UNIT - 1

Sensor and Transducers

§ **Measurement System:**

The main function is to collect the information on system status and to feed it to the micro-processor(s) for controlling the whole system.

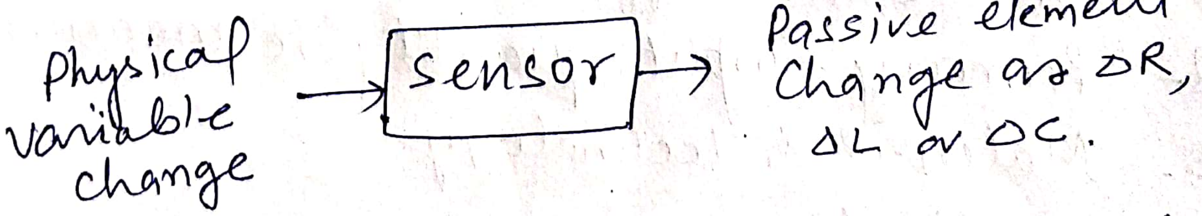
Measurement system comprises of sensors, Transducers and signal processing devices.

Sensors is basically employed to automatically carry out the information as well as process monitoring activity.

Sensor has following important advantage.

- Reduce the requirement of skilled and experienced labors.
- Utra precision can be achieved.
- Reduce downtime, Alarm the failure of any subsystem,

§ **Sensor(s)/Detector(s)**



" A device which provides a usable output in response to a specified measurand."

In measuring system sensor or sensing element takes information about the variable been measured and transform it into a suitable form to be measured. sensor is also called primary sensing element.

§ Transducers :

The sensor sense the condition, state or value of the process variable and produce an output which reflects this condition, state or value. The transducers transform the energy of the process variable to an output of some other type of energy which is able to operate some control device.

§ Classification of Sensors

It is very difficult to classify sensor under one criterion and hence, different ~~criterion~~ criteria may be adopted for the purpose.

1- Transduction principle using physical or chemical effect.
2- Primary input quantity (ie measurand)
3- Material & Technology
4- Application
5- Property
6- Cost & accuracy.

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Classification of sensors on the basis of their applications:

A - Displacement, position & proximity sensors.
- potentiometer
- strain-Gauged element
- capacitive element
- Differential transformers
- Eddy current proximity sensors
- Inductive proximity ~~sensors~~. switch
- optical Encoders
- Pneumatic sensors
- Proximity switches (magnetic)
- Hall effect sensors.

B - Velocity and motion:
- Increamental encoder.
- Tachogenerator
- Pyroelectric sensors.

C - Force:
strain gauge & load cell.

D - Fluid pressure:
- Diaphragm pressure gauge
- Capsules, bellows, pressure tubes
- Piezoelectric sensors
- Tactile sensor.

E - Liquid flow
- orific plate
- Turbine meter

F- Liquid levels :-

- Floats
- Differential pressure

G- Temperature :

- Bimetalic strip
- Resistance temperature detectors
- Thermistors
- Thermodiodes & transistors
- Thermocouples
- light sensors
- Photo diodes
- Photo resistors.
- photo transistors

Application

- Industrial Process control, Measurement and automation.
- Non industrial
  - ~~Metalic~~ Medical
  - Aircraft
  - Consumer electronics
  - Other Sensor (MISC)
  - Automobiles

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SENSORS Classification Based on property:

	Property				
	Flow	*Level*	*Temperature*	*Pressure*	*Proximity and displacement*
Technology	Differential Pressure, positional displacement, vortex, thermal mass, electromagnetic, Coriolis, ultrasonic, anemometer open channel.	Mechanical, magnetic, differential pressure, thermal displacement, vibrating rod, magnetostrictive, ultrasonic, radio frequency, capacitance type, microwave/radar, nuclear.	Filled-in systems, RTDs, thermistors, IC, thermocouples, inductively coupled, radiation (IR).	Elastic, liquid-based manometers, inductive/LVDT piezoelectric, electronic, fibre optic, MEMS, vacuum.	Potentiometric inductive/LVDT, capacitive, magnetic, photoelectric, magnetostrictive, ultrasonic.

	Property				
	Acceleration	*Image*	*Gas and Chemical*	*Biosensors*	*Other*
Technology	Accelerometers, gyroscopes.	CMOS, CCDs (charge coupled devices).	Chemical bead, electrochemical, thermal conductance, paramagnetic, ionization, infrared, semiconductor.	Electrochemical, light-addressable potentiometric (LAP), surface plasmon resonance (SPR), resonant mirror	Mass, force, load humidity, moisture, viscosity.

SENSORS Classification based on Technology:

Sensors

	Image sensors	Motion detectors	Biosensors	Accelerometers
	Technology CMOS-based	Technology: IR, ultrasonic micrwave/radar	Technology: electrochemcial	Technology MEMS-based
Applications	Traffic and security surveillance, blind-spot detection as autosensors (robots etc.), video conferencing, consumer electronics, biometrics, PC imaging	Obstruction detection (robots, auto), security detection (intrusion), toilet activation, kiosks videograms and simulations, light activation	Water testing, food testing (contamination detection), medical care device, biological warfare agent detection	Vehicle dynamic system (auto) patient monitoring (including pace makers etc.)

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Transducers

Basically transducer is defined as a device, which converts energy or information from one form to another. These are widely used in measurement work because not all quantities that need to be measured can be displayed as easily as others. 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. For example, the common mercury thermometer converts variations in temperature into variations in the length of a column of mercury. Since the variation in the length of the mercury column is rather simple to measure, the mercury thermometer becomes a convenient device for measuring temperature. On the other hand, the actual temperature variation is not as easy to display directly. Another example is manometer, which detects pressure and indicates it directly on a scale calibrated in actual units of pressure.

Thus the transducer is a device, which provides a usable output in response to specific input measurand, which may be physical or mechanical quantity, property or condition. The transducer may be mechanical, electrical, magnetic, optical, chemical, acoustic, thermal nuclear, or a combination of any two or more of these.

Mechanical transducers:

Are simple and rugged in construction, cheaper in cost, accurate and operate without external power supplies but are not advantageous for many of the modern scientific experiments and process control instrumentation owing to their poor frequency response, requirement of large forces to overcome mechanical friction, in compatibility when remote control or indication is required, and a lot of other limitations. All these drawbacks have been overcome with the introduction of electrical transducers.

Electrical Transducers:

Mostly quantities to be measured are non-electrical such as temperature, pressure, displacement, humidity, fluid flow, speed etc., but these quantities cannot be measured directly. Hence such quantities are required to be sensed and changed into some other form for easy measurement.

Electrical quantities such as current, voltage, resistance inductance and capacitance etc. can be conveniently measured, transferred and stored, and therefore, for measurement of non-electrical quantities these are to be converted into electrical quantities first and then measured. The function of converting non-electrical quantity into electrical one is accomplished by a device called the electrical transducer. Basically an electrical transducer is a sensing device by which a physical, mechanical or optical quantity to be measured is transformed directly, with a suitable mechanism, into an electrical signal (current, voltage or frequency). The production of these signals is based upon electrical effects which may be resistive, inductive, capacitive etc in nature. The input versus output energy relationship takes a definite reproducible function. The output to input and the output to time behavior is predictable to a known degree of accuracy, sensitivity and response, within the specified environmental conditions.

Basic Requirements of a Transducer:

The main function of a transducer is to respond only for the measurement under specified limits for which it is designed. It is, therefore, necessary to know the relationship between the input and output quantities and it should be fixed. Transducers should meet the following basic requirements.

1. ***Ruggedness.*** It should be capable of withstanding overload and some safety arrangement should be provided for overload protection.
2. ***Linearity***. Its input-output characteristics should be linear and it should produce these characteristics in symmetrical way.

3. ***Repeatability.*** It should reproduce same output signal when the same input signal is applied again and again under fixed environmental conditions e.g. temperature, pressure, humidity etc.
4. ***High Output Signal Quality.*** The quality of output signal should be good i.e. the ratio of the signal to the noise should be high and the amplitude of the output signal should be enough.
5. ***High Reliability and Stability.*** It should give minimum error in measurement for temperature variations, vibrations and other various changes in surroundings.
6. ***Good Dynamic Response.*** Its output should be faithful to input when taken as a function of time. The effect is analyzed as the frequency response.
7. ***No Hysteretic.*** It should not give any hysteretic during measurement while input signal is varied from its low value to high value and vice-versa.
8. ***Residual Deformation.*** It should be no deformation on removal of local after long period of application.

Selection of Transducers:

In a measurement system the transducer (or a combination of transducers) is the input element with the critical function of transforming some physical quantity to a proportional electrical signal. So selection of an appropriate transducer is most important for having accurate results.

The first step in the selection procedure is to clearly define the nature of quantity under measurement (measurand) and know the range of magnitudes and frequencies that the measurand is expected to exhibit. Next step will be to examine the available transducer principles for measurement of desired quantity.

The type of transducer selected must be compatible with the type and range of the quantity to be measured and the output device.

In case one or more transducer principles are capable of generating a satisfactory signal, decision is to be taken whether to employ a commercially available transducer or build a suitable transducer. If the transducers are available in the market at a suitable price, the choice will probably be to purchase one of them, otherwise own transducer will have to be designed, built and calibrated.

The points to be considered in determining a transducer suitable for a specific measurement are as follows:

1. ***Range.*** The range of the transducer should be large enough to encompass all the expected magnitudes of the measurand.
2. ***Sensitivity.*** The transducer should give a sufficient output signal per unit of measured input in order to yield meaningful data.
3. ***Electrical Output Characteristics.*** The electrical characteristics-the output impedance, the frequency response, and the response time of the transducer output signal should be compatible with the recording device and the rest of the measuring system equipment.
4. ***Physical Environment.*** The transducer selected should be able to withstand the environmental conditions to which it is likely to be subjected while carrying out measurements and tests. Such parameters are temperature, acceleration, shock and vibration, moisture, and corrosive chemicals might damage some transducers but not others.
5. ***Errors.*** The errors inherent in the operation of the transducer itself, or those errors caused by environmental conditions of the measurement, should be small enough or controllable enough that they allow meaningful data to be taken.
   However the total measurement error in a transducer-activated system may be reduced to fall within the required accuracy range by adopting the following techniques.
   1. Calibrating the transducer output against some known standards while in use under actual test conditions. This calibration should be performed regularly as the measurement proceeds.

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2. Continuous monitoring of variations in the environmental conditions of the transducer and correcting the data accordingly.

Controlling the measurement environment artificially in order to reduce possible transducer errors artificial environmental control includes the enclosing of the transducer in a temperature-controlled housing and isolating the device from external shocks and vibrations.

Classification of Transducers:

The transducers may be classified in various ways such as on the basis of electrical principles involved, methods of application, methods of energy conversion used, nature of output signal etc as shown in table (1.1).

1. ***Primary and Secondary Transducers:*** Transducers, on the basis of methods of applications, may be classified into primary and secondary transducers. When the input signal is directly sensed by the transducer and physical phenomenon is converted into the electrical form directly then such a transducer is called the primary transducer.
   For example a thermistor used for the measurement of temperature fall in this category the thermistor senses the temperature directly and causes the change in resistance with the change in temperature.
   When the input signal is sensed first by some detector or sensor and then its output being of some form other than input signals is given as input to a transducer for conversion into electrical form, then such a transducer falls in the category of secondary transducers.
   For example, in case of pressure measurement, bourdon tube is a primary sensor which converts pressure first into displacement, and then the displacement is converted into an output voltage by an LVDT. In this case LVDT is secondary transducer.
2. ***Active and Passive Transducers:*** Transducers, on the basis of methods of energy conversion used, may be classified into active and passive transducers. Self-generating type transducers i.e. the transducers, which develop their output the form of electrical voltage or current without any auxiliary source, are called the active transducers. Such transducers draw energy from the system under measurement. Normal such transducers give very small output and, therefore, use of amplifier becomes essential.
   Transducers, in which electrical parameters i.e. resistance, inductance or capacitance changes with the change in input signal, are called the passive transducers. These transducers require external power source for energy conversion. In such transducer electrical parameters i.e. resistance, inductance or capacitance causes a change in voltages current or frequency of the external power source. These transducers may draw sour energy from the system under measurement. Resistive, inductive and capacitive transducer falls in this category.
3. ***Analog and Digital Transducers:*** Transducers, on the basis of nature of output signal, may be classified into analog and digital transducers. Analog transducer converts input signal into output signal, which is a continuous function of time such as thermistor, strain gauge, LVDT, thermo-couple etc. Digital transducer converts input signal into the output signal of the form of pulse e.g. it gives discrete output. These transducers are becoming more and more popular now-a-days because of advantages associated with digital measuring instruments and also due to the effect that digital signals can be transmitted over a long distance without causing much distortion due to amplitude variation and phase shift.
   Sometimes an analog transducer combined with an ADC (analog-digital convector) is called a digital transducer.
4. ***Transducers and Inverse Transducers:*** Transducer, as already defined, is a device that converts a non-electrical quantity into an electrical quantity. Normally a transducer and associated circuit has a non-electrical input and an electrical output, for example a thermo-couple, photoconductive cell, pressure gauge, strain gauge etc. An inverse transducer is a device that converts an electrical quantity into a non-electrical quantity. It is a precision actuator having an electrical input and a low-power non-electrical output. For examples a

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piezoelectric crystal and transnational and angular moving-coil elements can be employed as inverse transducers. Many data-indicating and recording devices are basically inverse transducers. An ammeter or voltmeter converts electric current into mechanical movement and the characteristics of such an instrument placed at the output of a measuring system are important. A most useful application of inverse transducers is in feedback measuring systems.

Classification of Electrical Transducers

Class	Electrical Parameters	Types of Transducers	Principle of Operation	Typical Applications
Passive Transducers	Resistance	Potentiometer	Variation of resistance in a potentiometer or a bridge circuit due to positioning of a slide contact by an external force.	Pressure, displace ment, position
		Resistance strain gauge	Variation of resistance of a wire or a semi-conductor b y elongation or compression due to externally applied stress.	Force, torque, displacement.
		Pirani gauge or hot-wire meter	Variation of resistance of a heating element by convection cooling of a stream of gas.	Gas flow, gas pressure.
		Resistance thermo-meter or pyrometer	Variation of resistance of pure metal wire with the variation in temperature	Temperature, radiant heat.
		Thermistor	Variation of resistance of certain metal oxides having negative temperature coefficient of resistance with the variation in temperature.	Temperature
		Resistance hygro-meter	Variation of resistance of a conductive strip with moisture content.	Relative humidity.
		Photoconductive cell	Variation of resistance of a cell as a circuit element with incident light.	Photosensitive relay.
Passive Transducers	Inductance	Magnetic circuit breaker	Variation of self or mutual inductance of an ac- excited coil by changes in the magnetic circuit	Pressure, displacement
		Reluctance pick up	Variation of reluctance of the magnetic circuit by changing the position of the iron core of a coil.	Pressure, displacement, vibration position.
		Differential trans-former	Variation of differential voltage of two secondary windings of a transformer by varying the position of the magnetic core by an externally applied force.	Force, pressure, position, displacement
		Eddy current gauge	Variation of coil inductance by the proximity of an eddy current plate	Displacement, thick ness

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		Magnetostriction gauge	Variation of magnetic properties by pressure and stress.	Force, pressure, sound.
	capacitance	Variable capacitance pressure gauge	Variation in capacitance due to variation of distance between two parallel plates by an externally applied force.	Pressure, displacement.
		Capacitor micro - phone	Variation of capacitance between a fixed plate and a movable diaphragm due to sound pressure.	Speech, music, noise.
		Dielectric gauge	Variation in capacitance because of changes in dielectric.	Liquid level, thickness.
Passive Transducers	Voltage and current	Hall effect pickup	Generation of a potential difference across a semiconductor(germanium) plate due to interaction of magnetic flux with an applied current.	Magnetic flux, current.
		Ionization chamber	Induced electron flow by gas ionization due to radioactive radiation.	Particle counting.
		Photoemissive cell	Electron emission due to incident radiation on photoemissive surface	Light and radiations.
		Photomultiplier tube	Secondary electron emission due to incident radiation on photosensitive cathode	Light and radiation, photosensitive relays.
Active Transducers	Voltage and current	Thermocouple and thermopile	Development of an emf across the junction of two dissimilar metals or semi conductors when that junction is heated.	Temperature, heat flow, radiation
		Moving-coil generator	Generation of an emf due to motion of a coil in a magnetic field.	Velocity, vibration
		Piezoelectric pickup	Generation of an emf on applying an external force to a certain crystalline material such as quartz.	Sound, vibration, acceleration, pressure variations.
		Photovoltaic cell	Generation of a voltage in a semi-conductor junction device when radiant energy stimulates the cell	Light meter, solar cell
Digital transducers	Train of pulses	Encoders	Translation of the shaft angular position into a digital number.	Angular position
		Even counting	Conversion of angular and translational motions into train of pulses by using either electromagnetic, capacitive or photo-electric method.	Motion.
		Frequency output	Conversion of analog signals into frequency. For example inductive or capacitive transducers can be incorporated in the tuned resonant circuit of an LC oscillator.	Displacement, force, pressure, vibration

§ Characteristics of Transducers -

while choosing a transducer for any application the input, transfer and output characteristics have to be taken into account.

1 - Input characteristics.
2 - Transfer characteristics
3 - Transducer Response.
4 - output characteristics.

Do yourself

§ Factor affecting the choice of transducers

Followings are the factor influencing the choice of transducer for the measurement of a physical quantity.

1 - operating principle
2 - Sensitivity
3 - operating Range
4 - Accuracy
5 - Cross sensitivity.
6 - Errors
7 - Transient and frequency response.
8 - Loading effect
9 - Environmental compatibility.

§ Measurement of displacement :

Using
- → potentiometer
- → LVDT
- → optical Encoder.

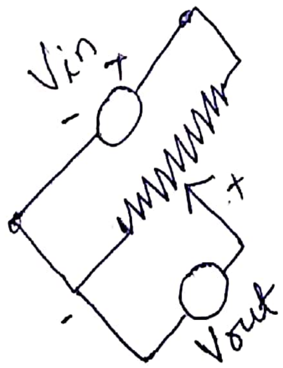
Potentiometer :

✓ A potentiometer is a three-terminal resistor with a sliding or rotating contact that forms an adjustable voltage divider. If only two terminal are used, one end and the wiper, it act as a variable resistor or rheostat.

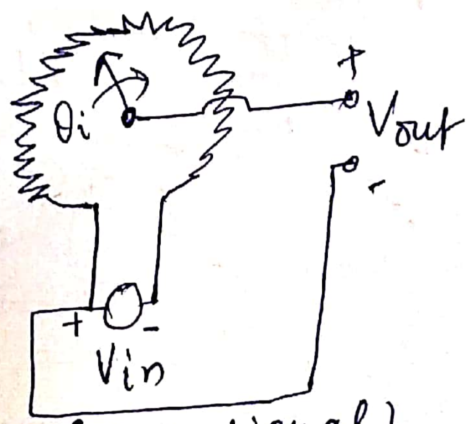
✓ Generally use for Audio control, TV brightness control, Motion control of motor (angle, speed, displacement)

✓ Potentiometers are widely used as a part of displacement transducer.

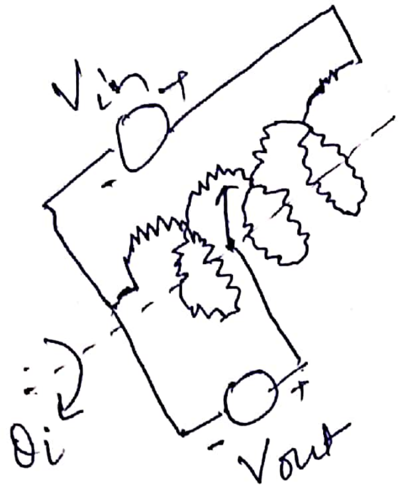
✓ Basically a resistance potentiometer, or simply a POT. (a resistive potentiometer used for the purpose of voltage division called POT).



(linear)

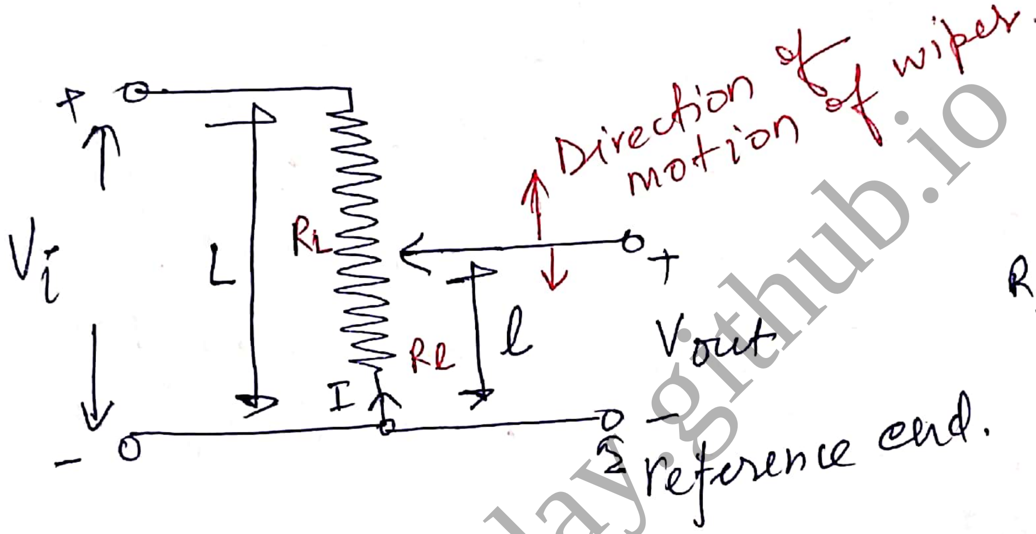


(Rotational)



(Helical)

✓ The POT is passive transducer since it require external power source for its operation.



$$\rho_L = \left(\frac{R}{L}\right)$$

$$R_l = \rho_L \cdot l = \left(\frac{R_L}{L}\right) l$$

$$V_{in} = i R_L \quad \text{—— (I)}$$

$$V_{out} = i R_l \quad \text{—— (II)}$$

$$= i \left(\frac{R_L}{L}\right) l$$

II/I

$$\boxed{\frac{V_{out}}{V_{in}} = l/L}$$

$$\boxed{V_{out} = \left(\frac{l}{L}\right) V_{in}} \quad \text{—— (III)}$$

$$\boxed{V_{out} = V_{in} \left(\theta_i / \theta_t\right)}$$

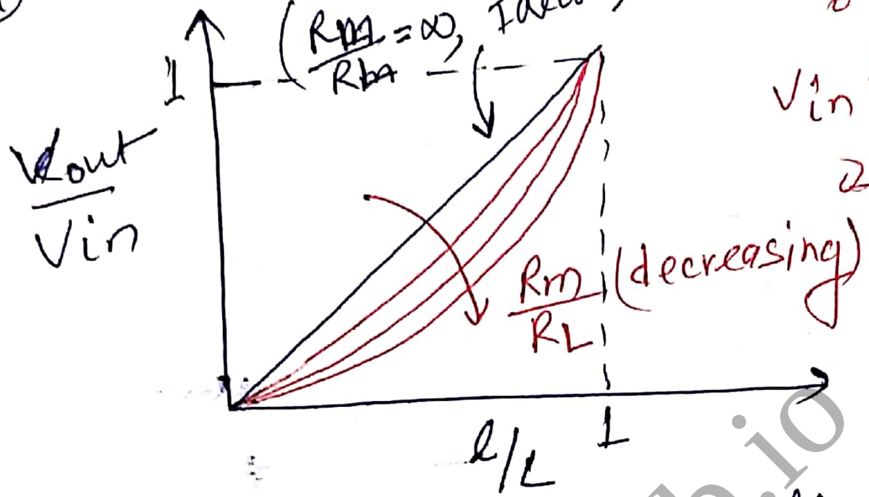
For rotatory

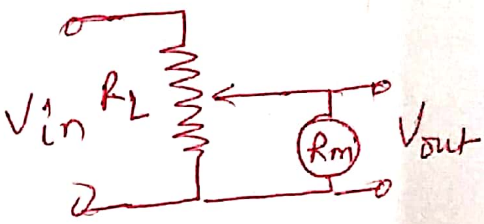
θ_i - input angular displacement (degree)

θ_t - Total travel of the wiper in degree

Characteristics of potentiometer;

Under ideal circumstances, the o/p voltage varies linearly with displacement as shown in fig ⓐ



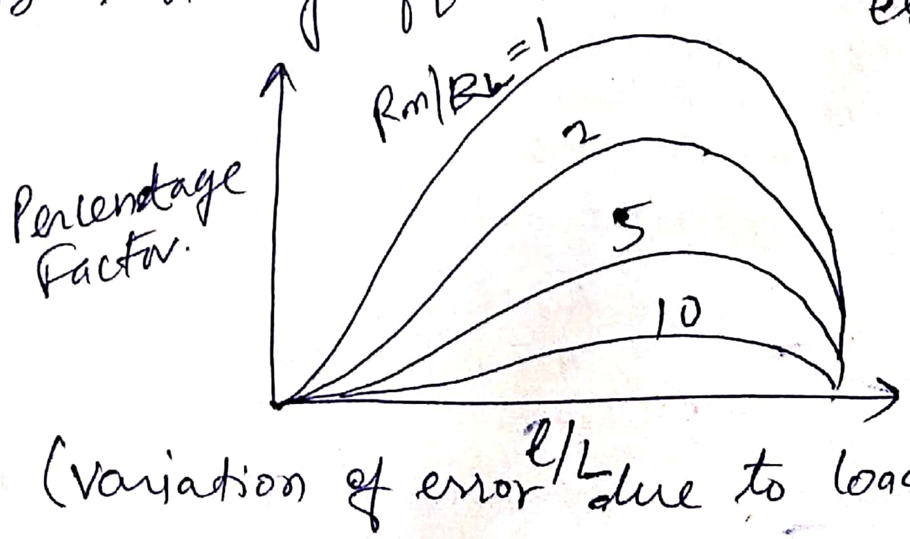


(Characteristics of potentiometer)

✓ In order to keep linearity the value of R_m/R_L should be as large as possible.

✓ The output of the POT are connected to a device whose impedance is finite (in practice) which form a load for the POT. Thus at the o/p indicated voltage is less than that given by $V_{out} = \left(\frac{l}{L}\right) V_{in}$, which is refered as loading effect.

error = (o/p voltage under load) − (o/p voltage under no load)



(Variation of error due to loading effect)

✓ if R_L is made small, linearity improves. and the sensitivity will decrease.

Advantage & disadvantage of potentiometer -

Adv. -

✓ They are inexpensive.
✓ Simple to operate.
✓ Useful for the measurement of large amplitude of displacement.
✓ o/p is sufficient, so no amplification is required.
✓ Having hig resolution.

DisAdv -

✓ Require large force to move their sliding contact.
✓ Contact can be contaminated.

Material Used for potentiometer - May be classified as.

→ 1 - Wire wound potentiometer :-
These are platinum, nickel chromium, nickel coper or some other precious resistance elements { temp coefficient of order $20 \times 10^{-6}/^\circ C$
resolution = 0.025 to 0.05 mm

→ 2 - Non-wire potentiometer :- called continous potentiometer.
Material used for this is :
cement, Hot moulded carbon, carbon film, Thin metal film,

Note - cement is very useful for A.C. Applications

LVDT (Linear Variable Differential Transformer)

This is an inductive motion transducers are replacing potentiometers as they have superior reliability. Two important inductive motion transducers are
- LVDT (Linear Variable differential Transducers)
- RVDT (Rotatory Variable differential Transducers)

Principle of operation

Variable inductance transducers are based on Faraday's law of Induction in a coil. The law specifies that the induced voltage is equal to the rate at which the magnetic flux through the ckt. changes.

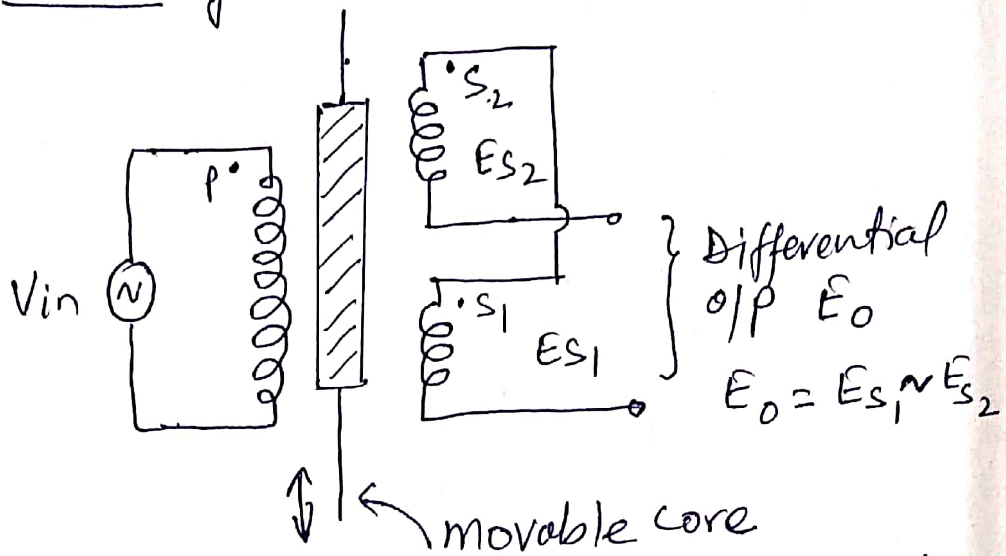
The induced voltage is given by $V = N\frac{d\phi}{dt}$.

$\phi = B \cdot A$, B is magnetic field
A is area of coil.

Application

- LVDT are mostly used transducer to translate linear displacement into electrical signal.
- LVDT find a number of application in both measurement & control systems.
- High resolution, High accuracy, Good reliability, and stability make them an ideal device for application involving short displacement measurement.

Construction & working -



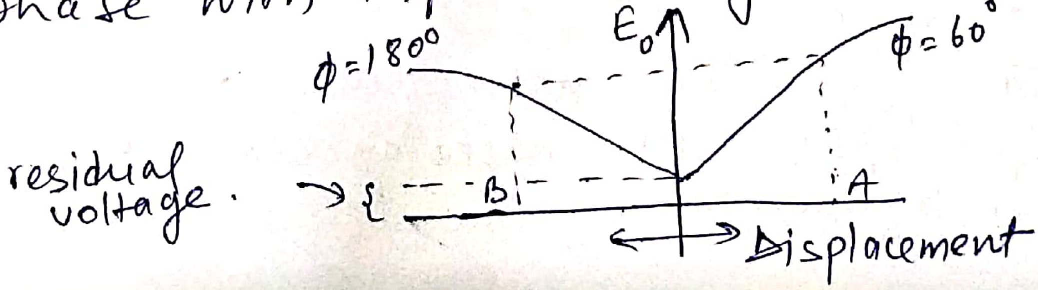
{ S_1 & S_2 are secondary winding connected in series.
P - Primary ~~Winding~~ winding.

Position of movable core determine the flux linkage between the primary and each of two secondary windings.

Let E_{s1} = output of secondary S_1
E_{s2} = ouput of secondary S_2

then, $\boxed{E_0 = E_{s_1} - E_{s_2}}$

✓ In bothe the direction we will get differential voltage but in one direction it will be in phase to input voltage and in other direction it will be out of phase with input voltage.



✓ Linear range = 2 × Full Scale deflection

slope of the curve = $\frac{|E_0|}{\text{core displacement from centre}}$.

$$m = \frac{|V_0|}{x}$$

LVDT equation is characterised by $|V_0| = mx$

✓ Sensitivity of LVDT = $\frac{\text{output voltage}}{\text{Displacement}}$.

✓ Sensitivity of measurement
= Amplification factor × sensitivity of LVDT.

Advantage:

1- High range (1.25 mm to 250 mm)
2- Give high o/p (mostly no need of amplifire)
3- Posses high sensitivity (up to 40 V/mm)
4. Repeatability is excellence (because low hysterisis)
5. Consume less power (less than 1 W)
6. Less friction, so less noise (absence of sliding contact)
7. Tolerate high degree of sock & Vibration.
8. ~~Cap~~ Can operate at −265 °C to 600 °C

Disadvantage:

1- Sensitive to stray magnetic field.
2- Displacement must be large for appreciable o/p.
3- Dynamic response is limitted ~~to~~ due to mass of core.

Optical Encoder :—

- Encoder
  - Linear
    - Absolute
    - Increamental
  - Rotatory
    - Absolute
    - Increamental

Technology
- Magnetic
- Optical
- Inductive
- Capacitive
- Laser.

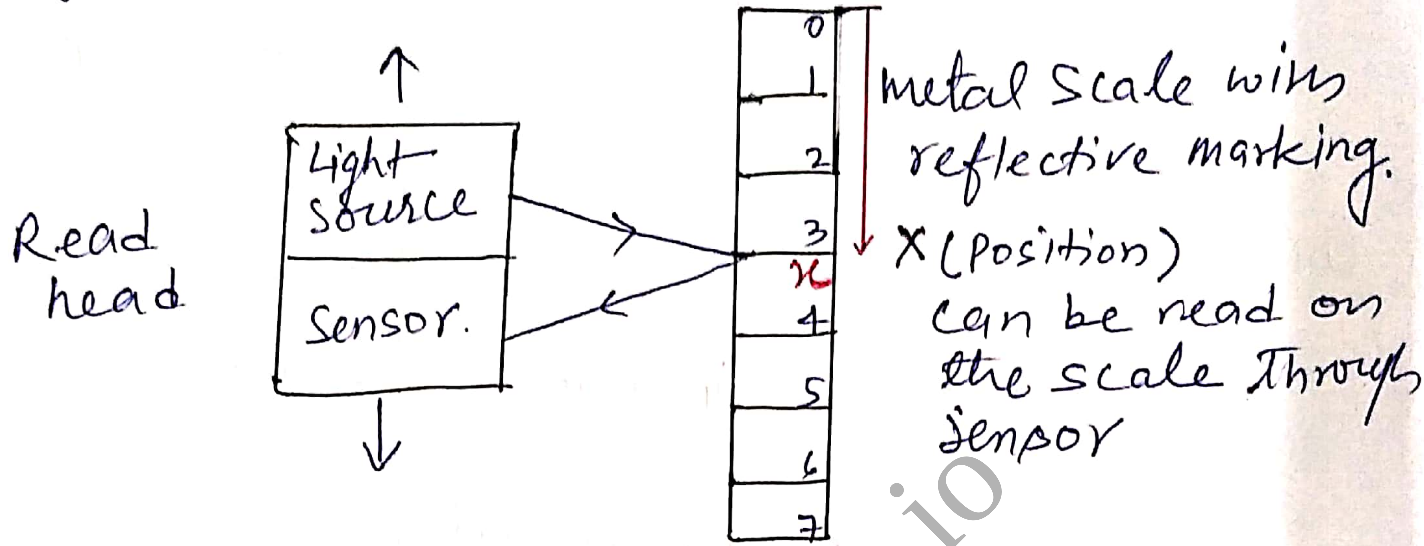
Encoder provides an information about the position information.

→ An Absolute Encoder provides specific location information

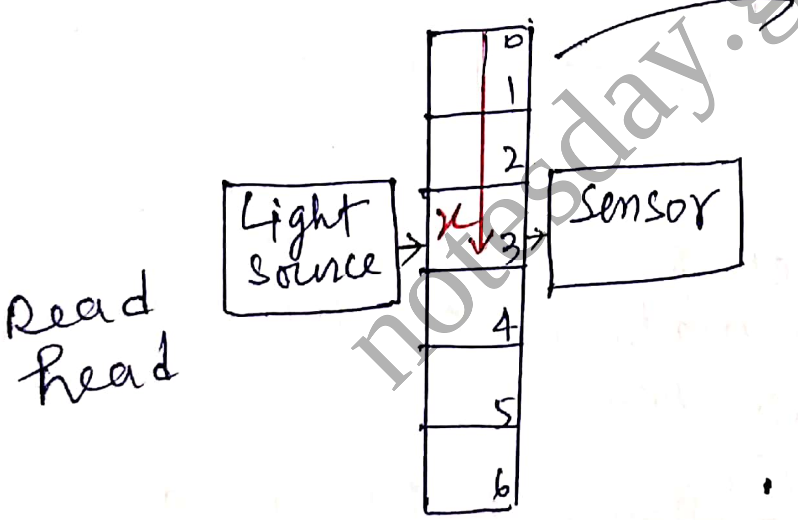
→ Increamental Encoder provide distance travelled and direction information. Machine needs to be referenced or homed.

. Optical encoder is composed of the "read head" and the scale.
. The read head travel with the axis while the scale is stationary (In case linear encoder)
The scale can be made of either glass or metal.
In the encoder to the left, the metal scale has reflective marking.

The light from the source in the read head, reflects on the marking and are picked up by the sensor.



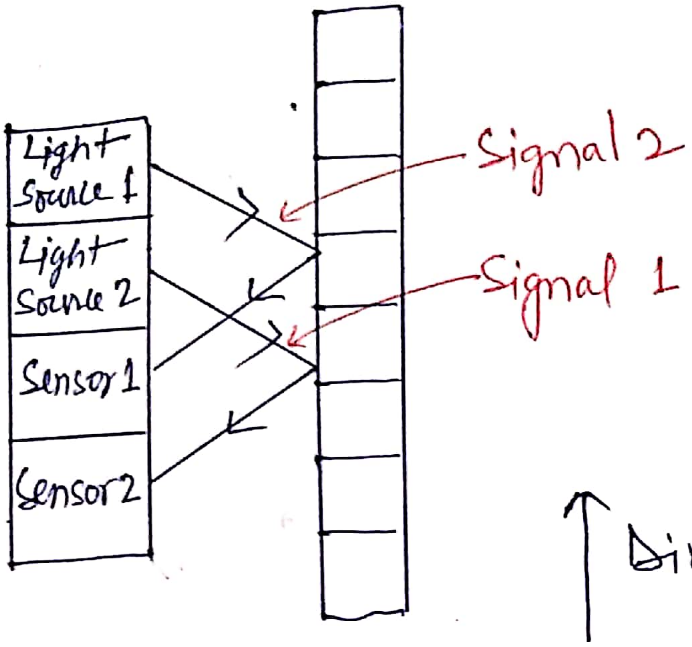
<u>Note</u> In similar way Glass scale can be used.

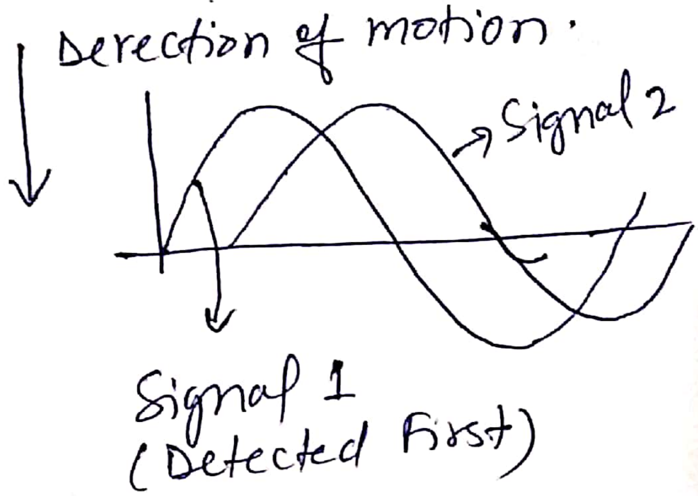


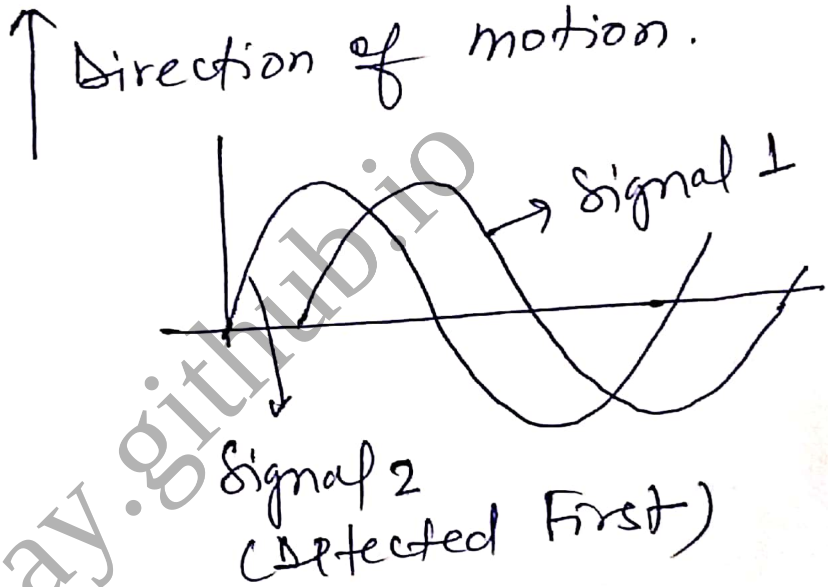
- Glass scale
- A read head travels, light passes through the glass to the sensor. some area are blackend to prevent the light
- x (position) can be read on the scale through sensor.

(Linear optical & absolute encoder)

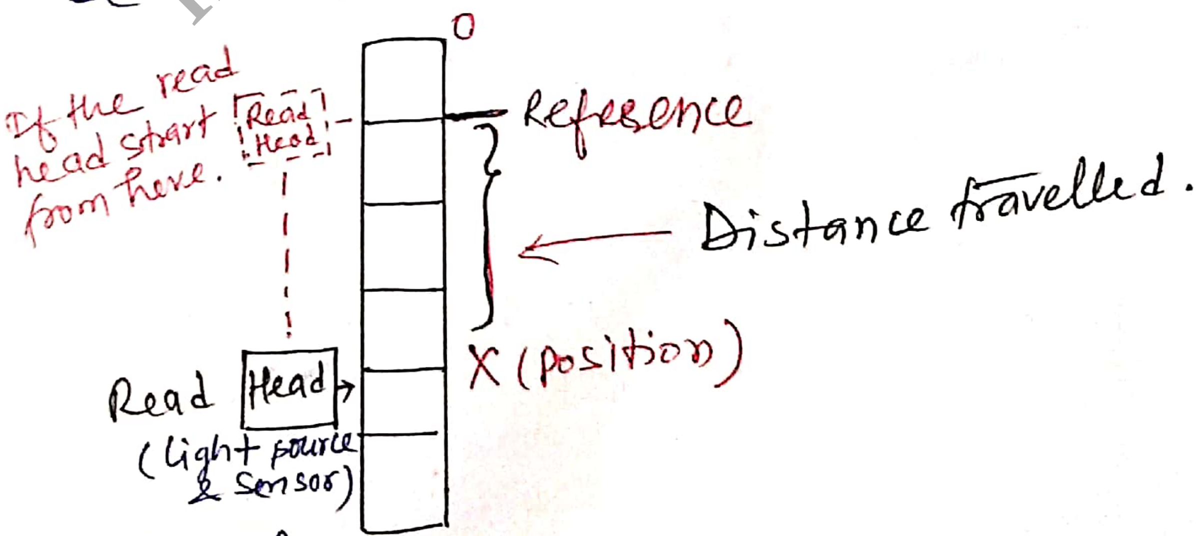
<u>Note</u> An additional light source and sensor can be added to determine the direction.







Note: For the increamental encoder we have to assume the refrence point (It may be home)



(optical Linear & increamental Encoder)

optical rotatory encoder.

§ Measurement of Force Using strain gauge.

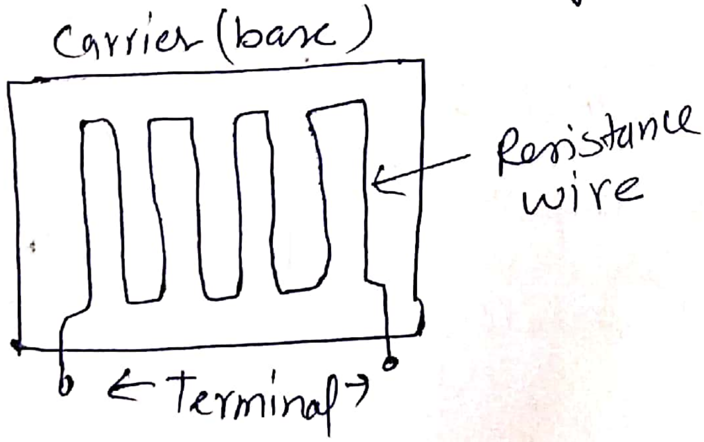
Strain Gauge:

When a metal conductor is streched or compressed, its resistance changes on account of the fact that both length and diameter of the conductor change. The value of resistivity of conductor also changes.
When it is strained its property is called piezo-resistance. Therefore, resistance strain gauge are also known as piezo-resitive gauses.

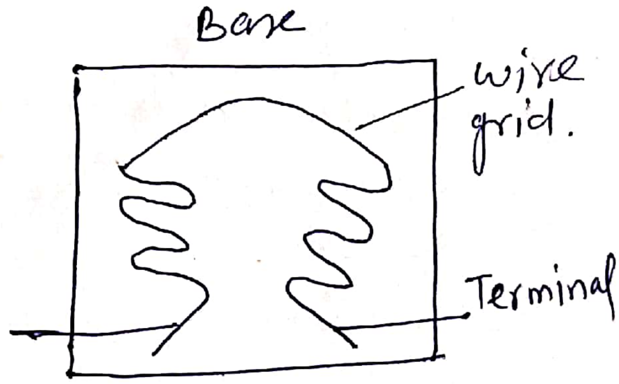
Type of strain Gauge -

1 — Wire-wound strain gauge < Bonded / Unbonded.
2 — Foil type strain gauge
3 — Semiconductor strain gauge
4 — Capacitive strain gauge.

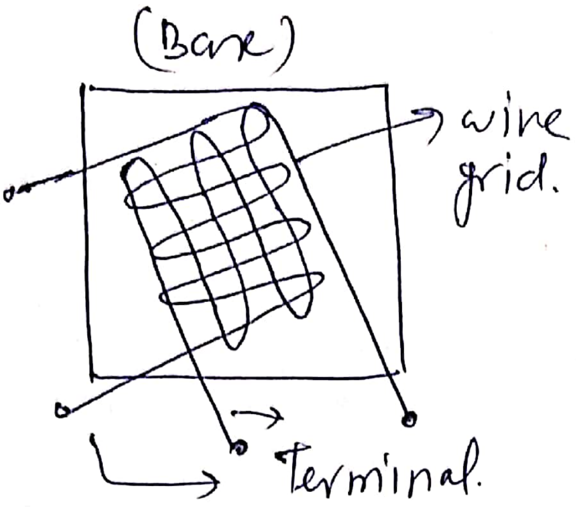
(1) Note — Wire Strain Gauge —
Bonded strain gauge, wire wound and cemented or a resilient insulating support, usually a wafer unit.



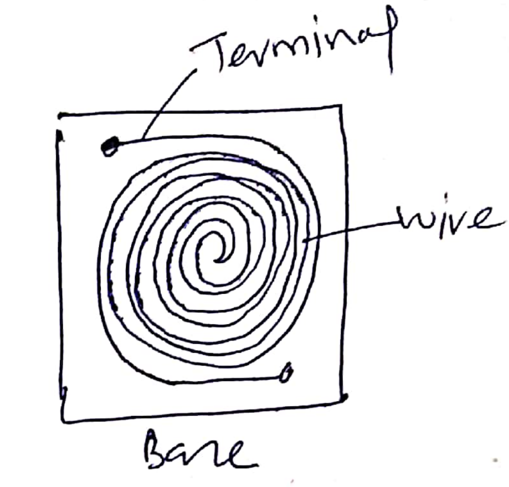
(Linear Strain Gauge)
(a)



(Torque Gauge)
(b)



(Ressetter) (C)

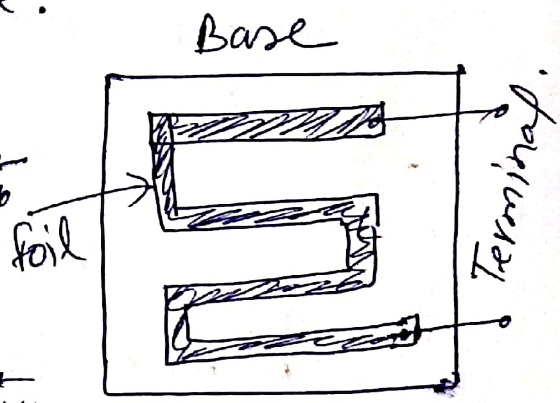


(Helical Gauge) (d).

(Resistance wire Strain Gauge)

② Foil Strain gauge.

In these gauges the strain is sensed with the help of metal foil. Foil gauge have a much greater dissipation capacity as compared with wire wound gauge on account of their greater surface area for the same volume. Due to this reason they can be employed for higher operating temperature range.



Advantage.

- excellent strain reproducibility
- low hysteresis and creep effect.
- Excellent mechanical stability.
- longer life
- Fabrication is easy.

Use: stress analysis & transducers.

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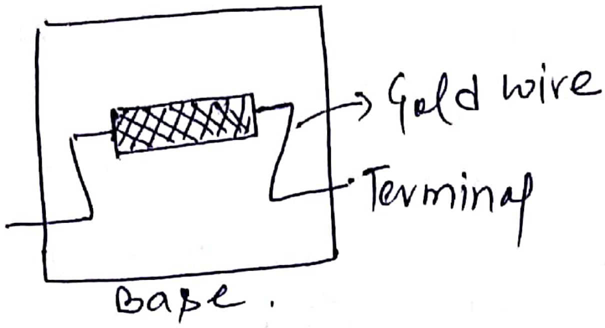
(3) Semiconductor strain Gauge -



(Semiconductor strain Gauge)

The resistance of semiconductors changes with change in applied strain. The semiconductor strain gauge depend on their action upon piezo-resistive effect ie change in the value of the resistance due to change in resistivity.

*(Unlike in the case of metallic gauge where the change in resistance is mainly due to change in dimensions (L, and A) when strained).

Advantage:

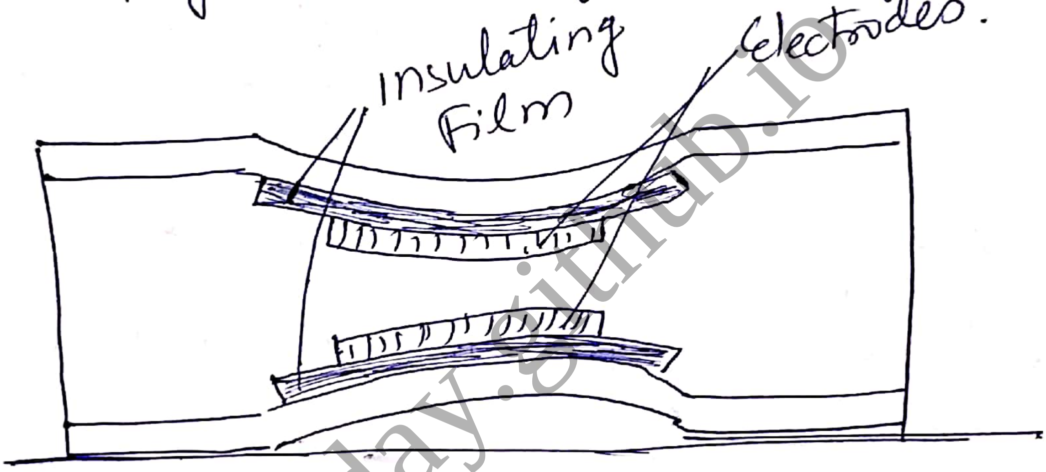
- ✓ Having high gauge factor
- ✓ They are chemically inert and have low cross-sensitivity.
- ✓ Almost free from hysterisis & creep effect.
- ✓ Fatigue life is in excess (10×10^5 operation)
- ✓ Range is small (0.7 to 7 mm) and used for local strains.

Disadvantage:-

- ✓ very sensitive to change in temperature.
- ✓ linearity is poor.

(4) Capacitive strain gauge:-

- Use the principle of variation of capacitance with variation in distance between electrodes. The electrodes are flexible metal strips of about 0.1 mm thickness. The strain to be measure is applied to top plate. This changes the distance between curved electrodes resulting in change of capacitance.
- Use a polyamide film of insulating material electrodes.



(Capacitive Strain Gauge)

Application of strain Gauge -

* Amount of stress on plane wings, bridge, railway track etc can be measure to take preventive action.

Property of Gauge Material:

High sensitivity, High gauge factor, high mechanical strength, High electrical stability, Low temperature sensitivity, low hysterisis, low thermal emf when joined with other material.

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Theory of Strain Gauge:

✓ when a strain gauge is subjected to tension (ie +ve strain) its length increases while its ~~length and~~ crossectional area decreases.

$$\boxed{R = \rho L/A} \quad -(I)$$

R changes when → { if L changes & A changes.
if ρ change then R will also change this property is known as piezoresistive effect.

✓ Strain gauge are most commonly used in wheatstone bridge circuit to measure the change in resistance of grid of wire.

Gauge factor = $\dfrac{\text{Per unit change in resistance}}{\text{Per unit change in length.}}$

$$\boxed{G_f = \frac{\Delta R/R}{\Delta L/L}} \quad -(II)$$

ΔR - Change in resistance
ΔL - change in length.

In order to find ΔR, depends upon the material physical quantity.
differentiate wrt stress(s)

$$\frac{dR}{ds} = \frac{\rho}{A}\frac{\partial L}{\partial s} - \frac{\rho L}{A^2}\frac{\partial A}{\partial s} + \frac{L}{A}\frac{\partial \rho}{\partial s} \quad (II)$$

Divide the eqn (III) by $R = \rho L/A$,

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

$$A = \frac{\pi}{4}D^2, \quad \frac{\partial A}{\partial s} = 2\frac{\pi}{4}\cdot D\frac{\partial D}{\partial s} \quad \text{—— (V)}$$

$$\Rightarrow \frac{1}{A}\frac{\partial A}{\partial s} = \frac{(2\pi/4)D}{(\pi/4)D^2}\frac{\partial D}{\partial s} = \frac{2}{D}\frac{\partial D}{\partial s} \quad \text{—— (VI)}$$

eqn (IV) can be written as:

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

Now

Poissons ratio $\nu = \dfrac{\text{lateral strain}}{\text{Longitudinal strain}} = \dfrac{\partial D/D}{\partial L/L}$ —— (VIII)

or, $$\frac{\partial D}{D} = -\nu\frac{\partial L}{L}$$

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

For small variations, the above relationship can be written as,

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

We know, $$G_f = \frac{(\Delta R/R)}{(\Delta L/L)}$$

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

$$\boxed{G_f = 1 + 2\nu + \frac{\Delta\rho/\rho}{\epsilon}} \quad -(xi)$$

where, ϵ = strain = $\frac{\Delta L}{L}$

$$G_f = \underbrace{1}_{\text{Resistance change due to change of length.}} + \underbrace{2\nu}_{\text{Resistance change due to change in area}} + \underbrace{\frac{\Delta\rho/\rho}{\epsilon}}_{\text{Resistan change due to piezo-resistive effect.}}$$

$$\boxed{G_f = 1 + 2\nu}$$

Valid only when change in resistance due to change in resistivity is negligible i.e Piezoresistive effect is negligible.

—o—

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Measurement of pressure

Using
- → Piezoelectric sensor
- → LVDT based diaphragm.

Piezoelectric Sensor :

"A piezoelectric material" is one in which an electric potential appears across certain surface of a crystal if the dimension of the crystal changed by the application of mechanical force.

This potential is produced by displacement of external charges. The effect is reversible, i.e., conversely, if a varying potential is applied to the proper axis of the crystal, it will change the dimensions of the crystal thereby deforming it. This effect is known as piezoelectric effect.

Some time it is also called electroresistive element.

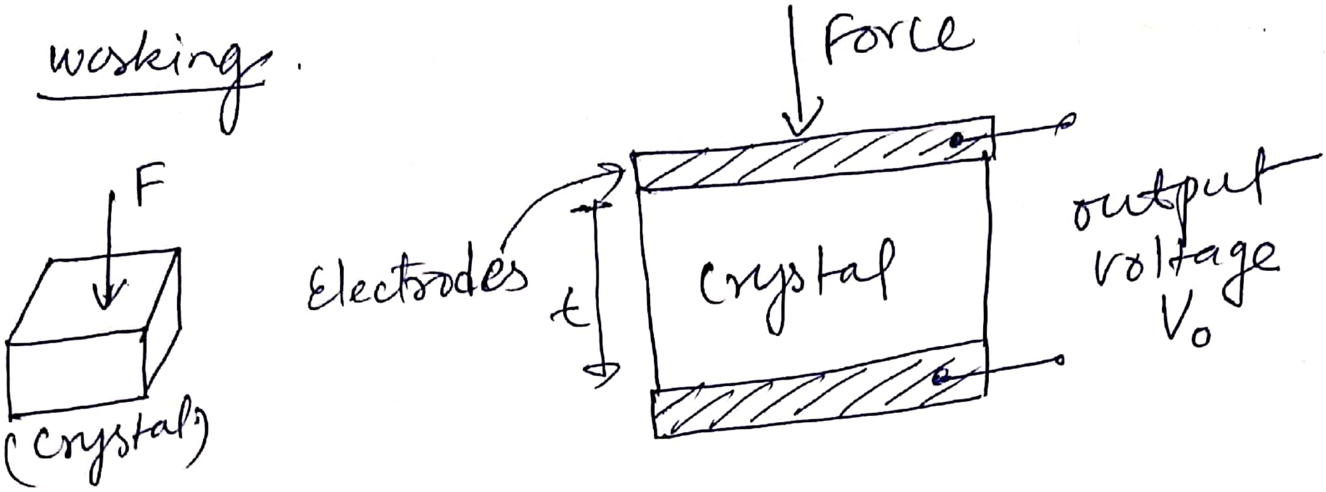
There are two main group of piezoelectric crystal:

1- Natural Crystal: eg. quartz & tourmaline

2- Synthetic Crystals: eg. Rochelle salt, Lithium sulphate, dipotassium tartrate etc.

Desirable property are
Sensitivity, stability, High output, insensitivity to temp and humidity, ability to form into most desirable shape.

working.



The polarity of induced charge will depends on the direction of applied Force

$$Q = d \times F \quad — (I)$$

F ← applied Force
d ← charge sensitivity

$$g = \frac{V_o}{tP} = \frac{V_o/t}{P} \quad — (II)$$

g ← voltage sensitivity of crystal

but V_o/t = Electric fied strength; V/m.

Let $\epsilon = V_o/t$ = Electric field.

$$\therefore \boxed{g = \frac{\text{Electric field}}{\text{Stress}} = \frac{\epsilon}{P}} \quad \text{Vm/N.}$$

$$\boxed{V_o = \frac{gtF}{A} = gtP}$$

F = Force in Newton.
A = Area of crystal, m^2
P = F/A, N/m^2.

Advantage:

✓ High frequency, small size, High output, rugged construction, Negligible phase shift.

Disadvantage:

✓ temperature affect.
✓ can not measure static condition.

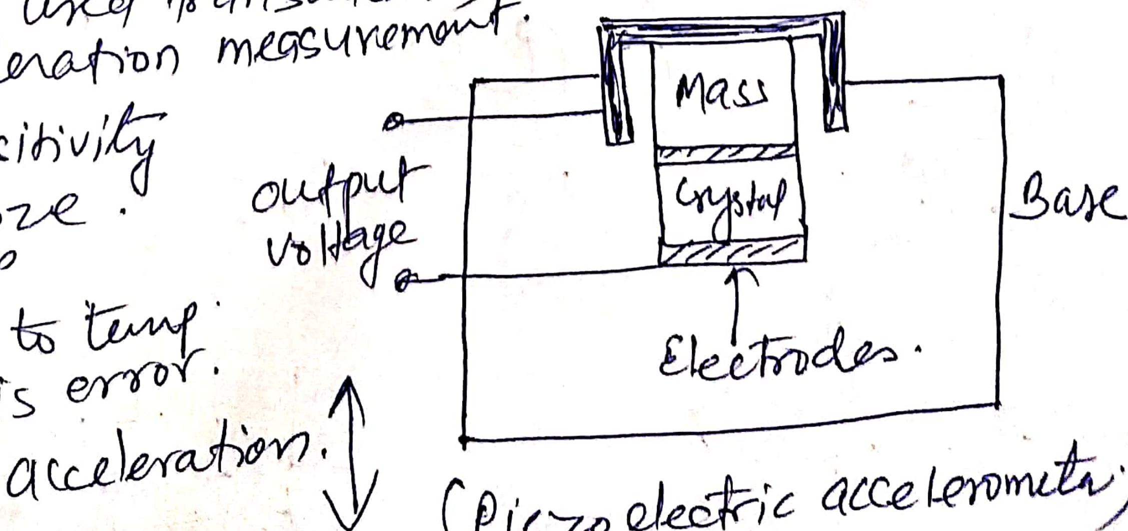
Application:

1- Accelerometer
2- Pressure cell
3- Force cell
4- ceramic microphones
5- phonograph pick-up
6- Cartridges
7- Industrial cleanging apparatus.
8- Under water detection systems

Piezoelectric Accelerometer -

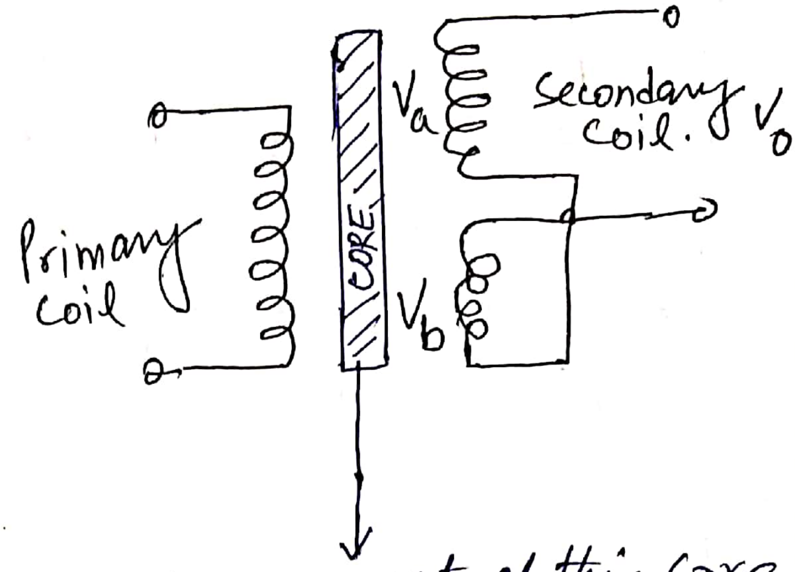
commonly used transducers for acceleration measurement.

- High sensitivity
- small size.
- High o/p
- Sensitive to temp.
- Hysterisis error.



(Piezoelectric accelerometer)

Pressure using LVDT based on diaphragm



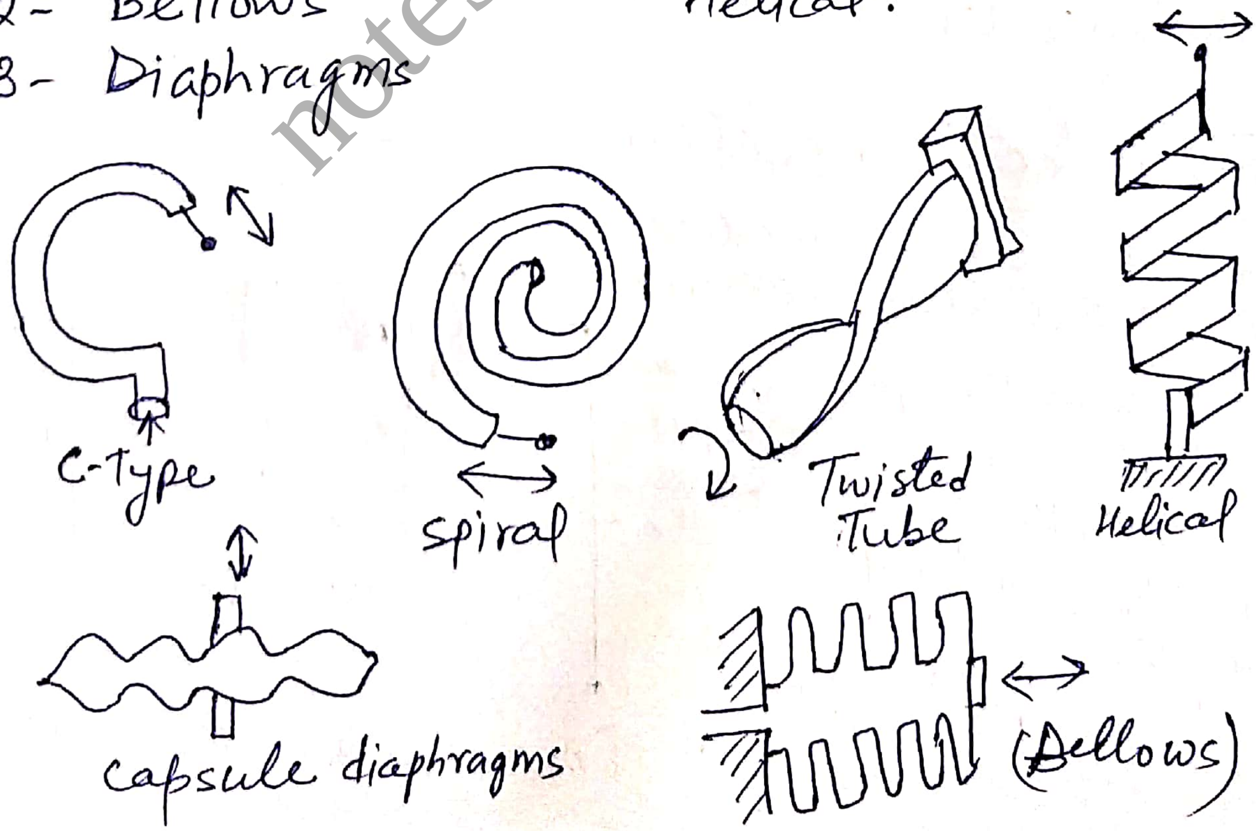
* The fluid whose pressure is to be measured is made to press the pressure sensitive device

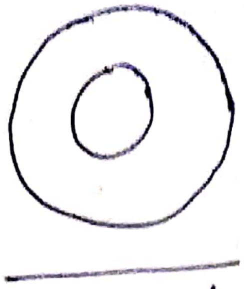
Movement of this core can be done using primary pressure sensitive devices.

Pressure sensitive primary device:

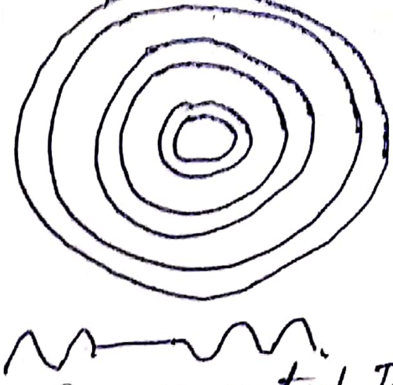
The commonly used pressure sensitive devices are as below:

1- Bourdon tubes
   - C type
   - spiral
   - Twisted tube
   - Helical.
2- Bellows
3- Diaphragms





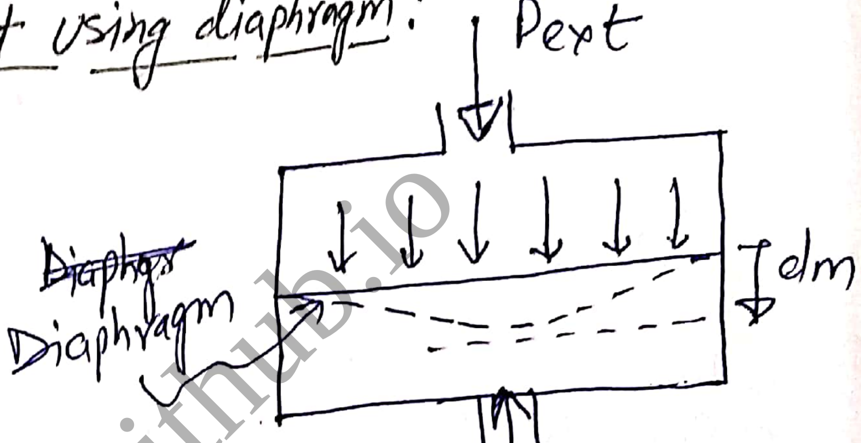
Flat type Diaphragm



Corrugated Type diaphgram

(Diaphragm)

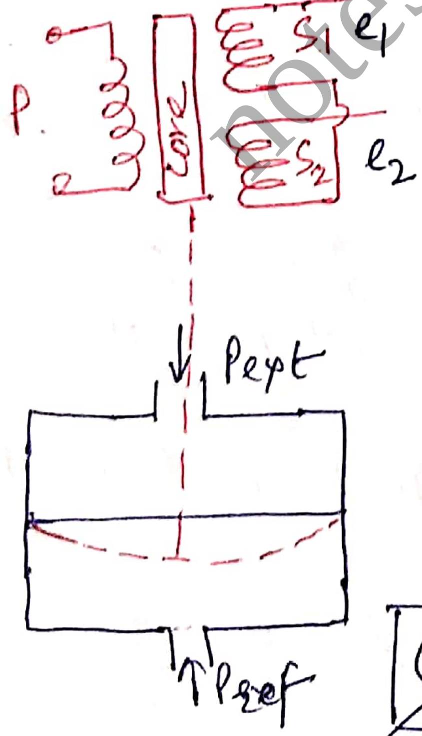
Pressure measurement using diaphragm:



$P_{ext} - P_{ref} = P$

$\boxed{P \propto dm}$

Pressure (P) $\propto$ dm (deflection of diaphragm)

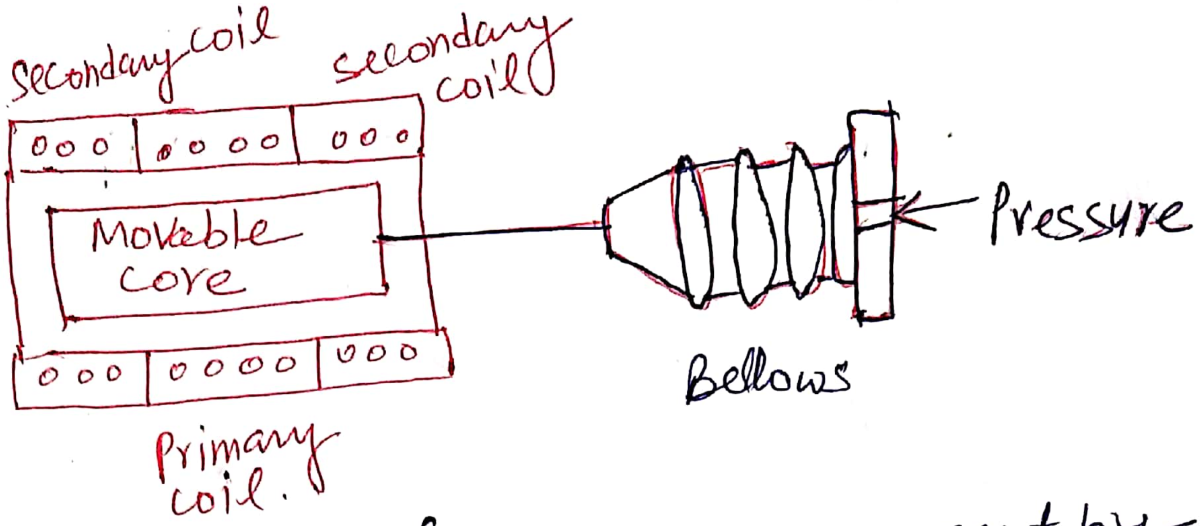


Deflection of diaphragm can be detected by:

- Using LVDT
- Using strain gauge
- Mechanically coupled indicating needle.
- Other velocity or displacement sensor.

$$\boxed{(e_2 \sim e_1) \propto P(P_{ext} - P_{ref}) \propto dm.}$$

Potential difference Pressure displacement



(LVDT) (Pressure measurement by LVDT using bellow as Primary sensing element)

Advantage:

- ✓ It gives high output (no need of Amp^r.)
- ✓ Sensitivity is high
- ✓ shows low hysterisis
- ✓ Repeatability is excellent
- ✓ Consume power less than 1 W.
- ✓ Less friction, less noise
- ✓ Tolerate high degree of sock.
- ✓ operate over −265°c to 600°c range

Disadvantage:

- ✓ Sensitive to stray magnetic field
- ✓ Relatively large displacement is required
- ✓ Affected by vibrations.
- ✓ Dynamic response is limitted due to core mass.

Application:

- ✓ Measurement of material thickness
- ✓ In accelerometer.
- ✓ Jet engine control.