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Subject: Instrumentation and control

Unit: 4

Topic: Measuring instrument for strain, displacement and force

STRAIN GAUGE

A **Strain gauge** (sometimes referred to as a **Strain gage**) is a sensor whose resistance varies with applied force;

Strain Gauge or Strain Gage was invented in 1938 by Edward E. Simmons and Arthur C. Ruge. It is one of the significant sensors used in the geotechnical field to measure the amount of strain on any structure (Dams, Buildings, Nuclear Plants, Tunnels, etc.). The resistance of a strain gauge varies with applied force and, it converts parameters such as force, pressure, tension, weight, etc. into a change in resistance that can be measured later on.

Whenever an external force is applied to an object, it tends to change its shape and size thereby, altering its resistance. The stress is the internal resisting capacity of an object while a strain is the amount of deformation experienced by it.

We know, resistance is directly dependent on the length and the cross-sectional area of the conductor given by:

$$\mathbf{R = \rho L/A}$$

Where,

R = Resistance

L = Length

A = Cross-Sectional Area

P = Resistivity of the material

The change in the shape and size of the conductor also alters its length and the cross-sectional area which eventually affects its resistance.

Characteristics of strain gauges:

The characteristics of strain gauges are as follows:

1. 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.
2. They are ideal for long distance communication as the output is an electrical signal.
3. Strain Gauges require easy maintenance and have a long operating life.
4. The production of strain gauges is easy because of the simple operating principle and a small number of components.
5. The strain gauges are suitable for long-term installation. However, they require certain precautions while installing.
6. All the strain gauges produced by Encardio-Rite are hermetically sealed and made up of stainless steel thus, waterproof.
7. They are fully encapsulated for protection against handling and installation damage.
8. The remote digital readout for strain gauges is also possible.

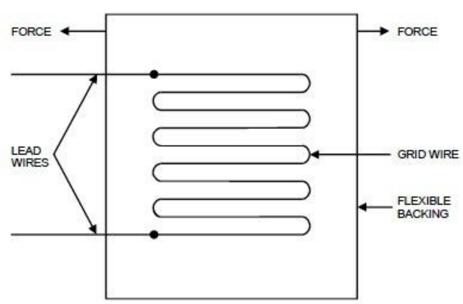
Types of strain gauges:

Strain gauges are basically available into four types of:

1. Wire wounded strain gauges
2. Foil type strain gauge
3. Semiconductor strain gauges
4. Capacitive strain gauges

1. **Wire wounded strain gauges:** In an electrical resistance **strain gauge**, the device consists of a thin **wire** placed on a flexible paper tissue and is attached to a variety of materials to measure the **strain** of the material. This change in resistance is proportional to the **strain** and is measured using a Wheatstone bridge.
   There are two main classes of wire wound strain gauges:
   a. Bonded strain gauge
   b. Unbonded strain gauge

a) Bonded strain gauge: These gauges are directly bonded (that is pasted) on the surface of the structure under study. Hence they are termed as bonded strain gauges. Along with the construction of transducers, a bonded metal wire strain gauge is used for stress analysis. A resistance wire strain gauge has a wire of diameter 0.25mm or less.



Bonded strain gauge

The grid of fine resistance wire is cemented to carrier. It can be a thin sheet of paper, Bakelite or a sheet of Teflon. To prevent the wire from any mechanical damage, it is covered on top with a thin sheet of material. The spreading of wire allows us to have a uniform distribution of stress over the grid. The carrier is bonded with an adhesive material. Due to this, a good transfer of strain from carrier to a grid of wires is achieved.

A resistance wire strain gauge must possess the following characteristics in order to have desirable results-

- The strain gauge should have a high value of gauge factor. As high gauge factor indicates a large change in resistance, which leads to high sensitivity.
- The gauge resistance should be high so as to minimize the effect of undesirable variations of resistance in measurement circuits.

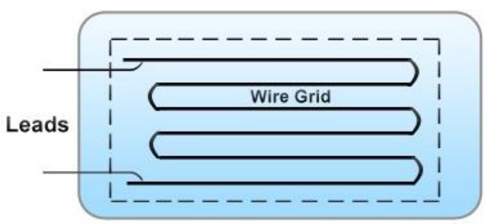
Typically, the resistance of strain gauges is 120Ω, 350Ω, 1000Ω. But a high resistance value results in lower sensitivity. Thus to have higher sensitivity, higher bridge voltages have to be used.

- The strain gauge should have low resistance temperature coefficient.

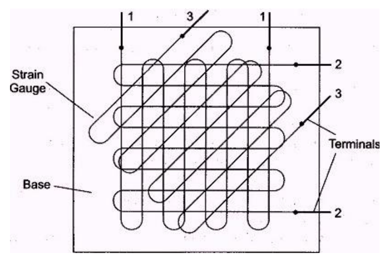
- It should possess linear characteristics in order to have the constancy of calibration over its entire range.
- Strain gauges must have a good frequency response. The linearity should be maintained within accuracy limits.

Various types of bonded strain gauges are:

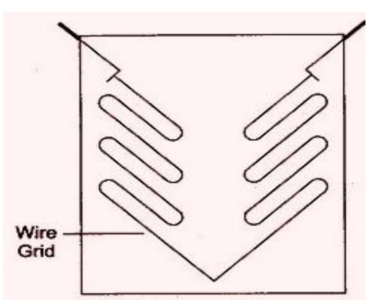
1. Grid type:
2. Rossette type: If the axis of the strain in a component is unknown, Strain Gauge Transducer Types may be used to determine the exact direction. The standard procedure is to place several gauges at a point on the member's surface, with known angles between them. The magnitude of strain in each individual gauge is measured, and used in the geometrical determination of the strain in the member. Shows a three-element strain gauge, called a **Rossette gauge**, in which the angle between any two longitudinal gauge axes is 45°.
3. Torque type:
4. Helical type:



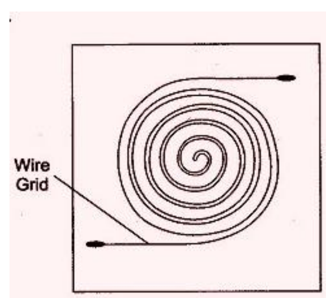
Grid type



Rossette type



Torque type

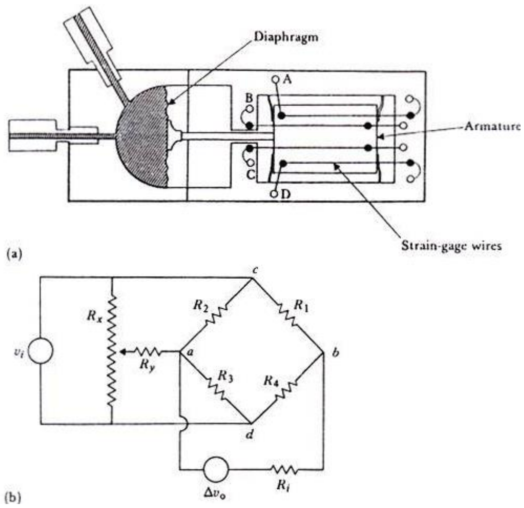


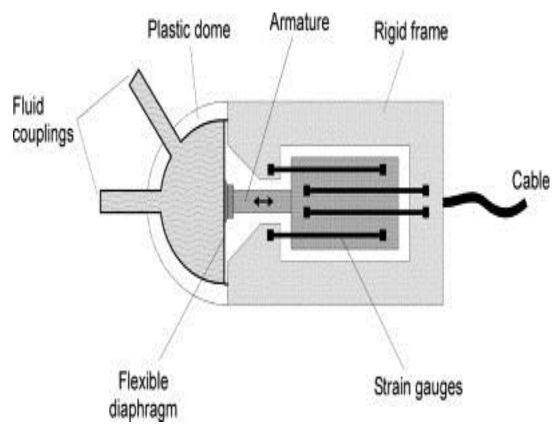
helical type

b) **Unbonded strain gauge:** It is a type of gauge in which a wire is stretched in an insulating medium in between two points. The insulating medium can be air. The wire can be made of alloys such as **copper-nickel**, **chrome nickel**, **nickel-iron** having a diameter of about **0.003 mm**. The **gauge factor** for this category of the strain gauge is about **2 to 4** and capable to withstand a force of **2mN**.

These are almost exclusively used in transducer applications where preloaded resistance wires are connected in a Wheatstone bridge configuration.

The arrangement of unbonded strain gauges consists of the following. Two frames P and Q carrying rigidly fixed insulated pins as shown in diagram. These two frames can move relative with respect to each other and they are held together by a spring loaded mechanism. A fine wire resistance strain gauge is stretched around the insulated pins. The strain gauge is connected to a wheat stone bridge.

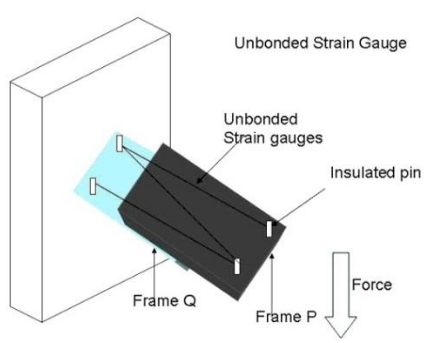


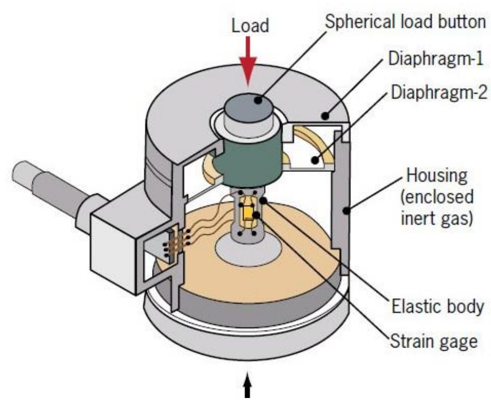


Unbonded strain gauges

Operation of Unbonded strain gauges:

When a force is applied on the structure under study (frames P & Q), frames P moves relative to frame Q, and due to this strain gauge will change in length and cross section. That is, the strain gauge is strained. This strain changes the resistance of the strain gauge and this change in resistance of the strain gauge is measured using a wheat stone bridge. This change in resistance when calibrated becomes a measure of the applied force and change in dimensions of the structure under study.





Application of Unbonded strain gauge:

- Unbonded strain gauge is used in places where the gauge is to be detached and used again and again.
- unbonded strain gauges are used in force, pressure and acceleration measurement.

Advantages of Unbonded strain gauge:

- The range of this gauge is +/- 0.15% strain.
- This gauge has a very high accuracy.

Limitation of unbonded strain gauges

It occupies more space.

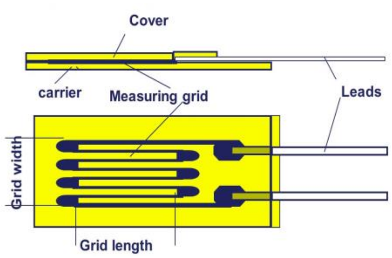
Foil Strain Gauge: This class of strain gauges is an extension of the resistance wire strain gauge. The strain is sensed with the help of a metal foil. The metals and alloys used for the foil and wire are nichrome, constantan (Ni + Cu), isoelastic (Ni + Cr + Mo), nickel and platinum.

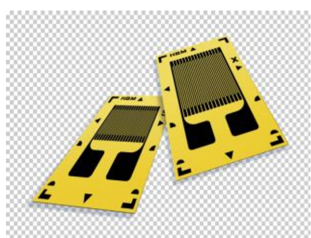
Foil gauges have a much greater dissipation capacity than wire wound gauges, on account of their larger surface area for the same volume. For this reason, they can be used for a higher operating temperature range. Also, the large surface area of foil gauges leads to better bonding. Foil type Strain Gauge Transducer Types have similar characteristics to wire strain gauges. Their gauge factors are typically the same. The advantage of foil type Strain Gauge Transducer Types is that they can be fabricated on a large scale, and in any shape. The foil can also be etched on a carrier. Etched foil gauge construction consists of first bonding a layer of strain sensitive material to a thin sheet of paper or bakelite. The portion of the metal to be used as the wire element is covered with appropriate masking material, and an etching solution is applied to the unit. The solution removes that portion of the metal which is not masked, leaving the desired grid structure intact.

This method of construction enables etched foil strain gauges to be made thinner than comparable wire units, this characteristics, together with a greater degree of flexibility, allows the etched foil to be mounted in more remote and restricted places and on a wide range of curved surfaces.

The longitudinal sensitivity of the foil gauge is approximately 5% greater than that of similar wire elements. The transverse strain sensitivity of this gauge is smaller 1/3 to 1/2 of similar wire gauges. The hysteresis of the foil gauge is also 1/3 to 1/2 of a wire strain gauge.

The resistance film formed is typically 0.2 mm thick. The resistance value of commercially available foil gauges is between 50 and 1000 Ω the resistance films are vacuum coated with ceramic film and deposited on a plastic backing for insulation.



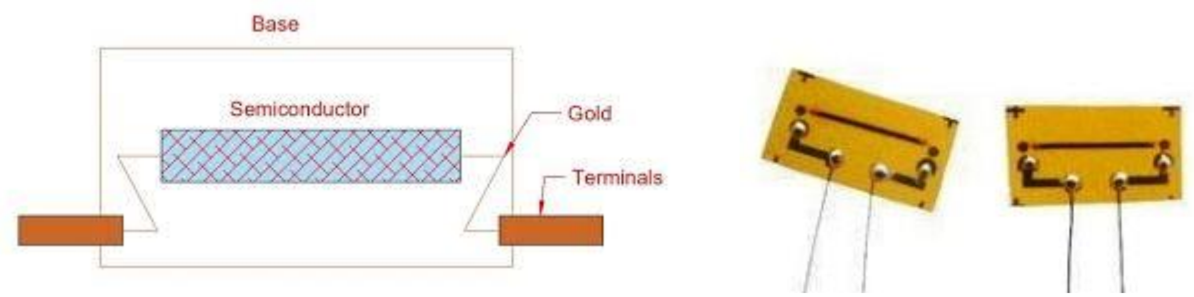


Foil Strain Gauge

Semiconductor Strain Gauge: Semiconductor strain gauges are used when a very high gauge factor is required. They have a gauge factor 50 times as high as wire strain gauges. The resistance of the semiconductor changes with change in applied strain to have a high sensitivity, a high value of gauge factor is desirable. A high gauge factor means relatively higher change in resistance, which can be easily measured with a good degree of accuracy.

Semiconductor strain gauges depend for their action upon the piezo resistive effect, i.e. change in value of the resistance due to change in resistivity, unlike metallic gauges where change in resistance is mainly due to the change in dimension when strained. Semiconductor materials such as germanium and silicon are used as resistive materials.

A typical strain gauge consists of a strain material and leads that are placed in a protective box, Semiconductor wafer or filaments which have a thickness of 0.05 mm are used. They are bonded on suitable insulating substrates, such as teflon.



Semiconductor Strain Gauge

Gold leads are generally used for making contacts. These strain gauges can be fabricated along with an IC Op Amp which can act as a pressure sensitive transducer. The large gauge factor is accompanied by a thermal rate of change of resistance approximately 50 times higher than that for resistive gauges. Hence, a semiconductor strain gauge is as stable as the metallic type, but has a much higher output.

Simple temperature compensation methods can be applied to semiconductor strain gauges, so that small values of strain, that is micro strains, can also be measured.

The gauge factor of this type of semiconductor strain gauge is 130 ± 10% for a unit of 350 Ω, 1″ long, 1/2″ wide and 0.005″ thick. The gauge factor is determined at room temperature at a tensile strain level of 1000 micro strain (1000 micro in/in. of length). The maximum operating tensile strain is ± 3000 micro strain, with a power dissipation of 0.1 W. The semiconductor strain gauge also has low hysteresis and is susceptible to regular methods of temperature compensation. The semiconductor strain gauge has proved itself to be a stable and practical device for operation with conventional indicating and recording systems, to measure small strains from 0.1-500 micro strain.

Advantages of Semiconductor Strain Gauge:

1. Semiconductor strain gauges have a high gauge factor of about + 130. This allows measurement of very small strains, of the order of 0.01 micro

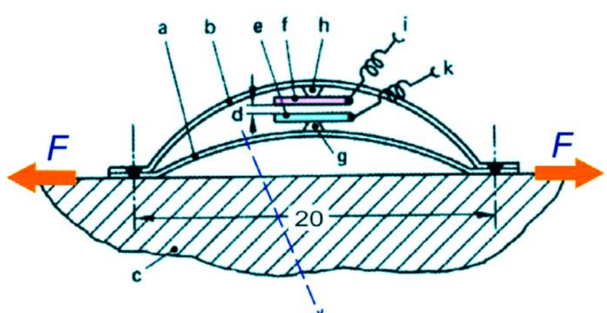
2. Hysteresis characteristics of semiconductor strain gauges are excellent, e. less than 0.05%.
3. Life in excess of 10 x 106 operations and a frequency response of 1012 HZ.
4. Semiconductor strain gauges can be very small in size, ranging in length from 0.7 to 7.0 mm.

Disadvantages of Semiconductor Strain Gauge

1. They are very sensitive to changes in temperature.
2. Linearity of semiconductor strain gauges is poor.
3. They are more expensive.

Capacitive strain gauges: A capacitive strain gauge based on the principle of variation of capacitance with variation of distance between electrodes. The electrodes are flexible metal strips of about 0.1 mm thickness. The strain to be measured is applied to the top plate. These change the distance between the curved electrodes resulting in changes of capacitance. The strain capacitance relationship in general not linear but variations in dimensions and shape allow gauge characteristics to be chosen so as to match the range of capacitance to be measured with good degree of accuracy. Specifications are:

1. Capacitance strain gauges have a range of about 0.5pF.
2. Its overall size is 5 mm x 17 mm x 1 mm
3. Temperature up to 300 ^{o}c
4. It uses a polyamide film of insulating material.



Capacitive strain gauge: d - Variable distance between plates

In the figure:

a-b = are the elastic strip
c = measurement base
e-f = electrodes
g-h = ceramic support
i-k = flexible cable

GAUGE FACTOR:

The gauge factor is defined as the unit change in resistance per unit change in length. It is denoted as G or S. It is also called sensitivity of the strain gauge.

$$\text{Gauge factor } G_f = \frac{\Delta R/R}{\Delta L/L}$$

Where ΔR = Corresponding change in resistance R
ΔL = Change in length per unit length.
The resistance of the wire of strain gauge R is given by:

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

Where ρ = resistivity of the material of wire
L = length of the wire
A= cross sectional Area of the wire, Kd^2 , K is constant and D is the diameter
As earlier stated when the wire is strained its length increases and the lateral dimension is reduced as a function of poisson's ratio (μ); consequently there is an increase in resistance.

$$R = \frac{\rho.L}{K\,D^2}$$

Differentiating it, we get

$$dR = \frac{K\,D^2\,(\rho.dL + L.d\rho) - \rho L(2KD.dD)}{(K\,D^2)^2}$$

$$= \frac{1}{K\,D^2}\left[(\rho.dL + L.d\rho) - 2\,\rho L\left(\frac{dD}{D}\right)\right.$$

$$\frac{dR}{R} = \frac{\frac{1}{K\,D^2}\left[(\rho.dL + L.d\rho) - 2\,\rho L\left(\frac{dD}{D}\right)\right.}{\frac{\rho.L}{K\,D^2}}$$

$$= \frac{dL}{L} + \frac{d\rho}{\rho} + 2\frac{dD}{D}$$

Now passion ration, $\mu = \dfrac{lateral\ strain(-\frac{dD}{D})}{longitudinal\ strain(\frac{dL}{L})}$

$\frac{dD}{D}$ = - μ x dL / L

For small variation the above relationship can be written as:

$$\frac{dR}{R} = \frac{\Delta L}{L} + \frac{\Delta\rho}{\rho} + 2\mu\frac{dD}{D}$$

Gauge factor $G_f = \frac{\Delta R/R}{\Delta L/L}$

$\frac{dR}{R} = G_f \frac{\Delta L}{L} = G_f \times e$

Where $e = \frac{\Delta L}{L}$

The gauge factor can be written as

$$\mathbf{G_f = 1 + 2\mu + \frac{\Delta\rho/\rho}{e}}$$

POWER ESTIMATION FROM ROTATING SHAFT.

Work done

Work done is *the force multiplied with the distance moved by the force* - and can be expressed as

$W = F.l$

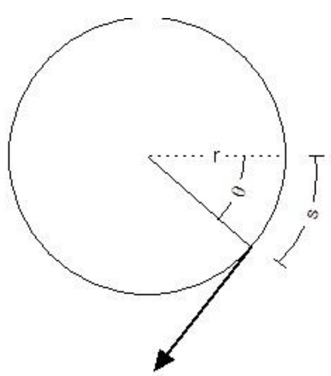
where

W = *work done (J, Nm)*

F = *force (N)*

l = *distance moved by force (m)*

For an angular motion



the work done can be expressed as

$W = F\,\theta\,r$

$= T\,\theta$

where

W = *work (Joules)*

θ = *angle (radians)*

r = *radius (m)*

T = *torque or moment (Nm)*

Power transmitted

Power is the ratio between the work done and the time taken and can be expressed as

$$P = W / dt$$

$$= T\,\theta / dt$$

$$= T\,\omega$$

$$= 2\,\pi\,n\,T$$

$$= 2\,\pi\,(n_{rpm} / 60)\,T$$

$$= 0.105\,n_{rpm}\,T \qquad (3)$$

where

P = *power (Watts)*

dt = *time taken (s)*

$\omega = \theta / dt = 2\,\pi\,n$ = *angular velocity (rad/s)*

n = *speed (rev/s)*

n_{rpm} = *speed (rev/min, rpm)*

Example - required Torque to produce Power

A machine rotates with speed *3000 rev/min (rpm)* and consumes *5 kW*. The torque at the shaft can be calculated by modifying (3) to

$T = P / 2\,\pi\,n$

$= (5\ kW)\ (1000\ W/kW) / 2\,\pi\,(3000\ rev/min) / (60\ sec/min)$

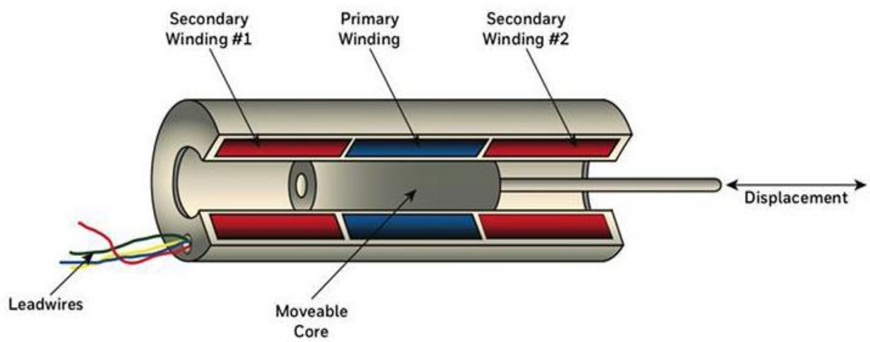
$= \underline{15.9}\ Nm$

L.V.D.T

LVDT (linear variable differential transformer:- An LVDT (linear variable differential transformer= is an electromechanical sensor used to convert mechanical motion or vibrations, specifically rectilinear motion, into a variable electrical current, voltage or electric signals, and the reverse.

LVDT or Linear Variable Differential Transformer is a robust, complete linear arrangement transducer and naturally frictionless. They have an endless life cycle when it is used properly. Because AC controlled LVDT does not include any kind of electronics, they intended to work at very low temperatures otherwise up to 650 °C (1200 °F) in insensitive environments.

The applications of LVDTs mainly include automation, power turbines, aircraft, hydraulics, nuclear reactors, satellites, and many more.



Different Types of LVDT

The different types of LVDTs include the following.

Captive Armature LVDT

These types of LVDTs are superior for lengthy working series. This LVDTs help to prevent incorrect arrangement because they are directed and controlled by low resistance assemblies.

Unguided Armatures

These types of LVDTs have unlimited resolution behavior, the mechanism of this type of LVDT is a no-wear plan that doesn't control the motion of calculated data. This LVDT is connected to the sample to be calculated, fitting limply in the cylinder, involving the linear transducer's body to be held independently.

Force Extended Armatures

Utilize internal spring mechanisms, electric motors to move forward the armature constantly to its fullest level achievable. These armatures are employed in LVDT's for sluggish moving applications. These devices don't need any connection between the armature and specimen.

Linear Variable Displacement Transducers are usually used in current machining tools, robotics, or motion control, avionics, and automated. The choice of an applicable kind of LVDT can be measured using some specifications

Advantages and Disadvantages of LVDT

The LVDT advantages and disadvantages include the following.

- The measurement of the displacement range of LVDT is very high, and it ranges from 1.25 mm -250 mm.
- The LVDT output is very high, and it doesn't require any extension. It owns a high compassion which is normally about 40V/mm.
- When the core travels within a hollow former consequently there is no failure of displacement input while frictional loss so it makes an LVDT as a very precise device.
- LVDT demonstrates a small hysteresis and thus repetition is exceptional in all situations
- The power consumption of the LVDT is very low which is about 1W as evaluated by another type of transducers.
- LVDT changes the linear dislocation into an electrical voltage which is simple to progress.
- It is accomplished that LVDTs are more beneficial as contrasted than any kind of inductive transducer.

Disadvantages of LVDT:

- LVDT gets damaged by temperature as well as vibrations.
- LVDT is responsive to move away from magnetic fields, thus it constantly needs a system to keep them from drift magnetic fields.

LVDT Applications:

The applications of the LVDT transducer mainly include where dislocations to be calculated that are ranging from a division of mm to only some cms.

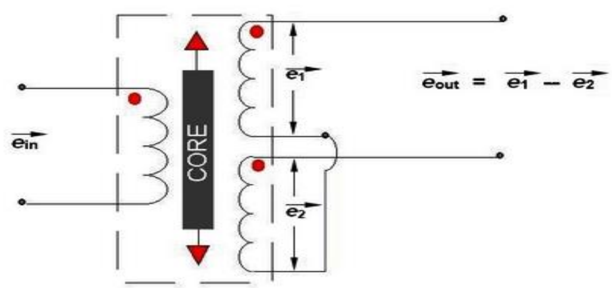
- The LVDT sensor works as the main transducer, and that changes dislocation to electrical signal straight.
- This transducer can also work as a secondary transducer.
- LVDT is used to measure the weight, force and also pressure
- Some of these transducers are used to calculate the pressure and load
- LVDT's are mostly used in industries as well as servomechanisms.
- Other applications like power turbines, hydraulics, automation, aircraft, and satellites

LVDT working principle:

The working principle of LVDT is based on the mutual induction principle. When AC excitation of 5-15 V at a frequency of 50-400Hz is applied to the primary winding, then a magnetic field is produced. This magnetic field induces a mutual current in secondary windings. Due to this, the induced voltages in secondary windings (S1 & S2) are E1 & E2 respectively.

Since both the secondary windings are connected in series opposition, So the net output voltage will be the difference of both induced voltages (E1 & E2) in secondary windings.

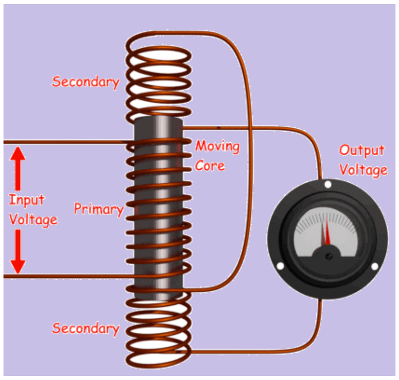
Hence Differential Output of LVDT will be **E0 = E1 – E2**

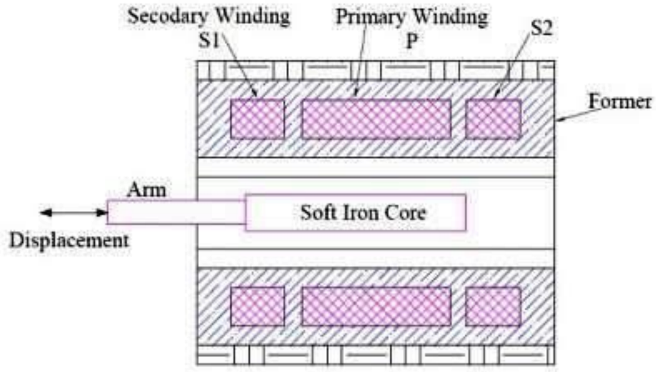


LVDT Construction:

LVDT consists of one primary winding P and two secondary windings S1 & S2 mounted on a cylindrical former. Both the secondary windings (S1 & S2) has an equal number of turns and placed identically on either side of the primary winding in such a way that the net output will be the difference of the voltage of both secondary windings.

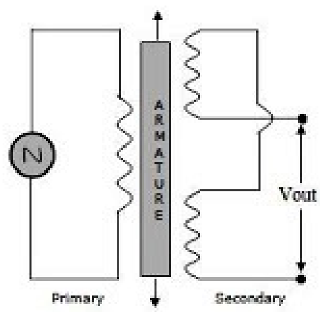
There is a movable soft iron core placed inside the former. Hydrogen annealing is done on Iron core to reduce harmonics, residual voltage of core and thus provides high sensitivity. The movable core also is laminated in order to reduce the eddy current losses. The displacement to be measured is attached to this movable soft iron core. LVDT is placed inside the stainless steel housing because it will provide electrostatic and electromagnetic shielding.



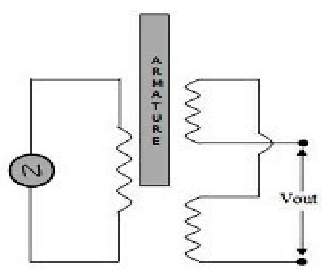


Now three cases arise according to the locations of core which explains the working of LVDT are discussed below as,

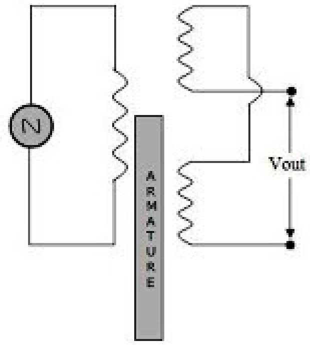
- CASE I When the core is at null position (for no displacement) When the core is at null position then the flux linking with both the secondary windings is equal so the induced emf is equal in both the windings. So for no displacement the value of output e_{out} is zero as e_1 and e_2 both are equal. Hence the Net differential output voltage **E0 = E1 – E2** will be zero **(E0 = E1 – E2 = 0)**. It shows that no displacement of the core.



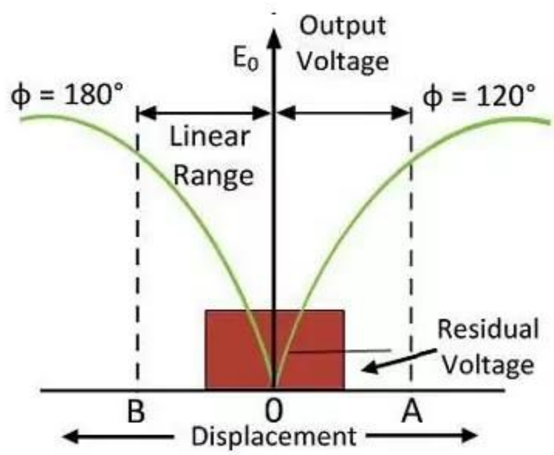
- CASE II - When the core is moved to upward of null position (For displacement to the upward of reference point), In the this case the flux linking with secondary winding S_1 is more as compared to flux linking with S_2. Hence **E1>E2** and Net differential output voltage **E0 = E1 – E2** will be positive. This means the output voltage E0 will be in phase with the primary voltage.



- CASE III When the core is moved to downward of Null position (for displacement to the downward of the reference point). In this case magnitude of e_2 will be more as that of e_1.. Hence **E2>E1** and Net differential output voltage **E0 = E1 – E2** will be negative. This means the output voltage **E0** will be in phase opposition (**180** degrees out of phase) with the primary voltage.



The Graph of variation of output with respect to its position is shown in the below figure.



AC Output of Conventional LVDT Versus Core Displacement

From all three cases, we can have the following conclusions:

1. The direction of the movement of an object can be identified with the help of the differential output voltage of LVDT. If the output voltage E0 is positive then this means an object is moving towards Left from the Null position.
2. Similarly, If the output voltage E0 is negative then this means the object is moving towards the Right of the Null position.
3. The amount or magnitude of displacement is proportional to the differential output of LVDT. The more the output voltage, the more will be the displacement of the object.
4. If we take the core out of the former then the net differential the output of LVDT will be zero.
5. In fact corresponding to both the cases, whether the core is moving either Left or Right to the Null position. Then the output voltage will be increased linearly up to 5mm from the Null position and after 5 mm output E0 will be non-linear.

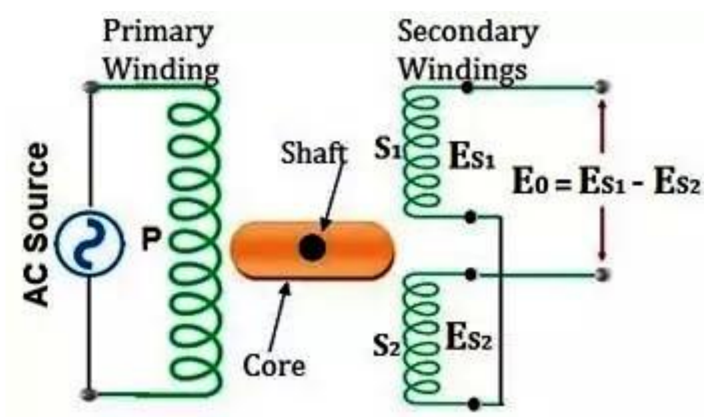
R.V.D.T

Introduction of RVDT:

RVDT full form stands for a Rotary variable differential transformer. It is an electro-mechanical type of inductive transducer that converts angular displacement into the corresponding electrical signal. As RVDT is an AC controlled device, so there is no any electronics component inside it. It is the most widely used inductive sensor due to its high accuracy level. Since the coil of RVDT is designed to measure an angular position, so it is also known as an angular position sensor. The electrical output of RVDT is obtained by the difference in secondary voltages of the transformer, so it is called a Differential Transformer. Unlike LVDT, RVDT is also a passive transducer.

RVDT Construction:

The design and construction of RVDT is similar to LVDT. The only difference is the shape of the core in transformer windings. LVDT uses the soft iron core to measure the linear displacement whereas RVDT uses the Cam-shaped core (Rotating core) for measuring the angular displacement. For understanding the construction of RVDT in detail, please follow our previous article about LVDT construction.



RVDT Theory:

If we denote both the secondary voltages by Es1 and Es2 (see in below fig.) and also the sensitivity of RVDT is G. Then the angular displacement of the shaft will vary as:

$$\theta = G.\left(\frac{E_{S1} - E_{S2}}{E_{S1} + E_{S2}}\right)$$

The secondary voltage is determined by the help of the equation given below as:

$$E_{S2} = E_{S1} \pm G.\theta$$

The differential output Es1 – Es2 will be determined as

$$\Delta E_s = 2.G.\theta$$

A total sum of voltages will be calculated as a constant C.

$$C = \sum E_s = 2.E_{S0}$$

RVDT working principle:

The working principle of RVDT and LVDT both are the same and based on the mutual induction principle. When AC excitation of 5-15V at a frequency of 50-400 Hz is applied to the primary windings of RVDT then a magnetic field is produced inside the core. This magnetic field induces a mutual current in secondary windings. Then due to transformer action, the induced voltages in secondary windings (S1 and S2) are Es1 and Es2 respectively. Hence the net output voltage will be the difference between both the induced secondary voltages.

Hence Output will be $\mathbf{E_0 = Es_1 – Es_2}$

Now according to the position of the core, there are three cases that arise. So let's discuss these three cases one by one in detail.

Case 1: When the core is at Null position.

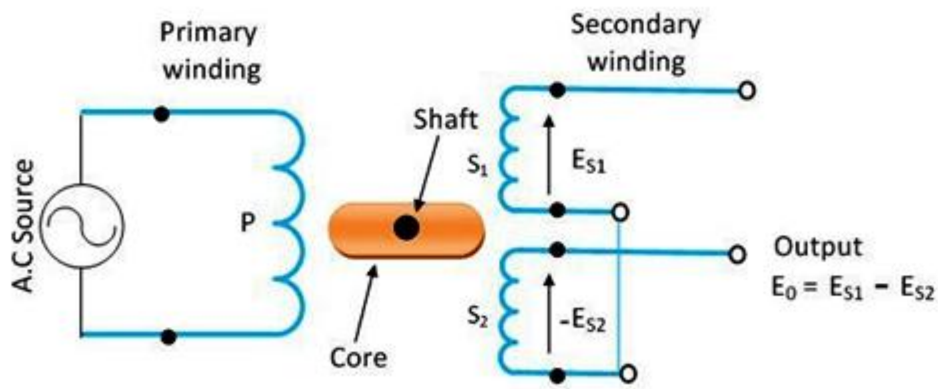
When the core is at the null position then the flux linkage with both the secondary windings will be the same. So the induced emf **(Es_1 & Es_2)** in both the windings will be the same. Hence the Net differential output voltage $\mathbf{E_0 = Es_1 – Es_2}$ will be zero **($E_0 = Es_1 – Es_2 = 0$)**. It shows that no displacement of the core.

Case 2: When the core rotates in the clockwise direction.

When the core of RVDT rotates in the clockwise direction. Then, in this case, the flux linkage with **S1** will be more as compared to **S2**. This means the emf induced in S1 will be more than induced emf in **S2**. Hence $\mathbf{Es_1>Es_2}$ and Net differential output voltage $\mathbf{E_0 = Es_1 – Es_2}$ will be positive. This means the output voltage E0 will be in phase with the primary voltage.

Case 3: When the core rotates in the anti-clockwise direction.

When the core of RVDT rotates in the anti-clockwise direction, in this case, the flux linkage with S2 will be more as compared to S1. This means the emf induced in S2 will be more than induced emf in S1. Hence Es2>Es1 and Net differential output voltage E0 = Es1 – Es2 will be negative. This means the output voltage E0 will be in phase opposition (180 degrees out of phase) with the primary voltage.



Advantages of RVDT:

Following are the main advantages of RVDT:

- High Accuracy.
- Compact and strong construction.
- The consistency of RVDT is high.
- Long life span.
- Very high Resolution.
- Low cost.
- High durability
- Linearity is excellent.
- The performance is repeatable.
- Easy to handle

Disadvantages of RVDT

The disadvantages of RVDT mainly include the following.

- Since the output of RVDT is linear (about +40 degrees or -40 degrees), so it restricts its usability.
- The contact among the measuring exteriors as well as the nozzle is not possible for all time.

Applications of RVDT

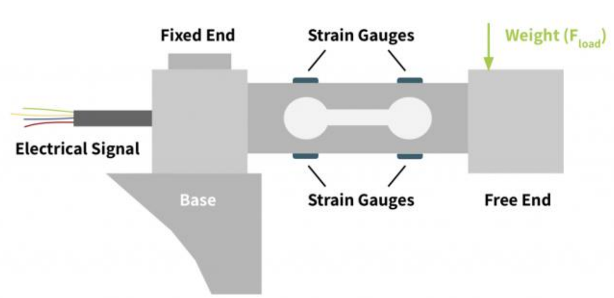
RVDT is most commonly is used as a sensor nowadays; also it doesn't experience any functional problem due to its contactless structure. Hence the main applications of RVDT include the following.

- Actuators for controlling flight as well as engine.
- Fuel valve as well as hydraulics.
- Brake with a cable system.

- Modern machine tools.
- Nose wheel steering systems.
- Weapon and Torpedo system.
- Engine fuel control system
- Aircraft and avionics.
- Engines bleed air systems.
- Robotics.

LOAD CELL

A **load cell** is a type of transducer, specifically a force transducer. It converts a force such as tension, compression, pressure, or torque into an electrical signal that can be measured and standardized. As the force applied to the **load cell** increases, the electrical signal changes proportionally.



Working of load cell:

A load cell works by converting mechanical force into digital values that the user can read and record. The inner working of a load cell differs based on the load cell that you choose. There are hydraulic load cells, pneumatic load cells, and strain gauge load cells. Strain gauge load sensors are the most commonly used among the three. Strain gauge load cells contain strain gauges within them that send up voltage irregularities when under load. The degree of voltage change is covered to digital reading as weight.

Application of load cell:

A load cell measures mechanical force, mainly the weight of objects. Today, almost all electronic weighing scales use load cells for the measurement of weight. They are widely used because of the accuracy with which they can measure the weight. Load cells find their application in a variety of fields that demand accuracy and precision. There are different classes to load cells, class A, class B, class C & Class D, and with each class, there is a change in both accuracy and capacity.

Load Cell Types:

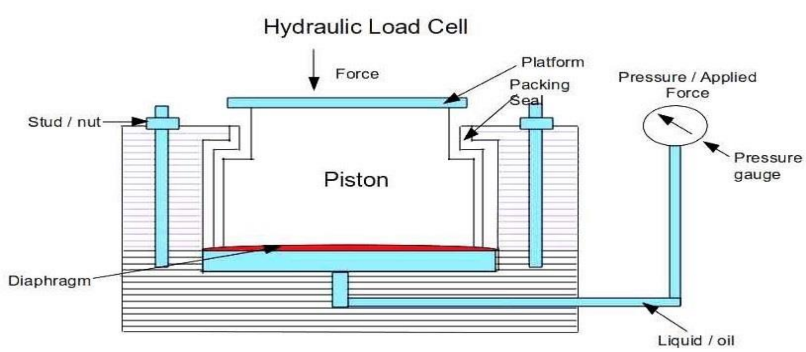
Load cell designs can be distinguished according to the type of output signal generated (pneumatic, hydraulic, electric) or according to the way they detect weight (bending, shear, compression, tension, etc.)

Hydraulic load cells

Hydraulic cells are force -balance devices, measuring weight as a change in pressure of the internal filling fluid. In a rolling diaphragm type hydraulic force sensors, a load or force acting on a loading head is transferred to a piston that in turn compresses a filling fluid confined within an elastomeric diaphragm chamber. As force increases, the pressure of the hydraulic fluid rises. This pressure can be locally indicated or transmitted for remote indication or control. Output is linear and relatively unaffected by the amount of the filling fluid or by its temperature. If the load cells have been properly installed and calibrated, accuracy can be within 0.25% full scale or better, acceptable for most process weighing applications. Because this sensor has no electric components, it is ideal for use in hazardous areas. Typical hydraulic load cell applications include tank, bin, and hopper weighing. For maximum accuracy, the weight of the tank should be obtained by locating one force sensor at each point of support and summing their outputs.

Principle of Hydraulic Load cell:

When a force is applied on a liquid medium contained in a confined space, the pressure of the liquid increases. This increase in pressure of the liquid is proportional to the applied force. Hence a measure of the increase in pressure of the liquid becomes a measure of the applied force when calibrated.



The main parts of a hydraulic load cell are as follows

- A diaphragm
- A piston with a loading platform (as shown in figure) placed on top of the diaphragm.
- A liquid medium which is under a pre-loaded pressure is on the other side of the diaphragm.
- A pressure gauge (bourdon tube type) connected to the liquid medium.

Operation of Hydraulic Load Cell

- The force to be measured is applied to the piston.
- The applied force moves the piston downwards and deflects the diaphragm and this deflection of the diaphragm increases the pressure in the liquid medium (oil).
- This increase in pressure of the liquid medium is proportional to the applied force. The increase in pressure is measured by the pressure gauge which is connected to the liquid medium.
- The pressure is calibrated in force units and hence the indication in the pressure gauge becomes a measure of the force applied on the piston.

Pneumatic load cells: A **pneumatic load cell** consists of an elastic diaphragm which is attached to a platform surface where the weight will be measured. There will be an air regulator that will limit the flow of air pressure to the system and a pressure gauge. The pressure gauge can convert the air pressure reading into an electrical signal.

Pneumatic load cells also operate on the force-balance principle. These devices use multiple dampener chambers to provide higher accuracy than can a hydraulic device. In some designs, the first dampener chamber is used as a tare weight chamber. Pneumatic load cells are often used to measure relatively small weights in industries where cleanliness and safety are of prime concern. The advantages of this type of load cell include their being inherently explosion proof and insensitive to temperature variations. Additionally, they contain no fluids that might contaminate the process if the diaphragm ruptures. Disadvantages include relatively slow speed of response and the need for clean, dry, regulated air or nitrogen.

Principle of Pneumatic Load Cell

If a force is applied to one side of a diaphragm and an air pressure is applied to the other side, some particular value of pressure will be necessary to exactly balance the force. This pressure is proportional to the applied force.

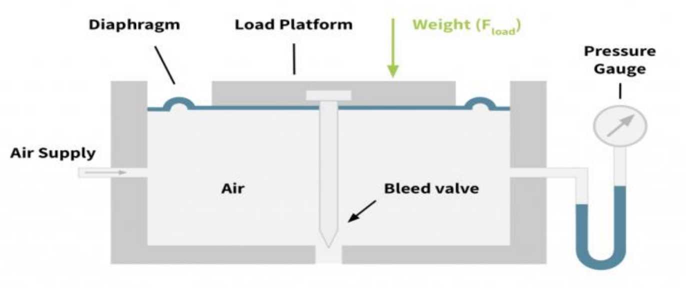
Pneumatic Load cell

The main parts of a pneumatic load cell are as follows:

- A corrugated diaphragm with its top surface attached with arrangements to apply force.
- An air supply regulator, nozzle and a pressure gauge arranged as shown in figure.
- A flapper arranged above the nozzle as shown in figure.

Operation of Pneumatic Load cell:

The force to be measured is applied to the top side of the diaphragm. Due to this force, the diaphragm deflects and causes the flapper to shut-off the nozzle opening. Now an air supply is provided at the bottom of the diaphragm. As the flapper closes the nozzle open, a back pressure results underneath the diagram. This back pressure acts on the diaphragm producing an upward force. Air pressure is regulated until the diaphragm returns to the pre-loaded position which is indicated by air which comes out of the nozzle. At this stage, the corresponding pressure indicated by the pressure gauge becomes a measure of the applied force when calibrated.



<u>Strain-gauge load cell</u>

Strain gauge load cells are a type of load cell where a strain gauge assembly is positioned inside the load cell housing to convert the load acting on them into electrical signals. The weight on the load cell is measured by the voltage fluctuation caused in the strain gauge when it undergoes deformation.

The gauges themselves are bonded onto a beam or structural member that deforms when weight is applied. Modern load cells have 4 strain gauges installed within them to increase the measurement accuracy. Two of the gauges are usually in tension, and two in compression, and are wired with compensation adjustments. When there is no load on the load cell, the resistances of each strain gauge will be the same. However, when under load, the resistance of the strain gauge varies, causing a change in output voltage. The change in output voltage is measured and converted into readable values using a digital meter.

Piezoresistive load cell:

Similar in operation to strain gauges, piezo resistive force sensors generate a high level output signal, making them ideal for simple weighing systems because they can be connected directly to a readout meter. The availability of low cost linear amplifiers has diminished this advantage, however. An added drawback of piezoresistive devices is their nonlinear output.

Inductive and reluctance load cells:

Both of these devices respond to the weight-proportional displacement of a ferromagnetic core. One changes the inductance of a solenoid coil due to the movement of its iron core; the other changes the reluctance of a very small air gap.

Magnetostrictive load cells:

The operation of this force sensor is based on the change in permeability of ferromagnetic materials under applied stress. It is built from a stack of laminations forming a load-bearing column around a set of primary and secondary transformer windings. When a force is applied, the stresses cause distortions in the flux pattern, generating an output signal proportional to the applied load. This is a rugged sensor and continues to be used for force and weight measurement in rolling mills and strip mills.

There are many different kinds of load cells. We offer resistive load cells and capacitive load cells.

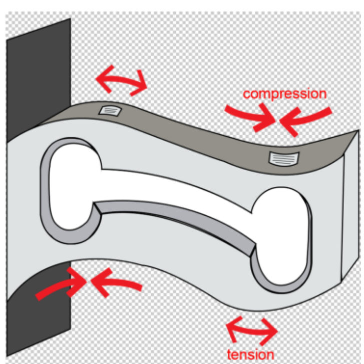
Resistive load cells work on the principle of piezo-resistivity. When a load/force/stress is applied to the sensor, it changes its resistance. This change in resistance leads to a change in output voltage when an input voltage is applied. Capacitive load cell works on the principle of change of capacitance which is the ability of a system to hold a certain amount of charge when a voltage is applied to it. For common parallel plate capacitors, the capacitance is directly proportional to the amount of overlap of the plates and the dielectric between the plates and inversely proportional to the gap between the plates.

Working of resistive load cell:

A load cell is made by using an elastic member (with very highly repeatable deflection pattern) to which a number of strain gauges are attached.

In this particular load cell shown to the right, there are a total of four strain gauges that are bonded to the upper and lower surfaces of the load cell.

When the load is applied to the body of a resistive load cell as shown above, the elastic member, deflects as shown and creates a strain at those locations due to the stress applied. As a result, two of the strain gauges are in compression, whereas the other two are in tension.

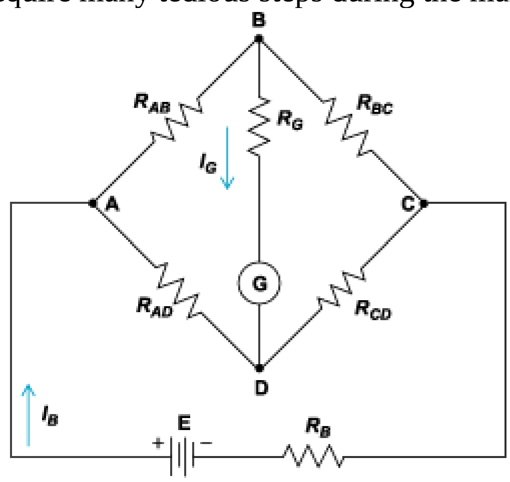


Wheatstone bridge Circuit:

The four strain gauges are configured in a Wheatstone bridge configuration with four separate resistors connected as shown in what is called a Wheatstone Bridge Network. An excitation voltage - usually 10V is applied to one set of corners and the voltage difference is measured between the other two corners.

At equilibrium with no applied load, the voltage output is zero or very close to zero when the four resistors are closely matched in value. That is why it is referred to as a balanced bridge circuit. When the metallic member to which the strain gauges are attached, is stressed by the application of a force, the resulting strain - leads to a change in resistance in one (or more) of the resistors.

This change in resistance results in a change in output voltage. This small change in output voltage (usually about 20 mVolt of total change in response to full load) can be measured and digitized after careful amplification of the small milli-volt level signals to a higher amplitude 0-5V or 0-10V signal. These load cells have been in use for many decades now, and can provide very accurate readings but require many tedious steps during the manufacturing process



Types of Resistive Load Cells

Resistive Load cells come in various shapes and sizes to meet diverse application needs. Here we show you a few common types:

1. **Single Point Load Cells: -** Generally used to build scales and in applications where space is not limited. They offer excellent off-center loading compensation. Range -100 g, 300 g, 500g, 1 kg, 2 kg, 3 kg

2. **Button Load Cells:-** Ideal for measuring compression forces that are applied axially. They are compact and easy to use.

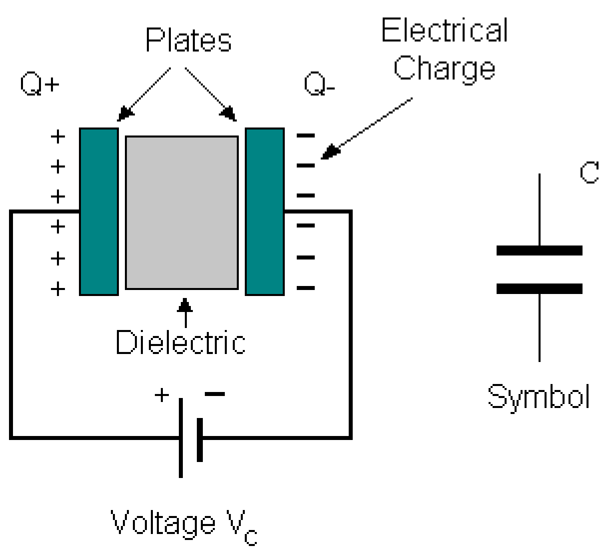
3. **S-Beam Load Cells** Ideal for tension (pull) or Universal (push and pull) force measurement applications

4. **Miniature Load Cells** Smallest miniature load cells we offer for compression force measurements only. Ideal for cramped locations.

5. **Through Hole Load Cells** Rugged, industrial load cells for compression and/or tension force measurements. Has a through hole with threads to attach accessories

6. **Pancake Load Cells** High Capacity load cells with capacities up to 100K lbs for compression and/or tension load cell measurements.

Capacitive load cells are built on the principal of a change in capacitance when a force is applied on the load cell. Capacitance is the ability of a system to store a charge. If a capacitor is built using the classic parallel plate approach then its ability to store a charge is directly proportional to the area between the two plates and inversely proportional to the gap between the plates.



When a force or load or pressure is applied this gap between the plates changes due to the deflection of the housing and results in a disproportionate change in capacitance making capacitive sensors extremely sensitive.

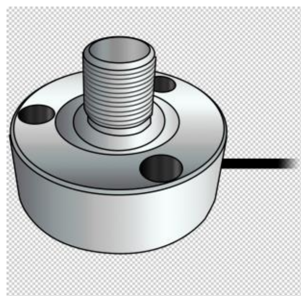
Types of Capacitive Load Sensors:

Ideal for controlled room temperature applications ~25C for short durations

1) **iLoad Mini with Threaded Stud** Compression and/or Tension Available

2) **iLoad Mini with Dome** Compression Only

3) **iLoad Mini Pro with Threaded Stud** Compression and/or Tension Available



4) **iLoad Mini Pro** Compression Only

5) **iLoad Pro** Compression and/or Tension Available

6) **iLoad TR** Compression and/or Tension Available

7) **iLoad Low Profile** Compression Only

STROBOSCOPE

Stroboscope Definition – A stroboscope is an instrument that emits a series of brief, intense flashing lights at specific intervals

The stroboscopic principle uses a high intensity light which flashes at precise intervals. This light may be directed upon a rotating or vibrating **object**. The stroboscopic effect is apparent when the rotational or vibratory speed is in a proper ratio with the **frequency** of the light flashes

A stroboscope has various uses, such as:

- It is used to measure the oscillation frequencies of mechanical and electronic systems
- It is used to measure resonance frequencies
- It is used to study the vibrations of various bodies
- It is used to visually monitor rapidly moving parts of machines.

Principle of Operation:

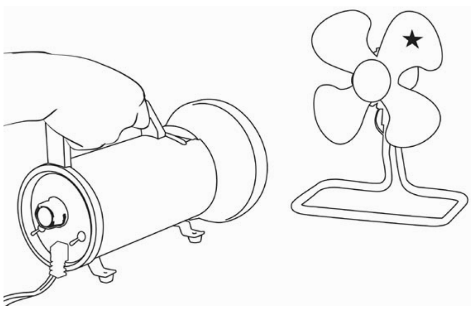
A stroboscope uses a flash lamp which is driven by an electronic oscillator. The flash lamp used is usually a xenon bulb, although LEDs are also used sometimes. The oscillator triggers the lamp at a steady rate of flash. The rate of flash can be varied and has a variable range from a few times per second to thousands of times per second. The flash lamp also consists a reflector to increase its brightness and to make the flash more directional.

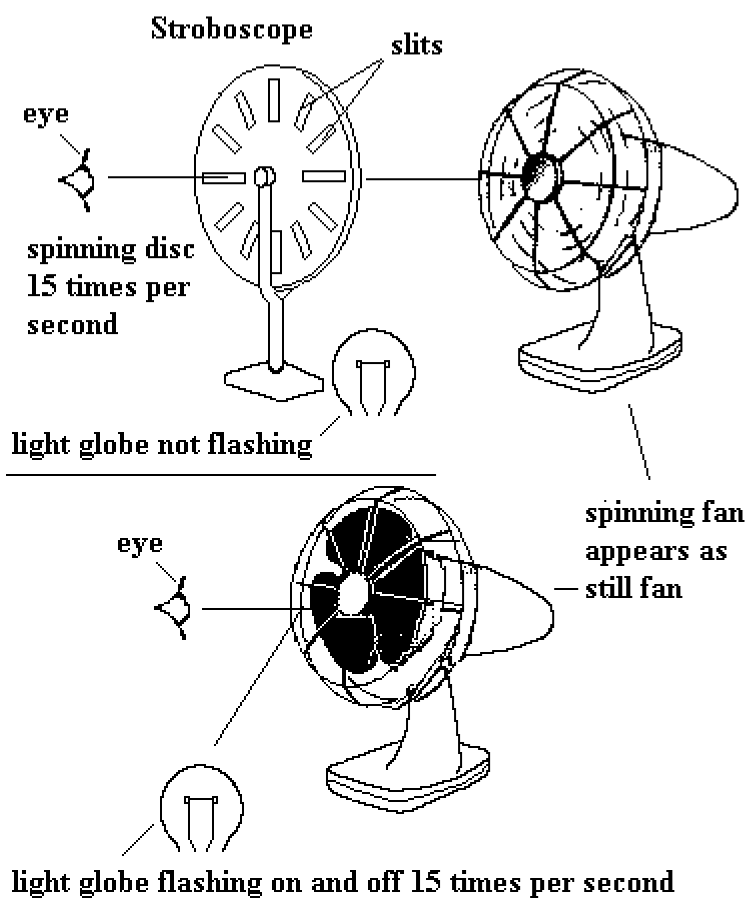
There are two basic types of stroboscope available:

- General purpose Stroboscope– used for entertainment
- Scientific Stroboscope – used for scientific or experimental purpose.

The entertainment / party models are speed-limited and have low cost. The rate of flash for entertainment purpose stroboscope is generally limited as it has been found that flashes at certain rates can induce epileptic seizures in some people. They may have some additional features like multiple colored lights (that flash in a sequence). The scientific models don’t have any such speed limits. They must be able to capture high-speed periodic motions.

Scientific or professional strobes may also have some external trigger inputs. The external trigger overrides the internal oscillator. With the help of these external trigger inputs, one can easily sync the stroboscope to moving machinery and slow down its motion for experiment/study.





Working of Stroboscopes:

Stroboscopes, commonly referred to as strobes, use a flash lamp generally xenon or LED driven by an oscillator to inspect or measure the rotational speed of spinning objects. The oscillator activates the lamp at a steady state which can be set at rates from a flash every few seconds to hundreds of flashes per second. The flashing light creates the perception of stop-motion which is ideal for diagnostic inspections of moving machinery and can also be used as a measuring instrument for determining cyclic speed as measured in rotations per minute (RPM).

The flashing light of the strobe creates an optical illusion known as aliasing. As the strobe flashes it provides intermittent glimpses of the moving target. When the flash rate of the stroboscope matches the rotational rate of the target, each flash illuminates the target at the same position in its rotational cycle creating the perception that the object is stationary. Once this point is reached the flash rate can increased or decreased to make it appear as if the object is rotating forward or backwards—the speed of which is dependent upon how much the flash rate of the stroboscope varies from the rotational rate of the target.

The ability to visually “stop and start” a spinning piece of machinery or adjust its rotational speed and direction is an important inspection and troubleshooting tool. Technicians can identify damage to gears, shafts, pulleys, and belts without having to stop the machinery. Additionally, any wobbles or alignment problems can be quickly noticed before the problem becomes severe.

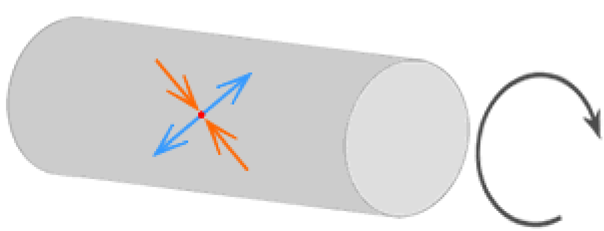
Though the ability of a stroboscope to visually stop the motion of a piece of machinery for inspection is the primary use of the instrument, it is also quite useful as a tool capable of measuring rotational speed. Measuring rotational speed involves matching the flash rate of the strobe to the rotational rate of the equipment being tested. Some sort of reference mark, such as reflective tape, makes this easier. Once the rates match, the stroboscope can convert the number of flashes per second to RPM.

TORQUE

Torque is a twisting or turning force about an axis that can be applied in a clockwise or counter-clockwise direction. A good example of this is a vehicle steering mechanism; to turn a corner the driver applies a force to the steering wheel which applies torque directly to the steering column. This torque is generated by a combination of the force from the driver’s hands and distance the hands are from the center of the wheel.

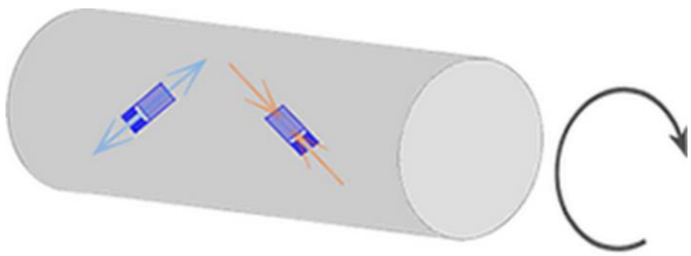
Torque Sensor Measurement Principle

The most common torque sensor measurement principle uses bonded strain gauge technology, where the strain gauges are bonded to a suitably designed shaft. Torque transducers with a circular shaft and with strain gauges applied at 45deg is a design that has been around for many years. However, the design and configuration of the device will be dictated by the application and the shaft may well be solid or hollow and the cross-section might differ with either a cruciform, square or the other custom design, in order to gain the maximum signal output available from the measurement.



Shear Stresses in a Torque Shaft

When torsion is applied to the shaft causing it to twist, shear stresses are induced. These are measured by bonding the strain gauges at 45° to the horizontal torque axis. As the shear stress induced in the shaft is the same throughout its length, the strain gauges can be bonded at any point along its length. However, it is normal practice to place them in the center, as far as possible from spurious stress that can be induced at the mechanical interfaces.



Strain Gauges Bonded to a Torque Shaft

Getting an Electrical Signal from the Torque Transducer

Typically four strain gauges are bonded and connected into a Wheatstone bridge configuration with temperature compensation components included within the bridge circuitry. With an excitation voltage applied to the bridge and torque induced into the shaft, an electrical output linearly proportionate to that torque will result.

For the strain gauged shaft to become a useful measuring instrument (torque sensor) it is necessary to calibrate it with a known reference standard. This can be either weight applied to the end of a cantilever arm of known length, or in line with a reference standard torque transducer.

The completed Wheatstone bridge requires a stable DC supply to excite the circuit. This is usually 5Vdc or 10Vdc but can be any value from 1Vdc up to 18Vdc

Torque Sensors and Torque Sensor Instrumentation

These low-level millivolt signals are compatible with a vast range of bespoke strain gauge sensors such as load cells and pressure transducers and their associated instrumentation. These instruments include digital displays, analogue and digital amplifiers. Typical analogue amplifiers will generate a higher level voltage (0-5Vdc, 0-10Vdc) or current (0-20mA, 4-20mA) for additional processing.

Typically digital amplifiers also provide RS232 or RS485 output using either industry standard or protocols specific to an industry such as MODbus. In many cases the signal conditioning is built in to the device, giving a direct analogue or digital output for further processing. One of the latest developments is incorporated into torque sensors in radio telemetry operating in the 2.4GHz frequency band. Operating with very low current consumption enables the use of small batteries on a power source. This latest technology has led to the design of contact-less rotary torque transducers.

A further benefit of radio telemetry torque sensors is their low cost (up to 50%) compared with equivalent slip ring or brushless types.

Selection of an appropriate device will be based on the following amongst other factors, all of which will impact on the accuracy and cost of the measurement, these include:

- Speed of rotation
- The environment in which the measurement is taking place
- The mechanical connection

- Test duration
- Information required of the measurement being taken

Static / Reaction Torque (less than 1 revolution) vs. Rotary Torque (greater than 1 revolution)
Torque measurements can be either Static (also known as Reaction) or Rotary.
A static or reaction torque measurement involves little or no rotation of the item being measured, such as during torque spanner testing. A rotary torque measurement would, as the name suggests, be subject to continuous rotation. This rotation could be constant, as you find in a system measuring the torque on a stirrer in a mixing vessel or periodical as you would find when measuring the torque produced by an electric screwdriver.
Dynamic Torque
A dynamic torque meanwhile is one that is subject to variation or change, for instance the torque on the motor drive shaft of an electric hover mower would be subject to dynamic torque, firstly as you turn on the power to make the blade spin up, and thereafter as you move the mower around your lawn between areas of varying grass density, or from cut to uncut grass.
When selecting a transducer to measure dynamic torque, it is important to ensure that Is has a sufficiently wide frequency response bandwidth so that the electrical output will react fast enough to capture the changes (peaks or troughs) as they occur, rather than smoothing or filtering them out.

Power & Signal Transmission In Rotary Torque Sensors

Slip Ring
The first rotating strain gauge torque transducer employed slip rings to make the electrical connections from the casing to the rotating shaft. Because the slip rings are carrying only millivolt signals from the strain gauges, the materials for both the slip rings and the brushes must be very carefully selected. The normal procedure is to use coin silver for the slip rings and silver graphite for the brush gear.

The conductive rings rotate with the sensor and use a series of sprung brushes to contact the rings and transmit the electrical signal. Slip rings are relatively straight forward with only minor drawbacks in that the brushes and to a lesser extent, the rings, do wear and as such have a finite life. Because of this, they don't lend themselves to long-term tests, very high speed or to applications where access to the sensor for servicing is limited.

At low speed the electrical connection between the rings and brushes are relatively noise-free, however, at higher speeds electrical noise will eventually degrade their performance. The maximum speed (rpm) for a slip ring is determined by the surface speed at the interface between the brush and ring. As a result, the maximum operating speed will be lower for larger, or higher torque capacity sensors because the larger slip rings will, therefore, have a higher surface speed at a given rpm. Typical maximum rpm will be in the range of 5,000rpm for a medium capacity torque sensor. For very low capacity measurements, the brush ring interface can be a source of 'drag torque' that can be a problem for the driving torque to overcome.

Rotary Transformer (Inductive Loop)
For higher speed (rpm) torque measurement applications the rotary transformer system might be used. The rotary transformer system consists of two coils, one static coil that is attached to the

transducer's housing and one rotating coil that is attached to the transducer shaft. This offers the distinct advantage of there being no contact between rotor and stator and incorporates both transmission of power to and signal back from the rotating strain gauge bridge circuit. Rotary transformer type torque sensors offer typical inaccuracies of ±0.2% and are capable of speeds up to 50,000rpm.

The rotary transformer system is versatile enough for use in special torque transducers and those where space is limited. However as this design incorporates bearings, the maximum rpm is more than the slip-ring design but limited by the maximum specified performance of the bearing. The system can also be susceptible to noise and errors, which are induced by the alignment of the transformer primary-to-secondary coils. Because of the special requirements imposed by the rotary transformers, specialized signal conditioning is also required in order to produce a signal acceptable for most data acquisition systems.

Wireless Radio Telemetry (Battery Powered, 2.4GHz)

Following the advent of modern low-power wireless telemetry acquisition and transmission electronics, it has become possible to manufacture battery-powered torque sensors that offer a sufficiently long period of operation between charges to make them viable in a wide range of industrial and research applications.

The avoidance of rotor and stator coils means that installing wireless torque sensors is a simplified process over other types as there is no cabling provision or coil alignment to consider, it also means that the measurement signal can be transferred over considerable distances (up to 120m) easily.

The data stream provided by the wireless telemetry system is broadcast and so can be read by multiple receiver units with different functions such as digital displays, analogue outputs and PC-based USB acquisition making multi-featured systems quick and easy to set up.

ELECTRICAL CIRCUIT

An **electrical circuit** is a path in which electrons from a voltage or current source flow. The point where those electrons enter an **electrical circuit** is called the "source" of electrons.

Types of Electric Circuit
There are following 5 main types of electric circuit:

Close Circuit- When load works on its own in a circuit then it is called Close Circuit or Closed Circuit. Under this situation, the value of current flow depends on load.

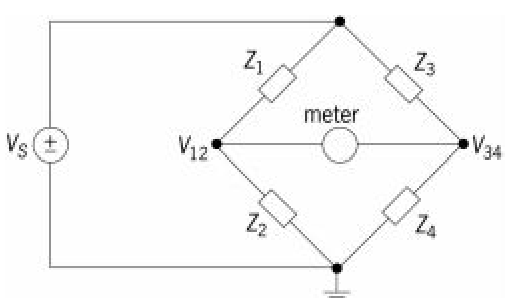
Open Circuit- When there is a faulty electrical wire or electronic component in a circuit or the switch is OFF, then it is called Open Circuit. In the below diagram you can see that the Bulb is Not glowing because either the switch is OFF or there is fault is the electrical wire.

Short Circuit- When both points (+ & –) of voltage source in a circuit gets joint with each other for some reason then it is called Short Circuit. Maximum current starts to flow under this situation. Short circuit generally happens when the conducting electrical wires get joint of even because of shorting in the load.

Series Circuit- When 2 or more loads (*Bulb, CFL, LED, Fan etc*) are connected to each other in a series, then it is called a Series Circuit. In a series circuit, if one load or bulb gets fuse, then rest of the bulbs will not get power supply and will not glow.

Parallel Circuit- When 2 or more loads (*Bulb, CFL, LED, Fan etc*) are connected to each other in parallel, then it is called Parallel Circuit. In this type of circuit, the voltage capacity of all loads must be equal to input supply. Power of "load" can be different. In a parallel circuit, if one load or bulb gets fuse, then rest of the bulbs will still get power supply and will glow.

A **bridge** circuit is one kind of **electrical** circuit wherein the two branches of the circuit are linked to a third branch –which is connected in between the first two branches at some middle point along them. These circuits are used in linear, nonlinear, power conversion, instrumentation, filtering, etc



One of the significant differences between the AC and DC bridge is that the AC bridge is used for measuring the unknown impedance of the circuit whereas the DC bridge is used for measuring the unknown resistance of the circuit. The other differences between the AC and DC bridge are shown below in the comparison chart.

Definition of AC Bridge

The Ac Bridge consists of source, balanced detector, and the four arms. The arms of the bridge consists the impedance. The AC bridge is constructed by replacing the battery with the ac source. The bridges are formed by replacing the DC battery with the AC source and galvanometer with the Wheatstone bridge. The bridge is used for detecting the inductance, capacitance, storage factor, dissipation factor etc.

Definition of DC Bridge

The DC Bridge is used for measuring the unknown electrical resistance. This can be done by balancing the two legs of the bridge circuit. The value of one of the arm is known while the other of them is unknown.

Key Differences Between AC and DC Bridge

1. The bridge which is used for measuring the unknown impedance of the circuit is known as the Wheatstone bridge. The DC bridge is used for measuring the unknown resistance of the circuit.
2. The AC bridge uses the AC supply. The DC bridge uses the DC supply for measuring the resistance.
3. In AC bridge the current is detected by using the AC detector. While in DC bridge the current is detected by using the DC detector.
4. The resistive and reactive components are used in the AC bridge circuit while in the DC circuit only resistive components are used.
5. The AC bridge circuit uses the Wagner earth device for removing the earth capacitance from the circuit. It also reduces the harmonics and the error which occurs because of the stray magnetic field. The Wagner earthling device is not used in the DC bridge circuit.
6. The AC bridges take less time to come in balance condition while the DC bridge uses comparatively more time to comes in the balanced condition.
7. Wheatstone Bridge and the Kelvin bridge are the types of the DC bridge. The AC bridges are classified into seven types. These are capacitance comparison bridge, inductance Comparison Bridge, Maxwell’s bridge, Hay’s bridge, Anderson Bridge, Schering bridge, Wein bridge.

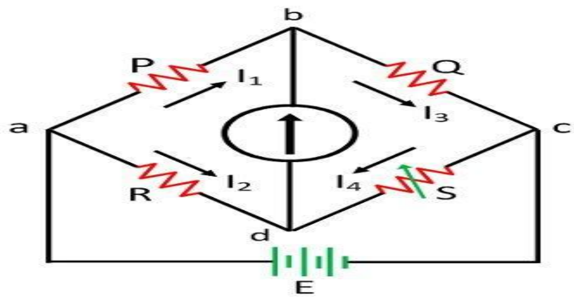
The best known bridge circuit is the Wheatstone bridge; the term was invented by “Samuel Hunter Christie” and popularized by “Charles Wheatstone”. A bridge circuit is mainly used to measure resistance. This circuit is built with four resistors: R1, R2, R3 and RX; wherein the two resistors are with known values R1 & R3, one resistor’s resistance is to be concluded Rx, and one which is changeable and adjusted R2. Two opposite vertices are associated with a supply of electric current like a battery, and a galvanometer is connected across the additional two vertices. The variable resistor is familiarized until the galvanometer reads zero.

Definition: The device uses for the measurement of minimum resistance with the help of comparison method is known as the Wheatstone bridge**.** The value of unknown resistance is determined by comparing it with the known resistance. The Wheatstone bridge **w**orks on the principle **o**f null deflection, i.e. the ratio of their resistance are equal, and no current flows through the galvanometer. The bridge is very **r**eliable and gives an accurate result.

In normal condition, the bridge remains in the unbalanced condition, i.e. the current flow through the galvanometer. When zero current passes through the galvanometer, then the bridge is said to be in balanced condition. This can be done by adjusting the known resistance P, Q and the variable resistance S.
The working of the bridge is similar to the potentiometer. The Wheatstone bridge is only used for determining the medium resistance. For measuring the high resistance, the sensitive ammeter is used in the circuit.

Construction of Wheatstone Bridge:
The basic circuit of the Wheatstone bridge is shown in the figure below. The bridge has four arms which consists two unknown resistance, one variable resistance and the one unknown resistance along with the emf source and galvanometer.

The emf supply is attached between point a and b, and the galvanometer is connected between point c and d. The current through the galvanometer depends on the potential difference across it.



Wheatstone Bridge

Working of Galvanometer:
The bridge is in balance condition when no current flows through the coil or the potential difference across the galvanometer is zero. This condition occurs when the potential difference across the a to b and a to d are equal, and the potential differences across the b to c and c to d remain same.
The current enters into the galvanometer divides into I_1 and I_2, and their magnitude remains same. The following condition exists when the current through the galvanometer is zero.

$$I_1 P = I_2 R \ldots\ldots\ldots equ(1)$$

$$I_1P = I_2R \ldots\ldots\ldots\ldots\ldots\ldots 1$$

The bridge in a balanced condition is expressed as

$$I_1 = I_3 = \frac{E}{P+Q}$$

$$I_2 = I_4 = \frac{E}{R+S}$$

Where E = emf of the battery.
By substituting the value of I_1 and 1_2 in equation (1) we get.

$$\frac{PE}{P+Q} = \frac{RE}{R+S}$$

$$P(R+S) = R(P+Q)$$

$$PR + PS = RP + RQ$$

$$PS = RQ \ldots\ldots\ldots equ(2)$$

$$R = \frac{P}{Q} \times S \ldots\ldots\ldots equ(3)$$

The equation (2) shows the balance condition of the Wheatstone bridge.

The value of unknown resistance is determined by the help of the equation (3). The R is the unknown resistance, and the S is the standard arm of the bridge and the P and Q are the ratio arm of the bridge.

Errors in Wheatstone Bridge

The following are the errors in the Wheatstone bridge.

- The difference between the true and the mark value of the three resistances can cause the error in measurement.
- The galvanometer is less sensitive. Thus, inaccuracy occurs in the balance point.
- The resistance of the bridge changes because of the self-heating which generates an error.
- The thermal emf cause serious trouble in the measurement of low-value resistance.
- The personal error occurs in the galvanometer by taking the reading or by finding the null point.

The above mention error can be reduced by using the best qualities resistor and galvanometer. The error because of self-heating of resistance can minimize by measuring the resistance within the short time. The thermal effect can also be reduced by connecting the reversing switch between the battery and the bridge.

Limitation of Wheat Stone Bridge

The Wheatstone bridge gives inaccurate readings if it is unbalanced. The Wheatstone bridge measures resistance from few ohms to megaohms. The upper range of the bridge can be increased with the help of the applied emf, and the lower range is limited by connecting the lead at the binding post.

POTENTIOMETERS

Potentiometer :- an instrument for measuring an electromotive force by balancing it against the potential difference produced by passing a known current through a known variable resistance.

Potentiometer Types

There are two main types of potentiometers:

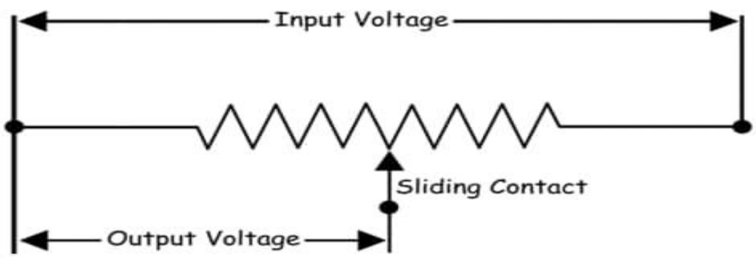
- Rotary potentiometer
- Linear potentiometer

Even though the basic construction and working principle of potentiometers are the same, they differ in one aspect that is the geometry of the moving terminal. Mostly the potentiometers what we find has a wiper that rotates over an arc shaped resistive material, there is another type of pot where the wiper slides linearly over a straight resistive strip. Based on the geometry of the resistive strip, the potentiometer can be broadly classified into two types, discussed below.

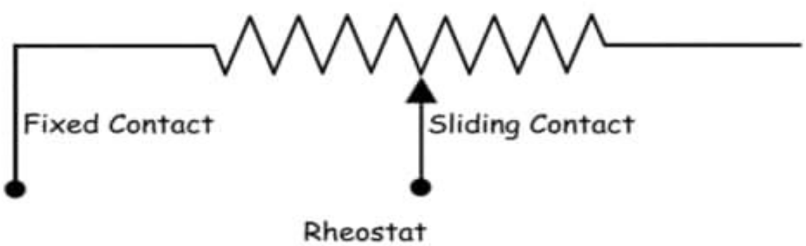
1. **Rotary type potentiometers**: As the name suggests, this type of potentiometer has a wiper which can be rotated across the two terminals, to vary the resistance of the potentiomer. They are one of the common types of Pots. Depending upon how many times, one can turn the wiper, they are further classified into the following categories:
2. **Single turn** : These pots are one of the commonly used type of pots. The wiper can take only a single turn. It usually rotates a 3/4th of the full turn.
3. **Multi turn**: These pots can make multiple rotations like 5, 10 or 20. They have a wiper in the form of a spiral or helix, or a worm-gear, to make the turns. Known for their high precision, these type of Pots are used where high precision and resolution are required.
4. **Dual gang**: From the name of this pot it can be assumed what it is. It is nothing but two pots with equal resistance and taper are combined on the same shaft. The two channels are set in parallel.
5. **Concentric pot**: Here two pots are combined together on shafts placed ina concentric manner. The advantage of using this type of pot is that two controls can be used in one unit.
6. **Servo pot**: “Servo” meaning motor pot is a motorized pot. This means its resistance can be adjusted or controlled automatically by a motor.

How Does a Potentiometer Work?

A potentiometer is a passive electronic component. Potentiometers work by varying the position of a sliding contact across a uniform resistance. In a potentiometer, the entire input voltage is applied across the whole length of the resistor, and the output voltage is the voltage drop between the fixed and sliding contact as shown below.

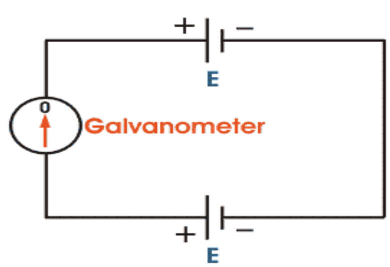


A potentiometer has the two terminals of the input source fixed to the end of the resistor. To adjust the output voltage the sliding contact gets moved along the resistor on the output side.

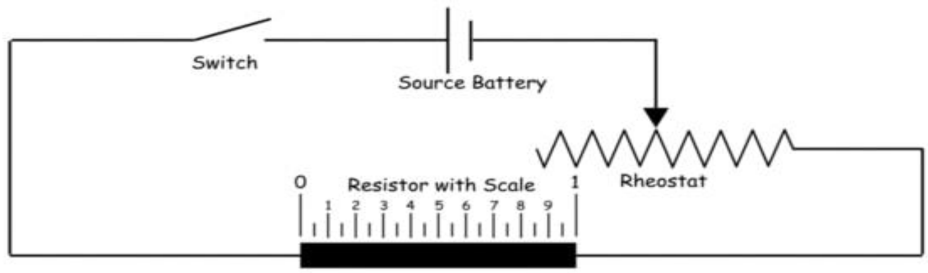


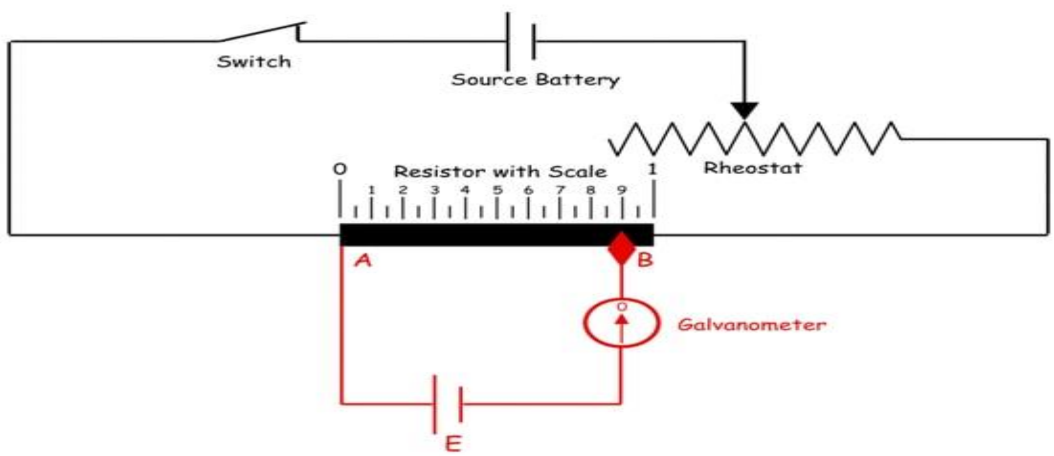
This is different to a rheostat, where here one end is fixed and the sliding terminal is connected to the circuit, as shown below

This is a very basic instrument used for comparing the emf of two cells and for calibrating ammeter, voltmeter, and watt-meter. The basic working principle of a potentiometer is quite simple. Suppose we have connected two batteries in parallel through a galvanometer. The negative battery terminals are connected together and positive battery terminals are also connected together through a galvanometer as shown in the figure below.



Here, if the electric potential of both battery cells is exactly the same, there is no circulating current in the circuit and hence the galvanometer shows null deflection. The working principle of potentiometer depends upon this phenomenon.





Now let’s think about another circuit, where a battery is connected across a resistor via a switch and a rheostat as shown in the figure below.

The resistor has the uniform electrical resistance per unit length throughout its length. Hence, the voltage drop per unit length of the resistor is equal throughout its length. Suppose, by adjusting the rheostat we get v volt voltage drop appearing per unit length of the resistor. Now, the positive terminal of a standard cell is connected to point A on the resistor and the negative terminal of the same is connected with a galvanometer. The other end of the galvanometer is in contact with the resistor via a sliding contact as shown in the figure above.
By adjusting this sliding end, a point like B is found where there is no current through the galvanometer,
Hence there is no deflection in the galvanometer.
That means, emf of the standard cell is just balanced by the voltage appearing in the resistor across points A and B. Now if the distance between points A and B is L, then we can write emf of standard cell E = Lv volt.

This is how a potentiometer measures the voltage between two points (here between A and B) without taking any current component from the circuit. This is the specialty of a potentiometer; it can measure voltage most accurately.

Applications of Potentiometer:

There are many different uses of a potentiometer. The three main applications of a potentiometer are:

1. Comparing the emf of a battery cell with a standard cell
2. Measuring the internal resistance of a battery cell
3. Measuring the voltage across a branch of a circuit

FORCE MEASUREMENT

In science, **force** is the push or pull on an object with mass that causes it to change velocity (to accelerate). **Force** represents as a vector, which means it has both magnitude and direction. **Forces** can be **measured** using a device called **force** meter. The unit of **force** is called the Newton. It is represented by the symbol N.

Force measurement methods may be divided into two categories:

- Direct comparison
- Indirect comparison.

In a direct comparison method, an unknown force is directly compared with gravitational force acting on a known mass. A simple analytical balance is an example of this method.
An indirect comparison method involves the use of calibrated masses or transducers.
A summary of indirect comparison methods is given below:

1. Lever-balance methods
2. Force-balance method.
3. Hydraulic pressure measurement.
4. Acceleration measurement.
5. Elastic elements.

The **PROVING RING** is a device used to measure force. It consists of an elastic ring of known diameter with a measuring device located in the center of the ring. Proving rings come in a variety of sizes. They are made of a steel alloy. Manufacturing consists of rough machining from annealed forgings, heat treatment, and precision grinding to final size and finish.
Proving rings can be designed to measure either compression or tension forces. Some are designed to measure both. The basic operation of the proving ring in tension is the same as in compression. However, tension rings are provided with threaded bosses and supplied with

pulling rods which are screwed onto the bosses. The proving ring consists of two main elements, the ring itself and the diameter-measuring system, shown on the right in the exploded view of a proving ring. Forces are applied to the ring through the external bosses. The resulting change in diameter, referred to as the deflection of the ring, is measured with a micrometer screw and the vibrating reed mounted diametrically within the ring.

The micrometer screw and the vibrating reed are attached to the internal bosses of the ring. In modern rings, the upper and lower internal and external bosses are machined as an integral part of the ring to avoid mechanical interferences during the application of the force.

To read the diameter of the ring, the vibrating reed is set in motion by gently tapping it with a pencil. As the reed is vibrating, the micrometer screw on the spindle is adjusted until the usa button on the spindle just contacts the vibrating reed, dampening out its vibrations. When this occurs a characteristic buzzing sound is produced.

At this point a reading of the micrometer dial indicates the diameter of the ring.The number of divisions on the micrometer dial and the graduations of the vernier index vary by type of proving ring. Typically, proving rings are designed to have a deflection of about 0.84 mm (0.033 in) to 4.24 mm (0.167 in). The relative measurement uncertainty can vary from 0.075 % to about 0.0125 %.