18ECO133T

# Sensors and Transducers

# 3 Credit Course

UNIT II

**BOOKS**

*1. Patranabis, D., "Sensors and Transducers", 2nd Edition, Prentice Hall India Pvt. Ltd, 2010.*

*2. Doeblin, E.O., "Measurement Systems: Applications and Design", 6thEdition, Tata McGraw-Hill Book Co., 2011.*

*3. Bentley, J. P., "Principles of Measurement Systems", 4th Edition, Addison Wesley Longman Ltd., UK, 2004.*

*4. Murthy, D.V.S., "Transducers and Instrumentation", Prentice Hall of India Pvt. Ltd., New Delhi, 2010.*

*5. Neubert H.K.P., "Instrument Transducers – An Introduction to their performance and Design", Oxford University Press, Cambridge, 2003.*

# UNIT II

- ❖Introduction to Inductive sensor
- ❖Sensitivity and linearity of the sensor
- ❖Transformer type transducer
- ❖Electromagnetic transducer
- ❖Magnetosrtictive transducer
- ❖Materials used in inductive sensor
- ❖Mutual Inductance change type
- ❖LVDT: Construction-Material, input output relationship
- ❖Synchros-Construction
- ❖Capacitive sensor
- ❖Introduction-Parallel plate capacitive sensor
- ❖Variable thickness dielectric capacitive sensor
- ❖Electrostatic transducer-Piezoelectric elements
- ❖Ultrasonic Sensors-Calculation of sensitivity
- ❖Capacitor microphone, response characteristics

# Introduction to Inductive Sensor
# Basic Concept

- Uses the principle of electromagnetic induction to detect or measure objects
- An inductor develops a magnetic field when a current flows through it; alternatively, a current will flow through a circuit containing an inductor when the magnetic field through it changes. This effect can be used to detect metallic objects that interact with a magnetic field.
- Non-metallic substances such as liquids or some kinds of dirt do not interact with the magnetic field, so an inductive sensor can operate in wet or dirty conditions.

The inductive sensor is based on Faraday's law of induction.

The temporal variations of the Magnetic Flux $\Phi$ through a N turns circuit will induce a voltage e which follows:

$$e = -N\frac{\mathrm{d}\Phi}{\mathrm{d}t}$$

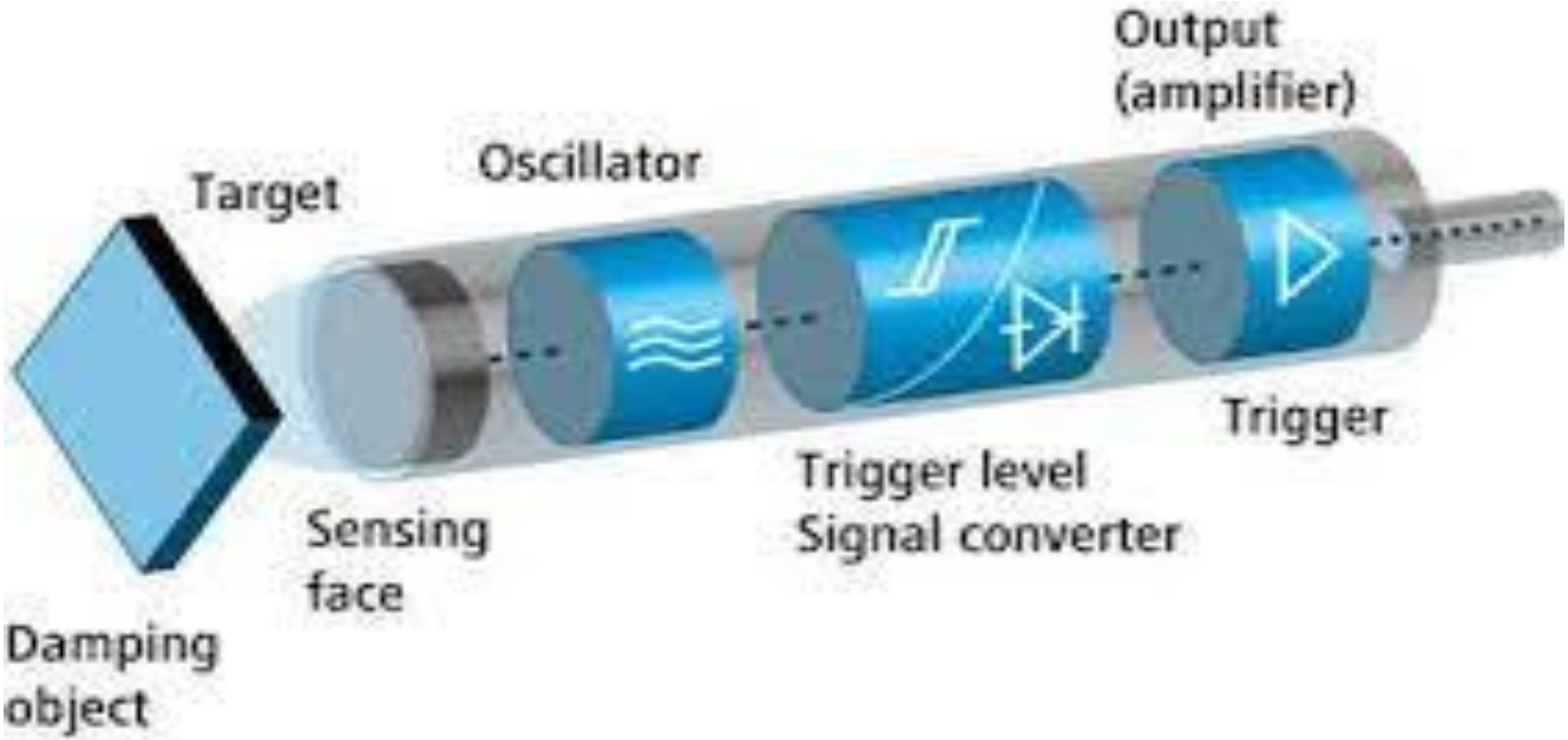
which can be expressed in a simpler way:

$$e = -N \times S\frac{\mathrm{d}B}{\mathrm{d}t}$$

by assuming that the induced magnetic field B is homogeneous over a section S (the Magnetic flux will be expressed $\Phi$ =B X S

- One form of inductive sensor drives a coil with an oscillator.
- A metallic object approaching the coil will alter the inductance of the coil, producing a change in frequency or a change in the current in the coil.
- These changes can be detecte, amplified, compared to a threshold and use to switch an external circuit.
- The coil may have a ferromagnetic core to make the magnetic field more intense and to increase the sensitivity of the device.
- A coil with no ferromagnetic core ("air core") can also be used, especially if the oscillator coil must cover a large area.
- Another form of inductive sensor uses one coil to produce a changing magnetic field, and a second coil (or other device) to sense the changes in the magnetic field produced by an object, for example, due to eddy currents induced in a metal object

# Types of Inductive Sensor



Target
Oscillator
Output
(amplifier)
Trigger
Trigger level
Signal converter
Sensing
face
Damping
object

# APPLICATIONS

- Search coil magnetometer
- Inductive proximity sensor
- Metal detectors
- Traffic lights
- Car washes
- Many automated industrial processes.

The sensor does not require physical contact it is particularly useful for applications where access presents challenges or where dirt is prevalent

**Reluctance-**the opposition offered in a magnetic circuit to magnetic flux

**Mutual Inductance-**When two coils are brought in proximity with each other the magnetic field in one of the coils tend to link with the other. This further leads to the generation of voltage in the second coil. This property of a coil which affects or changes the current and voltage in a secondary coil is called Mutual Inductance

**Eddy currents -** are loops of electrical current induced within conductors by a changing magnetic field in the conductor according to Faraday's law of induction

The two most common methods of achieving variation in inductance are

(i) by changing the reluctance of the magnetic path and

(ii) by coupling two or more elements.

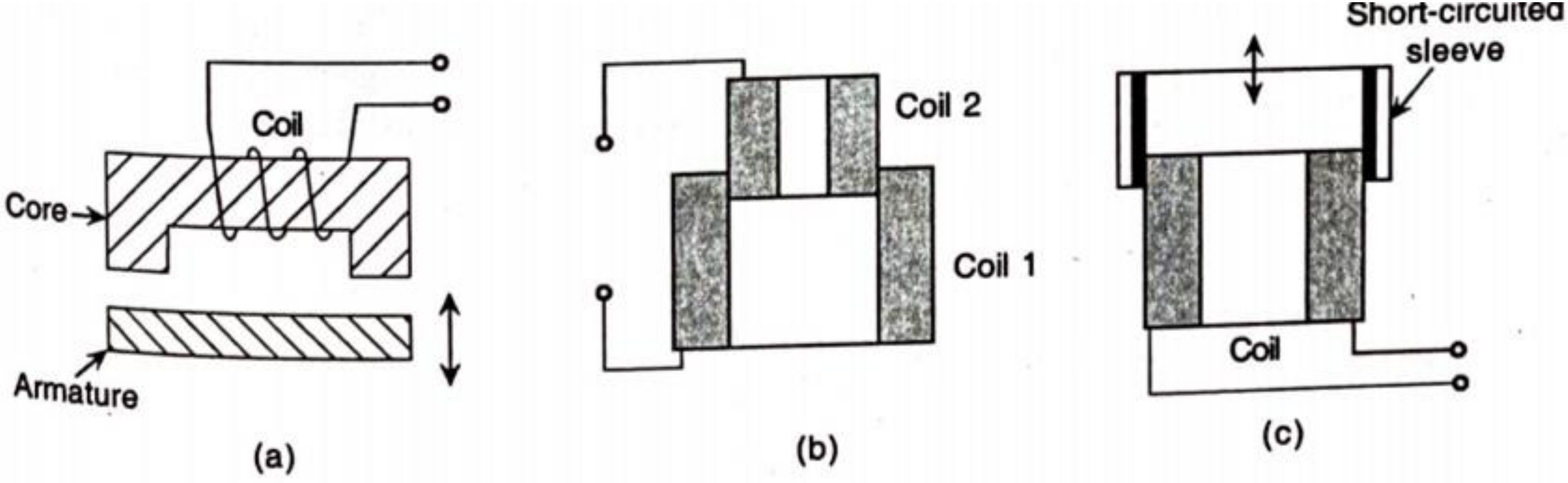
The latter technique works by

(a) change of mutual inductance,

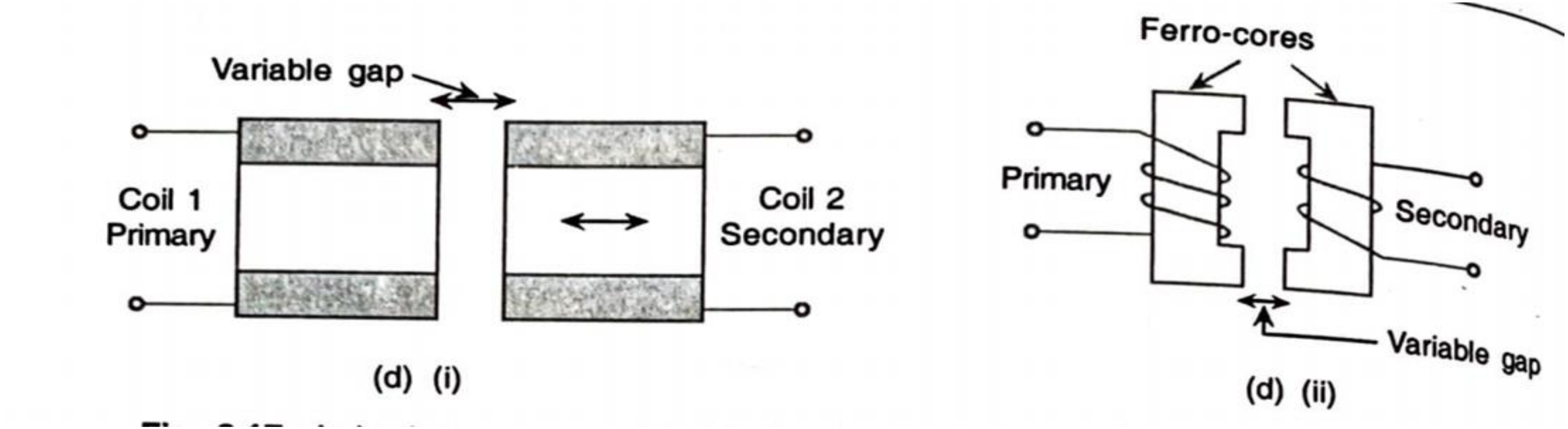
(b) change of eddy current when one element is just a

short-circuited sleeve, and

(c) transformer action




(a) change of reluctance of magnetic path, (b) change of mutual inductance between two coils, (c) change of mutual inductance between a coil and a sleeve,




(d) (i) and (ii) transformer action

# TYPES

Inductive sensors of

(i) the electromagnetic type which are bilateral in operation with electrical and mechanical input/output relationship and (ii) the magnetostrictive Type

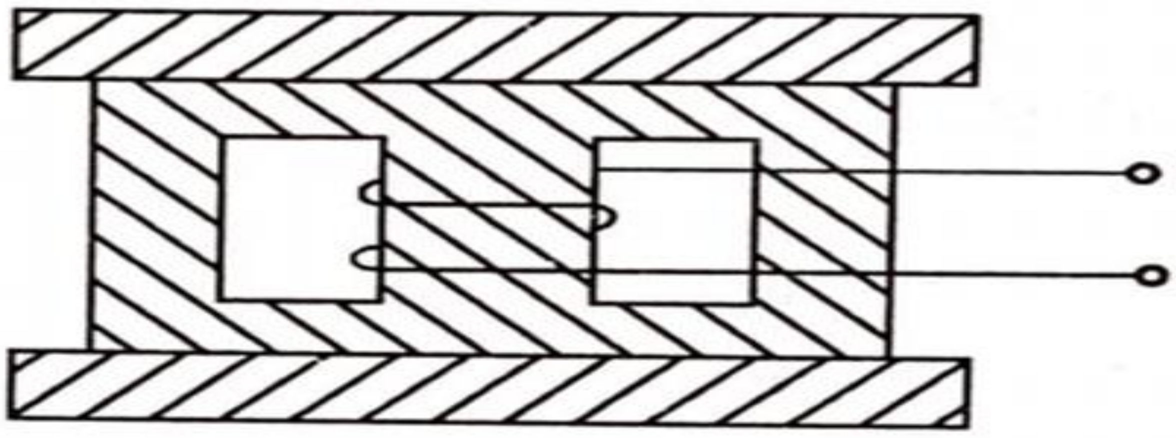


Fig. 2.18 Sensor using a magnetostrictive effect.

A coil is an essential part of inductive transducers

The coil may be wound on a metal (iron) core or an air core.

**In the variable reluctance type,**

the core is a ferromagnetic material as also the armature.

This type of sensors are, perhaps, the most extensively used because it (i) is the most sensitive one, (ii) is least affected by external fields as the air gap is least, and (iii) requires less number of turns than in air core design for same value of inductance so that interwinding or self-capacitance and stray effects are less.

Using Eq. (2.16), one derives

$$L = \frac{\mu n^2 a}{l} \quad \text{(Henries)} \tag{2.18}$$

The copper resistance $R_c$ is also easily calculated if the coil wire diameter $d$ and the copper resistivity $\rho$ are known, so that

$$R_c = \frac{4\rho n l_t}{\pi d^2} \tag{2.19}$$

where $l_t$ is the average length per turn of the coil. The coil dissipation factor $D_c$ is usually defined as

$$D_c = \frac{R_c}{\omega L} \tag{2.20}$$

which decreases with increasing frequency.

For reducing eddy loss or core loss as it is called (the core is usually made of laminations of certain thickness, say $t_l$), the depth of penetration of eddy current, $d_p$ is given by

$$d_p = \sqrt{\frac{\rho_e}{\pi \mu f}} \tag{2.21}$$

where $\rho_e$ is the resistivity of the core material and $f = \omega/(2\pi)$ is the frequency. The eddy loss resistance is then given by

$$R_e = \left(\frac{2d_p\omega L}{t_l}\right)\left[\frac{\cosh\left(\frac{t_l}{d_p}\right) - \cos\left(\frac{t_l}{d_p}\right)}{\sinh\left(\frac{t_l}{d_p}\right) - \sin\left(\frac{t_l}{d_p}\right)}\right] \tag{2.22}$$

Equations (2.21) and (2.22) are valid only for low frequencies when $\rho_t = (t_l/d_p) \leq 2$. The frequency range, however, varies depending on the core material as well as lamination thickness. Figure 2.20 shows the plots of $f$ versus $t$ for different materials of commercial importance for $\rho_t \approx 2$, so that within this range of frequency Eq. (2.22) can be simplified using Eqs. (2.18) and (2.21) as

$$R_e \approx \frac{6\omega L}{(t_l/d_p)^2} = \frac{12\rho_e a n^2}{(l t_l)^2} \tag{2.23}$$

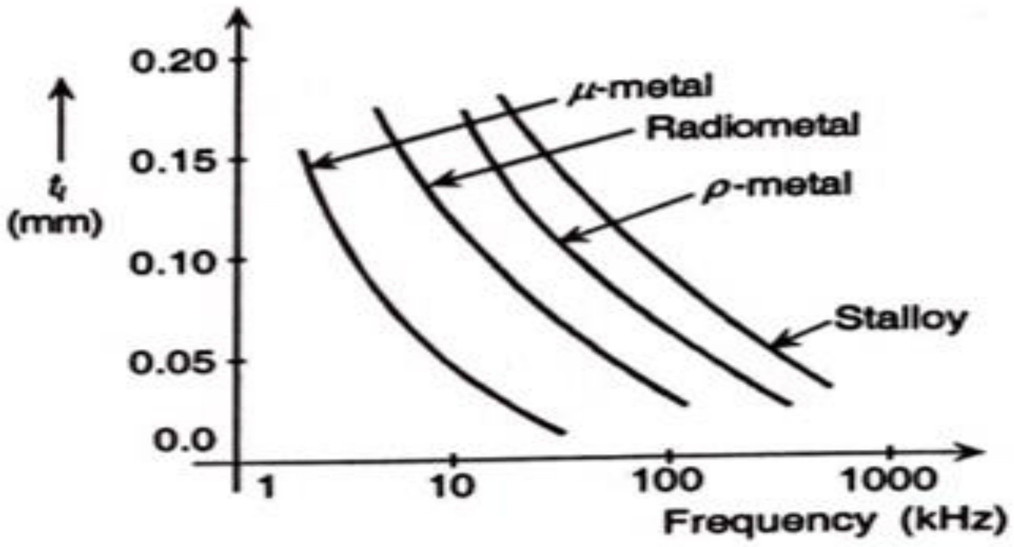



**Fig. 2.20** Sheet thickness versus frequency plots for different magnetic materials.

This figure (Fig. 2.20) shows what frequency range can be covered by a specific material with specified thicknesses.

The eddy loss dissipation factor is defined by

$$D_e = \frac{\omega L}{R_e} \tag{2.24}$$

and is directly proportional to frequency.

Magnetic material undergoes hysteresis and this causes dissipation or loss. The area within the hysteresis curve is given by

$$A_h = \int B \cdot dH \tag{2.25}$$

where $H$ is the magnetic field strength and $B$ is the magnetic induction.

The $B$–$H$ loop for a ferromagnetic material is schematically shown in Fig. 2.21. Following Rayleigh's procedure, the area $A_h$ has been computed and hence, the energy dissipated per unit volume. For a core of cross-sectional area $a$, and length $l$, total hysteresis loss, in this way, is obtained as

$$P_h = \left(\frac{16\pi}{3}\right) a l \alpha_r H_l^3 f \times 10^{-7} \quad \text{(watts)} \tag{2.26}$$

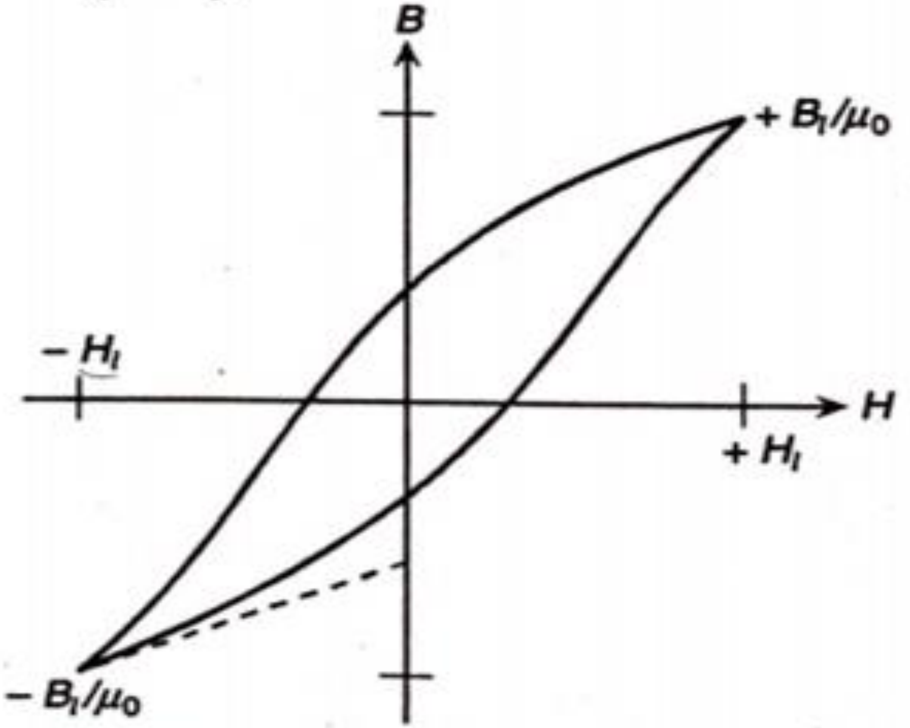



Fig. 2.21 The $B$–$H$ loop for a magnetic material.

where $\alpha_r$ is the Rayleigh's constant which may be defined by the equation

$$\alpha_r = 2\frac{\left(\dfrac{\Delta B}{\mu_0} - \mu_i H\right)}{(\Delta H)^2} \tag{2.27}$$

where $\mu_i$ is the initial permeability, that is, permeability at $H = 0$. With change from zero values of $B$ and $H$, Eq. (2.27) is written as

$$\alpha_r = \frac{2(B/\mu_0 - \mu_i H)}{H^2} \tag{2.28}$$

Using $P_h = E^2/R_h$, $R_h$, being the equivalent hysteresis loss resistance, is

$$R_h = \frac{\omega^2 L^2 I^2}{P_h} \tag{2.29}$$

which is proportional to the square of the frequency. However, the hysteresis dissipation factor $D_h$ is given by

$$D_h = \frac{\omega L}{R_h} = \frac{2\alpha_r H_l}{(3\pi \mu_i)} \tag{2.30}$$

which is independent of frequency.

A sensor or a transducer involves the movement of an armature, that is, the situation demands that the core has an air gap, the length of which varies with the value of the measured quantity such as a motion. This is taken into consideration by determining the effective permeability of the core when the sample permeability $\mu_s$ is known and a relation between $L$ and the gap length $l_g$ can be found. Thus, for a torroidal ring sample of total path length $l$, gap length $l_g$, cross-sectional area $a$, the effective permeability $\mu$, we obtain

$$\frac{\left(\dfrac{(l-l_g)}{\mu_s}+l_g\right)}{a}=\frac{l}{\mu a} \tag{2.31}$$

yielding

$$\mu=\frac{\mu_s}{\left\{1+\left(\dfrac{l_g}{l}\right)(\mu_s-1)\right\}} \tag{2.32a}$$

Since $\mu_s >> 1$,

$$\mu\approx\frac{\mu_s}{\left\{1+\left(\dfrac{l_g}{l}\right)\mu_s\right\}} \tag{2.32b}$$

Substituting this in Eq. (2.18),

$$L=\left[\frac{\mu_s}{\left\{1+\left(\dfrac{l_g}{l}\right)\mu_s\right\}}\right]\left(\frac{n^2a}{l}\right)\quad\text{(Henries)} \tag{2.33}$$

Before moving on to the analysis of change of inductance with air gap and its nature, the effect of the capacitor $C$ of Fig. 2.19 is considered. This capacitance arises, as already mentioned, due to the coil self-capacitance, that is, interwinding capacitance as also due to the connecting cable capacitance. The effect of parallel resistance $R_e$ can be considered in series with the inductance so that the total series resistance $R$, is then used to calculate the impedance $Z$ as

$$Z = \frac{R + j\omega L}{(1 - \omega^2 LC) + j\omega RC} \tag{2.34}$$

which, on rationalization, can be written as

$$Z = \frac{R}{(1 - \omega^2 LC)^2 + (\omega^2 LC/Q)^2} + j\omega L \frac{(1 - \omega^2 LC) - (\omega^2 LC/Q^2)}{(1 - \omega^2 LC)^2 + (\omega^2 LC/Q)^2} \tag{2.35}$$

where $Q = L/R$.

For a good inductor with $Q^2 >> 1$, we get

$$Z = \frac{R}{(1 - \omega^2 LC)^2} + \frac{j\omega L}{(1 - \omega^2 LC)} = R_{eq} + j\omega L_{eq} \tag{2.36}$$

indicating that both $R_{eq}$ and $L_{eq}$ increase but the effective $Q$, $Q_{eq}$ decreases

$$Q_{eq} = \frac{\omega L\,(1 - \omega^2 LC)}{R} \tag{2.37}$$

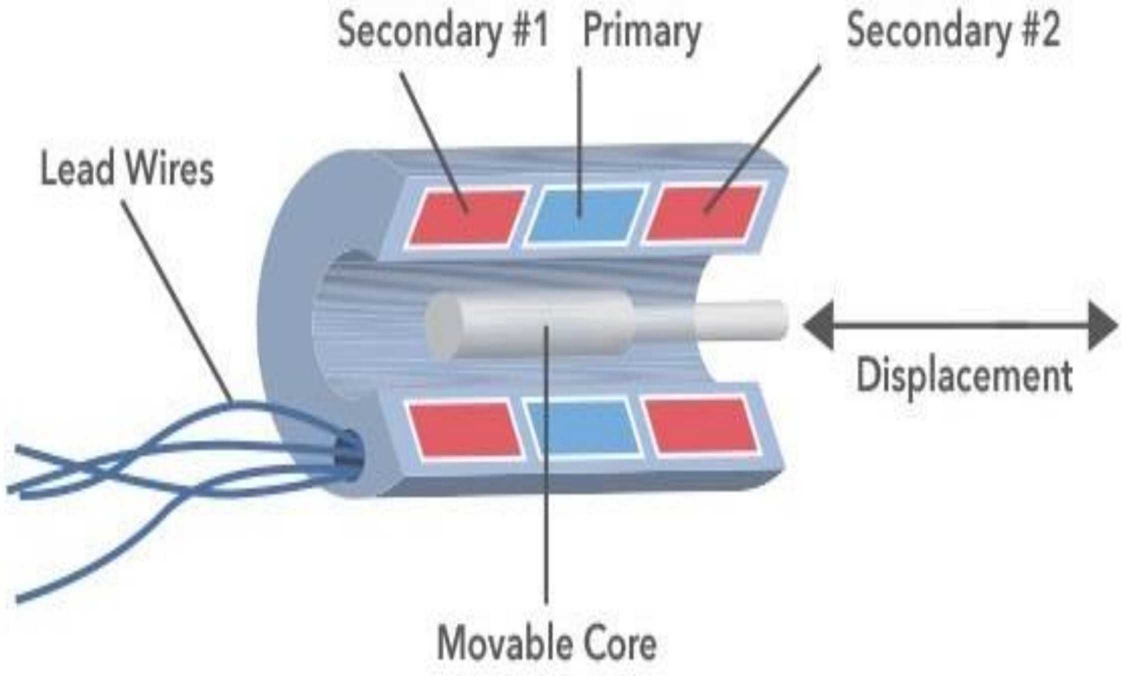
- For transformer type transducer , refer the pdf
- For electromagnetic type transducer , refer the pdf
- https://www.youtube.com/watch?v=zyJZJu_1lgE -LVDT

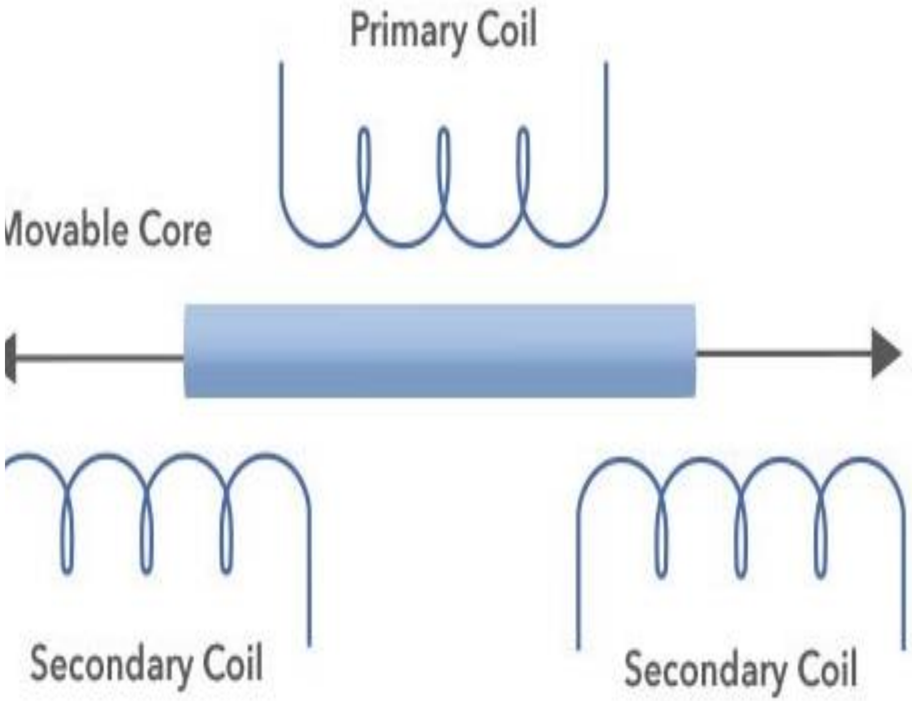
- https://www.youtube.com/watch?v=N20lO9cWL9w -- lecture series I on sensor and transducer
- https://www.youtube.com/watch?v=s2o600RiEGU - LVDT

# ELECTROMAGNETIC TRANSDUCER

- Bilateral double-function type transducer('mechanical input-electrical output' and 'electrical input-mechanical output)
- These transducers can be used both as 'generators' and 'sensors' often termed as 'senders' and 'receivers' respectively
- Governed by (i) Faraday's law of electrodynamics and (ii) piezoelectric effect
- Consists of an inductance coil wound on a ferromagnetic core and a variable gap provides the variation in the output.
- For producing unidirectional flux, a magnetizing coil with a bias current may be provided or the core
- Generally, a permanent magnet is used as a core

# LVDT


Secondary #1
Primary
Secondary #2
Lead Wires
Displacement
Movable Core

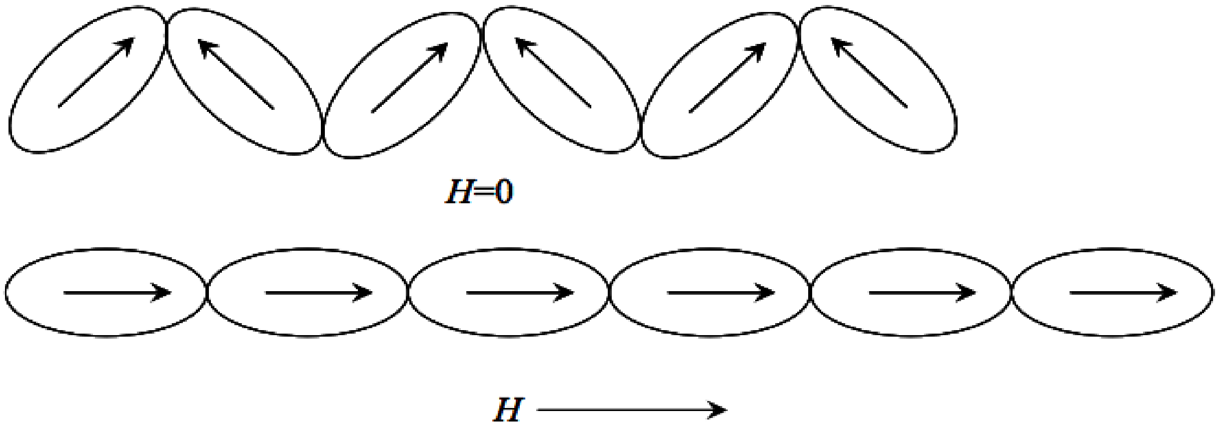

Primary Coil
Secondary Coil
Secondary Coil

# LVDT/RVDTS CAN PROVIDE ABSOLUTE POSITIONING IN HARSH ENVIRONMENT APP

# What is Magnetostriction?

- Magnetostriction is a property of ferromagnetic materials that causes them to change their shape or dimensions (expand or contract) during the process of magnetization.

- The effect was first identified in 1842 by **James Joule** when observing a sample of nickel.

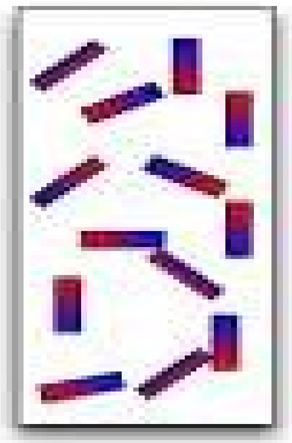


# Magnetostriction - Working

Magnetostriction - Working

- Internally, ferromagnetic materials have a structure that is divided into domains, which are **randomly oriented** when the material is not exposed to a magnetic field and each domain is a region of uniform magnetic polarization.

- **When a magnetic field is applied**, the boundaries between the domains shift and the **domains rotate**; both of these effects cause a change in the material’s dimensions.



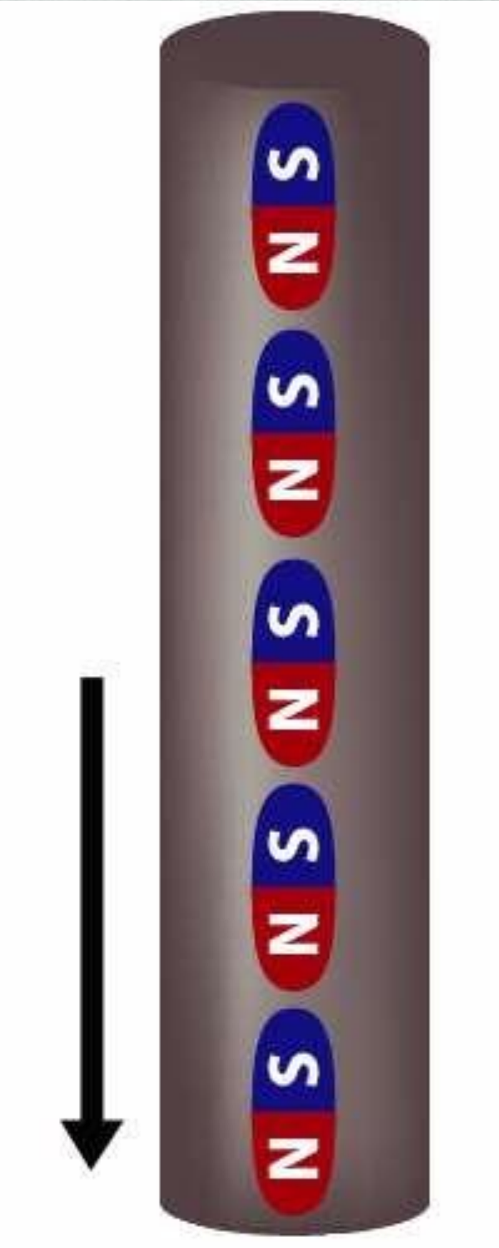
Non-Magnet: Random Arrangement of Magnetic Domains

# RESULT OF MAGNETOSTRICTION

- The orientation of these small domains by the imposition of the magnetic field creates a strain field.
- As the intensity of the magnetic field is increased, more and more magnetic domains orientate themselves so that their principal axes of anisotropy are collinear with the magnetic field in each region and finally saturation is achieved.

Effect of increasing and decreasing applied or external magnetic field(H) on a ferromagnetic material can be seen here.

The arrow mark indicates the change in value (increase or decrease) and direction of applied magnetic field.



# MAGNETOSTRICTIVE TRANSDUCER

Magnetostrictive position sensors are non-contact linear position sensors

They use the momentary interaction of two magnetic fields to produce a strain pulse that moves along a waveguide. One field is from a magnet that moves along the outside of the waveguide. The other field is from the waveguide itself.

Magnetostrictive position sensors a unique signal for each point along the axis of travel.

The advantage to this type of sensor is that it is non-contact and there is no wear or friction. It is also not affected by vibrations so there is no limit on the number of operating cycles.

The disadvantage is the dead band on both sides of the sensor which cannot be reduced to zero.

# MAGNETOSTRICTIVE TRANSDUCER

It is not popular because of its limitations with respect to materials

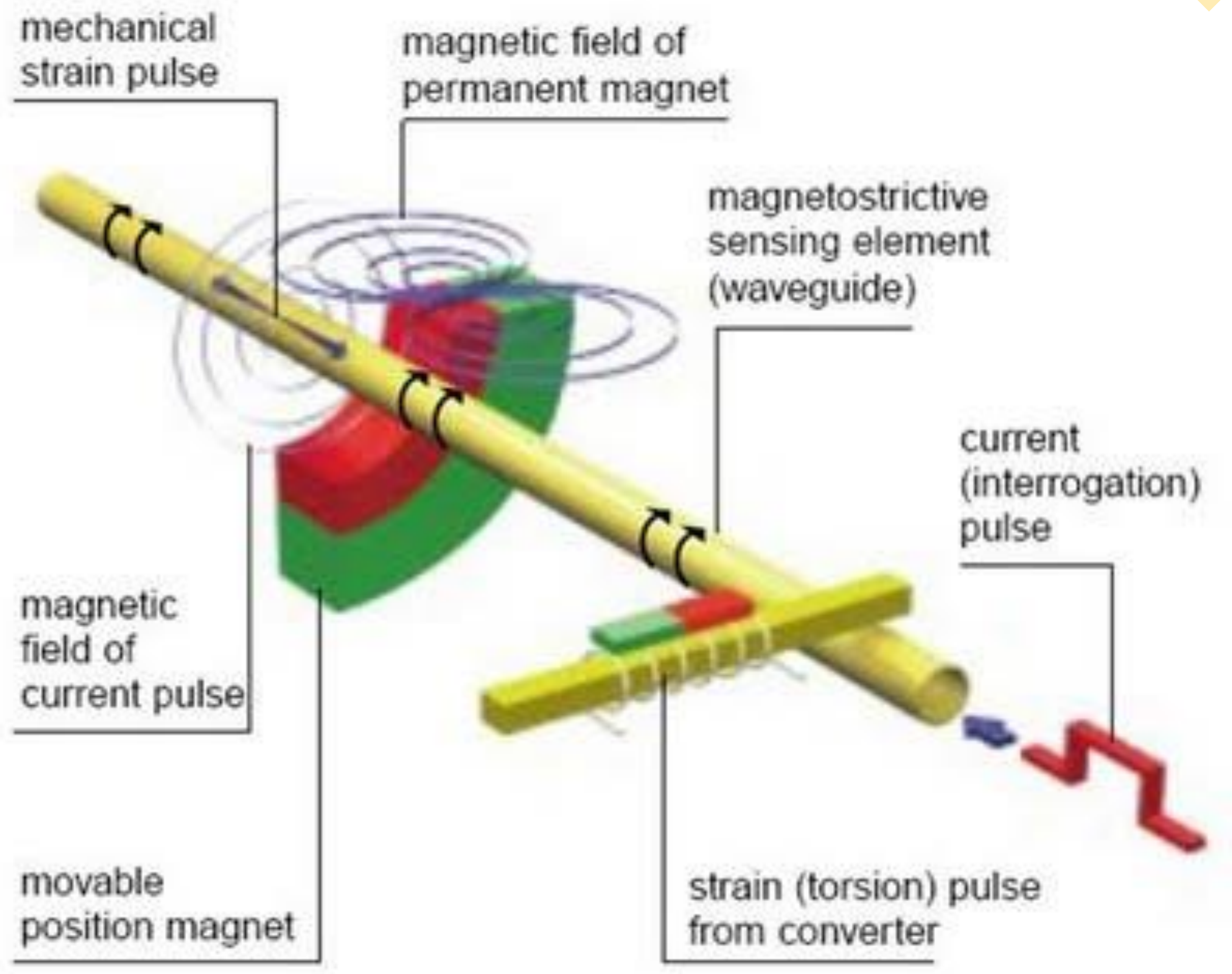
Types:

(a) Variable permeability type
(b) Variable remanence type

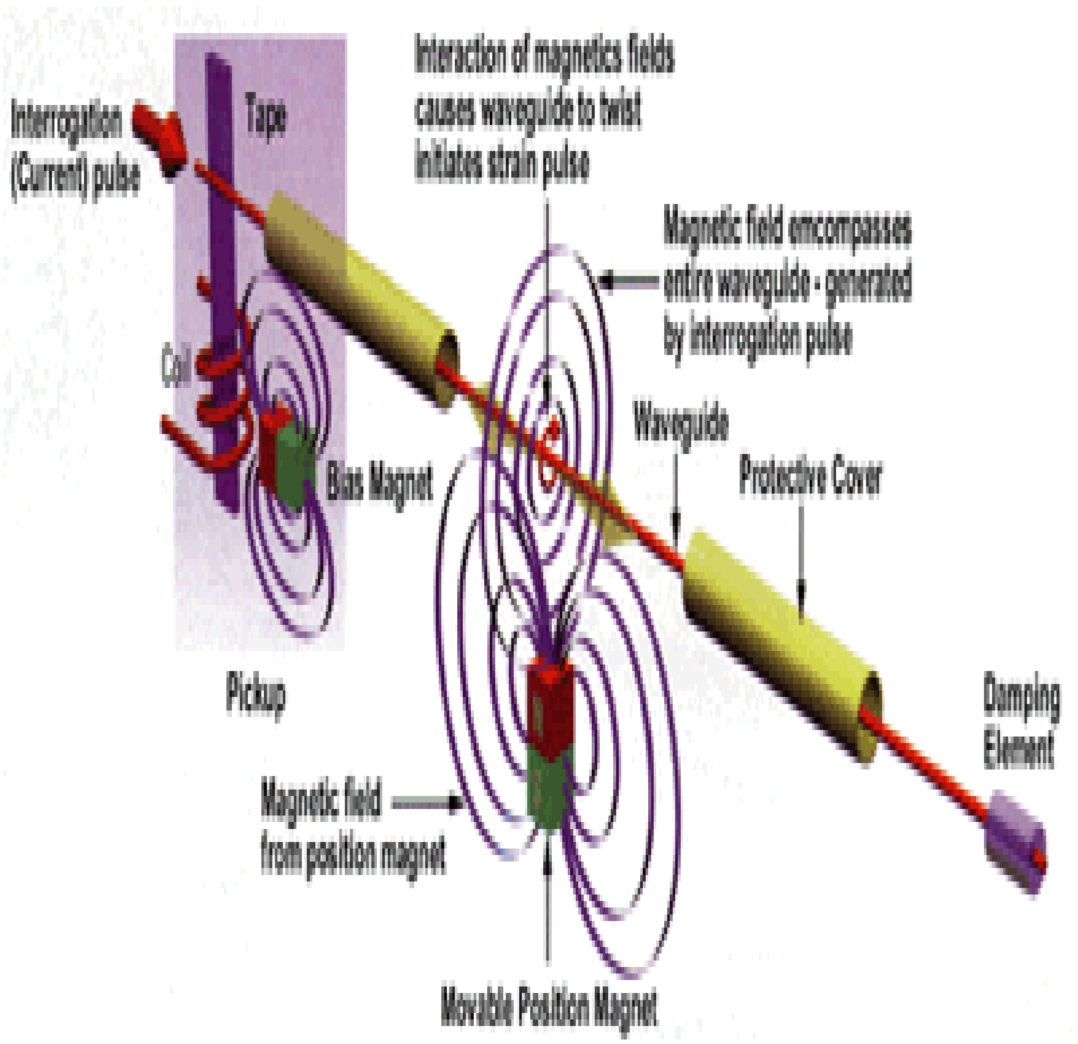
In general slope of hyteresis curve decreases with increasing tension-this changes the value of permeability-hence inductance of the coil wound on the material

With increasing tension the remanence magnetism B0 decreases(e.g. Ni is with negative magnetsriction.

- Magnetrostriction is a property of ferromagnetic materials to expand or contract when placed in a magnetic field. T
- The sensor senses the position of the permanent (position) magnet to determine the distance between the permanent magnet and the sensor head.
- There are five main components of the magnetostrictive sensor: Waveguide, position magnet, electronics, strain pulse detection system, and damping module.



- Typically, the waveguide wire is enclosed within a protective cover and attached to the device that is being measured.
- Applying a current pulse generates a sonic wave that travels along the waveguide to a small piece of magnetostrictive material that passes through a coil and is magnetized by a small, permanent magnet.
- The stress induced by the sonic wave causes a wave of changed permeability in the magnetostrictive material, resulting in a change in its magnetic flux and the production of voltage output from the coil.
- Electronic circuitry detects the voltage pulse and conditions it into the desired output.
- At the sensor rod tip, at the end opposite the head, there is an unusable area called the dead zone. The system must be designed so that the front face of the position magnet will come no closer to the tip than the specified dead zone distance.



# MAGNETOSTRICTIVE TRANSDUCER

# APPLICATIONS

- Magnetostrictive transducers are used for position measurement.
- The sensors are used to measure the stroke of hydraulic cylinders.
- Industrial application
- Installation in hydraulic cylinders.
- Packing machines, plastic machines, steel rolls or in beverage bottling plants.

# MAGNETOSTRICTIVE TRANSDUCER

- https://www.youtube.com/watch?v=R9CAmjVK3SI Magnetostrictive technology
- https://www.youtube.com/watch?v=YFq94BpWGEE

| INDUSTRY | APPLICATION |
|---|---|
| Automotive | Production machinery, on-board suspension, transmission, and steering. |
| Chip & Wafer Handling | Precision measurement and no wearing parts enable this application. |
| Electric Actuators | Linear and rotary position can be measured using two position magnets. |
| Hydraulic/Pneumatic Cylinders | Sensor mounted within the rod and the magnet is fixed to the cylinder. |
| Food & Beverage | Milk tanks and can filling machines |
| Liquid Level | Process control, leakage detection, inventory control |
| Medical | Hospital bed positioning |
| Metalworking | Measurement & control in forges, presses, bending, and cutoff machines. |
| Mobile Equipment | Garbage trucks, agriculture, grading and paving. |
| Paper Converting | Used to control slitters and flexographic presses. |
| Plastics | Injection molding: injector, ejector and mold halves, also blowmolding. |
| Primary Metal | Walking beams and ladle control |
| Primary Wood | Sawmills, lathes, cutoff saws, positioning knees, and presses. |
| Secondary Wood | Saw positioning and tennoners |
| Testing Equipment | Materials, automotive,military/ aerospace, earthquake and wavemakers |
| Textiles | Used in carpet tufters |

# MATERIALS

- Permeability, Hysteresis loss, Curie temperature, Eddy current loss

- Core and Armature- Ferromagnetic material- High permeability, low loss, high curie temperature, low cost

- Soft magnetic Ni-Fe alloy is good- commercial variety-

Mu metal (permeability varies from 60X10^3 to 240x10^3 ,Hysteresis loss- 4 & Curie temperature 350 degree)and Radimetal (permeability varies from 4X10^3 to 65x10^3 ,Hysteresis loss- 40 & Curie temperature 540 degree)

- https://www.youtube.com/watch?v=DyI7OieCbxs

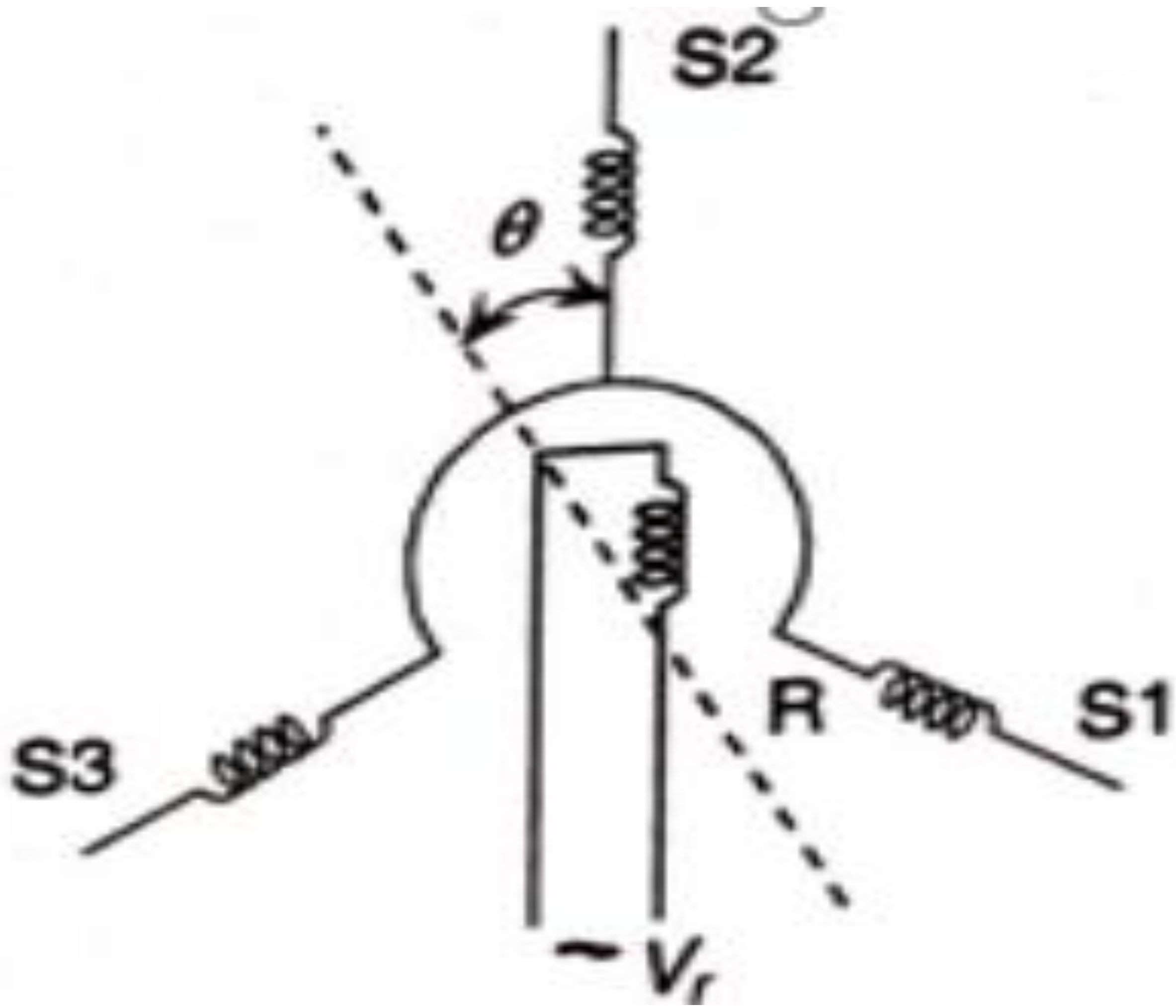
# BASIC PRINCIPLE-SYNCHRO

- Synchros are electromechanical devices which produce an output voltage depending on angular position of the rotor and not on rotor speed and it is different from a DC generator.
- The trade name for Synchros are Selsyn, Antosyn and Telesyn.
- Synchros are used primarily for the rapid and accurate transmission of information between equipment and stations.
- Examples of such information are changes in course speed and range of targets or missiles; angular displacement (position) of the ship's rudder; and changes in the speed and depth of torpedoes
- (*Note: A modern torpedo is an underwater ranged weapon launched above or below the water surface, self-propelled towards a target, and with an explosive warhead designed to detonate either on contact with or in proximity to the target*).

# Basic Principle-Synchro

- Synchros, are simply **variable transformers**.
- They differ from conventional transformers by having one **primary winding** (the rotor), which may be rotated through 360º and **three stationary secondary windings** (the stator) spaced 120º apart.
- It follows that the magnetic field within the synchro may also be rotated through 360º.
- If an iron bar or an electromagnet were placed in this field and allowed to turn freely, it would always tend to line up in the direction of the magnetic field.
- This is the basic principle underlying all synchro operations.

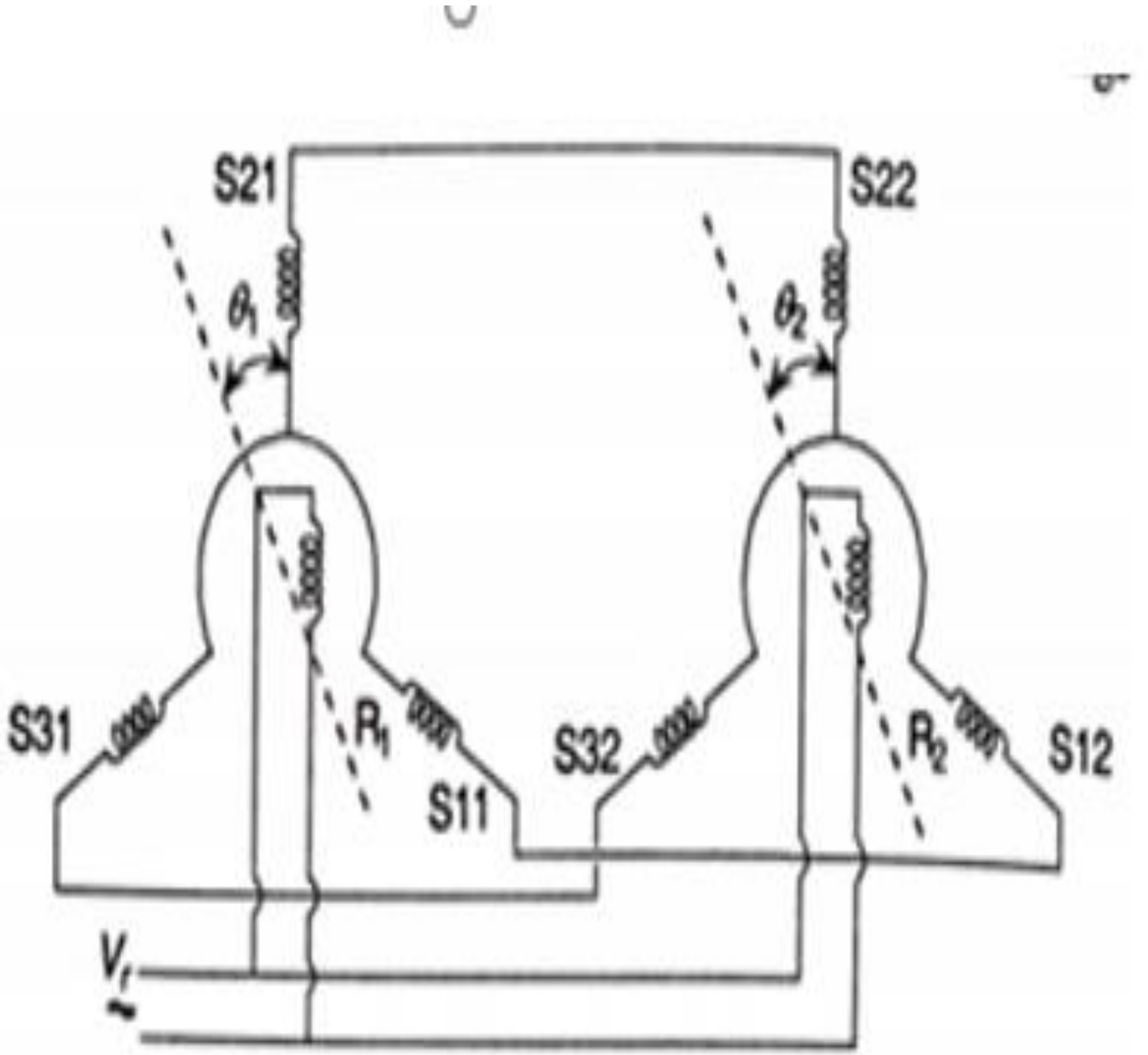
# CONSTRUCTIONAL FEATURE OF A SYNCHRO



# Synchros –Construction

- By changing the magnetic coupling between coils, ac-excited electromechanical sensors have been developed.
- For measurement at distant points, such devices are adopted and are known as synchros.
- Synchros, as sensors, are of two types, namely (i) torque type and (ii) control type.
- The general constructional features of a synchro are represented in figure
- It consists of a stator with three windings S1,S2 and S3 separated by 120 degree in space and a rotor R, which is supplied with an ac voltage .

# Torque Type Synchro Sensor



# TORQUE TYPE SYNCRO SENSOR

A rotation of the rotor R1 by an angle θ changes the voltages induced into the stator windings S11,S21 and S31 in magnitude and phase.

And since these windings are connected electrically to S12,S22 and S32 same voltages with phases as in those of windings of stator 1 produce a field so that rotor R2.

If not oriented as rotor R1 would receive a torque and rotation till it attains the same rotational position as that of R1.

With a scale arrangement the rotated angle thus produced, may be measured.

For single synchro unit such as that Fig 4.45 with the rotor angle θ for an input sinusoidal voltage $V_r = V_{ro} \sin\omega t$, the voltages induced in windings S1 and S2 and S3 are

$$V_{s1} = KV_{ro} \sin\omega t \cos(\theta + 120°) \tag{4.70a}$$

$$V_{s2} = KV_{ro} \sin\omega t \cos\theta \tag{4.70b}$$

and

$$V_{s3} = KV_{ro} \sin\omega t \cos(\theta + 240°) \tag{4.70c}$$

where $K$ is a constant, such as the ratio of the rotor to the stator turns. From Eqs. (4.70), the line voltages are

$$V_{s12} = K\sqrt{3}\, V_{ro} \sin\omega t \sin(\theta + 240°) \tag{4.71a}$$

$$V_{s23} = K\sqrt{3}\, V_{ro} \sin\omega t \sin(\theta + 120°) \tag{4.71b}$$

and

$$V_{s31} = K\sqrt{3}\, V_{ro} \sin\omega t \sin\theta \tag{4.71c}$$

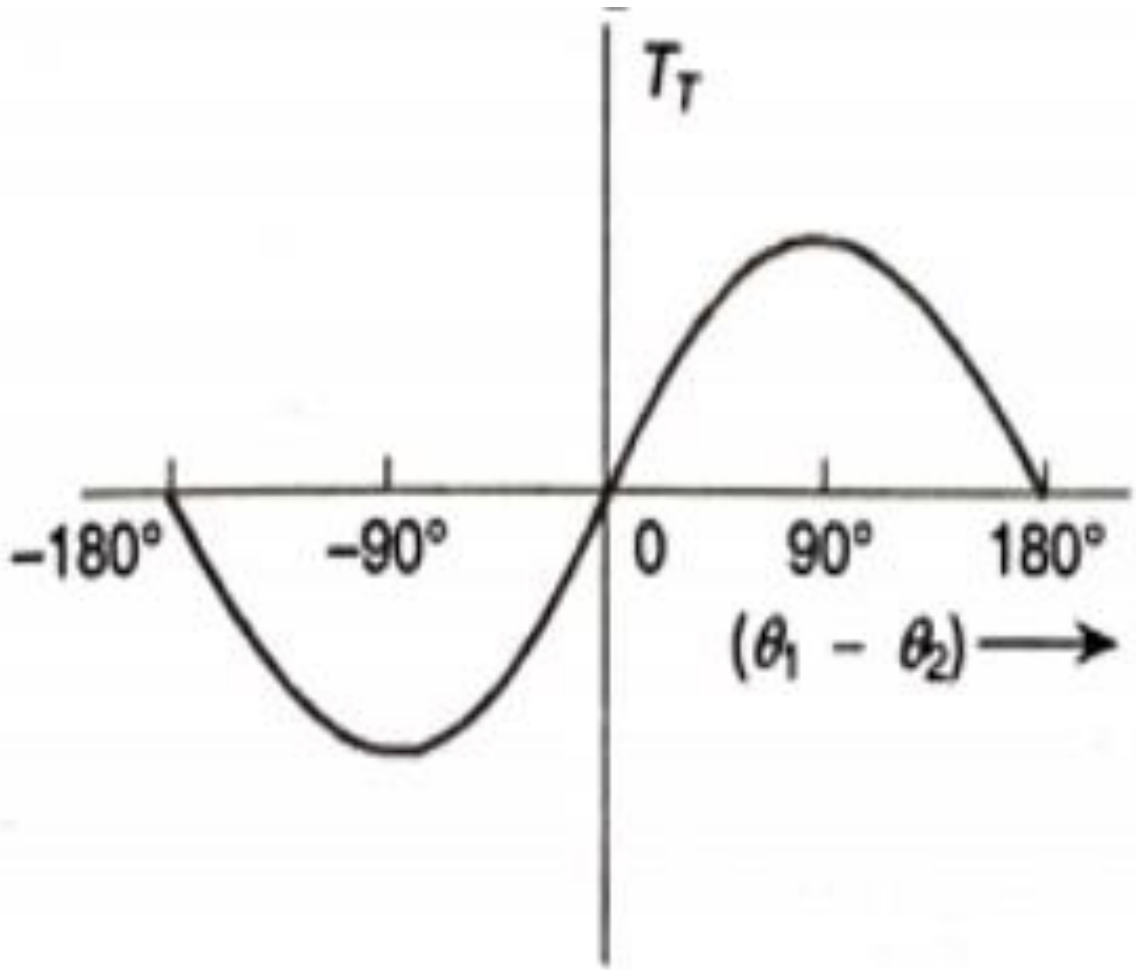
- If $\theta=0^0$ ,$V_{s2}=KV_{ro}$ $\sin\omega t$ that is a maximum and $V_{s31} = 0$.
- This position of the rotor is marked as the zero position or the reference position.
- In torque type sensors, it is tacitly assumed that $\theta_1=\theta_2$ .In such a situation there is no compensation current because of any unbalanced terminal voltages.
- If however $\theta_1 \neq \theta_2$ a torque would be produced on the receiver synchro rotor till the equality is achieved.

$$T \approx K_t \sin(\theta_1 - \theta_2)$$

- The torque is approximately sinusoidal in form
- maximum torque occurs at $\theta_1 \sim \theta_2 = 90^0$
- For $\theta_2$ approaches $\theta_1$ that is $\theta_1 - \theta_2$ being small, torque versus

  $(\theta_1 - \theta_2)$ curve is approximately linear

# TORQUE ANGLE CHARACTERISTICS CURVE



# CAPACITIVE SENSOR

- A capacitive sensor will react to an object acting as a dielectric material as well as a conductive object.
- Inductive sensors use a magnetic field to detect objects. Capacitive sensors use an electric field. In order to be sensed by an inductive sensor an object must be conductive
- Capacitive sensors are used for detecting a range of objects, from non-conductive and conductive material, to tiny objects, like insects, and larger ones, like a human. Using capacitance, sensing brings many advantages compared to other sensing technology.

# Capacitive Sensor-Types

1. Variable capacitance type with varying distance between two or more parallel electrodes
2. Variable capacitance obtained by variable area between the electrodes. An interesting variation of this is obtained by making serrated electrodes or electrodes with teeth, one of which moves
3. Variable capacitance obtained by having variable dielectric constant of the intervening material. For this the material has to move between the pair of electrodes, and the change in capacitance is obtained and measured
4. Piezoelectric type, depends on the piezoelectric properties of specific kinds of dielectric materials

# Capacitive Sensor-types

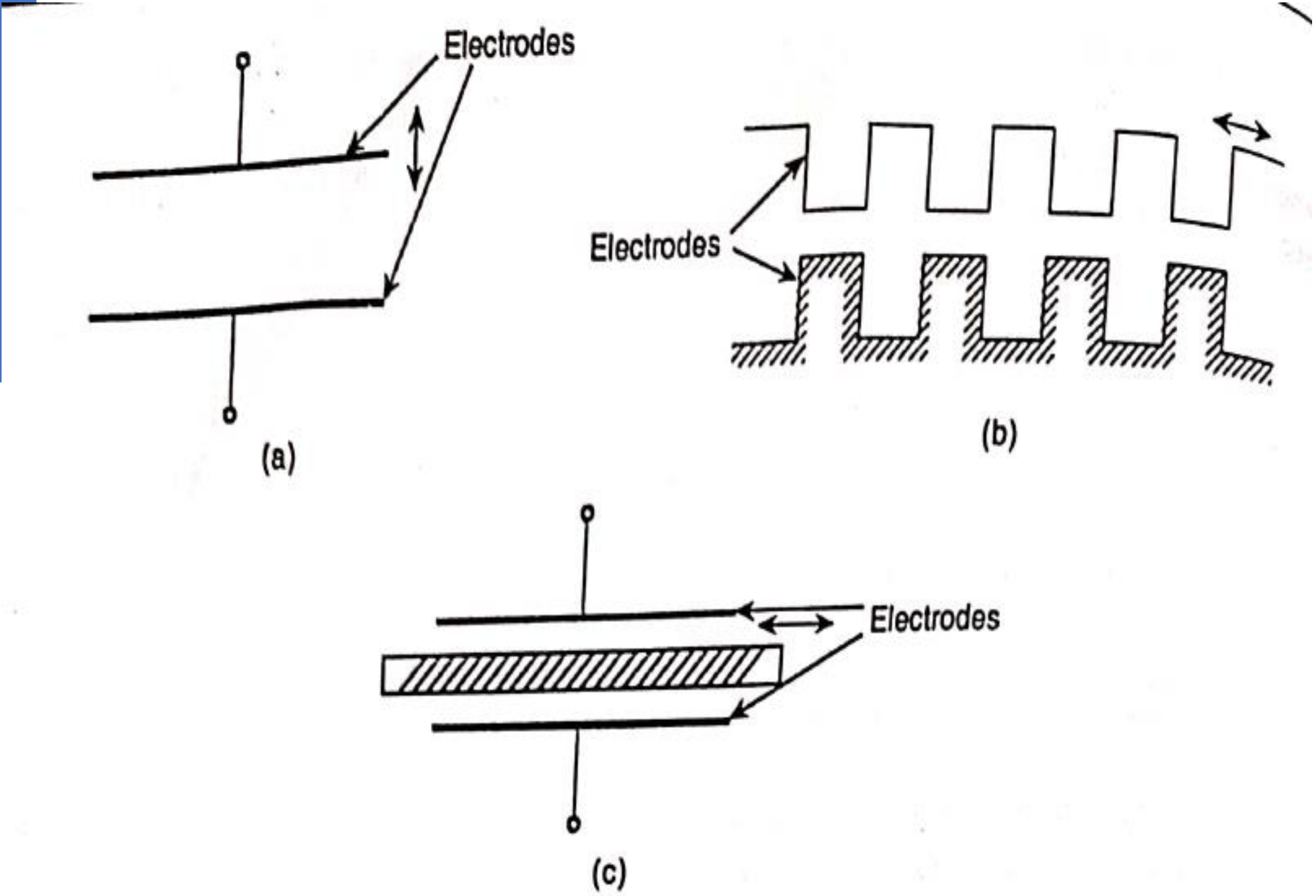


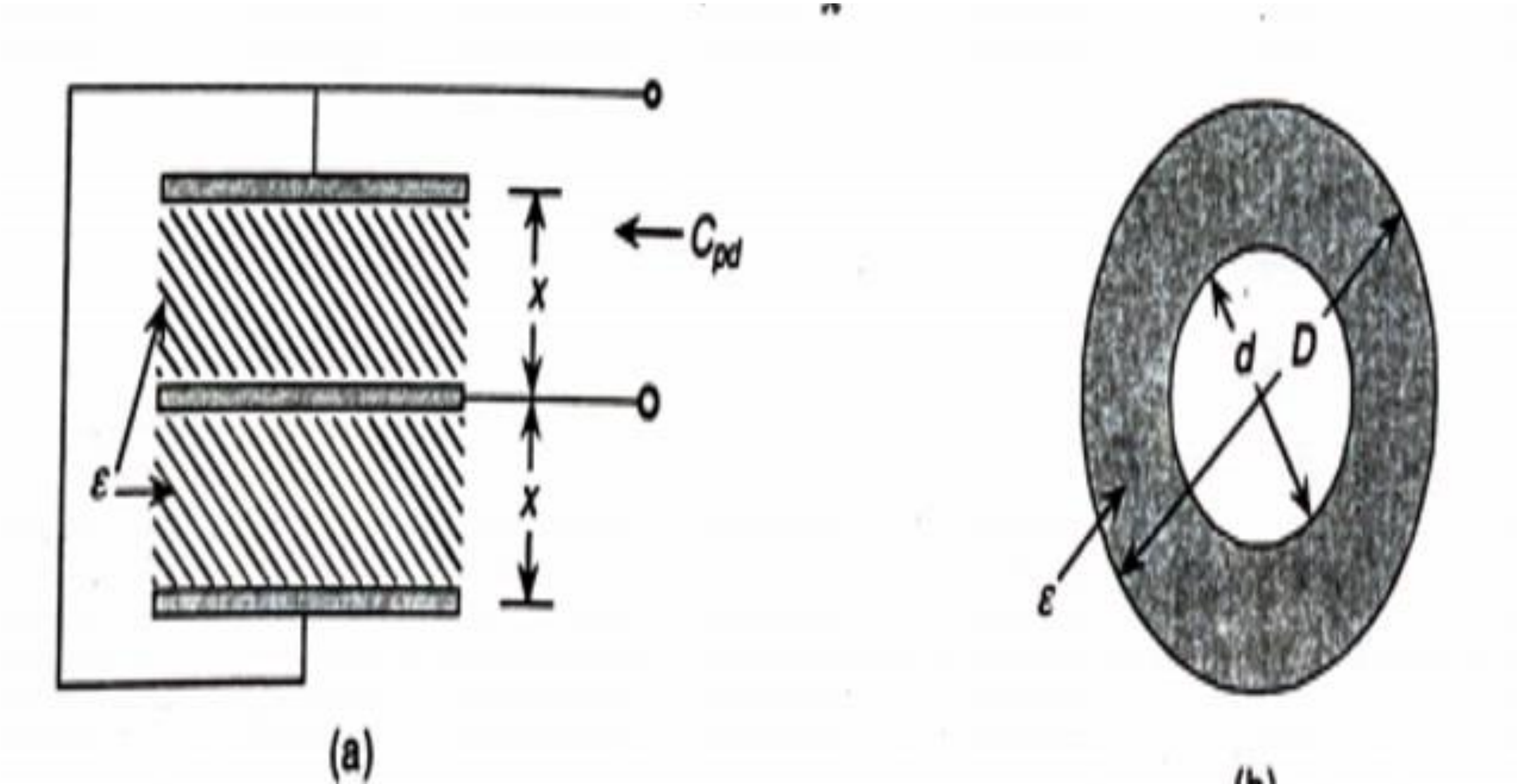

Fig. 2.35 (a) Parallel plate capacitance type, (b) capacitance type with serrated electrodes, and (c) capacitance type with varying dielectric type material.

# Capacitive Sensor

- A variation in parallel type design is the cylindrical design.
- Besides, the parallel plate capacitive sensor is often used in a differential form with three plates as shown in a Figure
- For a parallel plate capacitor with dielectric constant or permittivity $\varepsilon$ , which is the product of its relative permittivity and the permittivity of the free space (vacuum, often taken as air) of value 8.85 x $10^{-12}$ F/m and plate area a, each separated by a distance x from the other, the capacitance is

$$C_p = \varepsilon \alpha / x$$

# Capacitive Sensor
## a. Parallel plate capacitive sensor-3 plates,
## b. Cylindrical type



# Capacitive Sensor

$$C_c = \frac{2\pi\varepsilon l}{\ln(D/d)} \tag{2.88}$$

where $l$ is the cylinder length.
For very thin layer of dielectric material, Eq. (2.88) can be approximated to

$$C_{ca} = \frac{\pi\varepsilon l(D+d)}{(D-d)} \tag{2.89}$$

If in a parallel plate pair the dielectric has a number of layers of dielectric constants with corresponding permittivity $\varepsilon_i$ for thickness $x_i$, the relation (2.86) can be modified to

$$C_{pi} = \frac{\alpha}{\sum x_i/\varepsilon_i} \tag{2.90}$$

# Capacitive Sensor

- The capacitance is, in general, associated with a high resistance, called leakage, because the dielectric materials do not have infinite permittivity.
- This leakage is represented by a parallel resistance Rp, particularly at lower frequencies of measurement.
- This loss consists of dc conductance, dielectric loss of insulators supporting the electrodes, and the actual dielectric loss.
- With increasing frequency, the load resistances $R_l$ contribute to loss factors and the complete equivalent circuit is given by the circuit , where the inductance L represents the inductance between the terminals as also the cable inductance whenever such cable is used.

# Capacitive Sensor

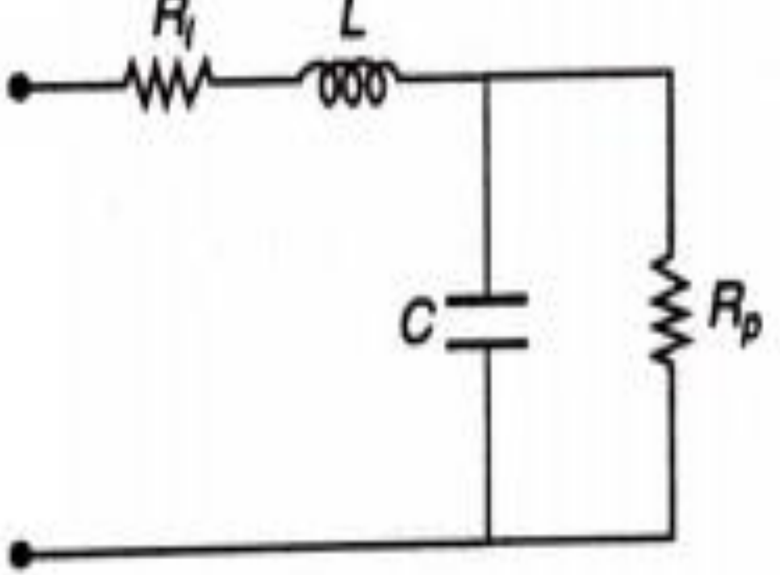



Fig. 2.37 Equivalent circuit of the capacitance transducer.

# PARALLEL PLATE CAPACITIVE SENSOR

- Considering now a general case of a pair of parallel plates with a solid dielectric of a certain thickness $x_s$ and an air gap $x_a$ as shown, the capacitance C is given by

$$C = \frac{\alpha}{\left(\frac{x_a}{\varepsilon_a}\right) + \left(\frac{x_s}{\varepsilon_s}\right)} \qquad (2.91)$$

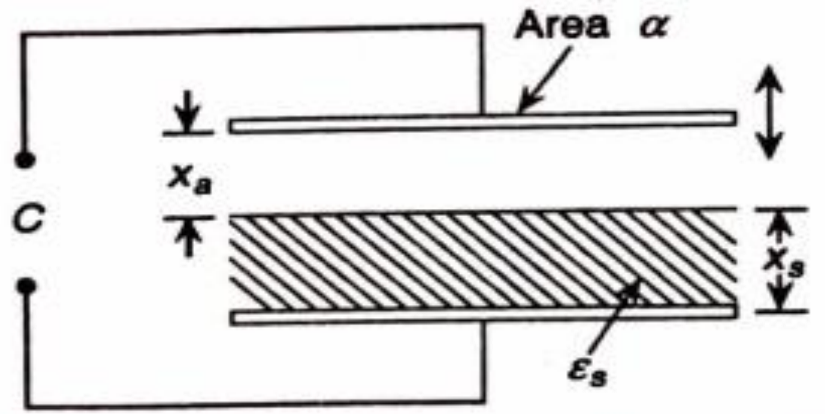



**Fig. 2.38** Parallel plate sensor with different dielectric materials.

# PARALLEL PLATE CAPACITIVE SENSOR

- It must be stressed here that capacitors have fringing effects which are usually taken care of by providing guard ring which is a ring surrounding a plate of the capacitor, the ring and the plate both being at the same potential.(refer pdf)

$$C = \frac{\alpha}{\left(\frac{x_a}{\varepsilon_a}\right) + \left(\frac{x_s}{\varepsilon_s}\right)} \tag{2.91}$$

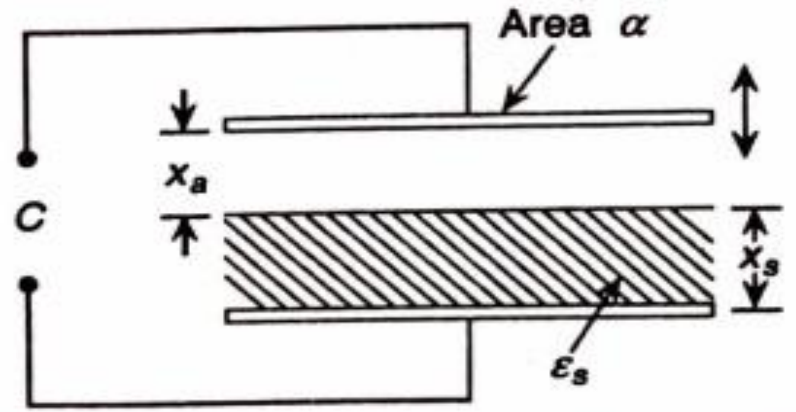



Fig. 2.38 Parallel plate sensor with different dielectric materials.

# Capacitive Sensor

- https://www.youtube.com/watch?v=QItuf6lNvmI - capacitive sensor
- https://www.youtube.com/watch?v=cFvh7qM6LdA - how do touch screen works?

## What is Dielectric Capacitive sensor

- Capacitance sensors (or Dielectric sensors) use capacitance to measure the dielectric permittivity of a surrounding medium.

*TO Know Real time application!*

- One application for such a device is measuring the water content of soil, where the volume of water in the total volume of soil most heavily influences the dielectric permittivity of the soil because the dielectric of water (80) is much greater than the other constituents of the soil (mineral soil: 4, organic matter: 4, air: 1). When the amount of water changes in the soil, a probe will measure a change in capacitance due to the change in dielectric permittivity that can be directly correlated with a change in water content. Capacitance sensors are now widely used in irrigation scheduling in agriculture around the world

## Cont…

- The normalized change in Capacitance

$$\left(\frac{\partial C}{C}\right)_{\varepsilon_d} = \pm\frac{\partial \varepsilon_d}{\varepsilon_d}\frac{1/[1+\varepsilon_d(l-x)/x]}{1 \pm \dfrac{1}{1+x/(\varepsilon_d(l-x))}\cdot\dfrac{\partial \varepsilon_d}{\varepsilon_d}}$$

Here, $1/(1+\varepsilon_d(l-x)/x)$ is the sensitivity factor $\beta_s$ and the nonlinearity factor $\eta_n = 1/(1+x/(\varepsilon_d(l-x)))$. If $\eta_n \partial \varepsilon_d/\varepsilon_d$ is small, we obtain, with first order approximation,

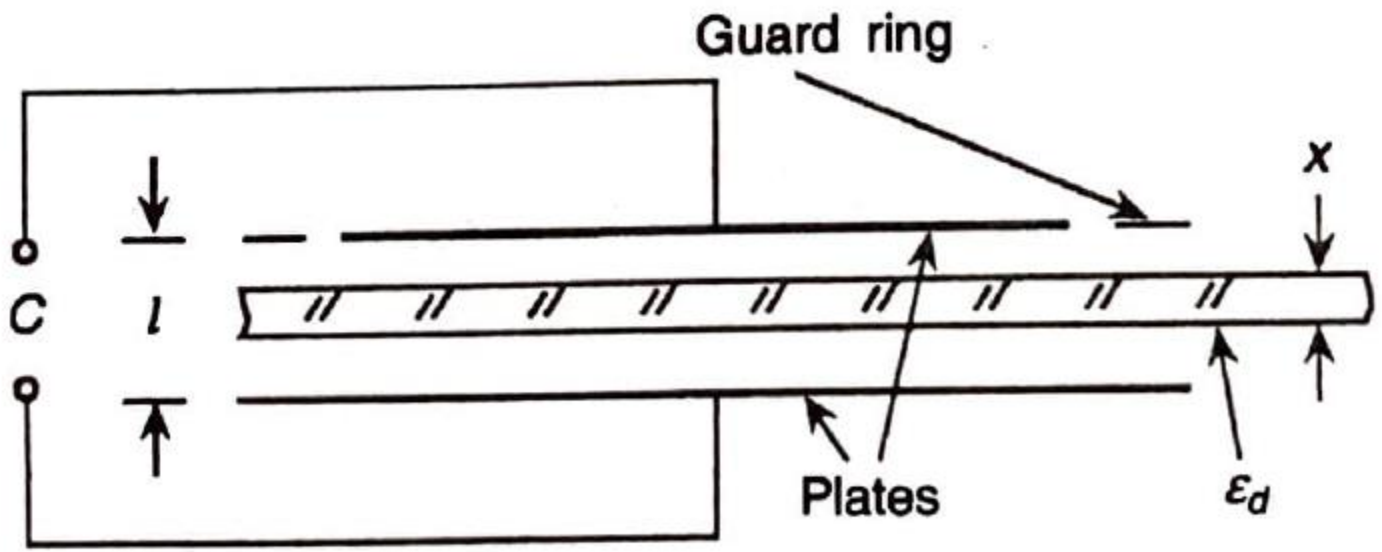
$$\left(\frac{\partial C}{C}\right)_{\varepsilon_d} = \frac{\partial \varepsilon_d}{\varepsilon_d}\cdot\frac{1}{1+\varepsilon_d(l-x)/x}\left[1 \mp \frac{\partial \varepsilon_d/\varepsilon_d}{1+x/(\varepsilon_d(l-x))}\right] \quad (2.1$$

Obviously, with $x/(l-x)$ high, $\beta_s$ is high and $\eta_n$ is low which must be a good choice. Instead of variation in $\varepsilon_d$, there may be variation in $x$, so that we have

$$\left(\frac{\partial C}{C}\right)_{x} = \frac{\partial x}{x}\frac{\dfrac{\varepsilon_d-1}{1+\varepsilon_d(l-x)/x}}{1 \mp \dfrac{\varepsilon_d-1}{1+\varepsilon_d(l-x)/x}\dfrac{\partial x}{x}} \quad (2.1($$

# Variable thickness dielectric capacitive sensor

- This type of capacitive sensors can be represented as shown below:




$\alpha$ is plate effective area

C is Capacitance

$\varepsilon_d$ is Permittivity of dielectric material

$$C = \frac{\alpha}{l - x + \frac{x}{\varepsilon_d}}$$

## Cont...

Obviously, with $x/(l - x)$ high, $\beta_s$ is high and $\eta_n$ is low which must be a good choice.

Instead of variation in $\varepsilon_d$, there may be variation in $x$, so that we have

$$\left(\frac{\partial C}{C}\right)_x = \frac{\partial x}{x} \frac{\dfrac{\varepsilon_d - 1}{1 + \varepsilon_d (l - x)/x}}{1 \mp \dfrac{\varepsilon_d - 1}{1 + \varepsilon_d (l - x)/x} \dfrac{\partial x}{x}} \tag{2.101}$$

and if $[(\varepsilon_d - 1)/(1 + \varepsilon_d (l - x)/x)]\partial x/x << 1$, taking the first order term only, the expression for $(\partial C/C)_x$ is obtained as

$$\left(\frac{\partial C}{C}\right)_x = \frac{\partial x}{x} \frac{\varepsilon_d - 1}{1 + \varepsilon_d (l - x)/x} \left[1 + \frac{\varepsilon_d - 1}{1 + \varepsilon_d (l - x)/x} \frac{\partial x}{x}\right] \tag{2.102}$$

In this case, the sensitivity factor and the nonlinearity factor are identical and given by $(\varepsilon_d - 1)/(1 + \varepsilon_d (l - x)/x)$. It means that the sensitivity is good with high $x/(l - x)$ as also $\varepsilon_d$, but the nonlinearity also increases.

# Electrostatic transducer

- A transducer consisting of a fixed electrode and a movable electrode, charged electrostatically in opposite polarity; motion of the movable electrode changes the capacitance between the electrodes and thereby makes the applied voltage change in proportion to the amplitude of the electrode's motion.

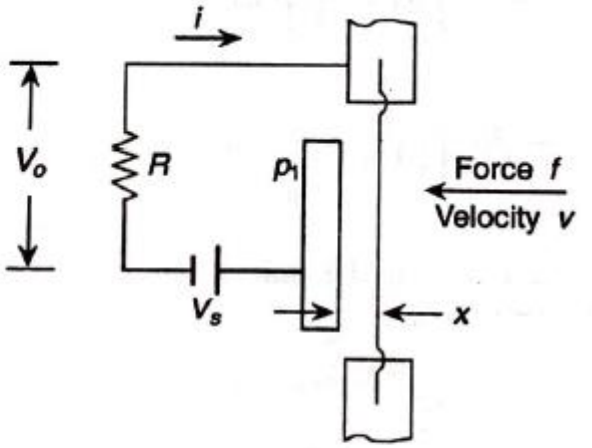
# Electrostatic transducer

- https://www.youtube.com/watch?v=KGhFYSk4zJI -

  Electrostatic Loudspeaker (ESL) Technology

# Electrostatic transducer

- Similar to the electromagnetic transducer, capacitive type transducer can also be developed with bilateral characteristics, where it is used with dc polarization. Such a transducer is also referred to as an ***electrostatic transducer***.




- A capacitor is formed with a 'flexible' diaphragm which can move due to application of force and a rigid plate $p_1$. There is bias voltage $V_s$ which is sufficiently large.

# Cont...

- When the system acts as a transducer, the gap x between the plates changes as by some pressure in case of an 'electrostatic microphone'.
- This pressure may be considered sinusoidal in nature for analysis purpose.
- A circuit consisting of a resistance $R$ and capacitance $C$ 'varying sinusoidally' allows $V_s$ to send a sinusoidal current $i$ to flow in it and hence, a sinusoidal output $V_0$ across resistance $R$ is obtained.
- Analysing as in the case of electromagnetic transducer, $V_o$ corresponding to a force $f$ can be obtained in terms of $V_s$, $x$, $R$, $C$, $\omega$, mass $m$, stiffness $k$, and damping $(\zeta)$

# Cont…

- The dynamic transfer function is given by

$$\frac{V_o(s)}{f(s)} = \frac{s x_o R C_o V_s}{s^3 x_o^2 m R C_o + s^2 (m x_o^2 + x_o^2 R C_o \zeta) + s(x_o^2 \zeta + x_o^2 R C_o k) + (x_o^2 k + V_s^2 C_o)}$$

- Where *Co* and *xo* are the initial values of *x* and *C*
- Where *S* can be replaced by $j\omega$ , where ω is the input circular frequency
- Frequency response of this shows a flat response up to a frequency $\omega_o = (k/m)^{1/2}$,

at which a resonance occurs and range is obviously specified by the same.

- Also below $\omega_o = (k/m)^{1/2}$, the response is not constant.
- Hence the frequency $(\omega_o - \omega_b)$
- In case of generating action, along with bias *Vs* , a sinusoidal input voltage is also applied.
- So that the diaphragm undergoes electrostatic vibration.

# Photoelectric Elements

https://www.youtube.com/watch?v=P33-CQlwKLQ -photo electric transducer|Photoelectric working|Animation

# PIEZOELECTRIC ELEMENTS

- Piezoelectricity is the ability of certain crystals to produce a voltage when subjected to mechanical stress (the substance is squeezed or stretched)
- Conversely, a mechanical deformation (the substance shrinks or expands) is produced when an electric field is applied- “reverse piezoelectric effect” ...
- https://www.slideshare.net/iamaproudindian/44-azeem
- https://www.teachengineering.org/activities/view/uoh_piezo_lesson01_activity1 - Building a Piezoelectric Generator
-

# Cont…

- Crystals of certain classes are said to show piezoelectric effect which essentially means electric polarization produced by mechanical strain in the crystals. Such a polarization is believed to occur because of asymmetric crystal structure.
- The effect is reversible in the sense that a strain may be produced in the crystal by electrically polarizing it using an external source .
- While the mechanical input to electrical output form is used in developing transducers extensively, the reverse effect is used in many modem gadgets such as sonar systems, ultrasonic non-destructive test equipment, ultrasonic flowmeters, pump for inkjet printers, and so on.

# Cont…

- Also a piezoelectric crystal is represented by a · set of three Cartesian coordinates so that the
- polarization P can be represented in the vector form as

$$\mathbf{P} = P_{xx} + P_{yy} + P_{zz}$$

- However, Pxx, Pyy, Pzz are again related to the stresses, axial and shear, σ and *X* in terms of axes-dependent coefficients caned d-constants of the crystal. With the axial and shear axe as shown in figure with reference to the crystal axes X-Y-Z, we obtain

$$\begin{bmatrix} P_{xx} \\ P_{yy} \\ P_{zz} \end{bmatrix} = \begin{bmatrix} d_{11} & d_{12} & d_{13} & d_{14} & d_{15} & d_{16} \\ d_{21} & d_{22} & d_{23} & d_{24} & d_{25} & d_{26} \\ d_{31} & d_{32} & d_{33} & d_{34} & d_{35} & d_{36} \end{bmatrix} \begin{bmatrix} \sigma_{xx} \\ \sigma_{yy} \\ \sigma_{zz} \\ \chi_{yz} \\ \chi_{zx} \\ \chi_{xy} \end{bmatrix}$$

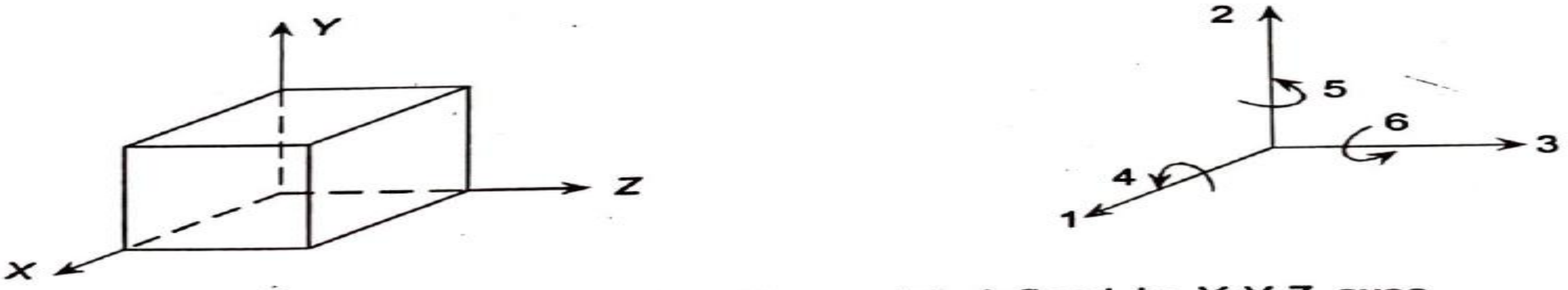



Fig. 2.44 The piezoelectric crystal defined in X-Y-Z axes.

# Cont…

- The d-constants are defined as:
- $d_{ij}$ = Charge generated in direction i/ force applied in direction j

  $= Q_i / f_j$
- The reverse effect d-coefficients are similarly defined as

  $d_{ij}$ = Strain in direction i/ field applied in direction j

  $= \varepsilon / E$ expressed as (m/m) / (V/m)
- Once other coefficient which is of importance in practical design is the g-coefficient and its related to the d-coefficient by the dielectric constant of the material.

# Cont…

- It is defined as the voltage gradient or field in the crystal per unit pressure imparted to it.
- Maintaining the direction as before, it can be shown that

$$g_{ij} = \frac{Q_i}{\varepsilon_d f_i} = \frac{d_{ij}}{\varepsilon_d}$$

- The third coefficient h-coefficient is defined as the voltage gradient per unit strain which also appears to be the reciprocal of $d_{ij}$.
- The h coefficient is easily obtained by g-coefficient by multiplying it with young's modulus in the appropriate direction.

# Cont…

- Crystals of various uses are characterized by coupling coefficient which actually is a measure of the efficiency of the crystal as energy converter.
- The numerical value of coupling coefficient is given by

$$K_{ij} = (d_{ij}\ h_{ij})^{1/2}$$

- The value of $d_{11}$ for
  - quartz is $2.3 \times 10^{-12}$ coulombs/N
  - dielectric constant is $4.06 \times 10^{-11}$ F/m.
  - $g_{11}$ is $56 \times 10^{-3}$ (V/m)/(N/m2)

# Piezoelectric materials

- Materials are divided into 2 groups:

(i) Occur naturally such as Quartz, Rochelle salt $NaKC_4H_4O_6$, $4H_2O$, tourmaline

(ii) those produced synthetically such as lithium sulphate (LS), $NH_4H_2PO_4$ or ammonium dihydrogen Phosphate (ADP), $BaTiO_3$ or barium titanate (BT).

- Barium titanate is actually a ferroelectric ceramic and requires to be polarized before use.
- Besides, there are certain polymer films which also exhibit the piezoelectric property.

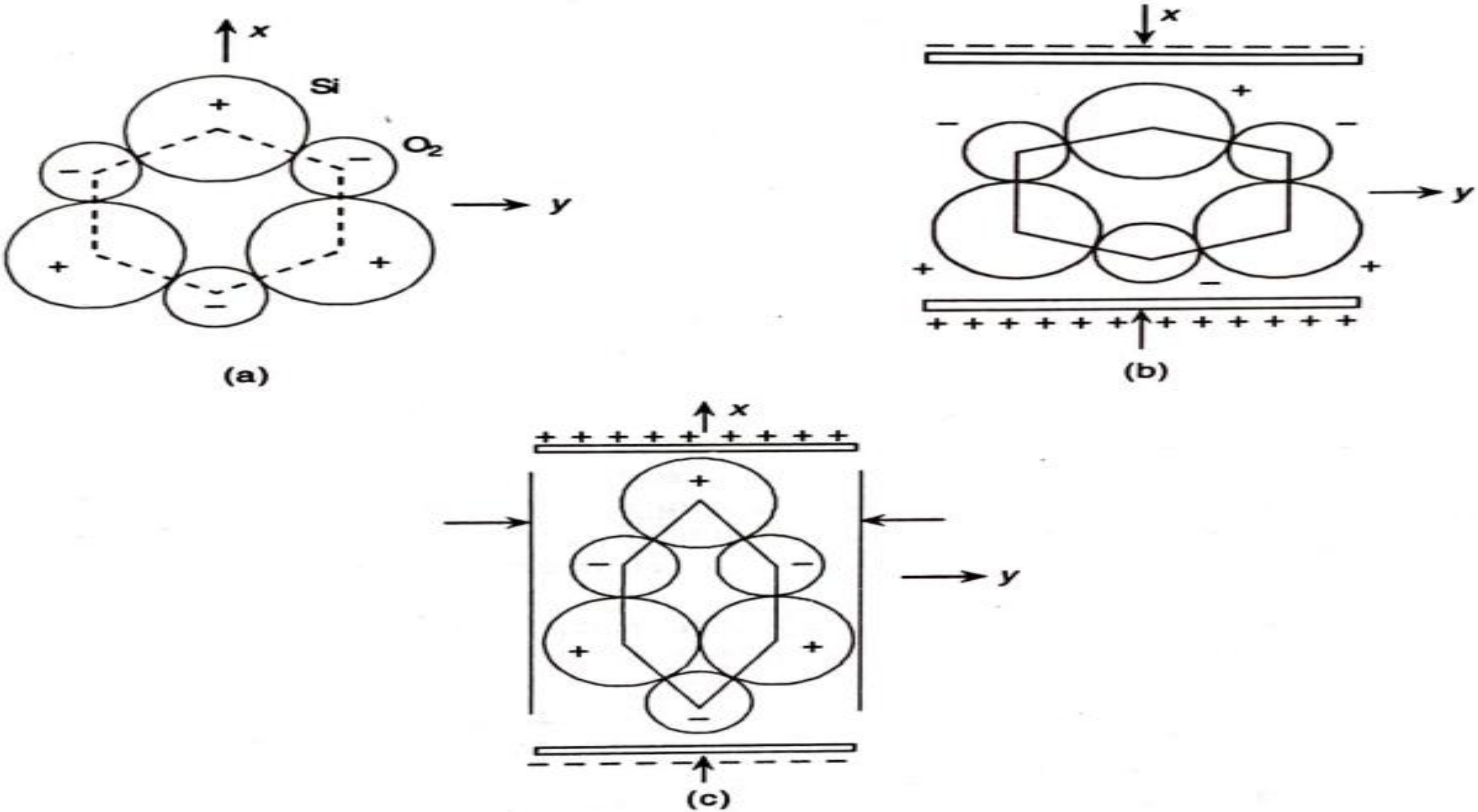



**Fig. 2.45** (a) The quartz crystal model, (b) charge generation with force applied in the direction of the electrodes, and (c) charge generation with the force applied perpendicular to the position of electrodes.

- The material properties that are relevant to the piezoelectric sensors are

  (i) dielectric constant,

  (ii) d-coefficients (xx, say),

  (iii) resistivity (specifically, volume resistivity is considered),

  (iv) Young's modulus,

  (v) humidity range (since above or below this range large absorption of moisture occurs changing volume resistivity and performance characteristics),

  (vi) temperature range, and

  (vii) density.

- A comparative study of these properties is made in Table

**Table 2.5** Properties of piezoelectric materials

| Material | $d$ (relative) | $d_{xx}$ ($\times 10^{-12}$) (cou/N) | $\rho_v$ ($\Omega - m$) | $Y$ ($\times 10^9$) ($N/m^2$) | $H_R$ (%) | $T_R$ (°C(max)) | Density ($\times 10^3$) ($kg/m^3$) |
|---|---|---|---|---|---|---|---|
| Quartz | 4.5 | 2.3 | $10^{12}$ | 80 | 0–100 | 550 | 2.65 |
| Rochelle Salt | 350 | 550 | $10^{10}$ | 10–20 | 40–70 | 45 | 1.77 |
| Tourmaline | 6.7 | 2–2.25 | $10^{11}$ | 160 | 0–100 | 1000 | 3.10 |
| LS | 10.3 | 13–16 | $10^{10}$ | 46 | 0–95 | 75 | 2.05 |
| ADP | 15.3 | 25–45 | $10^{8}$ | 19.5 | 0–94 | 125 | 6.8 |
| Titanates | 500–1750 | 80–500 | $10^{9}$–$10^{13}$ | 47–80 | — | 200–400 | 5.8–7.8 |

- Inspite of some deficiencies such as

❖ low mechanical strength,

❖ limited humidity and temperature range,

❖ large hysteresis, and

❖ fatigue,

- **Rochelle salt** is often used in microphones also in gramophone pickups because of high shear sensitivity and peimittivity.

- **Tourmaline** has poor sensitivity ($d_{xx}$ = 2-2.5) and is costly. It is, therefore, rarely used as a sensor of this type. But it has two specific advantages-

(i) it has a long, perhaps the longest, temperature range

(ii) it is the only naturally occurring variety that shows large volume expander mode capability, that is, with high force in all three directions it gives a large d-value in *x*-*x* direction.

- **Lithium Sulphate** is good in volume-expander mode but ammonium dihydrogen phosphate is used quite extensively for acceleration and pressure sensing purposes although it has low permittivity. It can also be used in twisting applications.
- **Barium titanate (BaTiO3)-**a polycrystalline ceramic has high $\varepsilon_d$ and with induced polarization is very conveniently used in many transducers.
- Ferroelectric materials can be analyzed analogous to the ferromagnetic ones and its polarization is effectively explained with the help of the **'domain'** structure.
- The material is assumed to consist of **'zones'** with spontaneous polarization (for example, Weiss zones in ferromagnetic) which can be partially oriented by the application of external electric field.

# Cont…

- A barium titanate crystal is modelled as shown in figure

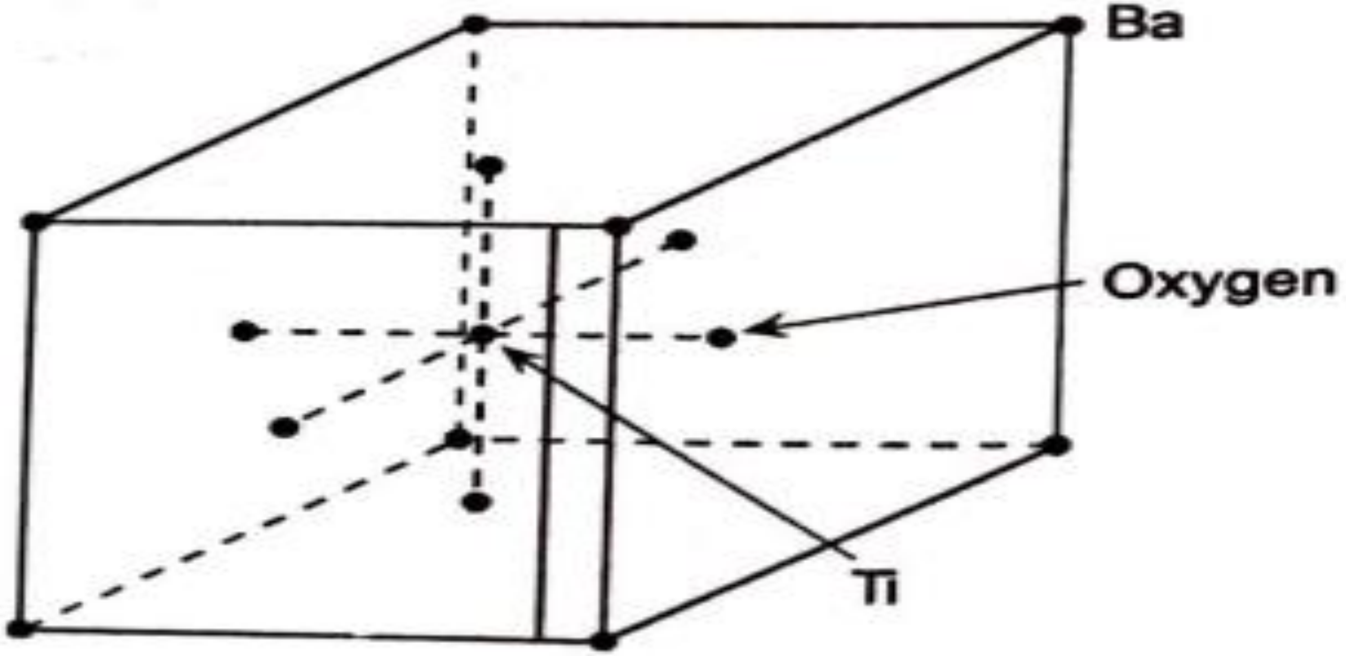



Fig. 2.46 The model of a $BaTiO_3$ crystal.

- For transducers, **Lead Zirconate titanate** has been found to be more suitable than the simple ones suggested previously.
- Lead zirconate titanate is a solid solution of lead titanate and lead zirconate which is only 10-60 mole percent of the former.
- Depending on the amount of lead zirconate and also on processing techniques, values of d-coefficients differ greatly, the **Curie point** being pushed up in almost all the cases from **200° to 300°-350°C**.
- Another composition consists of lead actaniobate which has the highest Curie point.
- The dielectric constant, d-coefficients, and dissipation in a ferroelectric ceramic change with temperature.

# Cont…

- The nature of such changes are shown in relative response plots in Figure.

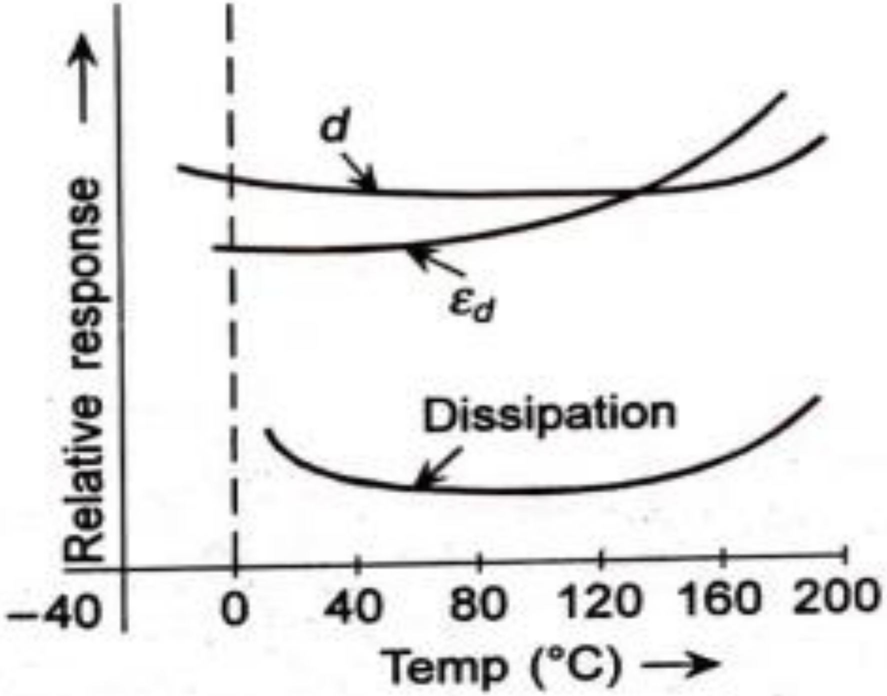



**Fig. 2.47** Relative response-temperature curves for *d*-coefficients, dielectric constant and dissipation of $BaTiO_3$.

# Cont…

- These can be compared with those of quartz, specially the variation of d-coefficients and $\varepsilon_d$ as shown in figure

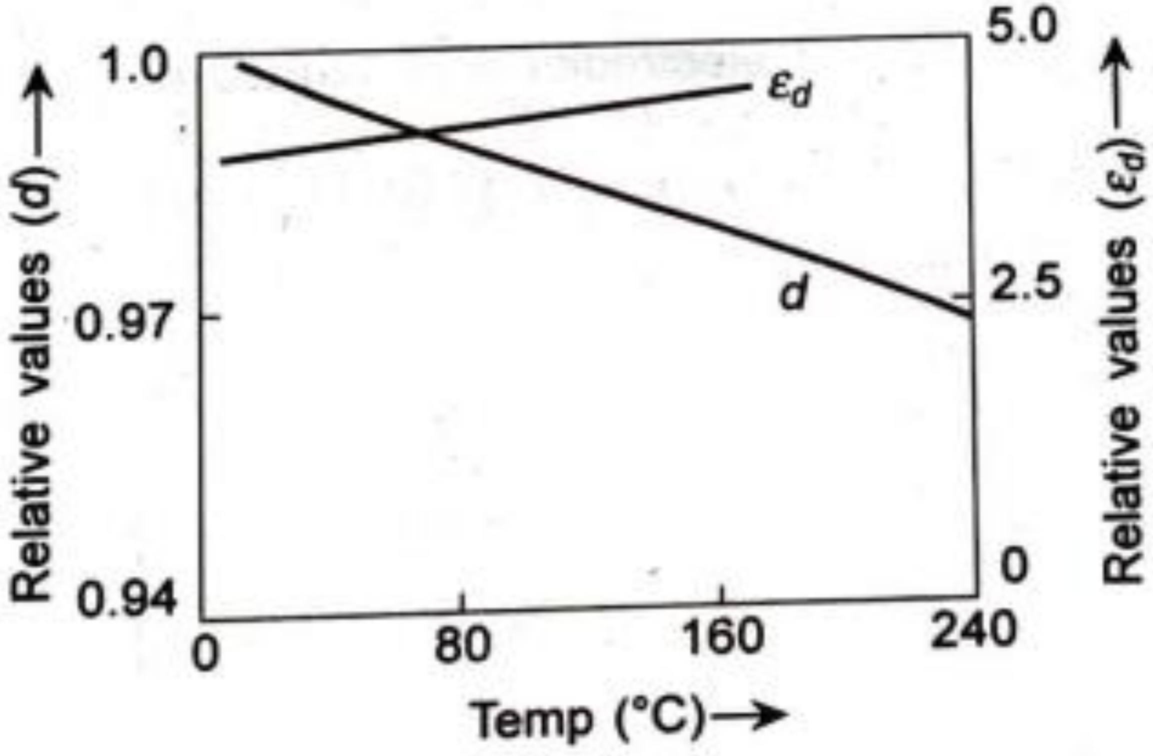



**Fig. 2.48** Variation of *d*-coefficients, dielectric constant with temperature for quartz.

- **Titanates** are synthetically produced by pressure, film-casting or extrusion, and finally sintering-the ohmic contacts are obtained by silver or palladium coating on which soldering of lead-wires can he done before polarization.
- Polarization is usually affected at a voltage, of 2 KV/mm and is kept for a few minutes depending on the material.
- Considering quartz sensor of thickness *t* obtained by cutting perpendicular to its x-axis, two faces which have same areas (alpha each) and are perpendicular to axis are metalized.
- Consider force $f_x$ in x direction

Charge $Q_x$ $$Q_x = d_{11} f_x$$

# Cont…

$$Q_x = d_{12}\left(\frac{l_y}{l_x}\right) f_y$$

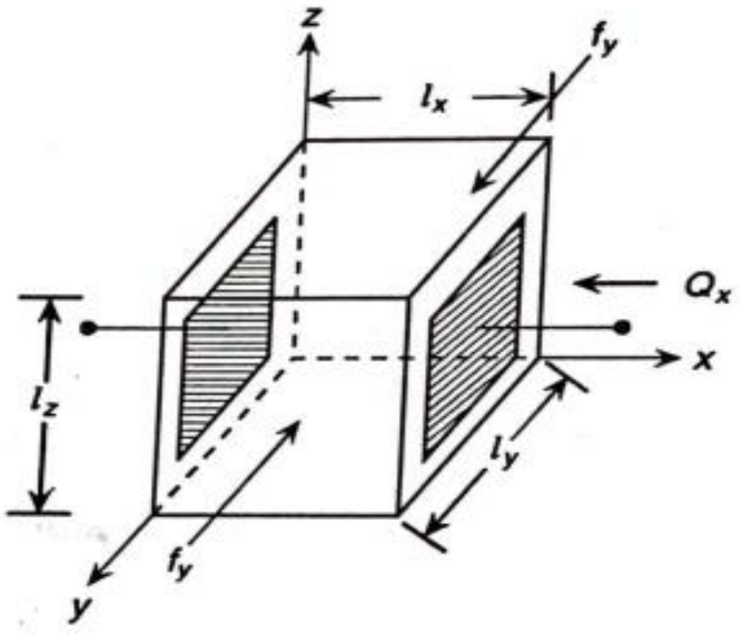



**Fig. 2.49** A crystal with electrodes and marked dimensions.

- Capacitance $C_x$ is given by

$$C_x = \frac{\varepsilon_d \alpha}{t}$$

- Voltage $V_x$

$$V_x = \frac{Q_x}{C_x} = \frac{d_{11} f_x t}{\varepsilon_d \alpha}$$

- For a crystal of dimension as shown in figure, force $f_y$ in y direction and the charge in perpendicular to x-direction is given by,

$$Q_x = d_{12}\left(\frac{l_y}{l_x}\right) f_y$$

- However, for quartz, all the d-coefficients given in below Equation are not finite nonzero values. In fact, the d-matrix for quartz is given as

$$[d] = \begin{bmatrix} d_{11} & -d_{11} & 0 & d_{14} & 0 & 0 \\ 0 & 0 & 0 & 0 & -d_{14} & -2d_{11} \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

- The Q $_x$ equation is modified as $$Q_x = -d_{11}\left(\frac{l_y}{l_x}\right)f_y$$

- Voltage V $_s$ $$V_x = \frac{-d_{11} f_y}{\varepsilon_d \, l_z}$$

# DEFORMATION MODES AND MULTIMORPHS

- Piezoelectric sensors can produce outputs in the form of charge or voltage with force, acceleration, velocity (as displacement) and deformation (in crystals)
- The deformation are of different types depending on application of input, accordingly number of modes are listed:

  TEM (Thickness Expander Mode)

  LEM (Length Expander Mode)

  TSM (Thickness Shear Mode)

  FSM (Face Shear Mode)

  VEM (Volume Expander Mode)

Note: Shear stress, force tending to cause deformation of a material by slippage along a plane or planes parallel to the imposed stress. Shear stress may occur in solids or liquids; in the latter it is related to fluid viscosity.

# Deformation modes

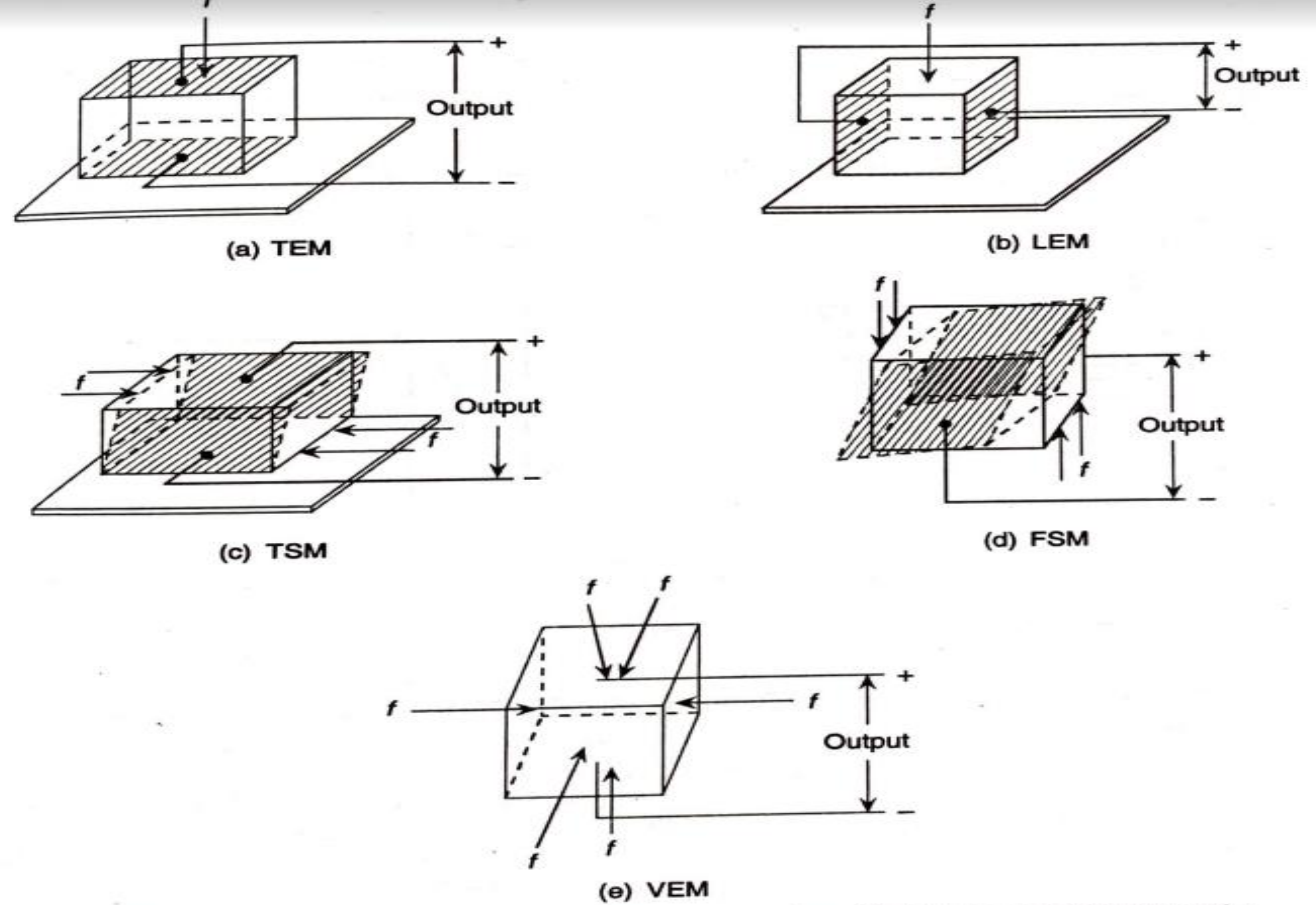



**Fig. 2.50** Representation of different deformation modes: (a) thickness expander mode, (b) length expander mode, (c) thickness shear mode, (d) force shear mode, and (e) volume expander mode.

# DEFORMATION MODES AND MULTIMORPHS

- **Bimorphs :** Instead of a single element sensor, it is possible to cement together two such elements as in a sandwich to obtain larger (ideally double) output called bimorphs.
- Can be obtained by series sandwiching or by parallel arrangement
- **Multimorphs:** If more than two elements are connected then they are called as multimorphs
- In figure, polarization of two plates with respect to each other is different so that the parallel or series arrangement can be achieved.

# Multimorphs

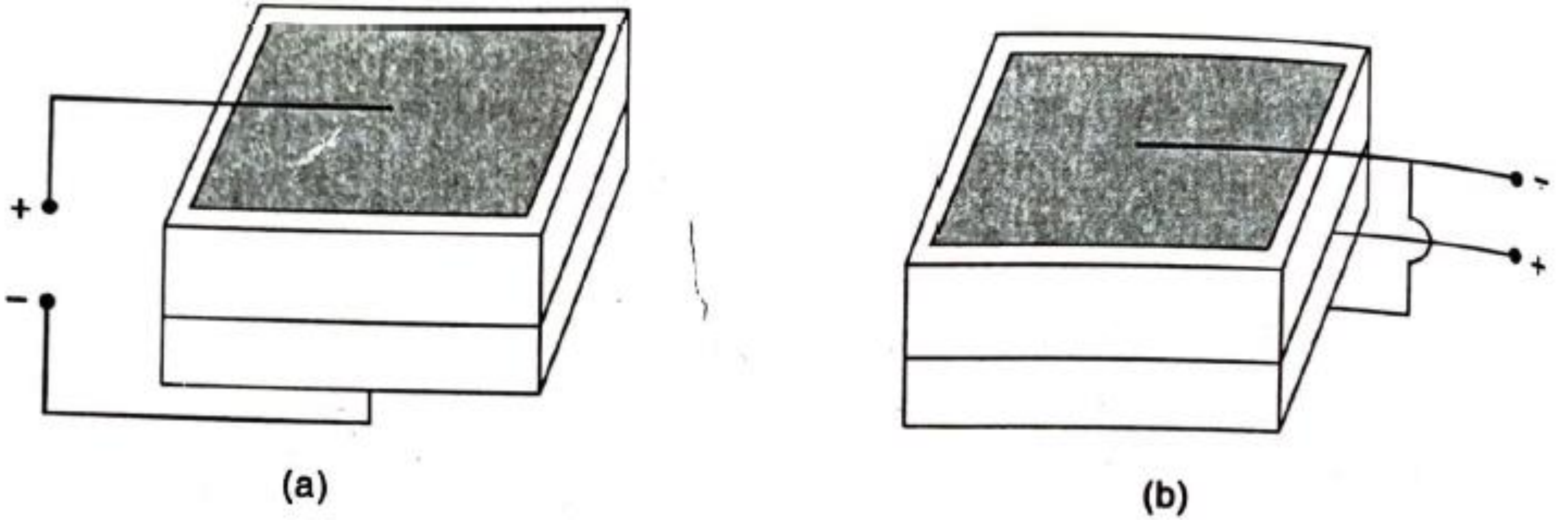



Fig. 2.51 Multimorphs: (a) series, (b) parallel.

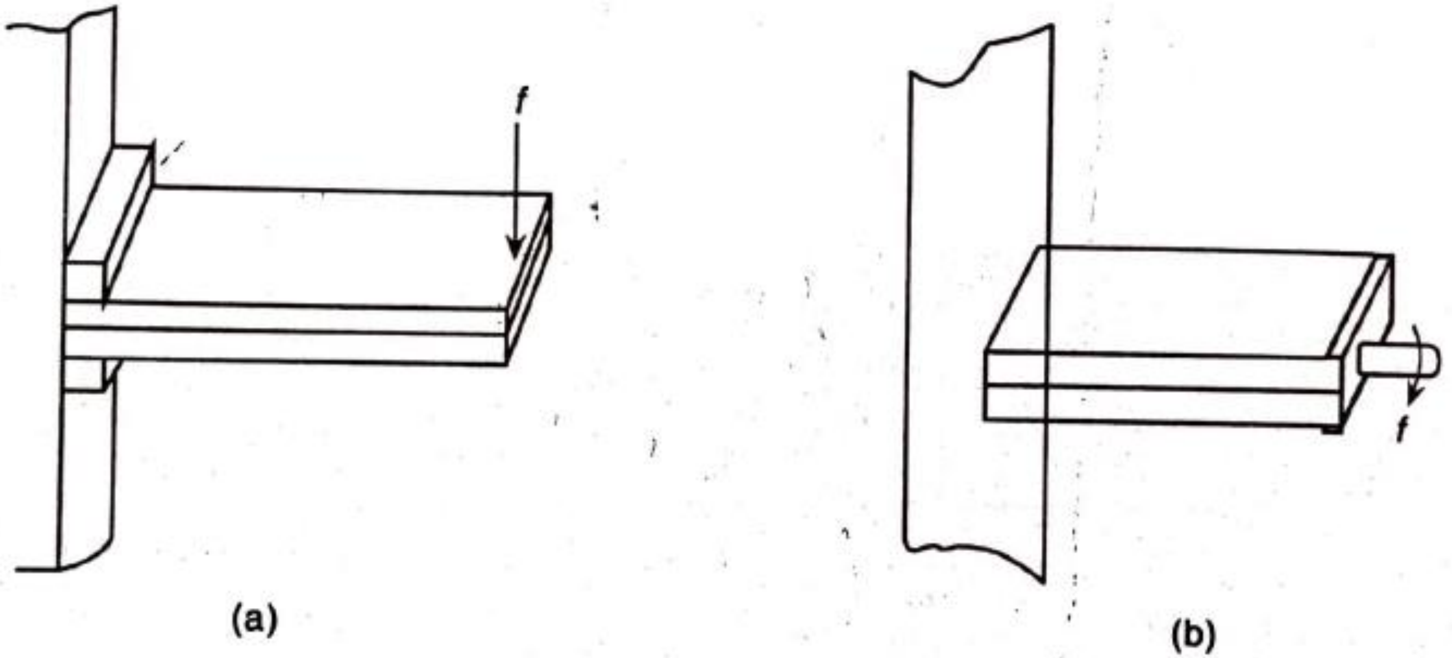
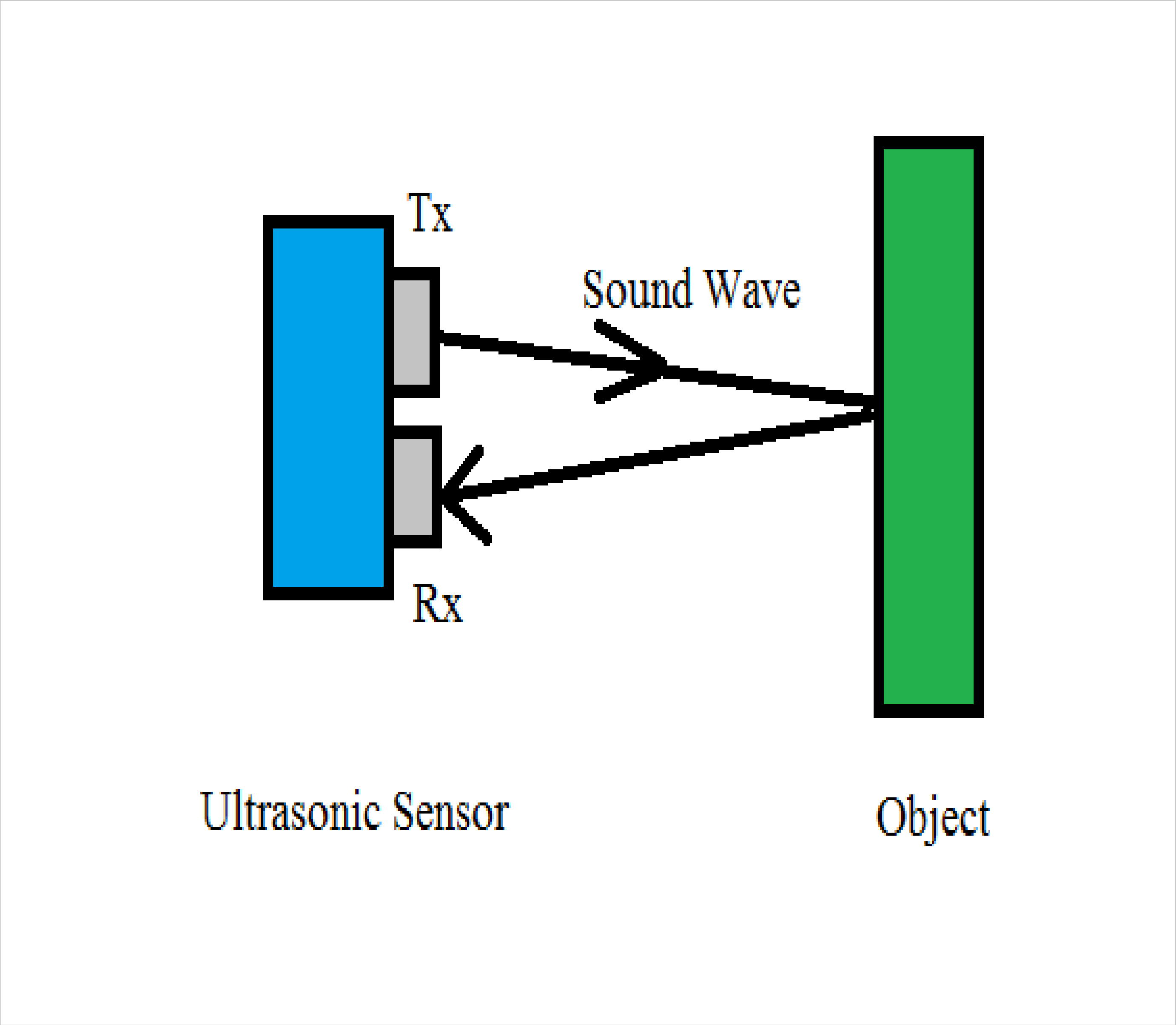



Fig. 2.52 Multimorphs applied in (a) bending, (b) torque.

# ULTRASONIC SENSORS

- Ultrasonic sensors work **by emitting sound waves at a frequency too high for humans to hear**. They then wait for the sound to be reflected back, calculating distance based on the time required. This is similar to how radar measures the time it takes a radio wave to return after hitting an object



# ULTRASONIC SENSORS

- https://www.youtube.com/watch?v=vf2lW4LkmMQ - Ultrasonic sensor working principle
- https://www.youtube.com/watch?v=JNQAH3VMFTU - Ultrasonic sensors – the alternative for difficult surfaces

# Calculation of Sensitivity

- Sensitivity is an important parameter to describe the electro-acoustic transducer energy conversion efficiency, and is a key indicator of transducer performance.
- Sensitivity is simply defined as the ratio of an output quantity to an input quantity.
- For an ultrasonic transducer characterized as a two-port network, there are the mechanical quantities of force and velocity (F, v) at the acoustic port and quantities of voltage and current (V, I) at the electrical port.
- Since an ultrasonic transducer can be used as either a transmitter or a receiver, there are a variety of sensitivities that can be defined from these quantities

## Cont…

- The sensitivity is measured based on reciprocity and pulse-echo methods.
- One transducer always used as receiving. Two another transducers were used sequentially as transmitters. The radiating sensitivities of these transducers were compared with each other.
- The sensitivity in logarithmic units can be written as

$$S = 20\log_{10}\left(\frac{V_{out}}{V_{in}}\right),$$

- Where, $V_{in}$ – voltage applied to transmitting transducer

  $V_{out}$ – amplitude of voltage recorded at receiving transducer.

# HOW CAPACITOR MICROPHONE WORKS?

- The vast majority of capacitor microphones works by which, both 'true' DC-polarized condensers and back-electret models that are based around a metal-covered plastic diaphragm.
- Gold evaporated or sputtered onto mylar is a popular combination, the resultant diaphragm membrane being thinner than a human hair.
- This diaphragm is supported in front of a metal backplate, and these two conductive 'plates' form a simple capacitor — a device which can be used to store electrical charge.

- https://www.youtube.com/watch?v=ekIYaHgzt5c -Capacitive transducer
- https://www.youtube.com/watch?v=PE6Qn4ZiEyo-A Quick Guide to Microphones

# ROLE OF CAPACITOR IN MICROPHONE

- The amount of charge that can be stored is proportional (amongst other things) to the distance between the two plates.
- Consequently, most capacitor microphones work by detecting the minuscule changes in stored charge which occur when the diaphragm moves relative to the backplate in response to passing sound waves.
- The stored charge can be generated in a couple of different ways: either by using a relatively high DC polarization voltage, usually derived from phantom power; or by using a permanently charged film fixed to the backplate of the mic (the so called 'back electret' design).

- In both cases, it is vital that the stored charge doesn't leak away, so the audio output circuitry has to present an extremely high impedance.
- Thus all capacitor microphones incorporate a suitable impedance-matching preamplifier very close to the capsule, based either on solid-state FETs or valves.
- The aim is to present an extremely high input impedance to the capsule, but a very low output impedance to the microphone cable.
- Regardless of the way in which the stored charge is generated, both kinds of capacitor microphone obviously require power for the internal impedance-matching preamp.
- This is usually obtained from phantom power again, but some mics can be operated from an internal battery instead, and valve microphones are usually powered from a dedicated mains PSU.

# MICROPHONE RESPONSES AND MEASUREMENTS

- Microphones have various properties that determine how they interact with sound.
- There are five key properties to consider, including:
    - Frequency Response
    - Transient Response
    - Self-Noise
    - Maximum Sound Pressure Level
    - Dynamic Range

# FREQUENCY RESPONSE

- The frequency response is the output level or sensitivity of a microphone over its operating range from the lowest to highest frequency.
- A frequency response curve is a graphical representation of how a microphone will respond in the audio spectrum and so, how it will affect a signal's overall sound timbre.
- On a frequency response curve graph, the x-axis represents the signals measured frequency and relative response in decibels (dB) on the y-axis.

## Cont…

- Microphone manufacturers list the frequency response, such as 20-20,000 Hz, and usually provide a frequency response curve graph.

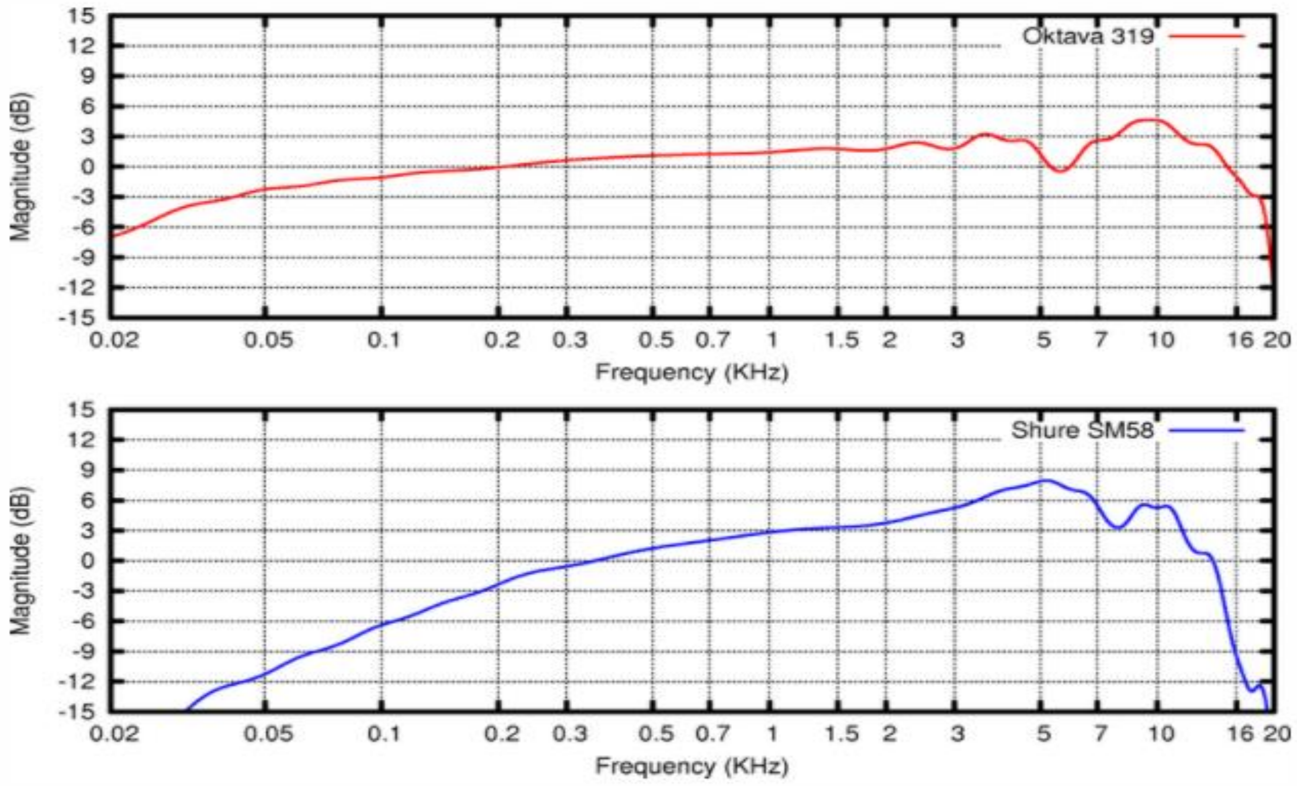



*Figure 1 - Two different frequency response curves for different microphones; Top: Oktava 319, Bottom: Shure SM58*

- A microphone that has a flat frequency response produces equal output at all frequencies and is known as a flat response microphone. On the graph, the curve will be drawn as a flat line.
- Flat response microphones are usually desirable for recording natural instruments such as a piano or acoustic guitar.
- A microphone that has a varied frequency response produces a differing output of frequencies and is known as a shaped response microphone. On the graph, the curve will contain peaks and troughs.
- A shaped response microphone is designed to enhance or detract certain applications. For example, a microphone may have a peak around 5 kHz to increase the presence of a vocal.
- Shaped response microphones are especially useful for reducing pickup of unwanted sound and noise outside the frequency range of an instrument.


Thank you!

# Photoelectric Elements

## What's Phtoto electric effect?

It is the emission of electrons from matter upon the absorption of electromagnetic radiation, such as ultraviolet radiation or x-rays.-refers to the emission, or ejection, of electrons from the surface of, generally, a metal in response to incident light.

## Photoelectric Transducer

Can be categorized as: photoemissive, photoconductive, or photovoltaic.

| No. | Types | Characteristics |
|---|---|---|
| 1. | Photoemmisive | radiation falling into a cathode causes electrons to be emitted from cathode surface. |
| 2. | Photoconductive | the resistance of a material is change when it's illuminated. |
| 3. | Photovoltaic | Generate an output voltage proportional to radiation intensity |

# Applications of photoelectric transducer

(i) The Photomultiplier Tube

(ii) Photoconductive Cells or Photocells the electrical resistance of the materials varies with the amount of light striking.

(iii) The Photovoltaic Cell or solar cell- produce an electrical current when connected to the load.

# ULTRASONIC SENSORS

- Piezoelectric effect of certain crystalline materials has been successfully utilized in ultrasound production and sensing
- When a electric field is applied to the crystal it changes its shape. This property is utilized in generating acoustic or ultrasound wave
- For transmitting such wave good medium and interfacing should be chosen.
- Barium titanate (BaTiO3) matrial is chosen, but requires prior polarization
- https://www.youtube.com/watch?v=vf2lW4LkmMQ - Ultrasonic sensor working principle
- https://www.youtube.com/watch?v=JNQAH3VMFTU - Ultrasonic sensors – the alternative for difficult surfaces

# Cont…

- It consists of randomly oriented tiny piezoelectric crystallites which are properly oriented mostly by DC polling field of several thousand volts per cm and the material is cooled through Curie temperature.
- A strong piezoelectric effect has been observed in compounds such as PbZrO3-PbTiO3 called PZT materials.
- Piezoelectric transducers can generate continuous wave ultrasound or pulsed ultrasound latter being used in SONAR or other similar systems.
- Ultrasonic piezocrystals operate in the range 0f 0.5-10 MHz.
- They are directly attached to the transmittmg medium or are separated by a small distance which is filled with coupling materials of suitable acoustic properties.
- Typical couplants at low temperatures are water, grease, and petrojelly and for higher temperatures special polymer couplants may be used.

# Cont…

- For continuous wave operation, the sensor is energized by a tuned oscillator while for pulsed application 'relaxation' oscillators are used to charge a capacitor which is discharged across the sensor.
- Analytical models describing the interactions of electrical and mechanical phenomena in piezoelectric media have been proposed but found to be inadequate for the design of piezoelectric transducers with realistic geometries and parameters of the material.