Module - III

Sensors And Transducers.

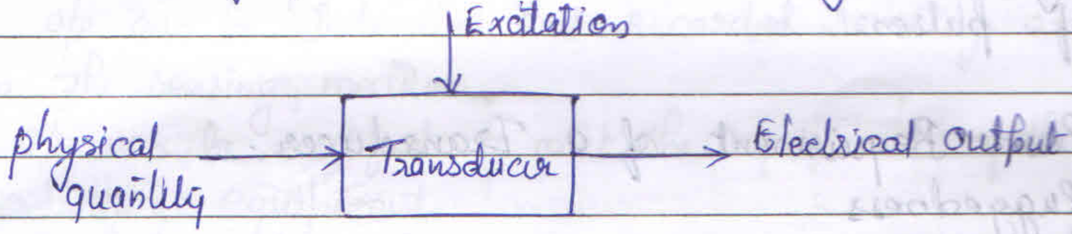
Definition: A transducer is a device which converts the energy from One form to another.

Most transducers convert non electrical physical quantity (eg force, sound, temp, etc) to mechanical or electrical quantity and vise versa.

A transducer performs 2 function

1) Detects or senses the presence, magnitude and changes in physical quantity being measured

2) Provides a proportional electrical o/p signal.



CLASSIFICATION OF TRANSDUCERS

A. Primary and Secondary Transducers.

The primary sensing element (sensor) sense the condition, state or value of the process variable and produce an output which reflects this condition, state or value. The primary transducer converts the physical quantity in to mechanical displacement or non electrical quantity.

The secondary transducers are used to transform the o/p of the primary sensor to an electrical output signal.

B. Active and Passive transducer

Active transducers: They are also known as self-generating type transducer develop their own voltage or current. The energy required for production of an o/p signal is obtained from the physical phenomenon being measured.

eg Thermocouple and thermopiles, piezoelectric pick up, photovoltaic cell.

Passive transducer: They are known as externally-powered transducer. These transducer derive the power required for the energy conversion from an external power source. They may absorb some energy from the physical phenomenon under study.

c. Analogue transducer & Digital transducer.

Analog Transducer. These transducers convert the input physical phenomenon into an analogous o/p which is a continuous function of time.

eg Strain Gauge, a thermocouple, thermistar

Digital transducer: These transducer convert the input physical phenomenon into an electrical O/p which is in form of pulses.

Basic Requirment of a Transducer.

1. Ruggedness
2. Linearity
3. Repeatability
4. high output signal quality.
5. high reliability and stability
6. Good Dynamic response
7. No residual deformation
8. No hysteresis.

Specification for Transducer

While selecting the proper transducer for any application following specification should be considered.

1. Range of Operation
2. Squaring System
3. Sensitivity
4. Maximum working temperature.
5. Method of cooling employed
6. Mounting details
7. Linearity and hysteresis
8. O/p for zero input
9. Temp coefficient of zero drift.
10. Natural frequency.

Advantages and disadvantages of electrical Transducer.

Advantage :-

1. Very Small power is required for controlling the electrical system.
2. The electrical o/p can be amplified to any desired level.
3. The effect of friction is reduced to the minimum possible.
4. Mass - Inertia effects are reduced to minimum possible.
5. The size and shape of the transducer can be suitable designed to achieve the optimum weight and volume.
6. The o/p can be Indicated and recorded remotely at a distance from the sensing medium.
7. The o/p can be modified to meet the requirement of the indicating or controlling equipment.
8. The signal can be conditioned or mixed to obtain any combination with outputs of Similar transducer.

Displacement Transducer :-

1. Resistive Transducer
2. Capacitive Transducer
3. Inductive Transducer
4. Piezoelectric Transducer.

1. Resistive Transducer

The resistance of a metal conductor is expressed by

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

R = Resistivity Ω.

ρ = Resistivity of conductor material

L = Length of conductor

A = Cross-sectional area of the conductor.

Any method of varying one of the quantity involved in the above relationship can be the designed basis of an electrical resistance transducer. There are number of ways in which resistance can be changed by a physical phenomenon.

① Potentiometer

② Strain Gauge.

1) Linear and Angular Motion Potentiometers

Such potentiometer convert the linear motion or the angular motion of a rotating shaft into changes in resistance. The device is a variable resistor whose resistance is varied by the movement of a slider over a resistance element.

The potentiometer shown in figure below (a) and (b) form a part of the bridge circuit whose o/p. voltage is changed by the slider position.

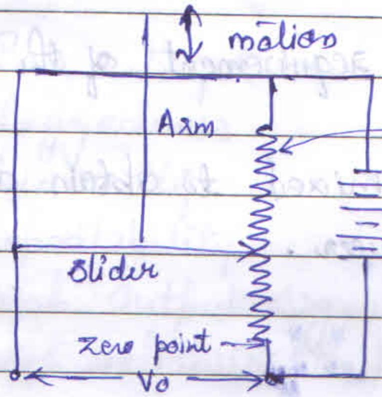


fig (a) linear motion

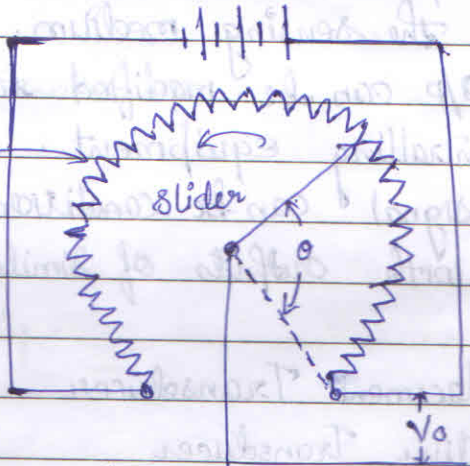


fig (b) Angular Motion

- The slider is powered by the mechanical part on which the linear displacement or angular measurement are to be made.
- Due to arm movement, the slider moves over the resistance element and thus shorts out a portion of the resistance. The change in resistance in the potentiometer is then an indication of the amount of motion and the direction of movement is indicated by whether the resistance is increasing or decreasing. The unbalanced voltage is measured directly or fed into an amplifier and recorded.

The potentiometer are used to measure Pressure, Force, acceleration and liquid level.

Advantages: 1) high output
2) less expensive
3) Available in different sizes, shape and range
4) Simple to operate.

5) Their electrical efficiency is very high.
6) Rugged construction.
7) Insensitivity towards vibration and temperature.

Disadvantages
1) Limited life due to early wear of the sliding arm.
2) The o/p tends to be noisy and erratic is high speed operation or when in high vibration environment.
3)

II) Strain Gauges
When a metal conductor is stretched or compressed, its resistance changes on account of the fact that both length and diameter of conductor changes. The value of resistivity of the conductor also changes. when it is strained its property is called piezo-resistance. Strain gauge is also known as piezo-resistive gauges. The strain gauge is a measurement transducer for measuring strain and associated stress in experimental stress analysis.

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

Type of strain Gauges.
1. Wire-wound strain gauge.
2. Foil-type strain gauge.
3. Semiconductor strain gauge.

1. Wire-wound strain gauge
i) Bonded strain gauge.
ii) Unbonded strain gauge.

i Bonded strain gauge.
It is composed of fine wire, wound and cemented on a resilient insulating support. Such units may be mounted upon or incorporated in mechanical elements or structures whose deformation under stress are to be determined.

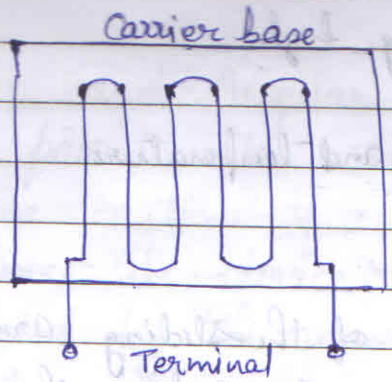


fig (a) Linear strain gauge

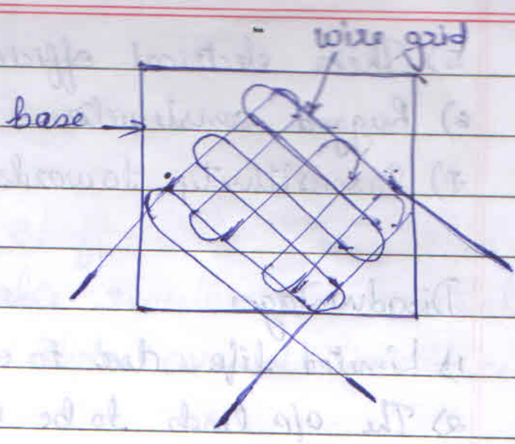


fig (b) Ressetter

ii Unbonded Strain Gauge

The unbonded strain gauge consists of stationary frame and an armature that is supported in the center of the frame. The armature can move only in one direction. Its travel in that direction is limited by 4 filaments of strain-sensitive wire, wound betn rigid insulators that are mounted on the frame and on the armature. The filaments are of equal length and arranged as shown in fig 2.

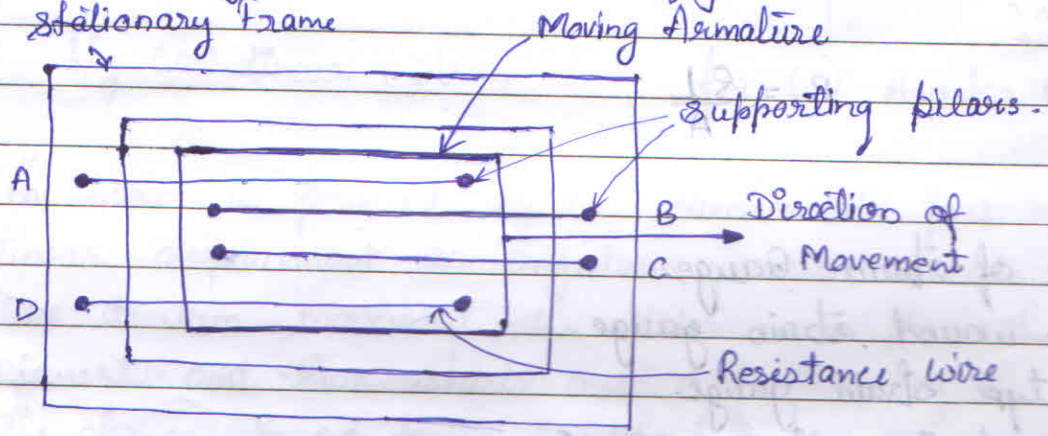


fig (a) Construction

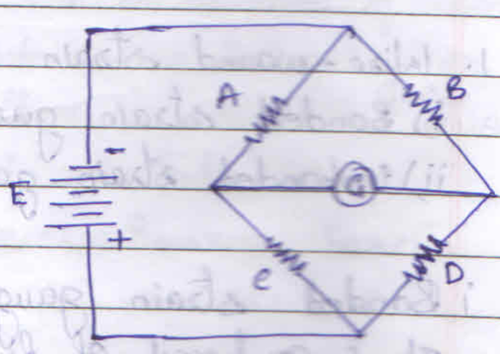


fig (a) wheatstone bridge

When an external force is applied to the strain gauge, the armature moves in the direction indicated. Element A and D increases in length, whereas elements B and C decreases in length. The resistance change of the four filaments is proportional to their change in length and this change can be measured with a wheatstone bridge. The unbalance current indicated by the current meter is calibrated to read the magnitude of the displacement of the armature.

2. Foil strain Gauges.

In these gauges the strain is sensed with the help of metal foil. Foil gauges have a much greater dissipation capacity as compared with wire wound gauges on account of their greater surface area for the same volume. Due to this reason they can be employed for higher operating temperature range.

In these gauge the bonding is better due to large surface area of the foil.

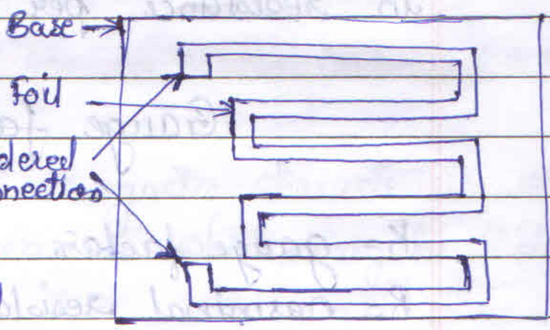


fig Foil Gauge.

Advantages:

1. Excellent strain reproducibility.
2. Low hysteresis and creep effects.
3. Superior stability under prolonged strain and high temp conditions.
4. long life.

3. Semiconductor strain Gauge

Semiconductor strain gauge depends for their action upon piezo-resistive effect ie the change in value of the resistance due to change in resistivity.

- These gauges are used where a very high gauge factor and small envelope are required.
- For semiconductor strain gauges semiconducting material such as silicon and germanium are used.
- The production of these gauge uses semiconducting wafer or filaments of thickness of 0.05mm and bonding them on suitable insulating substance such as teflon.
- The strain sensitive crystal material and leads that are sandwiched in a protective matrix.

Advantage:

1) These gauges have high gauge factor.
2) They are chemically inert and have low cross-sensitivity.
3) They are almost free from hysteresis and creep effects.

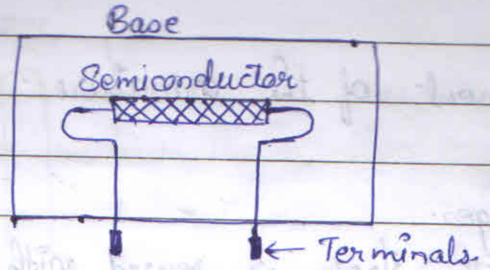


fig Semiconductor strain Gauge.

Gauge Factor

The sensitivity of strain gage is described in terms of gage factor K, defined as the unit change in resistance, per unit change in length

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

K = gauge factor
R = norminal resistance
ΔR = change in guage resistance
L = normal specimen length
ΔL = Change in specimen length

The term $\Delta L/L$ is the strain σ, $\therefore K = \frac{\Delta R/R}{\sigma}$

The resistance change ΔR of a conductor with length L can be calculate using expression

$$R = \rho \frac{\text{length}}{\text{area}} = \frac{\rho \times L}{(\pi/4) d^2}$$

ρ = specific resistance of the conductor material
L = length of the conductor
d = diameter of the conductor

Tension on the conductor causes an increase ΔL in its length and decrease Δd in its diameter. The resistance of conductor changes to

$$R_s = \frac{\rho (L + \Delta L)}{(\pi/4)(d - \Delta d)^2} = \rho \frac{L(1 + \Delta L/L)}{(\pi/4) d^2 (1 - 2\Delta d/d)}$$

using poison ratio $\mu = \frac{\Delta d/d}{\Delta L/L}$

Substitution of μ in R_s eqn.

$$R_s = \rho \frac{1}{(\pi/4) d^2} \left(\frac{1 + \Delta L/L}{1 - 2\mu \Delta L/L} \right)$$

which can be simplified to

$$R_s = R + \Delta R = R\left[1 + (1+2\mu) \frac{\Delta L}{L}\right]$$

The increament of resistance ΔR as compared to the increment of length ΔL is K gauge factor.

$$K = \frac{\Delta R/R}{\Delta L/L} = 1 + 2\mu$$

Continued ***

<u>Inductive Transducer</u>

These are based on change in the magnetic characteristic of an electrical ckt in response to measure, which may be displacement, velocity, acceleration etc.

Variable inductive transducers are classified as.

1. Self-generating type
   i) Electromagnetic type
   ii) Electrodynamic type
   iii) Eddy current type

i) <u>Electromagnetic type</u>

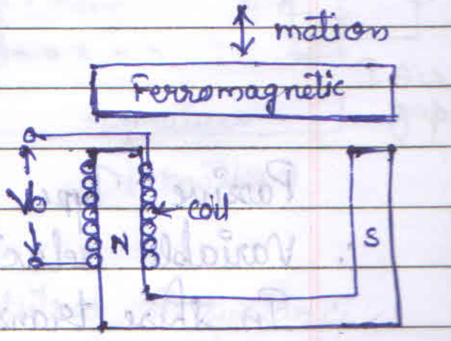


fig self generating Electromagnetic

- It consists of a permanent magnet core on which a coil is directly wound
- when a plate of iron or other ferromagnetic material is moved with respect to the magnet, the flux field expands or collapses and voltage is induced in the coil.
- This device is used for indication of angular speed. The measurements of speed can be made with great accuracy when the pick-up is placed near the teeth of a rotating gear.

ii) Electrodynamic type

In this type coil moves within the field of the magnet. The turns of the coil are perpendicular to the intersecting lines of force.

When the coil moves it induces a voltage which at any moment is proportional to the ~~coil~~ velocity of the coil.

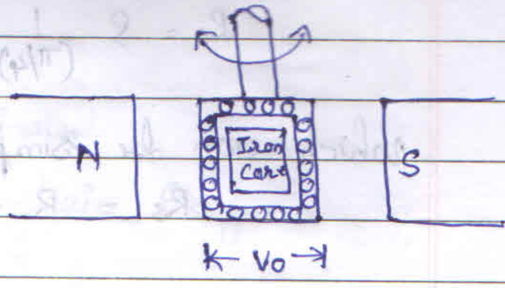


fig Electrodynamic

iii) Eddy current or drag cup tachometer

In this type of Tachometer the test-shaft rotates a permanent magnet and this induces eddy current in a drag cup of disc held close to the magnet. The eddy current produce a torque which rotates the cup against the torque of a spring. The disc turns in the direction of rotating magnetic field until the torque developed equals that of the spring. A pointer attached to the cup indicates the rotational speed on a calibrated scale.

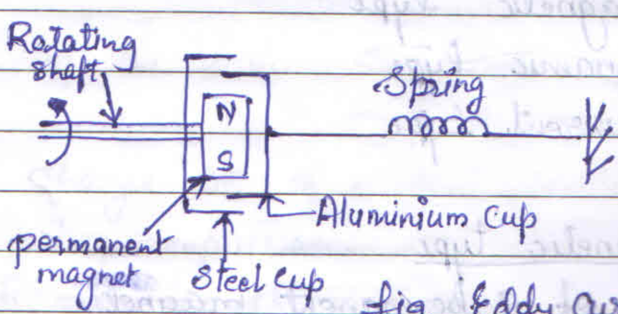


fig Eddy current or drag cup tachometer

Passive Type

1. Variable reluctance transducer

In these transducer a change in the reluctance of the magnetic ckt by a mechanical input results in a similar change both in the inductance and inductive reactance of the coils. The change in inductance is then measured by suitable ckt and related to the value of mechanical input.

Here the inductance of a single coil is changed through the variable air gap. The change in inductance may be calibrated in terms of movement of the armature.

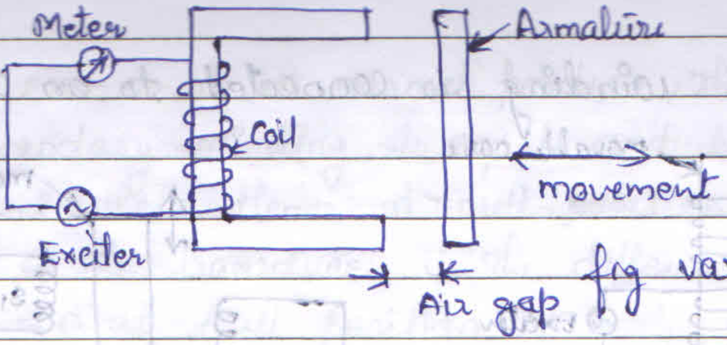


fig variable reluctance transducer

2. <u>Variable permeability transducer.</u>

In variable permeability transducer in which the inductance of coil is changed by varying the core material.

- The transducer consists of a coil of many turns of wire wound on a tube or insulating material with a moveable core of magnetic material

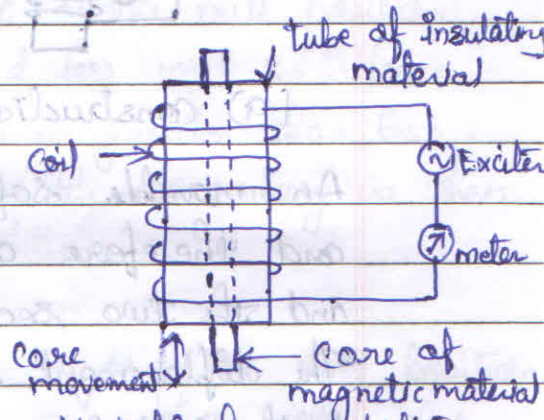


fig Variable permeability.

- When the coil is energized and the core enters the solenoid cell, the inductance of the coil increases in proportional to the amount of metal within the coil.

3. <u>Mutual inductance transducer.</u>

It consists of two coils, an energizing coil x and a pick-up coil. Y.

A change in the position of the armature by a mechanical i/p changes the air gap. This causes a change in the O/p from coil Y, which may be used as measure of the displacement of the armature ie mechanical input.

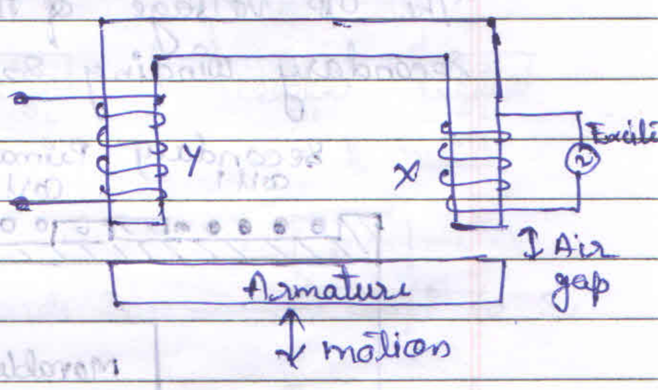
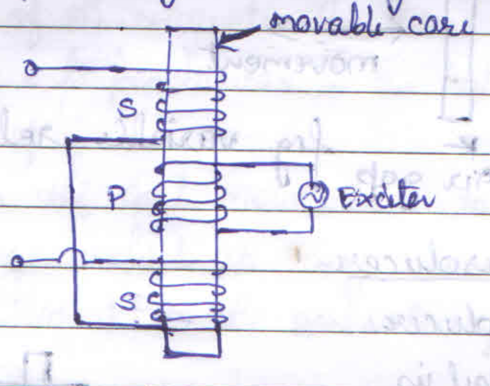


fig Mutual Inductance

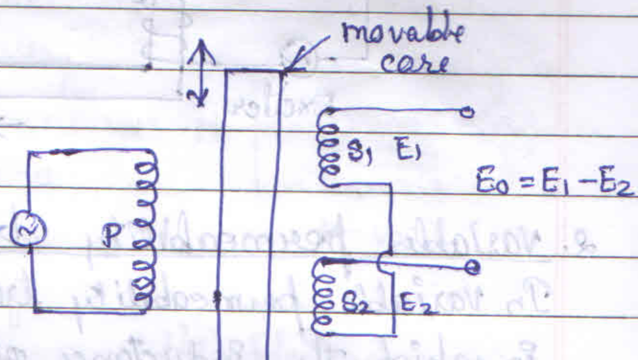
4. <u>Linear Variable differential Transducer (LVDT)</u>

The LVDT consists of a single primary winding P_1 and two secondary windings S_1 and S_2 wound on a hollow cylindrical former. The secondary windings have an equal no. of turns and are identically placed on either side of the primary windings.

The primary winding is connected to an ac source.



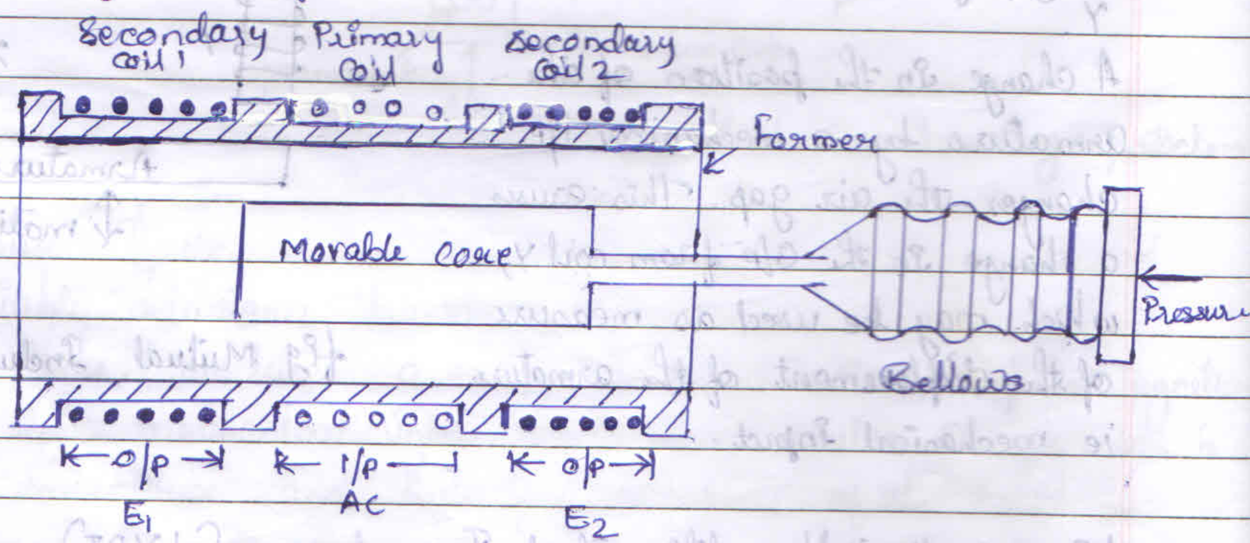
(a) construction



(b) basic ckt.

An movable soft iron core slides within the hollow former and therefore affects the magnetic coupling betn the primary and the two secondarys.
The displacement to be measured is applied to an arm attached to the soft iron core.

When the core is in the normal position, equal voltages are induced in winding of the two secondary windings.
The frequency of the ac applied to the primary winding ranges from 50 Hz to 20 Hz.
The o/p voltage of the secondary winding S_1 is E_{S_1} and that of secondary winding S_2 is E_{S_2}.



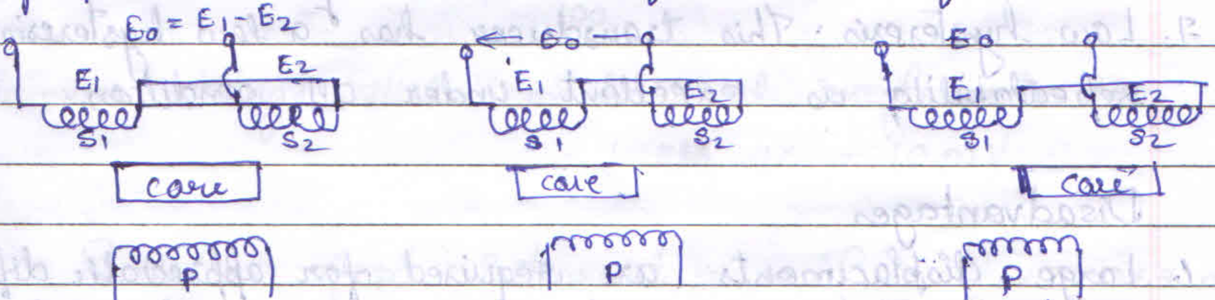
In order to convert the o/p from S_1 to S_2 into single voltage signal the two secondaries S_1 and S_2 are connected in series opposition. Hence the o/p voltage of the transducer is the difference of the two voltages. i.e. $E_0 = E_{S_1} - E_{S_2}$

When the core is at its normal position, the flux linking with both secondary winding is equal, and hence equal emf are induced in them. Hence at null position $E_{S1} = E_{S2}$. The o/p voltage of the transducer is the difference of the two voltages
$\therefore$ $E_0 = 0$ at null position.

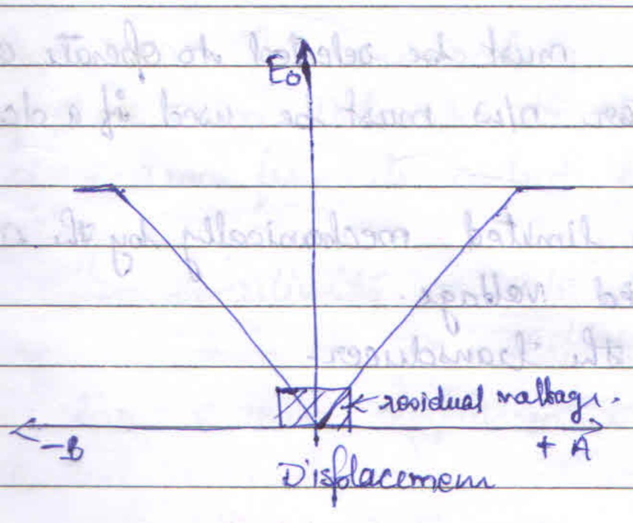
Now, If the core is moved to the left of the null position, more flux links with winding S_1 and less with S_2. Hence o/p volt E_{S1} of secondary winding S_1 is greater than E_{S2}. The magnitude of the o/p voltage of the secondary is then $E_{S1} - E_{S2}$ in phase with E_{S1}

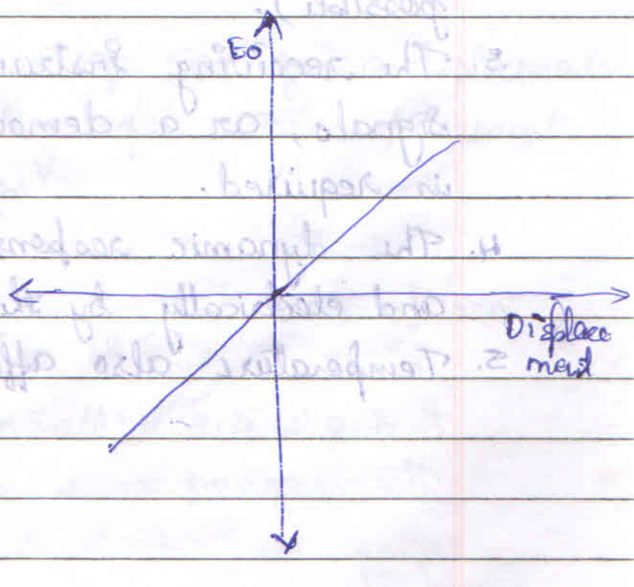
Similarly if the core is moved to the right of the null position, the flux linking with winding S_2 becomes greater than that linked with winding S_1. This results in E_{S2} becoming larger than E_{S1}. The o/p voltage is in phase with E_{S2}.

The amount of voltage change in either secondary winding is proportional to the amount of movement of the core.



a) null position b) shift to wards S_1 c) shift to S_2





As the core is moved in one direction from the null position the difference voltage ie the difference of the two secondary volt increases, while maintaining an in-phase relation with the voltage from the input source. In the other direction from the null position, the difference voltage increases but is 180° out of phase with voltage from the source.

Advantages of LVDT

1. Linearity: The o/p voltage of this transducer is practically linear for displacement upon 5mm.
2. Infinite resolution: The change in o/p voltage is stepless. The effective resolution depends more on the test equipment than on the transducer.
3. High Output: It gives a high o/p
4. High sensitivity: The transducer possesses a sensitivity as high as 40V/mm.
5. Ruggedness: These transducers can usually tolerate a high degree of vibration and shock.
6. Less Friction: There are no sliding contacts.
7. Low hysteresis: This transducer has a low hysteresis, hence repeatability is excellent under all condition.

Disadvantages

1. Large displacements are required for appreciable differential o/p.
2. They are sensitive to stray magnetic fields (but shielding is possible).
3. The receiving instrument must be selected to operate on ac signals, or a demodulator n/w must be used if a dc o/p is required.
4. The dynamic response is limited mechanically by the core and electrically by the applied voltage.
5. Temperature also affects the transducer.

Applications:-

1. Measurement of material thickness in hot strip or slab steel mills.
2. In accelerometers.
3.

Ex 1: The O/P of LVDT is connected to a 4V voltmeter through an amplifier whose amplification factor is 500. An O/P of 1.8 mV appear across the terminal of LVDT when the core moves through a distance of 0.6 mm. If the millivoltmeter scale has 100 divisions and the scale can be read $\frac{1}{4}$ of a division, calculate.

i) The sensitivity of LVDT.

ii) The resolution of the instrument in mm.

Soln

I) The sensitivity of LVDT $= \dfrac{\text{O/P volt}}{\text{Displacement}} = \dfrac{1.8}{0.6} = 3\ \text{mV/mm}$

II) Sensitivity of measurement = Amplification factor × sensitivity

$= 500 \times 3$

$= 1500\ \text{mV/mm}$

1 Scale division $= \dfrac{4}{100}\ V = 40\ \text{mV}$

minimum voltage that can be read on the voltmeter

$= \frac{1}{4} \times 40 = 10\ \text{mV}$

∴ Resolution of the Instrument $= 10 \times \left(\dfrac{1}{1500}\right) = 0.0067\ \text{mm}$

Ex 2. An LVDT has a secondary voltage of 5V for a displacement of ± 12.5 mm. Determine the O/P voltage for a core displacement of 8.0 mm from its central position.

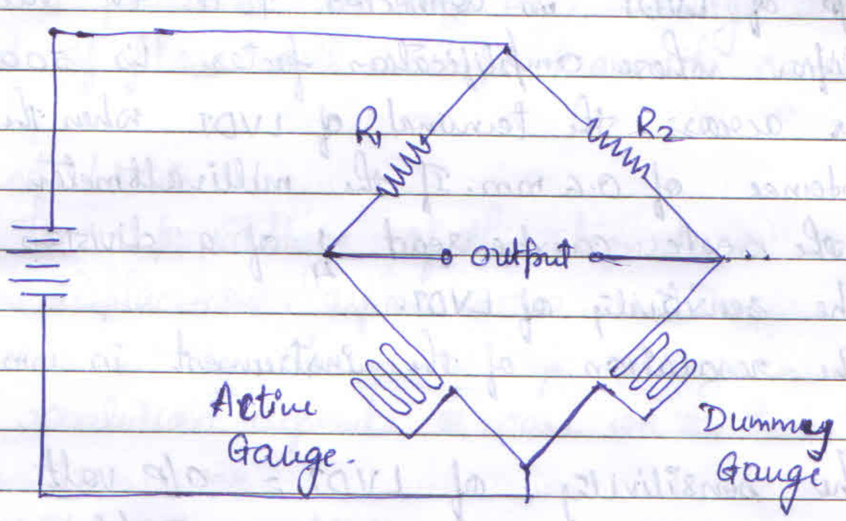
Soln

The sensitivity $= \dfrac{\text{O/P volt}}{\text{Displacement}} = \dfrac{5}{12.5} = 0.4\ \text{V/mm}$

∴ For 8.0 mm displacement O/P volt $= 0.4 \times 8\ \text{mm}$

$= 3.2\ \text{V}$

*** Measurement of applied strain using bridge configuration
The strain gauge is normally used in a bridge arrangement in which the gauge forms one arm of the bridge. The bridge may be ac or dc actuated.



Only one of the guage is an active element, producing an output proportional to the strain. The other (dummy) gauge is not strained, by simple balance the bridge (compensation). Since the resistance of the fine wire element is sensitive to temperature as well as stress variation, any change in temperature will cause a change in the bridge balance conditions. This effect can cause error in strain measurement. Hence when temp variations are significant, and high accuracy is reqd. compensation is used in form of dummy gauge. Because both are placed in same temp environment

The dummy gauge is placed in the same temp environment as the active gauge, but not subjected to strain. The temperature causes the same change of resistance in the two strain gauges and the bridge is not affected by the temperature.
If R_1 & R_2 have negligible temperature coefficient, the bridge retains its balance under conditions of no-strain, at any temperature within its operating range
The dummy gauge remains insensitive to strain and only active gauge responds to strain causing bridge unbalance.

Capacitive Transducers

The principle of operation of capacitive transducer is based upon the eqn for capacitance of a parallel plate capacitor.

$$\text{Capacitance } C = \frac{\varepsilon A}{d} = \frac{\varepsilon_r \varepsilon_0 A}{d}$$

ε = Permitivity of medium

ε_r = relative permitivity

ε_0 = Permitivity of free space

A = Overlapping area of the plates

d = Distance betn the two plates.

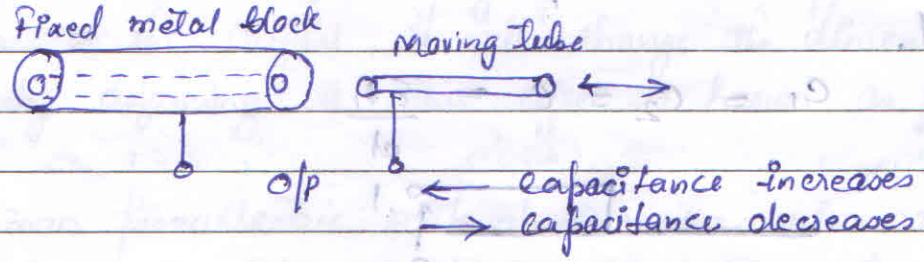
Any physical quantity which can cause a change in ε, A or d can be measured by the capacitance gauge.

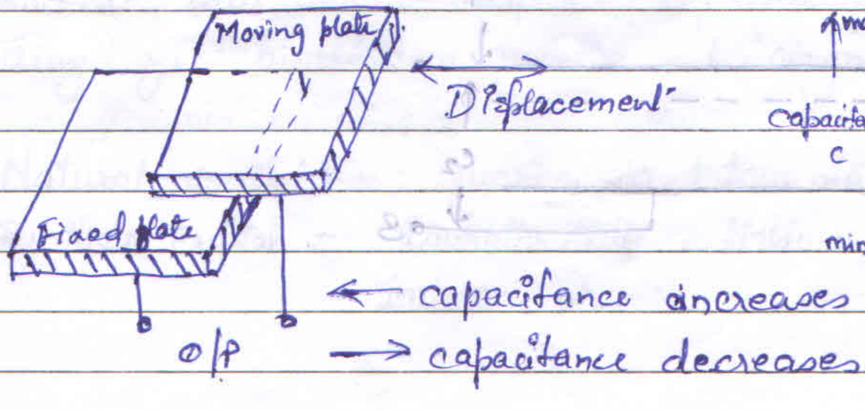
The displacement is measured by measuring the changes in capacitance brought about by:

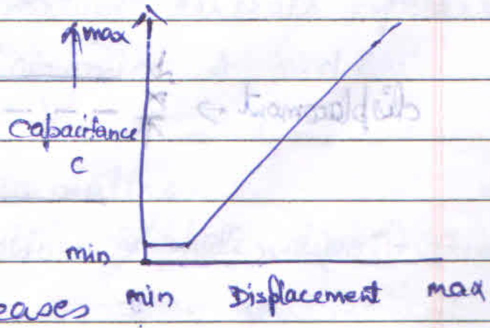
1) change in area
2) change in distance between the plates
3) change in Permitivity.

1) Capacitive Transducer - Using change in Area of plates

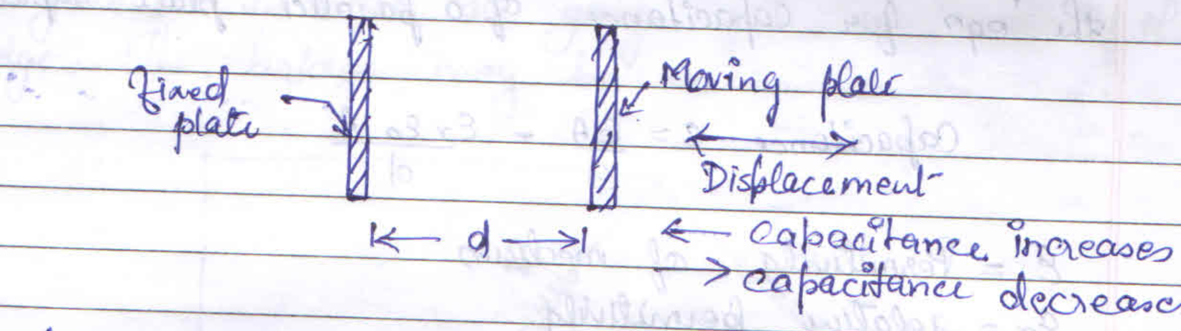
Since capacitance is directly proportional to the effective area of the plates, response of such a system is linear.





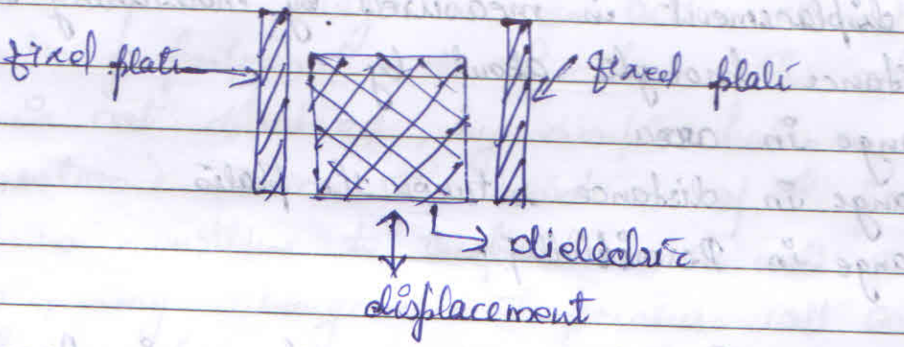


Capacitive Transducer - Using Change in Distance Between the plates



One plate is fixed and displacement to be measured is applied to the other plate which is movable. Since the capacitance c is inversely proportional to distance betn the plates the response of this transducer is not linear.

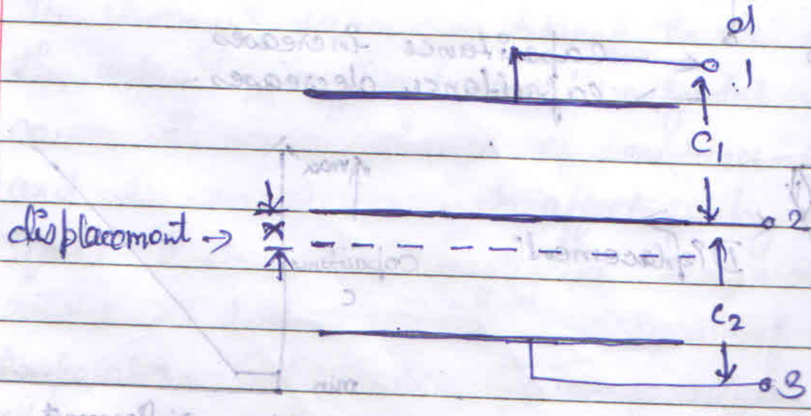
Capacitive Transducer - Using Variable permittivity



Differential capacitor system.

let the normal position of the central plate be represented by a solid line. The capacitances c_1 and c_2 are then identical.

$$c_1 = c_2 = c = \frac{\varepsilon A}{d}$$



when the central plate is displaced parallel to itself through a distance x, the capacitance are

$$C_1 = \frac{\varepsilon A}{d+x} \quad , \quad C_2 = \frac{\varepsilon A}{d-x}$$

For an alternating voltage E applied betn the terminal 1 & 2, the voltages across C_1 and C_2 are given by

$$E_1 = \frac{E C_2}{C_1 + C_2} = E \frac{d+x}{2d}$$

$$E_2 = \frac{E C_1}{C_1 + C_2} = E \frac{d-x}{2d}$$

when the differential measurement ckt is fed with o/p from the terminal pair 1 and 3 and 2 and 3 the difference voltage would be recorded.

$$E_1 - E_2 = E \frac{x}{d}$$

The difference voltage is a linear function of the displacement of the central plate.

Piezoelectric Transducer

A piezoelectric material is one in which an electric potential appear across certain surface of a crystal if the dimensions of the cystals are changed by the application of a mechanical force. This potential is produced by the displacement of external charges. The effect is reversible ie if varying potential is applied to the proper axis of the crystal, it will change the dimension of the crystal thereby deforming it. This effect is known as piezoelectric effect.

Common piezoelectric materials are: Ammonium dihydrogen phosphate, Rochelle salts, lithium sulphate, dipotassium tartrate, potassium dihydrogen phosphate, quartz and ceramics A and B.

Natural crystal — quartz and tourmaline.
Synthetic crystal — Rochelle salt, lithium sulphate, dipotassium tartrate etc.

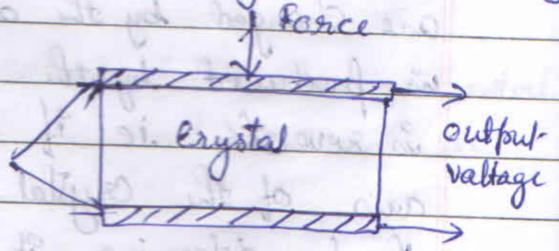
Desirable properties of piezoelectric material

1. Stability
2. High output.
3. Insensitivity to temperature and humidity.
4. The ability to be formed into most desirable shape.

- Quartz is the most stable piezoelectric material but its o/p is small
- Rochelle Salt provides the highest o/p but it can be worked over a limited humidity range and has to be protected against moisture. The highest temperature is limited to 45°C.
- Barium titanate has an advantage that it can be formed into a variety of shapes and sizes since it is polycrystalline. It has also higher dielectric constant.

Working of Piezoelectric Device.

Piezoelectric device employed for measuring varying force applied to a simple plate shown in fig. The magnitude and polarity of the induced charge on the crystal surface is proportional to the magnitude and direction of the applied force. The charge at the electrode give rise to voltage E given by



$$E = g\frac{tF}{A} = gtp$$

Piezoelectric transducer

g = Voltage sensitivity in V/m /N

F = Force in N (Newton)

A = Area of the crystal in m^2

p = Pressure $\left(= \frac{F}{A}\right)$ in N/m^2

$g = \frac{k}{t}$

K = Piezoelectric constant

t = Thickness of the crystal.

Advantages

1. High freq response
2. Small size.

3. High output
4. Rugged construction
5. Neglible phase shift

Disadvantages:
1. O/P affected by change in temperature
2. Cannot measure static condition.

Application
1. Accelerometer
2. Pressure cells
3. Force cells
4. Ceramic microphones.

Measurement of Velocity / Speed.

1. Measurement of Linear Velocity

The following type of transducer are used for measurement of linear velocity

Electromagnetic transducer

① Moving magnet type

② Moving coil type.

Electro-magnetic transducer utilizes the voltage produced in a coil on account of change in flux linkage resulting from change in reluctance.

Moving magnet type: A moving type electromagnetic transducer uses permanent magnet which provides a constant polarizing field as shown in fig below. It consists of rod rigidly coupled to the device whose velocity is being measured. The rod is a permanent magnet which is surrounded by a coil.

Working: When the magnet moves a voltage is induced in the coil which is directly proportional to the velocity. The voltage induced in the coil is given by

$$e = BANV$$

ie $e \propto V$, where B = Flux density wb/m^2

A = Area of coil m^2

N = Number of turns of coil

V = Relative velocity of magnet with respect of coil.

The direction of motion is determine by the polarity of the o/p voltage.

Advantages: 1) The o/p voltage is linearly proportionaly to velocity.

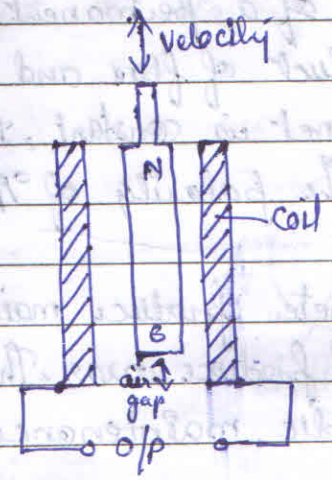
11) Negligible maintenance.

Disadvantages: 1) Limited freq response.

11) Unsuitable for measurement of vibrations.

111) Stray magnetic fields adversely affect their performance.

Moving coil type: This type of transducer operates essentially through the action of a coil moving in a magnetic field, the voltage generated in the coil being proportional to the velocity of coil.



Measurement of Angular Velocity

Angular velocity may be measured with the help of a tachometer. Tachometer is an instrument used for measurement of angular velocity of the shaft by indicating directly the no. of revolution per minutes.

1. DC tachometer generator

In a DC generator the emf generated depends upon the following two factors i) Field of excitation ii) Speed.

If for the field system permanent magnet pole pieces are used, then the generated voltage depends only on the speed. Hence the speed can be computed by measuring the generated emf.

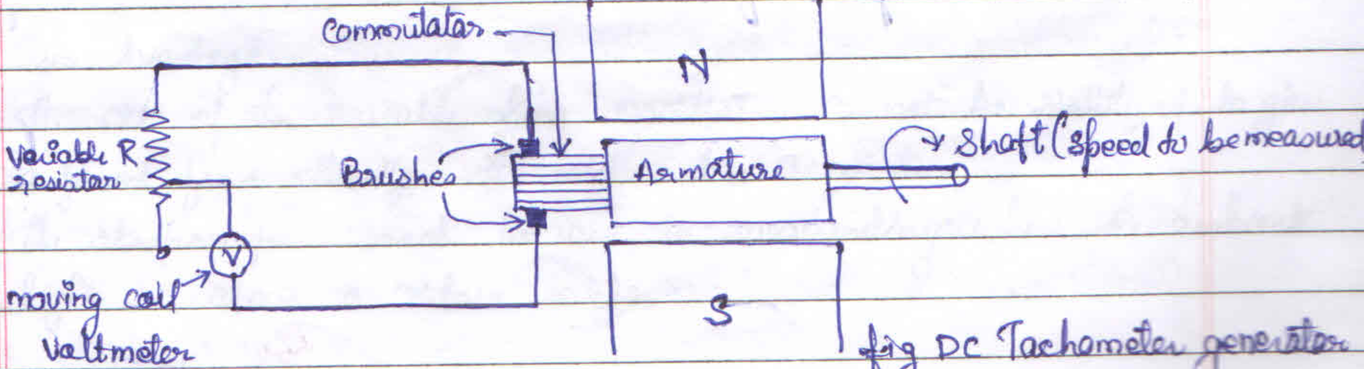
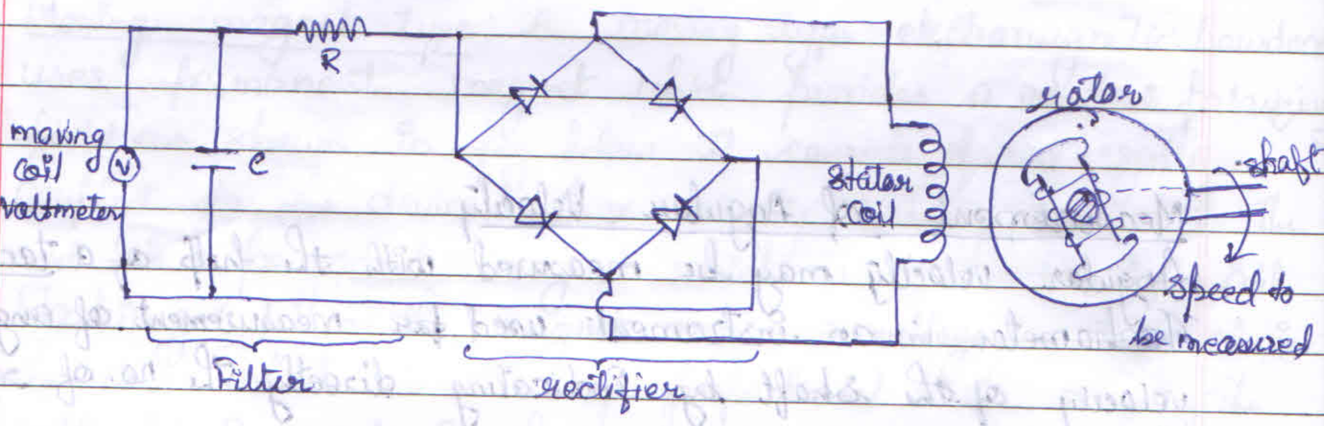


fig DC Tachometer generator

- The shaft whose speed is to be measured is coupled to the armature.
- A moving coil voltmeter is connected across the brushes to measure the generated voltage. The variable resistance R is incorporated to limit the current through the voltmeter.
- The armature revolves in the field of a permanent magnet. The emf generated is $\propto$ to the product of flux and speed. Since the flux of the permanent magnet is constant, the voltage generated is $\propto$ to speed. The polarity of o/p volt. indicates the direction of rotation.

Disadvantage: Brushes on small tachometer produce maintenance problem, their contact resistance vary and produce error. Thus commutator & brushes require periodic maintenance.

<u>AC Tachometer Generator</u>

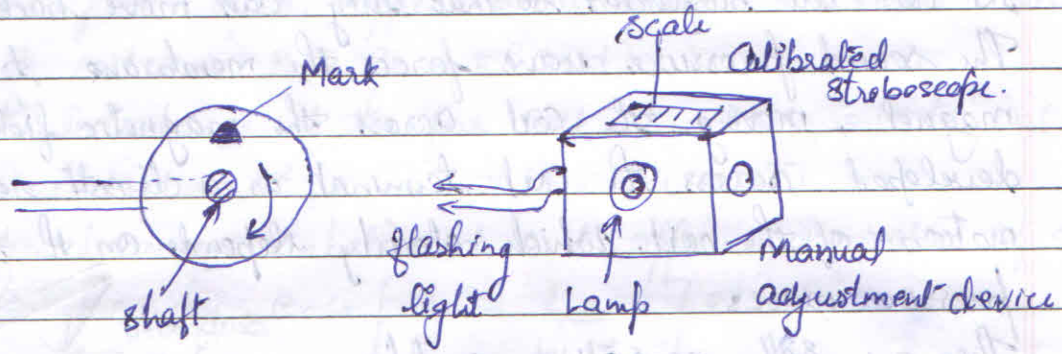


The above mentioned problems are over come by ac tachogenerator. It has rotating magnet which may be either a permanent magnet or electromagnet. The coil is wound on the stator and therefore the problems associated with commutator are absent.

- The rotation of magnet causes an emf to be induced in the stator coil. The amplitude and freq of this emf is are both $\propto$ to speed of rotation.

Stroboscope

Stroboscope is simple portable manually operated device which may be used for measurement of periodic or rotary motion. This Instrument is a source of variable freq flashing brilliant light, the flashing frequency being set by the operator.



The circuit used is based upon variable freq oscillator which control the flashing freq. The speed is measured by adjusting the freq so that moving objects are visible only at specific intervals of time.

A distinctive mark is made on a shaft or on a disc attached to the shaft. A stroboscope is made to flash light directly on the mark. The flashing freq is adjusted until the mark appears stationary. Under this condition, the speed is equal to the flashing frequency provided The scale of the stroboscope is calibrated in terms of speed which can be directly read off.

Advantages

1. It requires no special attachment with the shaft.
2. This method imposes no load on the shaft.
3. This mtd is useful where it is inconvenient or impossible to make contact with the shaft.

Disadvantage.

1. The ckt of the variable freq oscillator cannot be stabilised to give a fixed freq. Therefore the mtd is less accurate.
2. The stroboscope cannot be used in surrounding where the ambient light is above a certain level.

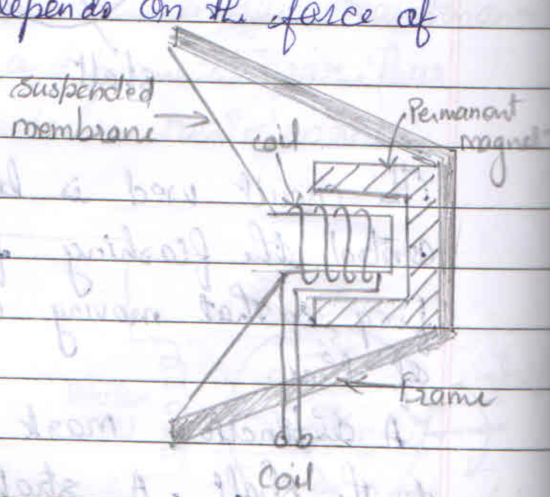
Measurement of Pressure

Inductive Transducer

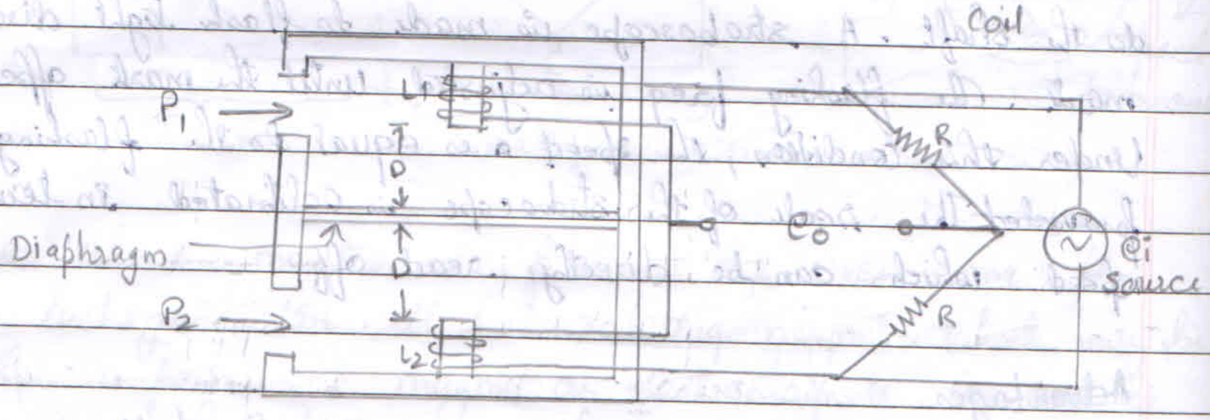
1. An ac voltage is generated when the coil is moved in a magnetic field. A membrane is mechanically linked to a moving coil surrounded by a permanent magnet. The membrane and the coil are suspended so that they can move back and forth. The sound pressure wave forces the membrane towards the magnet, moving the coil across the magnetic field. The volt. developed across the coil terminal is a direct result of the motion of the coil, which clearly depends on the force of pressure waves.

They are self-generating and have low sensitivity.

- Application: used for microphone, precision measurement.



2. Differential Pressure measurement.



An arrangement uses 2 coils an upper and lower coil which form the two arms of an ac bridge. The coils have equal no. of turns. The other two arms of the bridge are formed by 2 equal resistance each of value R.

The diaphragm is symmetrically placed with respect to the coil and so when $P_1 = P_2$ the reluctances of the paths of magnetic flux for both the coils are equal and hence the inductances of the coils are equal.

Initial self inductance $= N^2/R_0$ where N = no. of turns

R_0 = initial reluctance of flux path.

under this condition the bridge is balanced and the o/p e_0 of the bridge is zero.

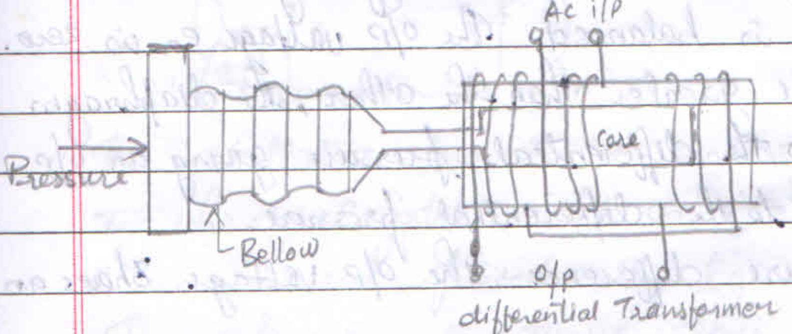
Suppose P_2 is greater than P_1 and therefore the differential pressure $P = P_2 - P_1$, deflects the diaphragm upwards through a distance d. For small displacement of diaphragm, the reluctance of the flux path of the upper coil is $R_1 = R_0 + K(D-d)$ and that of the lower coil is $R_2 = R_0 + K(D+d)$.

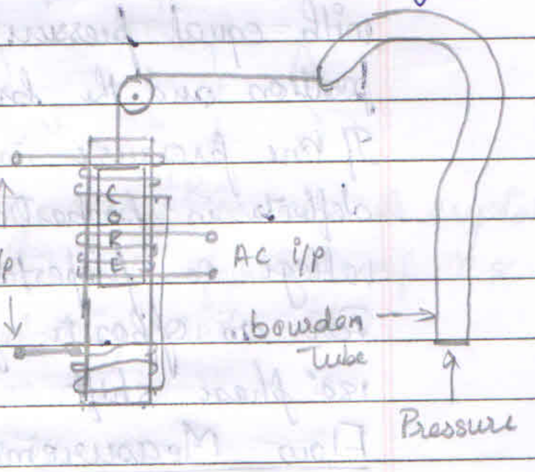
Hence the inductance of the upper coil $L_1 = N^2/R_1 = N^2/[R_0 + K(D-d)]$ and lower coil $L_2 = N^2/R_2 = N^2/[R_0 + K(D+d)]$.

The bridge becomes unbalanced and approximate value of o/p voltage is given by $e_0 = \left[\frac{1}{2} - \frac{L_2}{L_1 + L_2}\right] e_i$.

$$e_0 = \frac{K d e_i}{2(R_0 + KD)}$$

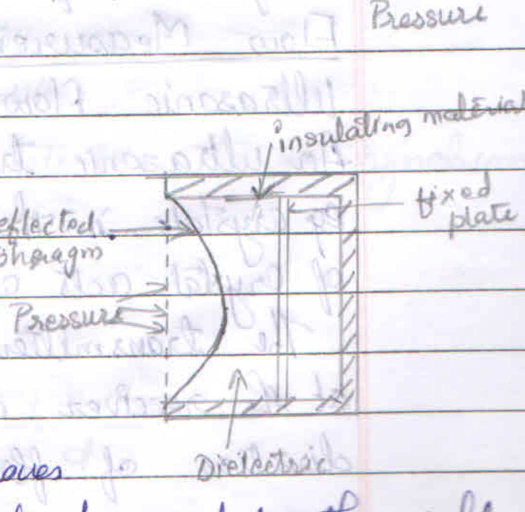
3. LVDT. The LVDT is used as a secondary transducer for measurement of pressure with Bellows or Bourdon tube acting as the primary transducer ie force summing device.
The pressure is converted into displacement which is sensed by the LVDT and transduced into a voltage.





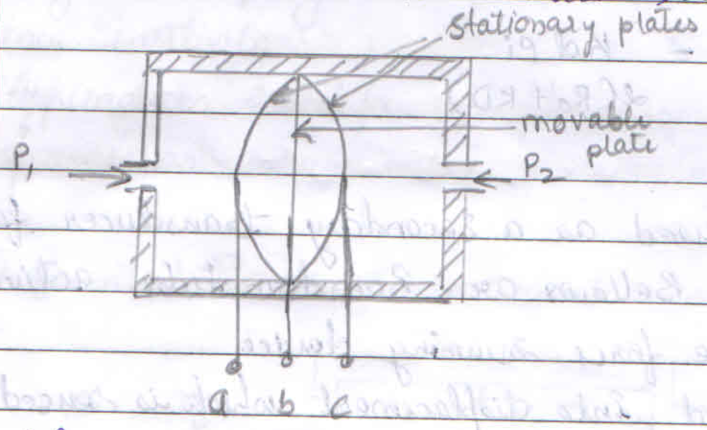
Capacitive Transducer

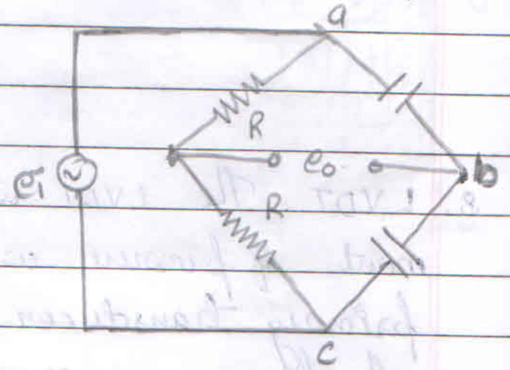
1. The fig shows a transducer that make use of the variation in capacitance resulting from a change in spacing between the plates. This transducer is design to measure pressure. Enclosed in an airtight container is a metallic diaphragm which moves to the left when pressure is applied to the chamber and to the right



when vaccum is applied. This diaphragm is used as one plate of variable capacitor. Its distance from the stationary plate to its left, as determine by the pressure applied to the unit; determine the capacitance between the two plates.

2. Differential Pressure measurement using capacitance.
Capacitive transducers are used for measurement of pressure by converting the pressure into a displacement. The displacement is sensed by a capacitive transducer using a differential arrangement shown in fig. This arrangement gives a linear relationship between o/p voltage and displacement, terminals a, b and c are used to measure the variable differential capacitance





with equal pressure applied $(P_1 = P_2)$ the diaphragm is in neutral position and the bridge is balanced. The o/p voltage e_o is zero. If one pressure is made greater than the other, the diaphragm deflects in proportion to the differential pressure giving an o/p voltage e_o proportional to the differential pressure.
For an opposite pressure difference, the o/p voltage shows an 180° phase shift.

Flow Measurement

Ultrasonic Flow Transducer

An ultrasonic transducer for flow rate consist of two piezoelectric eg crystals in the liquid or gas separated by a distance. One of crystal acts as a transmitter and the other as a receiver.
The transmitter emits an ultrasonic pulse which is received at the receiver a time Δt later. The transit time in the direction of flow is

$$\Delta t = \frac{d}{C+V}$$

d = distance betn T^x & R^x; m.

C = Velocity of sound propagation in medium ; m/s.

v = linear velocity of flow ; m/s.

$\therefore \Delta t_2 = \frac{d}{C-V}$ - signal travelling in the opposite direction against the flow.

Sinusoidal signal of freq f Hz travelling in the flow direction has a phase shift of

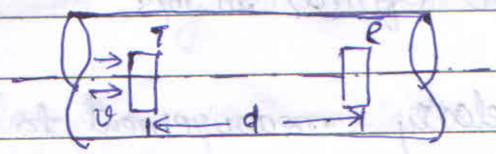
$$\Delta\phi_1 = \frac{2\pi f d}{c+V} \text{ rad}$$

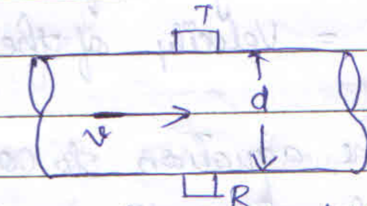
& travelling against the direction of flow has a phase shift of

$$\Delta\phi_2 = \frac{2\pi f d}{c-V} \text{ rad}$$

Velocity can be determine by either measuring the transit time or the phase shift.

System consist of pipe carrying the liquid and T & R (ie transmitter & receiver) crystal. They are either pressed to the exterior of pipe or are immersed in the liquid so that signal is transmitted through the liquid.





The oscillator provides a sinusoid signal of 100 kHz to crystal T whereas crystal R act as the receiver. The function of T & R are reversed periodically by commutating switches.

The difference in transit time

$$\Delta t = \Delta t_2 - \Delta t_1 = \frac{2dV}{c^2 - V^2}$$

This is measured by a phase sensitive detector driven synchronously with commutator. Usually $c >> v$.

$$\Delta t = \frac{2dV}{c^2}$$

$$\Delta t_1 = \frac{d}{c + V\cos\theta}, \quad f_1 = \frac{c + v\cos\theta}{d}$$

$$\Delta t_2 = \frac{d}{c - V\cos\theta}, \quad f_2 = \frac{c - v\cos\theta}{d}$$

Hence difference in freq

$$\Delta f = f_1 - f_2 = \frac{2v\cos\theta}{d}$$

The O/P is linearly proportional to flow velocity v.

Electromagnetic flowmeter.

These meter works on the principle of faraday's law of electromagnetic field of given field strength a voltage is induced in the conductor proportional to the relative velocity between the conductor and the magnetic field. This concept is used in electric generators. In this flowmeter, electrically conductive flowing liquids work as the other conductor.

The induced voltage is given by the

$$E = C \times B \times L \times V$$

E = Induced voltage in volts

C = Dimensional constants

B = Magnetic flux in Wb/sq.m.

L = length of the conductor (fluid) in m

V = Velocity of the conductor (fluid) in m/s.

The equation to convert a velocity measurement to volumetric flow rate is

$$Q = V \times A$$

Q = Volumetric flow rate

V = fluid velocity

A = Cross-sectional area of the flowmeter.

$$V = \frac{E}{CBL}$$

$$Q = \frac{EA}{CBL}$$

For a given flowmeter A, C, B, L are constant.

$$Q = K \times E \qquad \text{where } K = \frac{A}{CBL}$$

∴ the induced voltage is directly proportional & linear to Q.

Construction: The magnetic flow meter consists of an electrically insulated or non conducting pipe, such as fibre glass, with a pair of electrodes mounted opposite each other & flush with the inside walls of the pipe, and with the magnetic coil mounted around the pipe so that a magnetic fields is generated in a plane mutually perpendicular to the axis of the flow meter body and to the plane of the electrodes. If a metal pipe is used, an electrically insulating liner is provided on the inside of the pipe.

The basic operating principle of a magnetic flowmeter in which the flowing liquid acts as a conductor. The length L is the distance between the electrodes and equals the pipe diameter. As liquid passes through the pipe section, it also passes through magnetic field set up by the magnetic coils, thus inducing a voltage in the liquid, which is detected by a pair of electrodes mounted on the pipe walls. The amplitude of the induced voltage is proportional to the velocity of the flowing liquid. The magnetic coils may be excited by either ac or dc voltage.

- Magnetic flow meter are available in sizes from 2.54 - 2540 mm in diameter, with an accuracy range of ±0.5 to ±2%.
- The measurement taken by these meters are independent of viscosity, density, temperature and pressure.

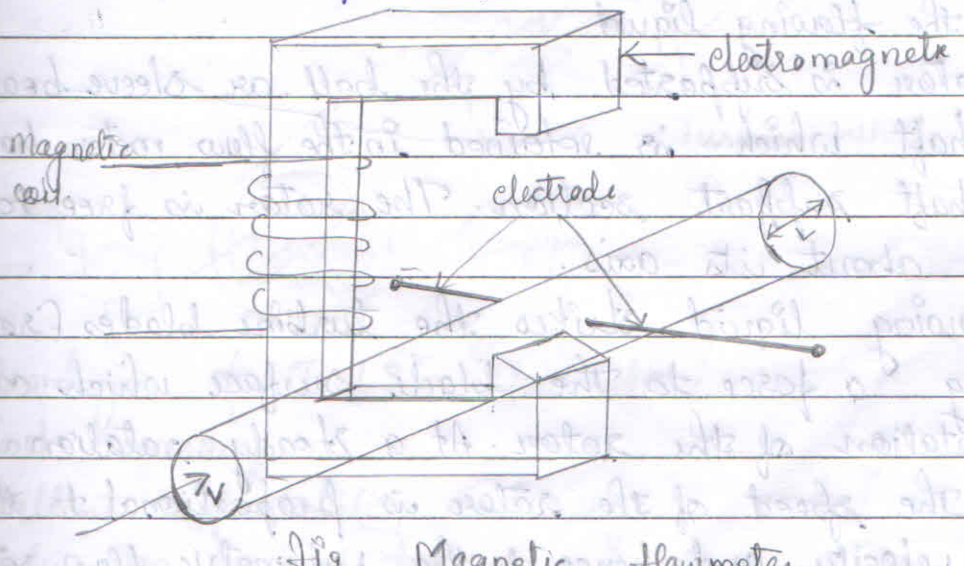


fig Magnetic flowmeter.

Advantages of Magnetic Flowmeter
1. It can handle slurries and greasy materials.
2. It can handle corrosive fluids.
3. It has very low pressure drop.
4. It is totally obstructionless.
5. It is available in large pipe sizes and capacity as well as in several construction material.
6. It is capable of handling low flows and very high volume flow rate.
7. It can be used as bidirectional meter.

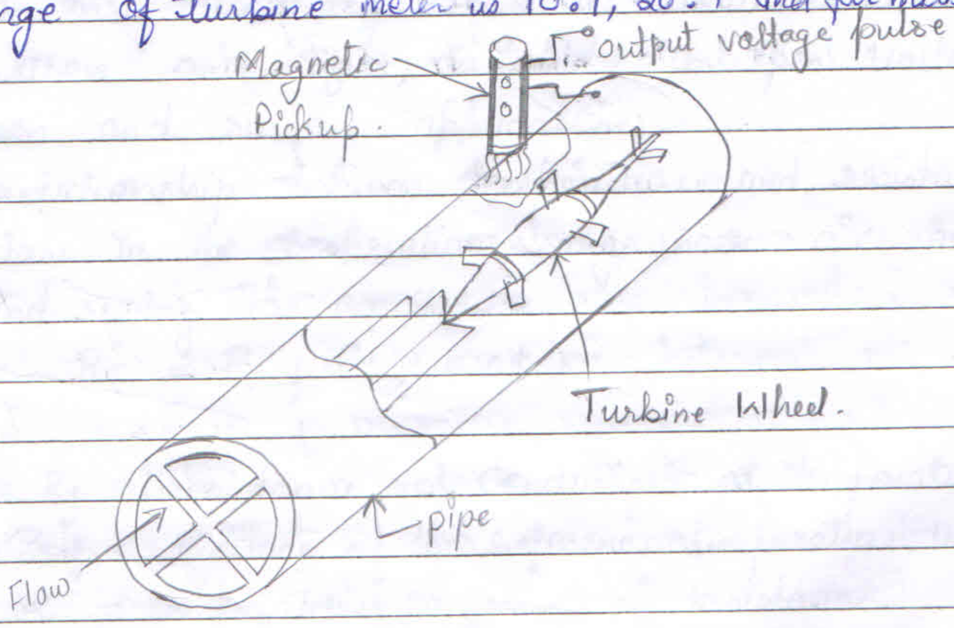
Disadvantage of Magnetic Flowmeter -
1. It is relatively expensive
2. It works only with fluids which are adequate electrical conductors.
3. It is relatively heavy, especially in larger sizes.
4. It must be full at all times.
5. It must be explosion proof when installed in hazardous electrical area.

Turbomagnetic flowmeter -
The turbine flowmeter is used for the measurement of liquid gas and gases of very low flow rate. It works on the principle of turbine. It consists of a multibladed rotor (called turbine wheel) which is mounted 90° to the axis of the flowing liquid
The rotor is supported by the ball or sleeve bearings on a shaft which is retained in the flow meter housing by a shaft support section. The rotor is free to rotate about its axis.
The flowing liquid strikes the turbine blades (rotor) imparting a force to the blade surface which causes the rotation of the rotor. At a steady rotational speed, The speed of the rotor is proportional to the fluid velocity and hence to the volumetric flow rate.

The speed of rotation is monitored by a magnetic pick up which is fitted to the outside of the meter housing.
The magnetic pick-up coil consists of a permanent magnet with coil windings which is mounted in close proximity to the rotor but internal to the fluid channel. As each rotor blade passes the magnetic pick-up coil, it generates a voltage pulse which is a measure of the flow rate. The total no. of pulses gives a measure of the total flow.
The number of pulses generated per gallon of flow, called K factor is given by

$$K = \frac{T_k f}{Q}$$

where K = pulses per volume unit
T_k = time constant in minutes
f = frequency in Hz.
Q = Volumetric flow rate in gpm (gallon per minute)
Turbine flow meters provide very accurate flow measurement over a wide flow range. The accuracy range is ± 0.25 to ± 0.5% with excellent repeatability ie precision ranging from ± 0.25% to as good as ± 0.02%.
The range of turbine meter is 10:1, 20:1 and for military it is 100:1



Advantages of Turbine Flowmeter-
1. Good accuracy
2. Excellent repeatability and range.
3. Fairly low pressure drop.

4. Easy to Install and maintain.
5. Good temperature & pressure ratings.
6. Can be compensated for viscosity variations.

Disadvantages:
1. High cost (Expensive).
2. Limited use for slurry applications.
3. Problems caused by non-lubricating fluids.

Application
1. T.F meter are mostly used for military application.
2. They are also used in blending system in the petralem industry.
3. They are effective in aerospace and airborne applications for energy fuel & cryogenic (liquid oxygen & nitrogen) flow measurements.

Temperature Transducers.

Temperature is one of the most widely measured and controlled variable in industry, as a lot of products during manufacturing requires controlled temperature at various stages of processing. Most of the temperature transducers are of Resistance Temperature Detectors (RTD), Thermistor and Thermocouple.

- RTD's and Thermistor are passive devices whose resistance changes with temperature hence need an electrical supply to give a voltage output.
- Thermocouples are active transducers. It operates on see back effect, when two dissimilar metals are connected together to form a junction called the sensing junction, an emf is generated proportional to the temperature difference of the junctions. They have high speed of response. Thermocouples can be connected in series/parallel to obtain greater sensitivity called a Thermopile.

Resistance Temperature Detector (RTD)

RTD commonly use platinum, nickel or any resistance wire whose resistance varies with temperature and which has a high intrinsic accuracy. They are available in many configuration and sizes, as shield or open units for both immersion and surface applications.

- The relationship between temperature and resistance of conductors in the temperature range near $0°c$ can be calculated using the equation.

$$R_t = R_{ref} (1 + \alpha \Delta t)$$

where R_t = resistance of conductor at temperature $t°c$.
R_{ref} = resistance of the reference temperature, usually $0°c$.
α = temperature coefficient of resistance.
Δt = difference between operating reference temperature.

A high value of 'α' is desired in a temperature sensing element, so that sufficient change in resistance occurs for a relatively

Small change in temperature. This change in resistance (ΔR) can be measured with a wheatstone's bridge which can be calibrated to indicate the temperature, that caused the resistance change rather than the resistance ~~itself~~ self.

RTD are wire-wound resistance with ~~resistan~~ moderate resistance and a PTC of resistance.

Platinum, Copper & Nickel are widely used in RTD. Platinum RTD is highly accurate and stable.

Advantages

1. Linearity over a wide operating range.
2. Wide operating range.
3. Higher temperature operation.
4. Better stability at high temperature

Disadvantages.

1. Low sensitivity
2. It can be affected by contact resistance, shock and vibration
3. Requires no paint sensing.
4. Higher cost than other temperature transducers.
5. Requires 3 or 4 wire for its operation and associated instrumentation to eliminate errors due to lead resistance.

RTD's are not adaptable to applications requiring fast response or small area temperature sensing.

RTD instruments use a wheatstone's Bridge. The RTD & its leads are connected in one of its arms. This bridge is essentially a resistance measuring device which converts the resistance of the RTD into an electrical signal that is used for monitoring or controlling temperature.

The basic wheatstone's brigdge with a two wire RTD connected.

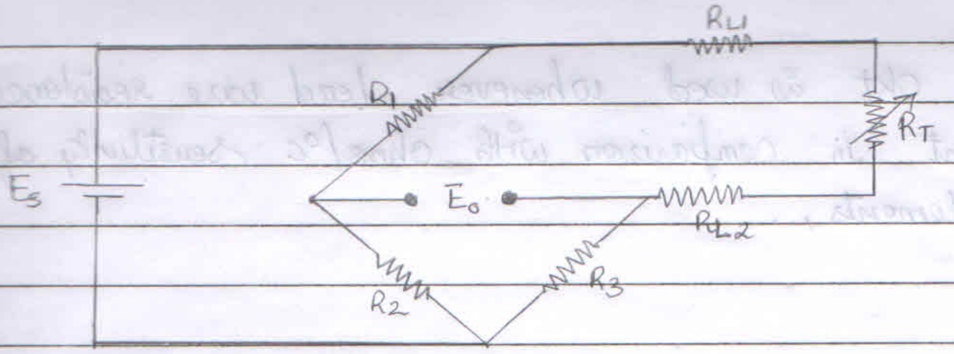


fig Two wire RTD Connection

E_s = Supply voltage
E_o = Output voltage used for monitoring or controlling temperature.
R_1-R_2 and R_3 = fixed value resistors.
R_T = resistance of temperature sensing element in RTD.
R_{L1} & R_{L2} = resistance of the two lead connected in the RTD element.
The value of R_T at control point or at the mid point of the temperature range to be monitored will influence the arm resistors R_1, R_2 & R_3. Also, these values must be selected to limit bridge current to avoid self-heating of RTD. For high accuracy, the bridge must be stable and insensitive to ambient temperature variations.

Lead resistance Compensation Techniques.
If the value of the lead resistance is small and also variation of the lead resistance is small over the temperature range as compared to that of the RTD values, then the errors introduced by the lead resistance are not significant.
But the error introduced by the long leads is significant and can be reduced by using thick lead wire.
more effective methods to obtain highly accurate result lead error eliminating techniques such as three wire and Four wire RTD connections are used.

1) Three Lead Wire RTD: Three lead wire RTD, is used for lead wire compensation and is sufficiently accurate for most of Industrial applications. The bridge ckt automatically Compensates resistance change due to ambient temperature change, which is the input to the instrument.

Bridge ckt is used whenever lead wire resistance is significant in comparison with ohms/°c sensitivity of the RTD elements, .