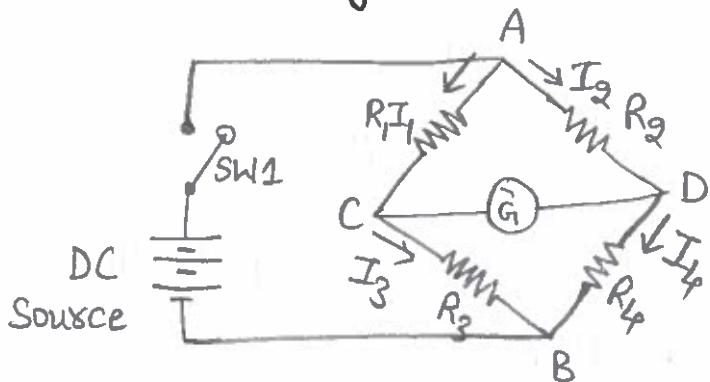


## UNIT-5 - BRIDGES & MEASUREMENT OF PHYSICAL PARAMETERS

### BRIDGES

①

Wheatstone Bridge :



The Bridge circuit consists of a n/w of 4 resistance arms forming a closed circuit with the DC source of current apply to two opposite junctions & a current detector connected to the other two junctions as shown. Bridge circuits are extensively used for measuring component values such as R,L,C. The accuracy measurement of bridge circuit is very high.

The Wheatstone's bridge is the most accurate method available for measuring resistances & this popular for laboratory use.

The source of emf & switch is connected to points A & B while sensitive current indicating meter i.e., galvanometer is connected to points C & D. The Galvanometer is a sensitive Ammeter with a zero centered scale i.e., when there is no current through the meter, the galvanometer pointer resets at zero i.e., midscale.

When SW1 is closed, the current flows & divides into the two arms at point A i.e., I<sub>1</sub> & I<sub>2</sub>. The

bridge is balance when there is no current through the galvanometer or when the potential difference at points C & D is equal.

To obtain the bridge balance equation,

$$I_1 R_1 = I_2 R_2 \quad \text{--- } ①$$

For the galvanometer current to be zero, the following conditions should be satisfied

$$I_1 = I_3 = \frac{E}{R_1 + R_3} \quad \text{--- } ②$$

$$I_2 = I_4 = \frac{E}{R_2 + R_4} \quad \text{--- } ③$$

Substitute eq's ② & ③ in eq ① we get,

$$\frac{ER_1}{R_1 + R_3} = \frac{ER_2}{R_2 + R_4}$$

$$R_1(R_2 + R_4) = R_2(R_1 + R_3)$$

$$R_1 R_2 + R_1 R_4 = R_2 R_1 + R_2 R_3$$

$$R_4 = \frac{R_2 R_3}{R_1}$$

In a practical, wheatstone's bridge atleast one of the resistance is made adjustable to permit balancing. When the bridge is balanced, the unknown resistance ( $R_4$ ) may be determined from the setting of the adjustable resistor, which is called a standard resistor because it is a precision device having very small tolerance hence,

$$R_x = \frac{R_2 R_3}{R_1}$$

## Applications of Wheatstone Bridge:

→ A Wheatstone Bridge may be used to measure the DC resistance of various types of wire either for the purpose of quality control of the wire itself or of some assembly in which it is used.

Ex: The resistance of motor windings, transformers, solenoids & relay coils can be measured.

→ It is extensively used by telephone companies & others to locate cable faults.

## Limitations of Wheatstone's Bridge:

→ For low resistance measurement, the resistance of the leads & contacts becomes significant & introduces an error, this can be eliminated by Kelvin's double bridge.

→ For high resistance measurement, the resistance presented by the bridge becomes so large that the galvanometer is insensitive to imbalance i.e., if the resistance is in terms of megaohms ( $10^6$ ) this bridge is cannot be used.

→ Another difficulty in Wheatstone's bridge is the change in resistance of the bridge arms due to the heating effect of current through the resistance i.e., the rising temperature causes a changes in the vary of resistance, & excessive current may cause a permanent changing value.

Kelvin's Bridge:

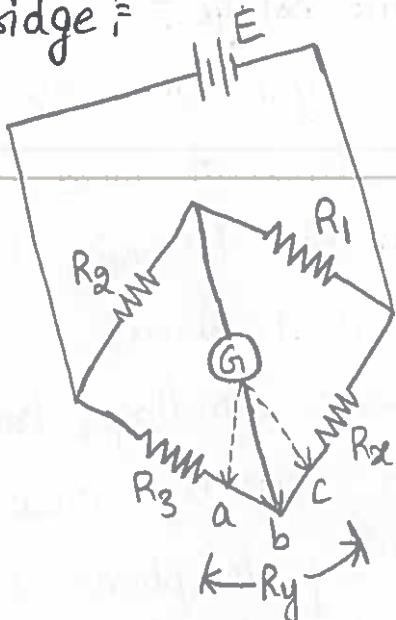


figure ①

When the resistance is to be measured of the order of magnitude of bridge contact & lead resistance a modified form of wheat stone's bridge i.e., Kelvin bridge is employed.

This Kelvin's Bridge is used to measure values of resistance below  $1\Omega$ .

Consider the circuit diagram as shown, where  $R_y$  represents the resistance b/w  $R_3$  &  $R_x$ . The galvanometer can be connected either to point C or point A. When it is connected to point A, the resistance  $R_y$  of the connecting lead is added to the unknown resistance  $R_x$  resulting in too high indication for  $R_x$ . When the connection is made to point C,  $R_y$  is added to the bridge arm  $R_3$  & the resulting measurement of  $R_x$  will be lower than the actual value because the actual value of  $R_3$  is higher than the nominal value by the resistance  $R_y$ .

If the Galvanometer is connected to point B in b/w A & C in such away that the ratio of the resistance from c to b & that from a to b equals the ratio of  $R_1$  &  $R_2$  then  $\frac{R_{cb}}{R_{ab}} = \frac{R_1}{R_2}$  — ①

& the usual balance eq's for bridge gives the relationship,

$$(R_x + R_{cb}) = \frac{R_1}{R_2} (R_3 + R_{ab}) \quad \text{— ②}$$

$$\text{But, } R_{ab} + R_{cb} = R_y \quad \& \quad \frac{R_{cb}}{R_{ab}} = \frac{R_1}{R_2}$$

$$\frac{R_{cb}}{R_{ab}} + 1 = \frac{R_1}{R_2} + 1$$

$$\frac{R_{cb} + R_{ab}}{R_{ab}} = \frac{R_1 + R_2}{R_2}$$

$$\frac{R_y}{R_{ab}} = \frac{R_1 + R_2}{R_2}$$

$$\therefore R_{ab} = \frac{R_2 R_y}{R_1 + R_2}$$

$$\begin{aligned}\therefore R_{cb} &= R_y - R_{ab} \\ &= R_y - \frac{R_2 R_y}{R_1 + R_2}\end{aligned}$$

$$R_{cb} = \frac{R_y R_1 + R_y R_2 - R_2 R_y}{R_1 + R_2} = \frac{R_y R_1}{R_1 + R_2}$$

Substitute  $R_{cb}$  &  $R_{ab}$  values in eq ②

(6)

$$R_x + \frac{R_1 R_y}{R_1 + R_2} = \frac{R_1}{R_2} \left( R_3 + \frac{R_2 R_y}{R_1 + R_2} \right)$$

$$R_x = \frac{R_1}{R_2} \left( R_3 + \frac{R_2 R_y}{R_1 + R_2} \right) - \frac{R_1 R_y}{R_1 + R_2}$$

$$= \frac{R_1}{R_2} \left( \frac{R_1 R_3 + R_2 R_3 + R_2 R_y}{R_1 + R_2} \right) - \frac{R_1 R_y}{R_1 + R_2}$$

$$= \frac{R_1 R_1 R_3 + R_1 R_2 R_3 + R_1 R_2 R_y}{R_2 (R_1 + R_2)} - \frac{R_1 R_y}{R_1 + R_2}$$

$$= \frac{R_1 R_1 R_3 + R_1 R_2 R_3 + R_1 R_2 R_y - R_1 R_y R_2}{R_2 (R_1 + R_2)}$$

$$= \frac{R_1 R_3 (R_1 + R_2)}{R_2 (R_1 + R_2)}$$

$$R_x = \frac{R_1 R_3}{R_2} \quad \text{--- (3)}$$

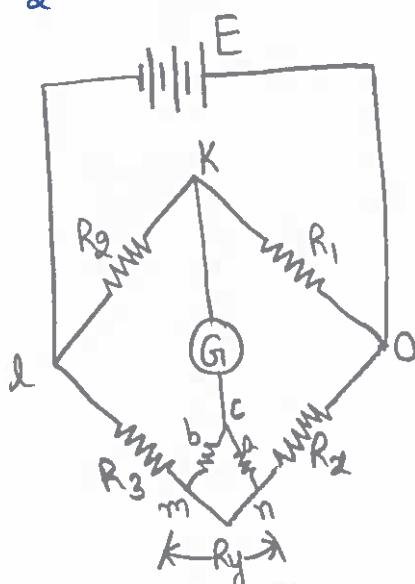


figure (2)

Eq (3) is called Wheatstone's ~~bridge~~ balance equation, it indicates that the effect of the resistance of the connecting leads from point A to point C has been

eliminated by connecting the galvanometer to an intermediate position B.

The above principle forms the base for the construction of Kelvin's double bridge popularly known as Kelvin's bridge. It is a double bridge because it incorporates second set of ratio arms. Above figure ② shows a schematic diagram of Kelvin's double bridge.

The 2<sup>nd</sup> set of arms a & b connects the galvanometer at point c, at the appropriate potential b/w m & n connection i.e.,  $R_y$ .

The ratio of the resistances of arms a & b is same as the ratio of resistance  $R_1$  &  $R_2$ .

The Galvanometer indication is zero, when the potentials at k & c are equal.

Therefore, the potential  $E_{lk} = E_{lmc}$  — ④

$$\text{But } E_{lk} = \frac{R_2}{R_1 + R_2} \times E \quad \text{--- ⑤}$$

$$\& E = I \left[ R_3 + R_x + \frac{(a+b)R_y}{a+b+R_y} \right]$$

Substitute the value of E in eq ⑤

$$E_{lk} = \frac{R_2}{R_1 + R_2} \times I \left[ R_3 + R_x + \frac{(a+b)R_y}{a+b+R_y} \right]$$

$$\text{Similarly, } E_{lmc} = I \left[ R_3 + \frac{b}{a+b} \left( \frac{(a+b)R_y}{a+b+R_y} \right) \right]$$

Substitute  $E_{lk}$  &  $E_{lmc}$  values in eq (4)

$$\frac{R_2}{R_1+R_2} I \left[ R_3 + R_x + \frac{(a+b)R_y}{a+b+R_y} \right] = I \left[ R_3 + \frac{b}{a+b} \left( \frac{(a+b)R_y}{a+b+R_y} \right) \right]$$

$$R_3 + R_x + \frac{(a+b)R_y}{a+b+R_y} = \left[ R_3 + \frac{b}{a+b} \left( \frac{(a+b)R_y}{a+b+R_y} \right) \right] \left( \frac{R_1}{R_2} + 1 \right)$$

$$R_3 + R_x + \frac{(a+b)R_y}{a+b+R_y} = \left[ R_3 + \frac{bR_y}{a+b+R_y} \right] \left( \frac{R_1}{R_2} + 1 \right)$$

$$R_x + \frac{(a+b)R_y}{a+b+R_y} + R_3 = \frac{R_1 R_3}{R_2} + R_3 + \frac{b R_1 R_y}{R_2 (a+b+R_y)} + \frac{b R_y}{a+b+R_y}$$

$$R_x + \frac{a R_y + b R_y}{a+b+R_y} = \frac{R_1 R_3}{R_2} + \frac{b R_1 R_y}{R_2 (a+b+R_y)} + \frac{b R_y}{a+b+R_y}$$

$$R_x = \frac{R_1 R_3}{R_2} + \frac{b R_1 R_y}{R_2 (a+b+R_y)} + \frac{b R_y}{a+b+R_y} - \frac{a R_y - b R_y}{a+b+R_y}$$

$$R_x = \frac{R_1 R_3}{R_2} + \frac{b R_1 R_y}{R_2 (a+b+R_y)} - \frac{a R_y}{a+b+R_y}$$

$$R_x = \frac{R_1 R_3}{R_2} + \frac{b R_y}{a+b+R_y} \left[ \frac{R_1}{R_2} - \frac{a}{b} \right]$$

But  $\frac{R_1}{R_2} = \frac{a}{b}$

$\therefore R_x = \frac{R_1 R_3}{R_2}$

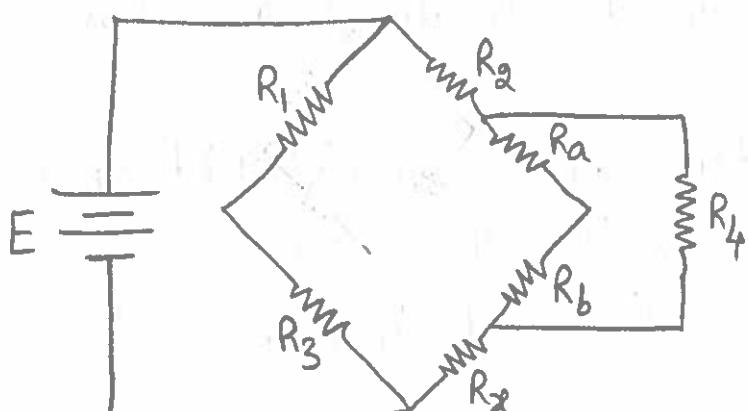
This is the usual eqn for Kelvin's Bridge.

Which indicates that the resistance of the connecting lead  $R_y$  has no effect on the measurement provided, that the ratio of the resistances of the two sets of ratio arms are equal.

The range of resistance measured by Kelvin's bridge is in b/w  $1-0.0001 R_2$  ( $10\mu\Omega$ ) with an accuracy of  $\pm 0.05\%$  to  $\pm 0.2\%$ .

### Problem

→ If in the figure the ratio of  $R_a$  to  $R_b$  is  $1000\Omega$ ,  $R_1$  is  $5\Omega$  &  $R_1 = 0.5R_2$ . What is the value of  $R_x$ ?



Sol: Resistance,  $R_x$  can be calculated as follows

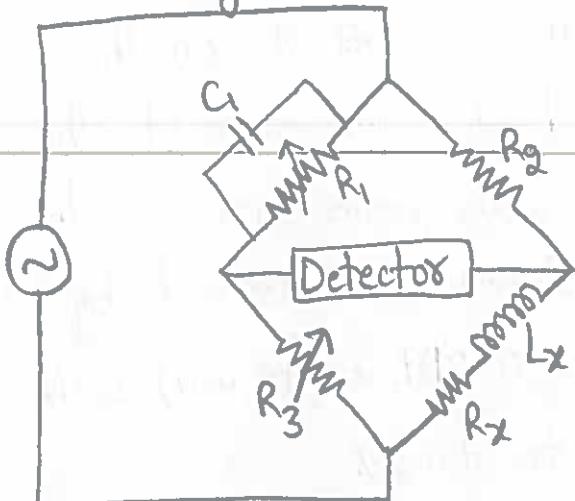
$$\frac{R_x}{R_2} = \frac{R_a}{R_b}$$

$$\frac{R_x}{R_2} = \frac{1}{1000}$$

$$R_1 = 5\Omega, R_1 = 0.5R_2 \Rightarrow R_2 = \frac{5}{0.5} = 10\Omega$$

$$\frac{R_x}{10} = \frac{1}{1000} \Rightarrow R_x = \frac{10}{1000} = 0.01\Omega$$

## Maxwell's Bridge:



Maxwell's Bridge is used to measure an unknown inductance in terms of known capacitors. The use of standard arm offers the advantage of compactness & easy shielding. The capacitor is almost a lossless component.

1 arm has a resistance  $R_1$  in parallel with  $C_1$  & hence it is easier to write the balance equation using the admittance of arm 1 instead of the impedance.

The general equation for the bridge balance is given by,  $Z_1 Z_x = Z_2 Z_3$

$$Z_x = \frac{Z_2 Z_3}{Z_1} = Z_2 Z_3 Y_1 \quad \text{--- ①}$$

where,  $Z_1 = R_1$  in parallel with  $C_1$  i.e.,  $Y_1 = \frac{1}{Z_1}$

$$Y_1 = \frac{1}{R_1} + j\omega C_1$$

Here,  $Z_2 = R_2$ ,  $Z_3 = R_3$ ,  $Z_x = R_x$  in series with  $L_x = R_x + j\omega L_x$

From eq(1) we have,

$$R_x + j\omega L_x = R_2 R_3 \left[ \frac{1}{R_1} + j\omega C_1 \right]$$

$$R_x + j\omega L_x = R_2 R_3 \left[ \frac{1}{R_1} + j\omega C_1 \right]$$

$$R_x + j\omega L_x = \frac{R_2 R_3}{R_1} + j\omega C_1 R_2 R_3$$

equating real & imaginary parts, we get

$$R_x = \frac{R_2 R_3}{R_1} \quad \& \quad L_x = C_1 R_2 R_3 \quad \text{--- (2)}$$

$$\text{also } Q = \frac{\omega L_x}{R_x} = \frac{\omega C_1 R_2 R_3}{\frac{R_2 R_3}{R_1}} = \omega C_1 R_1$$

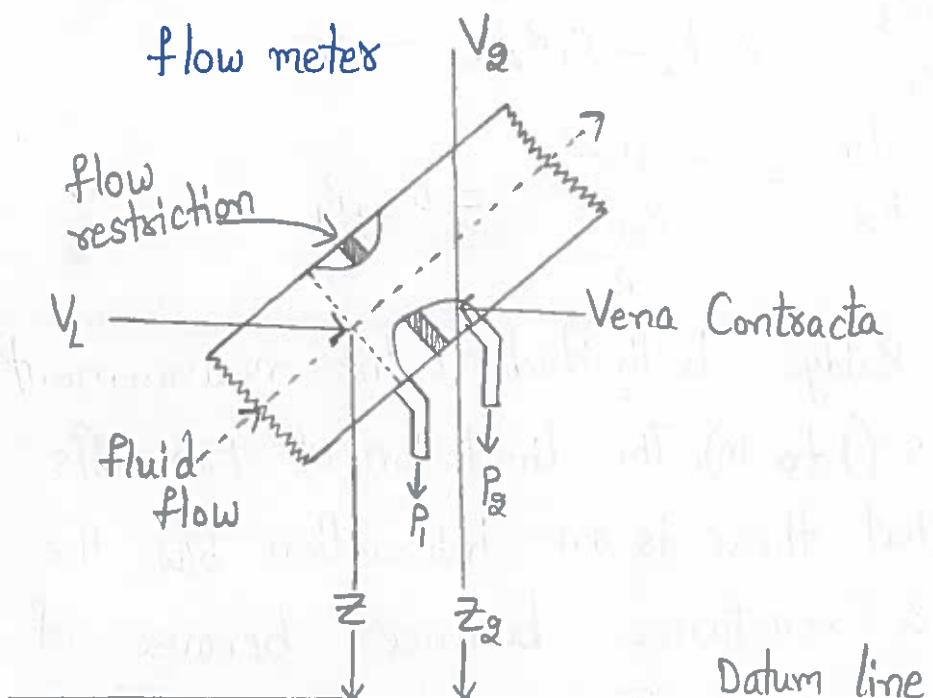
Maxwell's Bridge is limited to the measurement of low  $Q$  values (1 to 10). The limitation of Maxwell's bridge is that there is an interaction b/w the resistance & reactance balances because of using fixed capacitors. This can be avoided by varying the capacitances instead of  $R_2$  &  $R_3$  to obtain a reactance balance. They are used to measure the inductances b/w 1-1000 H with  $\pm 2\%$  error.

## MEASUREMENT OF PHYSICAL PARAMETERS

Introduction :

In this unit, describes the instruments which are used to measure other physical parameters like force, pressure, velocity, humidity, moisture, speed, proximity and displacements.

Flow Measurements :



$\gamma$  = Specific weight

$v$  = average stream velocity

$g$  = acceleration due to gravity

Principle : Movement of the fluid stream that flows through the primary element of the rate meter is directly or indirectly used to actuate a secondary device & the rate of flow is inferred from known physical loss are from empirical relation.

Head meters are those that operate by the measurement of the pressure differential or head across a suitable restriction to flow in the pipeline.

Principle of Head flow meter:

It is assumed that the fluid is flowing through an inclined pipeline as shown in the above figure. The relation b/w pressure-differential (Head) & velocity can be derived from Bernoulli's equation.

For ideal in-compressible fluids this takes the form

$$z_1 + \frac{P_1}{\gamma} + \frac{V_1^2}{2g} = z_2 + \frac{P_2}{\gamma} + \frac{V_2^2}{2g}$$

where,  $z$  = elevation of the centre line

$P$  = static pressure, absolute

For the upstream suffix 1 is used & for downstream suffix 2 is used. If the pipe is horizontal then

$$\frac{V_2^2 - V_1^2}{2g} = \frac{P_1 - P_2}{\gamma} = \text{effective load}$$

Since  $A = aV_2 = AV_1$

$$V_1 = V_2 \left( \frac{a}{A} \right)$$

$a$  = area of restriction

$A$  = Area of pipe

$$V_2^2 = \frac{2gh}{1 - \frac{a^2}{A^2}} = \frac{2gh}{1 - \left(\frac{d}{D}\right)^2}$$

$$\therefore V_2 = \sqrt{\frac{2gh}{\left(1 - \left(\frac{d}{D}\right)^4\right)}}$$

$q_t$  = theoretical value of flow

$$= V_2 a$$

$$= a \sqrt{2gh / \left(1 - \left(\frac{d}{D}\right)^4\right)}$$

where,  $\beta = \text{ratio of diameters} = \frac{d}{D}$

In terms of weight,  $w_t = q_t = a \sqrt{\frac{2gh}{1 - \beta^4}}$

In order to correct the equations for  $q_t$  &  $w_t$  from theoretical to actual flow rate based upon experimental data,

$$C = \frac{\text{Actual rate of flow}}{\text{Theoretical rate of flow}} = \frac{q}{q_t} = \frac{w}{w_t}$$

$$\text{let } K = \frac{C}{\sqrt{1 - \beta^4}}$$

where,  $K$  = discharge coefficient

$$q = K a \sqrt{2gh}$$

$$w = K a \sqrt{2gh}$$

Displacement Meters :

1) Basic Requirements:

→ Simplicity of design is required.

→ Accuracy within state & limits.

- Availability in a wide variety.
- Availability in different materials & calibrations of the measurement.
- Reasonably low pressure loss.

### 2) Nutating Piston Meters:

It is also known as Disc meter. Each cycle of the measuring piston or disc displaces a fixed volume of liquid. Here, piston is the moving part. The liquid enters through the inlet port & fills the spaces above & below the piston which fix closely in the measuring chamber.

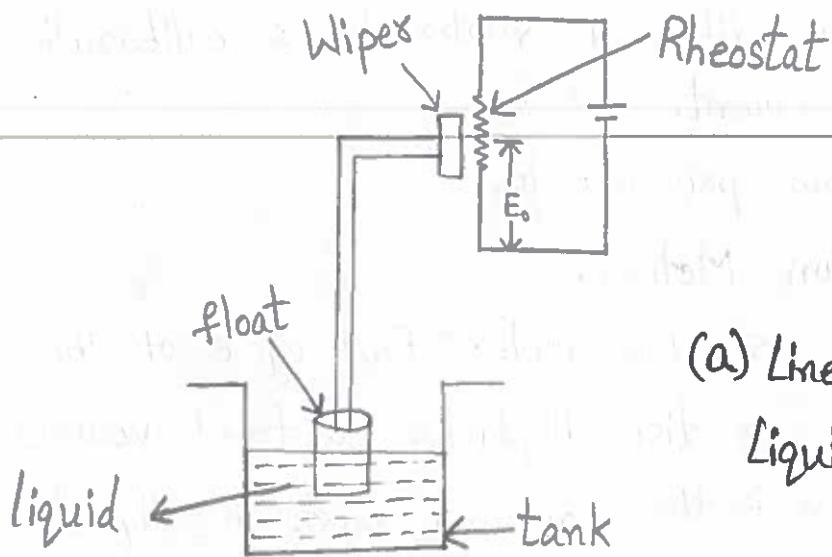
### 3) Rotating Meters:

They are currently known as Current meters or velocity meters & they operate on turbine principle that is the volume is measured by the movement of a wheel or turbine type of impeller which is actuated by the velocity of the liquid flowing through it.

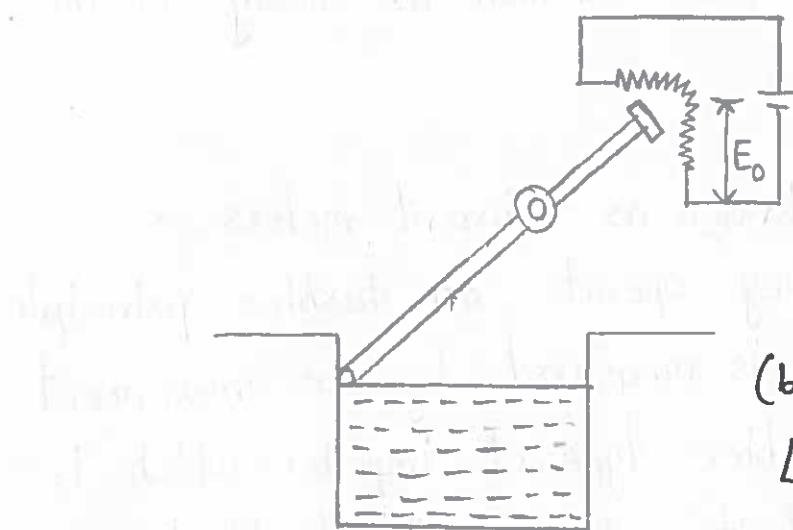
### 4) Oscillating Piston Meters:

In this type the measuring chamber is cylindrical & division plate separates the inlet port on 1 side & outlet port on the other side in this the balanced piston is also cylindrical but has a horizontal web carry the port in the center & is slotted to clear the division plate.

## Liquid Level Measurements:



(a) Linear potentiometer  
Liquid-level gauge



(b) Rotary potentiometer  
Liquid-level gauge.

The Liquid level measurements are made to measure the quantity of liquid held in a container or vessel. This affects both pressure and rate of flow in a container & therefore its measurement and/or control becomes quite important in a variety of processes.

Liquid-level measurements can be broadly classified as

- i) Direct Methods
- ii) Indirect Methods.

## Direct Methods :

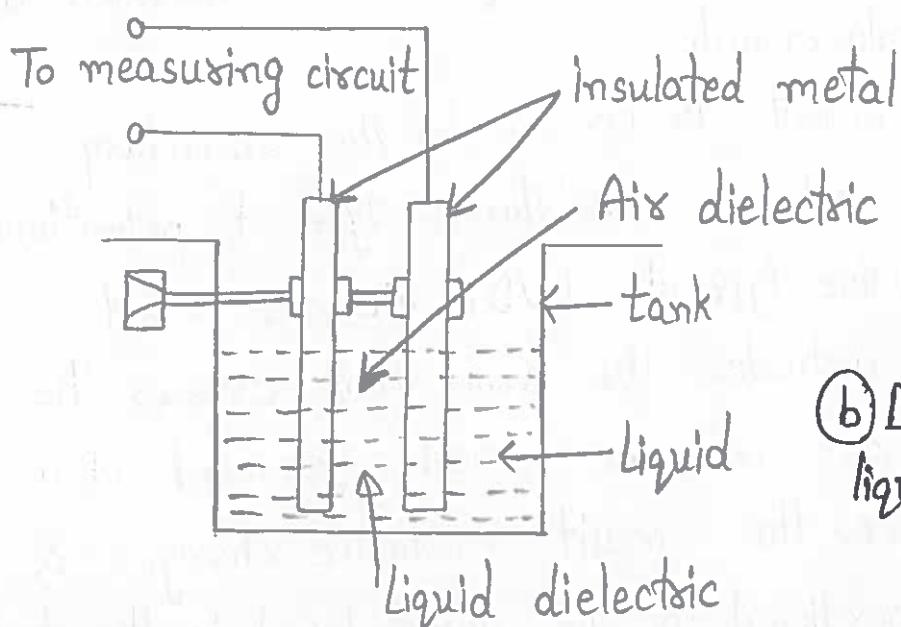
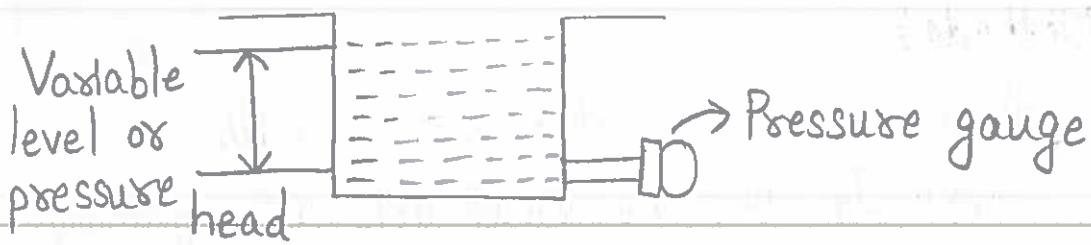
Here, we discuss float operated scheme with electrical output. In this, the float acts as a primary transducer that converts liquid-level variation into a suitable displacement.

This displacement is sensed by the secondary transducers such as resistance type of potentiometric device, inductive type of LVDT etc. The float displacement actuates the arm that crosses the slides to move over the resistive element of a rheostat. Hence, the circuit resistance changes & is directly proportional to the liquid-level in the tank.

## Indirect Method :

In Indirect Liquid-level measurement the hydrostatic pressure created by a liquid is directly related to the liquid column. ( $P = \rho gh$ ) therefore, a pressure gauge is installed at the bottom or on the side of a tank containing the liquid as shown in the below figure. The rise & fall of the liquid level causes a corresponding increase or decrease in the pressure which is directly proportional to the liquid-level  $H/h$ .

② Hydrostatic pressure type-level measuring device.



(b) Dielectric liquid-level gauge.

Measurement of Humidity & Moisture :

The amount of water vapour content in the atmosphere is called Humidity. It is an important process which is variable in a no. of industrial process because of humidity/moisture content affects the behavior of many commercial materials such as paper, textile, paint, soap powder, fertilizers, leather, wood products, etc.

Humidity measurement & control are necessary during many industrial processes as well as heating & air conditioning systems.

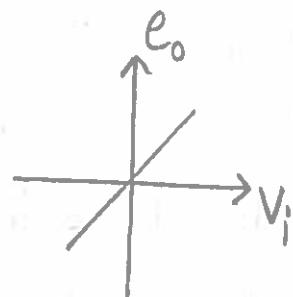
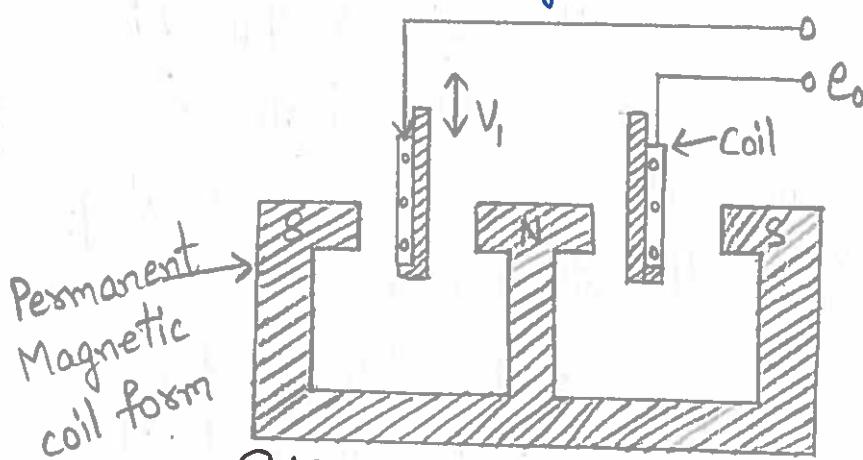
Humidity is generally expressed in terms of absolute humidity or relative humidity.

The absolute humidity of a gas is defined as the mass of water vapour present in the unit volume of gas & is usually expressed in gms/m<sup>3</sup>.

Relative Humidity (RH) compares the humidity of air with the humidity of saturated air at the same temperature & pressure & this RH is defined as the ratio of the mass of water vapour present in a given volume of gas to the mass of water vapour necessary to saturate the same volume of gas at the same temperature.

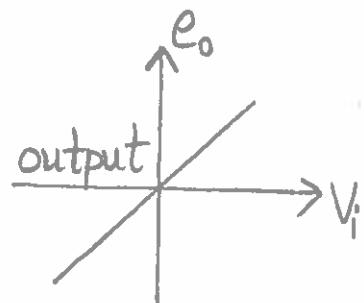
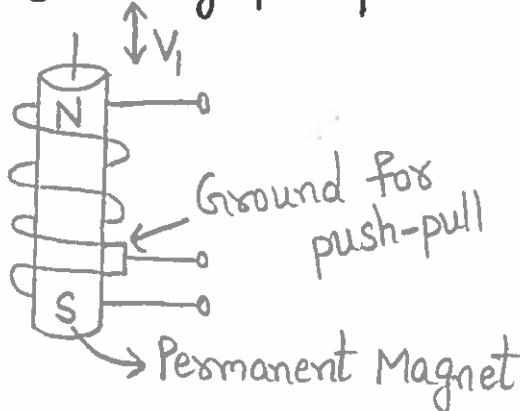
Measurement of Velocity :

→ Translational Velocity Transducer Moving Coil pickup



(a) Moving coil pickup

(b) Velocity pickup



Moving coil pickup is based on the law of induced voltage,

$$e_0 = BlV_r \times 10^{-8}$$

where,  $V_r$  = relative velocity of coil & magnet; (cms/sec)

$B$  = flux density (webex/m)

$l$  = length of the coil (cms)

Here,  $V$  &  $l$  are constants & the output voltage follows the input velocity linearly & reverses polarity when the velocity changes sign.

Since the flux density available from permanent magnets is limited to the order of 10,000 G, an increase in sensitivity can be achieved only by increasing in the length of wire in the coil. To keep the coil small, this requires fine wire & thus high resistance. High resistance coils require high resistance voltage measuring device at  $e_0$  to prevent loading.

As shown in fig(b) the transducer uses a permanent magnet core moving inside a form wound with two coils connected as shown. Units are available in full range strokes from above 0.5 to 20 cm & sensitivity varies from 0.5 to 0.05 V/cms/sec and non-linearity supports 1%.

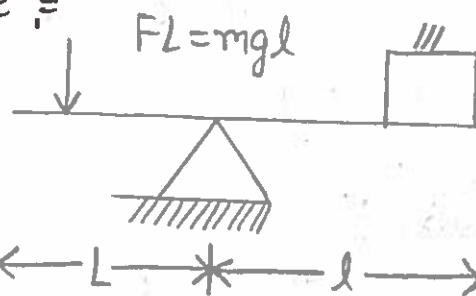
## Force Measurement:

The transducers or devices used for Force Measurement are also called as load cells. Both static & dynamic measurements will be considered, which may vary from a fraction of newtons to several mega newtons which may especially for extreme cases.

For dynamic measurements, electromechanical transducers are used often the following are the used of types of devices.

- 1) Balance
- 2) Hydraulic load cell
- 3) Elastic force devices.

→ Balance :

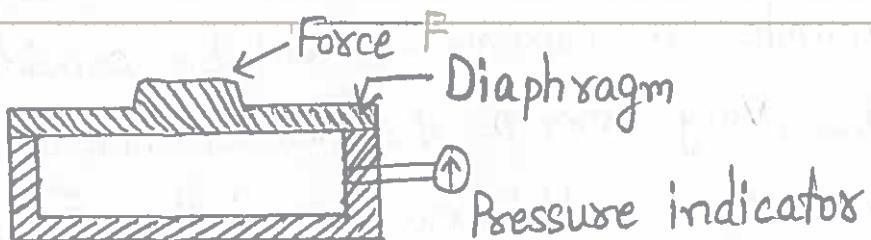


### (a) Balance principle

- A simple lever system shown in figure (a) called a Balance as long been used has a force measuring device.
- To measure the unknown force 'F' at a distance 'L' from the pivot, a mass 'm' at a distance 'l' from the pivot is used.
- The system is in equilibrium when  $FL = mgl$ , with knowledge of other parameters i.e.,  $L, l, \text{mass } m$

and gravitational constant ' $g$ ', force ' $F$ ' can be calculated.

→ Hydraulic Load Cell :

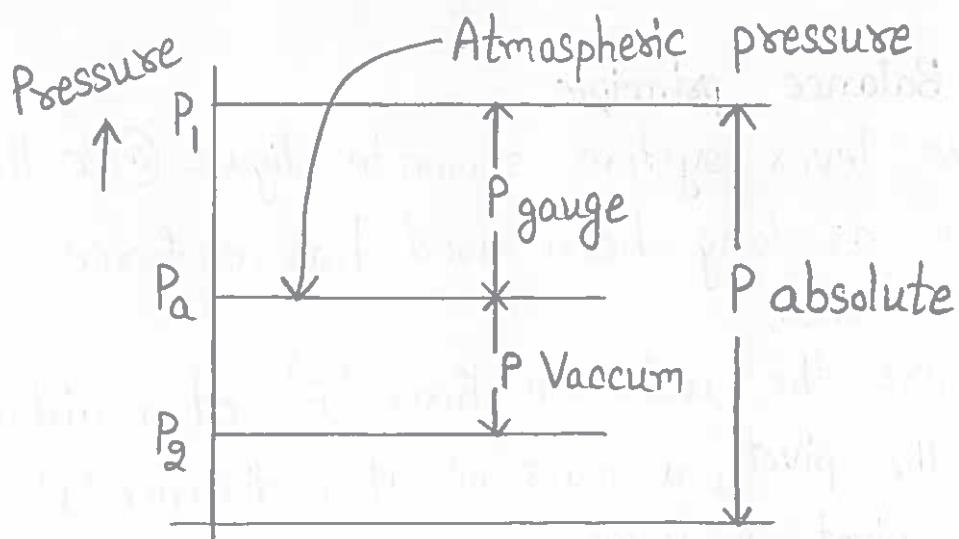


### (b) Hydraulic Cell

→ In this type of device, Hydraulic pressure shown in figure (b) is used to indicate the force ' $F$ ' applied to the diaphragm or some other type of force transmitting element.

→ When force  $F$  is applied, pressure is developed in the fluid which is normal to the coil this can be used up to very large sources of the order of millions of newtons.

Measurement of Pressure :



Pressure means force per unit area.

Absolute pressure means the fluid pressure above the reference value of a perfect vacuum or

the absolute zero pressure.

Gauge pressure represents the value of pressure above the reference value of atmospheric pressure it is the difference between the absolute and local atmospheric pressure. The atmospheric pressure at the sea level is 760mm of Hg, the above figure shows various terms used to express pressure.

Vacuum represents the amount by which the atmospheric pressure exists the absolute pressure.

### Temperature Measurements:

The temperature is probably the most widely measured and frequently controlled variable in the numerous industrial processes. Temperature is defined as the degree of "hotness" or "coldness" of a body or an environment on a definite scale.

Temperature cannot be measure directly but must be measured by absorbing the effect the temperature variation causes on the measuring device.

Temperature measurements methods can be broadly classified as follows

1) Non-electrical methods

2) Electrical methods

3) Radiation methods.

→ Non-electrical methods of temperature measurement can be based on any one of the following principles.

- Change in the physical state
- Change in chemical properties
- Change in physical properties.
- Electrical methods of temperature measurements can be based on
  - Change in volume of a liquid when its temperature is change.
  - Change in pressure of a gas when its temperature is change.
  - Change in vapour pressure when its temperature is change.
  - Change in dimensions of a solid when its temperature is change.

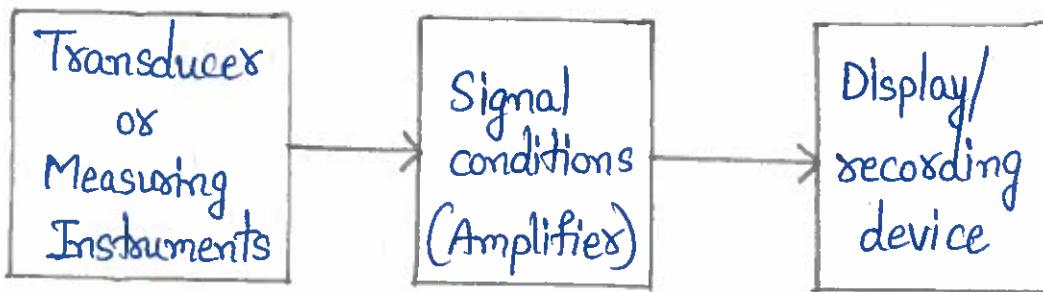
## Data Acquisition Systems:

The Data Acquisition System implies acquiring the data and record the data. The signals are obtained from the Transducers or Measuring instruments and are processed (Signal conditioning) and display or recorded.

Data Acquisition System can also be classified as follows:

- Analog Systems
- Digital Systems.

### Analog Data Acquisition System



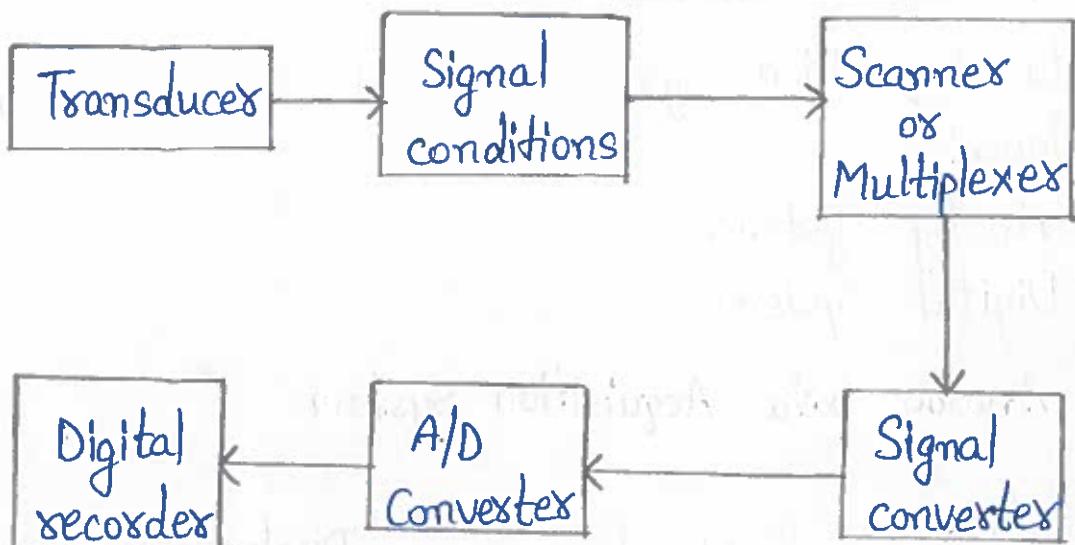
The signals in data acquisition systems are obtained from

1) Direct Measurement - The signals are obtained from measuring instruments such as DC or AC, voltmeters, ammeters, frequency counters, RLC bridge circuits, etc.

2) Transducers - Signals are obtained from various sensors, for pressure, velocity, force, etc., strain gauges, thermocouples,

physical quantity such as acceleration, flow are converted into electrical signals by the transducers and given to the Data Acquisition System.

## Digital Data Acquisition System



The Signal conditioning device may be an amplifier, a filter, a rectifier, a mixer, etc. The display or recording device may be a CRO, x-y recorder, magnetic tape recorder.

A Scanner or Multiplexer accepts multiple analog inputs and sequentially connects them to the measuring instruments.

Signal converter converts the signal to a form at an acceptable level to the A/D converter.

Data Acquisition Systems are used where large no. of parameters are to be measured, monitor & controlled.

## Applications :-

- Industries
- Biomedical applications
- Scientific Research
- Aerospace
- Telemetry

