

UNIT-4 - TRANSDUCERS

(1)

Introduction :-

Transducer is a device which when actuated by energy in one form supplies energy either in the same form or in another form to a second transmission system i.e., a device which converts one form of energy into another form is called a Transducer.

Ex :- 1) A Mechanical force or displacement being converted into an electrical signal.

2) A photo cell changes in light intensity.

3) Measurement of Electrical noise

4) Telemetering System - When I/p & O/p are in electrical form.

Classification of Transducers :-

Transducers may be classified according to their application, method of energy conversion, nature of O/p signal, etc.

Transducers are classified as

1) Passive transducers

2) Active transducers

Further, the Passive transducers are classified as

→ ~~Potentiometric~~ Resistance transducers

→ Capacitive transducers

→ Inductive transducers

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Active transducers are classified as

- Thermocouple
- Photo voltaic cell
- Piezo electric pickup

Passive transducers	Principle	Parameters to be measured
Resistance transducers	Positioning of the slides by an external force results in variation of resistance.	Pressure, force, displacement
1. Potentiometric		
2. Resistance strain	Resistance is change by compression due to externally applied stress.	Force & Torque
3. Pirani gauge	Resistance of a heating element is vary by convection cooling of a stream of gas.	Gas flow, gas pressure
4. Resistance Thermo - couple	Resistance of a pure metal with a large +ve temperature coefficient varies with temperature.	Temperature measurement, Radiation, Heat.
5. Thermistors	Resistance of certain metal oxides with a -ve	Temperature

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temperature coefficient varies with temperature.

6. Photo conductiv \rightarrow cell.

Resistance varies with light intensity.

Light Intensity.

Capacitance transducer

1. Variable Distance b/w the two Capacitance parallel plates is varied pressure gauge by an externally applied force.

Displacement, pressure.

2. Capacitor microphone

Sound pressure varies the capacitance b/w a fixed plate under movable diaphragm.

Sound, music, speech.

3. Dielectric gauge.

Variation in ' C ' by changing to a dielectric constant.

Liquid level.

Inductance Transducers

1. Magnetic H of an excited circuit transducers coil is varied by change in the magnetic circuit.

Pressure and displacement.

2. Differential Voltage

The differential voltage of two secondary windings of a transformer is varied by positioning the magnetic circuit.

displacement, pressure.

3. Magneto -static transducers	Magnetic properties are varied by pressure & stress changes the value of permeability - μ .	Force, sound, pressure.
4. Magnetostriuctive effect.	Change in dimensions due to magnetization	To produce ultrasonic waves.
Active transducers	Principle	Parameters to be measured
1. Thermo - couple	An end is generated across the junction.	Temperature.
2. Photo voltaic cell	Voltage is generated.	Light meter solar cell, (light intensity).
3. Piezo electric pickup	An emf is generated when an extended force is applied to certain crystalline materials like quartz.	Vibration sound force

Factors that affect the performance of a transducer:

- 1) Physical conditions - Mounting provisions, corrosion resistance, mechanical & electrical conditions.

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2) Environmental conditions - Temperature effective, shocks, vibration

3) Compatability of Associated equipment -

Impedance matching, Insulation resistance, zero balance, etc.

4) Transducer parameters - Time and range of sensitivity, excitation, and

Strain gauges :-

1) Resistance strain gauges :-

It is a kind of transducer making use of Resistance variation as the fundamental property.

If a conductor is subjected to a stress this resistance will change because of change in dimension.

If we differentiate the equation for resistance we will know how the change dR in R depends on the basic parameters.

$$dR = \frac{a(\alpha dL + L d\alpha) - \alpha L da}{a^2}$$

\div LHS by R & RHS by $\frac{\alpha L}{a} = R$ we get,

$$da = a \left(1 - r \frac{dL}{L} \right)^2 - a ; r = \text{poisson's ratio}$$

$$\frac{da}{a} = -2r \frac{dL}{L} + r^2 \left(\frac{dL}{L} \right)^2$$

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Neglecting the second term as it is very small

$$\frac{dR}{R} = \frac{dL}{L} + \frac{d\alpha}{\alpha} + 2r \frac{dL}{L}$$

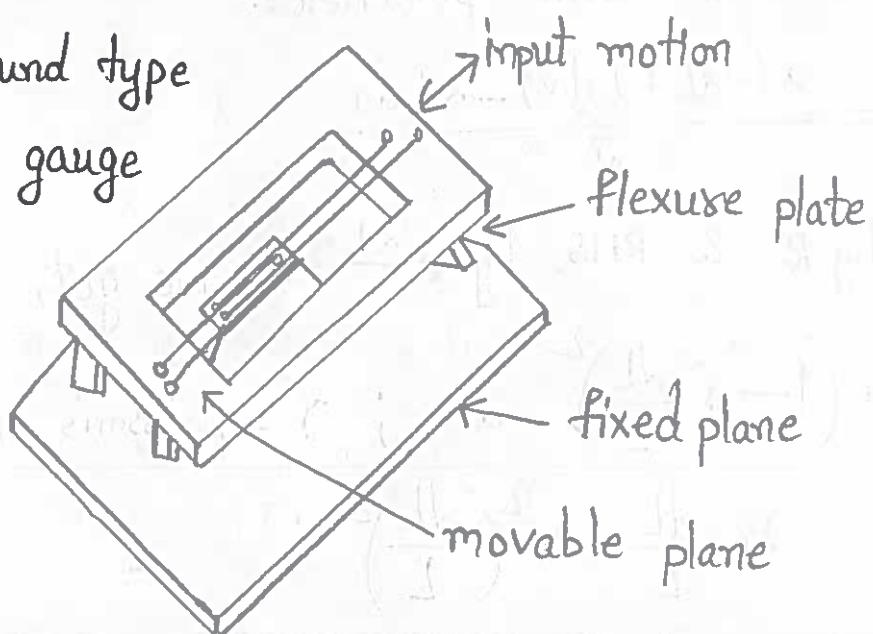
$$\left(\frac{dR/R}{dL/L} \right) = 1 + 2r + \frac{d\alpha/\alpha}{dL/L}$$

The LHS of the equation is called gauge factor. The gauge factor is the unit resistance change per unit change, which is due to 3 factors as revealed by the above equation.

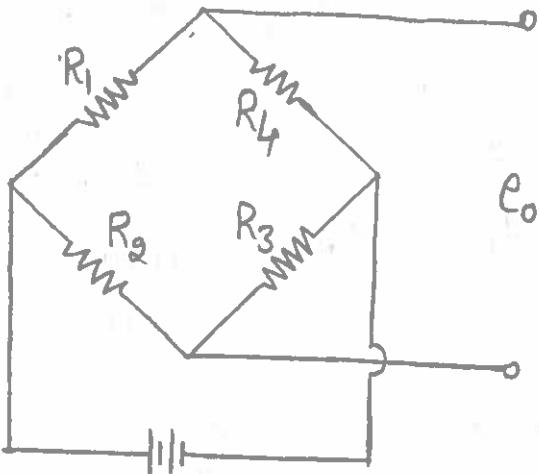
- * The 1st term is the Resistance change due to length change.
- * The 2nd term is the Resistance change due to Area change.
- * The 3rd term is the resistance change due to piezoresistance effect.

(a) Unbound type

Strain gauge



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⑥ Bridge circuit.

Force & Displacement Transducers :

1) Potentiometer :

The resistance of the wire is given by, $R = \frac{\rho l}{A}$

where, ρ = specific resistance of the material

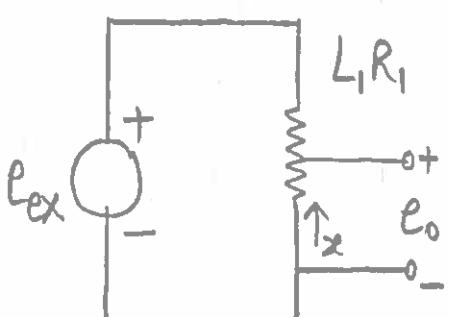
l = length of the wire and

A = cross sectional area of the wire.

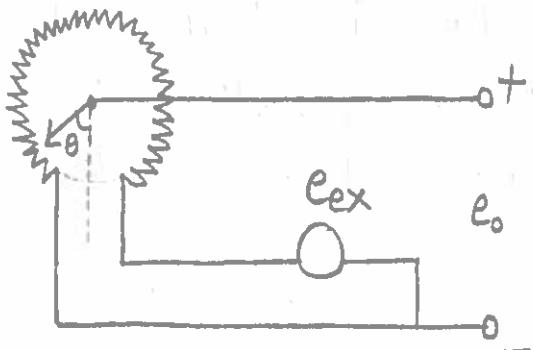
If any one of the value changes, the resistance of the wire varies. Hence, the electrical quantity varies.

2) Potentiometric Transducers :

① Linear Type



② Angular type



A Resistive potentiometer is a resistance element (8) provided with the sliding contact & an auxiliary excitation source either AC or DC.

The motion of the slider can be translational, rotational or a combination of these two such as helical potentiometers. Thus, permitting measurement of rotary or translational displacements.

Resistance elements in common use may be classified as

- ① Wire wound
- ② Carbon film
- ③ Conducting plastics

The resistance b/w the output terminals is proportional to the displacement.

$$R_x = \frac{x}{y} R_t ; R_t \text{ & } L \text{ are constants.}$$

$$C_o = \frac{R_x}{R_t} \cdot e_{ex} ; R_t \text{ & } e_{ex} \text{ are constant}$$

where, e_{ex} = source voltage

thus output voltage is proportional to displacement.

If the source voltage is sinusoidal, then output will also be sinusoidal with no phase shift i.e., Magnitude is proportional to the displacement. From the figure, the output voltage,

$$e_o = \frac{\theta}{360^\circ} \cdot e_{ex}$$

Resistance Thermometers:

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A Resistance Thermometer consists of a resistive element exposed to the environment whose temperature is to be measured.

Materials normally used for temperature measurement are broadly classified into

- i) Conductors
- ii) Semiconductors

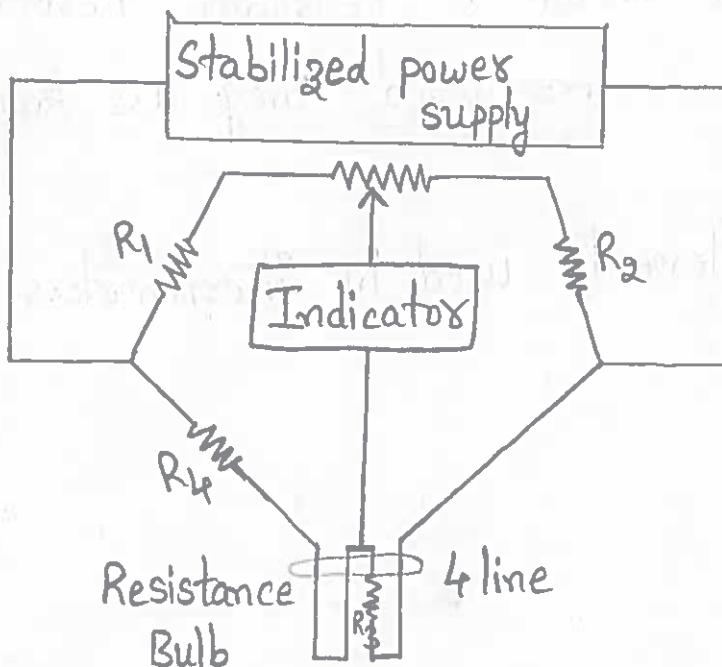
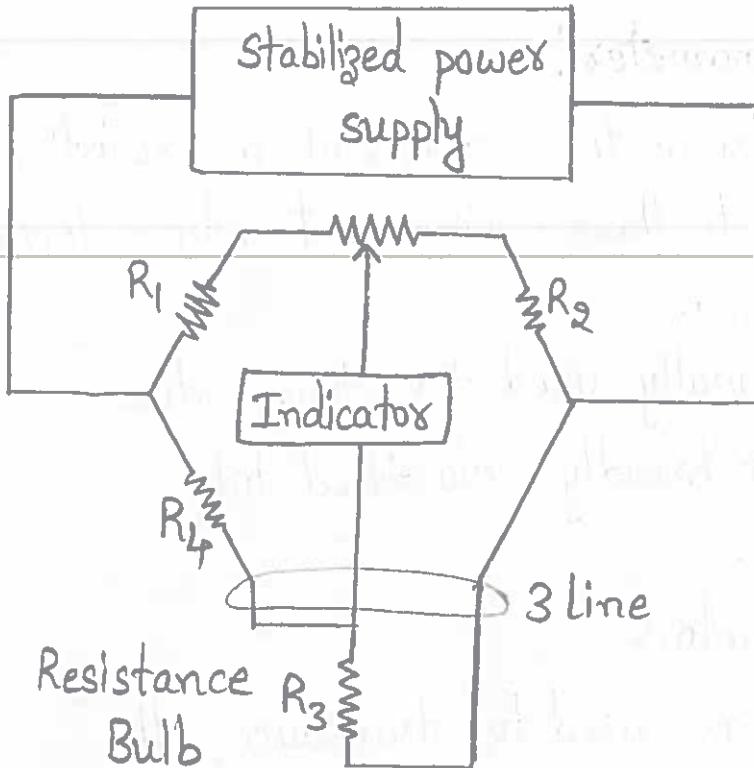
If conductors are used to transduce the temperature are known as Resistance Thermometers & if semiconductors are used they are known as Thermistors.

Conductive elements used in Thermometers are

- 1) Platinum
- 2) Nickel
- 3) Copper
- 4) Tungsten
- 5) Nickel/Iron Alloys

The variation in resistance R with temperature T for metallic materials can be represented by the equation of the form,

$$R_T = R_0 \left(1 + \alpha_1 T + \alpha_2 T^2 + \alpha_3 T^3 + \dots + \alpha_n T^n \right)$$

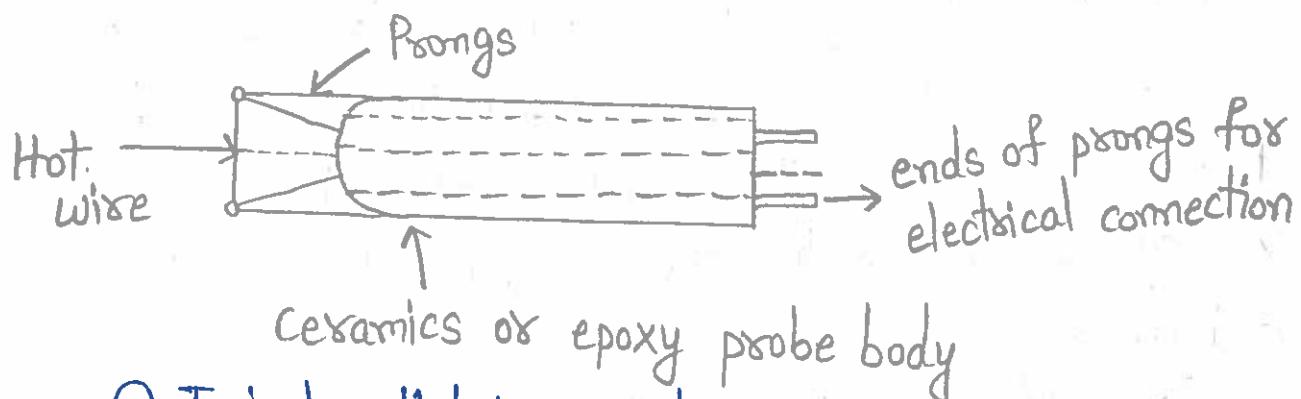


Here the contact resistance in the adjustable resistor has no influence on the resistance of the bridge legs. If long lead wires subjected to temperature variations are unavoidable then the circuit shown above are utilized. To get a fairly linear relationship b/w the output voltage & the

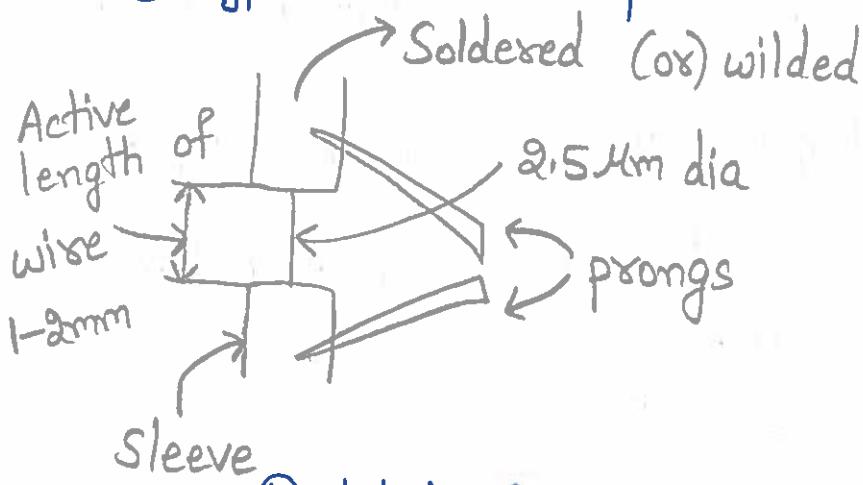
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temperature the values of R_1 & R_2 of the above circuit are made atleast 10 times greater than that of the thermometer.

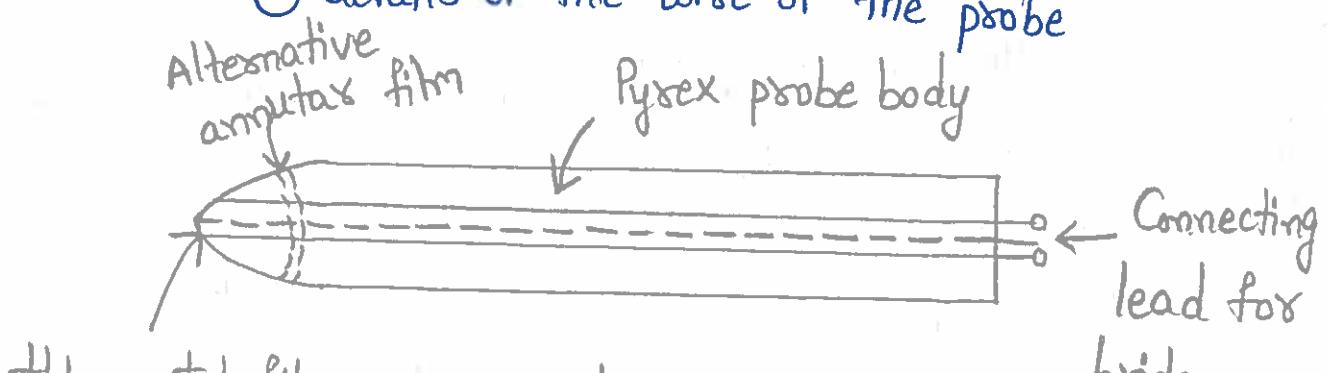
Hotwire Anemometers:



(a) Typical Hotwire probe



(b) details of the wire of the probe



thin metal film on conical
chisel top coated with thin layer of epoxy

thin metal film on conical
chisel top coated with thin layer of epoxy

(c) Hot film probe

Hotwire Anemometer is a device used to measure mean & velocities of fluid flow. The flow sensing element is a short length of 5.4μm diameter, platinum-tungsten wire welded b/w two prongs of the probe & heated electrically as a part of Wheatstone-bridge.

When the probe is introduced in the fluid stream it tends to get cooled by the instantaneous velocity & consequently there is a decrease in resistance.

The rate of cooling of the wire depends on the following

- * Shape, Size & Physical Properties of the Hotwire.
- * Difference in temperature b/w the heated hotwire & the fluid stream.
- * Physical properties of flowing fluid.
- * Velocity of the fluid stream.

Generally, the 1st 3 conditions are effectively constant in the Hotwire operation & the instruments response is then a direct measure of the flow velocity.

The wire needs to be strong enough to give adequate resistance & have an extremely small thermal capacity in order to follow the fluctuations in velocities faithfully & with infinite time lag.

Hotwire Anemometers use resistance wire as a

sensor they can be broadly classified into 2 categories.

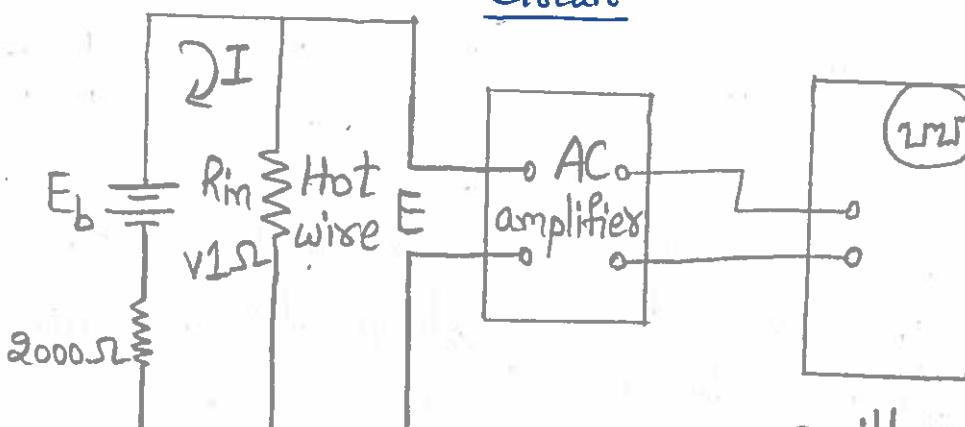
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→ Constant Current Type

→ Constant temperature Type

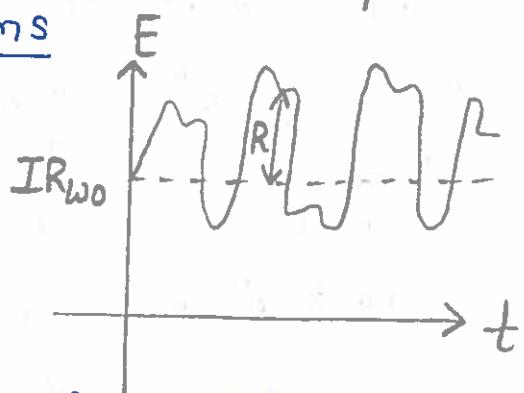
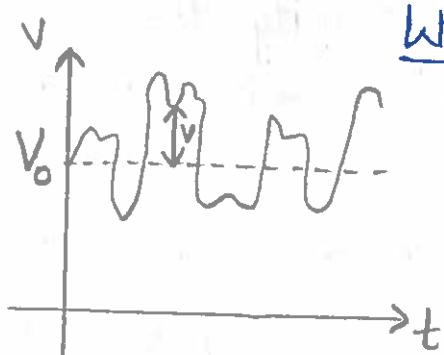
Constant Current type Anemometers:

Circuit



oscilloscope

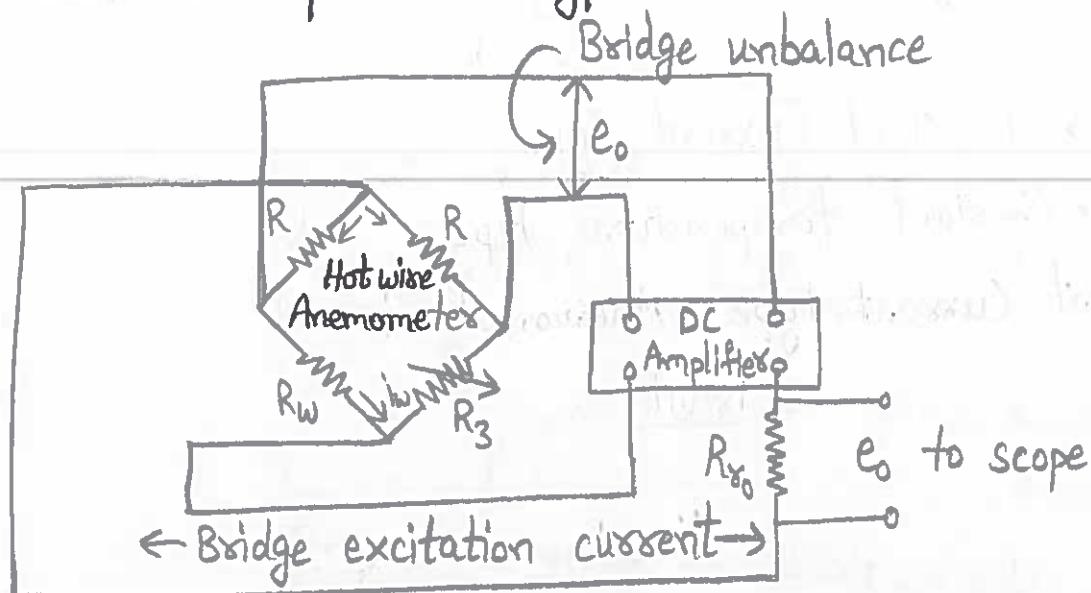
Waveforms



In constant current type a fine resistance wire carrying a fixed current is exposed to the flow velocity. The wire attains an equilibrium temperature when the I^2R heat generated in it is equally balanced by the convective heat loss from its surface. Here, the circuit is desired so that I^2R heat generated in it is balanced & I^2R heat is essentially constant. Therefore, the wire temperature must adjust itself to change the convective heat until the equilibrium is heat.

Constant Temperature type Anemometer:

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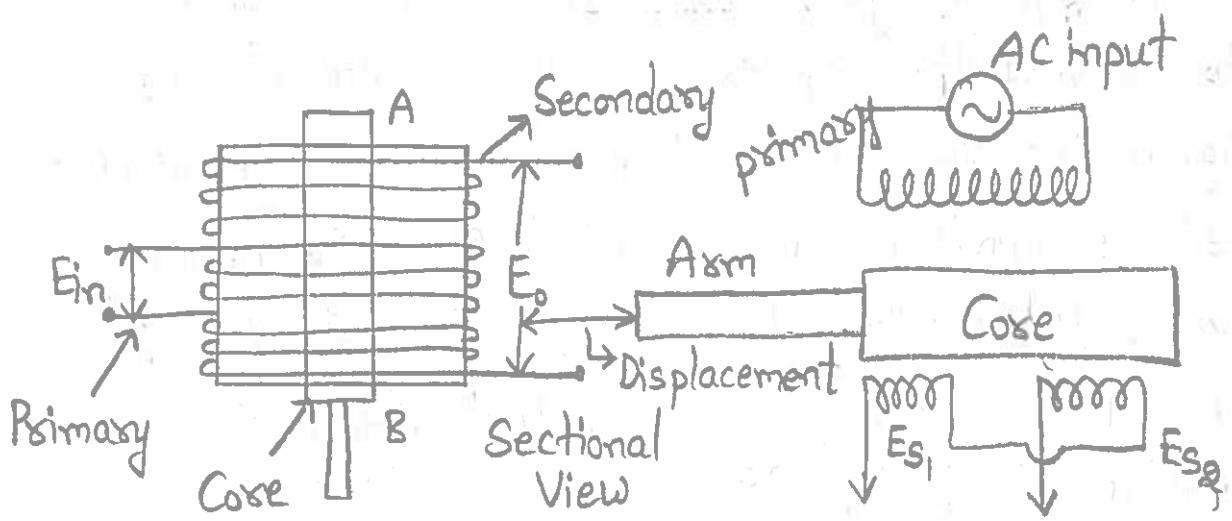
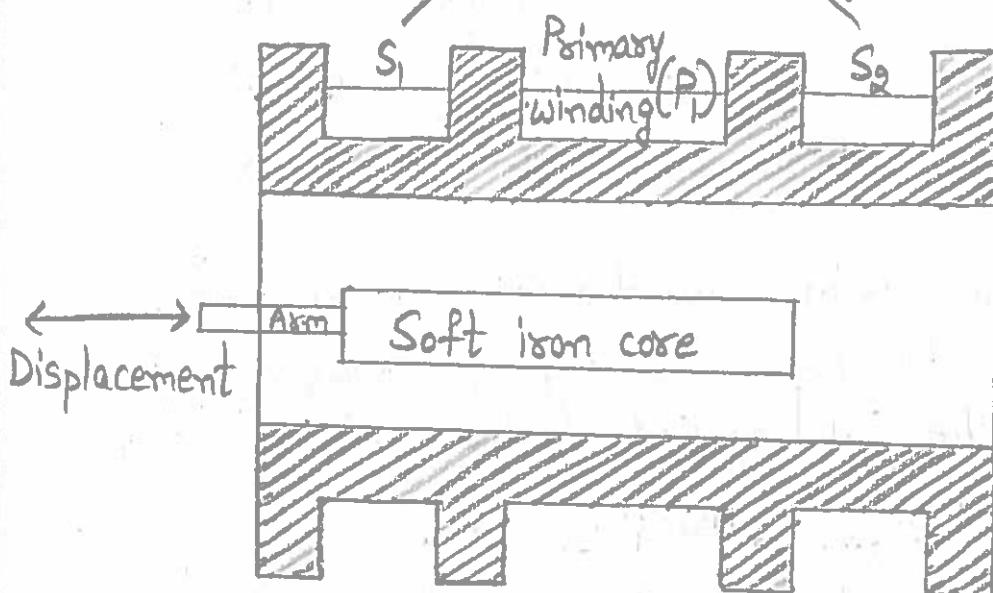


In constant temperature form the current through the wire is adjusted to keep the wire temperature constant. The current required to do this is a measure of velocity. For measurement of average velocity the constant temperature mode of operation is often used, this instrument is used for measure in steady velocities & can be extended through measure both average & fluctuating components of velocity by making the bridge balancing operation automatic rather than manual through the use of feedback.

With zero flow velocity, the bridge excitation is shut off ($I_w=0$) & the hot wire assumes the fluid temperature. The variable Resistor R_3 is then manually adjusted so that $R_3 > R_W$ thereby balance in the bridge.

(LVDT) Linear Variable Differential Transducer: Construction

Construction:-



@ Construction

(b) Basic Circuit

The Differential Transformer is a passive inductive transformer it is also known as Linear Variable Differential Transducer (LVDT).

The transformer consists of single primary winding P_1 & two secondary windings S_1 & S_2 bound on a Hollow cylindrical former. The secondary windings have equal no.of turns & they identical place on either side of the primary winding.

The primary winding is connected to AC source.

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A Movable soft iron core slides within the Hollow former & therefore affects the magnetic coupling b/w the primary & two secondary windings. The displacement to be measured is applied to an Arm attached to the soft iron core.

When the core is in normal position equal voltages are induced in the two secondary windings & the frequency of the AC applied to the primary winding ranges from 50Hz to 20kHz.

The o/p voltage of S_1 is E_{S_1} & S_2 is E_{S_2} . So, in order to convert the o/p from S_1 to S_2 into a single voltage signal, the two secondaries S_1 & S_2 are connected in series opposition as shown in figure @ hence, the o/p voltage of a transducer is the difference of the two voltages. Therefore, the differential o/p voltage, $E_o = E_{S_1} - E_{S_2}$

When the core is at its normal position, the flux linking with both secondary windings is equal & hence equal emfs are induced in them.

At null position, $E_{S_1} = E_{S_2}$

Therefore, the o/p voltage E_o is 0 at null position.

Now, if the core is moved to the left of the null position more flux links with S_1 & less with S_2 . Hence, E_{S_1} of S_1 is greater than E_{S_2} . Hence, $E_o = E_{S_1} - E_{S_2}$

Similarly, if the core is moved to the right of the null position more flux links with S_2 & less with S_1 . Hence, E_{S_2} of S_2 is $> E_{S_1}$, hence, $E_o = E_{S_2} - E_{S_1}$

Advantages of LVDT:

- Linearity — The o/p voltage of this transducer is practically linear for displacements upto 5mm.
- Infinite Resolution — The change in o/p voltage is stepless, the effective resolution depends more on test equipment than on the transducer.
- High Output — It gives high o/p
- High Sensitivity — This transducer possesses a sensitivity as highly as 40 V/mm
- Ruggedness — These transducers can usually tolerate a high degree of vibration & shock.
- Less friction — There are no sliding contacts.
- Low hysteresis — These transducer has a low hysteresis hence repeatability is excellent under all conditions.
- Low Power consumption — It consumes less than 1 watt of power.

Disadvantages:

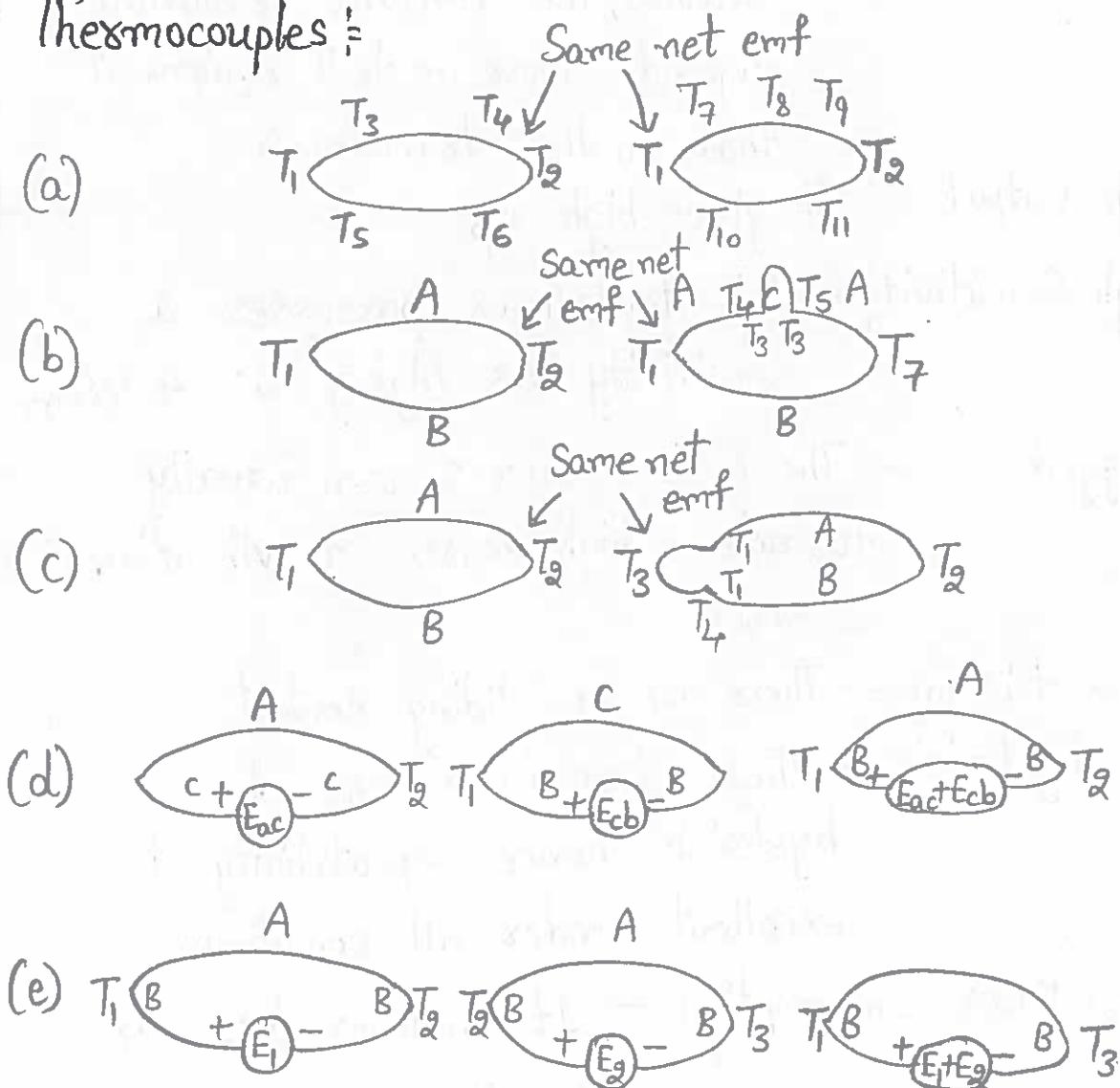
- Temperature effect the Transducer.

- They are sensitive to stray magnetic fields. (18)
- Large displacements are required for appreciable differential output.
- The dynamic response is limited mechanically by the mass of the core & electrically by the applied voltage.

Applications of LVDT:

Displacement measurement & Gauging.

The thermocouples:



Laws of Thermocouples - Diagrams

(P)

Thermocouples are used to measure low & high temperature. In 1821, Seebeck discovered that if two dissimilar metal wires are twisted together & heated a sensitive meter connected to the other end of the wire will indicate a voltage oftenly called as Electromotive force (emf) which is almost directly proportional to the difference in temperature b/w the heated or hot junction & the other end.

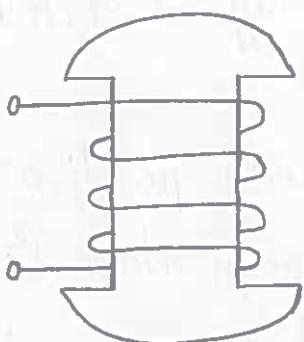
For the analysis of most practical thermocouple circuit, the law of thermocouple behavior may be stated as follows.

- (1) The thermal emf of a thermocouple with junctions at T_1 & T_2 is totally unaffected by temperature L^2 in the circuit if the two metals used are homogeneous shown in figure (a).
- (2) If a third homogeneous metal (c) is inserted into either A or B as long as two new thermojunctions are at like temperature, the net emf of the circuit is unchanged, as shown in figure (b).
- (3) If metal (c) is inserted b/w A & B at one of the junction the temperature of C at any point away from the AC & BC junctions is immaterial i.e., the net emf is the same as if C is not there.

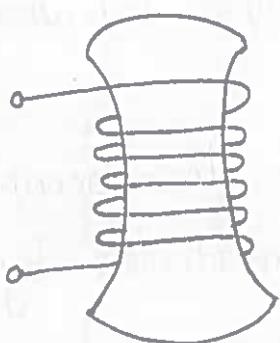
④ If the thermal emfs of the metals A & C is E_{AC} & that of metals B & C is E_{CB} , the net thermal emfs of the metals A & B is $E_{AC} + E_{CB}$ as shown in figure ①

⑤ If thermocouple produces emf E_1 when its junctions are at T_1 & T_2 and E_2 it will produce the net emf $E_1 + E_2$ at T_1 & T_3 as shown in figure ②.

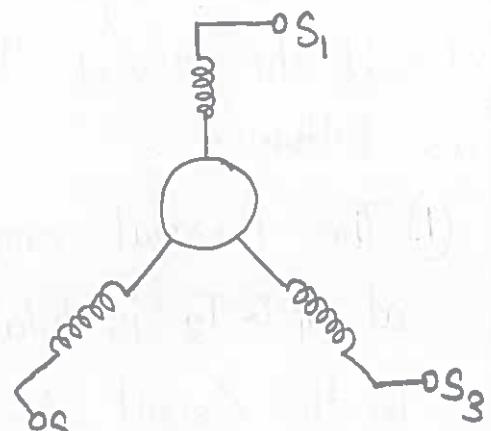
Synchros :



(a) Dumbbell shaped



(b) Cylindrical



(c) Circle

The term 'Synchro' means a family of AC electromechanical devices which in various forms performs the functions of angle measurement this device is also called as Selsyn and Autosyn which are acronyms for self synchronising & Automatic synchronising these are basically mutual inductance transducers.

The Synchro contains rotor & stator.

The rotor carries a winding shown in fig (a) & connections to this windings are made through slip rings.

The stator is bound exactly like an AC motor containing 3 windings and are connected in star shape shown in figure (c). Q1

The rotor sets up a flux in the stator place i.e., the flux induces voltage in the stator winding & the magnitude of voltage induced in each stator winding depends on the rotor position with respect to that winding the voltages in the stator winding are given by the equations.

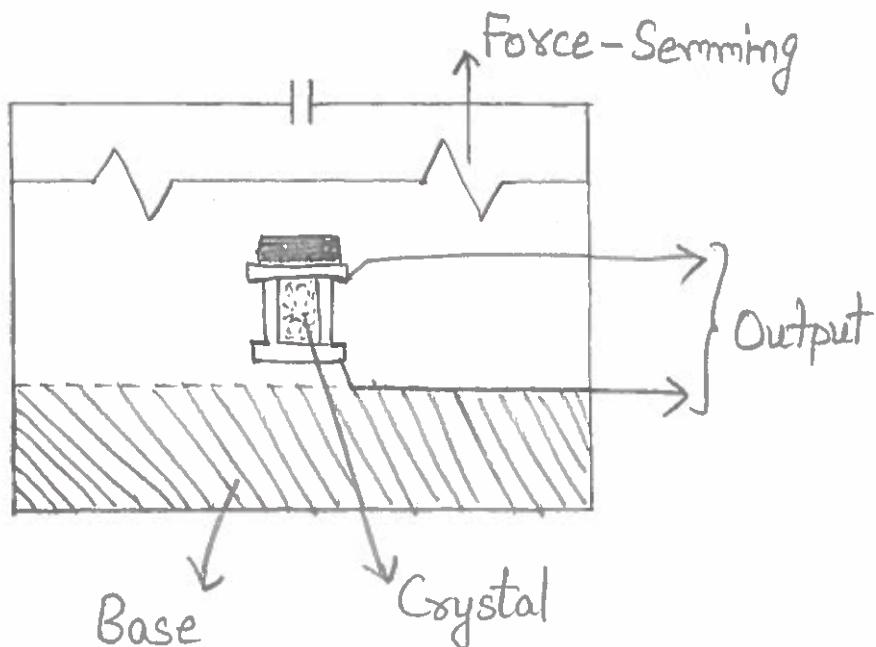
$$e_1 = E_{\max} \sin \omega t \cos \theta$$

$$e_2 = E_{\max} \sin \omega t \cos(120 - \theta)$$

$$e_3 = E_{\max} \sin \omega t \cos(120 + \theta)$$

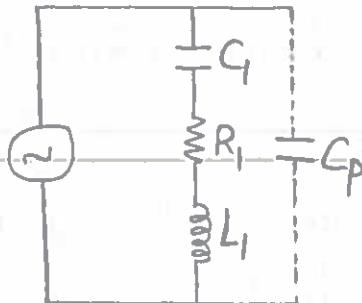
The frequency of the stator winding voltage is same as the frequency of the voltage applied to the rotor here, E_{\max} is the peak voltage induced in the coil.

Piezo-Electrical Transducer :



Equivalent circuit of crystal

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A symmetrical crystalline materials like Quartz, Rochelle salt & Barium titanate produce an emf when these are placed under stress.

This property is used in piezo-electric Transducers, where a crystal is placed b/w a solid base & the force-semming member.

An externally applied force entering the transducer through its pressure pads applies pressure to the top of a crystal this produces an emf across the crystal proportional to the magnitude of the applied pressure.

Since the transducer has a very good high frequency response its principle used is in high frequency accelerometers, in this application its o/p voltage is typically of the order of 1-30mV per g of acceleration. This device needs no external power source & its therefore self generating. The Disadvantage is that it cannot measure static conditions, the o/p voltage is also affected by temperature variation of the crystal.

The basic expression for o/p voltage is given by

$$E = \frac{Q}{C_p}$$

(Q3)

where, Q = generated charge and

C_p = Shunt capacitances.

For a piezo-electric element under pressure part of the energy is converted into an electric potential that appears on opposite phases of the element, & rest of the applied energy is converted to mechanical energy & when pressure is removed it returns to its original shape & losses its electric charge.

From these relationships the following formulas have been derived for coupling coefficient (K)?

$$K = \frac{\text{Mechanical energy converted to electrical energy}}{\text{Applied Mechanical energy}}$$

(08)

$$K = \frac{\text{Electrical energy converted to mechanical energy}}{\text{Applied electrical energy.}}$$

Variable Capacitance Transducers:

Capacitance is one of the 3 basic parameters of electrical circuit this capacitance is the function of Area b/w two plates, the separation b/w them & the dielectric medium in b/w.

C or parallel plate condensers is given by, $C = \frac{A\epsilon}{x}$

where, A = Area of plate
 ϵ = permittivity of the medium and
 x = distance b/w the plate & permittivity.

∴ The above if any one of the above 3 factors change the capacitance will change this change in capacitance can be suitably transduce into a voltage or frequency signal.

For a voltage signal, o/p bridge circuits & frequency variation oscillator circuits are employ. The capacitance is connected to the voltage & the charge by the equation, $Q = CV$

where, Q = charge in coulomb's

V = Voltage in volts

C = Capacitance in Farad's.

Let us consider a capacitor of area 4cm^2 and 0.02cm gap & permittivity is 1.

$$C = \frac{AE}{x}$$

$$C = \frac{4 \times 10^{-4} \times 8.85 \times 10^{-12}}{0.02 \times 10^{-2}}$$

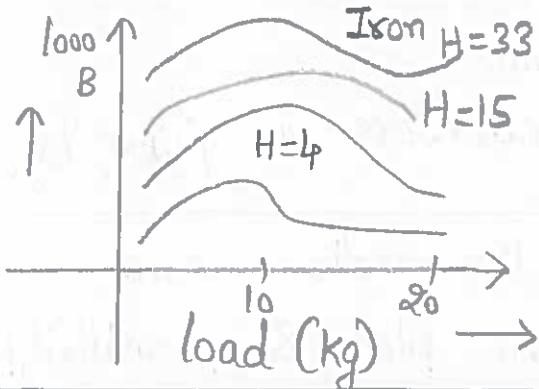
$$\left[\because \epsilon = 8.854 \times 10^{-12} \right]$$

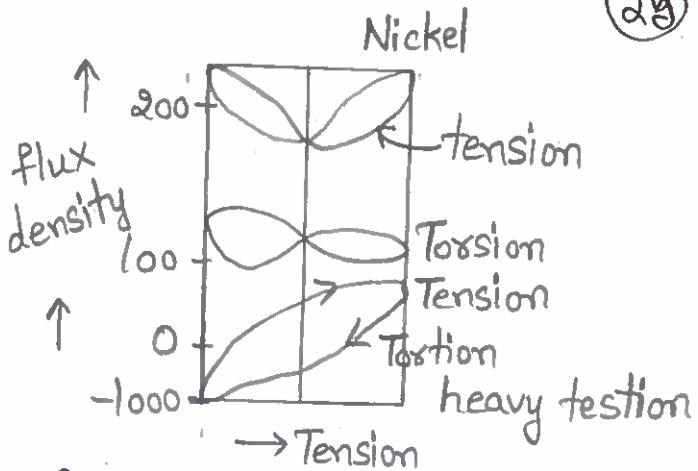
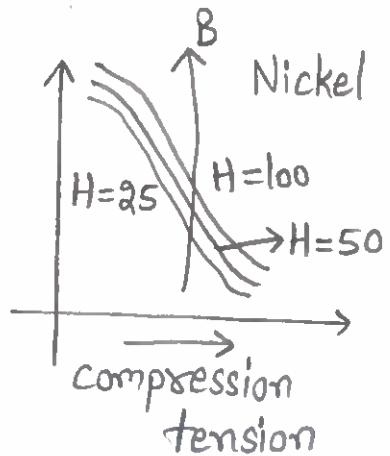
$$C = 17.78 \text{ PF}$$

if $f=10,000$

$$\text{impedance} = \frac{1}{2\pi f C} = 89 \text{ k}\Omega$$

Magnetostriictive Transducers:





BH Curves

Ferro Magnetic Materials like Iron, Nickel, 68 permalloy, etc change their magnetic permeability under Mechanical stress this is known as "Villari effect".

Permeability can increase or decrease depending upon the material, the type of stress (compression, tension, torsion) and the magnetic flux density in the sample.

The Ferromagnetic elements that have the above property are known as Magnetostriuctive or Magnetoelastic materials.

This property can be made use of in constructing the Transducers to convert a stress to a variation in induction as shown in the figure, below that the Magnetostriuctive materials are as follows.

- Nickel
- Permalloy - Nickel alloy with 68% Nickel
- Ferrite cube-B - Highly brittle therefore not used much.

