Transducer

Transducers: It is a device which converts energy or information from one part to another.

(ii) A better measurement of a quantity can usually be made if it may be converted to another form which is more conveniently or accurately displayed.

Ex:- A photoelectric conducts light intensity into change in resistance.

A thermocouple convert heat energy into electrical voltage.

Electrical Transducer: ~~It~~ It is a device by which physical, mechanical or optical quantity to be measured is transformed directly with a suitable mechanism into an electric signal (current, voltage, frequency)

→ The operation of these signals is based upon electrical effects which may be resistive, inductive, capacitive etc; in nature.

The transducer consist of two important and closely related part. are.

i) Sensing element

ii) Transduction element.

Sensing element: (i) A detector or sensing element is the part of transducer which responds to a physical phenomenon or change in physical phenomenon

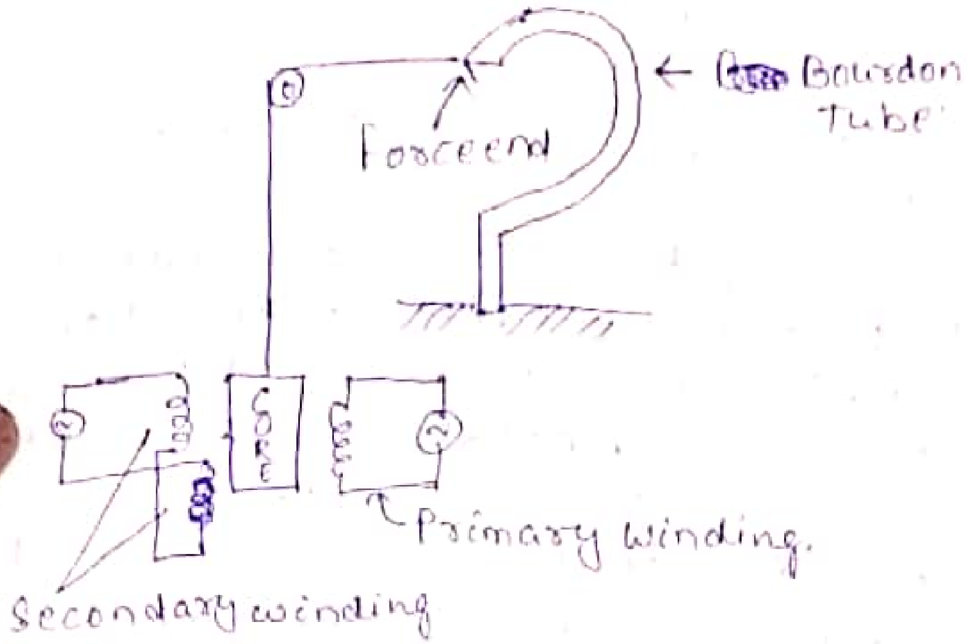
(ii) The respond of the sensing element ~~is the~~ ~~Part of transducer which responds to a physical~~ must be closely related to the physical phenomenon. The sensing element is known as detector transducer stage.

Transduction element :- (i) A transduction element transforms the output of a sensing element to an electrical output.

(ii) The transduction element in a way acts as secondary transducer.

Types of Transducer

Primary and Secondary Transducer



(i) The buordon tube acting as a primary detector senses the pressure and converts the pressure into displacement of its free end.

(ii) The displacement of force end moves the core of linear variable differential transformer (LVDT) which produces an output voltage which is proportional to the movement of core which is proportional to the displacement of free end which proportional to pressure.

(iii) There are two stages of transduction firstly the pressure is connected into a displacement by Bourdon tube then displacement is connected into an analogous voltage by LVDT

(iv) The bourden tube is called as "primary transducer" while LVDT is called "secondary transducer".

... LVDT is a secondary trans...

On the basis of method of energy conversion

Active transducers:- (i) Self generating type transducers i.e the transducers which develop their O/p in the form of electrical voltage or current without any auxillary source, are called the active transducers.

(ii) Such transducers draw energy from the system under measured, Normally such transducers provide very small O/p & therefore use of amplifier becomes essentially

(iii) Normally such transducers provide very small ckt.

-> Tachogenerators used for measurement of angular velocity, thermocouples used for measurement of temp, piezoelectric crystal used for measurement of force fall in this catagory

2) Passive Transducers:- Transducers in which electrical parameters i.e. resistance, capacitance and inductance changes with the change on i/p signal, are called passive transducers
Ex:- Resistive, inductive, capacitive transducers
-> These transducers regain external power source for energy conversion.
-> In such transducers electrical parameters causes a change in voltage, current or frequency of the external power source.
-> These transducers may draw some energy from the system under measurement.

On the basis of nature of o/p signal

1) Analog Transducer:- Analog Transducer converts i/p signal into o/p signal, which is a continuous function of time such as thermistor, strain gauge, LVDT, thermocouple etc.

2) Digital Transducer:- (i) It converts i/p signals into the o/p signal of the form of pulses
(ii) It gives discrete o/p

Transducers & Inverse Transducers

Transducer is a device that converts a non electrical quantity into an electrical quantity

An inverse transducer is a device that converts an electrical quantity into a non-elect quantity.

2.3

Resistive Transducer:- In such a transducer, resistance between the o/p terminals of a transducer gets varried according to the measurement.

(ii) It is preferred over other transducers because dc or ac both are suitable for resistance measurement

(ii) $R = \rho \frac{L}{A}$

(iii) Physical phenomemon i.e i/p signal to the transducer causes variation in resistance by changing any one of the quantities ρ, L & a

Ex: for measurement of displacement length of conductor is varied in potentiometer thereby resulting in change in resistance

→ Variation in temp causes change in the resistivity of the conductor material & so change in resistance takes place which is noted for measurement of temp

Resistance Thermometer (Resistance temp detector)

→ It operates upon the fact that almost all pure metals have the property of varying their resistance with temp. & change in resistance is almost directly proportional to the change in temp.

→ The range of temperature over which the is valid is decided by the temp coefficient of resistance, chemical inertness & its crystal structure which should not undergo permanent changes within the range.

→ $R_t = R_0 (1 + \alpha t)$

R_0 = Resistance in Ω at reference tempr.
R_t = " " " " temp t.
α = temp coefficient of resistance 1Ω, 1°C.

Constn :- RTD is simply a length of wire whose resistance is to be monitored as a function of temperature. The construction is typically such that the wire is wound on a form in a coil to achieve small size & thermal improve thermal conductivity to decrease response time. Coil is protected from environment by a sheath/protective type that increases response time. A loosely applied standard sets the resistance at multiples of 100Ω for a tempr of 10°C.

Resistance Materials used :- Platinum, Nickel, copper.

RTD appn.. for measurement of small temp differences as well as wide range of tempr.

Drawback :- → Large size & sophisticated inst.
→ doesn't generate its own voltage so voltage source required.

Thermistor (Thermal resistor)

→ It is thermal sensor that measures temp through changes of material resistance.
→ It is a semi conductor device behaves as resistor with high negative temp. coefficient.
→ It is at least 10 times as sensitive as the platinum resistance thermometer.

→ Resistance of thermistor at temp T.

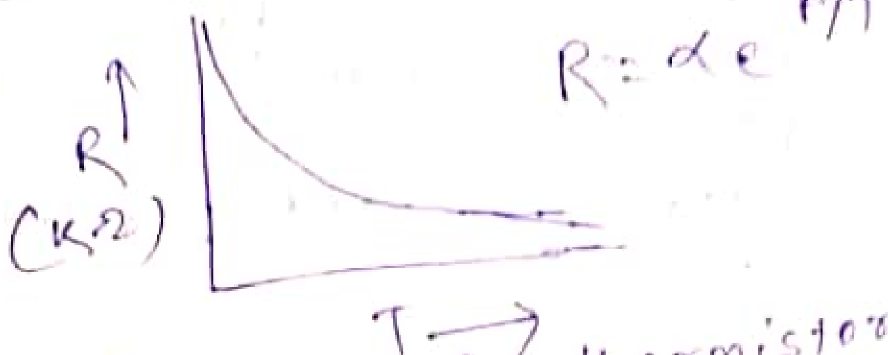
~~$R \propto e^{\beta/T}$~~

$$R = \alpha e^{\beta/T}$$

β = Thermistor constant.

α, β = Constants depend upon material and manufacturing technique used

→ These are bulk semiconductor & can be fabricated as disc, beads, rods of varying to provide a wide range of resistance value at any particular temp.



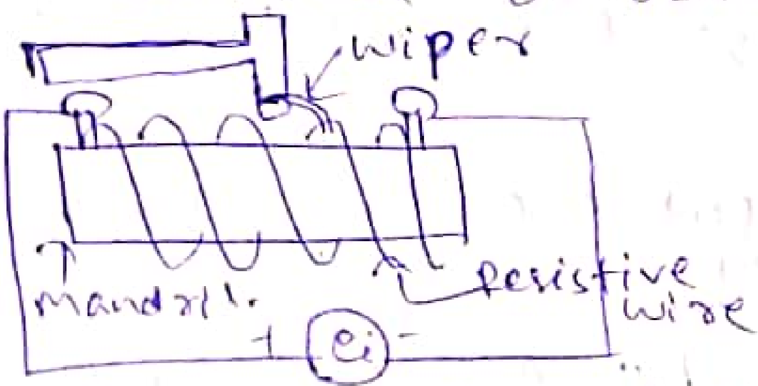
Materials used for thermistor manufacturing

(i) Oxides of manganese, nickel, cobalt, iron, zinc etc. These oxides or their sulphides & silicates are are milled, mixed to appropriate proportion pressed into desired shapes.

Potentiometers :- (i) It is a resistive potentiometer which is used for purpose of voltage diversion.

→ It consists of a resistive element provided with a sliding contact. This sliding contact is called wiper.

→ The motion of sliding contact maybe transational or rotational.



(a) Linear (translational) POT

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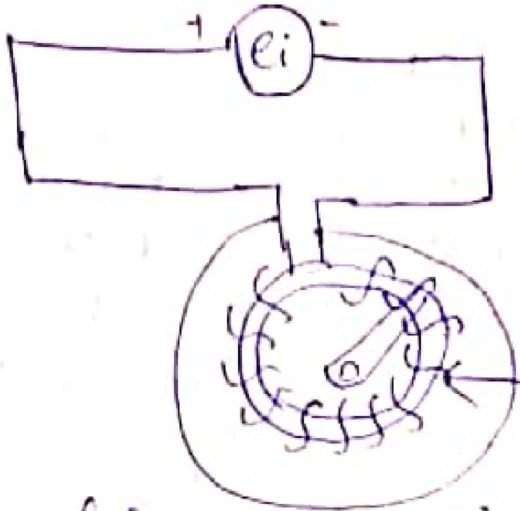
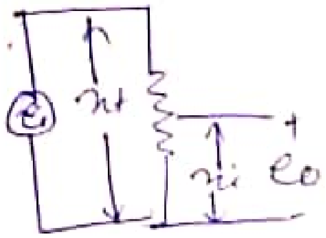
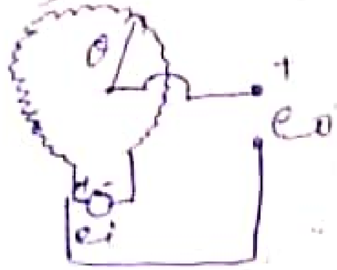


(Rotating POT)   POT → Potentiometer





→ Some POTs in the combination of two motion. So the resistive elements are in form of helipot. So they are called helipots.

→ The resistive element can be exited by ac or dc voltage.

→ These are also made up from carbon, hot moulded carbon, carbon fin and thin metal.

Let us consider dc exited translational potentiometers

e_i & e_o → input & output voltage respectively.

x_t → Total length of transitional pot.

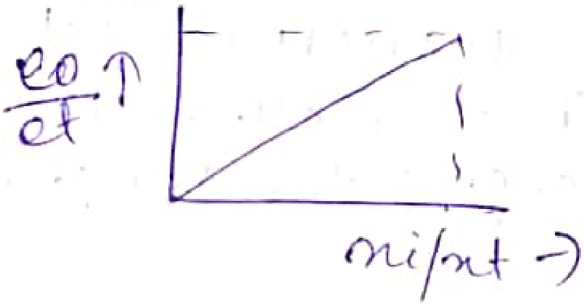
x_i → displacement of wiper from its zero position.

R_p → Total resistance of potentiometer.

$$e_o = \frac{\text{Resistance of output terminal}}{\text{Resistance of input terminal}} \times e_i$$

$$= \frac{R_p \cdot \frac{x_i}{x_t}}{R_p} \times e_i$$

$$e_o = \frac{x_i}{x_t} \times e_t \Rightarrow \frac{e_o}{e_t} = \frac{x_i}{x_t}$$



Under ideal circumstances the output voltage varies linearly with displacement

13
'30

Capacitive Transducer

The capacitive transducer are commonly used for measurement of linear displacement.

Principle: It is based upon the equation for the capacitance of a parallel plate capacitor.

Capacitance: $C = \epsilon A/d = \epsilon_r \epsilon_0 A/d$ --- (1)

where A = overlapping area of plates; m^2

d = Distance betn two plates, m

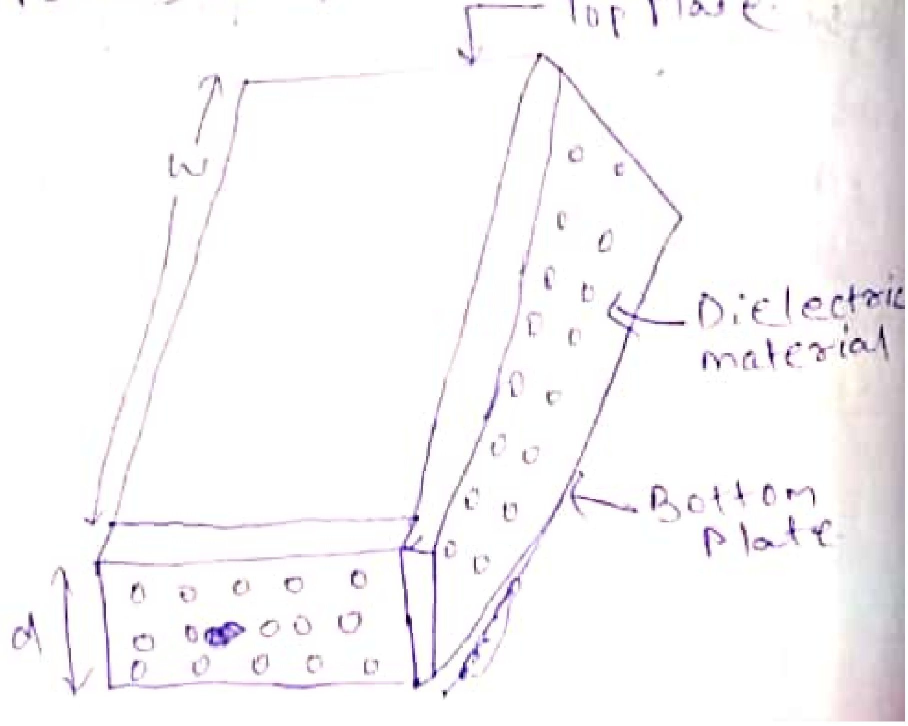
$\epsilon = \epsilon_0 \epsilon_r$ = Permitivity of medium; F/m

ϵ_r = Relative permitivity

ϵ_0 = Permitivity of free space; 8.85×10^{-12} F/m

→ It works on principle of change of capacitance which may caused by
(i) change in overlapping Area, A
(ii) Change in distance 'd' between the plates
(iii) change in dielectric constant

These are caused by physical variable like force, displacement and pressure.



The capacitance may be measured with bridge circuit.

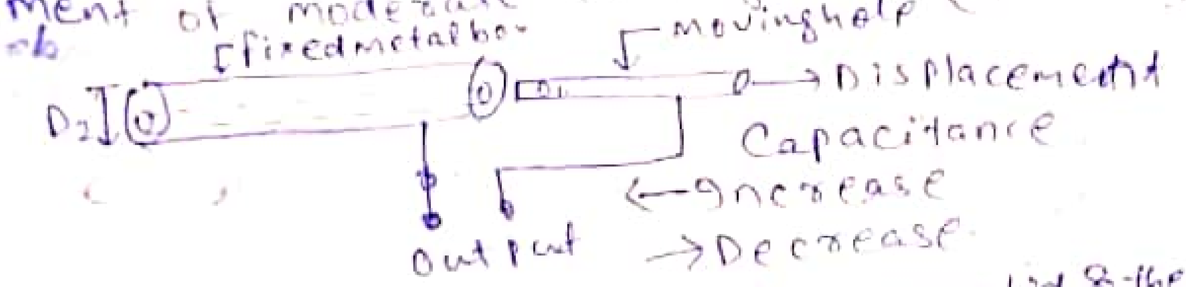
$$X_C = \frac{1}{2\pi f C}$$

C = Capacitance
f = frequency of excitation

Explain variable area of capacitive transducer

→ from the equation $C = \varepsilon_r \varepsilon_0 A/d$, the capacitance $C \propto A$ Area of the plate.

→ If capacitance changes linearly with change in area of plates. So this type of capacitive transducer is useful for measurement of moderate to large displacement (1mm to cm)



→ Most of dielectric materials are solid & they include procelin, mica, glass, plastic & the oxides of metal.

For a cylindrical capacitor the capacitance is

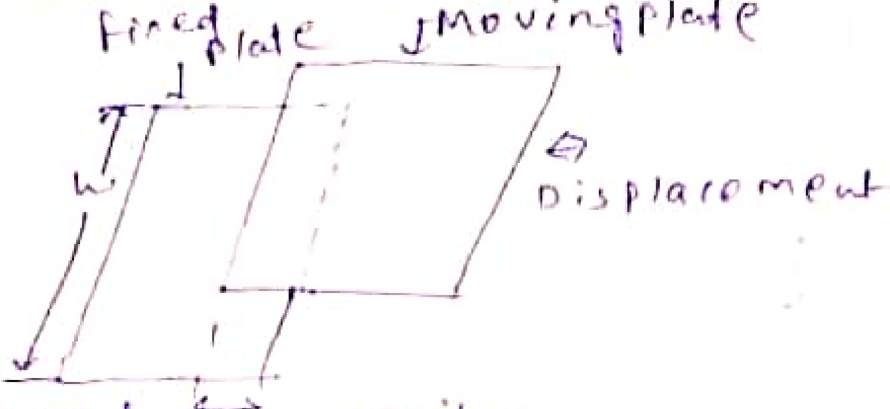
$$C = \frac{2\pi \varepsilon x}{\log_e (D_2/D_1)} \text{ faraday} \quad \text{--- (2)}$$

x = length of overlapping part of cylinders; mt

D_2 = inner diameter of outer cylindrical electrode; mt

D_1 = outer diameter of inner electrode; mt

$$\text{Sensitivity } S = \frac{\partial C}{\partial x} = \frac{2\pi \varepsilon}{\log_e (D_2/D_1)} \text{ F/mt} \quad \text{--- (3)}$$



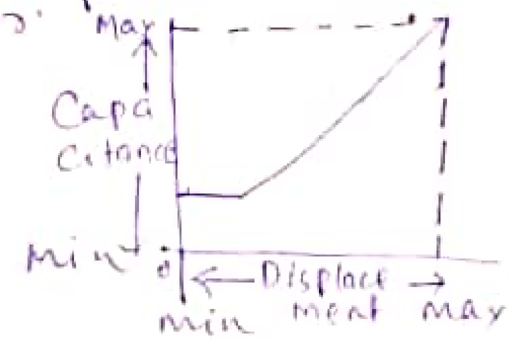
For a parallel plate capacitor

$$C = \frac{\varepsilon A}{d} = \frac{\varepsilon x w}{d} \text{ F}$$

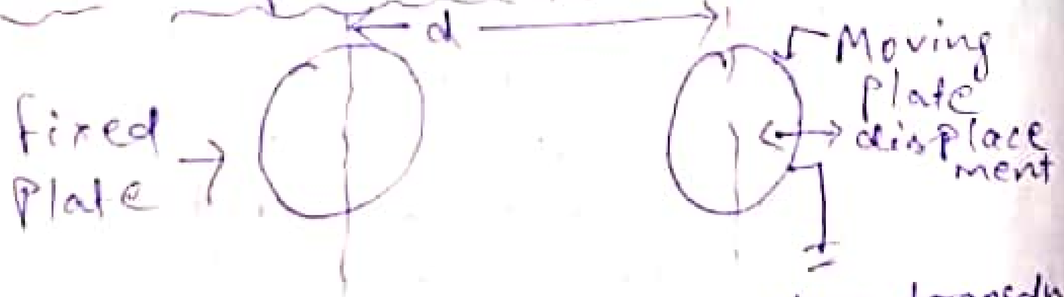
x: length of overlapping plates
w: width " " part of plate

Sensitivity, $S = \frac{\partial C}{\partial x} = \epsilon \frac{w}{d} \text{ F/m}$ —(5)

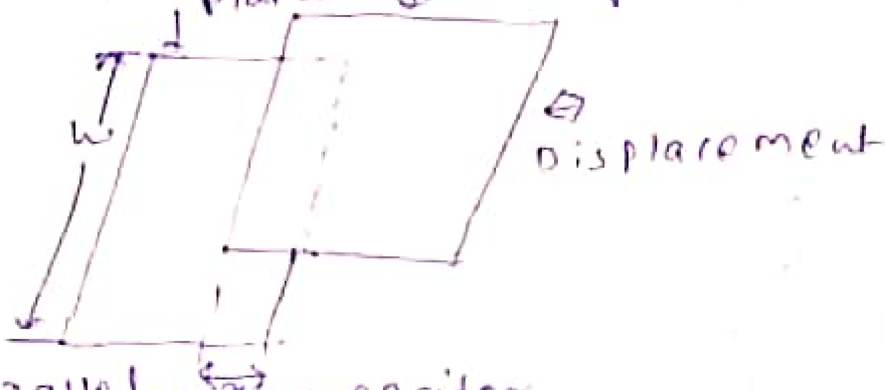
Sensitivity is constant in both cylindrical and parallel plate, the relationship of capacitance and displacement is linear:



Explain change in distance between plate capacitive transducer



This fig shows that a capacitive transducer utilising the effect of change of capacitance with change in distance betn plates



For a parallel plate capacitor

$$C = \frac{\varepsilon A}{d} = \frac{\varepsilon x w}{d} \; F$$

x = length of overlapping part of plates
w = width " "

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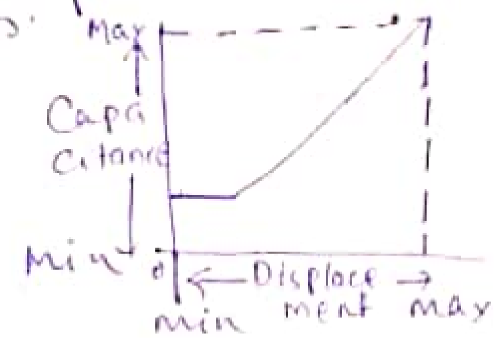

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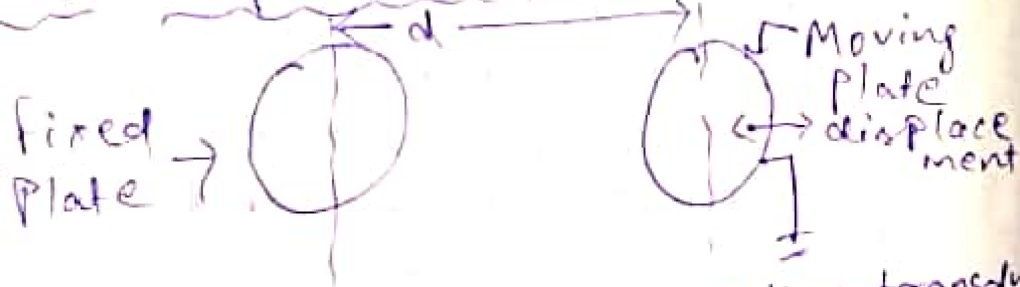
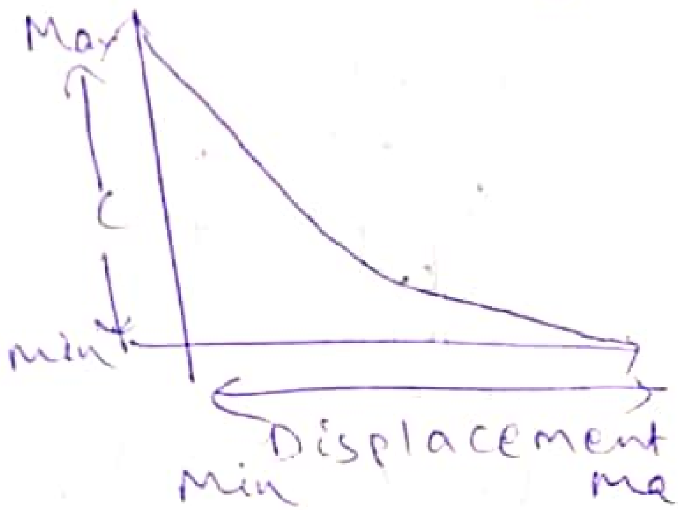


This fig shows that a capacitive transducer utilising the effect of change of capacitance with change in distance betn plates

→ One is fixed and displacement to be measured is applied to the other plate which is movable. So the capacitance 'C' varies inversly as the distance d.

→ The response of this transducer is not linear, so it is only useful for measurement of extremely small displacement.

Sensibility $S = \frac{\partial C}{\partial x} = \frac{\epsilon A}{x^2}$



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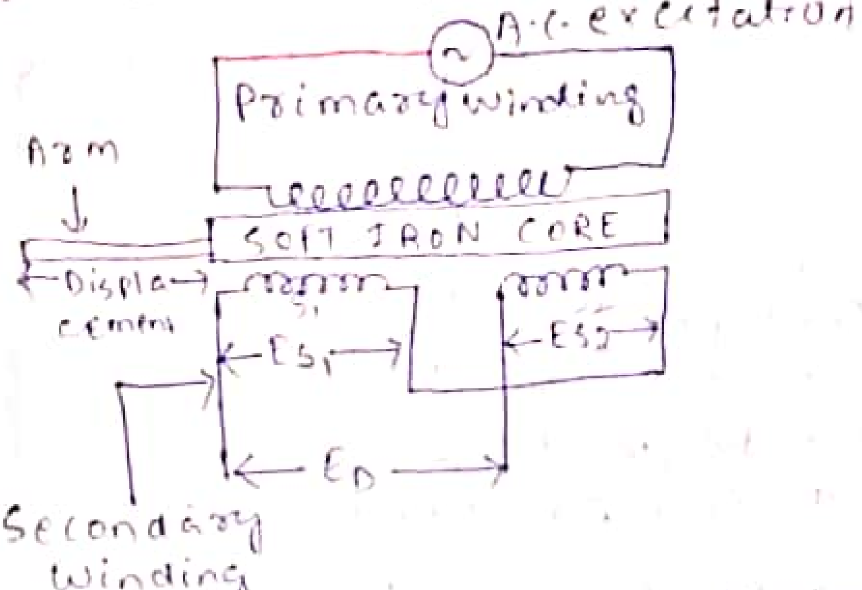
Linear variable differential transducer (LVDT)

(i) It is used to translate the linear motion into electric signals



Construction:- (i) It consist of single primary winding (P) and two secondary winding 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 the primary winding.

(iii) The primary winding is connected to the alternating current source.

(iv) The movable soft iron core is placed inside the former. The displacement to be measured is applied to the arm attached to the soft iron core.

(v) The soft iron core is made of high permeability nickel iron which is hydrogen annealed. This gives low harmonic, low null voltage and a high sensitivity.

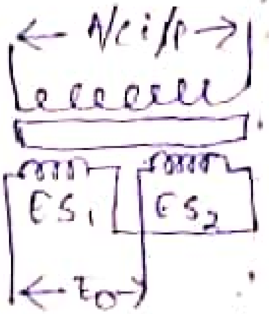
Operation: (i) Since the primary winding is excited by A.C. source it produces an alternating magnetic field which in turn induces alternating current, voltages in the secondary winding

(ii) The O/P voltage of secondary winding is S_1 is 'E_{S_1}' and from S_2 is 'E_{S_2}'.

(ii) In order to convert the o/p from S_1 and S_2 into a single voltage signal the two secondaries S_1 and S_2 are connected in series opposition.

(iii) Therefore the o/p voltage of transducer is $\boxed{E_0 = E_{S_1} - E_{S_2}}$

Case-1

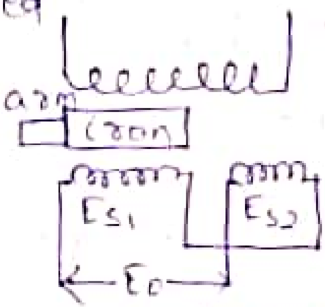


When the core is at its normal (null position) the flux linking with both the secondary winding is equal and hence equal emfs are induced in them.

Thus at normal position; $E_{S_1} = E_{S_2}$

Since $E_0 = 0$.

Case-2 :- If the core is moved to the left of the NULL position more flux links are with the winding 'S_1' and less with 'S_2'

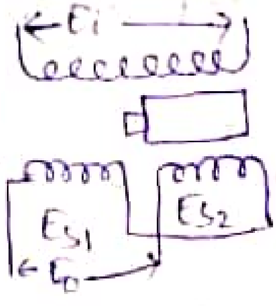


(ii). So the output voltage E_{S_1} of the secondary voltage is more than E_{S_2}.

$\boxed{E_0 = E_{S_1} - E_{S_2}}$ $E_{S_1} > E_{S_2}$

(iii) E_0 is in phase with the voltage from input source.

Case-3 :- When the core is moved to the right of the null position, the flux linking with winding S_2. This result in E_{S_2} becomes larger than E_{S_1}.



$\boxed{E_0 = E_{S_2} - E_{S_1}}$ It is out of phase with primary voltage.

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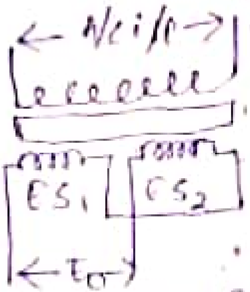
(ii) In order to convert the o/p from S_1 and S_2 the two voltage signal into a single voltage signal, the two secondaries S_1 and S_2 are connected in series opposition.

(iii) Therefore the o/p voltage of transducer is

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

Case-1



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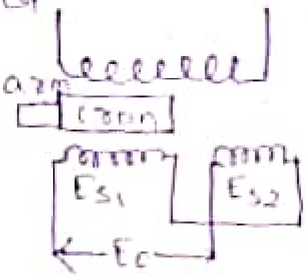
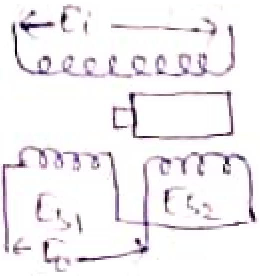


(ii). So the output voltage E_{S_1} of the secondary voltage is more than E_{S_2}.

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

(iii) E_0 is in phase with the voltage from input source.

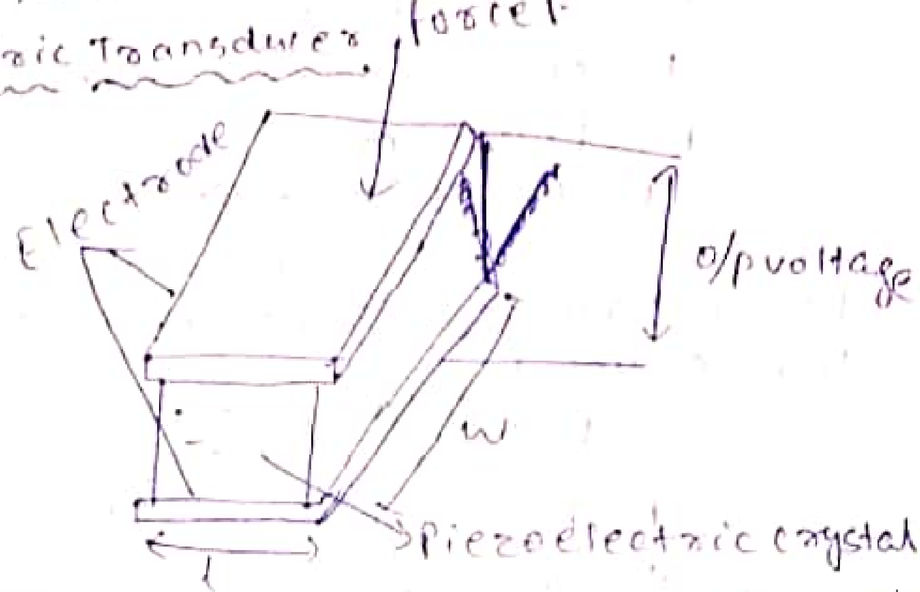
Case-3 :- When the core is moved to the right of the null position, the flux linking with winding S_2. This results in E_{S_2} becomes larger than E_{S_1}.



$$E_0 = E_{S_2} - E_{S_1}$$. It is out of phase with primary voltage.

Application: (i) This is used in applications where the displacements are too large for strain gauges to handle. It can be employed for measurement from a fraction of few mm to cm.
(ii) It can also be connected to other transducers whose outputs are mechanical displacement these are often employed together with other transducers for measurement of force, weight, pressure etc.

Piezoelectric Transducer



(i) whenever we apply the force to a piezo-electrical material it converts mechanical force to electrical force and the effect is called piezoelectric effect.
(ii) Elements exhibiting piezoelectric quantities are called as electro resistive element.
(iii) Some common piezoelectric materials are rochelle salts, lithium sulphate etc.
(iv) Quartz and Rochelle salt are belongs to natural group and other are synthetic group.
(v) The piezoelectric effect can be made to cause mechanical deformation of the material in many different mode.
(vi) These are used to convert mechanical force to electrical signal.
(vii) Mechanical deformation generates a charge, and this charge appears as a voltage across the electrode.

$V = \frac{Q}{C}$

(viii) It is direction sensitive, the tensile force produces a voltage of one polarity while a compressive force produces a voltage of opposite polarity.

(ix) The polarity of the induced charge depends upon the applied force.

Charge $Q = d \times F$ —— (1)

d = charge sensitivity of crystal

F = force,

$d = \frac{Q}{F}$ | Unit $\frac{\text{collumb}}{\text{Newton}}$

force causes a change in thickness of the crystal.

$F = \frac{AE\Delta t}{t}$ Newton

A = Area of crystal; m^2

t = Thickness " " , m

E = Young's modulus N/m^2

$E = \frac{\text{Stress}}{\text{Strain}} = \frac{F}{A} \cdot \frac{1}{\Delta t / t} = \frac{F \cdot t}{A \cdot \Delta t}$

$E = \frac{Ft}{A\Delta t} N/m^2$ —— (3)

where $A = wl$, w = width of crystal, l = length of crystal

$Q = d \times AE\left(\frac{\Delta t}{t}\right)$

Charge at the electrodes gives rise to an output voltage

$V_0 = \frac{Q}{C_p}$ —— (4)

where $C_p = \varepsilon_r \varepsilon_0 A/t$

$$V_0 = \frac{Q}{C_P} = \frac{dF}{\varepsilon_r \varepsilon_0 A/t} \Rightarrow V_0 = \frac{dt}{\varepsilon_r \varepsilon_0} \frac{F}{A}$$

But F/A = stress = P

$$V_0 = \frac{dt}{\varepsilon_r \varepsilon_0} \times P \Rightarrow V_0 = g t \cdot P$$

$$g = \frac{d}{\varepsilon_r \varepsilon_0}$$

'g' is voltage sensitivity of crystal & its constant for a given crystal unit is Vm/N.

$$V_0 = g t P \Rightarrow g = V_0 / t \times P$$

$$\Rightarrow g = \frac{V_0}{t/P}$$

But we know V_0/t = Electric field strength V/m

$$\boxed{g = \frac{E}{P}}$$

<u>Applications</u>:- (i) These are employed in high frequency accumulators. Output voltage is basically 1-300mV per g of acceleration.
(ii) It is used in ultrasonic generator.
(iii) It is used in automobile industry.
(iv) It is used in aerospace & Nuclear instrumentation.

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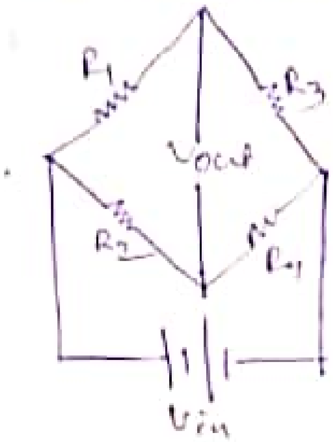
Strain Gauge:- If a metal conductor is stressed or compressed its resistance changes an account of the fact the both length does not change.

Wire Resistance strain Gauge:- (i) These are usually normal size. These are subject to minimal leakage and can be used in high temperature application.

(ii) In unbonded wire strain gauge, resistance wire is not bonded with the base instead strain is directly transferred to the resistance wires and a smaller force is required for changing the length.



Unbonded strain gauge (four element)

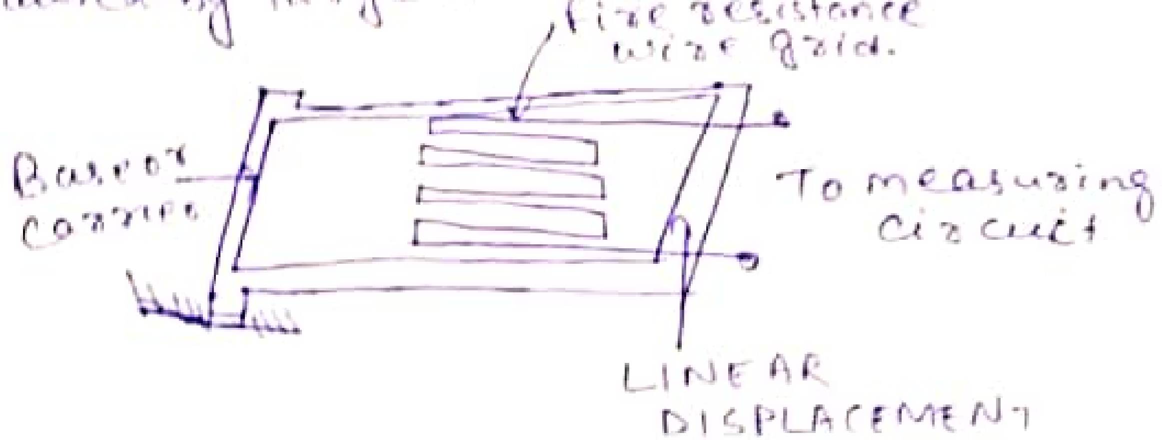
(iii) It is an example of wheatstone bridge. If no load applied then Vout = 0, then we can say the bridge is balanced. If we put an external force increases tensions in two wires and reducing between two other wires. The variation of resistance causes unbalanced between bridge causing an output voltage Vout in proportion to wire displacement.

(iv) strain gauge Advantage:- These are very low hysterisis and creep. These are force sensing component and can be adapted of high temperature environment due to welded construction.

(v) Drawback:- It has low sensitivity

(v) Application:- These are used mainly for measurement of force, pressure and acceleration rather than for measuring directly displacement for strain.

(vi) The most common type of bonded wire strain gauge used for detecting displacement caused by large forces is flat grid type



(vii) In this type of strain gauge fine resistance wire of diameter of 25 microns or less is wound back and forth in a grid format, with as many as loop as possible laid side by side. Two connected lead are welded to the grid.

(vii) Bonded straingauge is cemented with a special adhesive to the structure whose tensile or compressive strain to be measured.

(viii) The strain of wire grid is exactly same as the strain of the specimen. The strain of wire grid is measured with the wheatstone bridge connecting the gauge in one of the four while the remaining wires ~~are equal to~~ resistance are equal to gauge resistance.

(ix) Others type of bonded wire strain gauges are wrap around, single wire, and wooven ones

(x) Bonded wire strain gauge are easily to manufacture and are relatively cheaper in cost. The size varries with the application.

(xi) These gauges are employed for both stress analysis and for constsuction of transducers. It is very useful to measure only very small displacement voltage ...

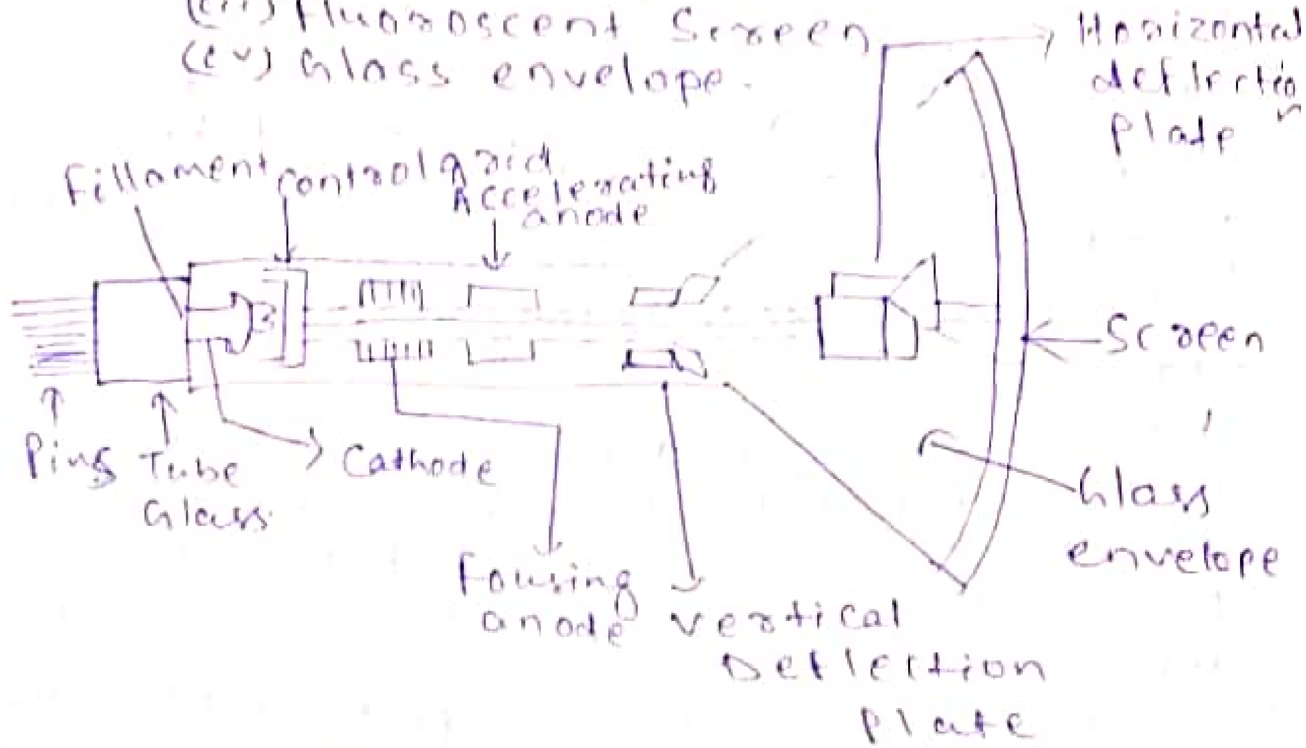
Chapter-8

Oscilloscope:

Principle of operation of Cathode Ray Tube (CRT):-

(i) It is the heart of the oscilloscope. It is a vaccume tube of special geometrical shape and converts an electric signal to visual one.

(ii) The main parts of CRT are
- (i) Electron gun assembly
- (ii) Deflection plate assembly
- (iii) Fluorescent Screen
- (iv) Glass envelope.



(i) Electron gun assembly:-

(i) The arrangement of electrode which produce a focous beam of electrons is called the electron gun.

(ii) It consists of indirectly heated cathode, a control grid, a foccusing anode and an accelerating anode.

(iii) The cathode consists of a nickel cylinder coated with oxide coating and provides plenty of electrons.

(iv) The control grid is held at negative potential w.r.t cathode.

(v) The control grid encloses the cathode and consists of a metal cylinder with a tiny circular opening to keep the electron beam small in size.

(vi) The two focussing anode are maintained at high positive potential w.r.t cathode.

(vii) The following anode focusses the electron beam into a sharp pinpoint by controlling the positive potential on it.

(viii) The +ve potential on the accelerating anode is much higher than on the focussing anode. For this reason, this anode accelerates the narrow beam to a high velocity.

(ix) Therefore, the electron gun assembly forms a narrow accelerated beam of electrons which produces a spot of light when it strikes the screen.

Deflection Plate assembly:-

(i) The deflection of the beam is accomplished by two sets of deflecting plates placed with in the tube beyond the accelerating anode. One set is vertical deflection plates and the other set is horizontal deflection plate.

(ii) the vertical deflection plates are mounted horizontally in the tube. By applying proper potential to these plates, the electron beam can be made to move up and down vertically on the fluorescent screen.

(iii) The horizontal deflection plates are mounted in the vertical plane. to appropriate potential on these plates can cause the electron beam to move right and left horizontally on the screen.

(iv) Fluorescent Screen :- (i) The screen is inside face of the tube and is coated with fluorescent material such as zinc orthosilicate, zinc oxide etc.

(ii) When high velocity electron beam strikes the screen, a spot light is produced at the point of impact. The colour of the spot depend upon the nature of the material.

(iii) If zinc orthosilicate is used, then green light spot is produced.

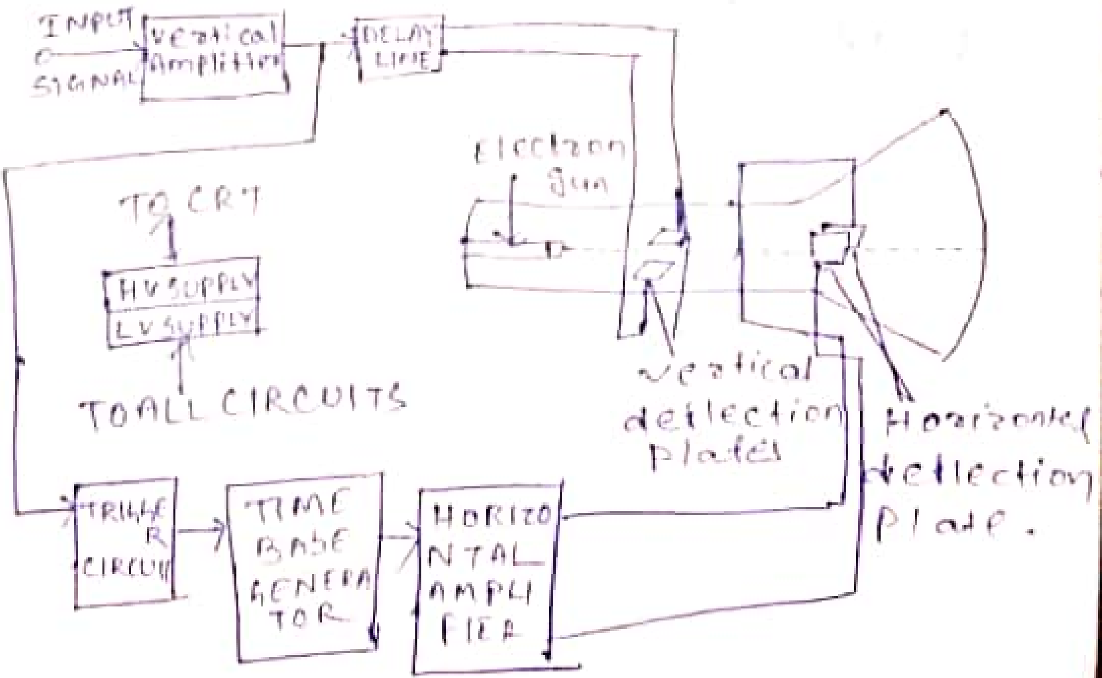
(v) Glass envelope :- (i) It is conical highly evacuated glass housing and maintains vaccum inside and supports the various electrodes.

(ii) The inner walls of CRT between neck and screen are usually coated with a conducting material called aquadag.

(iii) This coating is electrically connected to the accelerating anode so that electrons which are accidentally strikes the walls returned to the anode.

Principle of operation of oscilloscope :- (Block Diagram)

CRO (cathode ray oscilloscope)



(i) It is used to measure the voltage or current and also it shows on the screen.

(ii) It employs a CRT, which generates electron beam, accelerates beam to a high velocity, deflects the beam to create the image and contains a phosphor screen where the electron beam eventually becomes visible.

(iii) For this we need supply, Low voltage supply is required for electron gun, high voltage required for CRT to accelerate the beam. Normal voltage (few hundred volt) required for other control circuits. For this we use power supply circuit.

(iv) Horizontal and vertical deflection plates are fitted between electron gun and screen to deflect the beam according to input signal.

(v) The beam strikes the screen and creates a visible spot, which is deflected on the screen in horizontal dirn (x-axis)

(vi) The signal to be viewed is supplied to the vertical deflection plates through the vertical amplifier, which raises the potential of the input signal to a level that will provide deflection of the electron beam.

(vii) Now electron beam gives two direction horizontal on x-axis and vertical in Y-axis.

(viii) A triggering circuit is provided for synchronizing two types of deflections ~~starts at the same point~~ so that horizontal deflection starts at the same point of input vertical signal each time it sweeps.

(ix) Delay line: It provides some amount of delay to the signal which is obtained at the output of the vertical amplifier. The signal is then applied to vertical deflection plates of CRT.

(x) Time base generator produces a sawtooth signal, which is useful for horizontal deflection of electron beam.

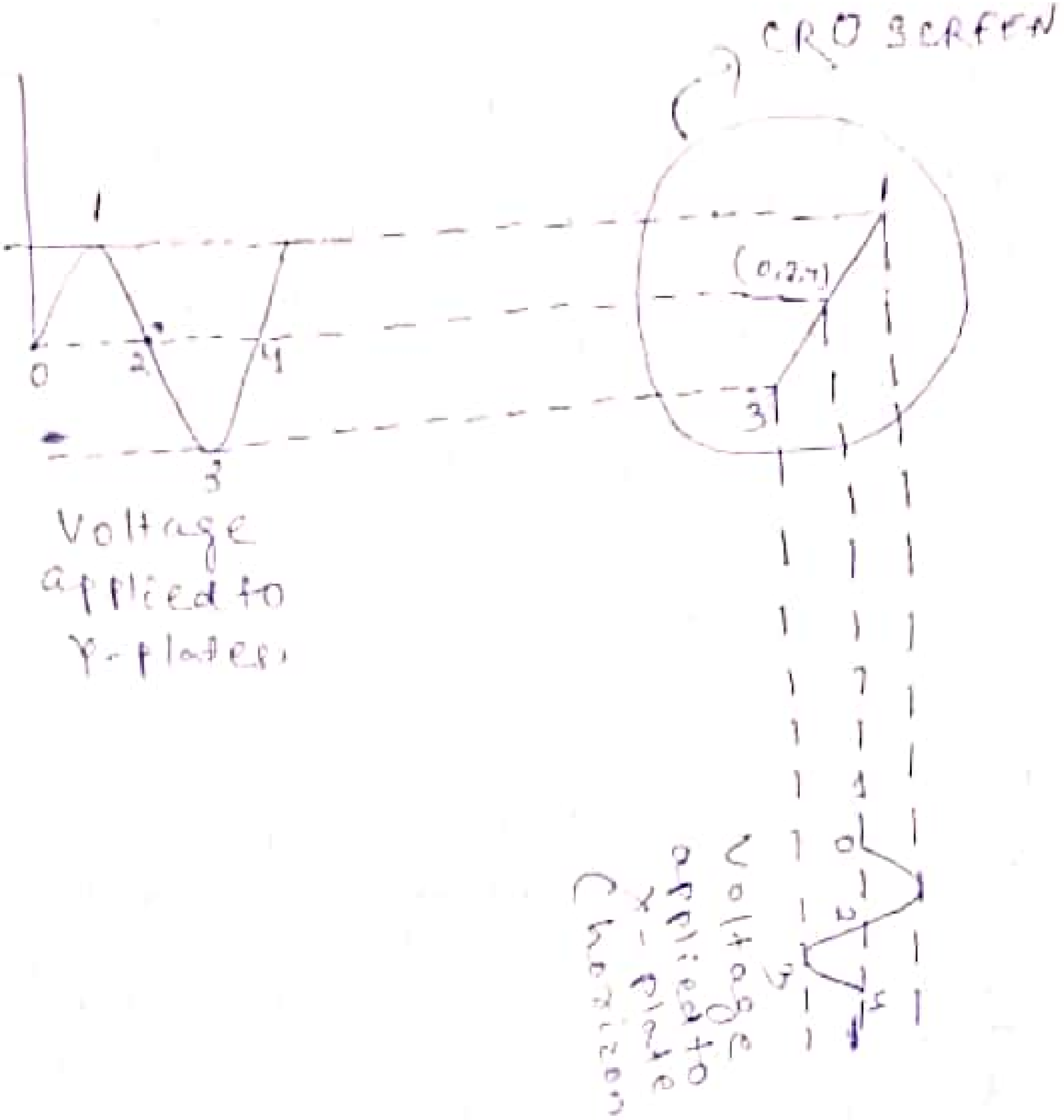
(xi) Vertical amplifier amplifies the input signal, which is to be displayed on the screen of CRT.

(xii) Horizontal amplifier amplifies the sawtooth signal and then connects it to the horizontal deflection plates of CRT.

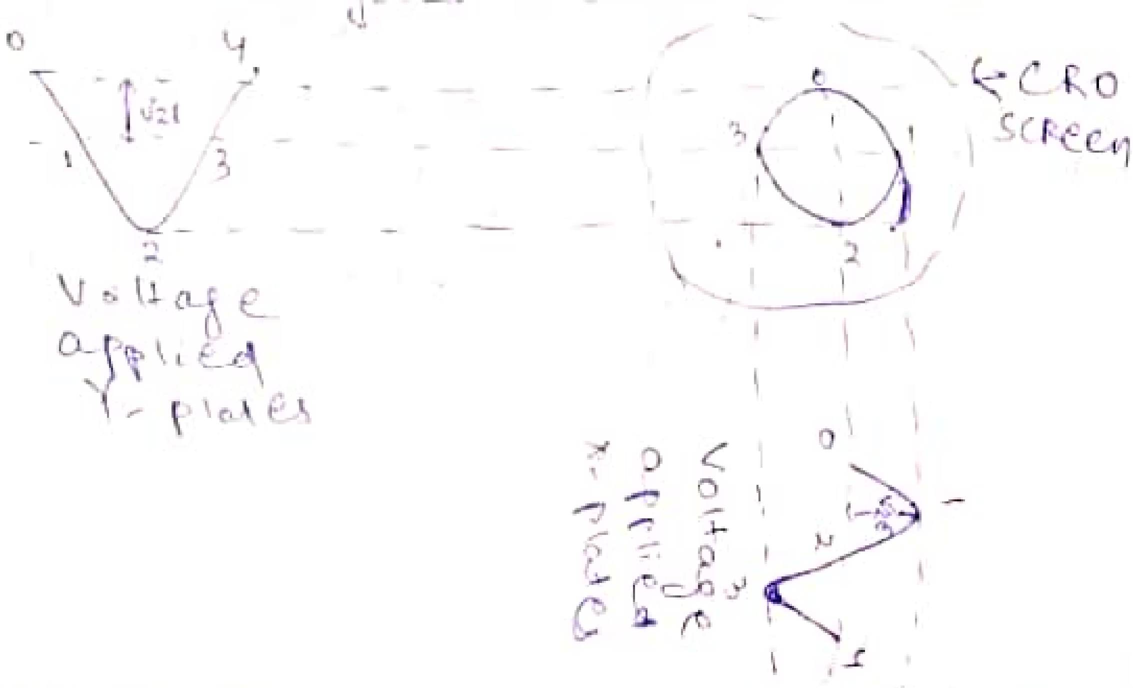
Measurement of phase and frequency

(i) In the measurement of phase and frequency sinusoidal voltage are simultaneously applied to both vertical and horizontal deflection plates. The resultant portion that appears on the screen of CRO is known as lissajous patterns.

*) when two sinusoidal voltages of equal frequency which are in phase with each other or 180° out of phase with each other are applied to the both deflection plates, the pattern appearing in the screen is straight line.



When two equal voltage of equal frequency 90° or 270° phase displacement are applied to a CRO this gives a circle in screen



→ When two equal voltage of equal frequency applied but with phase shift ϕ (not equal to $0°$ or $90°$). We obtain an ellipse. An ellipse is also obtained an un equal voltage applied to CRO of same frequency.

$$\sin\phi = \frac{Y_1}{Y_2} = \frac{x_1}{x_2}$$

Measurement of frequency:-

In the measurement of frequency unknown signal will be given to Y-plates, X-plates are fed with variable frequency. This frequency will be vary till meaningfull pattern appear on the screen.

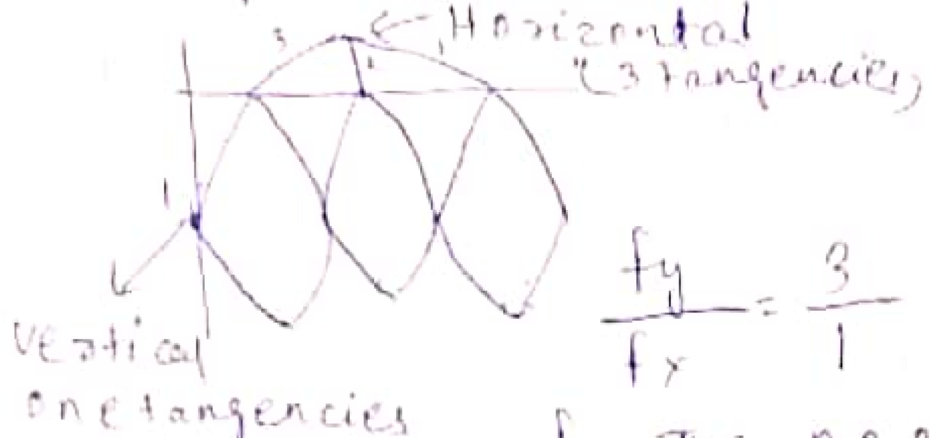
$$\frac{f_y}{f_x} = \frac{\text{number of times tangent touches top or bottom}}{\text{number of times tangent touches either side}}$$

$$= \frac{\text{no of horizontal tangencies}}{\text{no of vertical tangencies}}$$

where f_y = frequency of signal applied to Y axis

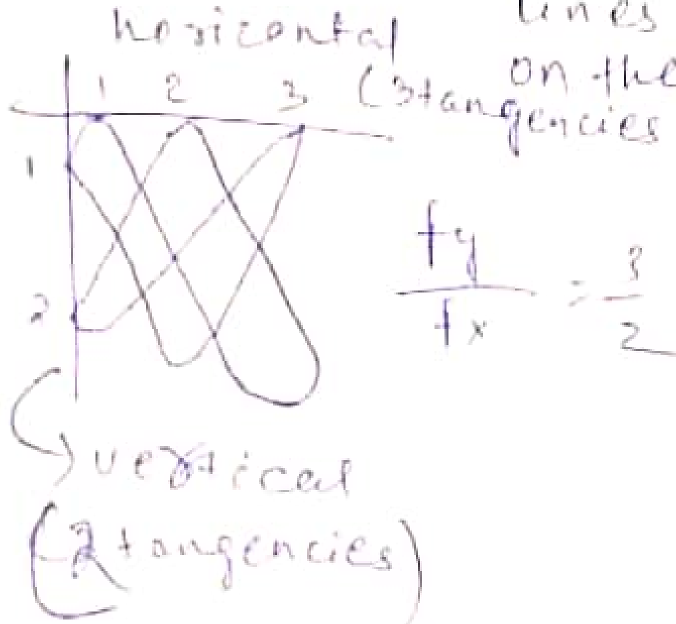
f_x = frequency of signal applied to X-axis

Let's give an example



$$\frac{f_y}{f_x} = \frac{3}{1}$$

f_x : The no of loops cut by the vertical lines gives the freq. on the horizontal plate



$$\frac{f_y}{f_x} = \frac{3}{2}$$

Measurement of voltage and current

CRO can be used for measurement of voltage of any electric signal.

→ For measurement of DC, firstly the spot is centred on the screen without applying any voltage signal to deflection plates. Then D.C. voltage to be measured is applied between two pair of deflection plates and the deflection spot observed in screen the magnitude of deflection multiplied by the deflection factor gives the value of d.c. voltage. By reading the scale voltage can be measured by CRO

→ In case of a.c voltage, it is applied between a pair of deflection plates and length of St. Line is measured. knowing the deflection sensitivity, the peak to peak value of applied a.c voltage can be measured.

→ For measurement of current a known non inductive resistance and the voltage drop across it is measured by CRO. The current can be determined simply by dividing the voltage drop measured, by the value of a non inductive resistance. When the current has to be measured in small value, the voltage has to be amplified by calibrated amplifier