III - UNIT

Magnetic sensors :-

INTroduction :-

Magnetic sensor usually referes to a sensor that converts the magnitude and variations of a magnetic field into 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 sensors :- 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 some way.

⇒ Torque / force sensors :-
'Wiedemann effect' is used to develop the torque / force sensors.

Magneto resistive sensor :-

→ Are developed on the baises of 'Thomson effect'.

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

⇒ Hall effect sensor :- (or) 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.

~~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.

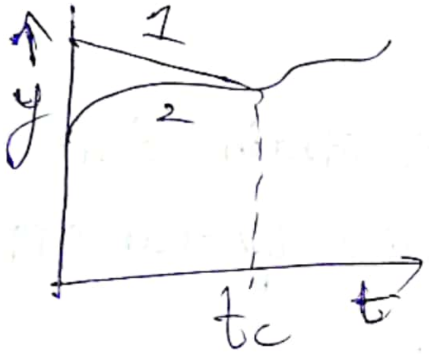
→ ~~And~~ hence ~~the~~ ~~Yound~~

Young's modulus becomes.

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

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

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



for the material mentioned,

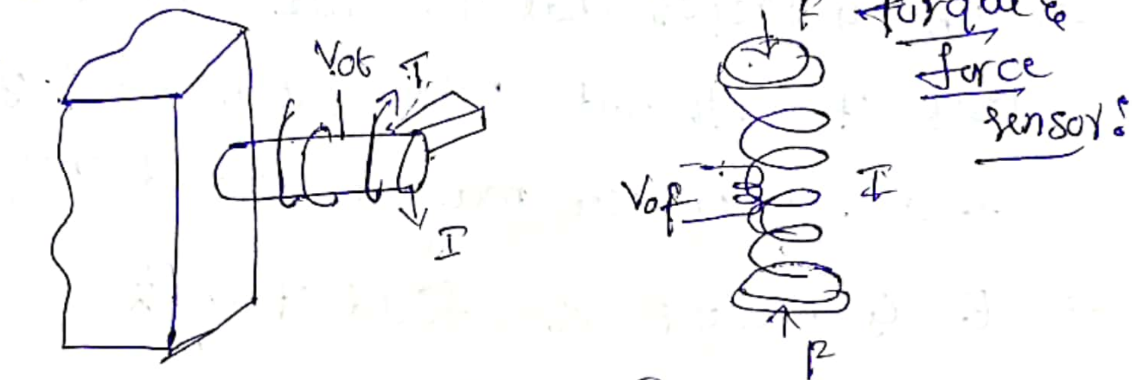
→ In this figure varies depending on the ~~am~~ annealing condition (temperature) of the material.

→ In this figure critical temperature is tc.. which usually is close to the annealing temperature.

→ Curve 1 in the figure corresponds to the magnetized state.

→ curve 2 in the nonmagnetized state.

→ Change in V_{of} of about 10% can be obtained at room temperature.

⇒ 

ⓐ Torque sensor ⓑ force sensor

→ Wiedemann effect is used to make torque/force sensor.

→ fig ⓐ & ⓑ 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 ⓑ V_{of}~~

In fig ⓑ. V_{of} is the output voltage for the force in the balanced condition.

Magnetoelastic Sensor :

Magnetoelastic 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

$$K_{33} = \frac{E_s}{E_s + E_m + E_{cr} + E_{ua} + E_N} \;..$$

Magnetoresistive sensors :-

Magnetoresistive 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 sometimes 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 state at the Fermi level.

→ The current lines becomes longer and the resistivity increases.

Anisotropic Magnetoresistive Sensing:

This type of magnetoresistive effect can be analyzed taking in to account the complex ferromagnetic.

→ The Relation between the direction of magnetization and resistivity is 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.

ρ.

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

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

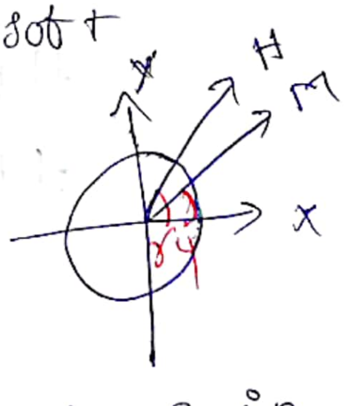
ρ_β is the value of ρ for $\phi = 0°$

→ 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 separated 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 φ · b/w M. and the axis of lowest energy.

→ The film can be considered to possess an elliptical shape. ~~in fig~~.

→ figure gives the geometry of the assumed structure.

→ The Major axis of the ellipse as the easy axis.

→ ~~E~~ Energy E has 3 components

(i) the field energy

$$E_H = -HM\cos(\gamma - \varphi)$$

(2) the anisotropy energy

$$E_A = K_m \sin^2\varphi$$

where K_m is a material constant

(3) the demagnetization energy.

$$H_{dx} = -N_x M \cos\varphi$$

$$H_{dy} = -N_y M \sin\varphi$$

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Semiconductor Magnetoresistors:-

→ Semiconductor material is exposed to magnetic field. its resistance increases.

→ The velocity v of a free charge carrier and the magnetic induction B.

→ The Hall angle θ_h between the electric field E_x and the direction of the current.

→ This change 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 propotional to the square of the component of the field perpendicular to the current vector, B_p^2.

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

H_R the coefficient of magneto-resistance.

→ If the magnetic field is large θ_h approaches $\pi/2$ and 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 $\theta_h \to \pi/2$

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

where ~~C_a, C_b~~.

C_a, C_b, C_c are factors dependent on the 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 field using the Hall effect.

→ Hall effect sensors are also galvanomagnetic effect sensors.

→ Hall effect is observed both in metals and Semiconductors.

The Hall effect:-

→ A current is sent through a very 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 $V_H = B_z I_x$ —(1)

→ Galvanomagnetic effects

→ The Lorentz force on the charge carrier transport phenomena in condensed medium.

→ The Lorentz force is expressed as

$$F = eE + e(v \times B) \quad -(2)$$

where
e is the charge of the carrier
E is the electrical field
v is the velocity and
B is the magnetic induction

If J is the total current density.
then the carrier transport eqns is

$$J = J_0 + \mu_H [J_0 \times B] \quad - (3)$$

→ the galvanomagnetic effects such as magnetoresistive 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

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which is defined as

$$h_c = -\frac{E_H}{J \times B}.$$

→ ~~Ho~~ 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 r_p and r_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.

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

A is coefficient

T = Temperature.

k = Boltzmann constant

Eg = band gap energy.

The Hall effect Sensor :-

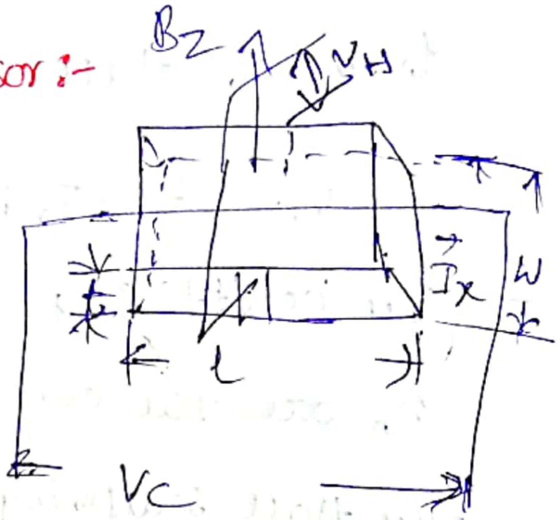


fig :- Hall sensor

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×w face shown in fig.

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

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

$$V_c = R_h I_x = \left(\frac{I_x}{e\mu n_n}\right)\left(\frac{1}{wt}\right)$$

V_H can be written as

$$\boxed{V_H = -\frac{\mu_{Hn}\, k_g B_z V_c W}{l}}$$

Inductance and eddy current sensor

→ Eddy current sensors are capable of high resolution measurement and are also reffered to as inductive sensor.

→ Eddy ~~sensor~~ ~~two~~ current sensors work 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 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 so on.

→ 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 so on.

→ Eddy current is produced by moving an electrical conductor in an alternating magnetic field and its effects is utilized in the same way.

~~Linear Variable~~

Angular / Rotary 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.

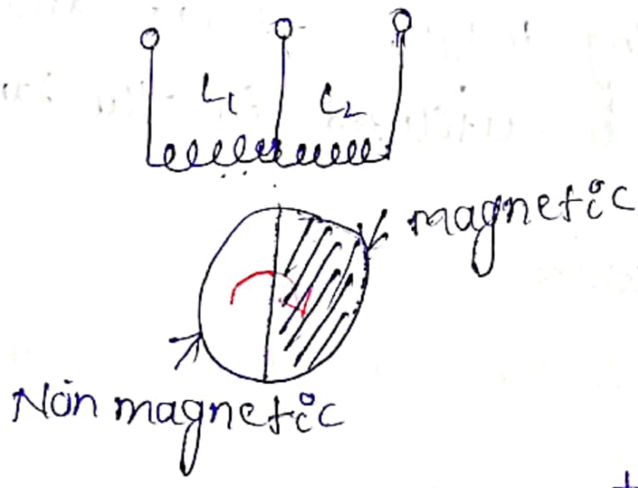
→ The half being made of non - magnetic material.

→ ~~Two~~ Two coils are arranged.

→ The inductance of the two parts

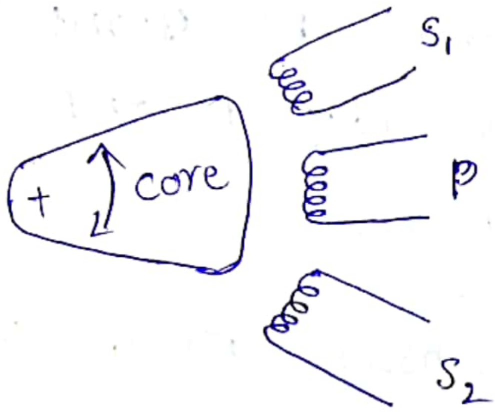
→ It depends on the amount of magnetic material in the linkage path of the coil fluxes.

→ The scheme is shown in fig.



A split coil rotary transducer

Another technique for rotary 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~~ ac-excited electromechanical sensors have been developed.

→ for measurement at distant points
It 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, and S_3 seperated
by $120°$ in space and a rotor R,

→ which is supplied with an ac
voltage.

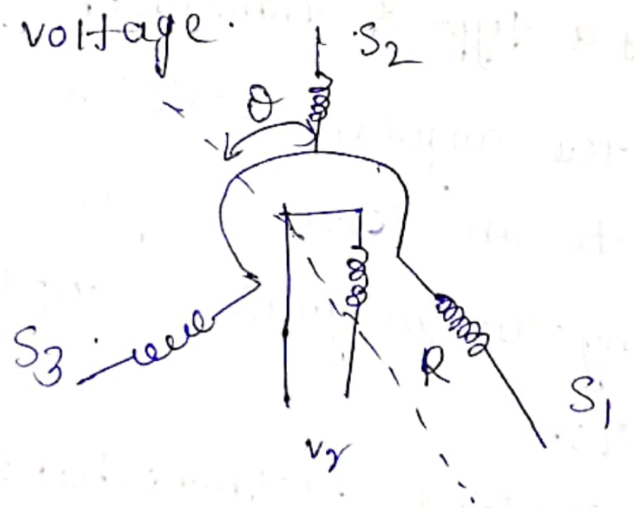


fig:- General constructional features
of a synchro.

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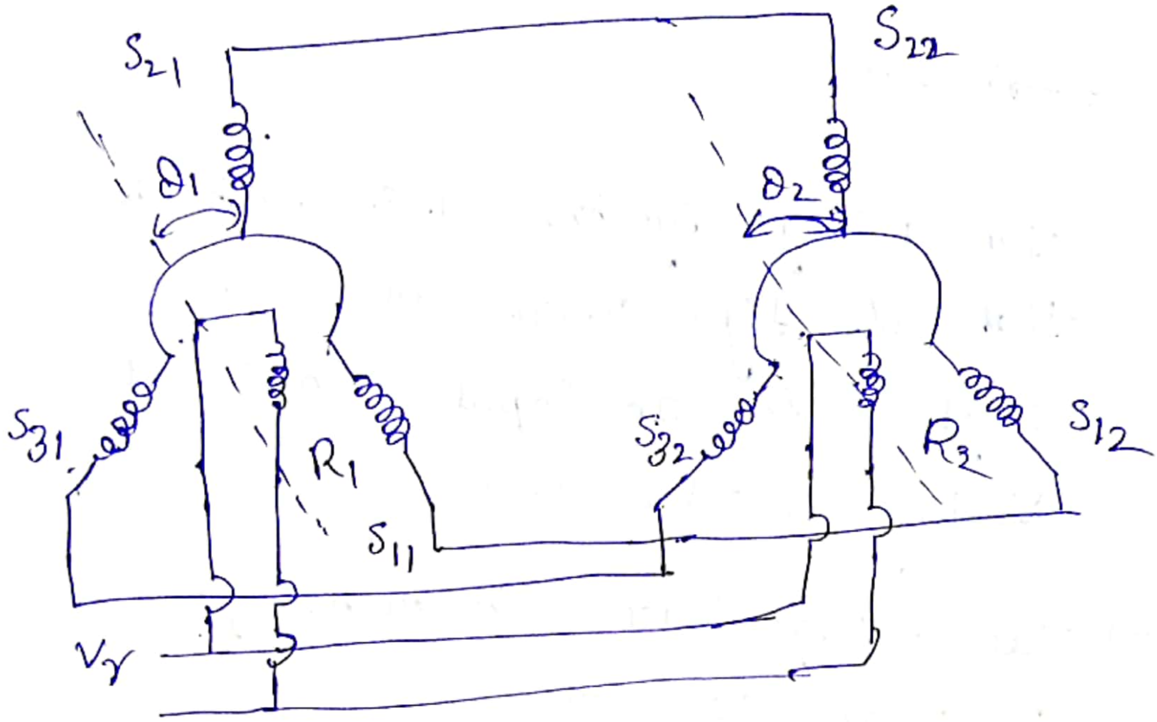

fig:- Torque type synchro sensor.

→ In magnitude and phase, these windings are connected electrically to S_{12}, S_{22} and S_{32}.

→ It's same voltage with phase 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 to the same rotational position as that of R_1.

~~for A~~ S..

→ for a single synchro unit such as that of fig. with the rotor angle θ for an input sinusoidal Voltage $V_r = V_{ro} \sin\omega t$.

→ The voltage induced in windings S_1, S_2, and S_3 are

$$V_{S_1} = K V_{ro} \sin\omega t \cos(\theta + 120^\circ) \quad \text{--- (1)}$$

$$V_{S_2} = K V_{ro} \sin\omega t \cos\theta \quad \text{--- (2)}$$

$$V_{S_3} = K V_{ro} \sin\omega t \cos(\theta + 240^\circ) \quad \text{--- (3)}$$

where k is a constant, such as the ratio of the rotor to the stator turns. from eq'n (3).

The line voltage are

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

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

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

→ In torque type sensors. It is assumed that $\theta_1 = \theta_2$.

→ ~~There~~ It 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 transformer.

→ The error voltage $V_e(t)$ is proportional to the cosine of the angle between the two rotors. $\cos(\theta_1 - \theta_2)$.

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

→ 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

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

$$\propto (\theta_1 - \theta_2) \quad - \quad 9.$$

the error voltage is proportional to the angular rotational difference. of the rotors. In case of synchro control transformer.

- To measure sums or differences of angles.
- The differential unit 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 a transmitter. when it rotor is a driven. one.
- Synchro torque units are used as transmitter S_{T1} and S_{T2} and the differential unit is used as Synchro differential receiver.