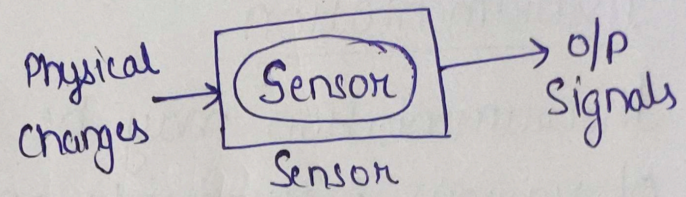
Sensors and Transducer

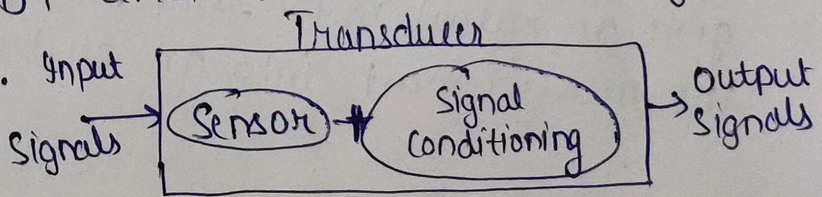


Definition

Sensor - A sensor is a device that detects and responds to some type of input from the physical environment. The specific input could be light, heat, motion, moisture, pressure or any one of a great number of other environmental phenomena. The o/p is generally a signal that is converted to human readable display at the sensor location or transmitted electronically over a network for reading or further processing.

Examples - Motion sensors in various system including home security lights, automatic doors and bathroom fixtures typically sendout some type of energy such as microwaves, ultrasonic waves or light beams and detect when the flow of energy is interrupted by something entering its path.

Transducer - A transducer is an electronic device (physical to electrical signal) that converts energy from one form to another. Common examples include microphones, loudspeakers, thermometers, position and pressure, sensors and antenna. Although not generally thought of as transducer, photocells, LED's and some common light bulbs are transducer.



Classification of Sensors

Classification ; Based on

1. Transduction Principle – Resistive, Inductive, capacitive etc.

2. Quantity based – Temperature, pressure, flow etc.

3. Material & Technology -

   Materials – Metal, optical, electromagnetic etc.

   Technology – Differential pressure, ultrasonic, displacement, optics etc.

4. Application -

   Industrial – Industries & process control

   Non-Industrial – Automobiles, medical, aircraft etc.

5. Primary Input Quantity -

   Active & passive sensors

Others :-

(i) Primary & secondary

(ii) Active & passive

(iii) Electrical & mechanical

Instrumentation

Instrumentation may be defined as an assembly of various instruments and other components interconnected to measure, analyze and control physical quantities in a process.

The basic purpose of instrumentation in any process is to obtain the required information that leads to beneficial completion of the process. The meaning of beneficial completion, in industrial terminology is maximum process efficiency with minimum cost of production and desired level of product quality.

Connect } sensing part

Compare } measure part

Calibrate → transduction part

Difference b/w Sensor and Transducer

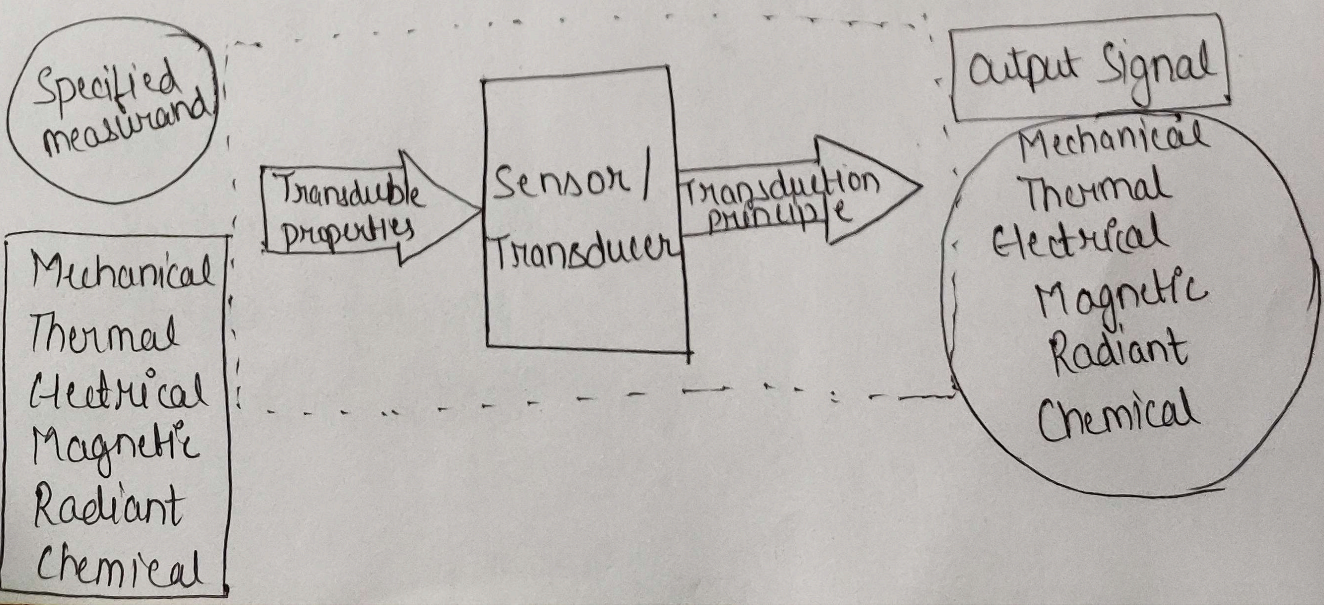
* The main difference b/w a sensor and a transducer is the output signal. Both a ~~signal~~ sensor and a transducer are used to sense a change within the environment they are surrounded by or an object they are attached to, but a sensor will give an output in the same format and a transducer will convert the measurment into an electrical signals.

Principle of Sensor

Principle of Transducer

An element that senses a variation in input energy
to produce a variation in another or same form
of energy is called a sensor whereas a transd-
ucer uses transduction principle to convert a spe-
cified measured into usable output. Thus a prope-
rly cut piezoelectric crystal can be called a sensor
whereas it becomes a transducer with appropriate
electrodes and input/output mechanisms attached
to it.
In general, however, the sensing principles are
physical or chemical in nature and the associated
gadgets are only secondary and hence, the disti-
nction is gradually being ignored. The principles
can be grouped according to the form of energy
in which the signals are recieved and generated.

Sensors: definition & principles



Physical Principles: Examples

* **Ampere's Law** - A current carrying conductor in a magnetic field experiences a force (eg. galvanometer)

* **Curie-weiss Law** - There is a transition temperature at which ferromagnetic materials exhibit paramagnetic behavior

* **Faraday's Law of Induction** - A coil resist a change in magnetic field by generating an opposing voltage/current (eg. transformer)

* **Photoconductive Effect** - when light strikes certain semiconductor materials, the resistance of the material decreases.

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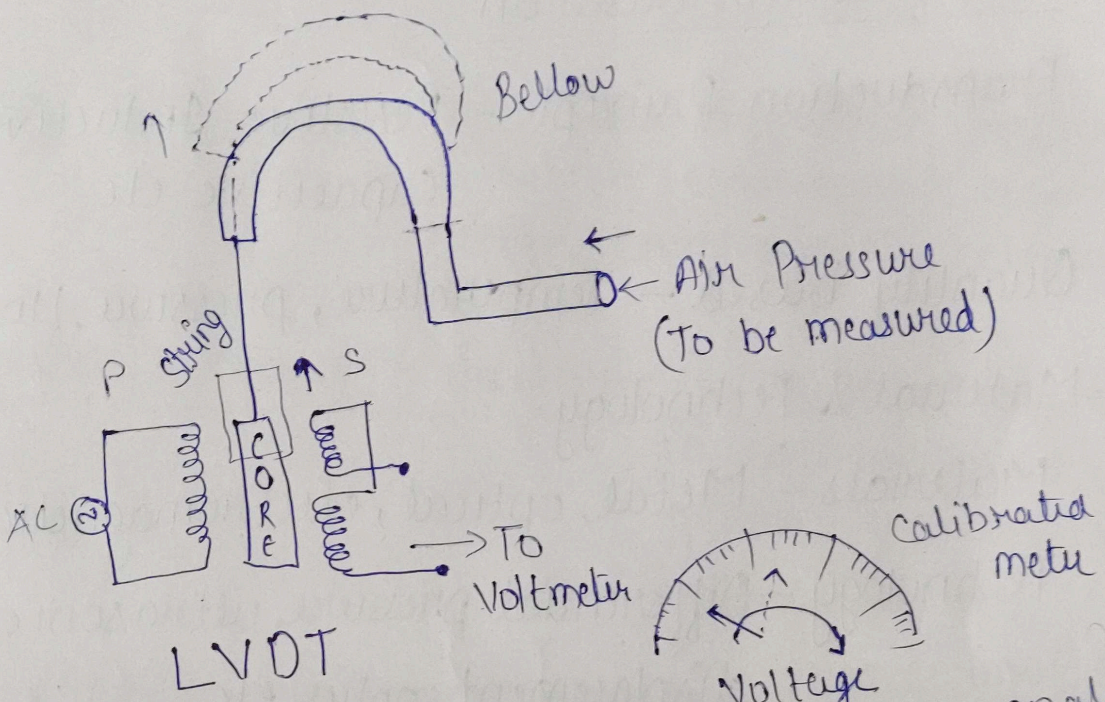
(i) Primary & secondary
(ii) Active & passive
(iii) Electrical & mechanical

(iv) Analog & Digital

(v) Tranducers & increase transducers



use of core

No leakage

analog form

Simple Air Pressure Monitoring

Tempe

Pressure

Displacement

Topic 1

Selection of Sensors

Static Characteristics — The set of criteria defined for the instruments, which are used to measure the quantities which are slowly varying with time or mostly constant i.e do not vary with time

(a) Accuracy - Degree of closeness with which an instruments reading approaches the true value of the quantity being measured.

$$A = \frac{X_m - X_T}{X_m} \times 100$$

Here,

T stand for true value

m for measured value

n stands for measurand.

(b) Precision - It is a measure of reproducibility of the measurement.

$$P = |X_T - X_{Avg}|$$

$$P = |X_m - X_A|$$

X_A = average of all reading

(c) Resolution - Defined as the smallest incremental change in the input that would produce a detectable change in the outbut. This is often expressed as percentage of the measured range, MR. The measured range is defined as the difference of the maximum input & min. input, that is

$$MR = x_{max} - x_{min}$$

For a detectable output Δf, if the min. change in x is (Δx) min, then the maximum resolution is

$$R_{max}(\%) = \frac{100 (\Delta x)_{min}}{MR}$$

Over the range of operation, an average resolution has also been defined as

$$R_{av}(\%) = 100 \frac{\sum_{1}^{n} \Delta x_i}{n \cdot MR}$$

(d) Minimum Detectable Signal (MDS) - Determine by main characteristics.

(e) Threshold - At zero value condition of measured, the smallest input changes that produces detectable output.

(f) Sensitivity - Ratio of incremental output to incremental input.

$$S = \frac{\Delta y}{\Delta x} \begin{matrix} \rightarrow \text{change in output} \\ \text{change in input} \end{matrix}$$

(g) Selectivity & Specificity - Affected by some parameter (environmental etc)

(h) Linearity - Propotionality between input & output.

(i) Range It is the difference between the maximum and minimum value that can be measured by the instrument

$$Range = \boxed{X_{max} - X_{min}}$$

Dynamic Characterstics

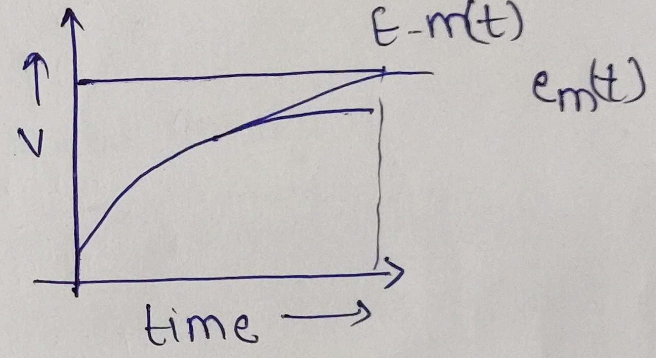
The set of criteria defind for the instruments, which are changes rapidly with time

(a) Fidelity (dynamic error) - Dynamic error occurs when the input quantity is varying with time. This is an account of the fact the systems conteins energy storage elements and due to this, the output con not follow the input exactly but with a time lay.

$$e_{ss} = Em(t)\left(1 - e^{t/RC}\right)$$

steady state error / dynamic error

RC - time constant



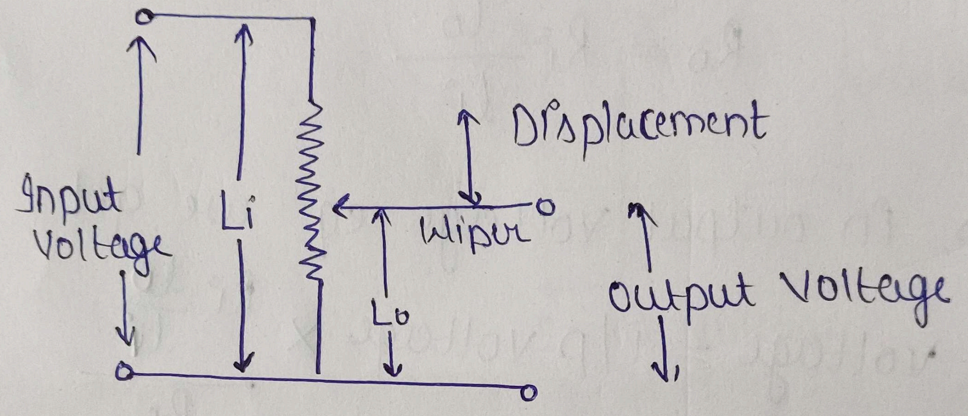
(b) Speed of Response - Response of changes in input to the change in output with respect to time.

eg - Impulse response & transforms

Measurement of displacement using Potentiometer - Linear

Potentiometer comes under resistive transducer. Potentiometer are passive transducer. The potentiometer converts linear or angular displacement in to voltage.

Linear



The linear or translation Pot has a starks of 2mm to 0.5m.

The wiper displacement is proportional to the displacement.

In case of linear POT the total span for input side is spread over length l_i. The wiper slides up or down depending upon the linear displacement. Suppose it slides over a distance of l_o. Thus

$$\frac{\text{output Voltage}}{\text{Input Voltage}} = \frac{l_o}{l_i} = \frac{R_o}{R_i}$$

$\therefore$ output voltage = (Input voltage) $\times \frac{l_o}{l_i}$

or output voltage = (input voltage) $\times \frac{R_o}{R_i}$

Let R_i is resistance of the POT at input side

$\therefore R_i \propto l_i$

Let R_o is resistance of POT at output side

$$R_o = R_i \frac{l_o}{l_i}$$

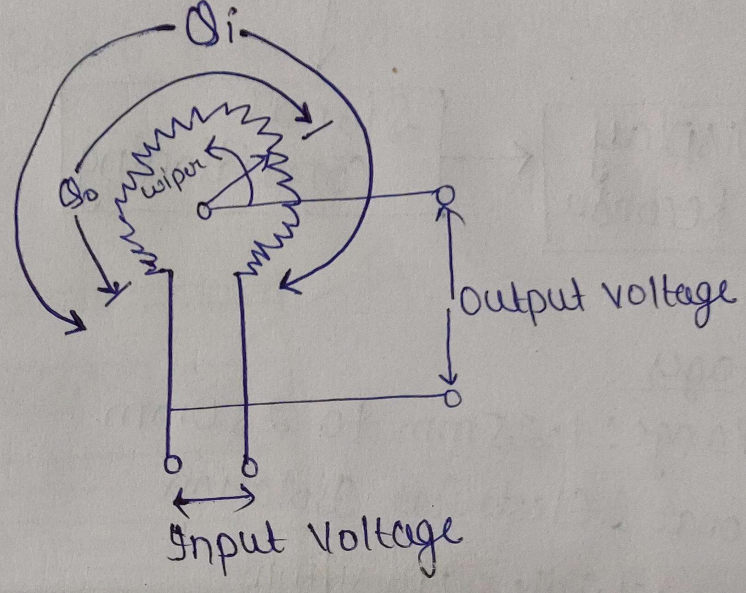
Put this, in output voltage eq^n we get -

$$\text{o/p voltage} = \text{i/p voltage} \times \frac{R_i \frac{l_o}{l_i}}{R_i}$$

$$\times \text{ o/p voltage} = \text{i/p voltage} \times \frac{l_o}{l_i}$$

Measurement of displacement using Potentiometer- Angular

Rotation POT =>



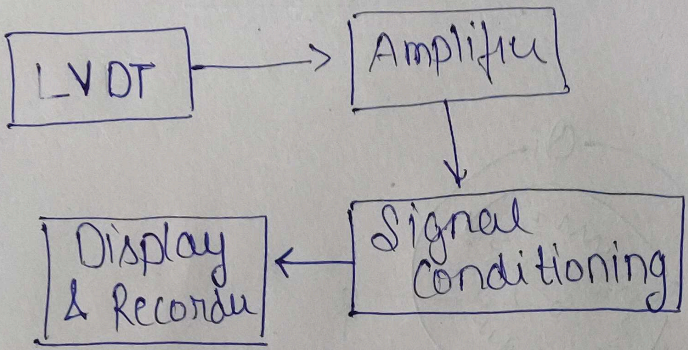
The rotational POT can detect angular movement from 10° to 357°

The wiper displacement is proportional to the displacement.

LVDT

→ linear motion converts in to electrically signal

→ Back to back connection



Advantages

1. High Range: 1·25mm to 250mm
2. Frictional & Electrical Isolation
3. High sensitivity: 40 V/mm
4. Rugged / Low power / Low Hysteresis

Disadvantage

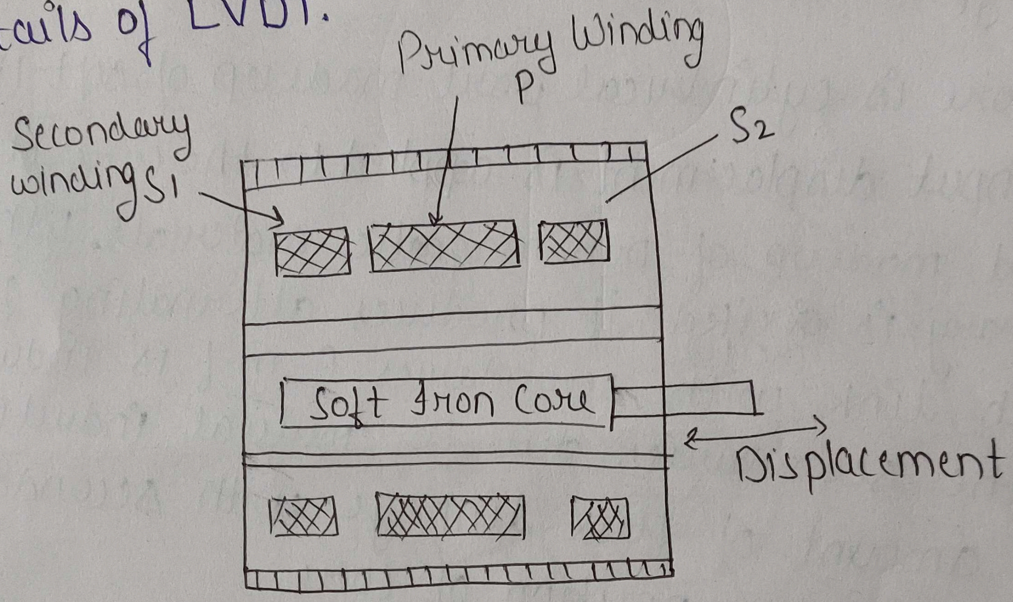
1. Residual magnetism / large displacement requires
2. Selected frequency response
3. Effect of vibrations on measured
4. Temp & Isolation (required) effects.

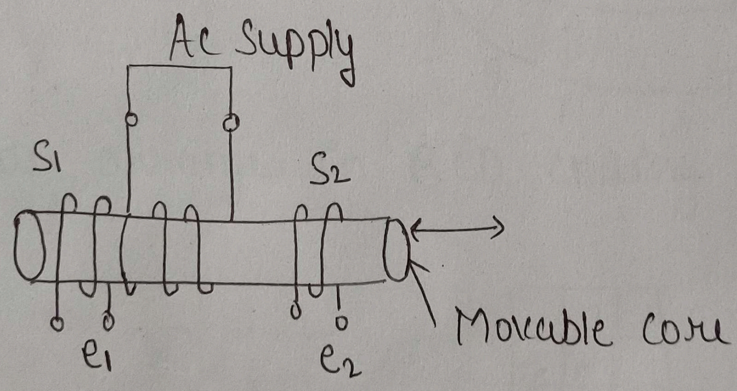
Applications

1. Measurement of low displacement
2. " of strain / pressure
3. Stress testing
4. Sheet thickness / wire diameter mmt

LVDT (Linear Variable Differential Transformer)

This is the most popular and widely used inductive transducer. It convert linear displacement into electrical signal. Below figure shows construction details of LVDT.





Output = $e_1 - e_2$

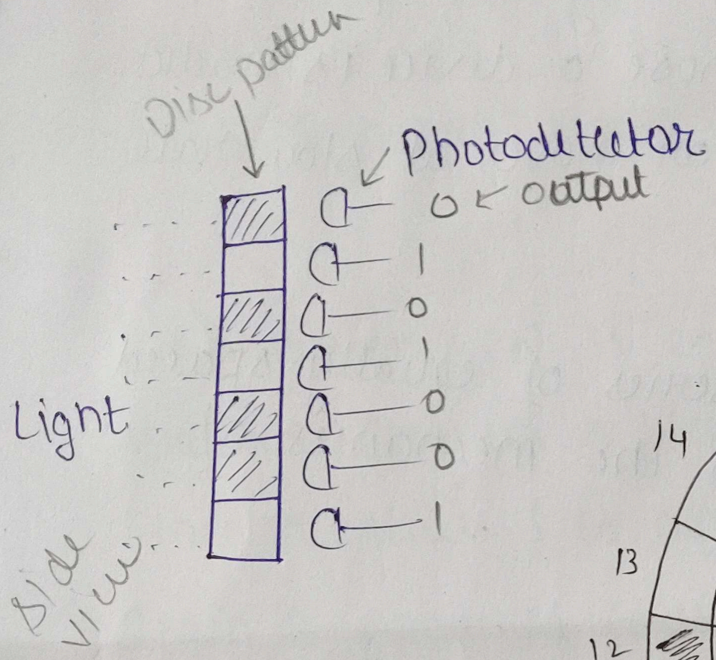
There is one primary winding and two secondary winding. These windings are arranged on cylindrical former. The two secondary winding is connected to a ac source. The frequency of source may be ranging from 50 Hz to 20 KHz

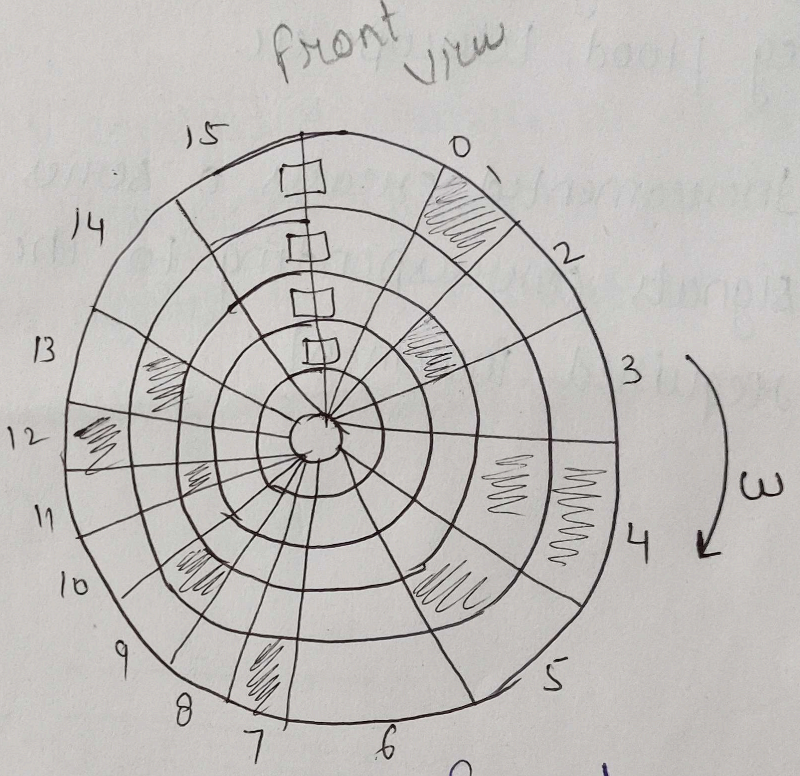
The typical value used is 8KHz

The core is cylindrical part made up of soft iron. The input displacement is applied to the core through a rod made up of non-magnatic materials. When primary is ~~excited~~ excited, it produces alternating flux which link with secondaries E.m.f is induced in the secondaries due to mutual induction. The amount of flux linkage with secondary is decided by the position of core.

Optical Encoder → are the digital encoders that produces a digital o/p directly for communication with computer.

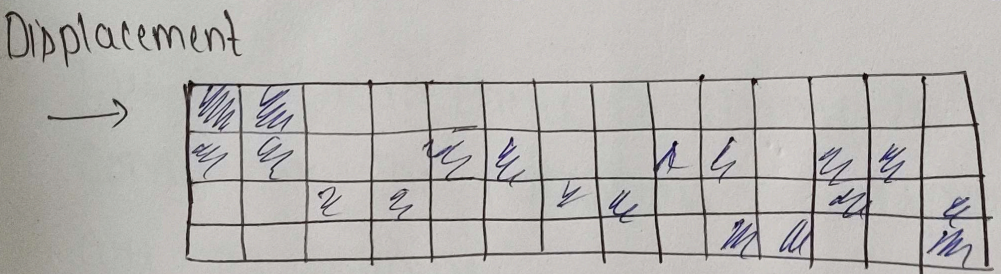
Measurement of Displacement - Optical encoder is a digital device used for measurement of linear ~~and~~/angular displacement and speed measurement





Tachometer 1cm

Plates arranged in BCD coding format



* High resolution
* not rugged
* Readable
* 12 Bit BCD only
* Digital

Types
- → Incremented types (tachometer)
- → Absolute type

Incremental type provides a pulse each time the shaft rotates through predifined distance.

Absolute provides a whole word o/p with a unique code pattern representing each position. It used in applications whose a device is inactive for long period of time or moves at slow rate eg flood, telescope etc.

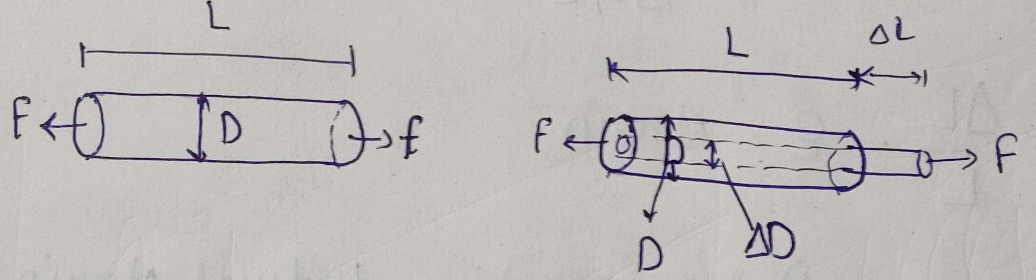
Increamented creates a series of equally spaced signals corresponding to the mechanics of required increment.

Measurement of force using strain gauge

Strain pops is used for measuring mechanical strain.

$$\text{Mechanical strain} = \frac{\text{Elongation}}{\text{Original length}}$$

The resistance of s conductor changes as it is strained. Consider a conductor shown in figure. When a stress s is applied to it, a positive strain is produced causing reduction in area a increase in length.



Due to strain there is change in parameters of conductor. The notations corresponding to this are as follows.

Due to strain there is change in parameters of conductor. The notations corresponding to this as follows -

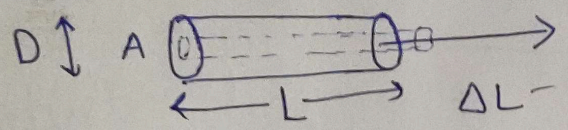
Conductor parameter without strain	Change in conductor
Resistance = R	ΔR
Length = L	ΔL
Area = A	ΔA
Diameter = D	ΔD
Resistivity = ρ	$\Delta \rho$

$$\frac{\Delta R/R}{\Delta L/L} = 1 + 2\mu + \frac{\Delta \rho/\rho}{\Delta L/L} = G = \text{Gauge factor}$$

when $\frac{\Delta L}{L} = \varepsilon$ = strain

μ = Poisson's ratio = $\frac{\text{Lateral strain}}{\text{Longitudinal strain}}$

Metalic Wire



ΔA - Change in area

ΔD - " " diameter

ΔL - Change in length

Relation b/w wire & resistance

$$R = \frac{\rho L}{A} \quad \xleftarrow{} \text{Resistivity}$$

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

$$\text{Area} = \frac{\pi D^2}{4}$$

$$\frac{dA}{ds} = \frac{\pi}{4} 2D\frac{\partial D}{\partial s}$$

$$\frac{1}{A}\frac{dA}{ds} = \frac{\cancel{\pi/4}\, 2 D \frac{\partial D}{\partial s}}{\frac{\cancel{\pi} D^{\cancel{2}}}{\cancel{4}}}$$

$$\frac{1}{A}\frac{dA}{ds} = \frac{2}{D}\frac{\partial D}{\partial s} \quad \text{— (2)}$$

Divide eq^n (1) by R

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

Put eq^n (2) in eq^n (A)

$$\boxed{\frac{1}{R}\frac{dR}{ds} = \frac{1}{L}\frac{\partial L}{\partial s} - \frac{2}{D}\frac{\partial D}{\partial s} + \frac{1}{\rho}\frac{\partial \rho}{\partial s}}$$

Poisson's ratio

$$\nu = \frac{\text{lateral strain}}{\text{longitudinal strain}}$$

lateral strain – across Diameter

longitudinal strain – across length

$$\nu = \frac{-\partial D/D}{\partial L/L}$$

Because strain is a opposition force

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

$$\frac{1}{R}\frac{dR}{ds} = \frac{1}{L}\frac{\partial L}{\partial s} + \frac{2\nu}{L}\frac{\partial L}{\partial s} + \frac{1}{\rho}\frac{\partial \rho}{\partial s}$$

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

$$\frac{\Delta R}{R} = \frac{\Delta L}{L}(1+2\nu) + \frac{\Delta \rho}{\rho} \rightarrow 4$$

$\frac{1}{x}\frac{\partial x}{\partial y} = \frac{\Delta x}{x}$

Change in x wrt y

$$\boxed{\text{Gauge factor} \rightarrow \frac{\Delta R/R}{\Delta L/L}} \rightarrow \text{sensitivity}$$

eqn 4 / $\Delta L/L$ → G_f

$$G_f = 1 + 2\nu + (\Delta\rho/\rho)/(\Delta L/L)$$

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

1 → Change in length

2ν → Change in area

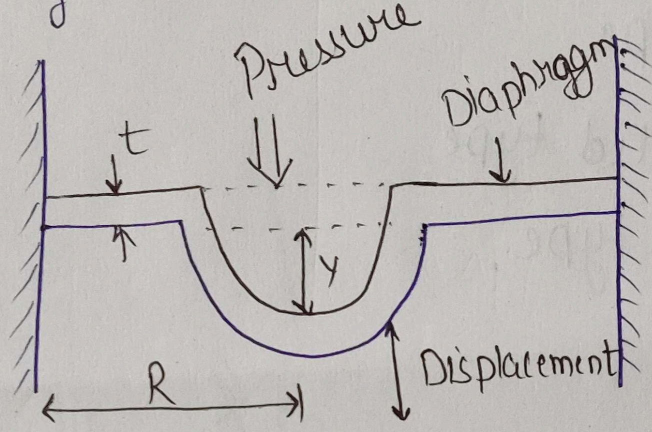
$\frac{\Delta\rho/\rho}{\Delta L/L}$ → Piezo-resistivity

→ Change in resistivity

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

Measurement of pressure using LVDT based diaphragm

The working principle of diaphragm is similar to bellows. Diaphragm is merely a thin filter of metal. The pressure is applied to one side of diaphragm. The pressure causes stretching of diaphragm along periphery, the displacement thus occurs.



The deflection (Y) is given, by the following impression:

$$Y = \frac{3}{16}\frac{(1-\nu^2)}{Et^3}R^4 p \qquad P = \frac{256\,E t^3\,dm}{3(1-\nu^2)D^4}$$

where

ν = Poisson's ratio

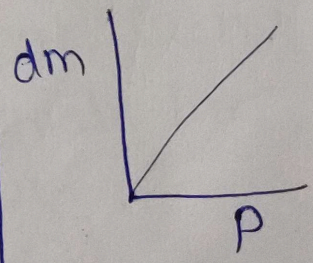
E = Modules of elasticity

t = Thickness of diaphragm

R = Radius of diaphragm

P = Pressure to be measured

$P \propto dm$



The displacement of diaphragm thus depends on its thickness and radius. The materials used for diaphragms are mainly elastic metal alloys such as bronze, phospher, beryllium copper, stainless steel etc.

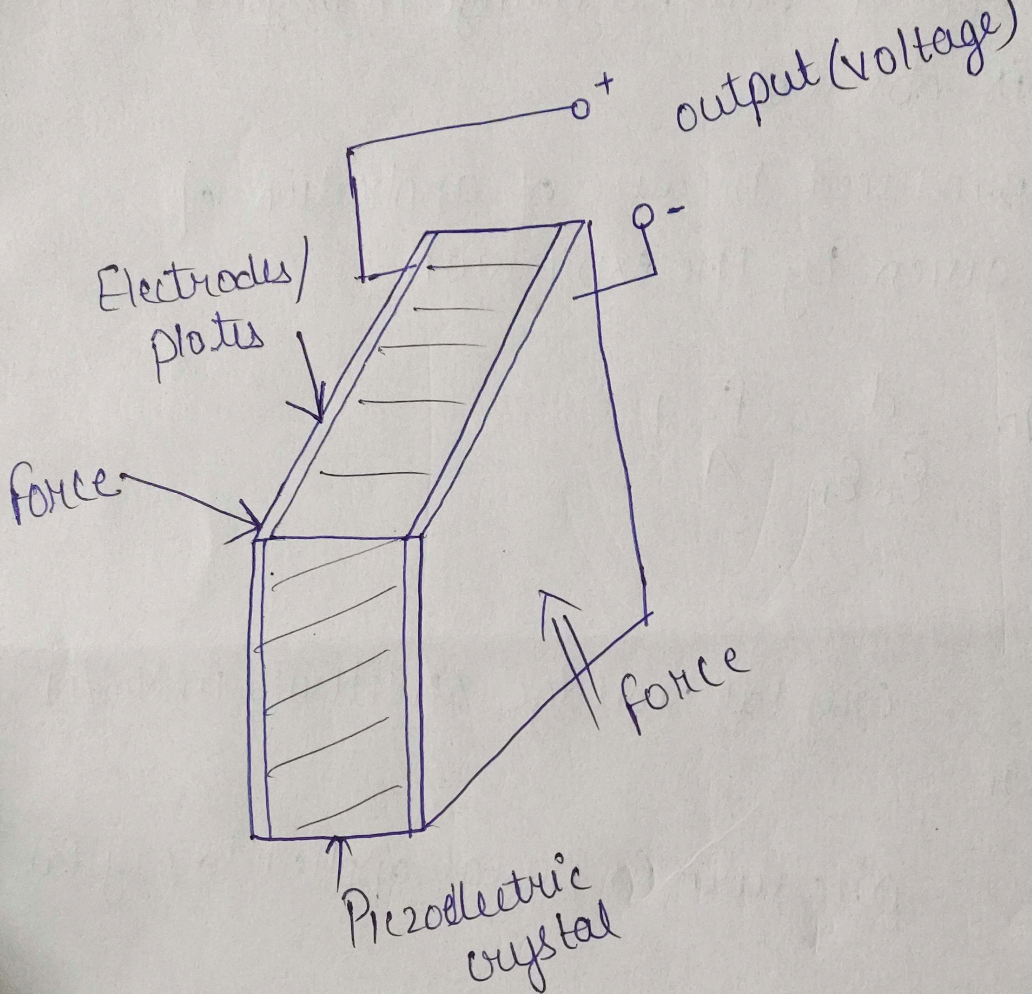
The diaphragm are three types -

(i) Flat type

(ii) Corrugated type

(iii) Capsule type

Measurement of pressure using LVDT based piezoelectric sensor



Types

* Natural
  - Quartz Crystal
  - Roschelle Salt
  - Turmaline Crystal
* Synthetic
  - Lithium sulphate
  - Ethylene diamine tartrate
  - PZT (Lead zirconate titanate)

When a piece of a quartz crystal is subjected to force, a voltage is induced across its opposite faces. This effect is known as piezoelectric effect. Thus mechanical input produces electrical output. Such materials are called as piezoelectric materials. The piezoelectric transducer are active transducer

Piezoelectric Crystal → is one of a small scale energy resource, when these crystal are automatically deformed then they produce a tiny voltage which is known as piezoelectricity. This kind of renewable energy cannot be suitable for industrial situations.

The applied force / pressure cause change in physical dimensions of the crystal piece. The effect is reversible i.e on application of voltage across the opposite faces, a change in physical dimensions is observed.

The voltage produced because of application of pressure is given by the expression

$$V_o = \frac{d}{\varepsilon_o \varepsilon_r} \frac{f}{A} t$$

where,

$\frac{d}{\varepsilon_o \varepsilon_r}$ = crystal voltage sensitivity in Vm/N

$\frac{f}{A}$ = pressure in pascal applied to crystal

t = Thickness of crystal in meters.