Bridges:

Introduction:

- A bridge circuit consists of a network of four resistance arms forming a closed circuit, with a dc current source applied to two opposite junctions and a current detector or galvanometer connected to other two junctions.
- Bridge circuits are used for measuring R, L and C values. It compares the value of an unknown component with the accurately known component with a high accuracy.
- The measurement accuracy is related to the accuracy of the bridge component and not to that of the null indicator used.

Wheatstone Bridge Circuit:

A Wheatstone Bridge Circuit in its simplest form consists of a network of four resistance arms forming a closed circuit, with a dc source of current applied to two opposite junctions and a current detector connected to the other two junctions, as shown in Fig. 11.1.

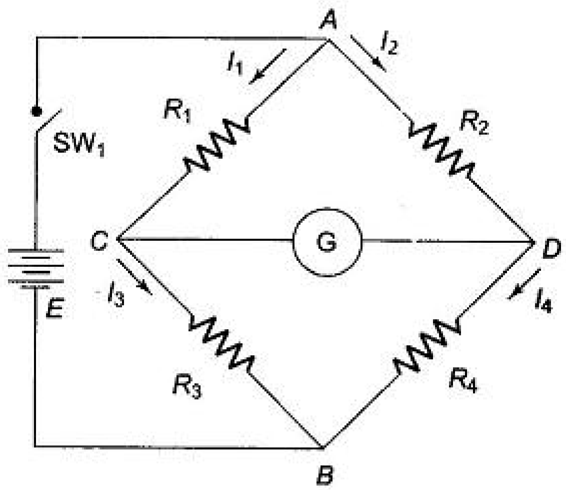


Fig. 11.1 Wheatstone's Bridge

Wheatstone Bridge Circuit are extensively used for measuring component values such as R, L and C. Since the bridge circuit merely compares the value of an unknown component with that of an accurately known component (a standard), its measurement accuracy can be very high. This is because the readout of this comparison is based on the null indication at bridge balance, and is essentially independent of the characteristics of the null detector. The measurement accuracy is therefore directly related to the accuracy of the bridge component and not to that of the null indicator used.

The basic dc bridge is used for accurate measurement of resistance and is called Wheatstone's bridge.

Wheatstone Bridge Circuit(Measurement of Resistance):

Wheatstone's bridge is the most accurate method available for measuring resistances and is popular for laboratory use. The circuit diagram of a typical Wheatstone Bridge Circuit is given in Fig. 11.1. The source of emf and switch is connected to points A and B, while a sensitive current indicating meter, the galvanometer, is connected to points C and D. The galvanometer is a sensitive microammeter, with a zero centre scale. When there is no current through the meter, the galvanometer pointer rests at 0, i.e. mid scale. Current in one direction causes the pointer to deflect on one side and current in the opposite direction to the other side.

When SW_1 is closed, current flows and divides into the two arms at point A, i.e. I_1 and I_2. The bridge is balanced when there is no current through the galvanometer, or when the potential difference at points C and D is equal, i.e. the potential across the galvanometer is zero.

To obtain the bridge balance equation, we have from the Fig. 11.1.

$$I_1 R_1 = I_2 R_2 \tag{11.1}$$

For the galvanometer current to be zero, the following conditions should be satisfied.

$$I_1 = I_3 = \frac{E}{R_1 + R_3} \tag{11.2}$$

$$I_2 = I_4 = \frac{E}{R_2 + R_4} \tag{11.3}$$

Substituting in Eq. (11.1)

$$\frac{E \times R_1}{R_1 + R_3} = \frac{E \times R_2}{R_2 + R_4}$$

$$R_1 \times (R_2 + R_4) = (R_1 + R_3) \times R_2$$

$$R_1 R_2 + R_1 R_4 = R_1 R_2 + R_3 R_2$$

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

This is the equation for the bridge to be balanced.

In a practical Wheatstone Bridge Circuit, at least one of the resistance is made adjustable, to permit balancing. When the bridge is balanced, the unknown resistance (normally connected at R_4) may be determined from the setting of the adjustable resistor, which is called a standard resistor because it is a precision device having very small tolerance.

Hence $$R_x = \frac{R_2\,R_3}{R_1} \qquad (11.4)$$

Sensitivity of a Wheatstone Bridge

When the bridge is in an unbalanced condition, current flows through the galvanometer, causing a deflection of its pointer. The amount of deflection is a function of the sensitivity of the galvanometer. Sensitivity can be thought of as deflection per unit current. A more sensitive galvanometer deflects by a greater amount for the same current. Deflection may be expressed in linear or angular units of measure, and sensitivity can be expressed in units of S = mm/μA or degree/μA or radians/μA.

Therefore it follows that the total deflection D is D = S x 1, where S is defined above and I is the current in microamperes.

Applications of Wheatstone's bridge:

i. It can be used to measure the dc resistance of the wire.
ii. It can be used to measure the resistance of motor winding, transformers, solenoids and relay coils.
iii. This bridge is used to locate cable faults.

Limitations of Wheatstone's bridge:

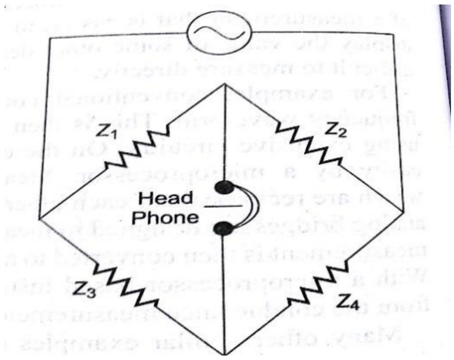
i) Resistance of the leads and contacts introduces error in low resistance measurement.
ii) At high resistance measurement, resistance of the bridge becomes large and galvanometer becomes insensitive to imbalance.
iii) Due to heating effect of current through the resistance, the values of the resistance
in the bridge arms changes.

Ac Bridges

Impedances at AF or RF are commonly determined by ac Wheatstone bridge. The ac bridge shown in the below figure consists of impedance in their bridge arms. The bridge is excited by an ac source rather than dc and galvanometer is replaced by a detector for detecting ac. At balance condition,

$$\frac{Z1}{Z3} = \frac{Z2}{Z4}$$

Where, Z1,Z2,Z3,Z4 are the impedances of the arms and are vector complex quantities that possess phase angles. The bridge must be balanced for both the reactance and resistive component.



Comparison Bridge:

There are two types of Comparison Bridge, Namely

1.Capacitance Comparison Bridge

2.Inductance Comparison Bridge

1.Capacitance Comparison Bridge

Figure 11.18 shows the circuit of a capacitance comparison bridge. The ratio arms R_1, R_2 are resistive. The known standard capacitor C_3 is in series with R_3. R_3 may also include an added variable resistance needed to balance the bridge. C_x is the unknown capacitor and R_x is the small leakage resistance of the capacitor. In this case an unknown capacitor is compared with a standard capacitor and the value of the former, along with its Fig. 11.18 me Capacitance Comparison leakage resistance, is obtained. Hence.

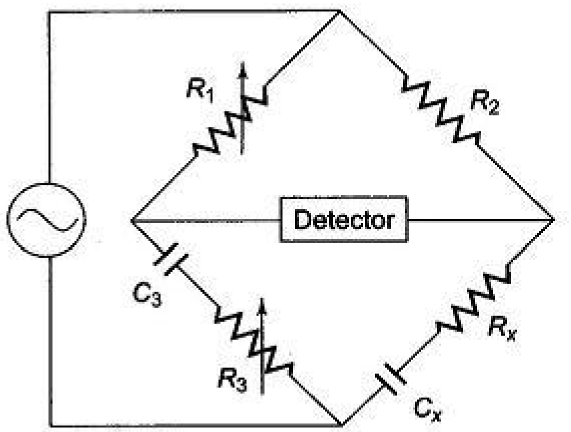


Fig. 11.18 Capacitance Comparison Bridge

$Z_1 = R_1$

$Z_2 = R_2$

$Z_3 = R_3$ in series with $C_3 = R_3 - j/\omega C_3$

$Z_x = R_x$ in series with $C_x = R_x - j/\omega C_x$

The condition for balance of the bridge is

$$Z_1 Z_x = Z_2 Z_3$$

i.e. $$R_1\left(R_x - \frac{j}{\omega C_x}\right) = R_2\left(R_3 - \frac{j}{\omega C_3}\right)$$

$\therefore$ $$R_1 R_x - \frac{jR_1}{\omega C_x} = R_2 R_3 - \frac{jR_2}{\omega C_3}$$

Two complex quantities are equal when both their real and their imaginary terms are equal. Therefore,

i.e. $$R_1 R_x = R_2 R_3 \qquad \therefore R_x = \frac{R_2 R_3}{R_1} \qquad [11.12(a)]$$

and $$\frac{R_1}{\omega C_x} = \frac{R_2}{\omega C_3} \qquad C_x = \frac{C_3 R_1}{R_2} \qquad [11.12(b)]$$

Since R_3 does not appear in the expression for C_x, as a variable element it is an obvious choice to eliminate any interaction between the two balance controls.

2.Inductance Comparison Bridge

Figure 11.20 gives a schematic diagram of an inductance comparison bridge. In this, values of the unknown inductance L_x and its internal resistance R_x are obtained by comparison with the standard inductor and resistance, i.e. L_3 and R_3.

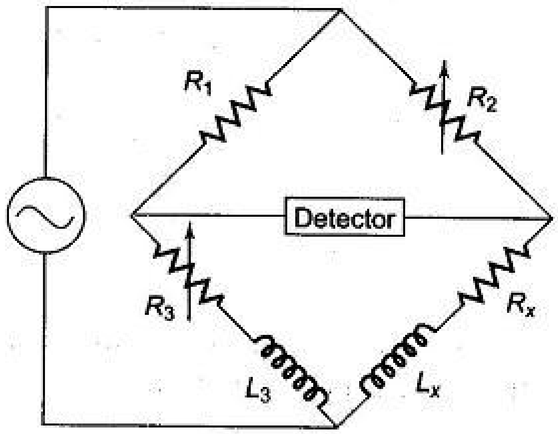


Fig. 11.20 Inductance Comparison Bridge

The equation for balance condition is

$$Z_1 Z_x = Z_2 Z_3$$

The inductive balance equation yields

$$L_x = \frac{L_3 R_2}{R_1} \qquad [11.13(a)]$$

and resistive balance equations yields

$$R_x = \frac{R_2 R_3}{R_1} \qquad [(11.13(b)]$$

In this bridge R_2 is chosen as the inductive balance control and R_3 as the resistance balance control. (It is advisable to use a fixed resistance ratio and variable standards). Balance is obtained by alternately varying L_3 or R_3. If the Q of the unknown reactance is greater than the standard Q, it is necessary to place a variable resistance in series with the unknown reactance to obtain balance.

If the unknown inductance has a high Q, it is permissible to vary the resistance ratio when a variable standard inductor is not available.

Wien Bridge Circuit Diagram:

The Wien Bridge Circuit Diagram shown in Fig. 11.27 has a series RC combination in one arm and a parallel combination in the adjoining arm. Wien's bridge in its basic form, is designed to measure frequency. It can also be used for the measurement of an unknown capacitor with great accuracy.

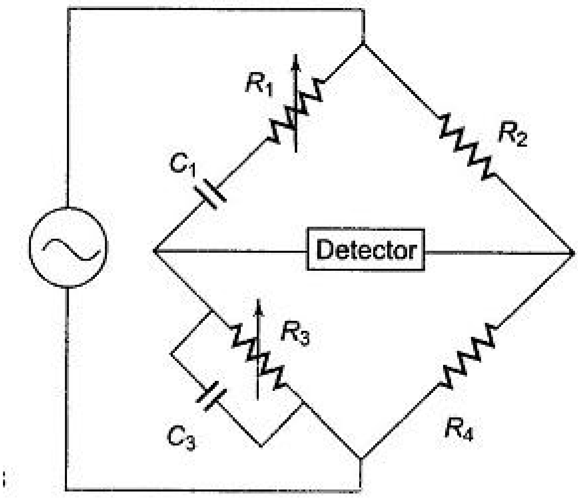


Fig. 11.27 Wien's Bridge

The impedance of one arm is

$$Z_1 = R_1 - j/\omega C_1$$

The admittance of the parallel arm is

$$Y_3 = 1/R_3 + j\,\omega\,C_3$$

Using the bridge balance equation,

we have

$$Z_1\,Z_4 = Z_2\,Z_3$$

Therefore,

$$Z_1\,Z_4 = Z_2/Y_3,\text{ i.e. } Z_2 = Z_1\,Z_4\,Y_3$$

$$R_2 = R_4\left(R_1 - \frac{j}{\omega C_1}\right)\left(\frac{1}{R_3} + j\omega C_3\right)$$

$$R_2 = \frac{R_1\,R_4}{R_3} - \frac{j\,R_4}{\omega C_1\,R_3} + j\,\omega\,C_3\,R_1\,R_4 + \frac{C_3\,R_4}{C_1}$$

$$R_2 = \left(\frac{R_1\,R_4}{R_3} + \frac{C_3\,R_4}{C_1}\right) - j\left(\frac{R_4}{\omega C_1\,R_3} - \omega\,C_3\,R_1\,R_4\right)$$

Equating the real and imaginary terms we have

$$R_2 = \frac{R_1 R_4}{R_3} + \frac{C_3 R_4}{C_1} \text{ and } \frac{R_4}{\omega C_1 R_3} - \omega C_3 R_1 R_4 = 0$$

Therefore $$\frac{R_2}{R_4} = \frac{R_1}{R_3} + \frac{C_3}{C_1} \qquad (11.21)$$

and $$\frac{1}{\omega C_1 R_3} = \omega C_3 R_1 \qquad (11.22)$$

$\therefore$ $$\omega^2 = \frac{1}{C_1 R_1 R_3 C_3}$$

$$\omega = \frac{1}{\sqrt{C_1 R_1 C_3 R_3}}$$

as $$\omega = 2\pi f$$

$\therefore$ $$f = \frac{1}{2\pi\sqrt{C_1 R_1 C_3 R_3}} \qquad (11.23)$$

The two conditions for bridge balance, (11.21) and (11.23), result in an expression determining the required resistance ratio R_2/R_4 and another expression determining the frequency of the applied voltage. If we satisfy Eq. (11.21) and also excite the bridge with the frequency of Eq. (11.23), the bridge will be balanced.

In most Wien Bridge Circuit Diagram, the components are chosen such that $R_1 = R_3 = R$ and $C_1 = C_3 = C$. Equation (11.21) therefore reduces to $R_2/R_4 = 2$ and Eq. (11.23) to f=112KRC, which is the general equation for the frequency of the bridge circuit.

The bridge is used for measuring frequency in the audio range. Resistances R_1 and R_3 can be ganged together to have identical values. Capacitors C_1 and C_3 are normally of fixed values.

The audio range is normally divided into 20 — 200 — 2 k — 20 kHz ranges. In this case, the resistances can be used for range changing and capacitors C_1 and C3 for fine frequency control within the range. The Wien Bridge Circuit Diagram can also be used for measuring capacitances. In that case, the frequency of operation must be known.

The bridge is also used in a harmonic distortion analyzer, as a Notch filter, and in audio frequency and radio frequency oscillators as a frequency determining element.

An accuracy of 0.5% — 1% can be readily obtained using this bridge. Because it is frequency sensitive, it is difficult to balance unless the waveform of the applied voltage is purely sinusoidal.

Module 5

Transducers

Introduction:

Transducer is a device that receives energy from one system and transmits it to another, often in a different form. It is capable of being actuated by an energising input from one or more transmission media and in turn generating a related output to one or more transmission systems. The energy transmitted by these systems may be electrical, mechanical or acoustical(branch of physics that relates to waves in gases, liquids). Depending on the design, transducer output may be analog, digital or frequency modulated. There are two types- electrical and mechanical transducers.

Electrical Transducer:

It 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 quantity or measureand.
An electrical transducer must have the following properties:

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. This should be high.
3. Dynamic range: the operating range of the transducer should be wide, to use it under a wide range of conditions.
4. Repeatability: the input output relationship for a transducer should be predictable over a long period of time.
5. Physical size: transducer must have minimal weight and volume, so that its presence does not disturb the existing condition

Advantages of electrical transducers:

- Amplification and attenuation of the signal can be easily done.
- Mass-inertia effects and frictional effects can be minimised.
- Transducer outputs can be recorded at a remote area from the sensing medium.
- Output can be modified to meet the requirements of controlling units.
- Signals of similar transducers can be conditioned to obtain any combination.
- Electrical transducers can be controlled with a small power level.
- Signal can be used, transmitted and processed for further measurement.

They are classified as active and passive transducers:
Active transducer: they generate an electrical signal directly in response to the physical parameter and does not require an external power source for its operation. They are self generating devices, which operate under energy conversion principle and generate equivalent output signal. Ex, piezoelectric sensors (converts input pressure to output electric potential) and photovoltaic cells(converts incident light rays to output voltage)

Passive transducer: external electrical source is used here to convert energy. They depend on the change in an electrical parameter(R, L or C) of the sensing element of the transducer.

ex, strain gauges(resistance changes in response to pressure) and thermistors(resistance changes corresponding to temperature). Here, sensing element converts the physical quantity into displacement. Displacement actuates secondary transducer and gives an electrical output proportional to the physical quantity or input. This electrical output is used for measurement.

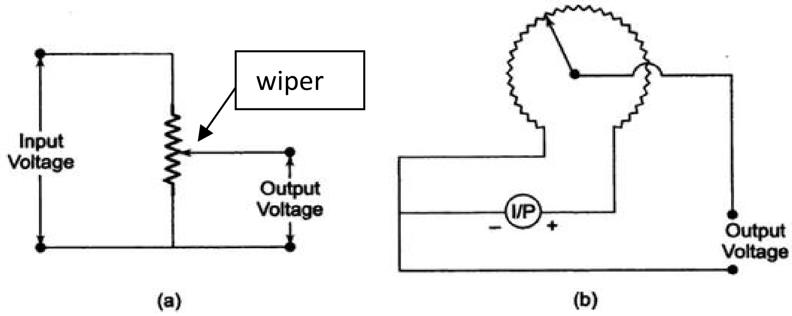
Selecting a transducer: Following factors have to be considered while selecting a transducer.

1. Operating range: It is chosen to maintain range requirements and good resolution.
2. Sensitivity: chosen to allow sufficient output.
3. Frequency response and resonant frequency: remain 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 input
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 load intensities versus size and weight of the transducer.
8. Electrical parameters: Length and type of cable required, signal to noise ratio when combined with amplifiers, and frequency response limitations.

Resistive transducer (passive transducers):

In these transducers, the resistance changes due to a change in some physical phenomenon. In strain gauges, resistance of a conductor or semiconductor changes when strained. This change can be used to measure displacement, force and pressure.

1. Potentiometer(Pot): a resistive potentiometer consists of a resistance element provided with a sliding contact called a wiper. The motion of the sliding contact may be translatory or rotational. Translatory resistive elements are linear, rotational elements are circular and helical resistive elements are multiturn rotational devices which can be used for measuring translator or rotator motion. Potentiometer is a passive transducer since it requires an external power source for its operation. Potentiometers are inexpensive and simple in operation. Large amplitudes of displacement can be measured. Electrical efficiency is also very high.



Here, displacement of wiper changes resistance of pot. This resistance generates a voltage proportional to it. Hence displacement of wiper is measured in terms of voltage. Disadvantage of pot is that the wiper may wear out, become misaligned and generate noise.

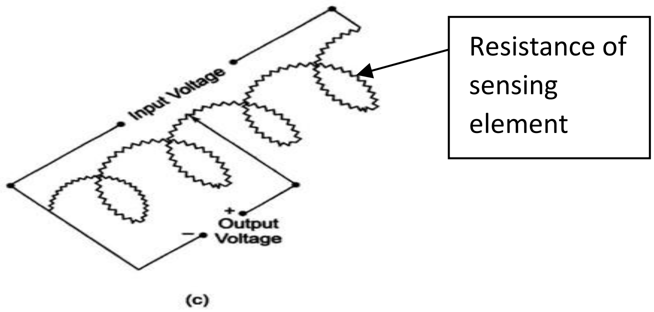


Fig1: a) translatory type b) rotational type c)Helipot type

2. Resistance pressure transducer:

Here, a change in the pressure results in a resistance change in the sensing elements. The electromechanical and strain gauge transducers are used for stress, position and displacement measurements. Figure 2 shows two ways by which the pressure acts to influence the sensitive resistance element. They are the bellow(a) and diaphragm(b) type. In each of these types, the element moved by the pressure change causes a change in the resistance of element. This change can be made part of a bridge circuit and taken as dc or ac output signal to indicate the applied pressure.

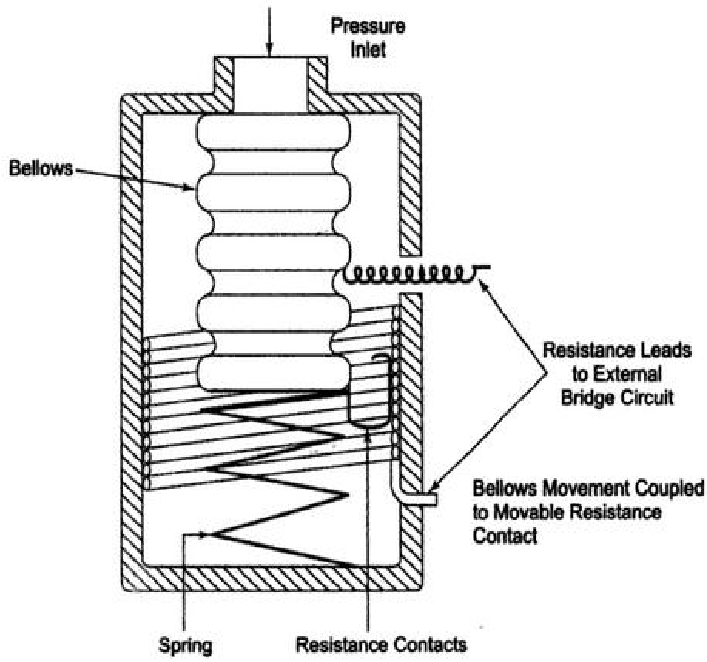


Fig 2: a) Resistance pressure type

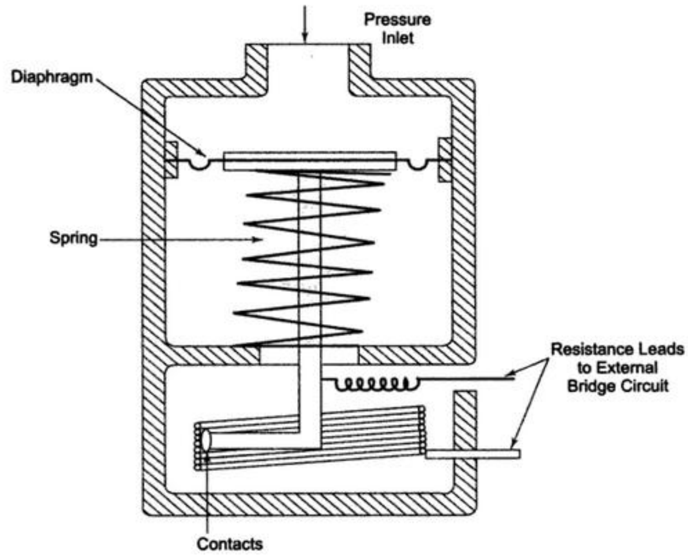


Fig 2 b) Sensitive diaphragm moves the resistance contact

Resistive position transducer:

In resistive transducer, the physical variable under measurement causes a resistance change in the sensing element. Sometimes, the position of the object or the distance of its movement needs to be measured. This displacement transducer uses a resistive element with a sliding contact or wiper linked to the object being monitored. Thus the resistance between the slider and one end of the resistance element depends on the position of the object. Figure 3a) shows the construction and b) shows the method of use. The output voltage depends on the wiper position and is therefore a function of shaft position. In fig b), if the circuit is unloaded, the output voltage V_o is a function of V_t, depending on the position of the wiper.

$$\frac{\mathbf{Vo}}{\mathbf{Vt}} = \frac{\mathbf{R2}}{\mathbf{R1+R2}}$$

When applied to resistive position sensors, this equation shows that output voltage is proportional to R_2, ie, the position of the wiper.

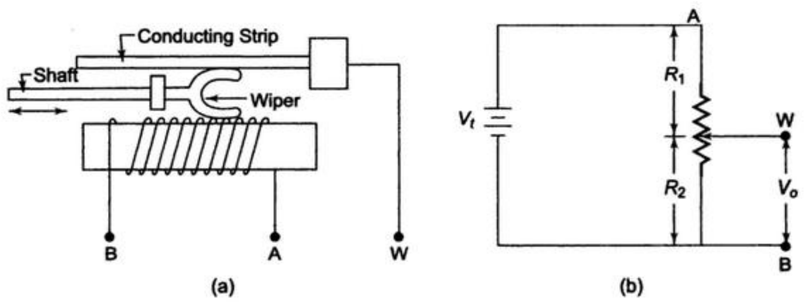


Fig 3: a) Construction b) typical method

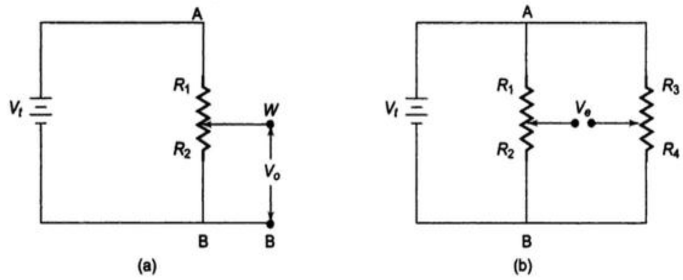
Example 1: A displacement transducer with a shaft stroke of 3 in, is applied to the circuit of fig 3 b). The total resistance of the potentiometer is 5KΩ. The applied voltage V_t is V. When the wiper is 0.9 in from B, what is the value of the output voltage?

Solution:

$$R_2 = \frac{0.9\text{ in.}}{3.0\text{ in.}} \times 5\text{ k} = \frac{9}{30} \times 5\text{ k} = 1500\ \Omega$$

Therefore $$\frac{V_o}{V_t} = \frac{R_2}{R_1 + R_2};\ V_o = \frac{R_2}{R_1 + R_2} \times V_t$$

$$V_o = \frac{1500}{5\text{ k}} \times 5\ V = \frac{1500}{1\text{ k}} = 1.5\ V$$



Strain Gauges:

Strain gauge is a passive transducer that uses variation in electrical resistance in wires to sense the strain produced by a force on the wires. Transducers used to measure strain as a index of pressure are known as strain gauges. If a metal conductor is stretched or compressed, its resistance changes due to change in length and diameter of the conductor. Resistivity, hence resistance of the conductor changes when subjected to strain due to property called piezoresistive effect. Hence, resistance strain gauges are known as **piezo resistive gauges**. Load cells, torque meters pressure gauges etc employ strain gauges as secondary transducers.

1.Resistance wire gauge:

a. Unbonded resistance wire gauge: An unbonded strain gauge consists of a wire stretched two points in an insulating medium, such as air. Diameter of wire is 25µm. The wires are kept under tension so that there is no sag and no free vibration. It is connected in a bridge circuit. Under external load, resistance of the strain gauge changes, creating an unbalance in the circuit resulting in an output voltage proportioal to the strain. Displacement of 50µm can be detected with these strain gauges.

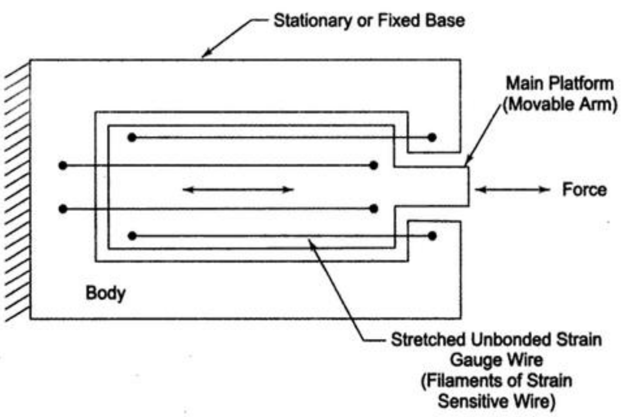


Fig: unbonded strain gauge

b. Bonded resistance wire gauge: A fine wire is looped back and forth on a carrier or mounting plate, which is cemented to the member undergoing stress. Wire is cemented on a carrier(paper, bakelite or teflon)or supporting base. It is then bonded to the device whose strain needs to be calculated. This permits a good transfer of strain from carrier to wire. The wire is covered with a thin material on the top to prevent damage. A tensile stress elongates the wire and increases its length and decrease its cross sectional area.

The change in the guage resistance and the change in its length will measure the strain applied to the device under study. The resistance increases when length increases and area decreases. The measurement of sensitivity of a material to strain is called the **gauge factor(GF).**

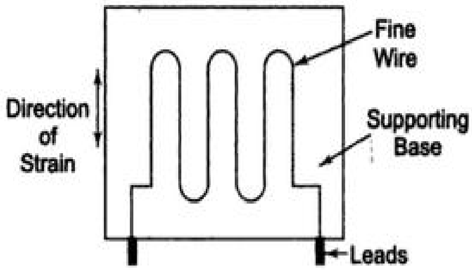


Fig: bonded resistance wire strain gauge

i.e. $$\text{GF } (K) = \frac{\Delta R/R}{\Delta l/l} \longrightarrow \boxed{1}$$

where $K =$ gauge factor

$\Delta R =$ the change in the initial resistance in Ω's

$R =$ the initial resistance in Ω (without strain)

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

Equation 1 can be written as,

$$K = \frac{\Delta R/R}{\sigma}$$

Where,σ is the strain in the lateral direction

The resistance of a conductor of uniform cross-section is

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

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

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

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

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

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

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

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

$$\mu = \frac{\Delta d/d}{\Delta l/l} \tag{13.5}$$

$$\frac{\Delta d}{d} = \mu \frac{\Delta l}{l} \tag{13.6}$$

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

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

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

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

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

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),

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

$$R_s = R + \Delta R \qquad (13.7)$$

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

The gauge factor will now be

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

$$= 1 + 2\mu$$

$$K = 1 + 2\mu \qquad (13.8)$$

The gauge factor can be derived as, K= 1+2µ.(Derivation)

Resistance Thermometer Transducer:

The resistance of a conductor changes when its temperature is changed. This property is utilised for the measurement of temperature. The Resistance Thermometer Transducer is an instrument used to measure electrical resistance in terms of temperature, i.e. it uses the change in the electrical resistance of the conductor to determine the temperature.

The main part of a resistance thermometer is its sensing element. The characteristics of the sensing element determines the sensitivity and operating temperature range of the instrument.

(There are three common types of temperature sensitive resistive elements in use, the wire wound resistance, the thermistor and the PTC semiconductor resistance.)

The sensing element may be any material that exhibits a relatively large resistance change with change in temperature. Also, the material used should be stable in its characteristics, i.e. neither its resistance nor its temperature coefficient of resistance should undergo permanent change with use or age.

To maintain the calibration of a resistance thermometer, it is necessary to consider its stability. The need for stability frequently limits the temperature range over which the sensing element may be used.

Another desirable characteristic for a sensing element is a linear change in resistance with change in temperature.

The speed with which a resistive element responds to changes in temperature is important when the measured temperature is subjected to rapid variations. The smaller a given sensing element, the less heat required to raise its temperature, and the faster its response.

Platinum, nickel and copper are the metals most commonly used to measure temperature. The resistivity of platinum tends to increase less rapidly at higher temperatures than for other metals, hence it is a commonly used material for resistance thermometers. The temperature range over which platinum has stability is — 260-1100°C.

Figure 13.11(a) shows an industrial platinum resistance thermometer. The changes in resistance caused by changes in temperature are detected by a Wheatstone bridge, as shown in Fig. 13.11(b). Hence, the temperature sensing element, which may be nickel, copper or platinum contained in a bulb or well, along with the balancing bridge, form the essential components of a temperature measuring system based upon this principle.

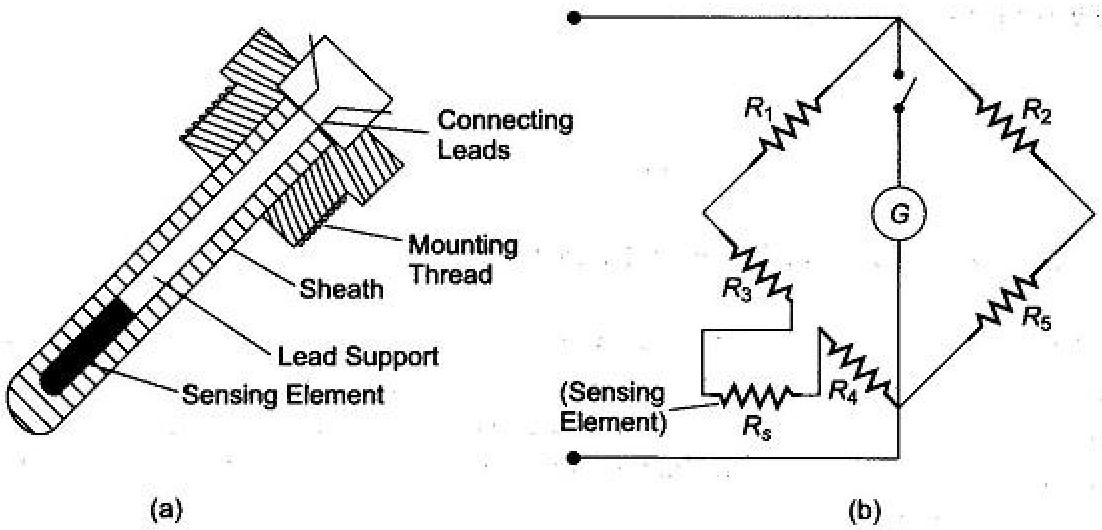


Fig. 13.11 (a) Industrial Platinum Resistance Thermometer (b) Bridge Circuit

The sensing element R_s is made of a material having a high temperature coefficient, and R_1, R_2, and R_5 are made of resistances that are practically constant under normal temperature changes.

When no current flows through the galvanometer, the normal principle of Wheatstone' s bridge states the ratio of resistance is

$$\frac{R_1}{R_2} = \frac{R_s}{R_5}$$

In normal practice, the sensing element is away from the indicator, and its leads have a resistance, say R_3, R_4.

Therefore,

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

Now it resistance R_s changes, balance cannot be maintained and the galvanometer shows a deflection, which can be calibrated to give a suitable temperature scale.

Advantages of Resistance Thermometer Transducer

The measurement of temperature by the electrical resistance method has the following advantages and characteristics.

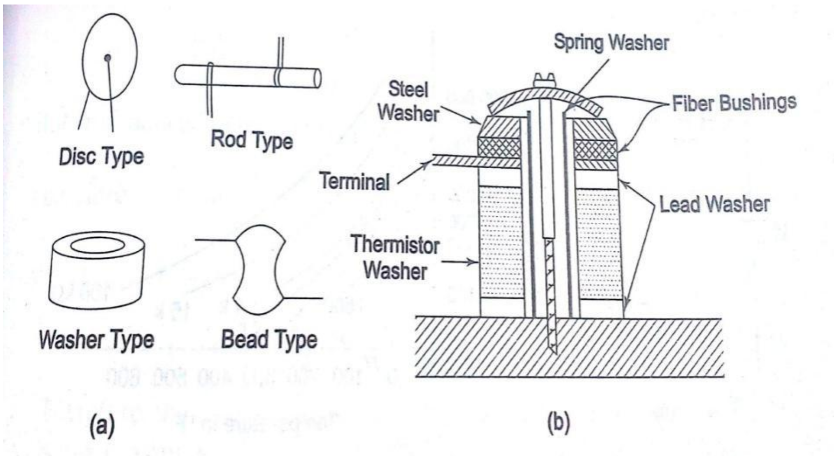
1. The measurement is very accurate.
2. It has a lot of flexibility with regard to choice of measuring equipment.
3. Indicators, recorders or controllers can also be operated.
4. More than one resistance element can be clubbed to the same indicating/ recording instrument.
5. The temperature sensitive resistance element can be easily installed and
6. The accuracy of the measuring circuit can be easily checked by substituting a standard resistor for the resistive element.
7. Resistive elements can be used to measure differential temperature.
8. Resistance thermometers have a wide working range without loss of accuracy, and can be used for temperature ranges (-200°C to + 650°C).
9. They are best suited for remote indication.
10. The resistive element response time is of the order of 2 to lOs
11. The limits of error of a resistive element are ± 0.25% of the scale reading.
12. The size of the resistive element may be about 6 — 12 mm in diameter and 12 — 75 mm in length.
13. Extremely accurate temperature sensing.
14. No necessity of temperature compensation.
15. Stability of performance over long periods of time.

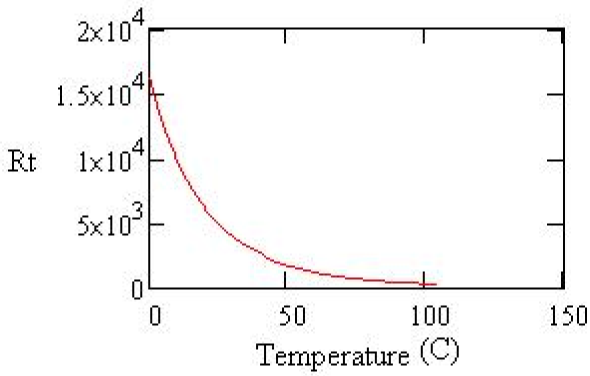
Limitations of Resistance Thermometer Transducer

1. High cost
2. Need for bridge circuit and power source
3. Possibility of self-heating
4. Large bulb size, compared to a thermocouple

Thermistors:

Thermistors are non-metallic resistors made by combinations of metallic oxides such as manganese, nickel, cobalt, copper and uranium. They have a negative temperature coefficient(NTC) i.e resistance decreases when temperature increases. The resistance of some thermistors at room temperature decrease by 5% for each 1°C temperature rise. Hence they are extremely useful in precision temperature measurements, control and compensation. They are bead, washer, rod and disc type. Thermistors can be connected in series or parallel combinations for applications requiring increased power handling capability. They are chemically stable and can be used in nuclear environments. Their wide range of characteristics permits them to be used in limiting and regulation circuits, as time delays, for integration of power pulses and as memory units. Thermistor typesare shown in figure a). Fig b) shows a bush type thermistor. Thermistors are connected in one arm of wheatstone's bridge to provide temperature information.





Advantages:

- Sensitivity of thermistor is approximately 3mV/°C at 200°C.
- They are small in size,
- low cost,
- good sensitivity in NTC region
- fast response over narrow temperature range.
- Contact and lead resistance problems are not encountered.

Limitations:

- These are non-linear in resistance vs temperature characteristics
- Require shielded power lines, filters etc due to high resistance.
- Very low excitation current has to be given to avoid self heating.

Different types of thermistors:

a. ***Bead type:*** they are glass coated or sealed in tip of solid glass probes. Diameter of glass probes is 2.5mm and length from 6-50mm.Temperature of liquids is measured by probes. Resistance is from 300-100MΩ.
b. ***Disc type:*** they are self supporting or mounted on samll plate and used for temperature control. They are made by pressing thermistor material under tons of pressure in a round die to produce thickness of 0.25-0.75mm. resistance of this type ranges from 1Ω-1M Ω. They have silver coating on both surfaces.
c. ***Washer type:*** these are similar to disc type but has home in the centre.they are suited to mount on a bolt.
d. ***Rod type:*** long cylindrical units of 1.25,2.75,4.25mm dia and 12.5-50mm long. Resistance varies from 1-50KΩ. Leads are brought out at ends of rods. Has high power handling capability.

Linear Variable Differential Transducer (LVDT):

The construction of linear variable differential transducer(LVDT) is shown in below. The transformer consists of one primary winding P_1 and two equal secondary windings S_1 and S_2 wound on a hollow cylindrical former. The primary winding is connected to an ac source. A movable soft iron core slides within the hollow former and affects the magnetic coupling between the primary and the secondaries. The displacement to be measured is applied to an arm attached to the iron. When the core is in the normal position, equal voltages are induced in S_1 and S_2.To convert the output from S_1 and S_2 into a single voltage, the two secondaries are connected in series opposition, as shown in fig 1). Hence the output voltage is the difference of the two voltages. At normal position, the flux linking, hence emf's with the secondaries are equal. $E_{s1}=E_{s2}$. Output voltage E_0 is zero at null. When core is at left of null position, E_{s1} is greater than E_{s2} since more flux links with S_1. Output is now $E_{s1}-E_{s2}$. When moved right, output is $E_{s2}-E_{s1}$. Movement of core indicates the change in voltage in either secondary winding. This indicates the linear motion. The direction of motion can be determined with the increasing or decreasing output. As the core passes the centre position, the output ac voltage is inverted. The amplitude of the output voltage is the function of the distance the core has moved and polarity indicates the direction of motion. The output signal measures the displacement. It can be applied to a recorder or to a controller that restores the moving system to its original position.

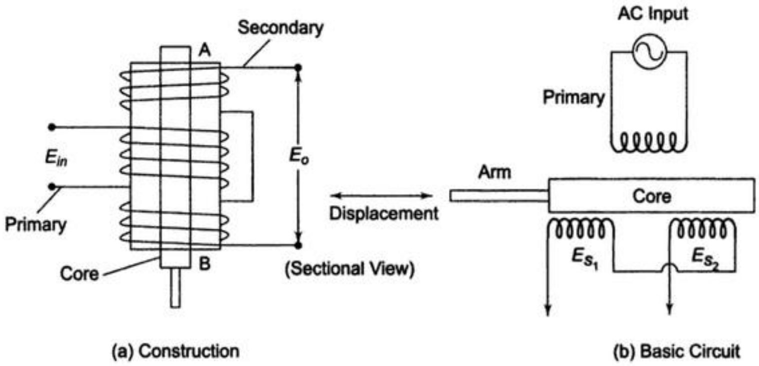


Fig 1): secondary winding connected to differential output

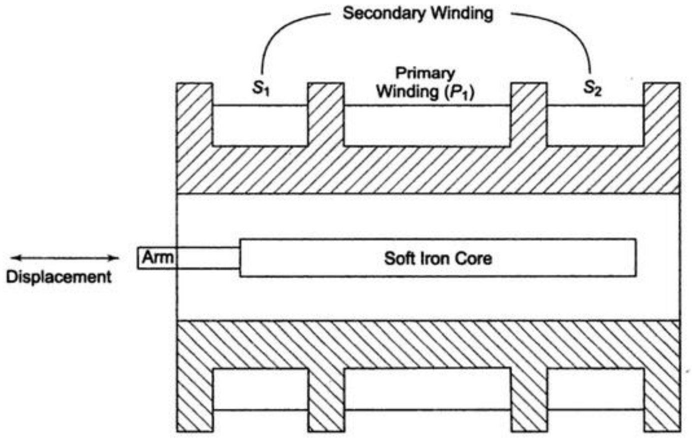


Fig 2) LVDT

Advantages:

1. It produces higher output voltage for small changes in core position. Hence no need for amplification devices.
2. Sensitivity as high as 40V/mm is available
3. The output voltage is practically linear for displacement upto 5mm.
4. The change in the output voltage is stepless. i.e, the transducer has infinite resolution.
5. These transducers can tolerate a high degree of vibration and shock.
6. Transducer has low hysteresis, hence measurements are repeatable under all conditions.
7. Power consumption of these transducers is less than 1W.

Disadvantages:

1. Large displacements are required for appreciable differential output
2. Sensitive to stray magnetic field.
3. The instrument at the receiving end must be able to operate on ac signals.
4. Transducers are also affected by temperature.

Instrumentation Amplifier using Transducer Bridge

Figure 14.25 shows a simplified circuit of a Differential Instrumentation Amplifier Transducer Bridge.

In this circuit a resistive transducer (whose resistance changes as a function of some physical energy) is connected to one arm of the bridge.

Let R_T be the resistance of the transducer and ΔR the change in resistance of theresistive transducer. Hence the total resistance of the transducer is $(R_T \pm \Delta R)$.

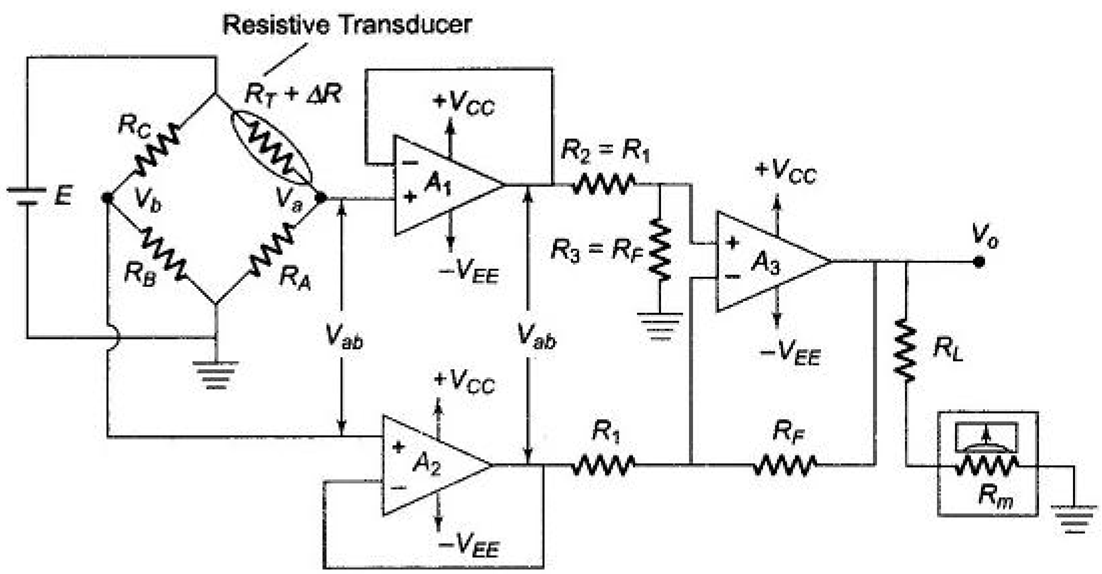


Fig. 14.25 Differential Instrumentation Amplifier using Transducer Bridge

The condition for bridge balance is Vb = Va, i.e. the bridge is balanced when Vb = Va, or when

$$\frac{R_B(E)}{R_B + R_C} = \frac{R_A(E)}{R_A + R_T}$$

Therefore, $$\frac{R_c}{R_B} = \frac{R_T}{R_A}$$

The bridge is balanced at a desired reference condition, which depends on the specific value of the physical quantity to be measured. Under this condition, resistors RA, RB and RC are so selected that they are equal in value to the transducer resistance RT. (The value of the physical quantity normally depends on the transducers characteristics, the type of physical quantity to be measured, and the desired applications.)

Initially the bridge is balanced at a desired reference condition. As the physical quantity to be measured changes, the resistance of the transducer also changes, causing the bridge to be unbalanced (Vb #). Hence, the output voltage of the bridge is a function of the change in the resistance of the transducer. The expression for the output voltage V0, in terms of the change in resistance of the transducer is calculated as follows.

Let the change in the resistance of the transducer be ΔR. Since RB and RC are fixed resistors, the voltage Vb is constant, however, the voltage Va changes as a function of the change in the transducers resistance.

Therefore, applying the voltage divider rule we have

$$V_a = \frac{R_A(E)}{R_A + (R_T + \Delta R)} \text{ and } V_b = \frac{R_B(E)}{R_B + R_C}$$

The output voltage across the bridge terminal is Vab, given by Vab=Va-Vb

Therefore,

$$V_{ab} = \frac{R_A(E)}{R_A + (R_T + \Delta R)} - \frac{R_B(E)}{R_B + R_C}$$

$R_A = R_B = R_C = R_T = R$, then

$$V_{ab} = \frac{R(E)}{2R + \Delta R} - \frac{R(E)}{2R} = E\left(\frac{R}{2R + \Delta R} - \frac{1}{2}\right)$$

$$V_{ab} = E\left(\frac{2R - 2R - \Delta R}{2(2R + \Delta R)}\right) = \frac{-\Delta R(E)}{2(2R + \Delta R)} \qquad (14.15)$$

The output voltage Vab of the bridge is applied to the Differential Instrumentation Amplifier Transducer Bridge through the voltage followers to eliminate the loading effect of the bridge circuit. The gain of the basic amplifier is (RF/R1) and therefore the output voltage Vo of the circuit is given by

$$V_o = V_{ab}\left(\frac{R_F}{R_1}\right) = \frac{-\Delta R(E)}{2(2R + \Delta R)} \times \frac{R_F}{R_1} \qquad (14.16)$$

It can be seen from the Eq. (14.16) that Vo is a function of the change in resistance ΔR of the transducer. Since the change is caused by the change in a physical quantity, a meter connected at the output can be calibrated in terms of the units of the physical quantity.

Applications of Instrumentation Amplifier Transducer Bridge

We shall now consider some important applications of instrumentation amplifiers using resistance types transducers. In these transducers, the resistance of the transducer changes as a function of some physical quantity. Commonly used resistance transducers are thermisistors, photoconductor cells, and strain gauges.

Temperature Indicators Using Thermistor

The Thermistor is a relative passive type of temperature resistance transducer. They are basically semiconductors.

In many respects, a thermistor resembles a conventional resistor. It is usually a two-terminal device. It has resistance as its fundamental property. It is generally installed and operated in the manner of an ordinary resistor. But its great difference is that it has a negative temperature coefficient (NTC) or positive temperature coefficient (PTC) type. Most thermistors exhibit an NTC characteristic. An NTC type is one in which its resistance decreases with increase in temperature. The temperature coefficient is expressed in ohms/°C.

Since it is a THERMally sensitive resISTOR, it has a high temperature coefficient of resistance and is therefore well suited for temperature measurement and control.

If in the bridge circuit of Fig. 14.25 the transducer used is a thermistor, the circuit can thus be used as a temperature indicator. The output meter is then calibrated in °C or °F. The bridge is balanced initially at a desired reference condition. As the temperature varies, the resistance of the thermistor also changes, unbalancing the bridge, which in turn produces a meter deflection at the output. By selecting the appropriate gain for the Differential Instrumentation Amplifier Transducer Bridge, the meter can be calibrated to read a desired temperature. In this circuit, the meter movement (deflection) depends on the amount of unbalance in the bridge, which is caused by a change in the value of thermistor resistance ΔR. The change ΔR for the thermistor can be determined as follows.

$$\Delta R = \text{temperature coefficient of resistance} \; [\text{final temperature} - \text{reference tamperature}]$$

If the meter in this circuit is replaced by a relay, and if the output of the Differential Instrumentation Amplifier Transducer Bridge drives the relay that controls the current in the heat-generating circuit, a temperature controller can be formed. A properly designed circuit should energise a relay when the temperature of the thermistor drops below a desired value, causing the heater unit to turn on.

Analog Weight Scale

Figure 14.25 can be converted into a simple analog weight scale by connecting strain gauges in the bridge circuit. These strain gauges are connected in all the four arms of the bridge,as shown in Fig. 14.26. The strain gauge elements are mounted on a base of the specially made weight platform, on which an external force or weight is placed. One pair of strain gauge elements in opposite arms elongates, (i.e. RT1 and RT3both increases in resistance) while the other pair compresses (RT2 and RT4 both decreases in resistance), and vice-versa.

The bridge is balanced when no external force or weight is applied, i.e. RTI = RT2 = RT3 = RT4 = R, and the output voltage of the weight scale is zero.

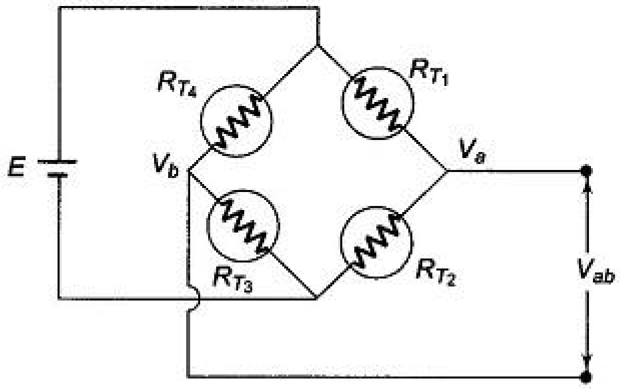


Fig. 14.26 Strain Gauge Bridge Circuit for Analog Weight Scale

Suppose a weight is placed on the scale platform and RT1 and RT3increases in resistance. Then RT2 and RT4 decrease in resistance by the same value AR and the bridge is unbalanced, thereby giving an unbalanced output voltage. This unbalanced voltage Vab, is given by

$$V_{ab} = + E\left(\frac{\Delta R}{R}\right)$$

Where ,E — excitation voltage of the bridge.

R = RT1 = RT2= RT3 = RT4 = unstrained gauge resistance

ΔR — change in gauge resistance.

The Differential Instrumentation Amplifier Transducer Bridge then amplifies the voltage Vab, giving a deflection on the meter movement. As the gain of the amplifier is (+ RF/R1), the output voltage Vo is given by

$$V_o = E \times \left(\frac{\Delta R}{R}\right) \times \left(\frac{R_F}{R_1}\right)$$

The gain of the amplifier is selected depending on the sensitivity of the strain gauge and on the full scale deflection requirements of the meter. The meter can be then calibrated in grams or kilograms.

For better accuracy and resolution, a micro based digital weight scale may be constructed. However, such a scale is much more complex and expensive then the analog scale.

(Programmable Logic Controller or Programmable Controller):

PLC Definition – Programmable Logic Controller (PLC) or commonly simply called a Programmable Controller, is a solid state, digital, industrial computer.

It is a device that was invented to replace the necessary sequential relay circuits for machine control. The PLC basically operates by looking at its inputs and depending upon their state, turning on/off its output. The user enters a program, normally through software, that gives the desired results.

PLCs are used in many real world applications such as machining, packaging, material handling, automated assembly, etc. Almost any applications that need some type of electrical control has a need for a PLC.

Let's assume that when a switch turns ON, we want to turn a solenoid ON for 10 seconds and then turn it OFF regardless of how long the switch is ON for. This can be done by a simple external timer. But if the process included 10 or more switches and solenoids, then we would need 10 or more external timers. But if the processes also needed to count how many times the switches individually turned ON, then a lot of external counters would be needed. As can be seen, the bigger the process, the more important is the need of a PLC. The PLC can be simply programmed to count its inputs and turn the solenoids ON for the specified time.

Since the PLC is a computer it should be told what to do. The PLC knows what to do through a program that is developed and then entered into its memory. The PLC however, without a set of instructions, is just a black box . consisting of electronic components only.

A PLC can control devices such as limit switches, push button, proximity or photo-electric sensors, float switches or pressure switches, etc. to provide the incoming control signals into the unit. The incoming control signal is called the

INPUT. These control signals or inputs, interact with the instructions specified in the user program, telling the PLC how to react to the incoming signals. The user program also directs the PLC on how to control field devices such as motor starters, pilot lamps and solenoids. A signal going out of the PLC control to a field device is called an OUTPUT.

PLC can also be defined as per National Electrical Manufacturer Association (NEMA) as a digitally operated electronic system, designed for use in industrial environment, which uses a programmable memory for internal storage of user-oriented instructions for implementing specific functions such as logic, sequencing, timing, counting and arithmetic to control, through digital or analog inputs and outputs, various types of machines or processes. Both the PLC Definition and its associated peripherals are designed so that they can be easily integrated into an industrial control system and easily used in all intended functions.

PLC Structure:

The PLC Structure mainly consists of a CPU, memory areas, and appropriate circuits to receive input/output data as shown in Fig. 21.22. A PLC can be considered as a box full of hundreds of thousands of separate relays, counters, timers and data storage locations. (These counters, timers, etc. really do not exists physically but rather they are simulated and can be considered software counters, timers, etc). These internal relays are simulated through bit locations in registers.

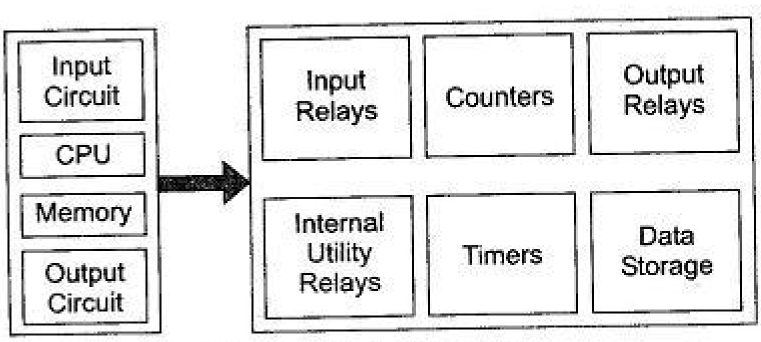


Fig. 21.22 PLC structure

The PLC structure consists of the following

1. **Input Relays:** (Contacts) These are connected to the outside world. They physically exist and receive signals from switches, sensors, etc. Typically they are not relays but are transistors.
2. **Internal Utility Relay:** (Contacts) These do not receive signals from the outside world nor do they physically exist. They are simulated relays and are what enables a PLC to eliminate external relays. There are also some special relays that are dedicated to performing only one task. Some are always ON

while some are always OFF. Some are ON only once during Power-on and are typically used for initializing data that was stored.

3. **Counters:** These again do not physically exist. They are simulated counters and they can be programmed to count pulses. Typically these counters can be up-count, down count or both. Since they are simulated they are limited in their counting speed. Some manufacturers also include high speed counters that are hardware based.
4. **Timers:** These also do not physically exist. They come in many Varieties and increments. The most common type is an ON-delay type. Others include OFF-delay and both retentive and non-retentive types. Increments vary from 1 ms — ls.
5. **Output Relays:** (Coils) These are connected to the outside world. They exist physically and send ON/OFF signals to solenoid, lamps, etc. They can be transistors, relays or triacs depending upon the type selected.
6. **Data Storage:** Typically there are registers assigned simply to store data. They are usually used as temporary storage for math or data They can also be used to store data in case of a power failure. These registers ensure that there is no loss of contents owing to disconnection of power.

PLC System Operation:

A PLC System Operation works by continually scanning a program. This scan cycle can be considered as made up of three important states as shown in Fig. 21.23. In addition there are also more than three states and these are used for checking the system and updating the internal counter and timer values.

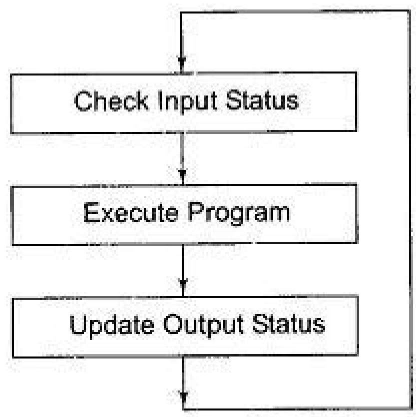


Fig. 21.23 PLC Operation Diagram

The three important states are:

Step 1: Check Input Status: First the PLC takes a look at each input to determine if it is ON or OFF. In other words, it checks and senses whether the sensor connected to the first input is ON, to the second input is ON, to the third input is ON… It records this data into its memory to be used during the next step.

Step 2: Execute Program: The PLC System Operation next executes the program, one instruction at a time. For example, if the program says that if the first input was ON then it should turn ON the first output. Since it already knows which inputs are ON/ OFF from the previous step, it will be able to decide whether the first output should be turned ON based on the state of the first input. It will store the execution results for use later during the third step.

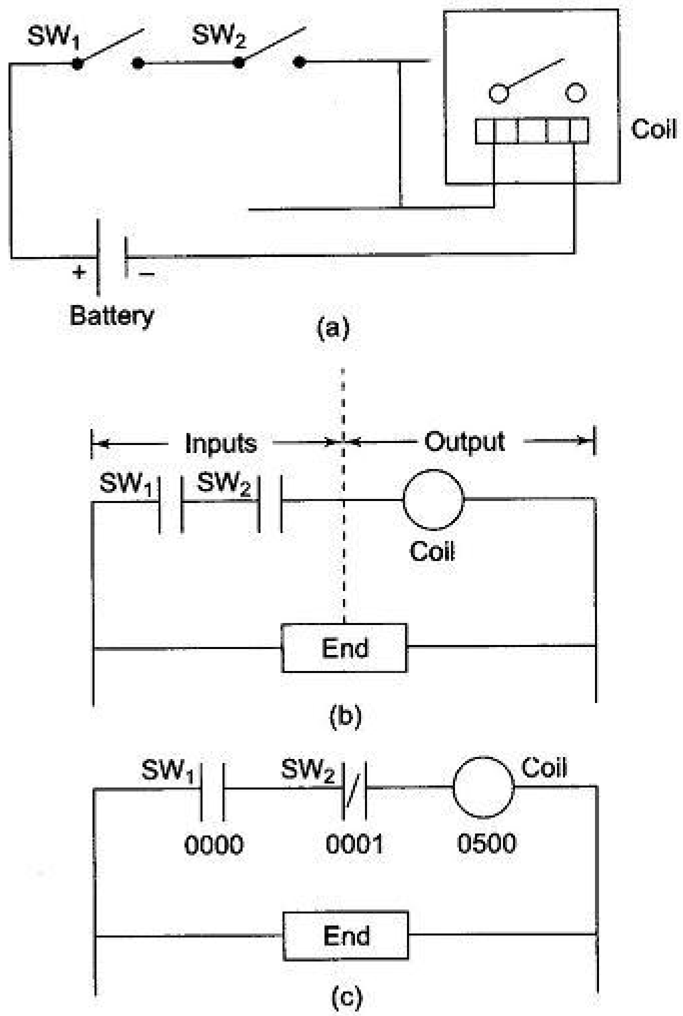
Step 3: Update Output Status: Finally the PLC updates the status of the outputs. It updates the outputs based on which inputs were ON during the first step and the results of executing the program during the second step. Based on example in step 2, it would now turn ON the first output because the first input was ON and the program said to turn ON the first output when this condition is true.

After the third step, the PLC System Operation goes back to step one and repeats the steps continuously.

The time taken to execute the above three steps or one instruction cycle is defined as the scan time.

PLC Register:

PLC Register – Let us consider a simple example and compare the ladder diagram with its real world external physically connected relay circuit. In Fig. 21.32 (a), the coil circuit will be energized when there is a closed loop between the '+' and '—' terminals of the battery. The same circuit can be drawn using ladder diagram. A ladder diagram consists of individual rungs. Each rung must contain one or more inputs and one or more outputs. The first instruction on a rung must always be an input instruction and last instruction on a rung should always be an output coil. The ladder diagram of Fig. 21.32(a) is shown in Fig. 21.32(b).



The PLC Register in use can be explained by using Fig. 21.32(b) and changing SW2 from normally open to normally closed as shown in Fig. 21.32(c).

Hence, in Fig. 21.32(c), SW1 will be physically OFF and SW2 will be physically ON initially. Each symbol or instruction has been given an address. This address sets aside a certain storage area in the PLC data files so that the status of the instruction (i.e. true/false) can be stored. Most PLCs uses 16 slots or bit storage locations. In the example given above, two different storage locations or PLC Register are used.

Register 00

15	14	13	12	11	10	09	08	07	06	05	04	03	02	01	00
														1	0

Register 05

15	14	13	12	11	10	09	08	07	06	05	04	03	02	01	00
															0

(d)

Fig. 21.32

In the tables of two registers 00 and 05 shown in Fig. 21.32(d), we can see that in register 00, bit 00 corresponding to input 0000 was a logic 0 and bit 01 corresponding to input 0001 was a logic 1. Register 05 shows that bit 00 corresponding to output 0500 was a logic 0. The logic 0 or 1 indicate whether an instruction is False or True.

The PLC will only energise an output when all conditions on the rung are TRUE. Hence, in the above example, SW1 must be logic 1 and SW2 must be logic 0, then and only then the output (coil) will be True, that is energized.

If any instruction on the rung before the output (coil) is false, then the output (coil) will be false (not energized).