment as the active gauge, but not subjected to the strain. Consequently, the temperature causes the same change of resistance in both the active and dummy strain gauges and the bridge balance is not affected by the temperature.

If the two resistors R1 and R3 have negligible temperature coefficients, the bridge retains its balance under conditions of no-strain, at any temperature within its operating range.

Strain Gauge Transducer Types:

Strain Gauge Transducers are three types, namely

1. Wire Strain Gauges

2. Foil Strain Gauge

3. Semiconductor Strain Gauge