Unit-4

Measurement Of Displacement And Strain

Resistive Transducers

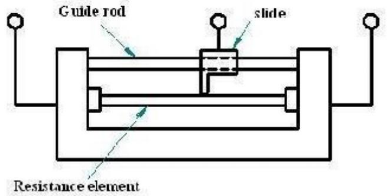
The resistance of an electrical conductor varies according to the relation,

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

where R= resistance in ohms, r= Resistivity of the material in ohm-cm, L= length of the conductor in cm, A= cross sectional area in cm2. Any method of varying one of the quantities involved may be the design criterion for the transducer. Following are some types:

Sliding contact devices:

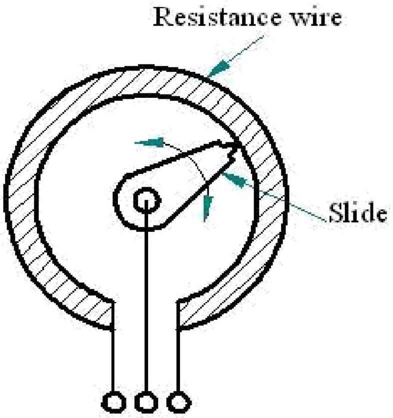
Convert mechanical displacement input into either current or voltage output - Achieved by changing the effective length of the conductor - The slide or contactor maintains electrical contact with the element and the slide is a measure of the linear displacement of the slide - Such devices are used for sensing relatively large displacements.



Sliding contact Resistive Transducer

Potentiometers:

The resistance elements may be formed by wrapping a resistance wire around a card as shown in fig. In this the effective resistance between either end of the resistance element and the slide is a measure of angular displacement of the slide.



Angular motion

Angular motion potentiometer

- **Inductance** is the property in an electrical circuit where a change in the current flowing through that circuit induces an electromotive force (EMF) that opposes the change in current.
- In electrical circuits, any electric current i produces a magnetic field and hence generates a total magnetic flux Φ acting on the circuit.
- This magnetic flux, according to *Lenz's law* tends to oppose changes in the flux by generating a voltage (*a counter emf*) that tends to oppose the rate of change in the current.
- The ratio of the magnetic flux to the current is called the *self-inductance* which is usually simply referred to as the *inductance* of the circuit

Mutual Inductance:

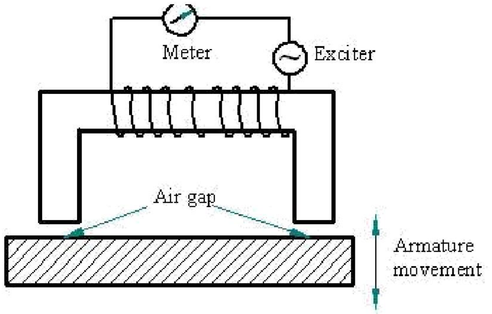
When the varying flux field from one coil or circuit element induces an emf in a neighboring coil or circuit element, the effect is called Mutual Inductance.

Magnetic reluctance

Magnetic reluctance or magnetic resistance, is analogous to resistance in an electrical circuit.
In likeness to the way an electric field causes an electric current to follow the path of least resistance, a magnetic field causes magnetic flux to follow the path of least magnetic reluctance. Permeance is the reciprocal of reluctance

VARIABLE SELF INDUCTANCE TRASDUCER (Single Coil)

When a single coil is used as a transducer element, the mechanical input changes the permeance of the flux path generated by the coil, thereby changing its inductance.



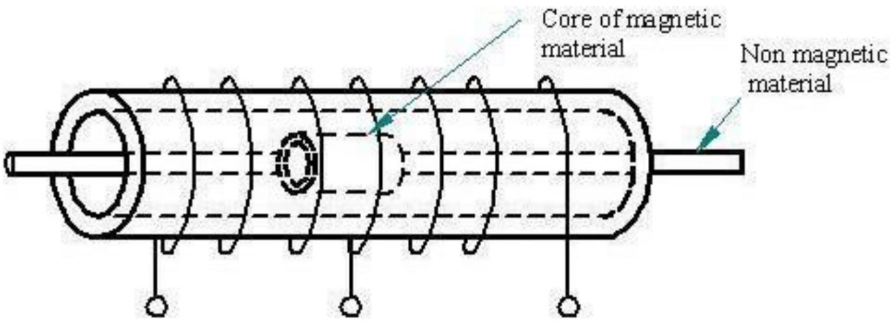
Single Coil

Self inductance arrangement

This change can be measured by a suitable circuit, indicating the value of the input. As shown in fig, the flux path may be changed by a change in the air gap.

The Two Coil arrangement, shown in fig, is a single coil with a center tap. Movement of the core alters the relative inductance of the two coils. These transducers are incorporated in inductive bridge circuit in which variation in inductance ratio between the two coils provides the output. This is used as a secondary transducer for pressure measurement.

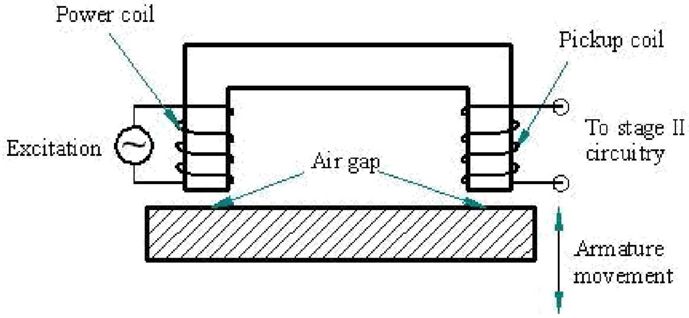
Variable self inductance -Two Coil (Single coil with center tap)



Variable Mutual inductance -Two Coil

- In this type, the flux from a power coil is coupled to a pickup coil, which supplies the output.
- Input information in the form of armature displacement, changes the coupling between the coils.
- The air gap between the core and the armature govern the degree of coupling.

Two Coil Mutual Inductance Transducer

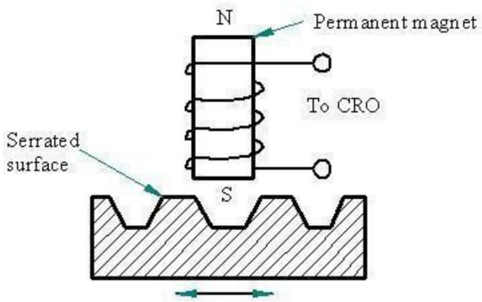


Note: Three Coil mutual inductance device (LVDT) is already discussed in Comparators Chapter.

A Variable reluctance Transducers are used for dynamic applications, where the flux lines supplied by a permanent magnet are cut by the turns of the coil. Some means of providing relative motion is included into the device.

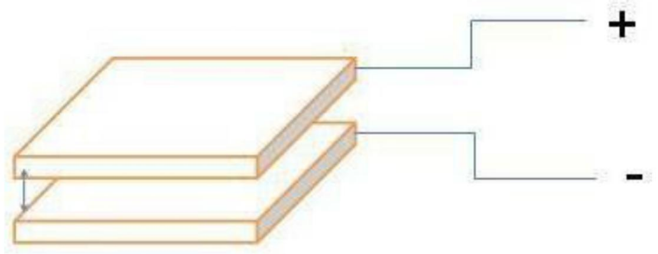
- The fig shows a simple type of reluctance pickup consisting of a coil wound on a permanent magnetic core.
- Any variation of the permeance of the magnetic circuit causes a change in the flux, which is brought about by a serrated surface subjected to movement.
- As the flux field expands or collapses, a voltage is induced in the coil.

Variable Reluctance Transducer



Capacitance Transducer

Generally it consists of two plates separated by a dielectric medium



The principle of these type is that variations in capacitance are used to produce measurement of many physical phenomenon such as dynamic pressure, displacement, force, humidity, etc.

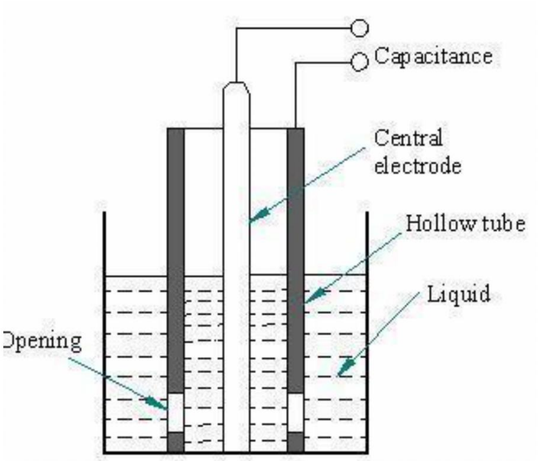
An equation for capacitance is $C = \frac{0.244KA(N-1)}{d}$ Farads

Where K= dielectric constant (for air K=1), A= area of one side of one plate, N= Number of plates, d= Separation of plate surfaces (cm)

The change in the capacitance may be brought about by three methods:

1. Changing the dielectric
2. Changing the area
3. Changing the distance between the plates
4. Fig shows a device used for the measurement of liquid level in a container.
5. The capacitance between the central electrode and the surrounding hollow tube varies with changing dielectric constant brought about by changing liquid level.
6. Thus the capacitance between the electrodes is a direct indication of the liquid level.
7. Variation in dielectric constant can also be utilized for measurements of thickness, density, etc.

Capacitance Pickup to measure liquid level (Changing dielectric constant)

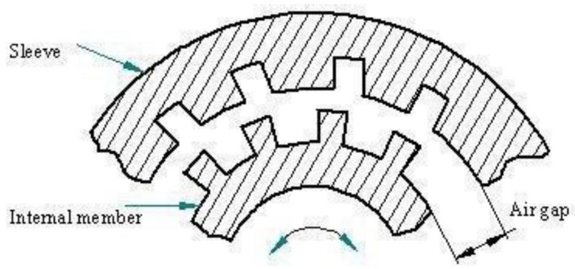


***__capacitance__** is the ability of a body to hold an electrical charge.
Capacitance is also a measure of the amount of electric charge stored for a given electric potential. A common form of charge storage device is a two-plate capacitor. If the charges on the plates are +Q and −Q, and V gives the voltage between the plates, then the capacitance is given by C=(Q/V)
The SI unit of capacitance is the farad; 1 farad = 1 coulomb per volt

Capacitive Transducer- Changing area:

- Capacitance changes depending on the change in effective area.
- This principle is used in the secondary transducing element of a *Torque meter.*
- This device uses a sleeve with serrations cut axially and a matching internal member with similar serrations as shown in fig.

- Torque carried by an elastic member causes a shift in the relative positions of the serrations, thereby changing the effective area. The resulting capacitance change may be calibrated to read the torque directly.

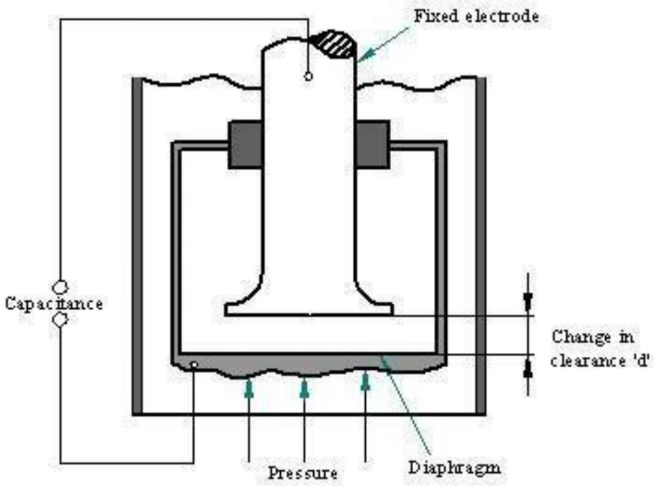


Torque Meter

(Capacitive type)

Capacitive Transducer-Changing distance

The capacitance varies inversely as the distance between the plates. The fig shows a capacitive type pressure transducer where the pressure applied to the diaphragms changes the distance between the diaphragm & the fixed electrode which can be taken as a measure of pressure.



Capacitive type pressure pickup

Advantages of Capacitive Transducers

(1) Requires extremely small forces to operate and are highly sensitive
(2) They have good frequency response and hence useful for dynamic measurements.
(3) High resolution can be obtained.
(4) They have high input impedance & hence loading effects are minimum.
(5) These transducers can be used for applications where stray magnetic fields render the inductive transducers useless.

Disadvantages of Capacitive Transducers

(1) Metallic parts must be properly insulated and the frames must be earthed.
(2) They show nonlinear behaviour due to edge effects and guard rings must be used to eliminate this effect.
(3) They are sensitive to temperature affecting their performance.
(4) The instrumentation circuitry used with these transducers are complex.
(5) Capacitance of these transducers may change with presence of dust particles & moisture.

Piezoelectric Transducers :

- Certain materials can produce an electrical potential when subjected to mechanical strain or conversely, can change dimensions when subjected to voltage. This effect is called *'Piezoelectric effect'*.
- The fig shows a piezoelectric crystal placed between two plate electrodes and when a force 'F' is applied to the plates, a stress will be produced in the crystal and a corresponding deformation. The induced charge Q=d*F where 'd' is the piezoelectric constant
- The output voltage E=g*t*p where 't' is crystal thickness, 'p' is the impressed pressure & 'g' is called voltage sensitivity given by g=(d/e), e being the strain.
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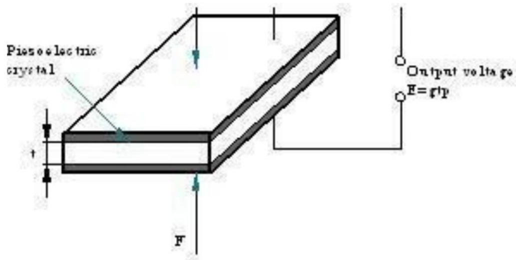


Piezoelectric effect

Piezoelectric materials

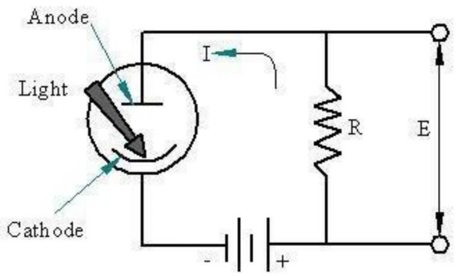
The common piezoelectric materials are quartz, Rochelle salt (Potassium sodium tartarate), ammonium dihydrogen phosphate and ordinary sugar. The desirable properties are stability, high output, insensitivity to temperature and humidity and ability to be formed into desired shape. Quartz is most suitable and is used in electronic oscillators. Its output is low but stable. Rochelle salt provides highest output, but requires protection from moisture in air & cannot be used above 45oC. Barium titanate is polycrystalline, thus it can be formed into a variety of sizes & shapes.

Piezoelectric transducers are used to measure surface roughness, strain, force & torque, Pressure, motion & noise. Desirable Properties of Piezoelectric Crystals Good stability, should be insensitive to temperature extremes, possess the ability to be formed to any desired shape.

Photoelectric Transducers:

A photoelectric transducer converts a light beam into a usable electric signal. As shown in the fig, light strikes the photo emissive cathode and releases electrons, which are attracted towards the anode, thereby producing an electric current in the circuit. The cathode & the anode are enclosed in a glass or quartz envelope, which is either evacuated or filled with an inert gas. The photo electric sensitivity is given by; I=s*f where I=Photoelectric current, s=sensitivity, f= illumination of the cathode. The response of the photoelectric tube to different wavelengths is influenced by

(i) The transmission characteristics of the glass tube envelope and
(ii) Photo emissive characteristics of the cathode material.

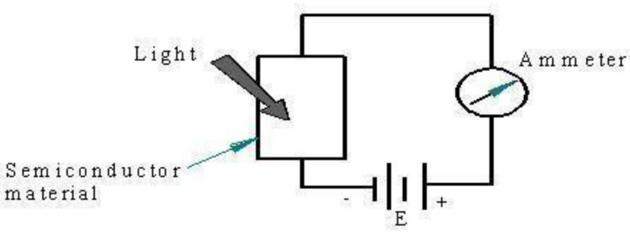


Photoelectric tubes are useful for counting purposes through periodic interruption of a light source

Photoconductive Transducers:

The principle of these transducers is when light strikes a semiconductor material, its resistance decreases, there by producing an increase in the current. The fig shows a cadmium sulphide semiconductor material to which a voltage is applied and when light strikes, an increase in current is indicated by the meter.

Photoconductive transducers are used to measure radiation at all wavelengths. But extreme experimental difficulties are encountered when operating with long wavelength radiations.



Photoconductive Transducer

The principle of *photovoltaic cell* is illustrated in the fig. It consists of a bas metal plate, a semiconductor material, and a thin transparent metal layer. When light strikes the transparent metal layer and the semiconductor material, a voltage is generated. This voltage depends on the load resistance R. The open circuit voltage is a logarithmic function, but linear behavior may be obtained by decreasing the load resistance.

- It is used in light exposure meter for photographic work.
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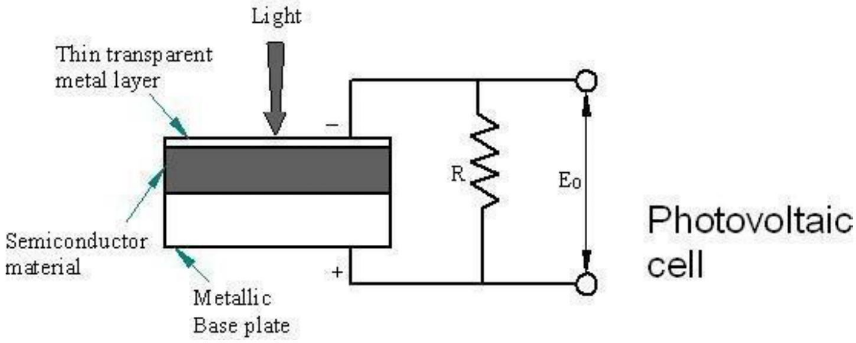


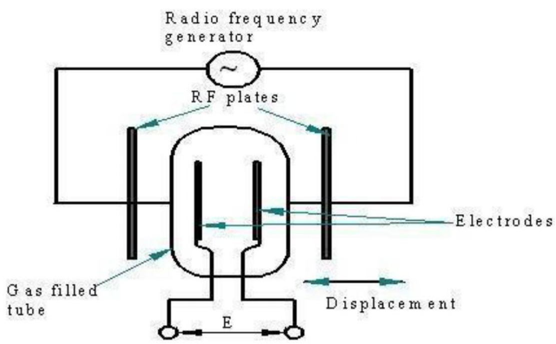
Ionization Transducers

- Ionization Transducers consist of a glass or quartz envelope with two electrodes A & B and filled with a gas or mixture of gases at low pressures.
- The radio frequency (RF) generator impresses a field to ionize the gas inside the tube.
- As a result of the RF field, a glow discharge is created in the gas, and the two electrodes A & B detect a potential difference in the gas plasma.
- It depends on the electrode spacing and the capacitive coupling between the RF plates and the gas
- When the tube is at the central position between the RF plates, the potentials on the electrodes will be the same, but when the tube is displaced from its central position, a D.C potential will be created.
- Thus ionization transducer is an useful device for measuring displacement.

Applications:

Pressure, acceleration & humidity measurements. They can sense capacitance changes of 10-15 farads or movements of 2.5x10-5 mm can be accurately measured with a linearity better than 1%.

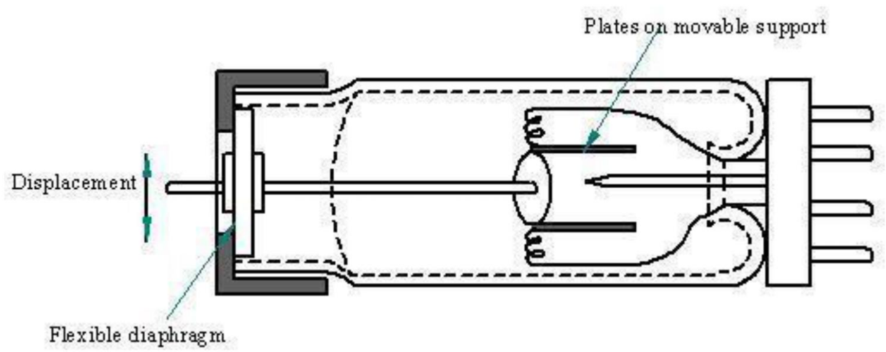
Ionization Transducer



- The fig shows the schematic diagram of an *Electronic transducer* element which is basically an electronic tube in which some of the elements are movable.
- Here, the plates are mounted on an arm which extends through a flexible diaphragm in the end of the tube.
- A mechanical movement applied to the external end of the rod is transferred to the plates within the tube thereby changing the characteristics of the tube.

Applications:

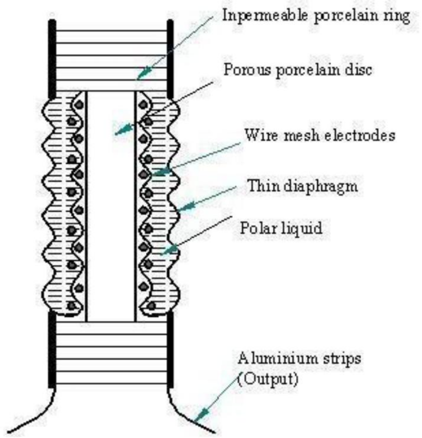
Electronic transducer element is used as surface roughness



Electrokinetic Transducer

- The Electrokinetic phenomenon is also referred to as 'Streaming Potential' which occurs when a polar liquid such as water, Methanol, or acetonitrile (CH3CN) is forced through a porous disc.
- When the liquid flows through the pores, a voltage is generated which is in phase with and directly proportional to the pressure across the faces of the disc.
- When direction of flow is reversed, the polarity of the signal is also reversed.

Electrokinetic Transducer



An unlimited supply of liquid is required on the upstream to measure static differential pressure with this type of pickup. Since this is impractical, finite amount of liquid is constrained within the electrokinetic cell. i.e. the device is used for dynamic rather than static pressure measurements.

- *Fig. shows a typical electrokinetic cell. It consists of a porous porcelain disc fitted into the center of an impermeable porcelain ring.*
- *The diaphragms are tightly sealed on either side to retain the polar liquid, which fills the space between the diaphragms.*
- *A wire mesh electrode is mounted on either side of the porous disc, with electrical connections via the aluminium strips.*
- *The whole assembly is fitted in a suitable housing.*

Applications: Measurement of small dynamic displacements, pressure & acceleration. **Limitations**: Can not be used for measurement of static quantities.

MEASUREMENT OF SPEDD, ACCLERATION AND VIBRATION

Introduction

Speed is a rate variable defined as the time-rate of motion. Common forms and units of speed measurement include: linear speed expressed in meters per second (m/s), and the angular speed of a rotating machine usually expressed in radians per second (rad/s) or revolutions per minute (rpm).
Measurement of rotational speed has acquired prominence compared to the measurement of linear speed.

Angular measurements are made with a device called tachometer. The dictionary definitions of a tachometer are:

* “an instrument used to measure angular velocity as of shaft, either by registering the number of rotations during the period of contact, or by indicating directly the number of rotations per minutes”

* “an instrument which either continuously indicates the value of rotary speed, or continuously displays a reading of average speed over rapidly operated short intervals of time”

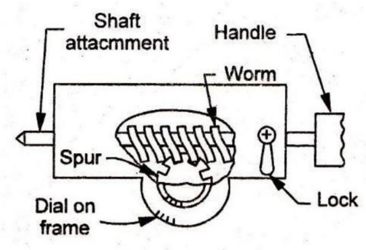
Tachometers may be broadly classified into two categories:

- Mechanical tachometers and
- Electrical tachometers.

Mechanical tachometers:

These tachometers employ only mechanical parts and mechanical movements for the measurement of speed.

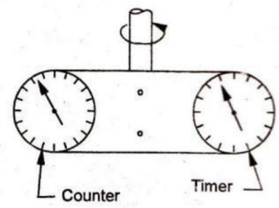
1. Revolution counter and timer:



Revolution counter

The revolution counter, sometimes called a speed counter, consists of a worm gear which is also the shaft attachment and is driven by the speed source. The worm drives the spur gear which in turn actuates the pointer on a calibrated dial. The pointer indicates the number of revolutions turned by the input shaft in a certain length of time. The unit requires a separate timer to measure the time interval. The revolution counter, thus, gives an average rotational speed rather than an instantaneous rotational speed. Such speed counters are limited to low speed engines which permit reading the counter at definite time intervals. A properly designed and manufactured revolution counter would give a satisfactory speed measure upto 2000-3000 rpm.

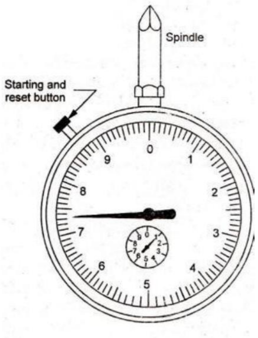
2. Tachoscope:



Tachoscope

The difficulty of starting a counter and a watch at exactly the same time led to the development of tachoscope, which consists of a revolution counter incorporating a built-in timing device. The two components are integrally mounted, and start simultaneously when the contact point is pressed against the rotating shaft. The instrument runs until the contact point is disengaged from the shaft. The rotational speed is computed from the readings of the counter and timer. Tachoscopes have been used to measure speeds upto 5000 rpm.

3. Hand speed indicator:

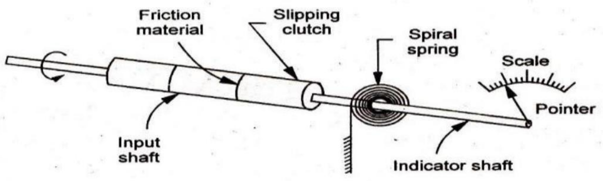


Hand speed indicator

The indicator has an integral stop watch and counter with automatic disconnect. The spindle operates when brought in contact with the shaft, but the counter does not function until the start and wind button is pressed to start the watch and engage the automatic clutch. Depressing of the starting button also serves to wind the starting watch. After a fixed time-interval (usually 3 or 6 seconds), the revolution counter automatically gets disengaged. The instrument indicates the average speed over the short interval, and the dial is designed to indicate the rotational speed directly in rpm. These speed measuring units have an accuracy of about 1% of the full scale and have been used for speeds within the range 20,000 to 30,000 rpm.

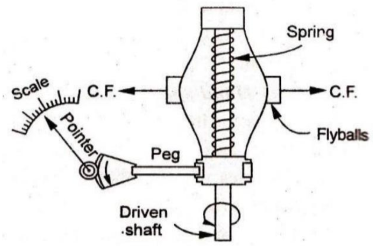
4. Slipping clutch tachometer:

The rotating shaft drives an indicating shaft through at slipping clutch. A pointer attached to the indicator shaft moves over a calibrated scale against the torque of a spring. The pointer position gives a measure of the shaft speed.



Slipping clutch tachometer

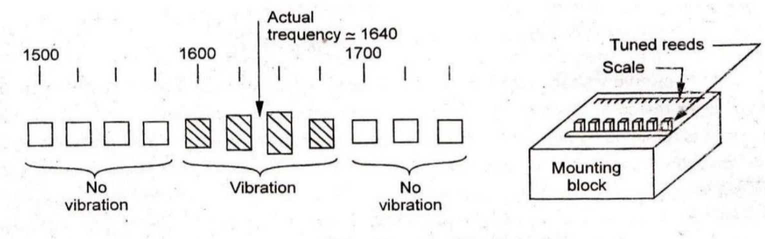
5. Centrifugal force tachometers:



Centrifugal tachometer

The device operates on the principle that centrifugal force is proportional to the speed of rotation. Two flyballs (small weights) are arranged about a central spindle. Centrifugal force developed by these rotating balls works to compress the spring as a function of rotational speed. A grooved collar or sleeve attached to the free end of the spring then slides on the spindle and its position can be calibrated in terms of the shaft speed. Through a series of linkages, the motion of the sleeve is usually amplified and communicated to the pointer of the instrument to indicate speed. Certain attachments can be mounted onto the spindle to use these tachometers for the measurement of linear speed.

6. Vibrating reed tachometer:

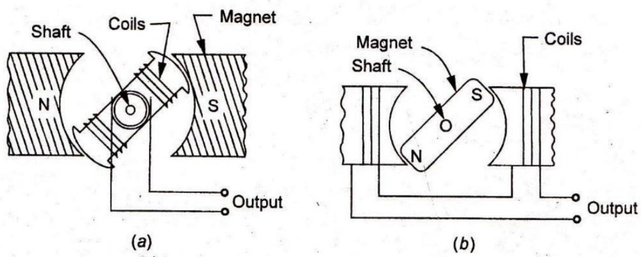


Vibrating reed tachometer

Tachometers of the vibrating reed type utilize the fact that speed and vibration in a body are interrelated. The instrument consists of a set of vertical reeds, each having its own natural frequency of vibration. The reeds are lined up in order of their natural frequency and are fastened to a base plate at one end, with the other end free to vibrate. When the tachometer base plate is placed in mechanical contact with the frame of a rotating machine, a reed tuned to resonance with the machine vibrations responds most frequently. The indicated reed vibration frequency can be calibrated to indicate the speed of the rotating machine.

(i) Indicating unit containing a voltage source, a capacitor, milliammeter and a calibrating circuit. When the switch is closed in one direction, the capacitor gets charged from d-c supply and the current starts flowing through the ammeter. When the spindle operates the reversing switch to close it in opposite direction, capacitor discharges through the ammeter with the current flow direction remaining the same. The instrument is so designed that the indicator responds to the average current. Thus, the indications are proportional to the rate of reversal of contacts, which in turn are proportional to speed of the shaft. The meter scale is graduated to read in rpm rather than in milliamperes. The tachometer is used within the range 200 - 10000 rpm.

1. Tachogenerators: These tachometers employ small magnet type d.c or a.c generators which translate the rotational speeds into d.c. or a.c voltage signal. The operating principle of such tachometers is illustrated in Fig. Relative perpendicular motion between a magnetic field and conductor results in voltage generation in the conductor.



(a) D.C. tachometer *(b) A.C. tachometer*

(i) D. C. tachometergenerator: This is an accurately made dc. generator with a permanent magnet of horse-shoe type. With rotation of the shaft, a pulsating dc. Voltage proportional to the shaft speed is produced, and measured with the help of a moving coil voltmeter having uniform scale and calibrated directly in terms of speed. The tachometer is sensitive to the direction of rotation and thus can be used to indicate this direction by the use of an indicator with its zero point at mid-scale. For greater accuracy, air gap of the magnetic paths must be maintained as uniform as possible. Further, the instrument requires some form of commutation which presents the problem of brush maintenance.

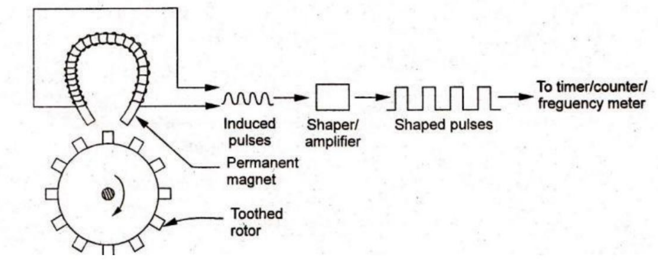
(ii) A.C. tachometer generator: The unit embodies a stator surrounding a rotating permanent magnet. The stator consists of a multiple pole piece (generally four), and the permanent magnet is installed in the shaft whose speed is being measured. When the magnet rotates, an a.c. voltage is induced in the stator coil. The output voltage is rectified and measured with a permanent magnet moving coil instrument. The instrument can also be used to measure a difference in speed of two sources by differentially connecting the stator coils.

Tachogenerators have been successfully employed for continuous measurement of speeds upto 500 rpm with an accuracy of ±1%.

2. Contactless electrical tachometers:

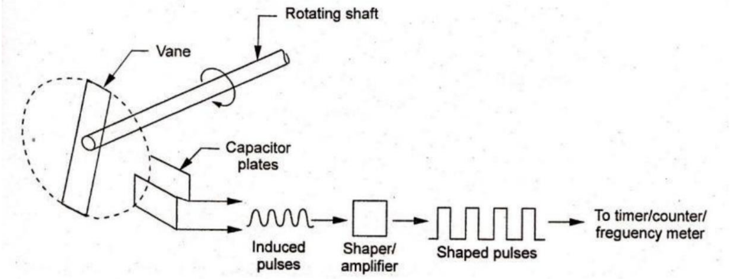
Tachometers of this type produce pulse from a rotating shaft without any physical contact between the speed transducer and the shaft. This aspect has the distinct advantage in that no load is applied to the machine.

(i) Inductive pick-up tachometer: The unit consists of a small permanent magnet with a coil round it. This magnetic pick up is placed near a metallic toothed rotor whose speed is to be measured. As the shaft rotates, the teeth pass in front of the pick-up and produce a change in the reluctance of the magnetic circuit. The field expands or collapses and a voltage is induced in the coil. The frequency of the pulses depends upon the number of teeth on the wheel and its speed of rotation. Since the number of teeth is known, the speed of rotation can be determined by measuring the pulse frequency. To accomplish this task, pulse is amplified and squared, and fed into a counter of frequency measuring unit.



$$\text{Speed } N = \frac{\text{pulses per second}}{\text{number of teeth}}$$

$$N = \frac{P}{T}\text{ rps} = \frac{P}{T} \times 60 \text{ rpm}$$

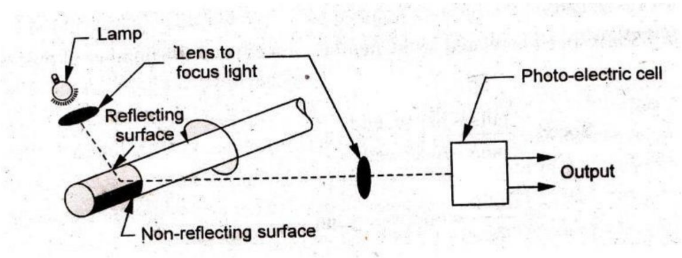


If the rotor has 60 teeth, and if the counter counts the pulses in one second, then me counter will directly display the speed in revolutions per minute.

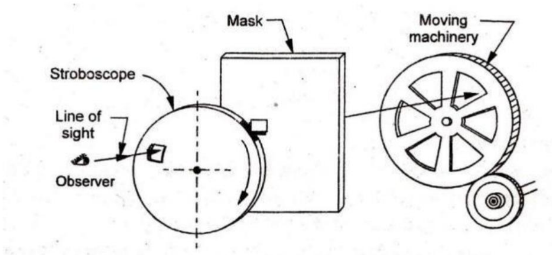
(ii) Capacitive type pick-up tachometer:

The device consists of a vane attached to one end of the rotating machine shaft. When the shaft rotates between the fixed capacitive plates, there occurs a change in the capacitance. The capacitor forms a part of an oscillator tank so that number of frequency changes per unit of time is a measure of the shaft speed. The pulses thus produced are amplified, and squared, and may then be fed to frequency measuring unit or to a digital counter so as to provide a digital analog of the shaft rotation.

(iii) Photo-electric tachometer: These pick-ups utilize a rotating shaft to intercept a beam of light falling on a photo-electric or photo conductive cell. The shalt has an intermittent reflecting (white) and non- reflecting (black) surface. When a bean) of light hits the reflecting surface on the rotating shaft, light pulses are obtained and the reflected light is focused onto the photo-electric cell. The frequency of light pulses is proportional to the shaft speed, and so will be the frequency of electrical output pulses from the photo-electric cell.



(i) Stroboscope:



Mechanical disk-type stroboscope

The stroboscope utilises the phenomenon of vision when an object is viewed intermittently. The human sense of vision is so slow to react to light stimuli that it is unable to separate two different light impulses reaching the eye within a very short Period of time (less than 0.1second). A succession of impulses following one another at brief intervals are observed by the eye as a continuous unbroken sequence. A mechanical disk type stroboscope consists essentially of a whirling disk attached to motor whose speed can be varied and measured. A reference mark on the rotating shaft on the shaft appears to be stationary. For this condition, the shaft speed equals that of rotating disk, or some even multiple of this speed and is given by:

- **Vibration amplitude and acceleration**

Vibration refers to the repeated cyclic oscillations of a system; the oscillatory motions may be simple harmonic (sinusoidal) or complex (non-sinusoidal). The oscillations are caused when acceleration is applied to the machine alternately in two directions

The excessive vibration level in a machine is an indication of the following troubles it can cause:

* Catastrophic failure as a result of stress caused by induced resonance and fatigue

* Excessive wear because of failure to compensate for vibration to which a product is subjected or which is created by the product

* Faulty production

* Incorrect operation of precision equipment and machinery because of failure to compensate for vibration and shock encountered in use.

human discomfort leading to adverse effects such as motion sickness, breathing and speech disturbance, loss of touch of sensitivity etc.

Characteristics and units of vibrations: Vibration is generally characterized by

(i) The frequency in Hz, or

(ii) The amplitude of the measured parameter which may be displacement, velocity or

acceleration. Further, the units of vibration depend on the vibration parameter as follows:

(a) Displacement, measured in m, (b) velocity, measured in m/s and (c) acceleration, measured in m/s^2.

Vibrating motions may be simple harmonic or complex. Assuming it to be simple harmonic,

$$\text{displacement } x = A \sin \omega t$$

$$\text{velocity } v = \frac{dx}{dt} = A\,\omega \cos \omega t$$

$$\text{acceleration } a = \frac{dv}{dt} = -A\,\omega^2 \sin \omega t$$

where $\omega = 2\pi f$ rad/s and f is the frequency of vibration in Hz. Obviously, the amplitude of the different parameters are :

displacement amplitude $= A$

velocity amplitude $= A\,\omega$

acceleration amplitude $= -A\,\omega^2$

The measured amplitude is normally expressed in decibels with reference to a fixed value. Let A_1 be the measured amplitude and A_0 be the reference amplitude. Then the vibration level expressed in decibels is

$$\text{vibration level} = 20 \log_{10} \frac{A_1}{A_0} \text{ dB}$$

The internationalyy accepted reference values are:

(a) for velocity, the reference value is 10^{-3} m/s, and

(b) for acceleration, the reference value is 10^{-5} m/s^2

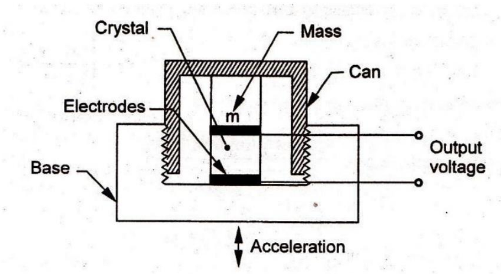
Measurement of acceleration:

There are two types of accelerometers generally used for measurement of acceleration:

(i) Piezo-eletric type, and (ii) seismic type.

(i)Piezo-electric accelerometer: The unit is perhaps the simplest and most commonly used transducer employed for measuring acceleration. The sensor consists of a piezo-electric crystal sandwitched, between two electrodes and has a mass placed on it. The unit is fastened to the base whose acceleration characteristics are to be obtained. The can threaded to the base acts as a 'spring and squeezes the mass against the crystal. Mass exerts a force on the crystal and a certain output voltage is generated. If the base is now accelerated downward, inertial reaction force on the base acts upward against the top of the can. This relieves stress on the crystal. From Newton's second law

$$\text{force} = \text{mass} \times \text{acceleration}$$



Advantages and limitations

* Rugged and inexpensive device

* High output impedance ’

* High frequency response from 010 Hz to 50 kHz

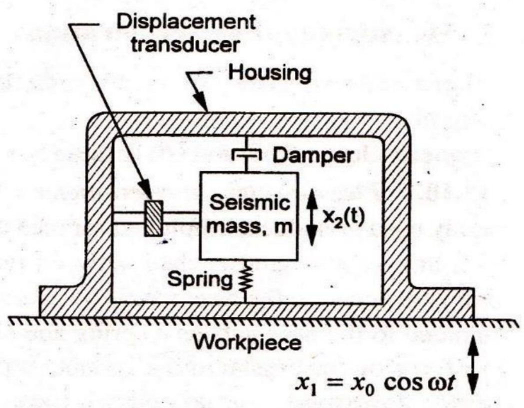
* High sensitivity varies from 10 to 100 mv/g where g = $9.807\ m/s^2$

* Capability to measure acceleration from a fraction of g to thousands of g

* Somewhat sensitive to changes in temperature

* Subject to hysteresis errors.

Displacement sensing (seismic) accelerometer: In a seismic accelerometer the displacement of a mass resulting from an applied forced is measured and correlated to the acceleration. Fig shows the schematics of a common spring mass damper system which accomplishes this task. The mass is supported by a spring and damper is connected to the housing frame. The frame is rigidly attached to the machine whose acceleration characteristics are to be determined. When an acceleration is imparted by the machine to the housing frame, the mass moves relative to the frame, and this relative displacement between the mass and frame is sensed and indicated by an electrical displacement transducer.



Seismic accelerometer

Theory of seismic accelerometer **:** The spring-mass-damper system of the seismic accelerometer can be represented by an equilibrium equation obtained through Newton's second law :

$$m\frac{d^2x_2}{dt^2}+c\frac{dx_2}{dt}+kx_2=c\frac{dx_1}{dt}+kx_1 \qquad ...(12.14)$$

where the damping force has been assumed to be proportional to the velocity. For a simple harmonic vibratory motion applied to the housing frame,

$$\text{displacement } x_1 = A\cos\omega t$$

$$\text{velocity } v=\frac{dx_1}{dt}=-\omega A\sin\omega t$$

$$\text{acceleration } a=\frac{dv}{dt}=-\omega^2 A\cos\omega t \qquad ...(12.15)$$

where $\omega = 2\pi f$ rad/s and f is the frequency of vibration in Hz. From these expressions for the instantaneous values of different parameters we have :

$$\text{displacement amplitude} = A$$

$$\text{velocity amplitude} = \omega A$$

$$\text{acceleration amplitude} = \omega^2 A \qquad ...(12.16)$$

A solution to equation 12.14 would show that the relative displacement $(x_2 - x_1)$ between the mass and housing is given by :

$$(x_2-x_1)=\frac{\omega^2 A}{\omega_n^2\left[\left\{1-\left(\frac{\omega}{\omega_n}\right)^2\right\}^2+\left\{2\left(\frac{c}{c_c}\right)\left(\frac{\omega}{\omega_n}\right)\right\}^2\right]^{\frac{1}{2}}} \qquad ...(12.17)$$

where the natural frequency ω_n and critical damping coefficient c_c are given by

$$\omega_n=\sqrt{\frac{k}{m}} \quad ; \quad c_c=2\sqrt{mk} \qquad ...(12.18)$$

The seismic instrument may be used either for displacement measurement by proper selection of the mass-spring-damper combination. Since velocity is rate of change of displacement and acceleration is rate of change of velocity, each quantity can be obtained by differentiating or integrating one of the quantity which has been measured. Since the process of integration is more common and easily done in electrical systems, it is a common practice to measure acceleration and then deduce the velocity or displacement by successive integration.

Displacement measurement : Let the frequency (ω) applied to the base be much higher than the natural frequency (ω_n), then the term $\left\{2\left(c/c_c\right)\left(\omega/\omega_n\right)\right\}^2$ can be neglected in comparison with $\left[\left(\omega/\omega_n\right)^2\right]^2$ and the approximate expression for $(x_2 - x_1)$ becomes :

$$(x_2 - x_1) = \frac{\omega^2 A}{\omega_n^2\left[\left\{\left(\frac{\omega}{\omega_n}\right)^2\right\}^2\right]^{\frac{1}{2}}} = \frac{\omega^2 A}{\omega_n^2\left(\frac{\omega}{\omega_n}\right)^2} = A \qquad \text{...(12.19)}$$

Thus the output is very nearly equal to the input amplitude *A*. This relation is valid for ω/ω_n ratios greater than 2. Thus for vibration pick-ups, the system is to be operated at frequencies higher than the natural frequency. The task is accomplished by keeping the natural frequency $\left(\omega_n = \sqrt{k/m}\right)$ low by employing soft spring and large mass.

Acceleration measurement : Let the input frequency ω be much smaller than the natural frequency ω_n, then

$$(x_2 - x_1) = \frac{\omega^2 A}{\omega_n^2} = \frac{1}{\omega_n^2} \times \text{maximum acceleration} \qquad \text{...(12.20)}$$

and this relation remains valid for $\omega/\omega_n \leq 0.4$ .This if the pick-up is to be used for acceleration measurement, ω_n should be large, *i.e.*, the system should have a stiff spring and small mass. That would enable to operate the system over a wide range of frequencies and still keep the response linear.

In a ***strain gauge accelerometer*** (Fig. 12.25), the sensing mass is mounted on a cantilever beam. A viscous liquid fills the housing and provides the necessary damping. Two strain gauges are attached to the beam, one on each and these sense the strain in the

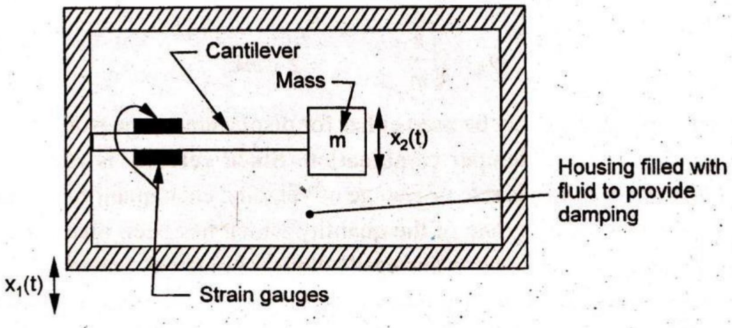


Fig. 12.25 Strain gauge accelerometer

beam which results from vibratory displacement. The leads from the strain gauges are taken to a wheatstone bridge whose output indicates the relative displacement between the mass and the housing form.

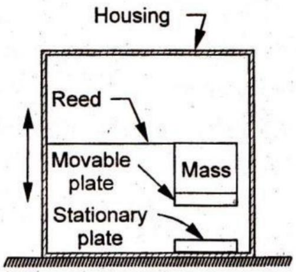


Fig. 12.26 (a)
Capacitance vibration sensor

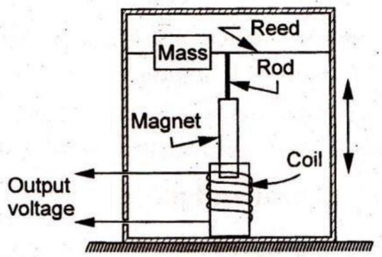


Fig. 12.26 (b)
Inductive vibration sensor

Quite often, vibration amplitudes are translated into an inductance and capacitance change of the system. Magnitude of the output voltage or capacitance is then taken as a measure of the amplitude of vibration. The schematics of such vibration pick-ups are shown in Fig. 12.26 which are self-explanatory.

A suitable estimate of frequency and amplitude of vibrations in light systems (where it is not possible to attach an electrical transducer) is best made by using either a stroboscope or a reed vibrometer.

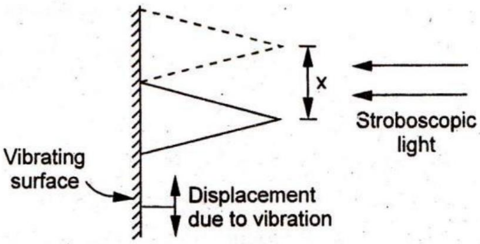
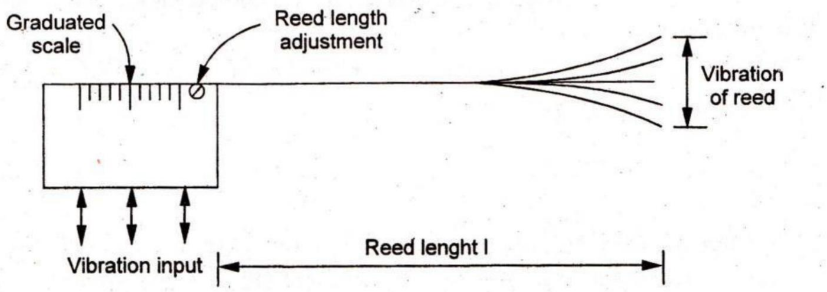


Fig. 12.27 Stroboscopic method for vibration measurement

A fixed pointer is attached to the vibrating surface (Fig. 12.27), flashes from a stroboscope are directed onto the pointer and frequency of light flashes is adjusted until a



stationary image or a slowly moving image of the pointer is obtained. The flash frequency is then related to the amplitude or frequency of vibration. The stroboscope method is quite suitable for small-amplitude vibrations having an upper frequency range of about 500 Hz.

The reed vibrometer employs a reed which is mounted onto the vibrating structure or mechanism. The length of the reed is adjusted so that its natural frequency is equal to the frequency of the vibrating surface. Under this resonance condition, the reed vibrates with maximum amplitude. The reed length is calibrated directly in frequency units ; typical range of frequency measurement is 5 Hz to 10000 Hz.

**********THE END**********

Strain Gauge

•The strain gauge is a passive, resistive transducer which converts the mechanical elongation and compression into a resistance change.

•This change in resistance takes place due to variation in length and cross sectional area of the gauge wire, when an external force acts on it.

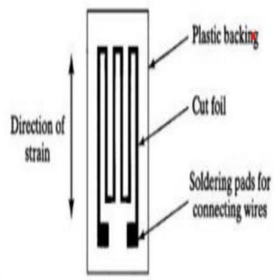
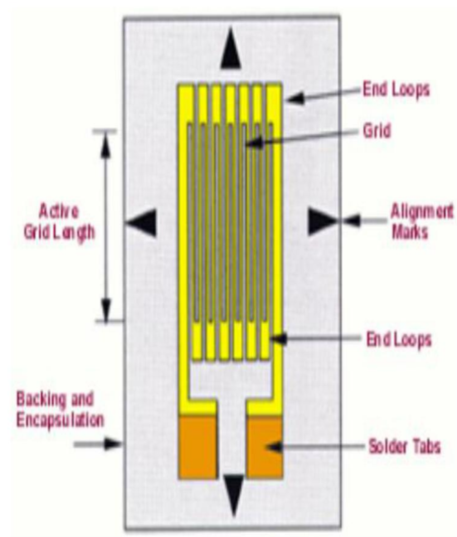


FIGURE 8.2
Foil strain gage.



Gauge factor

•The sensitivity of a strain gauge is described in terms of its characteristics called, gauge factor G.
•Gauge factor is defined as the unit change in resistance per unit change in length.

$$G = \frac{\Delta R/R}{\Delta l/l} = \frac{\Delta R/R}{S}$$

Types of Strain Gauge
•Unbondedstrain gauge.
.Bonded strain gauge
•Linear strain gauge
•Rosette •
Torque gauge
•Helical gauge

Unbonded strain gauge

•This gauge consists of a wire stretched between two point in an insulating medium such as air.

•The wires may be made of various copper, nickel, chromium nickel or nickel iron alloys.

•The element is connected via a rod to diaphragm which is used for sensing the pressure. The wire is tensioned to avoid buckling when they experience the compressive force.

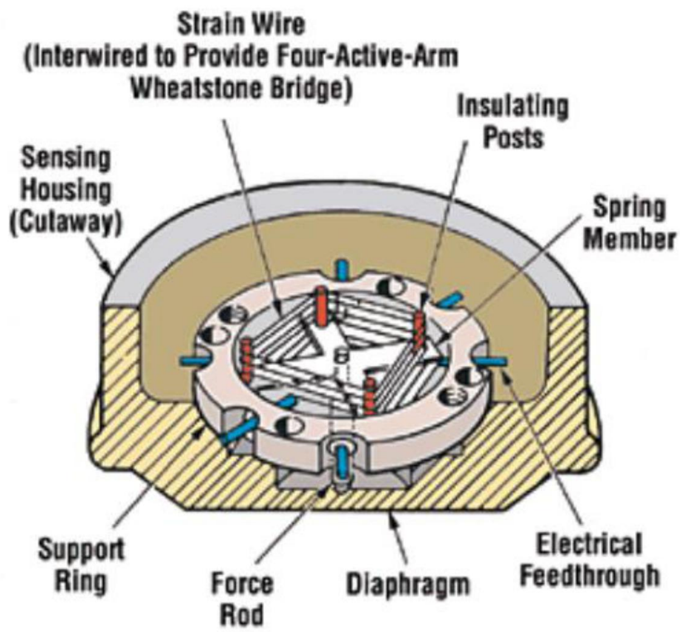
•Resistance wires are of equal length.

The unbounded meter wire gauges are used exclusively in transducer applications that employ preloaded resistance wire connected in Wheatstone bridge as shown in fig.

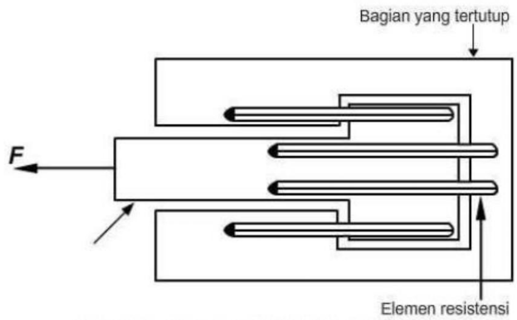
•At initial preload the strain and resistance of the four arms are nominally equal with the resultant output voltage of the bridge equal to zero.

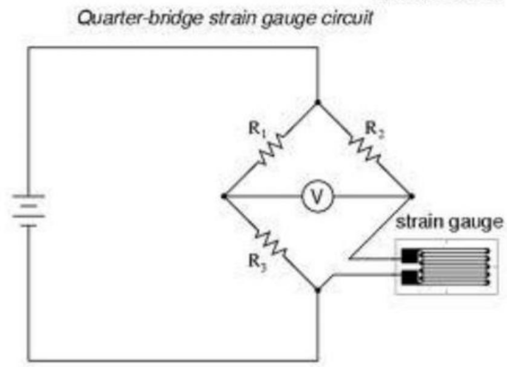
•Application of pressure produces a small displacement, the displacement increases the tension in two wires and decreases it in the other two thereby increase the resistance of two wires which are in tension and decreasing the resistance of the remaining two wire.

•This causes an unbalance of the bridge producing an output voltage which is proportional to the input displacement and hence to the applied pressure.



Unbonded strain gauge





Bonded wire strain gauge

•The bonded metal wire strain gauge are used for both stress analysis and for construction of transducer.

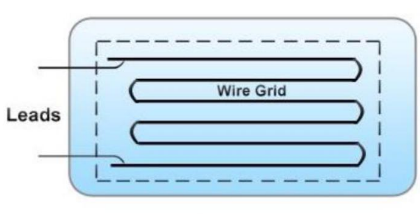
•A resistance wire strain gauge consists of a grid of fine resistance wire of 25 µm diameter. The grid is cemented to carrier which may be a thin sheet of paper Bakelite or teflon.

•The wire is covered on top with a thin sheet of material so as to prevent it from any mechanical damage.

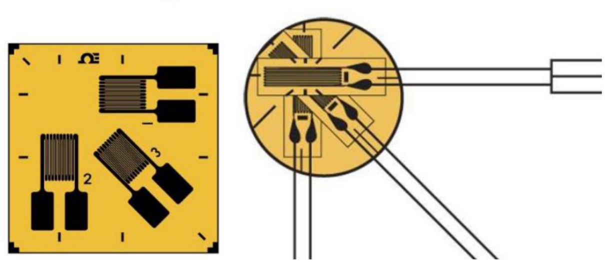
•The carrier is bonded with an adhesive material to the specimen which permit a good transfer of strain from carrier to grid of wires.

Bonded wire strain gauge

Linear strain gauge



Rosette type



Bonded Strain Gauges These gauges are directly bonded (that is pasted) on the surface of the structure under study. Hence they are termed as bonded strain gauges. The three types of bonded strain gauges are

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

Fine wire strain gauge

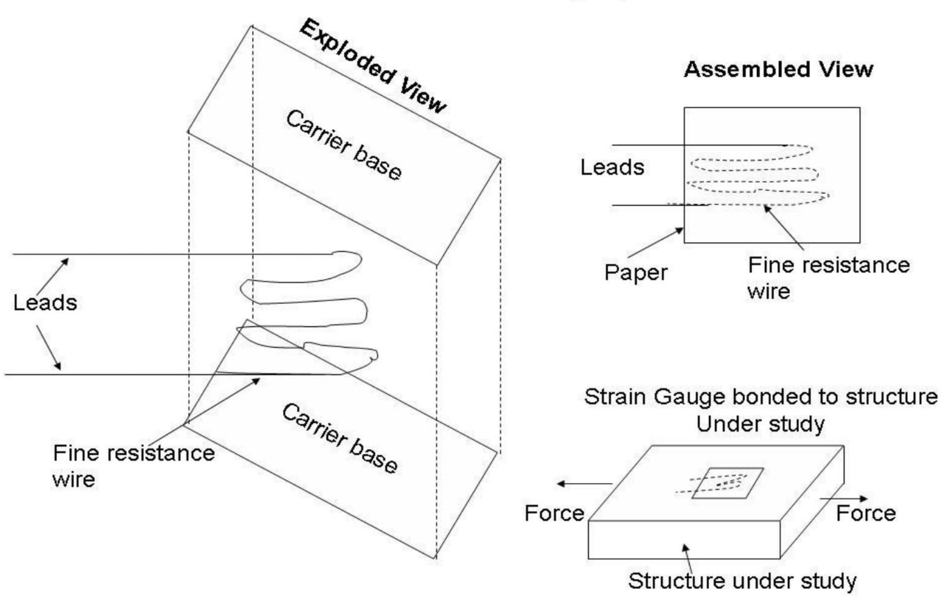
This is the first type of Bonded Strain Gauges.

Description

The arrangement consists of following parts,

A fine resistance wire diameter 0.025 mm which is bent again and again as shown in diagram. This is done to increase the length of the wire so that it permits a uniform distribution of stress. This resistance wire is placed between the two carrier bases (paper, Bakelite or Teflon) which are cemented to each other. The carrier base protects the gauge from damages. Leads are provided for electrically connecting the strain gauge to a measuring instrument (Wheatstone bridge).

Fine Wire Strain gauge



Operation

With the help of an adhesive material, the strain gauge is pasted/bonded on the structure under study. Now the structure is subjected to a force (tensile or compressive). Due to the force, the structure will change the dimension. As the strain gauge is bonded to the structure, the stain gauge will also undergo change in both in length and cross-section (that is, it strained). This strain (change in dimension) changes the resistance of the strain gauge which can be measured using a wheat stone bridge. This change in resistance of the strain gauge becomes a measure of the extent to which the structure is strained and a measure of the applied force when calibrated.

Fine Wire strain gauge Materials Material Composition
Nichrome Ni - 80% ; Cr – 20%
Constantan Ni – 45%; Cu – 55%
Nickel ----
Platinum ----
Isoelastic Ni – 36%; Cr – 8%; Mo – 0.5%

Advantages of Fine Wire Strain Gauge

The range of this gauge is +/- 0.3% of strain.
This gauge has a high accuracy.
Has a linearity of +/- 1%.

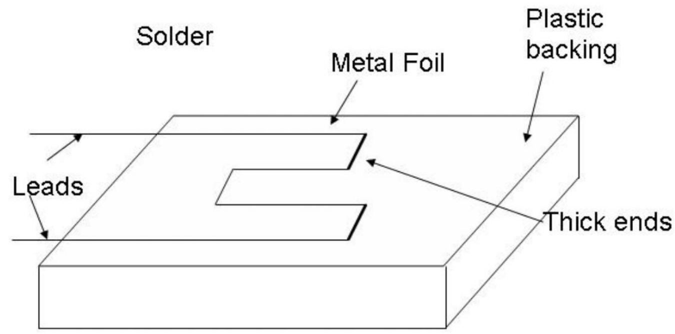
Limitation of Fine Wire strain gauge

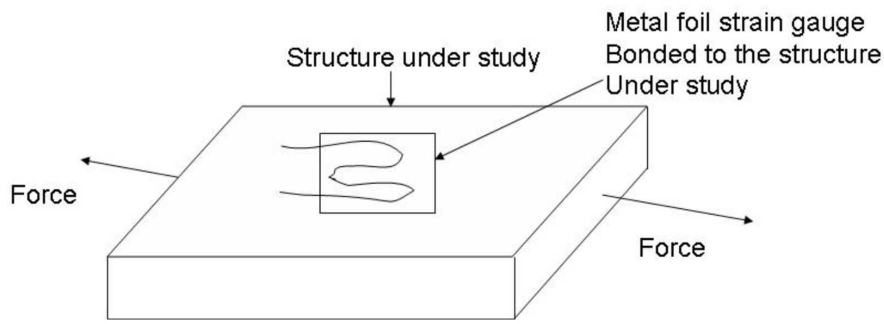
- These gauges cannot be detached and used again (because the gauges are bonded to the structure).
- These gauges are costly.

Metal Foil Strain Gauge

Description of Metal Foil Strain Gauge The arrangement consists of the following; The metal foil of 0.02mm thick is produced using the printed circuit technique. This metal foil is produced on one side of the plastic backing. Leads are soldered to the metal foil for electrically connecting the strain gauge to a measuring instrument (wheat stone bridge).

Metal Foil Strain Gauge





Operations of Metal foil Strain gauge

With the help of an adhesive material, the strain gauge is pasted/bonded on the structure under study. Now the structure is subjected to a force (tensile or compressive). Due to the force, the structure will change the dimension. As the strain gauge is bonded to the structure, the stain gauge will also undergo change in both in length and cross-section (that is, it strained). This strain (change in dimension) changes the resistance of the strain gauge which can be measured using a wheat stone bridge. This change in resistance of the strain gauge becomes a measure of the extent to which the structure is strained and a measure of the applied force when calibrated. Same as Fine Wire strain gauge operation.

Advantages of Metal foil Strain gauge

- These strain gauges can be manufactured in any shape.
- Perfect bonding of the strain gauge is possible with structure under study.
- The backing can be peeled off and the metal foil with leads can be used directly on the structure under study. In such cases, a ceramic adhesive is to be used.
- These gauges have a better fatigue life.
- Has good sensitivity and have stability even at high temperatures.

Semi – conductor or Piezo Resistive Strain Gauge

Description of Piezo Resistive Strain Gauge.

The arrangement of a semi-conductor strain gauge is as follows:

The sensing element is rectangular filament made as a wafer from silicon or geranium crystals. To these crystals, boron is added to get some desired properties and this process is called doping and the crystals are called doped crystals. This sensing element is attched to a plastics or stainless steel backing. Leads made of gold are drawn out from the sensing element for electrically connecting the strain gauge to a measuring instrument (wheat stone bridge).

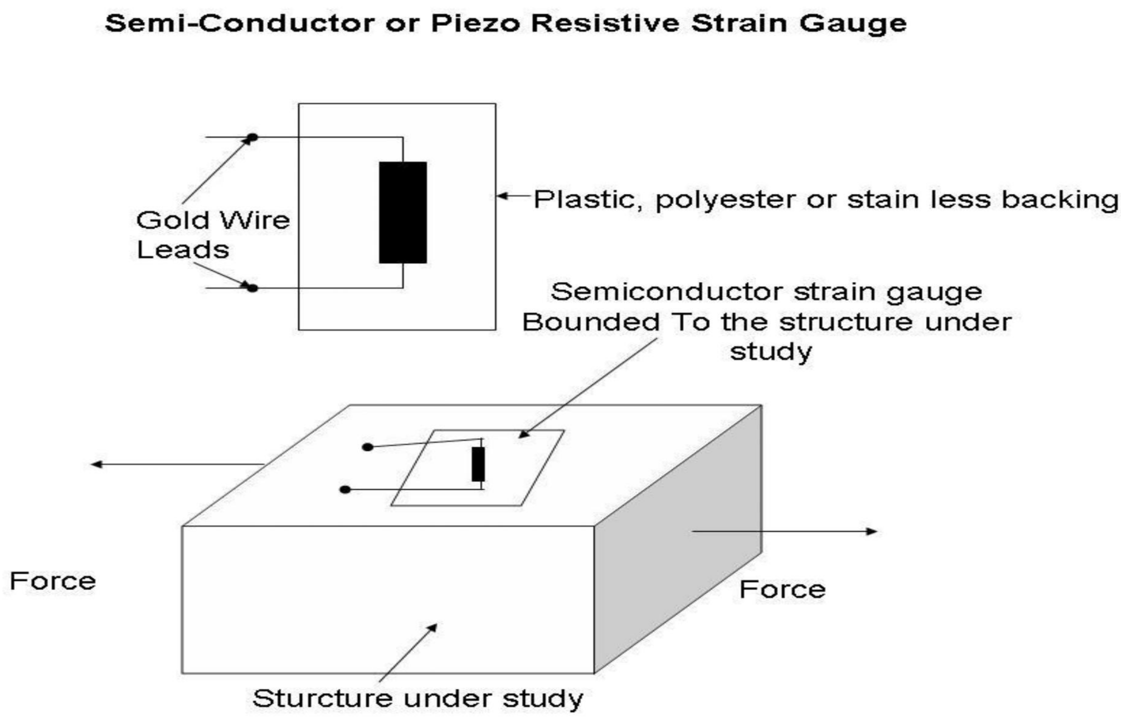
There are two types of sensing element namely:

Negative or n-type (resistance decrease with respect to tensile strain).

- Positive or P-type (resistance increase with respect to tensile strain).

Operation

With the help of an adhesive material, the strain gauge is pasted/bonded on the structure under study. Now the structure is subjected to a force (tensile or compressive). Due to the force, the structure will change the dimension. As the strain gauge is bonded to the structure, the stain gauge will also undergo change in both in length and cross-section (that is, it strained). When the sensing element (crystal) of the semiconductor strain gauge is strained, its resistivity changes contributing to a change in the resistance of the strain gauge. The change in the resistance of the strain gauge is measured using a wheat stone bridge. . This change in resistance of the strain gauge becomes a measure of the extent to which the structure is strained and a measure of the applied force when calibrated.



Advantages of semi-conductor Strain gauges

- These gauges have high gauge factor and hence they can measure very small strains.
- They can be manufactured to very small sizes.
- They have an accuracy of 2.3%
- They have excellent hysteresis characteristics.
- They have a good frequency of response.
- They have good fatigue life.

Limitation of semi-conductor Strain gauges

- These gauges are brittle and hence they cannot be used for measuring large strain.
- The gauge factor is not constant.
- These gauges have poor linearity.
- These gauges are very costly and are difficult to be bonded onto the structure under study.
- These gauges are sensitive to change in temperature