

Unit - IV

Transducers

Definition of transducers:-

The broad definition of transducers includes device which convert mechanical force into an electrical signal.

The I/P quantity for most instrumentation systems is a 'non-electrical quantity' in order to use electrical methods and techniques for measurement, manipulation & control. The non-electrical quantity is generally converted into an electrical form by a device called as 'transducer'.

Electric transducer:- In order to measure non-electrical quantities a detector is used which usually converts the physical quantity into a displacement. This displacement activates an electric transducer.

Advantages of electrical transducers:-

- 1) electrical amplification & attenuation can be done easily and that too with static devices
- 2) The mass-inertia effects are minimized.
- 3) The effects of friction are minimized
- 4) The electrical & electronic systems can be controlled with a very small power level
- 5) The electrical sig can be easily used, transmitted & processed for the purpose of measurement.
- 6) Telemetry is used in almost all sophisticated measurement systems. The entire aerospace research & development is based upon telemetry & remote control.

Classification of transducers:-

- 1) on the basis of transduction / can used
- 2) as primary & secondary transducer
- 3) as passive & active transducer
- 4) as analog & digital transducer
- 5) as transducer & inverse transducer.

i) based upon principle of transduction:-

The transducers can be classified on the basis of principle of transduction as resistive, inductive, capacitive etc. depending upon how they convert the i/p quantity into resistance, inductance, capacitance respectively.

ii) Primary & secondary transducers:- let us consider the case of a Bourdon tube. The Bourdon tube acting as a primary detector senses the pressure & converts the pressure into a displacement of its free end. The displacement of the free end moves the core of a linear variable differential transformer (L.V.D.T). Firstly the pressure is converted into a displacement by Bourdon tube then the displacement is converted into an analogous voltage by L.V.D.T. The Bourdon tube is called a 'primary transducer' while the L.V.D.T is called a 'secondary transducer'.

iii) Passive and Active transducer:-

Transducers may be classified according to whether they are passive (a) or active. Passive:- passive transducer derive the power required for transduction from an auxiliary power source. They also derive part of the power required for conversion from the physical quantity under measurement. It is also known as "externally powered transducer". Active:- Active transducers are those which do not require an auxiliary power source to produce their o/p. They are also known as self generating type, since they develop their own voltage (a) or current o/p.

iv) Analog & digital transducer:- the transducers can be classified on the basis of the o/p which may be a continuous function of time (a) or the o/p may be in discrete steps.

Analog:- These transducers convert the i/p quantity into an analog o/p which is a continuous function of time. Thus a strain gauge or L.V.D.T a thermocouple or a thermistor may be called as analog transducers.

Digital:- These transducers convert the i/p quantity into an electrical o/p which is in the form of pulses.

v) Transducers & Inverse Transducers:

Transducer: - a transducer can be broadly defined as a device which converts a non-electrical quantity into an electrical quantity. (2)

Inverse Transducer: - An inverse transducer is defined as a device which converts an electrical quantity into a non-electrical quantity.

Characteristics and Choice of Transducers:

When choosing a transducer for any application the input, transfer, o/p characteristics have to be taken into account.

i) Input Characteristics:

a) Type of input & operating range: - The foremost consideration for the choice of a transducer is the input quantity it is going to measure and its operating range. The type of input which can be any physical quantity, is generally determined in advance. The useful operating range of the transducer may be a decisive factor in selection of a transducer for a particular application. The upper limit is decided by the transducer capabilities while the lower limit of range is normally determined by the transducer resolution by the unavoidable noise originating in the transducer.

b) Loading effects: - Ideally a transducer should have no loading effect on the I/P quantity being measured. The magnitude of the loading effects can be expressed in terms of force, power & energy extracted from the quantity under measurement for working of the transducers.

i) Transfer characteristics: - Transfer characteristics of transducer require attention of three separate elements viz,
a) transfer function b) o/p c) response of transducer to environmental influences.

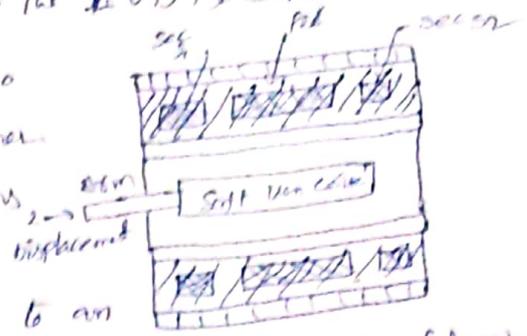
ii) output characteristics: - The three conditions in the o/p characteristics which should be considered are

- i) Type of electrical output
- ii) output impedance
- iii) useful range.

Linear Variable Differential Transducer (LVDT):— The most widely used inductive transducer to translate the linear motion into electrical signals is the LVDT. Construction is shown

The transducer consists of single primary winding 'P' & two secondary windings S_1 & S_2 wound on a cylindrical former.

The secondary windings have equal number of turns and are identically placed on either side of the primary winding. The primary winding is connected to an alternating current source. A movable soft iron core is placed inside former.



The amount of voltage change in either secondary winding is proportional to the amount of movement of the core. We have an indication of amount of linear motion. By noting which op voltage is increasing (or) decreasing we can determine the direction of motion.

applications of LVDT:—

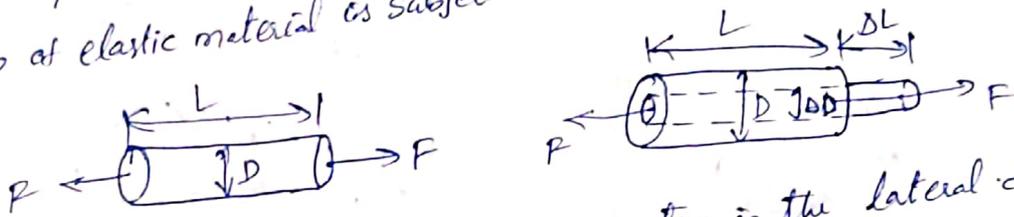
- 1) High range the LVDTs have a very high range for measurement of displacement. This can be used for measurement of displacement ranging from (1.25mm to 250mm)
- 2) Friction & electrical Isolation The LVDT has many commendable features that make it useful for a wide variety of applications.
- 3) Immunity from external effects: The separation b/w LVDT core & LVDT coils permits the isolation of media such as pressurized, corrosive, (or) caustic fluids from the coil assembly by a non-magnetic barrier interposed b/w the core & inside the coil.
- 4) High input & high sensitivity:— The LVDT gives a high output and many times there is no need for amplification. The transducer possesses a high sensitivity which is typically about 20 V/m.
- 5) Ruggedness:— These transducers can usually tolerate high degree of shock & vibration especially when the core is spring loaded without any adverse effects. They are simple in construction and by virtue of their being small and light in weight, they are stable & easy to align and maintain.

- (3)
- 6) Low Hysteresis:- LVDTs show a low hysteresis & hence repeatability is excellent under all conditions
- 7) Low power consumption. most of LVDTs consume power which is less than 1W.

Principle of operation of strain gauge:-

If a metal conductor is stretched (or) compressed, its resistance changes on account of the fact that both length & diameter of conductor change & also change in the value of resistivity of the conductor. when it is strained and this property is called piezoresistive effect. Pure resistance strain gauges are also known as piezoresistive gauges.

The change in the value of resistance by straining the gauge may be partly explained by the normal dimensional behaviour of elastic material. If a strip of elastic material is subjected to tension is shown below.



It will increase while there will be a reduction in the lateral dimension. So when a gauge is subjected to a positive strain, its length increases while its area of cross-section decreases. The resistance of a conductor is proportional to its length & inversely proportional to its area of cross-section. This property is called piezoresistive effect.

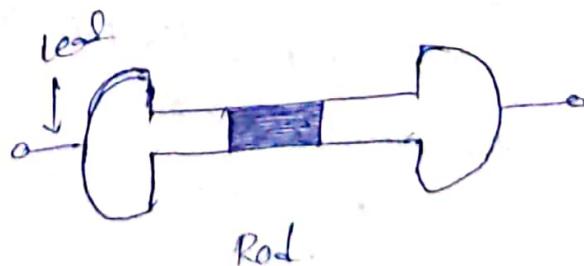
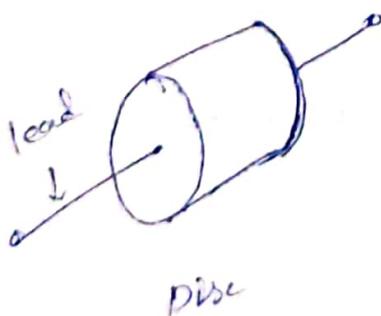
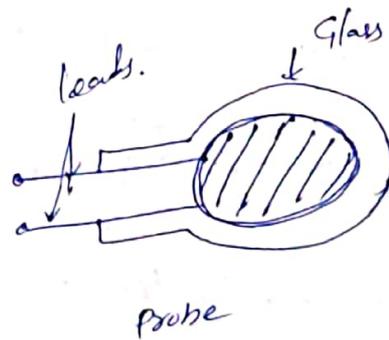
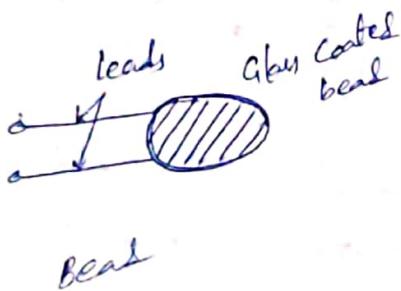
Resistance of unstrained gauge $\cdot R = \rho L/A$.

Thermistors :-

Thermistor is a construction of a term 'thermal resistors'. Thermistors are generally composed of semi-conductor materials. Although positive temperature coefficient of units are available most thermistors have negative coefficient of temperature of resistance. i.e. their resistance decreases with increase of temperature. The negative temperature coefficient of resistance can be as large as several percent per degree Celsius. This allows the thermistor circuits to detect very small change in temperature which could be not be observed with an RTD (or) Thermocouple.

Thermistors are widely used in applications which involve measurements in the range of -60°C to 15°C . The resistance of thermistors ranges from $0.5\ \Omega$ to $0.75\ \text{M}\ \Omega$.

The thermistors are composed of sintered mixture of metallic oxides such as manganese, nickel, cobalt, copper, iron & uranium. They are available in variety of sizes & shapes. These are beads, rods, discs, probe.



A thermistor in the form of a bead is smallest in size and the bead may have a diameter of $0.015\ \text{mm}$ to $1.25\ \text{mm}$.

Beads may be sealed in the tips of solid glass rods to form probes which may be easier to mount than the beads.

Glass probes have a diameter of about 2.5mm and a length which varies from 6mm to 50mm
Disks are made by pressing material under high pressure into cylindrical flat shapes with diameters ranging from 2.5mm to 25mm.

Applications of thermistors:-

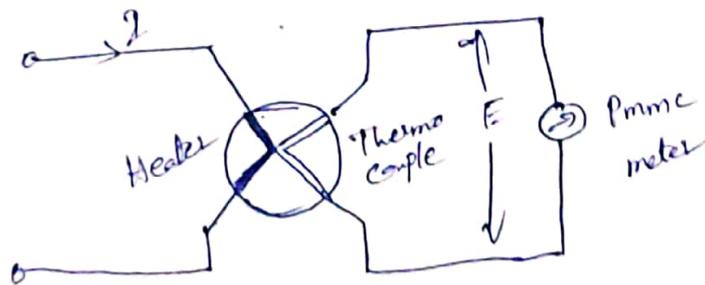
The major applications of thermistors are measurement of temperature of control temperature.

i) measurement of temperature:- Thermistor produces a large change of resistance with a small change in the temperature being measured. This large sensitivity of thermistor provides good accuracy of resolution.

ii) control of temperature:- a simple temperature control circuit may be constructed by replacing the micro-ammeter.

Thermocouples:-

When two metals having different work functions are placed together a voltage is generated at the junction which is nearly proportional to the temperature. This junction is called a "Thermocouple".



The heat at the junction is produced by the electrical current flowing in the heater element while the thermocouple produces an emf at its output terminals which can be measured with the help of PMMC instrument.

The emf produced is proportional to the temperature difference between the two junctions. The thermocouple type of instruments can be used for both DC & AC applications. The most attractive feature of thermocouple instruments is that they can be used for measurements of current and voltages at very high frequencies. These instruments are very accurate well above a frequency of 50 MHz.

$$E = a(T_1 - T_2) + b(T_1 - T_2)^2$$

The emf produced in a thermocouple circuit is given by

$$E = a(\Delta\theta) + b(\Delta\theta)^2$$

Transducers :-

The generalized measurement system consist of three major components. (7)

- i) i/p device
- ii) signal conditioning (or) processing device
- iii) o/p device.

The i/p device receives the quantity under measurement & delivers to the signal conditioning device. here signal is amplified, attenuated, filtered, modulated in format acceptable to the o/p device.

The input quantity for most instrumentation systems is a non-electrical quantity. In order to use electrical methods & techniques for measurement the non electrical quantity is generally converted into an electrical form by a device called a 'transducer'.

The definition of transducer is as the which converts mechanical force (non electrical quantity) into an electrical signal. is called transducer.

Transducers are consisting two components i) sensing element 2) transduction element.

Advantages of electrical transducers :-

In order to measure non-electrical quantities a detector is used which usually converts the physical quantity into a displacement. This displacement actuates an electric transducer which acting as a secondary transducer, gives an o/p that is electrical in nature.

- Advantages:
- i) electrical amplification & attenuation can be done easily & that too with static devices.
 - ii) The mass-inertia effects are minimized.
 - iii) The effects of friction are minimized.
 - iv) The electrical (or) electronic systems can be controlled with a very small power level.
 - v) The electrical o/p can be easily used, transmitted & processed for the purpose of measurement.
 - vi) Telemetry is used in almost all sophisticated measurement systems.

The entire aerospace research & development is based on telemetry only.

Classification of transducers:-

These are classified as

- i) on the basis of ^{principle of} transduction form used.
- ii) as primary & secondary transducers
- iii) as passive & active transducers
- iv) as Analog & digital transducers
- v) as transducers & inverse transducers.

i) based upon principle of transduction:- The transducers can be classified on the basis of principle of transduction as resistive, inductive, capacitive, etc. depending upon how they convert the input quantity into resistance, inductance, capacitance.

Ex:- Resistance

Potentiometer → Pressure, displacement.

Resistance strain gauge → Force, torque, displacement.

Thermistor → Temperature of flow.

Capacitance:-

Dielectric gauge → liquid level, thickness.

Inductance

differential t/f → pressure, force, displacement, position.

Gauge factor:-

(1)

Let a tensile stress 's' be applied to the wire this produces a positive strain causing the length to increase & area to decrease. Then when the wire is strained there are changes in its dimensions

Let ΔL = Change in length

ΔA \Rightarrow Change in area

ΔR = Change in Resistance

In order to find how ΔR depends upon the material physical quantities the expression for 'R' is differentiated with respect to stress 's'

They we get

$$\frac{dR}{ds} = \frac{d\left(\frac{\rho L}{A}\right)}{ds}$$

$$\frac{dR}{ds} = \frac{\rho}{A} \frac{\partial L}{\partial s} \Rightarrow \frac{\rho L}{A} \frac{\partial A}{\partial s} + \frac{1}{A} \frac{\partial \rho}{\partial s} \quad \text{--- (1)}$$

Dividing eqⁿ (1) by resistance $R = \frac{\rho L}{A}$ we get

$$\frac{1}{R} \frac{dR}{ds} = \frac{1}{L} \frac{\partial L}{\partial s} - \frac{1}{A} \frac{\partial A}{\partial s} + \frac{1}{\rho} \frac{\partial \rho}{\partial s} \quad \text{--- (2)}$$

Per unit change in length = $\Delta L/L$

Per unit change in area = $\Delta A/A$

Per unit change in resistivity = $\Delta \rho/\rho$

The ρ for circular wire area $\Delta A = \frac{\pi}{4} d^2$

$$\frac{\partial A}{\partial s} = \frac{\pi}{4} (2d) \frac{\partial d}{\partial s}$$

\Rightarrow Dividing by both sides by $A = \frac{\pi}{4} d^2$

$$\frac{1}{A} \frac{\partial A}{\partial s} = \frac{(2\pi/4) d}{(\pi/4) d^2} \frac{\partial d}{\partial s}$$

$$\Rightarrow \frac{1}{A} \frac{\partial A}{\partial s} = \frac{1}{A} \frac{\pi}{4} (2d) \frac{\partial d}{\partial s} \quad \frac{1}{A} \frac{\partial A}{\partial s} = \frac{2}{d} \frac{\partial d}{\partial s} \quad \text{--- (3)}$$

Substituting eqⁿ (3) into eqⁿ (2) we get

$$\frac{1}{R} \frac{dR}{ds} = \frac{1}{L} \frac{\partial L}{\partial s} - \frac{2}{D} \frac{\partial D}{\partial s} + \frac{1}{\rho} \frac{\partial \rho}{\partial s} \quad \text{--- (4)}$$

Now Poisson's ratio $\nu = \frac{\text{lateral strain}}{\text{longitudinal strain}} = \frac{-\partial D/D}{\partial L/L}$

Substituting eqⁿ (5) into eqⁿ (4)

$$\frac{\partial D}{\partial s} = -\nu \times \frac{\partial L}{L} \quad \text{--- (5)}$$

$$\frac{1}{R} \frac{dR}{ds} = \frac{1}{L} \frac{\partial L}{\partial s} + \nu \frac{2}{L} \frac{\partial L}{\partial s} + \frac{1}{\rho} \frac{\partial \rho}{\partial s} \quad \text{--- (6)}$$

If small variations above relationship can be written as

$$\frac{\Delta R}{R} = \frac{\Delta L}{L} + 2\nu \frac{\Delta L}{L} + \frac{\Delta \rho}{\rho} \quad \text{--- (7)}$$

The gauge factor is defined as the ratio of per unit change in resistance to per unit change in length.

gauge factor $G_f = \frac{\Delta R/R}{\Delta L/L} \quad \text{--- (8)}$

$$\frac{\Delta R}{R} = G_f \cdot \frac{\Delta L}{L} \Rightarrow \frac{\Delta R}{R} = G_f \times \epsilon \quad \text{--- (9)}$$

$\epsilon = \text{strain} = \frac{\Delta L}{L}$

The gauge factor can be written as

$$= 1 + 2\nu + \frac{\Delta \rho / \rho}{\epsilon} \quad \text{--- (10)}$$

↓

= Resistance change due to change of length

↘ Resistance change due to change in area

↘ Resistance change due to piezoresistive effect.

$$G_f = \frac{\Delta R/R}{\Delta L/L} = 1 + 2\nu + \frac{\Delta \rho / \rho}{\Delta L/L}$$

Measurement of non-electrical quantities

Measurement of strain:-

The Theory & Construction of strain gauges have already explained.

The gauge factor $G_f = \frac{\Delta R/R}{\epsilon} = 1 + 2\nu + \frac{\Delta P/P}{\epsilon}$

When we consider the sensitivity of a metallic strain gauge, we find that it is extremely versatile and reliable.

Typical values of gauge factor of resistance for commonly used strain gauges are.

$$G_f = 2 \quad \text{if } R = 120 \Omega$$

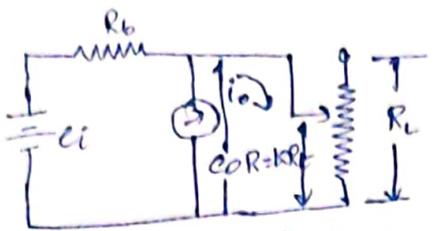
Strain gauges are used for measurements of strains as low as 1 micro strain. The corresponding change in resistance is

$$\Delta R = G_f \epsilon R = 2 \times 10^{-6} \times 120 = 2.4 \times 10^{-4} \Omega = 0.00024 \Omega$$

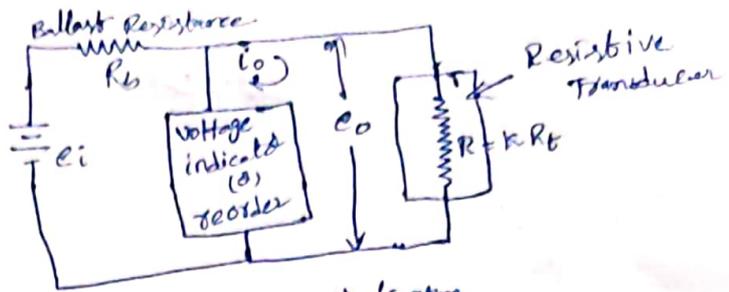
This small change in resistance which is 0.002% of original resistance has to be measured. It is quite evident that in order to measure a change in resistance of this low order will require the use of extremely sensitive and sophisticated instrumentation.

Strain gauges utilize circuits like voltage measuring potentiometer circuits, ballast circuits and Wheatstone bridges.

Ballast circuit:- A ballast circuit is only a simple variation of the current sensitive circuit. In this case a voltage sensitive device is connected across the transducer in place of a series connected current sensitive device. This circuit also called voltage sensitive circuit. The circuit includes a series resistance R_b , which is called "ballast Resistance".



(a) Schematic diagram.



(b) Circuit diagram.

The ballast circuit using a strain gauge \$E_s\$ is given below.

If the \$R_g\$ is the resistance of strain gauge the o/p voltage when the gauge is not strained \$E_s\$.

$$e_o = \frac{R_g}{R_b + R_g} e_i$$

Change in o/p voltage when the gauge is strained:

$$\Delta e_o = \frac{R_b}{(R_b + R_g)^2} \Delta R_g \cdot e_i = \frac{R_b R_g}{(R_b + R_g)^2} \frac{\Delta R_g}{R_g} e_i = \frac{R_b R_g}{(R_b + R_g)^2} G_f \epsilon e_i$$

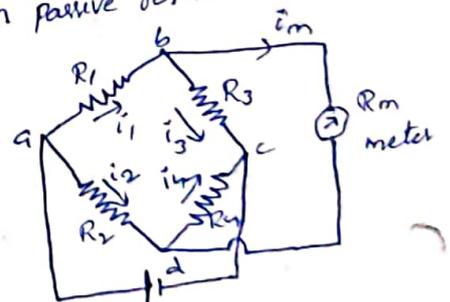
Change in o/p voltage when the gauge is strained is directly proportional to the strain.

Wheatstone bridges: - Wheatstone bridge is two types:

- i) Null type
- ii) Deflection type.

It is the most commonly used DC bridge for measurement of resistance. This bridge is used for measurement of small resistance changes that occur in passive resistive transducers like strain gauges.

It consists of four resistive arms with a source of emf (battery) & meter act as a detector.



i) Null type: - when using this type of measurement, adjustments are made in various arms of the bridge so that the voltage across the detector is zero & hence no current flows through it. when no current flows through detector the bridge is said to be balanced.

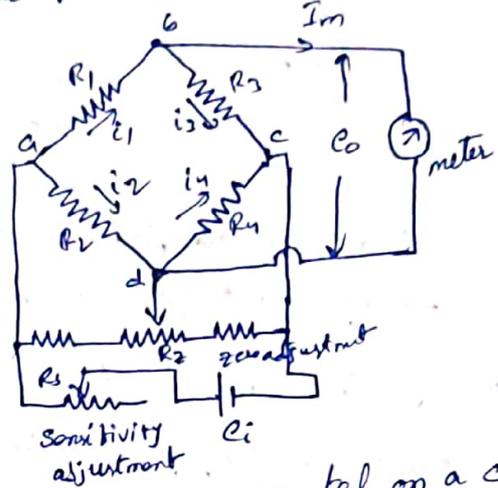
$$R_1 = R_2 (R_3 / R_4)$$

when the change \$\Delta R_1\$ in the transducer resistance \$R_1\$ which is to be found, the change unbalances the bridge and therefore resistor \$R_2\$ has to be adjusted by an amount \$\Delta R_2\$ to restore balance

$$\Delta R_2 = \Delta R_1 (R_4 / R_3)$$

deflection type bridges -

The null type wheatstone bridge is accurate but the problem with this bridge is that the balancing even if done automatically, is not instantaneous. This bridge is not suitable for dynamic applications, where the changes in resistance are rapid. For measurement of rapidly changing signals the deflection type bridge is used. When the input changes the resistance R_1 changes producing an unbalance causing a voltage to appear across the meter. The deflection of meter is indicative of the value of resistance and the scale of the meter may be calibrated to read the value resistance directly.



gauge sensitivity:- The below figure shows a single strain gauge mounted on a cantilever beam. When a force is applied to the beam the gauge is subjected to a tensile stress. The resistance of the strain gauge increases. This increase in resistance is measured using a wheatstone bridge as shown below.

The bridge is balanced under unstrained conditions, but becomes unbalanced when the gauge is strained. The change in resistance of gauge $\Delta R_g = \Delta R_2 (R_3/R_4)$

$\Delta R_2 = \text{change in } R_2, \Delta R_2 = (R_3/R_4) R_{g1}$

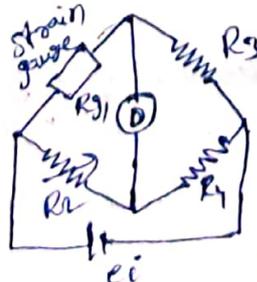
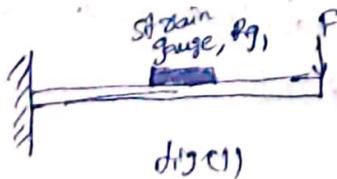
o/p of bridge = $k \Delta R_2$ where $k = \text{scale factor of } \Delta R_2 \text{ readout of indicator.}$

gauge sensitivity $S_g = \frac{k \Delta R_2}{\epsilon} = \frac{k \Delta R_2}{\Delta R_{g1}/R_{g1}} \cdot G_f$
 $= k \frac{R_4}{R_3} \frac{\Delta R_{g1}}{\Delta R_{g1}/R_{g1}} = k \frac{R_4}{R_3} R_{g1} G_f$

when $R_4 = R_3$ & $R_{g1} = R_g$

gauge sensitivity = $S_g = k R_g G_f$; $R_{g1} = R_2 = R_3 = R_4 = R$

The o/p voltage from the bridge $\Delta e_o = \frac{\Delta R/R}{4} e_i = \frac{G_f \epsilon}{4} e_i$



measurement of Linear velocity (or) velocity:- The most commonly used transducer for measurement of linear velocity is the electro-magnetic transducer. This transducer utilizes the voltage produced in a coil on account of change in flux linkages resulting from change in reluctance.

The o/p voltage o/p from a coil is given by

$$e_o = \frac{dd}{dt} = \frac{N}{R} \frac{di}{dt} - \frac{Ni}{R^2} \frac{dR}{dt}$$

• supposing i is constant: $e_o = \frac{Ni}{R^2} \frac{dR}{dt}$

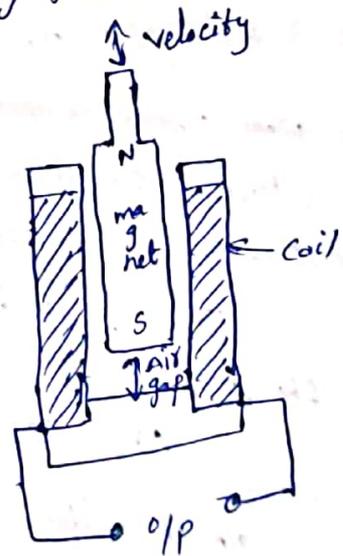
o/p voltage $\Rightarrow e_o \propto \frac{dR}{dt}$

These are classified into two categories:

- i) moving magnet type ii) moving coil type.

i) moving magnet type:- The constant mmf Ni , can be provided by a solenoid of N turns and carrying a constant current i . But electromagnetic transducer use a permanent magnet which provides a constant polarizing field.

a moving magnet type transducer is shown. The sensing element is a rod that is rigidly coupled to the device whose velocity is being measured. This rod is a permanent magnet. There is a coil surrounding the permanent magnet. The motion of the magnet induces a voltage in the coil and the amplitude of the voltage is directly proportional to the velocity. For a coil placed in a magnetic field, the voltage induced in the coil is directly proportional to the velocity.



advantages:- i) The maintenance requirements of these transducers are negligible, because there are no mechanical surfaces (or) contacts.

ii) The o/p voltage is linearly proportional to velocity

iii) These can be used as event markers which are robust and inexpensive to manufacture.

disadvantages:- i) These are affected by stray magnetic fields. These fields cause noise.

ii) The frequency response is usually limited if is stated.

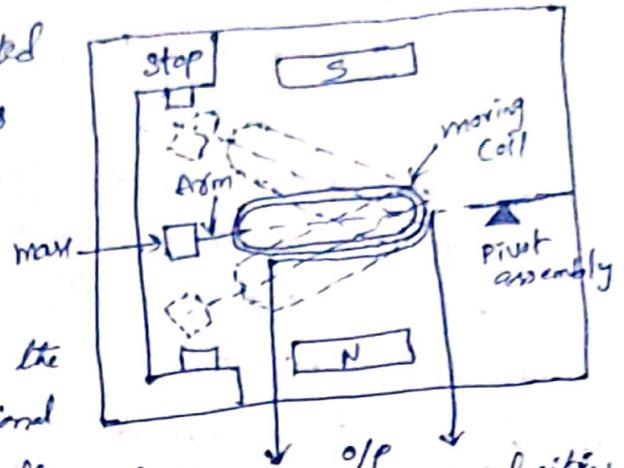
iii) It is not useful for measurement of vibrations.

③

moving coil type velocity transducer: - The moving coil type velocity transducer is shown below. It operates essentially through the action of a coil moving in a magnetic field. A voltage is generated in the coil which is proportional to the velocity of the coil.

Another type of velocity transducer uses a pivoted arm on which a coil is mounted. There is a mass attached at the end of the arm. The velocity to be measured is applied to the arm and therefore the coil moves in the field of a permanent magnet.

A voltage is generated on account of motion of the coil in the magnetic field. The o/p voltage is proportional to the velocity. This type of transducer is generally used for measurement of velocities developed in a linear, sinusoidal or random manner. Damping is obtained electrically thus ensuring high stability under varying temperature conditions.



advantages: - i) This is a more satisfactory arrangement as the system now forms a closed magnetic circuit with a constant air gap.
ii) The whole device is contained in an antimagnetic case which reduces the effects of stray magnetic fields.

measurement of Angular velocity: - In many cases the only way to measure linear velocity is to convert it into angular velocity. ex: speedometer.
The disadvantage with measurement of linear velocity arises because a fixed reference must be used and if the moving object has to travel large distances the detection becomes impossible. Hence angular velocity transducers are used.

The measurement of angular speed may be made with 'tachometers' which may be either mechanical or electrical type.

electrical tachometer: - The electrical tachometers are preferred over mechanical tachometers for all applications because these tachometers offer all the advantages associated with electrical transducers. The various types of electrical tachometers are discussed below.

i) Electromagnetic Tachometer generators: - There are two types of electromagnetic tachometer generators, called tachogenerators. These are
a) DC Tachometer generator b) AC Tachometer generator.

a) D.C Tachometer generators:- D.C tachometer generator consist of a small armature which is coupled to the machine whose speed is to be measured. This armature revolves in the field of a permanent magnet. The emf generated is proportional to the product of flux and speed. Since the flux of the permanent magnet is constant, the voltage generated is proportional to speed. The polarity of o/p voltage indicates the direction of rotation. This emf is measured with the help of a moving coil voltmeter having a uniform scale & calibrated directly in terms of speed.

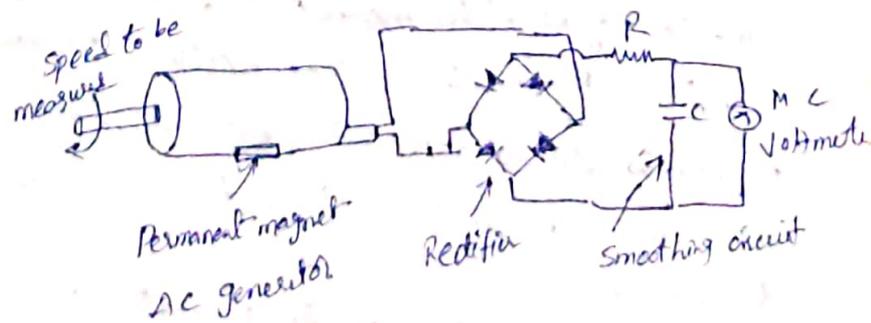
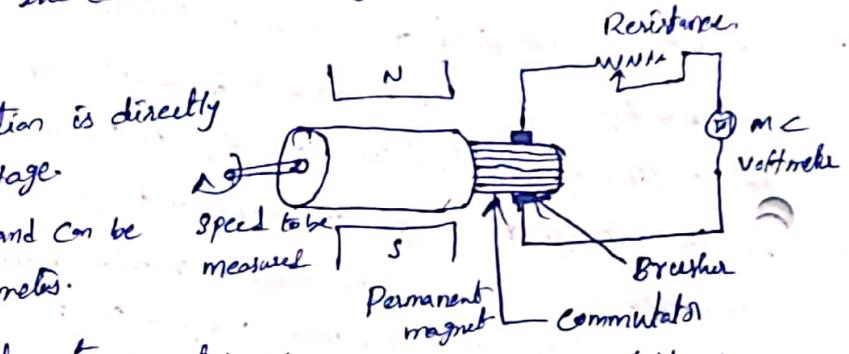
The D.C tachometer generator is shown below. A series resistance is used in the circuit for the purpose of limiting the current from the generator in the event of a short circuit on the o/p side.

Advantages:- i) The direction of rotation is directly indicated by the polarity of the o/p voltage.
 ii) The o/p voltage is typically 10mV/rpm and can be measured with conventional type D.C voltmeters.

disadvantages:- i) Brushes on small tachometer generator often produce maintenance problems.
 ii) The i/p resistance of meter should be very high as compared with o/p resistance of generator.

b) A.C Tachometer generators:- In order to overcome some of the difficulties mentioned above, a.c tachometer generators are used. The tachometer generator has rotating magnet which may be either a permanent magnet or an electromagnet. The coil is wound on the stator and therefore the problems associated with commutator are absent.

The rotation of the magnet causes an emf to be induced in the stator coil. The amplitude & frequency of this emf are both proportional to the speed of rotation. Thus either amplitude or frequency of induced voltage may be used as a measure of rotational speed. When amplitude of induced voltage is used as measure of speed. The ckt is shown below.



Measurement of Temperature :-

(9)

The following devices are used for the measurement of temperature.

- 1) Resistance thermometers
- 2) Semiconductor thermometers
- 3) Thermistors
- 4) Thermocouples
- 5) Bimetallic thermometers
- 6) Radiation pyrometers.

1) Resistance thermometry :- The resistance of a conductor changes when its temperature is changed. This property is utilized for measurement of temperature. The variation of resistance R with temperature T ($^{\circ}K$) can be represented by the following relationship for most of the metals as

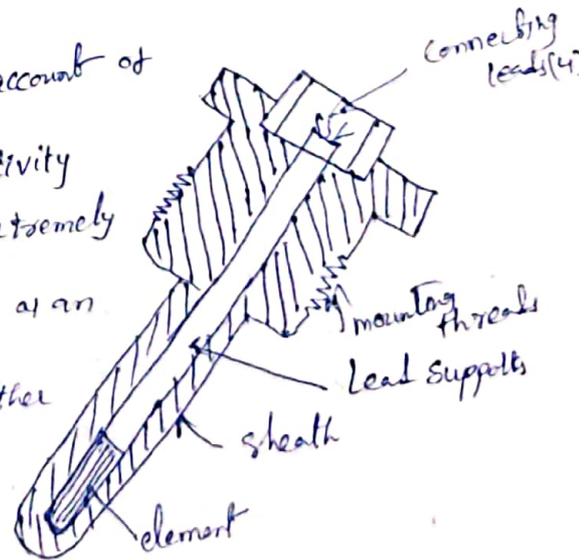
$$R = R_0 \left(1 + \alpha_1 T + \alpha_2 T^2 + \dots + \alpha_n T^n + \dots \right)$$

R_0 = resistance at temperature $T=0$ and $\alpha_1, \alpha_2, \alpha_3, \dots, \alpha_n$ are constants.

The resistance thermometer uses the change in electrical resistance of conductor to determine the temperature. The platinum is used to this day as the primary element in all high accuracy resistance thermometers. Platinum is especially suited for this purpose, as it can withstand high temperatures while maintaining excellent stability. As a noble metal it shows limited susceptibility to contamination. All metals produce a positive change in resistance with temperature. This is the main function of a RTD. This implies a metal with a high value of resistivity should be used for RTD's. The lower is the resistivity for the metal the more material we will have to use.

- The requirements of a conductor material to be used in RTDs are,
- i) The change in resistance of material per unit change in temperature should be as large as possible.
 - ii) The material should have a high value of resistivity so that minimum volume of material is used in the construction of RTD.
 - iii) The resistance of materials should have a continuous and stable relationship with temperature.

Gold & silver are rarely used for construction of RTDs on account of their low resistivities. Tungsten has relatively a high resistivity but is reserved for high temperature applications as it is extremely brittle and difficult to work. Copper is used occasionally as an RTD element. The most common RTDs are made of either platinum, nickel or nickel alloys. The economical nickel wires are used over a limited temperature range.



measurement of pressure:— Pressure measurements are one of the most important measurements made in industry. The number of instruments used are by far greater in number than the instruments used for any other type of measurement. The principles used in the measurement of pressure are also applied in the measurement of temperature, flow, liquid level. The pressure is represented as force per unit area. As such it may be considered as a type of stress since stress is also defined as force per unit area. The term 'pressure' refers to the force per unit area exerted by a fluid on a containing wall.

Types of pressure measurement devices:— In industrial applications the pressure is usually measured by means of indicating gauges (or) recorders. These instruments may be mechanical, electro-mechanical, electrical (or) electronic in operation.

i) Mechanical Instruments:— These instruments may be classified into two groups. The first group includes those instruments in which the pressure measurement is made by balancing an unknown force with a known force. Instruments using this principle include manometer and ring of bolt type of gauges.

ii) Electro-mechanical Instruments:— These instruments usually employ a mechanical means for detecting the pressure and electrical means for indicating (or) recording the detected pressure.

iii) Electronic Instruments:— Electronic pressure measuring instruments normally depend on some physical change that can be detected and indicated (or) recorded electronically.

Measurement of pressure using electrical transducers as secondary transducers:— The measurement of force (or) pressure can be done by converting the applied force (or) pressure into a displacement by elastic elements which act as primary transducers. This displacement which is a function of pressure may be measured by transducers which act as secondary transducers. The o/p of the secondary transducer is a function of displacement which in turn is a function of pressure. Mechanical methods have to be used to convert the applied force (or) pressure into displacement. These devices are called force summing devices. The choice of design of the type of summing element used depends on the magnitude of force (or) pressure to be measured.

The most commonly used summing devices are

- i) Flat (or) corrugated diaphragms.
- ii) Bellows.
- iii) circular (or) twisted Bourdon tube.
- iv) straight tube
- v) single (or) double mass cantilever suspension
- vi) pivot tongue.

Measurement of low pressure (vacuum): - These pressure gauge are used primarily for measuring pressure below atmospheric pressure, which is often referred to as vacuum. This range extends from the normal atmospheric pressure of 760 mm of mercury column down to 10^{-8} mm of mercury column. A common unit of low pressure is the micron which is one millionth of a metre (0.001 mm) of mercury column. Very low pressure may be defined as any pressure below 1 mm of mercury, & an ultra low pressure, is a pressure is less than a millimicron (10^{-3} micron) or 10^{-6} mm of mercury.

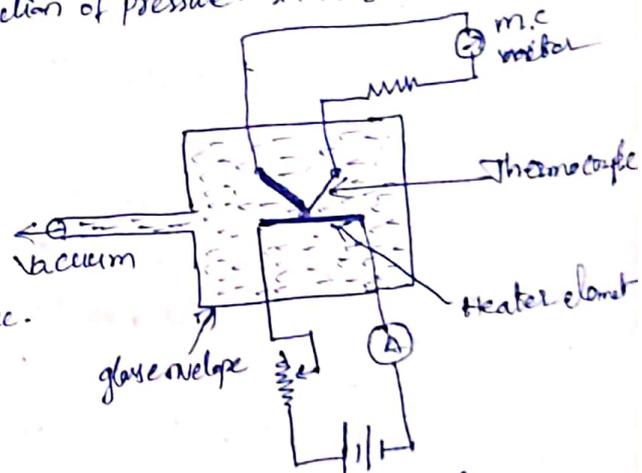
There are two basic methods for measurement of low pressure.

1) Direct methods: - The direct methods of measurement involve measurement of a displacement as a result of application of the pressure.

2) Indirect (or) Inferential methods: - These methods involve the measurement of pressure through measurement of certain other properties which depend upon the pressure to be measured. The pressure controlled properties which may be utilized for measurement of pressure are volume & thermal conductivity etc.

Thermocouple vacuum gauge: - This gauge operates on the principle that at low pressures the thermal conductivity of a gas is a function of pressure. It is shown below.

The heater element & Thermocouple are enclosed in a glass (or) metal envelope which is valed into vacuum system. The moving coil instrument may be directly calibrated to read the pressure.



Measurement of Torque: -

Dynamic measurement of torque transmitted by rotating shaft is based upon the angular displacement (or) twist. The strain is sensed by transducers and is measured. The strain measurements are then expressed in terms of torque by proper calibration.

Strain gauge Torque meters: The principle of this method is explained by figure below.

Two strain gauges are mounted on a shaft at an angle 45° to each other. The torque

is given by.

$$T = \frac{\pi G (R^4 - r^4)}{32L} \theta \text{ Nm}$$

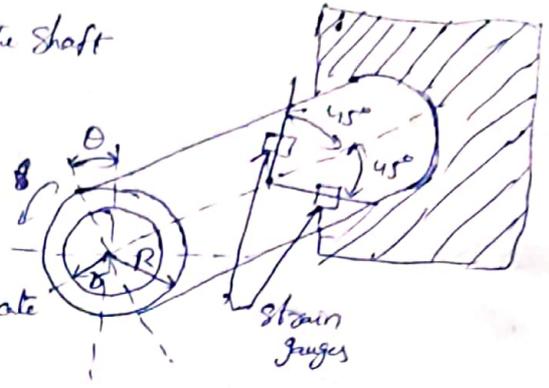
- G = modulus of rigidity
- R = outer radius of shaft
- r = inner " "
- L = length of shaft.
- θ = angular deflection of shaft.

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The strain gauges attached at 45° to the axis of the shaft as shown will indicate strains of

$$\epsilon_{45^\circ} = \pm \frac{TR}{\pi G(R^4 L^3)}$$

Strain may be measured by electrical means to indicate the torque.

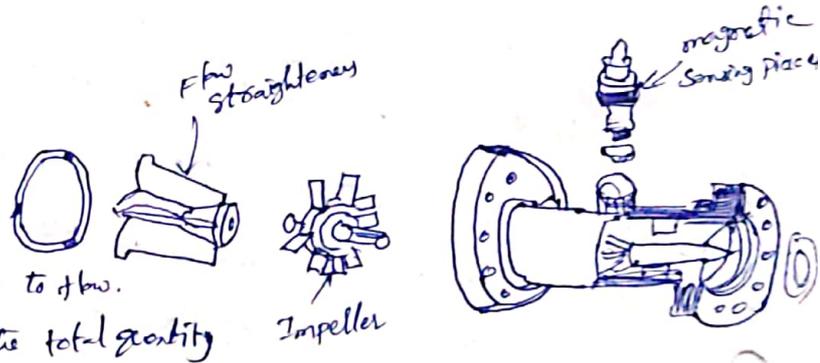


Measurement of flow:— There are number of devices for sensing the rate of fluid flow. They mainly operate on the principle of placing an obstruction in the path of fluid causing a change in fluid pressure which is dependent upon the rate of flow. Thus by measuring the difference in pressure before and after the obstruction by means of a differential pressure sensor, the rate of flow may be determined.

turbine meter:— There have been extremely rapid developments in turbine meters in recent years, partly because of the advances in electronics technology and the ease with which the o/p may be used to indicate rate of flow. The meter is

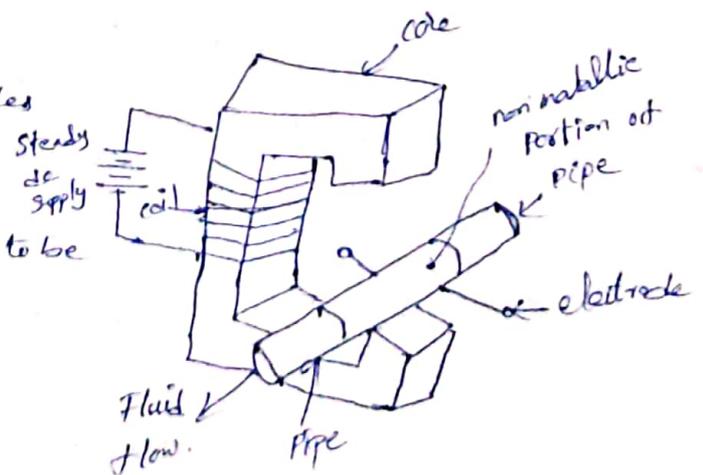
shown.

Turbine flow meters are volumetric flow meters and are available in wide ranges. The o/p is usually in the form of a digital electrical signal whose frequency is directly proportional to flow rate and whose total count is proportional to the total quantity as each pulse represents a discrete volume.



Electromagnetic flow meters:— electromagnetic flow meters are particularly suitable for the flow measurements and any electrically conducting liquid.

It consists basically of a pair of insulated electrodes buried flush in the opposite sides of non-conducting, non-magnetic pipe carrying the liquid whose flow is to be measured.



Measurement of liquid level: - The direct conversion to liquid level position to electrical signal is used in many instances. The measurement is generally done by two conversions, so that the liquid level is determined indirectly. The first conversion usually is liquid level to a displacement through a float in a liquid or a spring loaded plate in contact with the surface in the case of granular solids. This displacement is then converted into an electrical signal by a secondary transducer connected to float or plate. Many applications where this is not possible and other methods are used like gamma rays are used. (6)

No electric transducers used for level measurements are

1) Resistive 2) Inductive 3) Capacitive.

Resistive method: - This method uses mercury as a conductor as shown below.

A number of contact seals are placed at various liquid levels. As head 'h' increases, the rising level of mercury above the datum, shorts successive resistors 'R' and increases the value of 'h' directly.

