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Internal Assessment Test - I

Sub:	Sensors and Transducers							Code:	21EE641
Date:	04-06-2024	Duration:	90 mins	Max Marks:	50	Sem:	6th A & B	Branch:	EEE

Answer Any FIVE FULL Questions

			Marks	OBE CO	OBE RBT
1		What are transducers? What is a digital transducer? Explain about different frequency domain transducers. What are the advantages of them?	10	CO1	L1
2		With neat diagrams explain the working of Capacitive transducers based on: I. Change in the area of plates II. Change in the distance between the plates	10	CO2	L2
3		Give detailed classification of Variable Inductance Transducers with suitable diagrams for each type.	10	CO2	L2
4		Describe briefly about the working of Strain Gauge and derive the expression for Sensitivity of the Strain Gauge.	10	CO2	L2
5		Write Short notes on: (a) Thermoelectric Transducers (b) Load Cells	10	CO2	L1
6	a.	A parallel plate capacitive transducer uses plates of area 250mm^2 which are separated by a distance of 0.2mm. (i) Calculate the value of capacitance when the dielectric is air having a permittivity of $8.85*10^{-12}$ F/m. (ii) Calculate the change in capacitance, if a linear displacement reduces the distance between the plates to 0.18mm. Obtain the ratio of per unit change of capacitance to per unit change of displacement (iii) if a mica sheet of 0.01mm thick is inserted in the gap, calculate the value of original capacitance and change in capacitance for th same displacement Calculate the ratio of per unit change of capacitance to per unit change in displacement. The dielectric constant of mica is 8.	6	CO1	L3
7	a.	Discuss the advantages and disadvantages of Electrical Transducers.	4	CO1	L2
	b.	A strain gauge is bonded to a beam which is 10cm long and has a cross section area of 4cm^2. The unstrained resistance and gauge factor of the strain gauge are 220Ω and 2.2 respectively. On the application of the load the resistance of the gauge changes by 0.013 Ω. If the modulus of elasticity for steel is 207GN/m^2, calculate: i) The change in length of the steel beam ii) The amount of force applied to the beam.	6	CO1	L3
	c.	What is a Proximity sensor? Explain briefly about Eddy current proximity sensors.	4	CO2	L2

CCI **CI** **HOD**

Sensors and Transducers(21EE641) IAT I solution

1. What are transducers? What is a digital transducer? Explain about different frequency domain transducers. What are the advantages of them?

Transducer is a device that converts one type of energy into one type of energy into other type for the purpose of measurement or transfer of information.

Digital transducers:

- Most transducers used in digital systems are primarily analogue in nature and incorporate some form of conversion to provide the *digital output.*
- Many special techniques have been developed to avoid the necessity to use a conventional analogue - to-digital conversion technique to produce the digital signal.
- Examples of *Digital Transducers*: Encoder, Digital Resolver, Digital Tachometer etc.

2.

1. Changing Area of the Plates of Capacitive Transducers

The capacitance of the variable capacitance transducer also changes with the area of the two plates. The capacitance is directly proportion to the area of plates, thus the capacitance changes linearly with change in area of plates. This type of transducer is used for measurement of displacement. Fig. 14.14 show the parallel plate capacitor, in which one plate of the capacitor is fixed while other plate moves according to the displacement apply. The capacitance is given by,

$$C = \in \frac{A}{d} = \in \frac{xw}{d}$$

where x = is the length of overlapping part of plates

w = width of overlapping part of plates

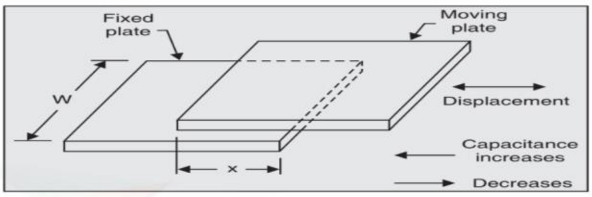


Fig. 14.14.

sensitivity of the transducer is given by,

$$S = \frac{\partial C}{\partial x} = \in \frac{w}{d}$$

From above equation its show that the sensitivity is constant and therefore there is linear relationship between capacitive and displacement. The sensitivity for a fractional change in capacitance,

$$S' = \frac{\partial C}{C \partial x} = \frac{1}{x}$$

This type of capacitance transducer is suitable for measurement of linear displacements.

2. Changing Distance between the Plates of Capacitive Transducers

In these capacitive transducers the distance between the plates is variable, while the area of the plates and the dielectric constant remain constant. This is the most commonly used type of variable capacitance transducer.

Figure 14.18 show that the measurement of the displacement of the object, one plate of the capacitance transducer is kept fixed, while the other is connected to the object. When the object moves, the plate of the capacitance transducer also moves, this results in change in distance between the two plates and the change in the capacitance. The capacitance varies inversely proportional to the distance between the plates. The response of the transducer is not linear as shown in Fig. 14.19.

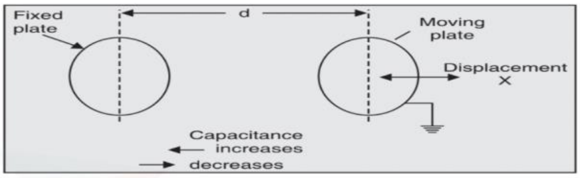


Fig. 14.18.

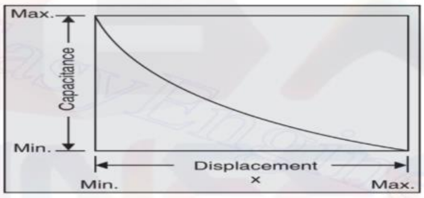


Fig. 14.19.

Time

Sensitivity of the transducer,

$$S = \frac{\partial C}{\partial x} = \frac{\partial C}{\partial x}\left(\in \frac{A}{x}\right) = -\frac{\in A}{x^2}$$

The sensitivity of this transducer is not constant but varies over the range of the transducer. The relationship between capacitance C and the distance between plates x is hyperbolic. This is linear over the small range of displacement.

3.

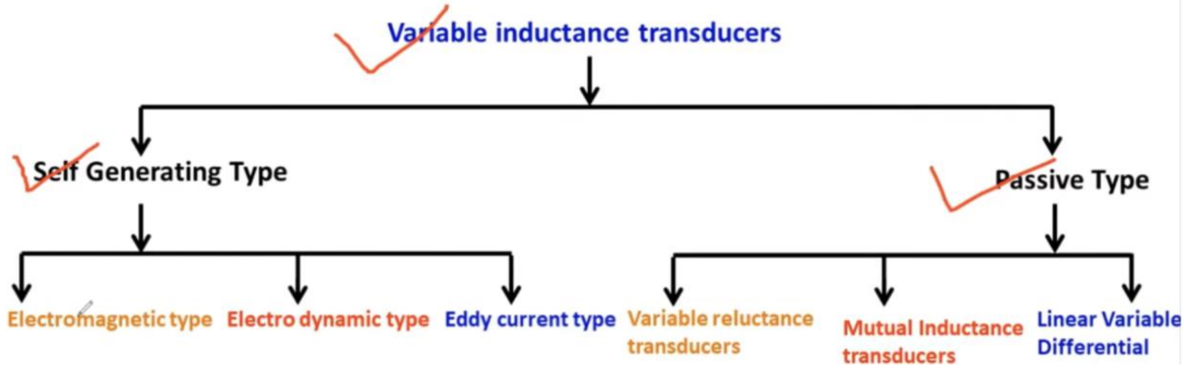
Variable Inductance Transducers

Info

- Variable inductance transducers works based on change in the magnetic characteristics of an electrical circuit in response to a measure and which may be displacement, velocity, acceleration etc.
- Classification: 2 types 1. Self-generating type & 2. Passive type

Variable Inductance Transducers

Classification of Variable inductance transducers



Variable Inductance Transducers

Electrodynamic type:

- The coil moves with in the field of magnet.
- The turns of the coil are *perpendicular* to the intersecting lines of force.
- When the coil moves it induces the voltage which is proportional to the velocity of the coil.
- *Magnetic flow meter* used the same principle of operation.

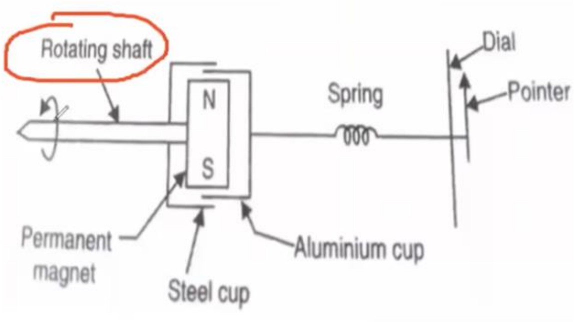
Variable Inductance Transducers

A. Self-generating type: Voltage is generated because of the *relative motion between conductor and a magnetic field*. Types of self-generating type transducers: Electromagnetic type, Electro dynamic type & Eddy current type

Electromagnetic type: It consists of i) permanent magnet core with wounded coil ii) Ferromagnetic material. When ferromagnetic material is in motion, voltage generates in the coil due to electromagnetic induction. It helps to indicate angular speed.

Variable Inductance Transducers

Eddy current type:



Variable Inductance Transducers

B. Passive type

i. Variable Reluctance Transducers

ii. Mutual Inductance Transducers

iii. Linear Variable Differential Transformer (LVDT)

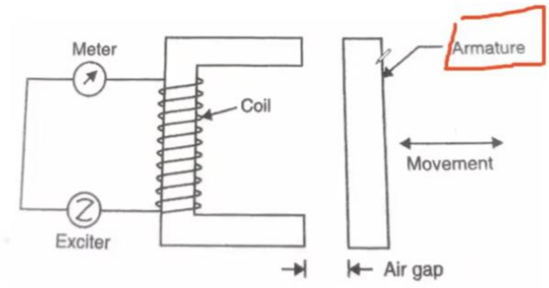
Variable Inductance Transducers

i. Variable Reluctance Transducers

- In these transducers, change in *reluctance of magnetic circuit* by a mechanical input results change in inductance and inductive reactance of the coil.
- The *change in inductance* proportional to *change in mechanical input.*
- The quantities such as pressure, force, displacement, acceleration etc can be measured using variable reluctance transducer.

Variable Inductance Transducers

i. Variable reluctance transducers



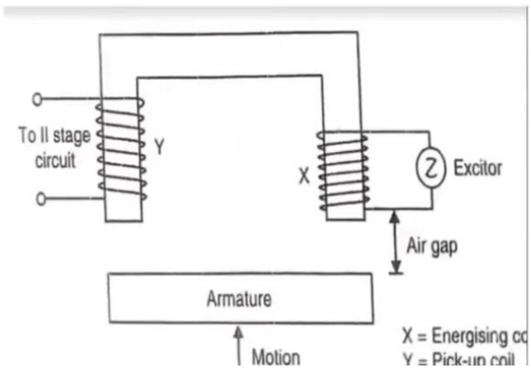
Variable Inductance Transducers

ii. Mutual Inductance transducers:

Mutual Inductance between two Coils is given by

$$M = K\sqrt{L_1 L_2}$$

$K \rightarrow$ Coefficient of Coupling



Inductive Transducers

The inductive transducers work on the principle of the magnetic induction of magnetic material.

- The induction of the magnetic material depends on a number of variables like the number of turns of the coil on the material, the size of the magnetic material, and the permeability of the flux path.
- In the inductive transducers the magnetic materials are used in the flux path and there are one or more air gaps. The change in the air gap also results in change in the inductance of the circuit and in most of the inductive transducers it is used for the working of the instrument.
- There are two type of inductive transducers

1. Linear Variable Differential Transformer

2. Rotary Variable Differential Transformer

4. **Strain Gauge:**

   A strain gauge is a device used to measure the strain of an object. It consists of an insulating flexible backing which supports a metallic foil pattern. The gauge is attached to the object by a suitable adhesive, such as cyanoacrylate. As the object is deformed, the foil is deformed, causing its electrical resistance to change. This resistance change, usually measured using a Wheat stone bridge, is related to the strain by the quantity known as the gauge factor.

The change in the value of resistance by straining the gauge may be partly explained by elastic material. Figure 14.4 shows a strip of elastic material, if the tension is applied, if longitudinal dimension will increase while there will be a reduction in the lateral dimension. When its positive strain, its length increase while its area of cross-section decreases.

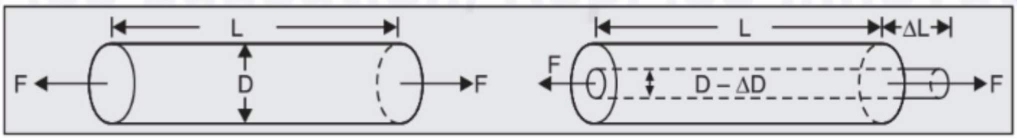


Fig. 14.4.

The resistance of the conductor is proportional to its length and inversely proportional to its area of cross-section. The resistance of the gauge increase with positive strain.

Let us consider a strain gauge made of circular wire. The wire has a resistivity ρ, the resistance of unstrained gauge,

$$R = \rho \frac{L}{A}$$

where L = length of conductor

A = area of conductor

The tensile stress is applied to the wire. The length is increase and area is decrease as shown in Fig. 14.4.

Fig. 14.4.

Lets differentiate the R with respect to stress S, we get,

$$\frac{dR}{dS} = \frac{\rho}{A}\frac{\partial L}{\partial S} - \frac{\rho L}{A^2}\frac{\partial A}{\partial S} + \frac{L}{A}\frac{\partial \rho}{\partial S}$$

Let divide the above equation with $R = \rho \frac{L}{A}$,

$$\frac{1}{R}\frac{dR}{dS} = \frac{1}{L}\frac{\partial L}{\partial S} - \frac{1}{A}\frac{\partial A}{\partial S} + \frac{1}{\rho}\frac{\partial \rho}{\partial S}$$

From the above equation we see that the per unit change in resistance is due to per unit change in length, per unit change in area and per unit change in resistivity.

$$A = \frac{\pi}{4} D^2$$

$$\frac{\partial A}{\partial S} = 2 . \frac{\pi}{4} D . \frac{\partial D}{\partial S}$$

$$\frac{1}{A}\frac{\partial A}{\partial S} = \frac{(2\pi/4)\, D}{(\pi/4)\, D^2} . \frac{\partial D}{\partial S}$$

$$= \frac{2}{D} . \frac{\partial D}{\partial S}$$

Substituting the above value in equation (*i*) we get,

$$\frac{1}{R}\frac{dR}{dS} = \frac{1}{L}\frac{\partial L}{\partial S} - \frac{2}{D}\frac{\partial D}{\partial S} + \frac{1}{\rho}\frac{\partial \rho}{\partial S} \quad ...(ii)$$

The Possion's ratio is given by

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

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

$$\frac{\partial D}{D} = -v \times \frac{\partial L}{L}$$

Substituting the value of $\frac{\partial D}{D}$ in equation (*ii*) we get,

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

The gauge factor of material is defined as the ratio of per unit change in resistance to per unit change in length.

$$\text{Gauge factor} = G_f = \frac{\Delta R/R}{\Delta L/L}$$

$$\frac{\Delta R}{R} = G_f\frac{\Delta L}{L}$$

$$= G_f \times \epsilon$$

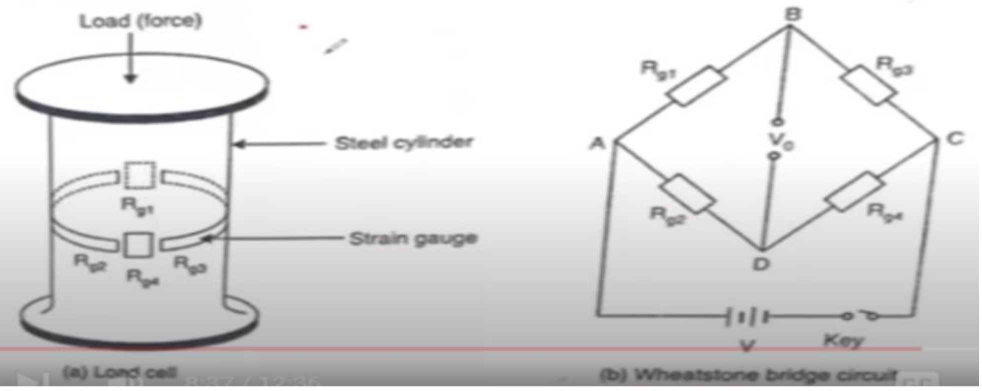
where ϵ = strain = $\frac{\Delta L}{L}$

The Poisson's ratio of all metals is between 0 and 0.5.

- Load Cells are *Elastic Device that can be used for measurement of Force* through indirect methods, through use of *Secondary Transducers*.
- Load cells utillize an elastic member as the primary transducer & Strain Gauge as secondary transducer.
- When the combination of the ***Strain Gauge-Elastic member*** is used for weighting , it is called a ***"Load Cell"***.

- The first process involves conversion of ***force into mechanical displacement*** which is done by the column , while the second process involves conversion of *mechanical displacement into change of resistance* which is done by ***strain gauges***.
- Thus we observe that the ***force is detected by the column in the first stage*** and hence it is called a ***Detector or a Primary Transducer***.
- The output signal from the primary transducer is converted subsequently into a usable output by the ***strain gauges*** and therefore they are known as ***Secondary Transducers***.

Strain gauge load cells

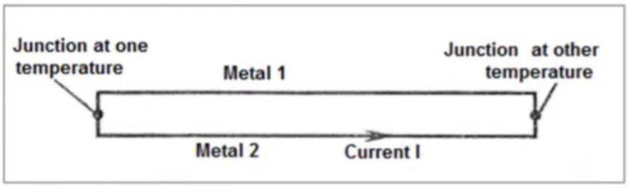


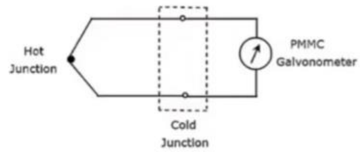
Strain gauge load cells

- These cells converts *Weight or Force* into Electrical outputs which are provided by the *Strain Gauge.*
- These output can be connected to various measuring Instruments for Indicating, Recording & Controlling the Weight or Force.

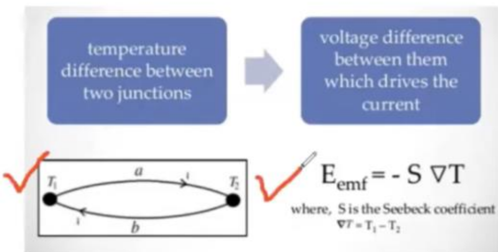
What is Thermoelectric Transducers?

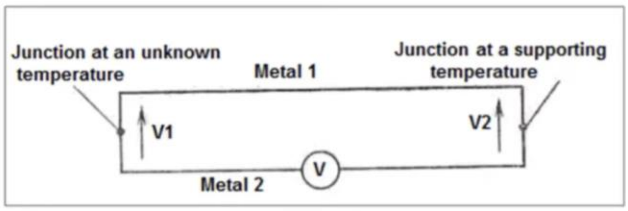
- Thermoelectric transducer elements *transform change of the measured value (temperature) to change the current/voltage*, arising from *differences in temperature* at junction of ***two dissimilar metals*** in which there is the **Seebeck effect**.





- Thermo electric transducer that converts *heat directly into electricity* according to the *seeback effect.*





- Two dissimilar metal conductors when joined at the ends and two junctions kept at different temperature, and then small ***emf*** is produced in the circuit.
- Thermo electric effect is used in ***Thermocouples***.
- Number of combinations: Iron and constantan (Alloy of copper and nickel), Chromel (Alloy of Chromium & Nickel) and Alumel (Alloy of Aluminium and Nickel)

6.a.

$$C = \frac{\epsilon A}{d}$$

$$= \frac{8.85 \times 10^{-12} \times 250 \times 10^{-6}}{0.2 \times 10^{-3}}$$

$$= 11.0625\ pF$$

change in capacitance with reduced distn

$d' = 0.18$ mm

$$C' = \frac{\epsilon_0 A}{d'} = \frac{8.85 \times 10^{-12} \times 250 \times 10^{-6}}{0.18 \times 10^{-3}} = 12.2917 \times 10^{-12} F$$

~~$= 11.0625 \times 10^{-12} F$~~

~~$= 11.0625\ pf$~~

$C' = 12.2917 \, pF$

change in capacitance

$\Delta C = C' - C$

$= 12.2917 - 11.0625$

$= 1.2292 \, pF$

The ratio of per unit change in capacitance to the per unit change in displacement

$$\frac{\Delta C}{\Delta d} = \frac{1.2292 \, pF}{(0.2 - 0.18) \times 10^{-3} \, m}$$

$= 61.46 \, nF/m$

(iii) capacitance with Mica sheet inserted.

The effective separation distance when the mica sheet is inserted can be calculated considering the series combination of capacitance formed by the mica and the air gap

$d_{mica} = 0.01 \times 10^{-3}$

The thickness of the mica sheet.

$d_{air} = 0.2 \times 10^{-3} - 0.01 \times 10^{-3}$

$= 0.19 \times 10^{-3} \, m.$

capacitance of mica part (C_{mica})

$$C_{mica} = \frac{\epsilon_0 k_{mica} A}{d_{mica}}$$

$$= \frac{8.85 \times 10^{-12} \times 8 \times 250 \times 10^{-6}}{0.01 \times 10^{-3}}$$

$C_{mica} = 1.77 \times 10^{-9} \, F$

$= 1.77 \, nF$

capacitance of air pad (Cair).

$$C_{air} = \frac{\epsilon_0 A}{d_{air}}$$

$$= \frac{8.85\times10^{-12}\times 250\times10^{-6}}{0.19\times10^{-3}}$$

$$C_{air} = 11.645\times10^{-12}\,f$$

$$C_{air} = 11.645\,pF$$

The total capacitance is found by considering the series combination of Cmica and Cair:

$$\frac{1}{C_{total}} = \frac{1}{C_{mica}} + \frac{1}{C_{air}}$$

$$= \frac{1}{1.77\times10^{-9}} + \frac{1}{11.645\times10^{-12}}$$

$$= 0.565\times10^{9} + 85.89\times10^{9}$$

$$= 86.455\times10^{9}$$

$C_{total} =$ [illegible] $\times10^{-12}\,f$

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6.b

- Very *small power is required* for controlling electrical or electronic system.
- The *electrical output can be amplified* to any desired level.
- The *effect of friction is reduced* to minimum possible.
- Mass-inertia effects are reduced to minimum possible.
- Available in *compact size* and shape.
- The output can be indicated and recorded remotely at a distance from the sensing medium.
- The *output can be modified* to meet the requirement of indicating/controlling equipment.
- Transducer signal can be conditioned.
- There is *no moving part, no wear and tear*.
- There is *no mechanical failure exist*.
- Display of data is possible on a CRO.

7.a

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

$$= \frac{(0.013 / 240) \times 0.1}{2.2}$$

$$= 2.462 \times 10^{-6}$$

$$E = \frac{\text{stress}}{\text{strain}} = \frac{\sigma}{e}$$

$$\sigma = E \times e = E \times \frac{\Delta L}{L}$$

$$= (207 \times 10^{9}) \times \frac{2.462 \times 10^{-6}}{0.1}$$

$$= 5100 \times 10^{3}$$

$$= 5.1 \times 10^{6} \ N/m^{2}$$

$$F = \sigma . A = 5.1 \times 10^{6} \times \text{~~2.46~~}$$

$$= \text{~~12.5664~~} \ 20.($$

$$\boxed{F = 2.04 \, kN}$$

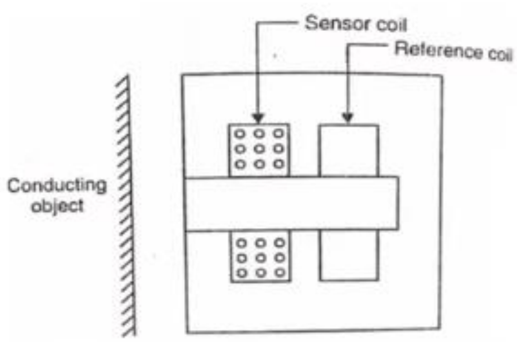
7. b

- A **proximity sensor** is a sensor able to detect the presence of *nearby objects* without any physical contact.
- A proximity sensor often emits an *electromagnetic field or a beam of electromagnetic radiation* (infrared, for instance), and looks for changes in the field or return signal.
- The object being sensed is often referred to as the *proximity sensor's target.*
- Different proximity sensor targets demand different sensors.
- For example, a *capacitive proximity sensor or photoelectric sensor might be suitable for a plastic target*; an *inductive proximity sensor always requires a metal target*

Types of Proximity Sensor

- **Eddy Current Proximity Sensor**
- **Capacitance Proximity Sensor**
- **Inductive Proximity Sensor**

Eddy Current Proximity Sensor



- Eddy current proximity sensors are used to detect ***non-magnetic but conductive materials***.
- When an alternating current is passed through this coil, an alternative magnetic field is generated. If a metal object comes in the close proximity of the coil, then ***eddy currents are induced*** in the object due to the magnetic field.
- These eddy currents create their own magnetic field which ***distorts the magnetic field responsible for their generation.***
- As a result, ***impedance of the coil*** changes and so the amplitude of alternating current.
- This can be used to trigger a switch at some pre-determined level of change in current.