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-3
Magnetic Sensors

Introduction:

Magnetic sensor usually refers to a sensor that converts the magnitude and variations of a magnetic field into the electric signal.

(or)

Magnetic sensor that detects the magnitude of magnetism generated by a magnet or current.

What is magnetic sensor:

- The sensor transducer which uses the change in magnetic field for their operation.
- Used to measure the current, speed, position & displacement.
- As the conventional sensor, magnetic sensor does not give output parameter directly.
- Signal processing is required for desired output.

→ A few are being conveniently used in developing sensors. Some of these are:

Magnetic field sensor: It developed following "Δy" effect. In effect, is observed as the change in young's modulus with magnetization.

Magneto elastic sensor: Based on the fact that in a longitudial field, given in a ferromagnetic rod changes its magnetization.

Magnetic elastic sensors: produced using compressive stress changes magnetization or affects magnetization in same way.

Torque/force sensors: 'widemann effect' is used to develop the torque/force sensors.

Magneto resistive sensors: Are developed on the basis of 'Thomson effect'.

which is basically a change in resistance of specified materials with magnetic field impressed.

Hall effect sensor/magnetogalvanic sensors:

- The most common and widely used type magnetic sensor

- These operate on the fact that a crystal carrying a current.
- To a magnetic field perpendicular to the direction of the current, produces a transverse voltage.

Sensors and the principles behind:

- In effect, the ΔY effect is an outcome of magnetostriction.
- A demagnetized ferromagnetic material.
- When undergoes a mechanical stress.
- It develops two types of stresses. In its namely:
  (1) the plain mechanical elastic strain ε_s and
  (2) the magnetoelastic strain ε_m
- The magnetic domains by the applied stress S_a given.
- The Young's modules of the demagnetized material as:

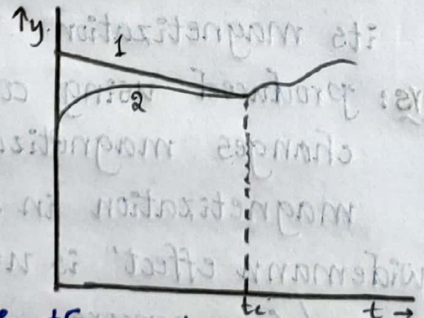
$$Y_{dm} = \frac{S_a}{\varepsilon_s + \varepsilon_m}$$

- for a saturated sample no magneto elastic strain is produced. no further reorientation is possible.
- And hence the Young's modulus becomes:

$$Y_{sm} = \frac{S_a}{\varepsilon_s}$$

where, Y_{sm} is the Young's modules of the saturated material.

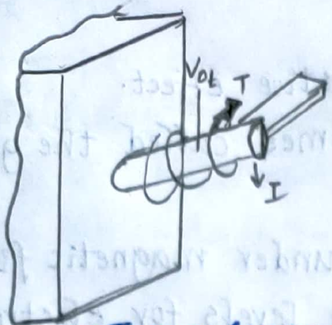
$$\frac{\Delta Y}{Y_{dm}} = \frac{Y_{sm} - Y_{dm}}{Y_{dm}} = \frac{\varepsilon_m}{\varepsilon_s}$$



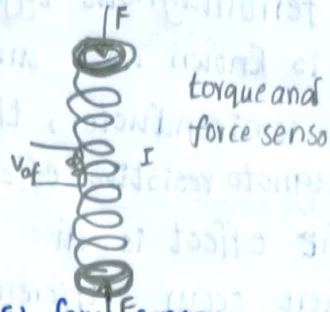
for the material mentioned.

- In this figure varies depending on the annealing condition (temperature) of the material.
- In this figure critical temperature is t_c which usually is close to the annealing temperature.
- Curve 1 in the figure corresponds to the magnetized state.
- Curve 2 is in the non magnetized state.

• change in v of about 10% can be obtained at room temperature.



(a) Torque Sensor



(b) force sensor

• widemann effect is used to make torque/force sensor.
• fig (a) and (b) with a current 'I' passing in direction as shown in fig. And a torque produced in the rod.
• An output voltage V_{ot} is obtained that gives a measure of the torque.
• In fig (b) V_{of} is the output voltage for the force. in the balanced condition.

Magneto elastic Sensor:

Magneto elastic sensor interactions and conversion of elastic energy E_s. into magnetic energy E_m take place.
• E_m is proportional to the product of field strength and polarization and is often called the magnetic field energy.
• E_s is product of field strength.
∴ called the elastic stress energy.
• depending on the material there appears a crystalline energy E_{cr}.
• An energy E_{ua} which is called the uniaxial anisotropy energy.
• The shape anisotropy energy E_N is developed.
• The magneto mechanical coupling factor k_{33} is defined as the ratio of the elastic stress. energy to the total storage energy is

$$k_{33} = \frac{E_s}{E_s + E_m + E_{cr} + E_{ua} + E_N}$$

Magneto resistive Sensors:

Magneto resistive sensor uses the fact that the electrical resistance in a ferromagnetic thin film alloy is changed through an external magnetic field.

- Magnetoresistive effects are observed in metals specially in ferromagnetic types.
- It is known as anisotropic magnetoresistive effect.
- In semiconductor, this effect is some times called the geometrical magnetoresistive effect.
- The effect is due to the fact that under magnetic field.
- There occur different shifts of energy levels for electrons having negative and positive spins.
- Resulting in a change in density of states at the fermi level.
- The current lines becomes longer and the resistivity increases.

Anisotropic Magneto resistive sensing:

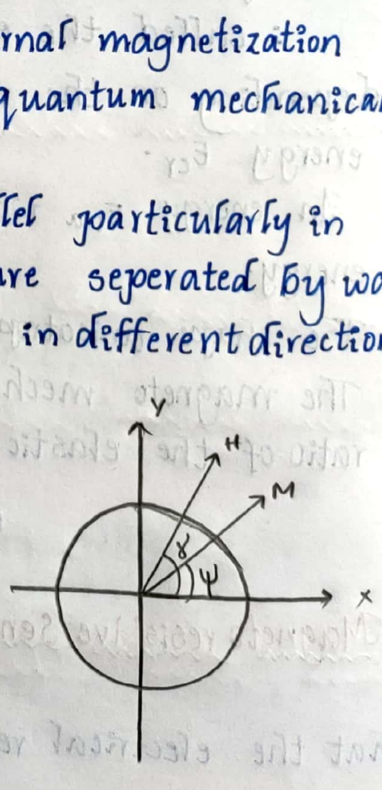
- This type of magnetoresistive effect can be analyzed taking into account the complex ferromagnetic.
- The relation between the direction of magnetization and resistivity is sufficient as also between the magnetization direction and external fields.
- If the angle between the direction of internal magnetization M and that of current in the sample I is ϕ then,
- the resistivity is given by

$$\text{Resistivity } \rho(\phi) = \rho_\alpha + (\rho_\beta + \rho_\alpha)\cdot\cos^2\phi$$

ρ_α is the value of ρ for $\phi = 90°$

ρ_β is the value of ρ for $\phi = 0°$

- Ferromagnetic materials have high internal magnetization because of exchange coupling at the quantum mechanical level.
- The electron magnetic moments parallel particularly in small areas known as domains which are seperated by walls.
- Since different domains have parallelism in different directions.
- This is specially true for soft ferromagnetic materials.
- An external field H, magnetization M rotates which can be calculated by evaluating the energy density E in terms of the angle ψ. b/w M and the axis of lowest energy.



- The film can be considered to possess an elliptical shape.
- figure gives the geometry of the assumed structure.
- The major axis of the ellipse as the easy axis.
- Energy ε has 3 components:
  - (i) the field energy $\varepsilon_H = -HM\cos(\gamma - \psi)$
  - (ii) the anisotropy energy $\varepsilon_A = Km \colon \sin^2\psi$
    where km is a material constant
  - (iii) the dimagnetization energy

$$H_{dx} = -N_x M \cdot \cos\psi$$

$$H_{dy} = -N_y M \cdot \sin\psi$$

Semiconductor Magneto resistors:

- Semiconductor material is exposed to magnetic field its resistance increases.
- The velocity v of a free change carrier and the magnetic induction B.
- The Hall angle θ_h between the electric field E_x and the direction of the current.
- This charge in the direction of the current.
- Its rotation increases the path length of the current flow as mentioned but is observed as an increases in the resistance of the material.
- The change in resistivity is proportional to the square of the component of the ~~eq~~ field perpendicular to the current vector, B_p^2

Thus $\rho_B = \rho_0 (1 + H_R B_p^2)$

- H_R be the coefficient of magneto resistance.
- If the magnetic field is large θ_h approaches $\pi/2$ & ρ_B
- It shows a linear dependence on field B.
- The semiconductor plate and magnetic field are included in the resistance ratio of the plate with and without field.

$$\frac{R_B}{R_0} = \frac{\rho_B}{\rho_0}\left[1 + C_a(\mu_H B)^2\right]$$

and for $\theta_h \to \pi/2$

$$\frac{R_B}{R_0}\left(\frac{\rho_B}{\rho_0}\right)(C_b + C_c \mu_H B)$$

where

C_a, C_b, C_c are factors dependent on plate geometry.

μ_H is the Hall mobility

Resistance is linearly proportional to field B.

Hall effect and Sensors:

- Hall effect sensor is a type of sensor.
  and magnitude of a magnetic fied using the hall effect.
- Hall effect sensors are also galvano magnetic effect sensor.
- Hall effect is observed both in metals and semiconductors.

The hall effect:

- A current is sent through avery long strip.
- Its homogeneous semiconductor in the x (long) direction.
- A magnetic field is applied to produce a flux density B_z, then electric field E_y in the direction of y which is called the Hall field.
- A voltage V_H; called the hall voltage is given by

$$V_H = B_z I_x \quad \text{—(1)}$$

- Galvanomagnetic effects
- The lorentz force on the charge carrier transport phenomena in condensed medium.
- The lorentz force is expressed as:

$$F = eE + e(v \times B); \quad \text{—(2)}$$

where e - the charge of the carrier

E - the electrical field

v - the velocity

B - magnetic induction

- If 'J' is the total current density:

then the carrier transport eq'ns is

$$J = J_0 + \mu_H [J_0 \times B] \quad \text{—(3)}$$

- The galvano magnetic effects such as magneto resistive and hall effects can be derived from the solutions of Eq-3 with appropriate boundary conditions.
- The Hall effect has varying intensity in different materials.
- The materials for this effect are characterized by hall coefficient which is defined as: $h_c = -\dfrac{E_H}{J \times B}$

- The hall voltage can be expressed in terms of Hall coefficient h_c

$$V_H = -h_c J_x B_z W$$

- The coefficient h_c is reduced ; if n_p and n_n are the concentrations γ_p and γ_n are the hall scattering factors.
- μ_p and μ_n are the holes and electrons respectively, then the coefficient is given by

$$h_c = \frac{1}{e} \frac{r_p n_p - r_n n_n (\mu_n/\mu_p)^2}{(n_p + n_n (\mu_n/\mu_p))^2}$$

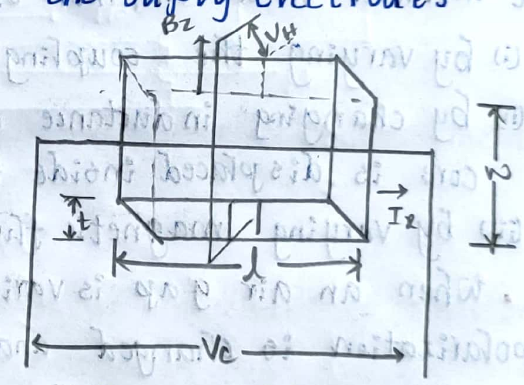
- Carrier density n_i equals n_p and n_n which is calculable from standard eq'n

$$n_i = AT^{3/2} \exp\left(\frac{-E_g}{2KT}\right)$$

A - Coefficient
T - Temperature
k - Boltzmann Constant
E_g - band gap energy

Hall effect sensor:

- In this fig. A voltage V_c across the supply electrodes produces a current I_x which flows along the length and for a magnetic induction B_z across $l \times w$ face shown in fig.



$$V_{Hi} = \frac{h_c B_z I_x}{t}$$

fig: Hall Sensor

- A geometrical correction factor needs to be introduced which is defined as $k_g = V_H / V_{Hi}$

so $$V_H = k_g \frac{h_c B_z I_x}{t}$$

- In large drop along the strip which may not be acceptable as a sensor.
- This voltage drop V_c is given by

$$V_c = R_h I_x = \left(\frac{I_x}{e \mu n_n}\right)\left(\frac{l}{wt}\right)$$

V_H can be written as

$$V_H = -\frac{\mu H n \, k_g B_z V_c W}{l}$$

Inductance and eddy current sensor:

- Eddy current sensors are capable of high resolution measurement and are also reffered to as inductive sensor.
- Eddy current sensors works in magnetic fields.
- Inductance and eddy current sensors follow the Faraday's law of induction which is mathematically as

$$\oint E\,dl = -\frac{d}{dt} \iint_A B \cdot dA$$

- The voltage induced in closed turns of a coil is proportional to the time rate of change of flux linkage.
- The inductance sensors use the effect of voltage induction.
- The eddy current types use ~~the~~ the current induced due to alternating magnetic field.
- Both these are the most useful they are easily adapted to measure displacement, rpm, force, weight, acceleration, torque, pressure and soon.
- A voltage in proportion to a variable to be measured can be induced in a number of ways such as

(i) by varying the coupling between the two coils.

(ii) by changing inductance of two coils when a soft magnetic core is displaced inside them.

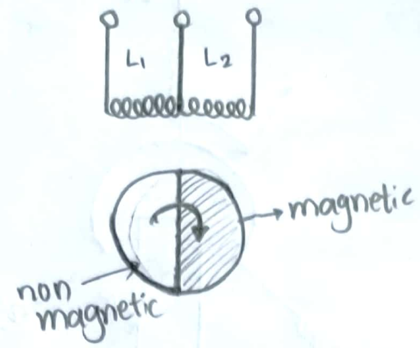
(iii) by varying magnetic flux linkage.

- When an air gap is varied or when the direction of magnetic polarization is changed and soon.
- Eddy current is produced by moving an electrical conductor in an alternating magnetic field and its effects is utilized in the same way.

Angular / Rotatory movement transducers:

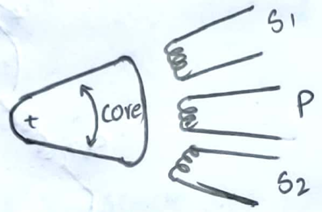
- An angular movement such as twist or torsion of a shaft.
- A section of the same may be made with half of it made of a ferromagnetic material.
- The half being made of non magnetic material.
- Two coils are arranged.
- The inductance of the two parts.
- It depends on the amount of magnetic material in the linkage path of the coil fluxes.

• The scheme is shown in fig



A split coil rotatory transducer

• Another technique for rotatory motion (rotor motion) measurement is a modified version of the LVDT as depicted in fig.



• Modified version of LVDT for angular movement measurement.

Synchros:

• A commonly used error detector of mechanical positions of rotating shafts in AC control systems is the synchro.

• A synchro is a type of transducer which transforms the angular position of the shaft in to an electric signal.

• By changing the magnetic coupling between coils.

• As ac-excited electromechanical sensors have been developed.

• for measurement at distant points. If 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 fig.

- It consists of a stator with three windings S_1, S_2, S_3. Seperated by 120° in space and a rotor R, which is supplied with an ac voltage.

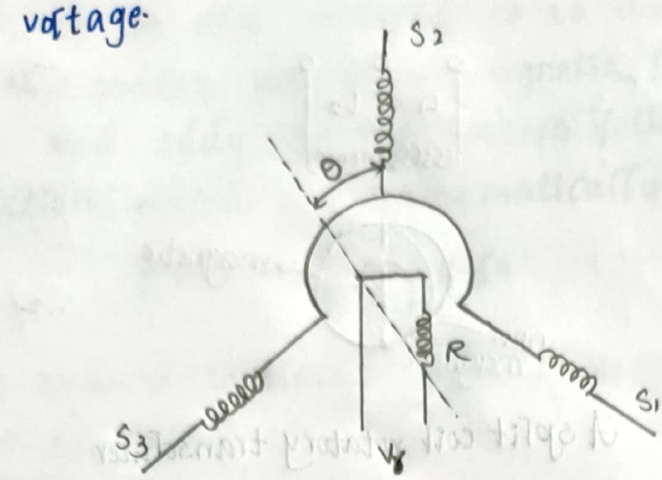


fig: General Constructional features of a synchro

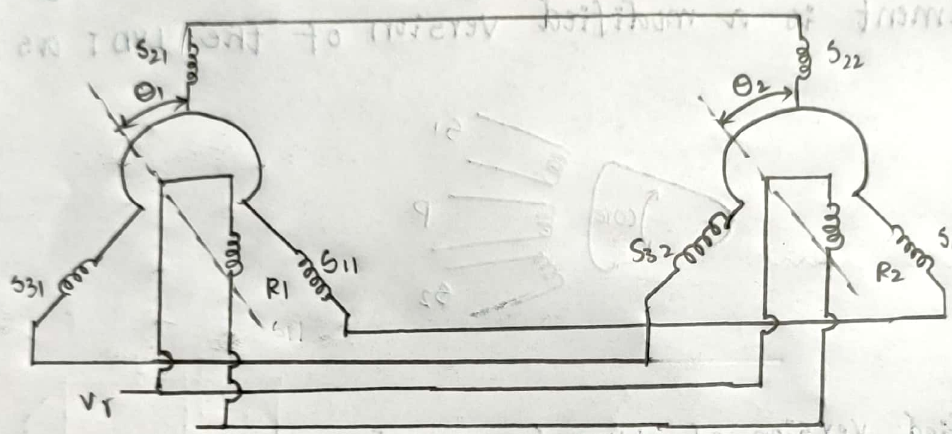


fig: Torque type synchro sensor

- In magnitude and phase, these windings are connected electrically to S_{12}, S_{22}, S_{32}.
- It's same voltage with phases as in those windings of stator 1 produce a field.
- The Rotor R_2, if not oriented as rotor R_1.
- If it is a receive a torque and rotation is the same rotational position as that of R_1.
- for a single synchro unit such as that of fig. with the rotor angle θ for an input sinusoidal voltage $V_r = V_{r_0} \sin\omega t$.
- The voltage induced in windings S_1, S_2, and S_3 are

$$V_{S1} = K V_{r_0} \sin\omega t \cos(\theta + 120°) \quad \text{—(1)}$$

$$V_{S2} = K V_{r_0} \sin\omega t \cos\theta \quad \text{—(2)}$$

$$V_{S3} = K V_{r_0} \sin\omega t \cos(\theta + 240°) \quad \text{—(3)}$$

- where K is a constant, such as the ratio of the rotor to the stator turns from $Eq^n(3)$.

the line voltage are:

$$V_{S12} = k\sqrt{3}V_{r0} \sin\omega t \sin(\theta+240^\circ) \quad -(4)$$

$$V_{S23} = k\sqrt{3}V_{r0} \sin\omega t \sin(\theta+120^\circ) \quad -(5)$$

$$V_{S31} = k\sqrt{3}V_{r0} \sin\omega t \sin\theta \quad -(6)$$

- In torque type sensors. It is assumed that $\theta_1 = \theta_2$.
- There is no unbalanced terminal voltages.
- The torque is approximately sinusoidal in form.

$$T = K_t \sin(\theta_1-\theta_2) \quad -(7)$$

- This arrangement is known as the synchro control transform -er.
- The error voltage $V_e(t)$ is proportional to the cosine of the angle between the two rotors. $\cos(\theta_1-\theta_2)$.

$$V_e(t) = K' V_{r0} \sin\omega t \cos(\theta_1-\theta_2). \quad -(8)$$

- If the two rotors are oriented at right angles. $V_e(t)=0$ and with $\theta_1=0$ and $\theta_2 = 90^\circ$.
- If $\theta_1-\theta_2$ is close to 90°.

then

$$V_e(t) = K' V_{r0} \sin\omega t \sin\{90^\circ-(\theta_1-\theta_2)\}$$

$$\alpha = (\theta_1-\theta_2) \quad -(9)$$

- The error voltage is proportional to the angular rotational difference of the rotors, In case of synchro control transformer.
- To measure sums of the differences of angles.
- The differential units has star connected windings on both the stator and the rotor.
- The rotor has a cylindrical structure.
- Synchro differential unit may also be used as transmitter when it rotor is a driven one.
- Synchro torque units are used as transmitter ST_1 and ST_2 and the differential unit is used as synchro differential receiver.