BASIC ELECTRONICS

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CHAPTER – 4

TRANSDUCERS AND MEASURING INSTRUMENT

Transducers :

An electronic instrumentation system consists of a no.of components to perform a measurement and record its signal. The three major components are :

(i) An input device

(ii) A signal conditioning or processing device.

(iii) An output device.

The input quantity for most instrumentation system is a non-electrical quantity. In order to use electrical methods and techniques for measurement, manipulation or control, the non-electrical quantity is generally converted into an electrical form by a device called a transducer.

Definition : A transducer is a device which converts mechanical force into an electrical signal.

Or

A transducer is a device which, when actuated transforms energy from one form to another.

Example : Physical parameters such as heat, intensity or flight, flowrate, liquid level, humidity and pH value may be converted into electrical form by means of transducers.

Electric Transducer : 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 output that is electrical in nature.

The advantages of converting physical quantities into analogous electrical quantities are :

(i) Electrical attenuation can be done easily.

(ii) The mass inertia effects are minimized.

(iii) The effects of friction are minimized.

(iv) The electrical and electric systems can be controlled with very small power level.

(v) The transducer consists of two important and closely related parts i.e.,

(a) Sensing or detector element : It is that part of transducer which responds to a physical phenomenon or a change in a physical phenomenon.

(b) Transduction element : A transduction element transforms the output of a sensing element into an electrical output.

Classification of Transducers :

The transducers can be classified :

1. On the basis of transduction form used
2. As primary and secondary transducers.
3. As passive and Active transducers.
4. As analog and digital transducers.
5. As Transducers and Inverse transducers

1. Classification on the basis of transduction form used :

On the basis of transducation form used transducers can be classified as

(a) Resistive

(b) Capacitative

(c) Inductive

(a) Resitive Transducer : In an resistive transducer an indication of measured physical quantity is given by a change in resistance.

Example : Potentiometer device, Resistance strain Gauge, Thermistor, Photo conducting cell etc.

(b) Capacitative Transducer : A capacitative transducer operates on the principle of variation in capacitance produced by the physical quantity being measured.

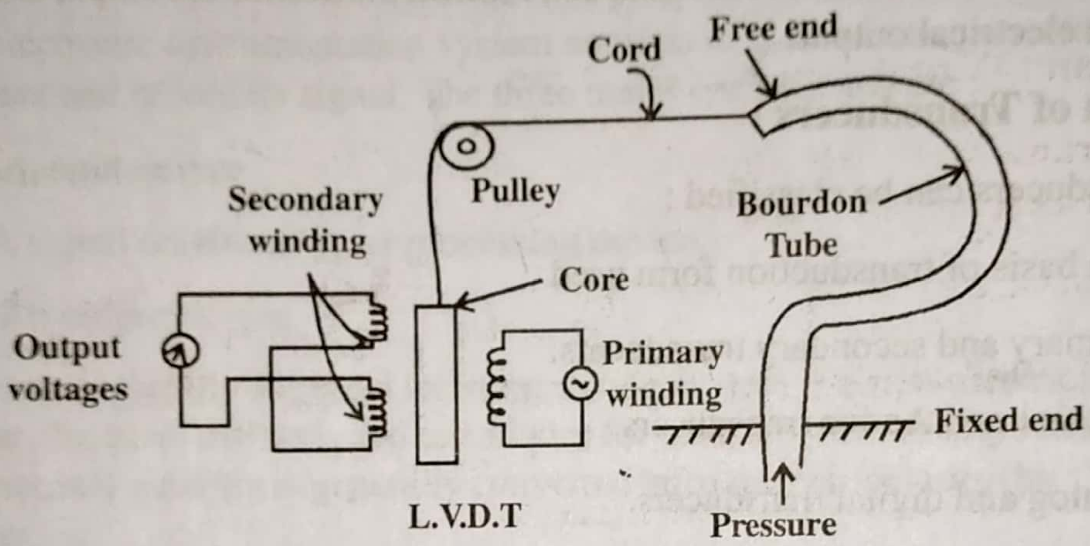
Example : Variable capacitance, Pressure gauge, Capacitor microphone, Dielectric gauge.

(c) Inductive transducer : In an inductive transducer an indication of measured physical quantity is given by a change in inductance.

Example : Magnetic ckt. transducer, reluctance pick up, Differential transformer, Eddy current gauge etc.

2. Primary and Secondary Transducer :

Let's consider the case of a Bourdon's tube as shown in figure below.



The Burden tube acting as a primary detector senses pressure and converts the pressure into a displacement of its free end. The displacement of free end moves the core of a linear variable differential transformer (L.V. D.T), which produces an output voltage which is proportional to the pressure. Thus, there are two stages of transduction, the pressure is converted into a displacement by Bourdon tube, then the displacement, is conversed into an analogous voltage by L.V. D.T. Hence the 'Bourdon Tube' is called as a primary transducer' while the L.V. D.T. is called as a 'Secondary transducer'.

Note : In most measurement systems, there is a suitable working combination where in a mechanical device acts as a primary detector transducer and the electrical device acts as secondary transducer with mechanical displacement serving as the intermediate signal.

3. Passive and Active transducer :

(a) Passive transducers : Passive transducers 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. They are also known as "extremely powered transducers."

Example : Resistive, inductive and capacitative transducers are passive transducers.

Active transducers : Active transducers are those which do not require an auxiliary power source to produce their output. They are also known as self generating type transducers, since they develop their own voltage or current output. The energy required for production of output signal is obtained from the physical quantity being measured.

Velocity, temp. light intensity and force can be transduced with the help of active transducers.

Ex. Thermocouple, photovoltaic cells and piezo electric crystals.

4. Analog and Digital Transducers :

Analog transducer : These transducers convert the input quantity into an analogus output which is a continuous function of time.

Ex : Strain Gauge, Thermocouple, Thermistors, LVDT.

Digital Transducer : These transducers convert the input quantity, into an electrical output which may be in the form of pulses.

5. Transducers and Inverse Transducers :

Transducers : A Transducer can be broadly defined as a device which converts a non-electrical quantity into an electrical quantity.

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

It is a precision actuator which has an electrical input and a low power non-electrical output.

A Piezoelectric crystal acts as an inverse transducer because when a voltage is applied across its surfaces, it charges its dimensions causing a mechanical displacement.

A current carrying coil moving in a magnetic field is also an inverse transducer because current carried by it is converted into a force which causes transitional or rotational displacement.

Mechanical Devices as Primary Detectors :

To extract information from mechanical systems, only mechanical displacement or velocity can be used and therefore they are of great importance. Some of the most commonly used mechanical elements are :

(i) Springs : which convert a force or a torque into a displacement.

(ii) A diaphragm a capsule, bellows or Bourdon tube - which convert pressure into displacement.

(iii) A bimetallic strip converts temp. into a displacement

(iv) A mass damper system - used for measurement of acceleration, velocity and displacement.

The initial concept of converting an applied force into a displacement is basic to many types of primary sensing elements.

The mechanical elements which are used to convert the applied force into displacement are usually elastic members. They can be classified into three categories such as :

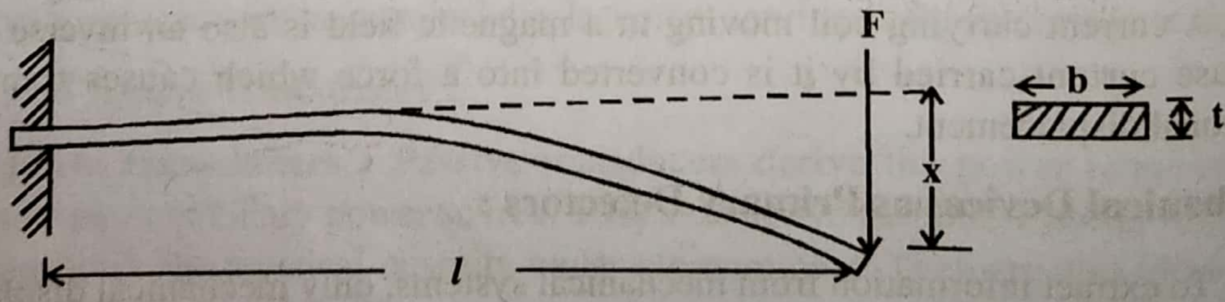
1. Direct tension or compression type
2. Bending type
3. Torsion type

Mechanical Spring Devices :

Most mechanical input measuring systems employ mechanical springs of one form or another. The displacement are usually small and engineering approximation for small displacements or deflections are valid.

Example : Cantilever, hellical and spiral springs, Torsion bars, prooving rings, spring flexure pivots.

Cantilever : A cantilever is shown in the figure below which is subjected to a force at its free end.



Deflection at the free end is $x = Fl^3/3\,EI$

Here F = Applied force in Newton

l = length of the cantilever in metre.

E = modulus of elasticity

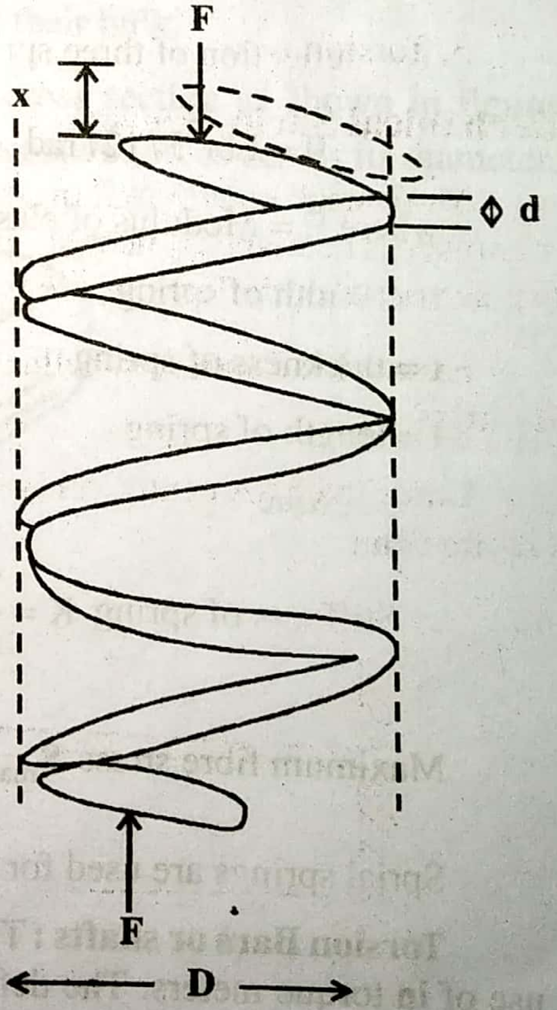
I = moment of inertia $= \left(\frac{I}{12}\right) bt^3$

b = Width of cantilever

t = Thickness of cantilever

Stiffness of cantilever $K = \frac{F}{x} = 3\frac{EI}{l^3}$

Hellical spring : The figure below shows a close coiled hellical spring subjected to a compressive force F.



Displacement of the spring is

$$x = \frac{8FD^3n}{Gd^4}$$

where F = Applied force

D = Mean diameter of coiled spring

d = diameter of spring wire

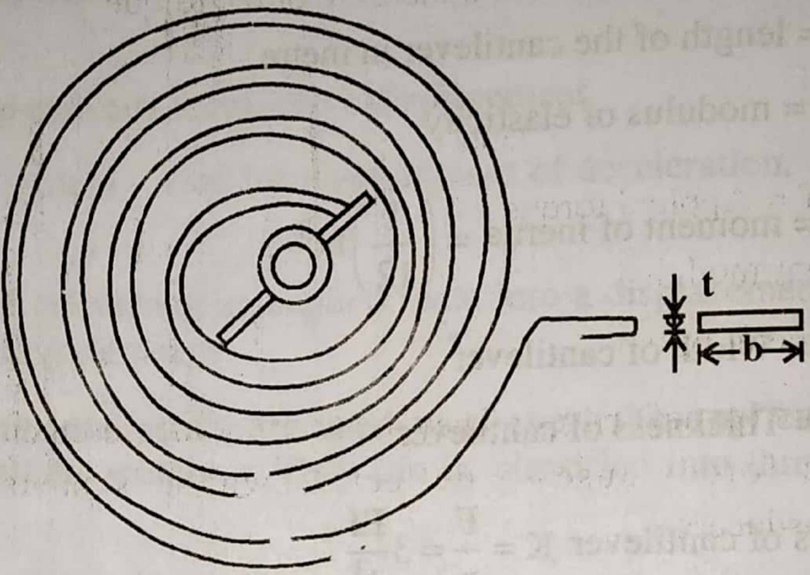
n = no. of wires

G = Shear modulus

Stiffness of spring is $K = \frac{F}{x} = \frac{Gd^4}{8} D^3 n$

Maximum shear stress is $z = \frac{8FD}{\pi d^3}$

Spiral spring : Figure given below shows a flat spiral spring subjected to a torque T.



(Flat spiral spring)

The deflection of three spring is

$$\theta = Ebt^3 J / 12l \text{ rad}$$

where E = Modulus of elasticity

b = Width of spring

t = thickness of spring

l = length of spring

T = Torque

$$\therefore \text{ Stiffness of spring } K = \frac{T}{\theta} = \frac{Ebt^3}{12l} \text{Nm / rad}$$

$$\text{Maximum fibre stress } S_{max} = \frac{6T}{bt^2} \text{N / m}^2$$

Sprial springs are used for production of controlling torque in analog instruments.

Torsion Bars or shafts : These primary sensing elements for torque. They are made use of in torque meters. The deflection or twist of the bar is proportional to the applied torque and the deformation is used as a measure of the torque.

Some torque meters are designed so that the angular displacement due to twisting of the bar is measured with the help of a displacement transducers. But in others the strain in the surface of the bar, which is proportional to the torque is measured with the help of strain gauges. The shear strain is a measure of the torque.

$$\pi Gd$$

where T = Applied torque

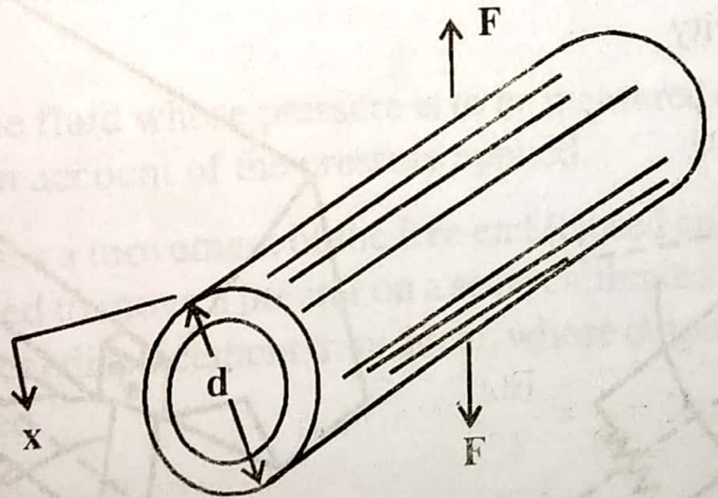
G = shear modulus

d = diameter of bar

Prooving (proof) rings : They are used for measurement of force, weight or load. The applied force causes a deflection which is measured with the help of electrical transducers.

Prooving rings are made up of steel and are used as force standards. They are particularly useful for calibration of material testing machines in situations where dead weight standards are impracticable to use an account of their bulk.

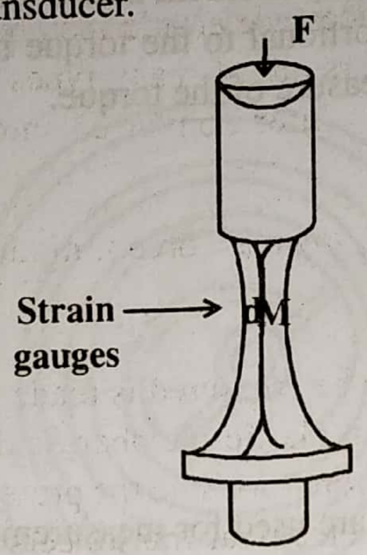
A proving ring is a circular ring of rectangular cross section as shown in figure below which may be subjected to either tensile or compressive forces across its diameter.



The deflection is given by $x = \frac{(\pi/2 - 4/\pi)d^3}{16EI}F$

d = outside ring diameter

Load cells : Load cells utilize an elastic member of the primary transducer and strain gauge as secondary transducer.



(Load Cells)

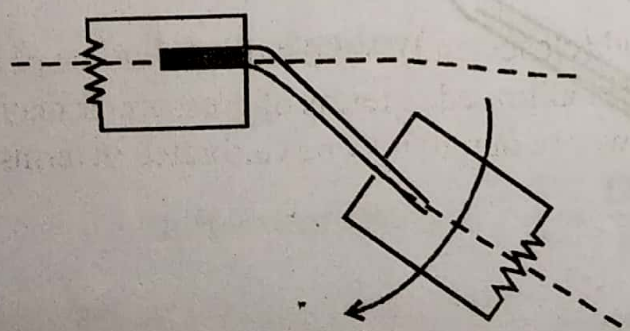
Spring Flexture Pivots :

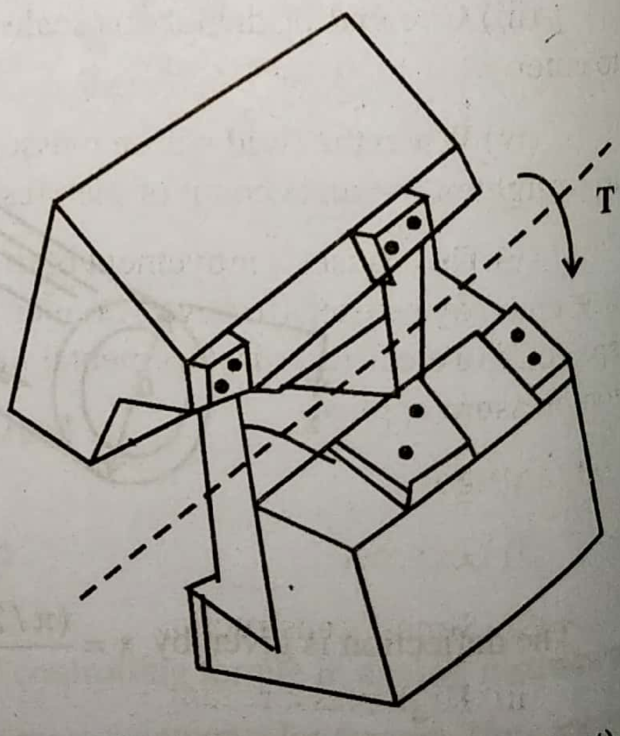
The figure given below shows two different types of arrangements for flexture pivots. One for the single spring flexture pivot and the second for crossed spring flexture pivot.

The crossed spring flexture pivot is widely used in measurement work for the following reasons :

(i) It is practically frictionless

(ii) The pivot sensitivity





(Single-spring flexture pivot)

(Crossed spring flexture pivot)

Pressure sensitive primary devices :

Most pressure measuring devices use elastic members for sensing pressure at the primary stage. These elastic members are of many types and convert the pressure into mechanical displacement which is later converted into an electrical form using a secondary transducer.

These devices are many time known as force summing devices.

Principle of Working :

The fluid whose pressure is to be measured is made to press the pressure sensitive element and since the element is an elastic member, it deflects causing a mechanical displacement. The displacement is proportional to the pressure applied. The displacement is then measured with the help of electrical transducers. The output of the electrical transducers is proportional to the displacement and hence to the applied input pressure.

The commonly used pressure sensitive devices are :

1. Bourdon Tubes : (i) Bourdon tubes are designed in various forms. These are -

(i) C - Type (ii) Special type (iii) Twisted tube (iv) Hellical

(ii) The Bourdon tubes are made out of an elliptically flattened tube bent in such a way as to produce the above mentioned shapes.

(iii) One end of the tube is sealed or closed and the other end is open for the fluid to enter.

(iv) When the fluid whose pressure is to be measured enters the tube, the tube tends to straighten out on account of the pressure applied.

(v) This causes a movement of the free end (closed end) and the displacement of the free end may be used to move a pointer on a scale calibrated in terms of pressure or may be applied to a electrical displacement transducer, whose output may be calibrated in terms of the pressure applied.

Advantages :

(i) Low cost

(ii) Simple construction

(iii) High pressure range

(iv) Good accuracy except at low pressure

Disadvantages :

(i) Low spring gradient

(ii) Susceptible to shocks and vibrations

1. C - Type :

(i) The C - Type Bourdon element is most commonly used for local indication but it is also used for pressure transmission and control applications.

(ii) The tube which is oval in section is formed into an arc of 250° and hence the name C for the configuration.

The displacement of the tip is

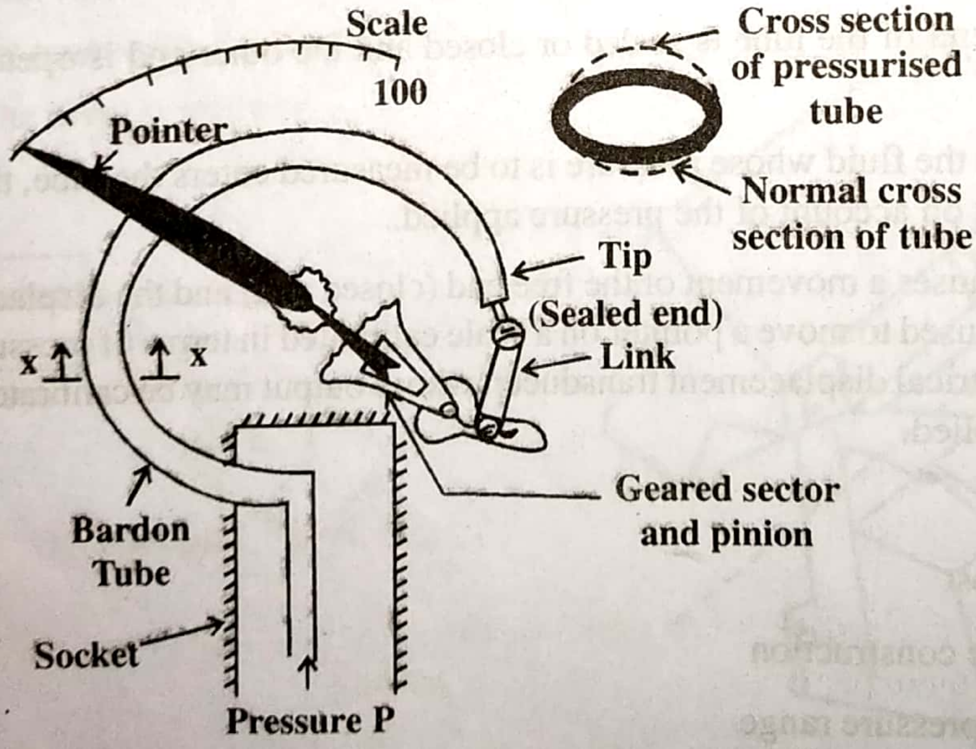
$$\Delta a = 0{\cdot}05\frac{ap}{E}\left(\frac{r}{t}\right)^{0{\cdot}2}\left(\frac{x}{y}\right)^{0{\cdot}33}\left(\frac{x}{t}\right)^{3}$$

Here E = modulus of elasticity

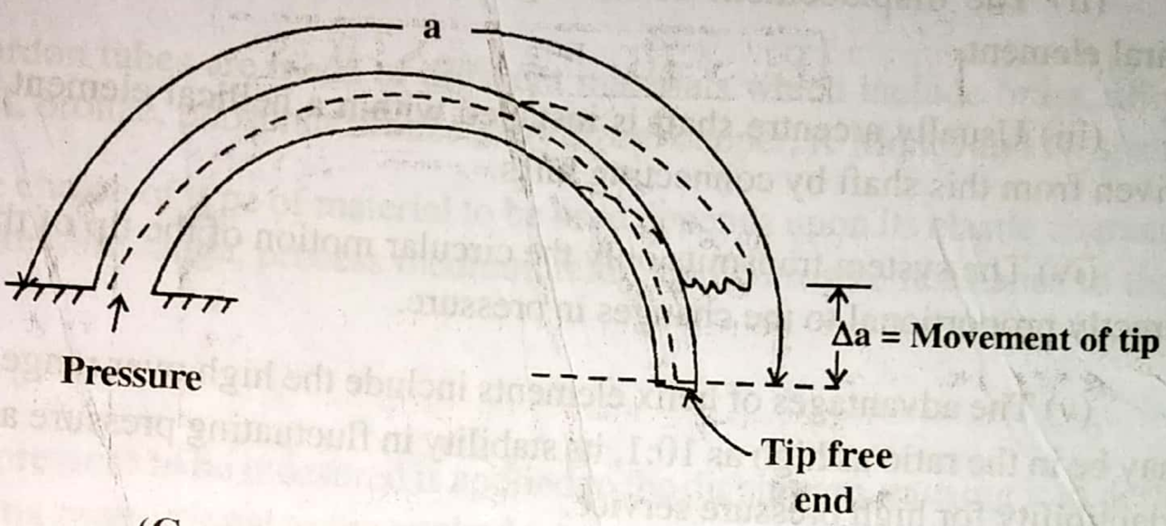
P = Applied pressure

(iii) The accuracy of C type Bourdon tubes varies from ±0·5 to ±2% or poorer.

(iv) However the normal accuracy is about ±1%.



(C-Type Boudon Tube)



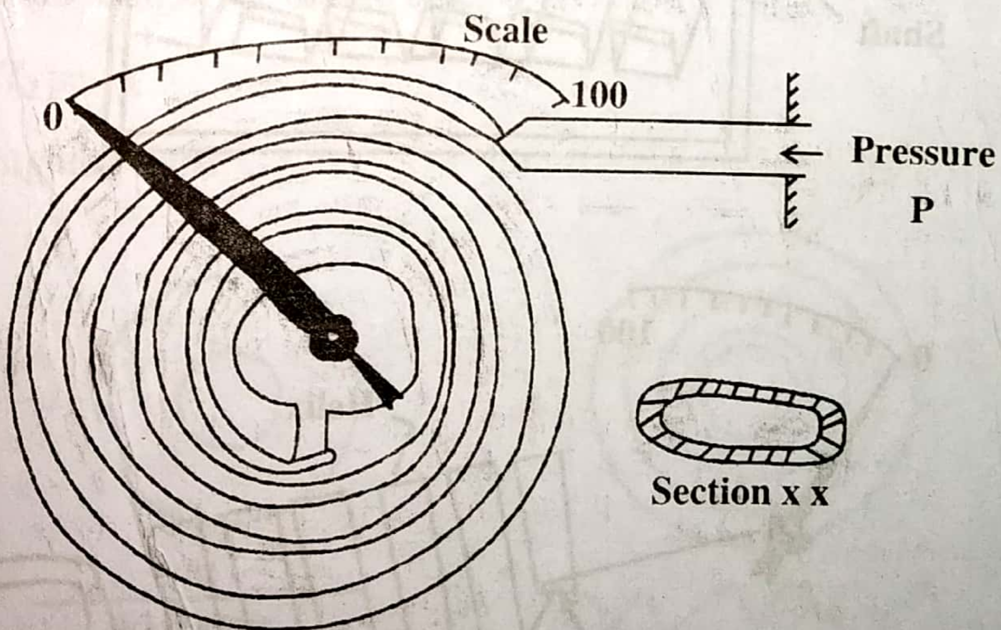
(Geometry of C type Bourdon Tube)

2. Spiral Type :

(i) Spiral type Bourdon tubes are made by winding several turns of the tube with its flattened cross section in the form of a spiral.

(ii) When the pressure to be measured is applied to the spiral, it tends to un coil producing a relatively long movement of the tip whose displacement can be used for indication or transmission.

(iii) The accuracy of spiral tube elements is higher than that of C type elements on account of absence of magnifying elements and is typically about ±0.5%.



3. Hellical Type :

(i) A Hellical Bourdon tube is similar to a spiral element, except it is wound in the form of a helix.

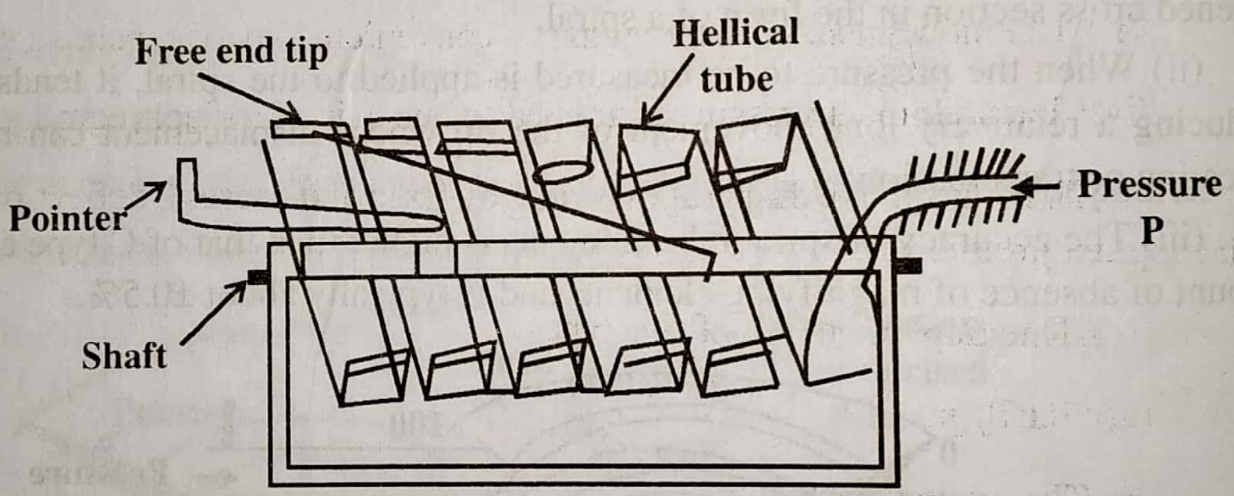
(ii) The displacement of the tip of a hellical element is larger than that of spiral element.

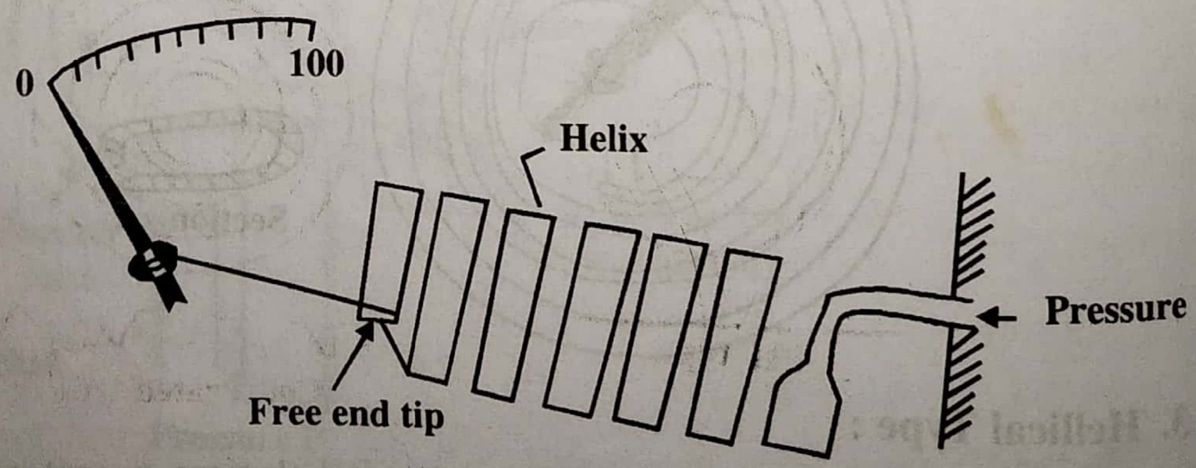
(iii) Usually a centre shaft is installed within a hellical element and the pointer is driven from this shaft by connecting links.

(iv) The system transmits only the circular motion of the tip of the pointer which is directly proportional to the changes in pressure.

(v) The advantages of helix elements include the high over range capabilities which may be in the ratio as high as 10:1, its stability in fluctuating pressure applications, and its adaptibility for high pressure service.

(vi) The accuracy obtainable from helical elements may vary from ±.5% to ±1% of span.





Note :

(i) Bourdon tubes are made of different materials which include brass, alloy steel, stainless steel, bronze, phosphur bronze, beryllizem copper, K Monel and N. span C.

(ii) The choice of type of material to be used depends upon its elastic characteristics suitable for pressure range, process medium, temp. and corrosive resistance to the media to be used.

Diaphragm :

(i) The pressure to be measured is applied to the diaphragm, causing it to deflect, the deflection being proportional to the applied pressure.

(ii) The movement of the diaphragm depends on its thickness and diameter. The movement is small.

(iii) The movement of diaphragm is a convenient way of sensing a pressure.

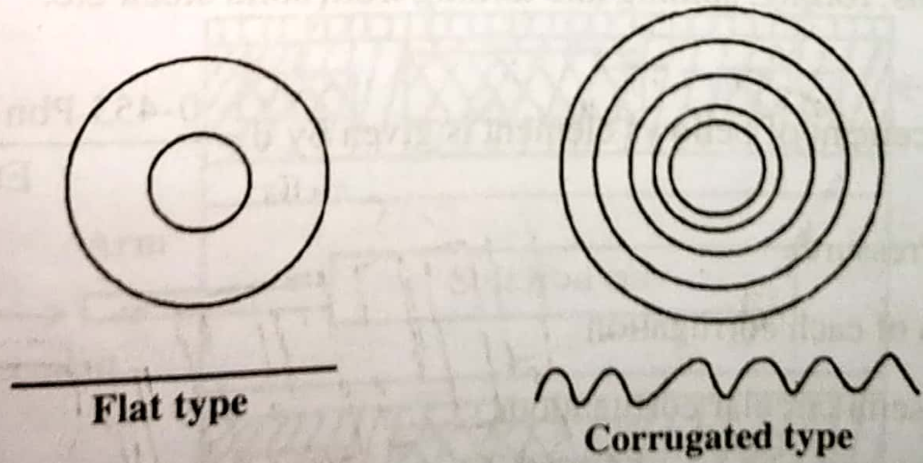
(iv) The unknown pressure is applied to one side of a diaphragm.

(v) The edge of the diaphragm is rigid by fixed and causes a deflection on account of the applied pressure P.

(vi) The diaphragm are of two types :

(a) Flat Type

(b) Corrugated Type



Single diapharagm elements

$$\text{Pressure } P = \frac{256\,Et^3\,dm}{3(1-v^2)D^4}\,N/m^2$$

Here E = Young's modulus

t = Thickness of diaphragm

D = Diameter of diaphragm

V = Poisson's ration

R = Radius of diaphragm

dm = deflection at the centre of the diaphragm

Bellows :

(i) A metallic bellow is a series of circular parts, resembling the folds in an accordian as shown in figure below.

(ii) These parts are joined in such a way that they are expanded or contracted axially by changes in pressure.

(iii) The metals used in the construction of bellows, must be thin enough to be flexible, docile enough for reasonable easy fabrication and have a high resistance to fatigue failure.

(iv) The materials used are brass, bronze, beryllian copper, steel and model.

(v) The materials used for manufacturing bellows are hydrallic, suldering and weilding of annular sections, rolling, spining and turning from solid stock etc.

The displacement of bellows element is given by $d = \frac{0\cdot453\,PbnD^2\sqrt{1-\gamma^2}}{Et^3}$

Here P = Pressure

b = Radios of each corrugation

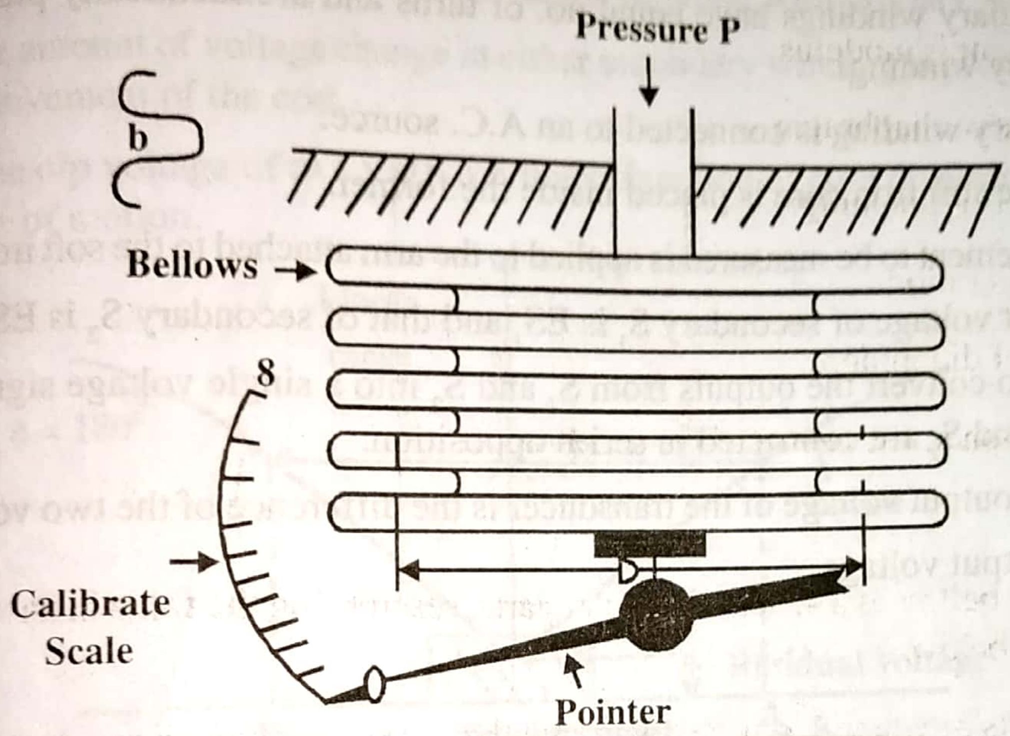
n = no. of semi circular corrugations

t = Thickness of wall

D = Mean diameter

E = Modulus of elasticity

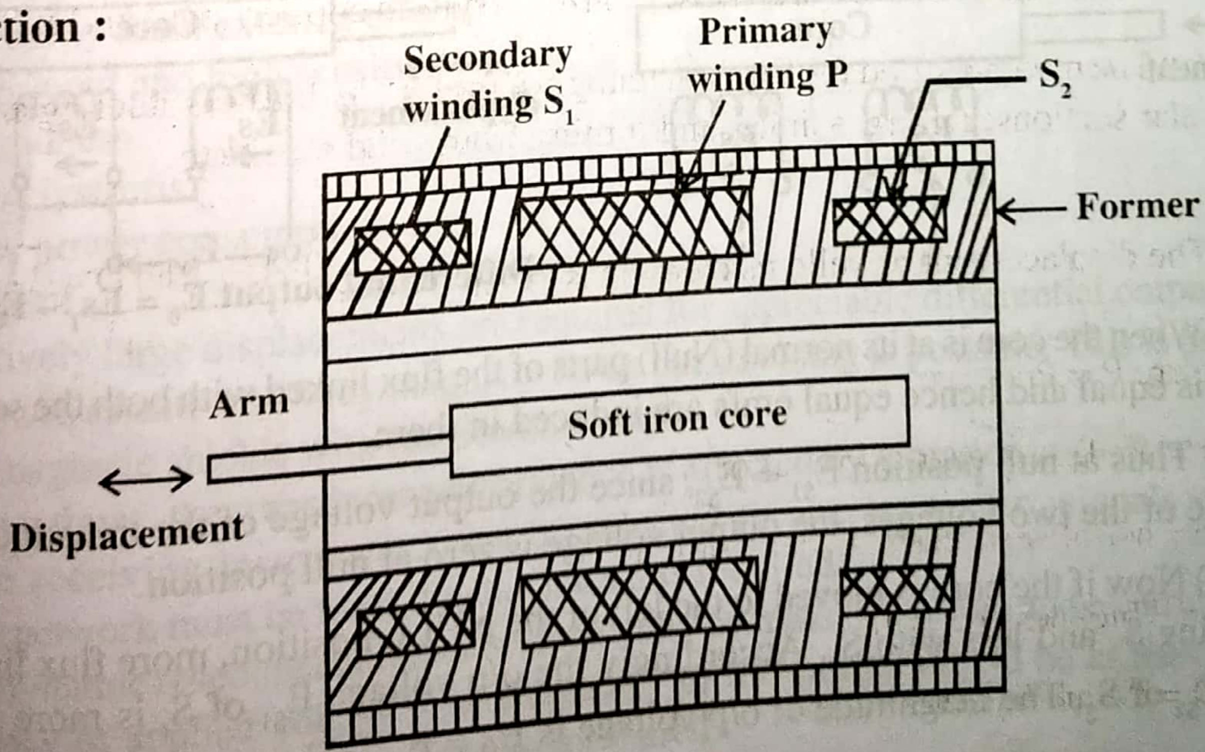
γ = Poisson's Ratio



Linear variable differential transformer (LVDT) :

The most widely used inductive transducer to translate the linear motion into electrical signals is the linear variable differential transformer (LVDT).

Construction :



(i) The transformer consists of a single primary winding P and two secondary windings S_1 and S_2 wound on a cylindrical former.

(ii) The secondary windings have equal no. of turns and are identically placed on either side of primary winding.

(iii) The primary winding is connected to an A.C. source.

(iv) A movable soft iron core is placed inside the former.

(v) The displacement to be measured is applied to the arm attached to the soft iron core.

(vi) The output voltage of secondary S_1 is ES_1 and that of secondary S_2 is ES_2.

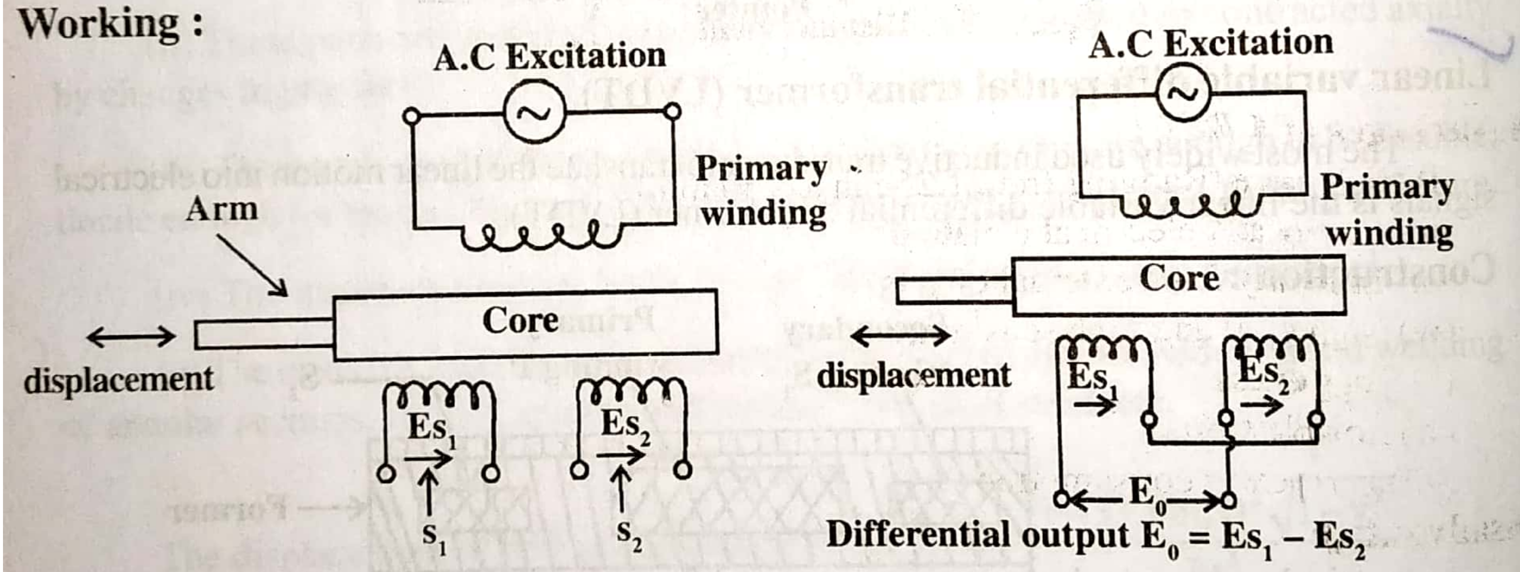
(vii) In order to convert the outputs from S_1 and S_2 into a single voltage signal, the two secondaries S_1 and S_2 are connected in series opposition.

(viii) Thus the output voltage of the transducer is the difference of the two voltages.

Differential output voltage

$$E_0 = E_{S_1} - E_{S_2}$$

Working :



(i) When the core is at its normal (Null) parts of the flux linked with both the secondary winding is equal and hence equal emfs are induced in them.

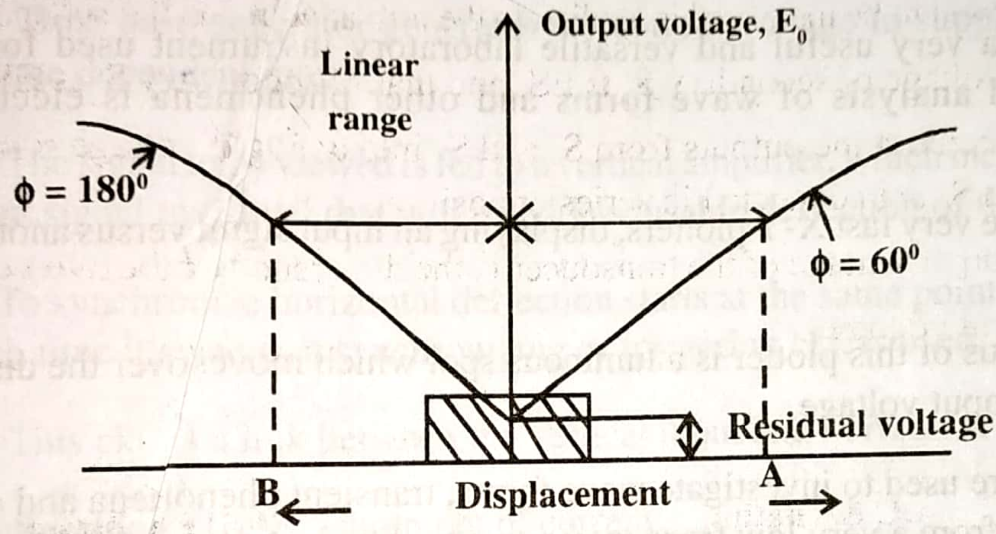
(ii) Thus at null position $E_{S1} = E_{S2}$, since the output voltage of the transducer is the difference of the two voltages, the output voltage is zero at null position.

(iii) Now if the core is moved to the left of the NULL position, more flux links with the winding S_1 and less with S_2. Accordingly the o/p voltage E_{S1} of S_f is more than o/p voltage E_{S2} of S_2. The magnitude of o/p voltage is $E_0 = E_{S_1} - E_{S_2}$.

(iv) If the core is moved to the right of the NULL position, the flux linking with winding S_2 becomes larger than that linking with winding S_1. This results in E_{S2} becoming large than E_S. Here $E_0 = E_{S2} - E_{S1}$ and is 180⁰ about of phase with primary voltage.

(v) The amount of voltage change in either secondary winding is proportional to the amount of movement of the core.

(vi) The o/p voltage of an LVDT is a linear function of core displacement within a limited range of motion.



Advantages of LVDT :

(i) High range (Ranging from 1.25mm to 250 mm)

(ii) Frictionand electrical isolation

(iii) Immuity from external effects

(iv) High nput and high sensitivity

(v) Ruggedness

(vi) LowHystresis .

(vii) Lov power consumption

Disadvantages :

(i) Relatively large displacements are required for appreciable differential output.

(ii) They are sensitive to stray magnetic fields but shielding is possible. This is done by providing magnetic shields with longitudinal slots.

(iii) Many times, the transducer performance is affected by vibrations.

(iv) The receiving instrument must be selected to operate an a.c. signals or a demodultion network must be used if a d.c. output is required.

(v The dynamic response is limited mechanically by mass of the core and electrically by the requency of applied voltage. The frequency of the carrier should be at least ten times.he highest frequency component to be measured.

Uses of LVDT :

(i) Accelerometers

(ii) Measurement of roll position

(iii) Measurement of material thickness

Cathode Ray Oscilloscope (CRO) :

(i) CRO is a very useful and versatile laboratory instrument used for display, measurement and analysis of wave forms and other phenomena is electrical and electronic ckts.

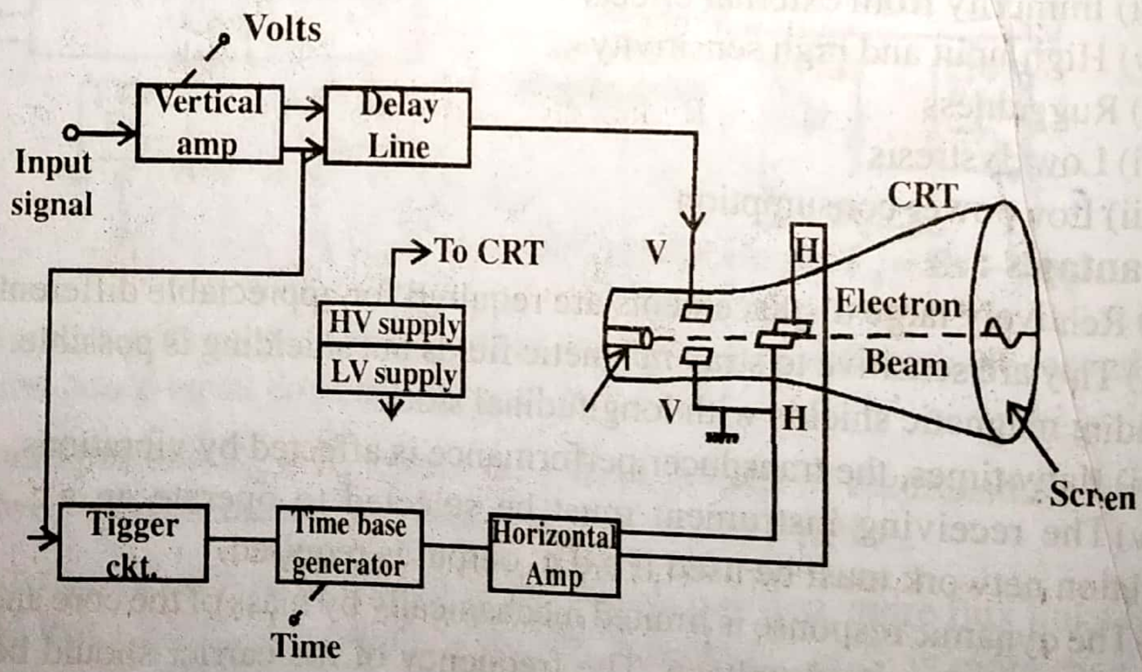
(ii) CROS are very fast X-Y plotters, displaying an input signal versus another signal or versus time.

(iii) The stylus of this plotter is a luminous spot which moves over the display area in response to an input voltage.

(iv) CROS are used to investigate wave forms, transient phenomena and other time varying quantities from a very low frequency range to the radio frequencies.

(v) Oscilloscope works as an eye for electronic engineers.

Block diagram of CRO :



(i) The heart of the oscilloscope is the CRT which generates the electron beam, accelerates the beam to high velocity, deflects the beam to create image and containing the phosphor screen where the electron beam becomes visible.

(ii) The power supply block provides the voltage required by the cathode ray tube to generate and accelerate the electron beam, as well as to supply the required oprating voltage for other ckts. of the oscilloscope.

(iii) Time base generator generates the correct voltage to supply the cathode in a constant time dependent rate.

(iv) The signal to be viewed is fed to a vertical amplifier, which increases the potential of the input signal to a level that will provide a usable deflection of the electron beam.

(v) To synchronize horizontal deflection starts at the same point of in input vertical signal each time it sweeps, a synchronizing or triggering ckt. is used.

(vi) This ckt. is a link between the vertical input and horizontal time base.

Applications : (i) Measurement of current.

(ii) Measurement of voltage.

(iii) Measurement of phase difference and frequency.

(iv) Study of Lissajous figure.

(v) Testing of television, Radars etc.

Photo emissive cells :

There are basically two types of photo emissive cells such as :

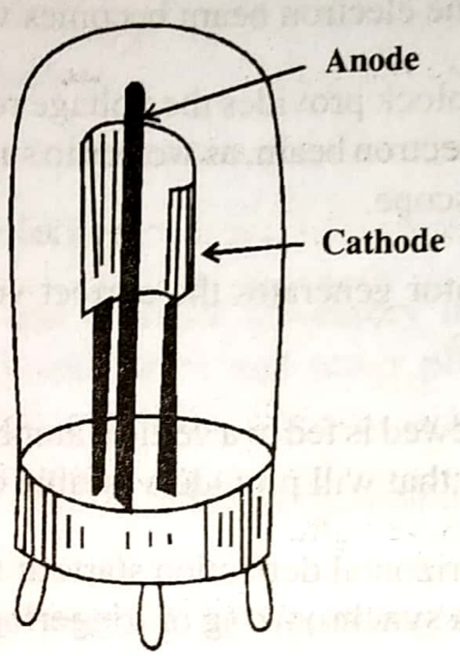
1. Vacuum Type

2. Gas filled Type

1. Vacuum Type Photo cell : (i) It consists of a curved sheet of thin metal with its concave surface coated with a photo emissive material which forms the cathode.

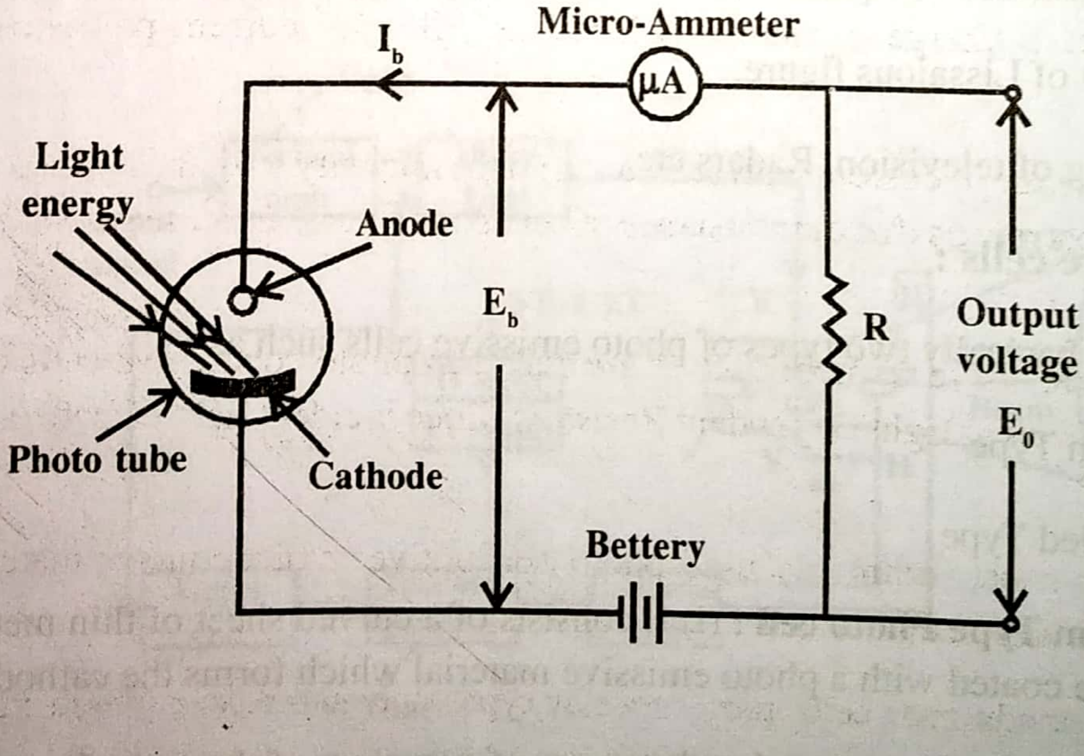
(ii) A Rod anode is mounted at the centre of curvature of the cathode.

(iii) The whole assembly is mounted in an evaluated glass envelope as shown in figure below.



(iv) The cathode is coated with emissive materials. These materials emit electrons when light radiation strikes them.

(v) The emitted electrons from the cathode are collected by a positive electrode (anode) forming an electric current.



(Ckt. for photoemissive cell)

The current through the tube depends upon the following :

(i) Intensity of light

(ii) Colour of light or its wavelength

(iii) Voltage applied between cathode and anode

The sensitivity of photo electric cells is moderate, the luminous sensitivity lies between 10 to 100 μA/1m and the radiant sensitivity lies between 0.002 to 0.1 μA/μw at peak spectral sensitivity.

The major advantage of photo electric cells is that they are stable and do not change their characteristics over long periods of time provided they are operated at low voltage and are protected against excessive light.

The disadvantage of photo emissive cells is that current through the highly evaluated tubes is very small which loads low sensitivity.

Photo conductive cells :

(i) Electrical conduction in semiconductor materials occurs when free charge carriers such as electrons are available in the material when an electric field is applied.

(ii) In certain semiconductors, light energy falling on them is of the correct order of magnitude to release charge carriers which increase flow of current produced by an applied voltage.

(iii) The increase of current with increase in light intensity with the applied voltage remaining constants means that the resistance of semiconductors decrease with increase in light intensity.

(iv) Therefore, these semiconductors are called as photo conductive cells or photo resistors or sometimes as light Dependent Resistors, since incident light effectively varies their resistance.

(v) The two most commonly used photo conductive semiconductor materials are cadmium sulphide and cadmium selenide.

(vi) Photo conductive cells use a special type of construction which minimises resistance while providing maximum surface.

(vii) Photo conductive cells are made by chemically sintering the required powder into tablets of the required stage and enclosing them in a protective envelope of glass or plastic.

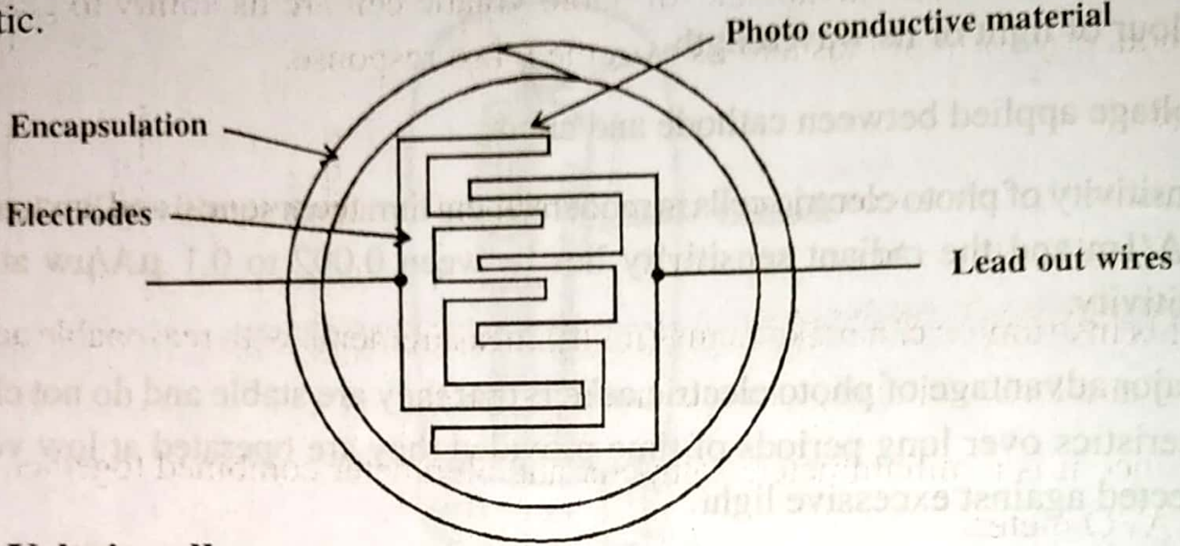


Photo Voltaic cell :

(i) This is an important class of photo detectors.

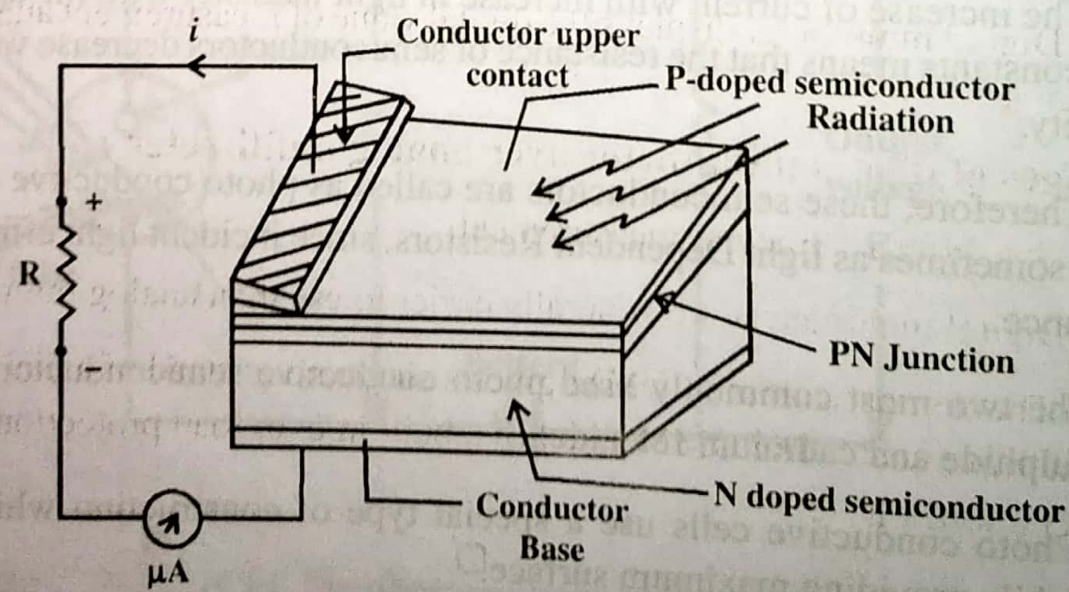
(ii) They generate a voltage which is proportional to EM radiation intensity.

(iii) They are called as photo voltaic cells because of their voltage generating characteristics.

(iv) A photo voltaic cell is a giant diode, constructing a PN junction between appropriately doped semiconductors.

(v) Photons striking the cell pass through the thin p-doped upper layer and are absorbed by electrons in the lower N-layer causing formation of conduction electrons and holes.

(vi) The depletion zone potential of the PN junction then separates these conduction holes and electrons causing a difference of potential to develop across the junction.



(vii) The photo voltaic cells can operate satisfactorily in the temp. range of –100 to 125°C.

(viii) The tremendous advantages of photo volatic cell are its ability to generate a voltage without any form of bias and its extremely fast response.

Multimeter :

(i) This is the most commonly used instrument by techniques and engineers in laboratory as well as the other repair works.

(ii) This instrument can make many (multi) measurements with reasonable accuracy such as A.C. and D.C. voltages, currents and resistances.

(iii) Since it is a miliammeter, voltmeter and ohmmeter combined together, so it is also called AVO meter.

(iv) It has various ranges to measure different voltages, currents and resistances.

Digital Multimeter :

(i) An analog multimeter contains a moving system, which is a moving coil galvanometer, while the digital multimeter contains typical nos. of moving parts.

(ii) When a voltage or current passes through the meter, it converts them into a digital code.

(iii) The ckt. used is called A/D converter. The code is then processed electronically to calculate the current or voltage.

(iv) Digital multimeter displays the digital value of measurement automatically with decimal point.

Advantages of digital multimeter over analog multimeter :

(i) It has high accuracy of measurement.

(ii) Digital multimeters are generally easier to use than analog multimeter.

(iii) The digital readout of DMM gives a single no. instead of a dial point to several no. on a multiple scale. The DMM also has a built in over load protection that the analog multimeter doesn't have.

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