JAWAHARLAL NEHRU TECHNOLOGICAL UNIVERSITY ANANTAPUR

B.Tech IV-I Sem

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(20A04704) ELECTRONIC SENSORS
(Open Elective Course –III)

Course Objectives:

- Learn the characterization of sensors.
- Known the working of Electromechanical, Thermal, Magnetic and radiation sensors
- Understand the concepts of Electro analytic and smart sensors
- Able to use sensors in different applications

Course Outcomes:

- Learn about sensor Principle, Classification and Characterization.
- Explore the working of Electromechanical, Thermal, Magnetic, radiation and Electro analytic sensors
- Understand the basic concepts of Smart Sensors
- Design a system with sensors

UNIT I

Sensors / Transducers: Principles, Classification, Parameters, Characteristics, Environmental Parameters (EP), Characterization

Electromechanical Sensors: Introduction, Resistive Potentiometer, Strain Gauge, Resistance Strain Gauge, Semiconductor Strain Gauges -Inductive Sensors: Sensitivity and Linearity of the Sensor – Types-Capacitive Sensors: Electrostatic Transducer, Force/Stress Sensors Using Quartz Resonators, Ultrasonic Sensors

UNIT II

Thermal Sensors: Introduction, Gas thermometric Sensors, Thermal Expansion Type Thermometric Sensors, Acoustic Temperature Sensor ,Dielectric Constant and Refractive Index thermo sensors, Helium Low Temperature Thermometer ,Nuclear Thermometer ,Magnetic Thermometer ,Resistance Change Type Thermometric Sensors, Thermo emf Sensors, Junction Semiconductor Types, Thermal Radiation Sensors, Quartz Crystal Thermoelectric Sensors, NQR Thermometry, Spectroscopic Thermometry, Noise Thermometry, Heat Flux Sensors

UNIT III

Magnetic sensors: Introduction, Sensors and the Principles Behind, Magneto-resistive Sensors, Anisotropic Magneto resistive Sensing, Semiconductor Magneto resistors, Hall Effect and Sensors, Inductance and Eddy Current Sensors, Angular/Rotary Movement Transducers, Synchros.

UNIT IV

Radiation Sensors: Introduction, Basic Characteristics, Types of Photo resistors/ Photo detectors, Xray and Nuclear Radiation Sensors, Fibre Optic Sensors

Electro analytical Sensors: The Electrochemical Cell, The Cell Potential - Standard Hydrogen Electrode (SHE), Liquid Junction and Other Potentials, Polarization, Concentration Polarization, Reference Electrodes, Sensor Electrodes, Electro ceramics in Gas Media.

UNIT V

Smart Sensors: Introduction, Primary Sensors, Excitation, Amplification, Filters, Converters, Compensation, Information Coding/Processing - Data Communication, Standards for Smart Sensor Interface, the Automation Sensors –Applications: Introduction, On-board Automobile Sensors (Automotive Sensors), Home Appliance Sensors, Aerospace Sensors, Sensors for Manufacturing – Sensors for environmental Monitoring

Textbooks:

1. "Sensors and Transducers - D. Patranabis" –PHI Learning Private Limited., 2003.
2. Introduction to sensors- John veteline, aravindraghu, CRC press, 2011

References:

1. Sensors and Actuators, D. Patranabis, 2nd Ed., PHI, 2013.
2. Make sensors: Terokarvinen, kemo, karvinen and villeyvaltokari, 1st edition, maker media,2014.
3. Sensors handbook- Sabriesoloman, 2nd Ed. TMH, 2009

UNIT-1

SENSORS / TRANSDUCERS

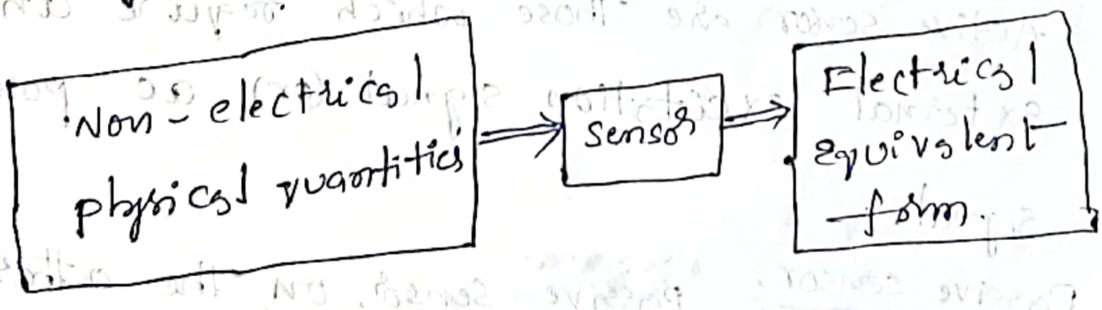
Sensor: A sensor is a device which converts physical quantities in to electrical form (or) converts non-electrical quantities in to electrical equivalent.

Transducer:- Transducer is a device which used to convert ~~one form~~ of energy to another ~~form~~.

→ In another word ~~transducer~~ which converts a Non-electrical quantity that means are a physical quantity In to an electrical quantity.

Introduction:

Sensors: A sensor is a device which converts Physical quantity in to electrical ~~form~~ (or) converts Non electrical quantities in to electrical quantity



→ The physical quantity can be temperature, pressure, force, motion and displacement, humidity, light, Flow, etc

→ These physical quantities are converted Into electrical form i.e, change in Resistance, Inductance, capacitance, etc

→ These are then converted into voltage (or) current signals with in a specified Range by the sensor for measurement purpose

Classification:-

To classify the different types of sensors according to different parameters.

1 → (i) Active sensor
(ii) passive sensor

Active sensor:-

Active sensor are those which require an External excitation signal (or) ac power signal.

Passive sensor: passive sensor, on the other hand do not require any external power signal and directly generates output response.

② → classification is based on the means of detection used in the sensor.

→ same of the means of detection are electric, Biological, chemical, Radio active...etc

③ → classification is based on the conversion phenomenon i.e, the Input and the output

→ same of the common conversion phenomena are photo electric, Thermoelectric electro chemical, Electromagnetic, Thermo optic ...etc

④ Analog and digital sensor:

Analog sensors produce an analog output i.e, a contineous output signal [usually voltage but sometimes other quantities like Resistance etc] with respect to the quantity being measured.

characteristics:

Sensor characteristics affect their measurement capabilities and define the suitability of a sensor for a particular application.

(i) static characteristics

(ii) Dynamic characteristics

(1) static characteristics:

a) Accuracy
b) precision
c) Resolution
d) sensitivity
e) Linearity
f) Hysteresis

(2) Dynamic characteristics

The properties of the system transient Response to an input.

→ Zero order system

→ First order system

→ second order system.

Static characteristics:

a) Accuracy:

→ Accuracy is defined in terms of closeness to the true value.

→ Error is defined as the difference between the measured value and true value

→ smaller the Error more accurate the Instrument

→ Accuracy is measured by the absolute and relative error.

$$\text{Absolute Error} = \text{Result} - \text{True value}$$

$$\text{Relative Error} = \frac{\text{Absolute Error}}{\text{True value}}$$

b) Precision:

→ Is the capacity of a measuring Instrument to give the same reading when Repetitively measuring the same quantity under the same prescribed conditions.

→ precision implies agreement successive Readings. NOT closeness to True value

→ precision is related to the variance of a set of measurements.

→ precision is a nessary but not sufficient condition for accuracy

→ Two Terms closely related to precision (i) Repetability (ii) Reproducibility

b) Repeatability

→ is the precision of a set of measurements taken over a short time Interval

Reproducibility

→ is the precision of a set of measurements.

but,

→ Taken over a long time interval
(or)
→ performed by different operator
(or)
→ with different instruments (or)

→ In different laboratories.

c) Resolution

→ Resolution is the smallest Increment that the sensor (or) measurement system can accurately and reliably detect.

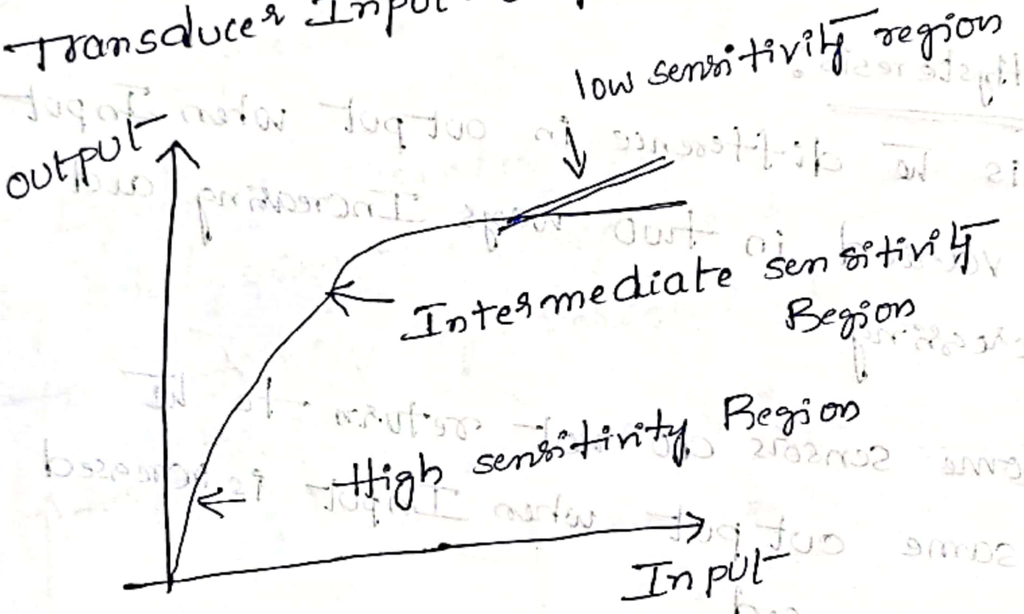
→ In case of analog sensors. the quality of the primary transducers decided the Resolution

→ In case of digital sensor the on board signal conditioning circuitry is as Important as the transducer it self.

d) Sensitivity

→ sensitivity of a sensor is defined in terms of the change in output with respect to the change in input on a per unit basis

→ For analog sensor it is the slope of the Transducer Input- output characteristics.

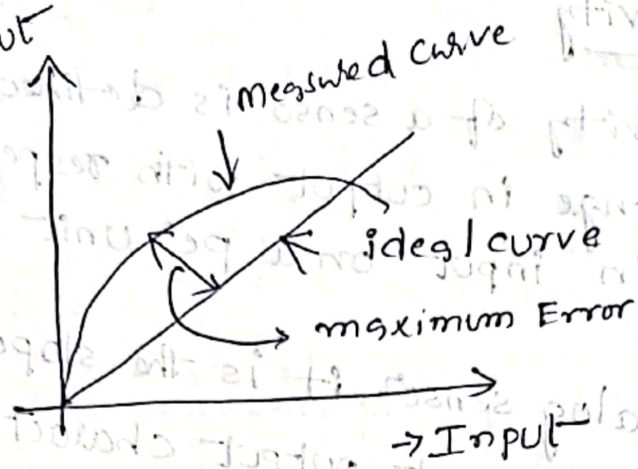


e) Linearity

→ Most sensor manufacturers specific the accuracy of measurement In terms of the sensors range

→ This is to account for errors due to any non- linearity in the sensor Input/output characteristics

→ linearity is the maximum deviation between the measured values of a sensor From ideal curve

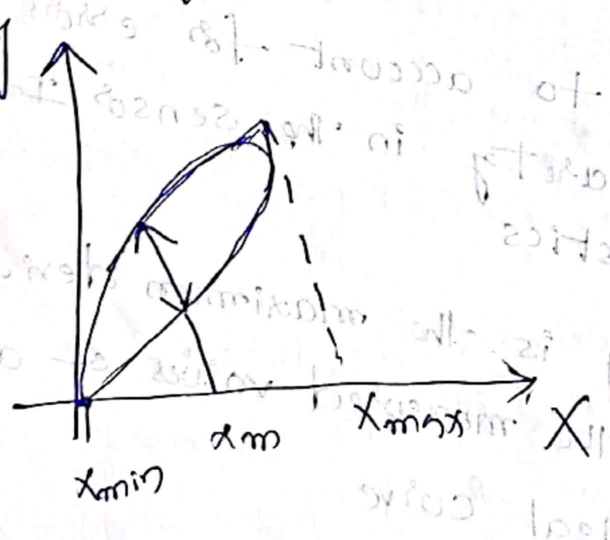


(f) Hysteresis:-

→ it is the difference in output when Input is varied in two ways Increasing and decreasing

→ some sensors do not return to the same output when Input is increased or decreased.

→ The width of expected error is terms of measured quantity is known as Hysteresis.

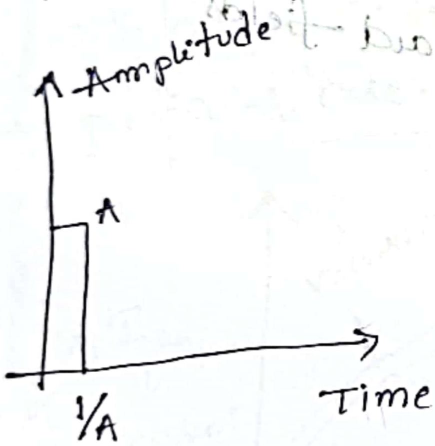


Dynamic characteristics:-

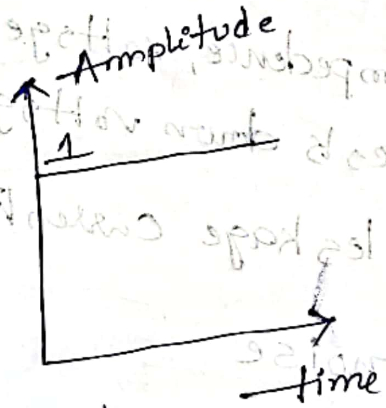
→ The sensor Response to a variable Input is different from that exhibited when the Input signals are constant.

→ The reason for dynamic characteristics is the presence of energy-storing elements

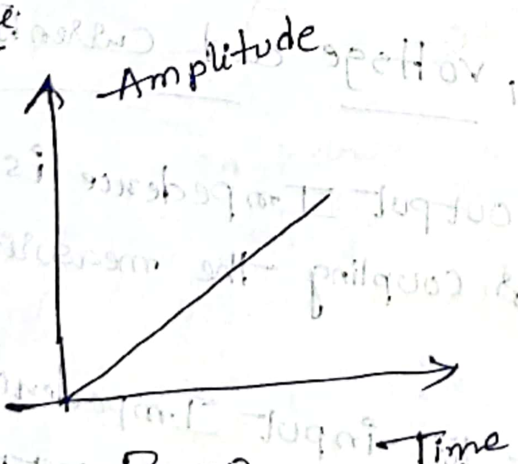
→ Dynamic characteristics are determined by analyzing the Response of the sensor to a family of variable Input waveforms



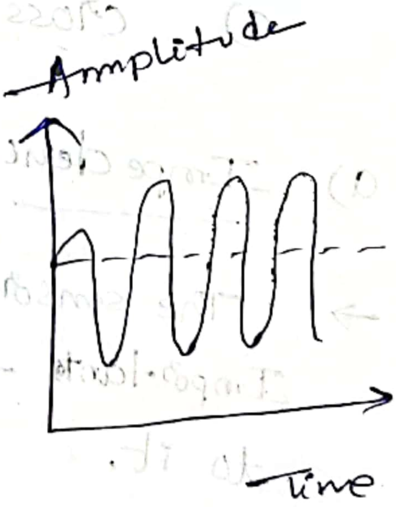
Impulse



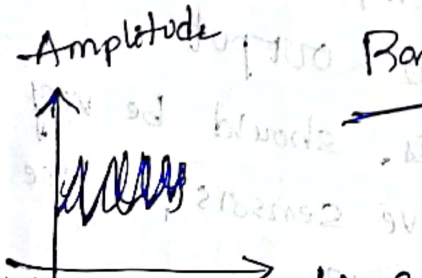
Step



Ramp



Sinusoidal.



white noise

characterization

→ characterization of the sensors can be done in many ways depending on the types of sensors, specifically microsensors.

→ These are electrical, mechanical, optical Thermal, chemical, bio-logical &

Electrical characterization,

→ it consists of evaluation of electrical parameters like

a) Impedence, voltage and currents
b) break down voltage and fields
c) leakage currents
d) noise
e) cross-talk

a) Impedence, voltage and currents:

→ The sensor output Impedence is very Important for coupling the measuring equipment to it.

→ The ratio of the input Impedence of the measuring Equipment to the output Impedence of the Transducers, should be very high, while for current, sensitive sensors, reverse is true.

b) Break down voltage and fields :-

→ Break Down of the insulating part of the sensor. is very critical as the health of the system depends on it.

→ For metal insulator — semiconductor

→ Three different types of break down are

(i) dielectric strength

(ii) wear out

(iii) current Induced break down.

→ Tests are also differents and are performed with a particular Independent parameter for a particular case.

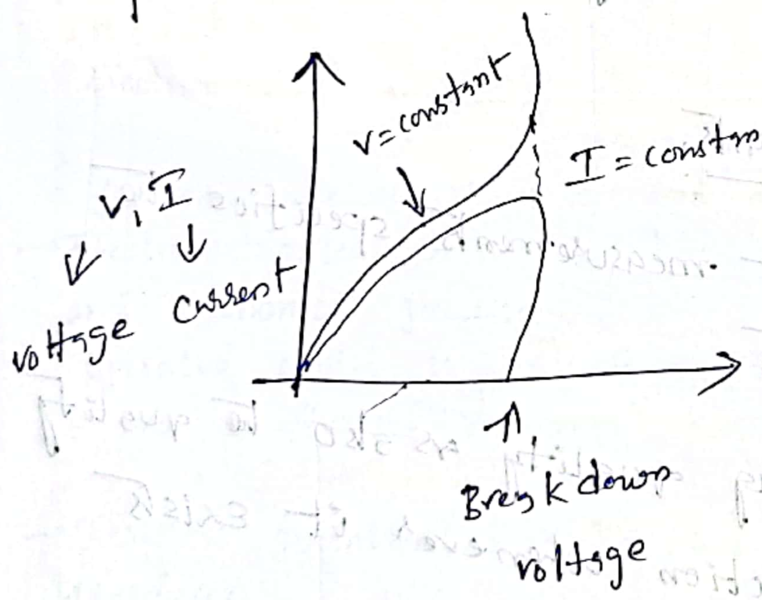


fig (a) voltage, current

(b)

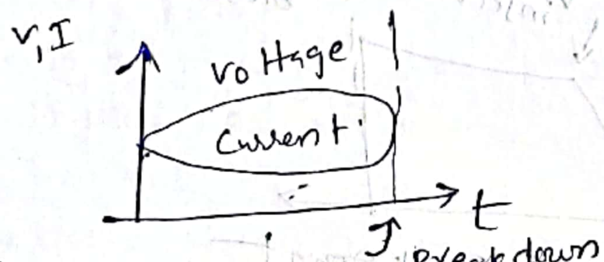
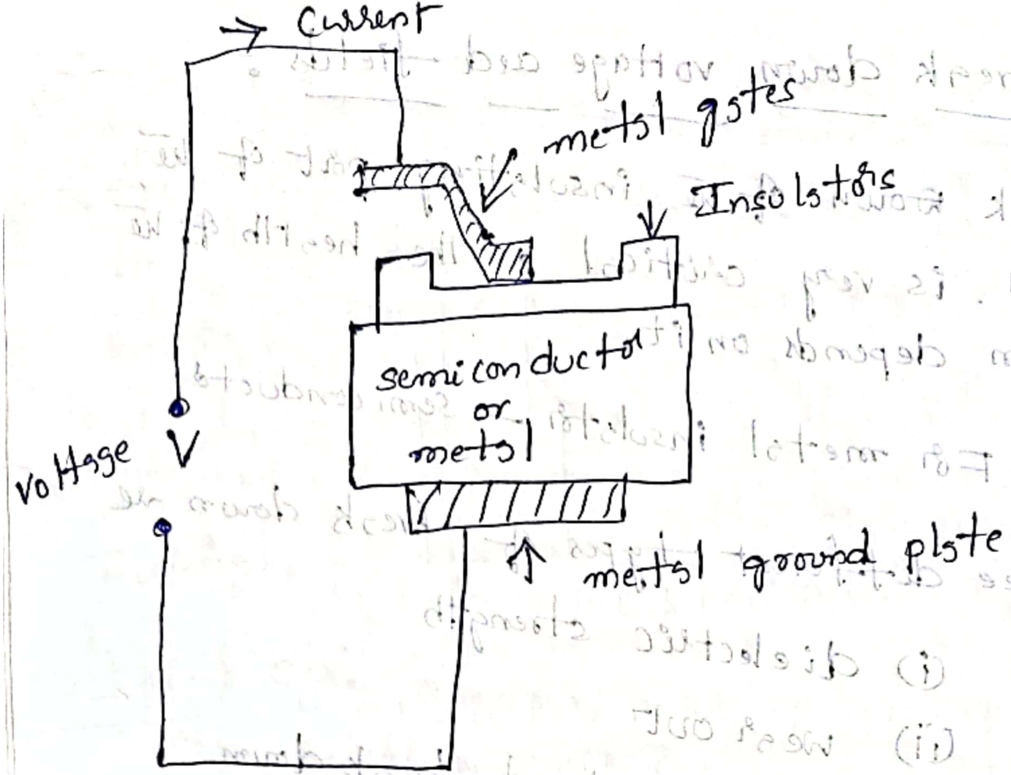


fig (b) Semiconductor (or) metal.

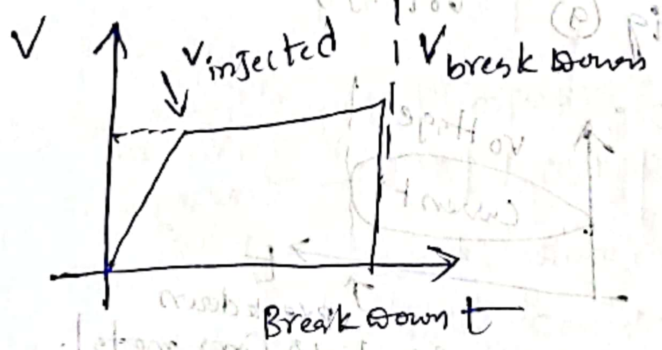


→ Break down - generally Implies i.e sudden (or) "avalanche" change in the voltage (or) current - voltage droping to a negligible value and current rising to a very high value.

(C) leakage currents.

→ Leakage current measurements specifies the sensor quality.

→ its Insulting quality as also the quality of P-N Junction whenever it Exists



(d) Noise:

→ Noise comes from electromagnetic interference, AC magnetic fluctuation, 50Hz supply pick up.
→ Mechanical or acoustical vibration or photon induced output.
→ Sensors are to be characterized for noise testing for immunity to such noise.
→ For testing purpose, different noise sources are developed.

(e) Cross Talk:

→ Cross talk may occur due to overlapping of signals between the two adjacent transducer elements.
→ A signal transducer system because of inductive or capacitive coupling or coupling through the common voltage source during transduction inside the element.

Electromechanical sensors:

Introduction:

Electromechanical sensors: To convert the input form into an electrical output form, for convenice of processing and display.
→ Electromechanical devices are ones which have both electrial and mechanical processes.
→ Operated switch is an electromechanical component due to the mechanical movement causing an electrical output.

Resistive Potentiometer:

→ Resistive potentiometer is a kind of variable resistance transducer.
→ These are strain gauges, RTD, Thermistor, wire anemometer, Piezo resistor and many more.
→ This, is a precision wire wound potentiometer, which is used as a sensor.

→ The wire wound potentiometer is shown in figure (a)

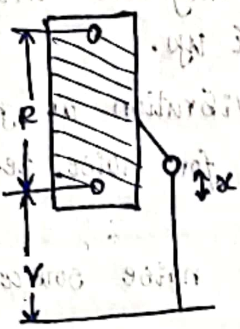


fig (a) wire wound potentiometer

→ for a voltage supply 'v' to the potentiometer the voltage Resolution would be

$$\Delta V = \frac{V}{x}$$

→ The solid line stairs show the output voltage steps each of which is equivalent to a value V/x.

→ Two adjacent wires are likely to be shorted as shown in figure (b).

→ A major resolution pulse of magnitude.

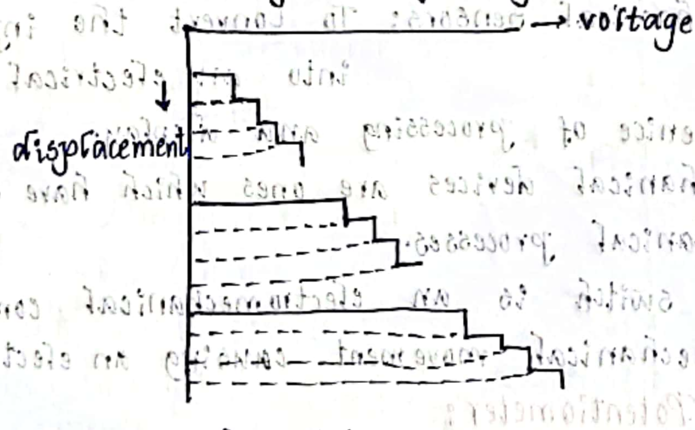


figure (b)

$$\Delta V_m = V_p \left[\frac{1}{x-1} - \frac{1}{x}\right]$$

→ This is an actual resolution value.

$$\Delta V - \Delta V_m = \frac{V}{x} - V_p \left[\frac{1}{x-1} - \frac{1}{x}\right]$$

→ The ratio of jockey radius to wire radius and geometry of wire winding should be considered for reducing ΔV_m.

→ Resistance wire and jockey are equally important, particularly from the wearing point of view and noise.

→ A few types of jockeys are shown.

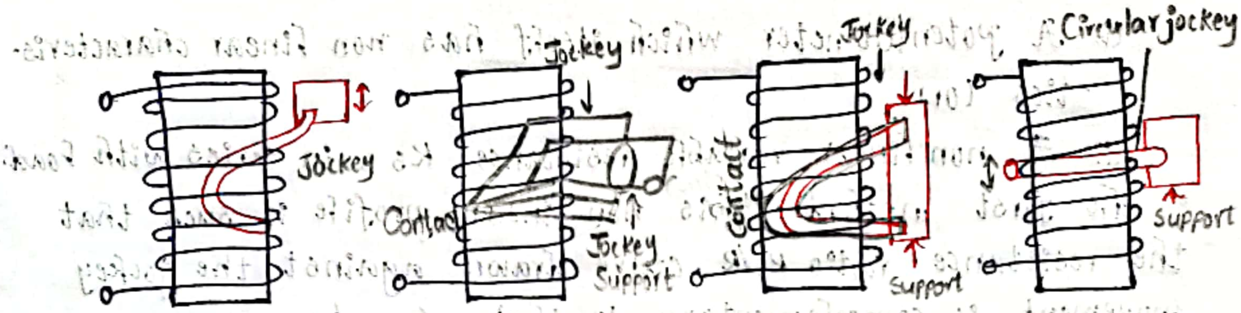
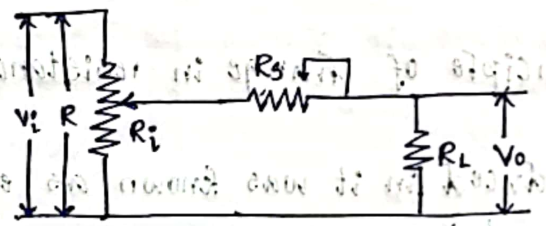


fig: different designs of jockeys

→ The performance of the potentiometer changes in the loaded condition.

→ It's linearity is badly affected.



→ Considering the circuit of figure, if R_L is the load resistance.

→ V_i and V_0 are input and output voltages.

→ R_i is the instantaneous tapped resistance across which V_0 is obtained.

→ The minimum $R_i = 0$ and maximum $R_i = R$, then

$$\frac{V_0}{V_i} = \frac{R_i/R}{1 + \frac{R_i}{R_L}\left(1 - \frac{R_i}{R}\right)}$$

→ The figure shows an variable series resistance R_S.

→ It has been obtained with $R_S = 0$.

→ for ideal condition, $V_{0i}/V_i = R_i/R$.

→ Representing R_i/R by p and R/R_L by λ.

→ The percentage error in output - input voltage ratio is given as:

$$\epsilon = \frac{(V_{0i}/V_i - V_0/V_i)}{(V_{0i}/V_i)} \times 100$$

$$= \left(1 - \frac{1}{1 + \lambda p (1-p)}\right) \times 100$$

→ Alternate method make use of :

(i) A potentiometer which itself has non linear characteristics (or)

(ii) A non linear variable resistance R_s, in series with load.

- The first method, this non linear profile is such that the resistance ratio R_i/R curve drawn against the jockey movement is complementary to that of V_o/V_i.
- In this second method R_s is also a variable.

A double jockey system one for R and the other for R_s with equal length to move should be used. A resistance $R_s = R/4$ with parabolic resistance.

- **Strain Gauge:**
  - The basic principle of change in resistance of a metallic wire
  - To strain produced in it was known as early as the mid nineteenth century.
  - Strain gauges are of two types, namely the resistance type and the semiconductor type.

Resistance Strain Gauge:

Resistance strain gauges can be divided into two categories : a) Unbonded and
b) Bonded

a) **Unbonded Strain gauge:**

- The unbonded strain gauge consists of a piece of wire stretched in multiple folds.
- Between a pair or more of insulated pins fixed to movable members of a body or even a single flexible member.
- These occurs a relative motion between the two members on strain and the wire gets strained as well with a corresponding change in its resistance value.

• The scheme of such a system is shown in figure:

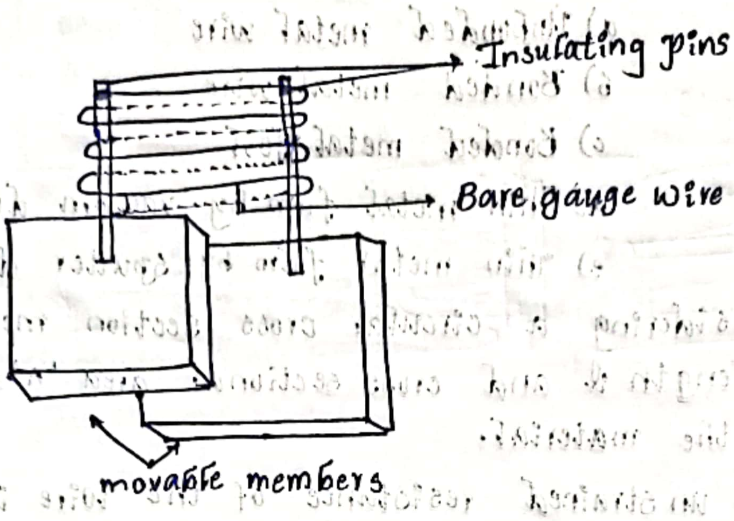


fig: Unbonded strain gauge

6) Bonded Strain gauge:

• The bonded type is more common and in its simplest form consists of wire / strip of resistance material arranged usually in the form of a grid for larger length and resistance value.

• The grid is bonded to the test specimen with an insulation layer between the gauge material and the specimen as shown in figure.

• If the insulating and the bonding material thickness is h. which also is the height of the wire above the specimen surface and H is the distance of the natural axis of the specimen from its surface.

• The actual strain ϵ, in terms of measured strain ϵ_m is given by :

$$\boxed{\epsilon = \epsilon_m \frac{H}{h+H}}$$

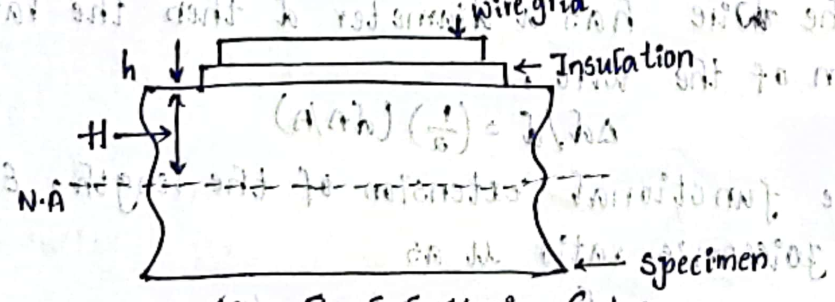


fig: Bonded Strain Gauge

- depending upon the implementation the resistance gauges can be classified as:
  - a) Unbonded metal wire
  - b) Bonded metal wire
  - c) Bonded metal foil
  - d) Thin metal film by vaccum deposition
  - e) Thin metal film by sputter deposition.
- Considering a circular cross section metal resistance wire of length l and cross sectional area 'A', with resistivity 'ρ' of the material.
- The unstrained resistance of the wire is given by:

$$R = \frac{\rho l}{A} \quad \text{(1)}$$

- If the wire is uniformly stressed along its length figure If the stress is given by σ, then;

$$\frac{dR}{d\sigma} = \frac{d}{d\sigma}\left(\rho \frac{l}{A}\right) \quad \text{(2)}$$

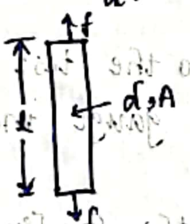


fig: strain of an elastic member

which gives

$$\left(\frac{1}{R}\right)\frac{dR}{d\sigma} = \left(\frac{1}{l}\right)\left(\frac{\partial l}{\partial \sigma}\right) - \left(\frac{1}{A}\right)\left(\frac{\partial A}{\partial \sigma}\right) + \left(\frac{1}{\rho}\right)\left(\frac{\partial \rho}{\partial \sigma}\right)$$

Eliminating all σ terms, we get

$$\frac{dR}{R} = \frac{\partial l}{l} - \frac{\partial A}{A} + \frac{\partial \rho}{\rho} \quad \text{(3)}$$

- If the wire has a diameter d then the lateral contraction of the wire,

$$\Delta d / d = \left(\tfrac{1}{2}\right)(dA/A)$$

- To the functional extension of the length, $\varepsilon = \Delta l / l$ by the poisson's ratio μ as

$$\frac{\Delta d}{d} = \frac{\mu \Delta l}{l} \quad \text{(4)}$$

sothat Eq^n(3);
$$\frac{\Delta R}{R} = (1 + 2\mu)\frac{\Delta l}{l} + \frac{\Delta P}{P} \quad \text{(5)}$$

- The strain sensitivity or the gauge factor λ is defined as the ratio $\left(\frac{\Delta R}{R}\right)/\left(\frac{\Delta l}{l}\right)$ and is given by:

$$\lambda = \frac{\Delta R/R}{\Delta l/l} = 1 + 2/u + \frac{\Delta \rho/\rho}{\Delta l/l} \quad \text{—(6)}$$

- It is generally assumed that resistivity of a metallic material is usually constant that gauge factor λ is constant.
- Unbonded strain gauges are used in preloaded conditions not to allow the strings to go slack.
- A bonded strain gauges are of a few types:
  (i) flat grid type (ii) wrap around type (iii) woven type.
- The gauge consists of the resistance element of proper design / shape.
- The gauge backing, cement, connection leads and often protective coating or other protective.
- The construction of the flat grid bonded strain gauge is shown.
- Such a construction has the advantage of better strain transmission from the member to the wire grid.

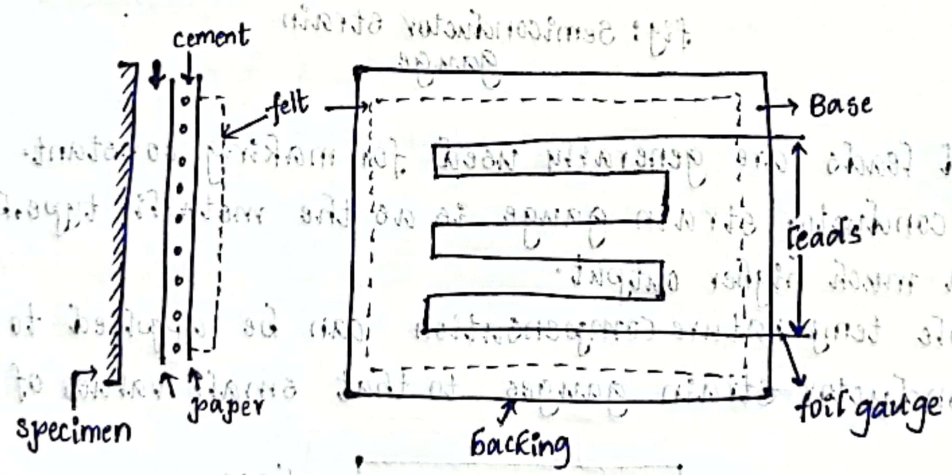


fig: Grid type gauge

- The foil gauges are fetched out from deposited films or sheets and have higher surface area to cross section ratio than wire gauges.

Semi Conductor Strain Gauge:

- These are the gauges manufactured from semiconducting materials like silicon and germanium with additives like boron.

• These gauges depends for their action of piezoresistive effect · i.e maximum resistive change due to change due to change in resistivity of material.

• It consists of the strain sensitive semiconductor material and leads sandwiched in a protective matrix.

• The elements are manufactured from filaments about 0·05 mm thick and more bonded to insulating materials such as Teflon, contacts are made of Gold.

• These gauges have high range of gauge factor of 100-200 Good response, long life but highly sensitive to temperature and have poor linearity. These are brittle and not suitable for large strain measurement.

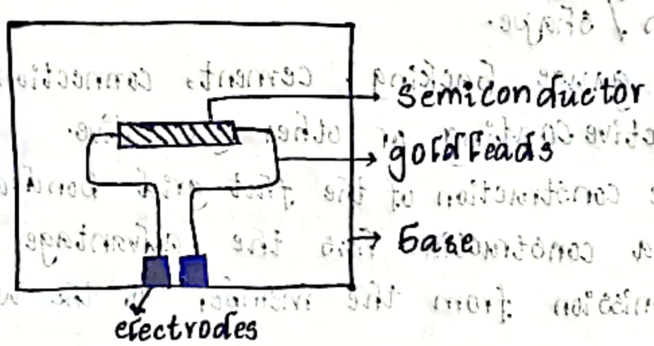
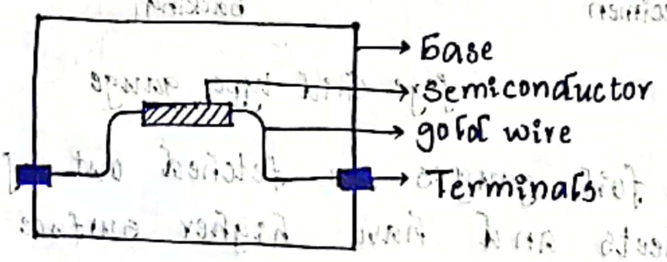


fig: Semiconductor strain gauge

• Gold leads are generally used for making constant.
• Semiconductor strain gauge is as the metallic type, but has a much higher output.
• Simple temperature compensation can be applied to the semiconductor strain gauges to that small valves of strain.



• Advantage:
  • Huge gauge factor.
  • Chemically inert and low resistivity.
  • Excellent hysteresis characteristics.
  • Semiconductor strain gauge can be very small.

in size: ranging in length from 0.7 to 7.0 mm.

- **Disadvantages:**
  - They are very sensitive to changes in temperature.
  - Linearity of semiconductor strain gauges is poor.
  - They are more expensive.

- **Capacitive Sensor:**

Three types of capacitive sensors.

a) Variable capacitive type

- It varying distance between two or more parallel electrodes.
- Variable area between the electrodes.
- Variable dielectric constant materials.
- The movement of the moving electrodes of the type shown in the figure.

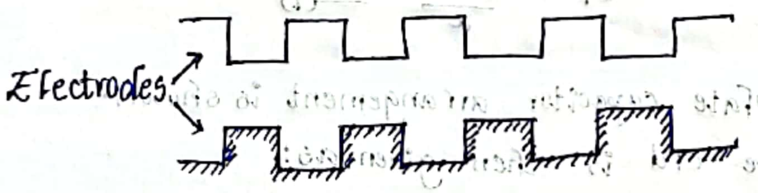


fig: Capacitive Type

b) Parallel plate Capacitive Type sensor

- It is often used in a differential form with three plates as shown in figure.

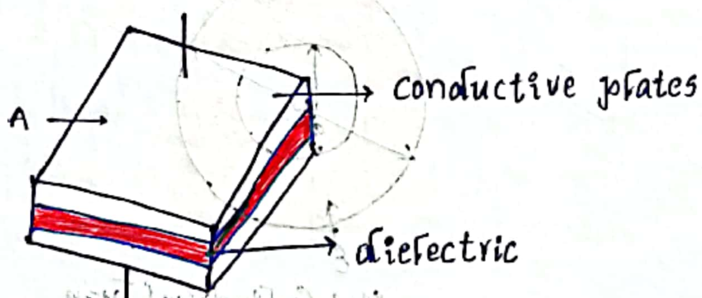
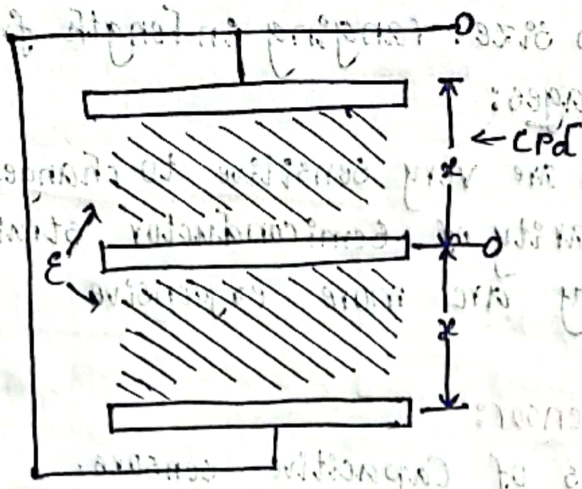


fig: parallel plate Capacitive sensor



fig

- For a parallel plate capacitor with dielectric constant or permitivity ε.
- Its relative permitivity and the permitivity of the free space of value 8.85×10^{-12} F/m and plate area α, each seperated by a distance x from the other Capacitance is

$$C_P = \frac{\varepsilon \alpha}{x} \quad \text{---(1)}$$

- The three plate capacitor arrangement is shown.
- The capacitive CPd is then given as:

$$CPd = \frac{2\varepsilon\alpha}{x} \quad \text{---(2)}$$

c) Cylindrical Type Sensor

- For the cylindrical sensor with the electrode thickness negligible as compared to dielectric thickness is shown in figure.

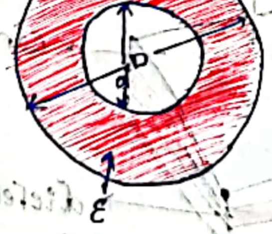


fig: Cylindrical Type

- The Capacitance is:

$$C_c = \frac{2\pi\varepsilon l}{\ln \frac{D}{d}} \quad \text{---(3)}$$

where; l is the cylinder length.

• for very thin layer of dielectric material in Eq^n (3) can be approximated to

$$C_{ca} = \frac{\pi \varepsilon l \,(D+d)}{L\,(D-d)} \quad —(4)$$

• In a parallel plate pair the dielectric has a number of layers of dielectric constant with corresponding permitivity ε_i for thickness x_i, Eq^n (1) can be modified to

$$C_{P_1} = \frac{\alpha}{\Sigma (x_i/\varepsilon_i)} \quad —(5)$$

• The capacitance is ingeneral associated with a high resistance called leakage, because the dielectric materials donot have infinite permittivity.

• The leakage represented by a parallel resistance R_P.

• Particularly at low frequencies of measurement.

• With increasing frequency, the load resistance R_1 contribute to loss factors and the complete equivalent circuit is given by:

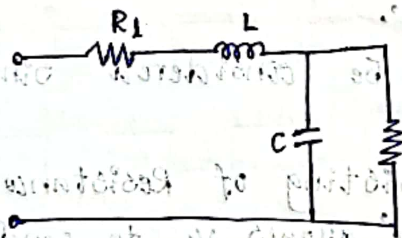


fig: Equivalent circuit of the capacitance transducer.

• The inductance L represents the inductance between the terminals as also the cable inductance.

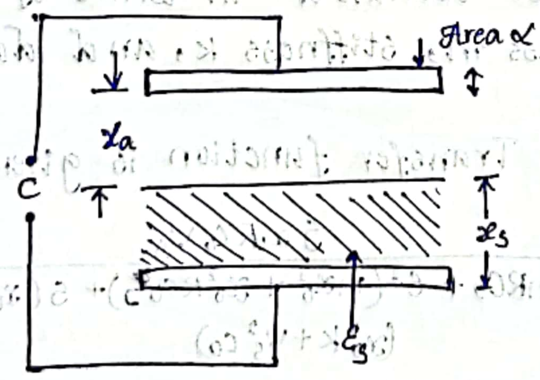


fig: Parallel plate Sensor

• Parallel plate with a solid dielectric of a certain thickness x_s, and an air gap x_a as shown in fig.
The capacitance is:

$$C = \frac{\alpha}{(x_a/\varepsilon_a) + (x_s/\varepsilon_s)}$$

Electrostatic Transducer:

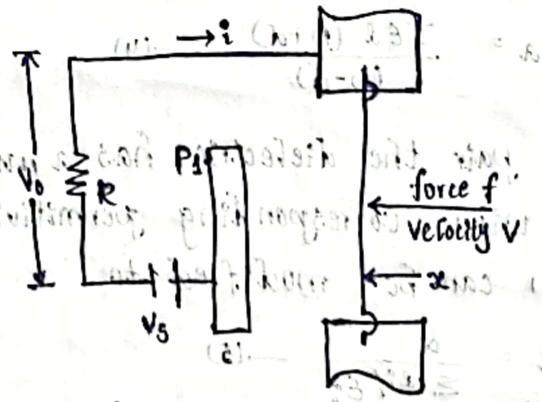


fig: Electrostatic transducer

- Transducer is also reffered to as an electrostatic transducer. A typical scheme of such system is shown in figure.
- A Capacitor formed with a flexible diagram which can move due to application of force and a grid plate P_1.
- There is a bias voltage V_s which is sufficiently large.
- When the system acts as a transducer, the gap x between the plates changes as by same pressure in case of an 'electrostatic microphone'.
- This pressure may be considered sinusoidal for analysis purpose.
- The circuit consisting of Resistance R and Capacitance C 'varying sinusoidally' allows V_s to send a sinusoidal current i.
- A sinusoidal output V_0 accross resistance R is obtained.
- In this case of electromagnetic transducer, V_0 corresponding to a force f can be obtained in terms of the parameters V_s, x, R, C, w, mass m, stiffness k, and damping ξ of the system.
- The dynamic Transfer function is given by:

$$\frac{V_0(s)}{f(s)} = \frac{s\, x_0 R C_0 V_s}{s^3 x_0^2 m R C_0 + s^2(m x_0^2 + x_0^2 R C_0 \xi) + s(x_0^2 \xi + x_0^2 R C_0 k) + (x_0^2 k + V_s^2 C_0)}$$

where; C_0 and x_0 are the initial values of x and C.

- In case of generating along with bias V_s, a sinusoidal input voltage is also applied so that the diaphragm undergoes electrostatic vibration.

Force / stress sensors using Quartz Resonators:

- stress is applied to a flexurally vibrating quartz beam through its mountings. The beam has a fundamental mode of flexural resonance frequency f is given by:

$$f = f_0 \sqrt{1 + k_1 \left(\frac{s}{y}\right)\left(\frac{l}{t}\right)^2} \quad \text{---(1)}$$

- with f_0 as the frequency in absence of stress and, given by

$$f_0 = k_2 \left(\frac{t}{l^2}\right)\left(\frac{y}{P}\right)^{1/2} \quad \text{---(2)}$$

where; s = stress
y = Young's modules
l = beam length
t = beam thickness
P = quartz density and
k_1 and k_2 are constants.

1

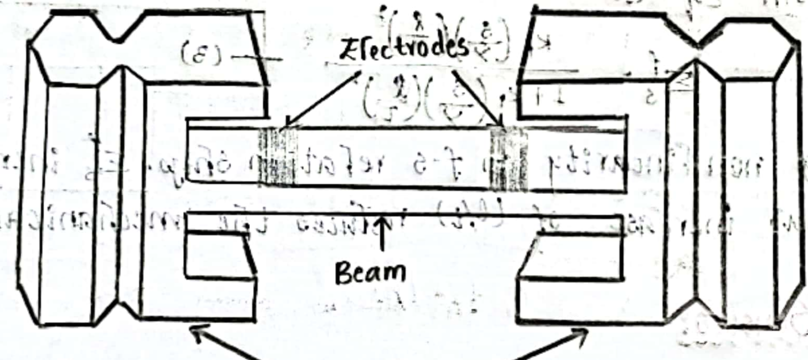


fig: A quartz beam with semiflexible mounting

2

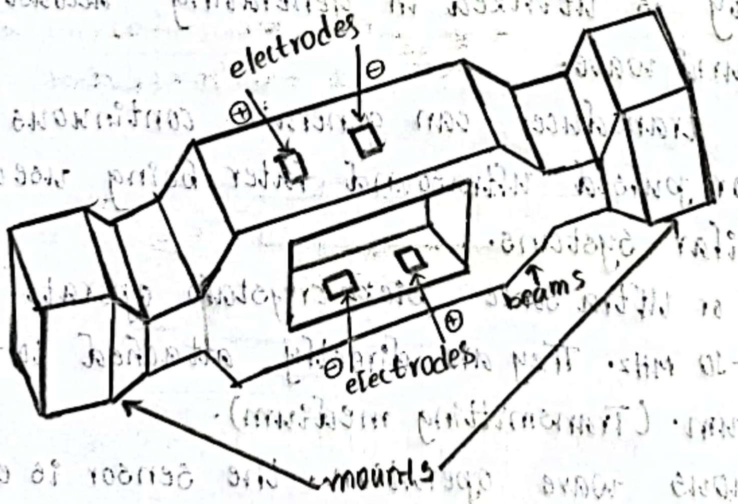


fig: Double beam design of the cantilever.

• The beam is generally machined out from a stock of quartz with semiflexible mounting. for minimizing the mounting misalignments that can effect the vibrating frequency mode shown in fig: 1.

• The vibrational : bending movements that might induce distortion are sought to be cancelled by a double beam design as shown in fig:2.

• The vibration in the two beams are opposite to each other.

• Tuning fork type design of the beams has also been developed using photolithographic techniques.

• Two schemes of which are shown in fig (a) and (b); The two beams are polarized by oscillator input in such away that the beams vibrate in opposite phase.

• vibrates in opposite to the side of beams.

• The sensitivity stress of frequency $\Sigma_s^f = (df/ds)/(f/s)$ is obtained from Eqⁿ (1).

$$\Sigma_s^f = \frac{k_1\left(\frac{s}{y}\right)\left(\frac{l}{t}\right)^2}{1+k_1\left(\frac{s}{y}\right)\left(\frac{l}{t}\right)^2} \quad \text{--- (3)}$$

• Indicating non linearity in f-s relation ship. Σ_s^f increases with (l/t), but increase of (l/t) reduces the mechanical strength

Ultrasonic Sensors:

• Piezoelectric effect of certain crystalline materials has been successfully utilized in ultrasound production and sensing.

• The property is utilized in generating accoustic or ultrasonic sound wave.

• Piezoelectric transducer can generate continuous wave ultrasound or pulsed ultrasound later being used in SONAR or other similar systems.

• Ultrasound or Ultra sonic piezo crystals operate in the range of 0.5 - 10 MHz. They are directly attached to the trans-mission medium. (Transmitting medium).

• For continuous wave operation, the sensor is energized by a tuned oscillator while for pulsed application 'relaxa-tion' oscillators are used to change a capacitor which is discharged across the sensor.

Sensitivity and Linearity of the Sensor:

- A small gap of air l_g and effective permeability of the core μ.

The inductance is given by Eqⁿ:

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

n and a are consists, using $k_l = 4\pi \times 10^{-7} n^2 a$.

- Now Eqⁿ (1) can be written as:

$$L = \frac{k_l}{\left(l_g + \frac{l}{\mu_s}\right)} \quad \text{---(2)}$$

Assuming, $l \gg l_g$. for small increase and decrease in gap l_g and ∂l_g.

$$\frac{\partial L}{L} = \frac{\partial l_g}{l_g \pm \partial l_g + \frac{l}{\mu_s}}$$

$$= \frac{\partial l_g / l_g}{1 + \frac{l}{l_g \mu_s}} = \frac{1}{1 + \frac{\partial l_g / l_g}{\{1 + l/l_g \mu_s\}}} \quad \text{---(3)}$$

and for $(\partial l_g/l_g)/(1 + l/l_g \mu_s) \ll 1$

$$\frac{\partial L}{L} = \frac{\partial l_g / l_g}{1 + \frac{l}{l_g \mu_s}}\left[1 \pm \frac{\partial l_g / l_g}{1 + \frac{l}{l_g \mu_s}} + \left(\frac{\partial l_g / l_g}{1 + \frac{l}{l_g \mu_s}}\right)^2 \mp \cdots\right] \quad \text{---(4)}$$

If only the first term is accepted for ∂l_g being very small, there appears to be a linear variation between L and l_g, and the sensitivity $S^L_{l_g} = (\partial L/L)/(\partial l_g/l_g)$ is given by

$$S^L_{l_g} = \frac{1}{1 + l/l_g \mu_s}$$

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Inductive Sensor:

- The inductive transducer utilizes the simple principle that the physical quantity.
- To be measured can be made to vary the inductance of a coil, maintaining a relation between the two.
- This variation of inductance can often be measured by ac bridge circuit.
- If a magnetostrictive core material is used.
- The most common methods of acheiving variation in inductance are by changing the reluctance of the magnetic path and by coupling two or more elements.

a) change of mutual inductance
b) change of eddy current
c) transformer action.

these are shown in fig(a),(b), (c) respectively:

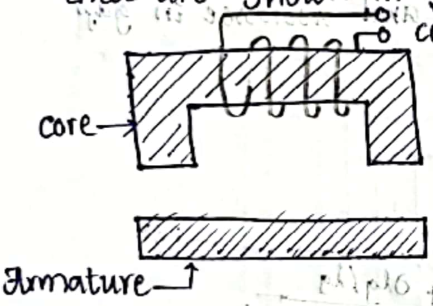

fig (a)

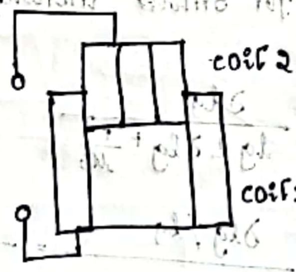

fig (b)

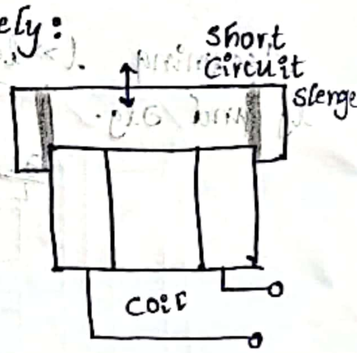

fig (c)

- There are inductive sensors of the magnetic type which are bilateral in operation with electrical and mechanical input/output relationship and magnetostrictive type.
- A sensor that was uses a magnetostrictive core material is shown in figure:

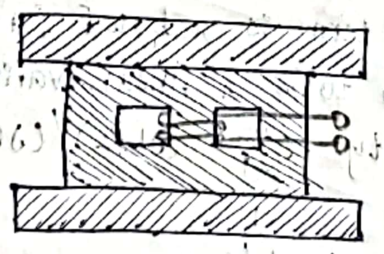

fig: Sensor using a magnetostrictive effect

- The copper coil on a ferromagnetic core has an equivalent circuit that consists of inductance L in series with copper loss resistance R_c and resistance R_e representing eddy loss resistance in the core in parallel with 'L' interwinding are self capacitance at high frequencies is in parallel to the coil resistance R_c and inductance L. the equivalent circuit is shown.

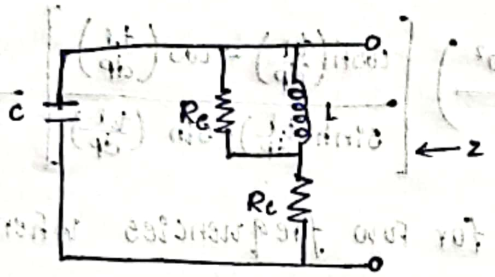

fig: Equivalent circuit of a ferromagnetic coil

- If a coil 'n' turns, a current I, and the core length l, the field strength H is given by:

$$H = \frac{nI}{l} \ (A/m) \quad \text{—(1)}$$

- for a core material of permeability μ, its relative permeability and the permeability of the free space or vaccum ($\mu_0 = 4\pi \times 10^{-7}$ H/m) and core cross section area a, the inductance L of the coil is the flux linkage per unit current so that

$$L = \frac{n\phi}{I} = n = \frac{Ba}{I} = n\frac{\mu H a}{I} \quad \text{—(2)}$$

- where B is in Tesla or wb/m² and ϕ is in wb using Eqⁿ (2)

$$L = \frac{\mu n^2 a}{l} \quad \text{—(3)}$$

- The copper resistance R_c is also calculated, if the coil wire diameter d and the copper resistivity P are known so that

$$R_c = \frac{u P n l_t}{\pi d^2} \quad \text{—(4)}$$

where l_t is the average length per turn of the coil.

- The coil dissipation factor D_c is usually defined:

$$D_c = \frac{R_c}{\omega L} \quad \text{—(5)}$$

with decreases with increasing frequency. for reducing eddy loss or core loss is called the depth of penetration of eddy current, dp is given by:

$$d_p = \sqrt{\frac{P_e}{\pi \mu f}} \quad \text{—(6)}$$

where P_e is the resistivity of the core material and $f = \omega/(2\pi)$ is the frequency.

- The eddy loss resistance is then given by:

$$R_e = \left(\frac{2 d_p \omega^2}{t_l}\right)\left[\frac{\cosh\left(\frac{t_l}{d_p}\right) - \cos\left(\frac{t_l}{d_p}\right)}{\sinh\left(\frac{t_l}{d_p}\right) - \sin\left(\frac{t_l}{d_p}\right)}\right] \quad \text{—(7)}$$

Eq^n (6) and (7) for low frequencies when $P_t = (tl/dp) \leq 2$.

- This range of frequency Eq^n (7) can be simplified using Eq^n (3) and (6).

$$R_e = \frac{6 \omega L}{(t l/dp)^2}$$

$$= \frac{12 P_e\, a n^2}{(l t_l)^2} \quad \text{—(8)}$$

- The eddy loss dissipation factor is defined by:

$$D_e = \frac{\omega L}{R_e} \quad \text{—(9)}$$

and is directly proportional to frequency of the hysteresis curve is given by

$$A_h = \int B \cdot dH \quad \text{—(10)}$$

where α_r is the Rayleigh's constant which may be defined by the Eq'n

$$\alpha_r = \frac{2\left(\frac{\Delta B}{\mu_0} - \mu_i H\right)}{(\Delta H)^2} \quad \text{—(11)}$$

is permeability $H=0$, with change from zero values of B and H Eq^n (11) is written as:

$$\alpha_r = \frac{2(B/\mu_0 - \mu_i H)}{H^2} \quad \text{—(12)}$$

using $P_h = E^2/R_h$, R_h the equivalent hysteresis loss resistance is:

$$R_h = \frac{\omega^2 L^3 I^2}{P_h} \quad \text{—(13)}$$

which is independent of the frequency.

• A sensor or a transducer involves the movement of the armature.

• The effective permeability of the core.

• The permeability μ_s and a relation between L and the gap length l_g.

• The total path length l, gap length l_g cross sectional area a, the effective permeability μ.

$$\frac{\left[\left(\frac{l-l_g}{\mu_s}\right)+l_g\right]}{a} = \frac{1}{\mu a} \quad \text{—(14)}$$

$$\mu = \frac{\mu_s}{\left\{1+\left(\frac{l_g}{l}\right)(\mu_s-1)\right\}} \quad \text{—(15)}$$

Since $\mu_s >> 1$

$$\mu \approx \frac{\mu_s}{\left[1+\left(\frac{l_g}{l}\right)\mu_s\right]} \quad \text{—(16)}$$

Substituting this Eq'n in (3) 3

$$L = \frac{\mu n^2 a}{l}$$

$$L = \left[\frac{\mu_s}{\left[1+\left(\frac{l_g}{l}\right)\mu_s\right]}\right]\left(\frac{n^2 a}{l}\right) \quad \text{—(17)}$$

UNIT - 1

Long Answer questions

1. Explain the function of a capacitive sensor in a robot end effector
2. Explain the principles of sensors
3. what is strain Gauge? write a short note on semi conductor strain Gauges.
4. Differentiate between sensor and Transducer
5. Discuss the working of Resistive potentiometer
6. write a short note on Ultrasonic sensor
7. Explain the working principle of the variable Inductance type transducer.